ISSUE 3
SEPTEMBER 2019
transformer-technology.com
ISSN 2642-2689

TRANSFORMER TECHNOLOGY MAG

TRANSFORMER TECHNOLOGY MAG

Best Practices Transformer Testing, Maintenance and Monitoring

Interview with John McDonald
GE Grid Solutions

Testing and Maintenance:
Best Practices for a Half Century

Tips for Reducing Wasted Time
When Testing Transformers

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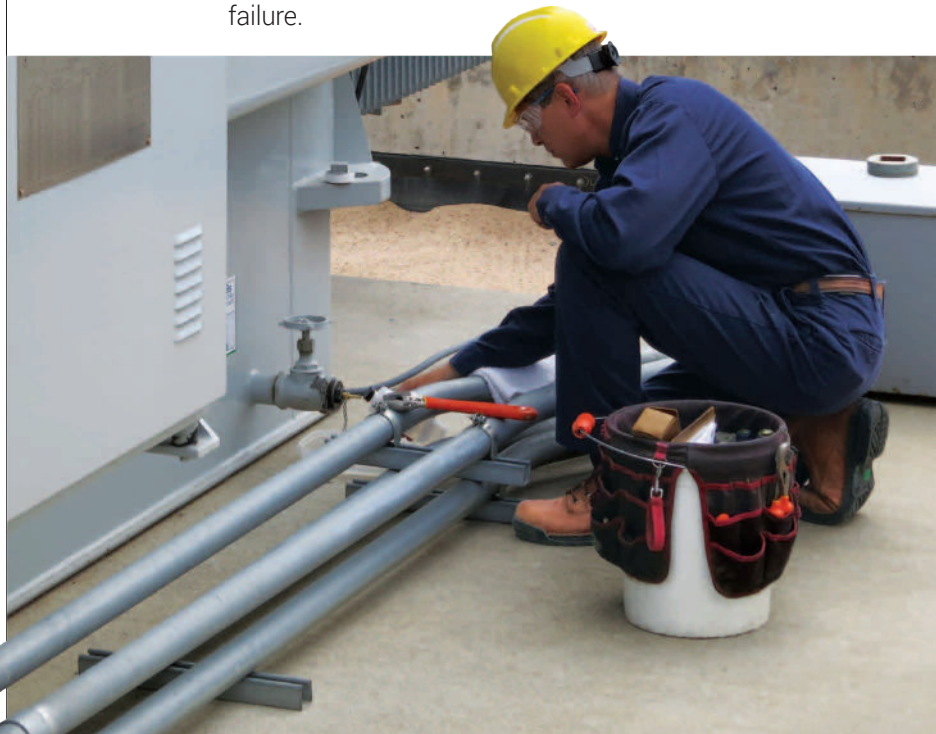

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This article identifies the electrical transformer tests that test equipment users often struggle to perform efficiently and correctly, offering three field-testing tips to address the transformer tests that are often “time-suckers”.

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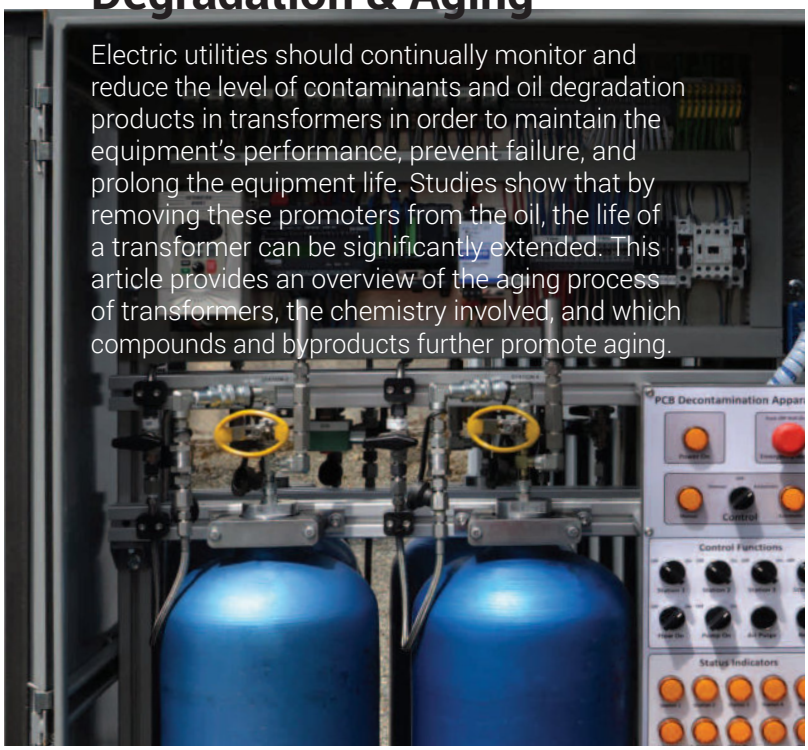
Electric utilities should continually monitor and reduce the level of contaminants and oil degradation products in transformers in order to maintain the equipment’s performance, prevent failure, and prolong the equipment life. Studies show that by removing these promoters from the oil, the life of a transformer can be significantly extended. This article provides an overview of the aging process of transformers, the chemistry involved, and which compounds and byproducts further promote aging.



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Transformer Oil Properties

The composition of transformer oils can play an important role in determining the performance and lifespan of transformers. This article highlights the key properties of transformer oils with different chemical compositions and the tests that were undertaken in determining if oils with a higher paraffinic carbon content can deliver enhanced performance versus those with a higher naphthenic carbon content.

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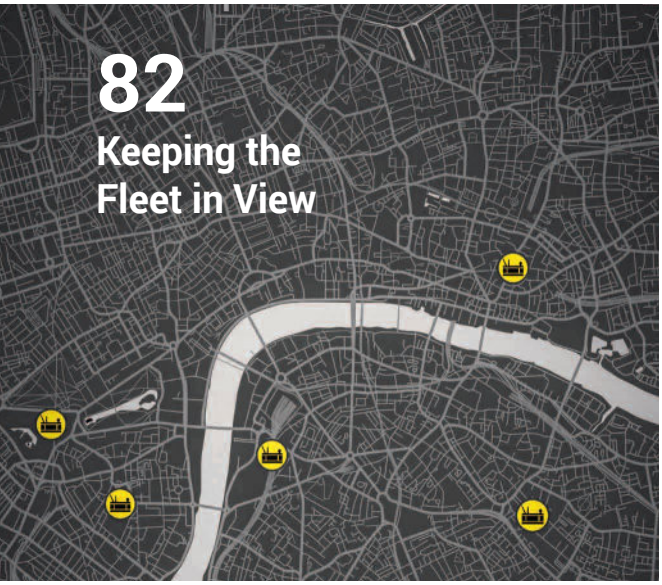

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Keeping the Fleet in View

Impressum

TRANSFORMER TECHNOLOGY MAG

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

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Cover Photo Courtesy of The Snell Group, Barre, VT

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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.

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Publisher:
APC MEDIA LLC
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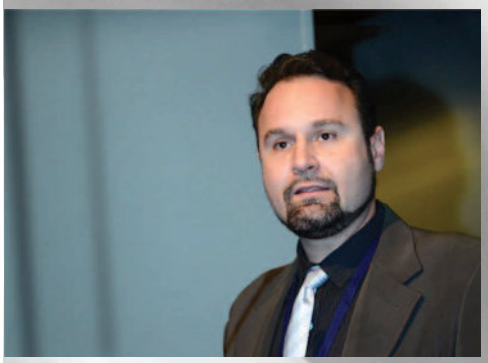


Contributing Editor
Alan Sbravati ME, MBA
Transformer insulating materials
18 years of experience

A Changing Landscape

This issue might well be a keepsake for anyone interested in "Best Practices for Testing, Maintenance and Monitoring" of transformers. There is past, current and future "Best Practices". How can we have future ones? If they are future practices, then they have not yet been proven or industry-wide accepted. That is what defines a best practice by the way. Proven and accepted practices!

But in the face of advancing technology and new methodologies, we have to know when to let go of the past and accept new advances. As I read Richard Harada with his article on the use of remote infrared monitoring, it is clear that he is sharing a future best practice. Bob Rasor, Jason Dennison and Brandon Dupuis shared the best of the past and current and of course, the monitoring article from Marco Tozzi hit the nail on the head in both current and future technology for monitoring.

Being involved with Transformer Technology has stretched me much more than I thought it would and it has done so in three very distinct ways:

1. I am being challenged technically. While our Contributing Editors add technical expertise in areas I cannot, I am making a commitment to at least understand what our authors are sharing, to grasp the fundamentals and make sure they will be of interest to the average reader. We are not writing to only the technologists but to a broad array of transformer professionals. To do that, we must be relevant, reliable and make sure we don't ever use the magazine articles as filler. Our goal is to create a publication that lives on, one that is shared digitally and in print because of the value of the information we publish. That leads me to my second area of growth.

> "If, like me, you are inundated with emails, blogs, magazines and conferences to attend, it can be overwhelming. How do we rise above all that clutter? We make it enjoyable, shareable and challenging to become part of our community online and in print.

2. It would be much easier if all we did was publish a few magazines a year. But that is not our vision for Transformer Technologies; it is to create a "collaborative community" of professionals within the transformer industry to learn, do and teach. While I have experience building this kind of community in the past, the challenge is to do that around a subject as technical as transformers. And to do it at a time when we are awash in information. If, like me, you are inundated with emails, blogs, magazines and conferences to attend, it can be overwhelming. How do we rise above all that clutter? We make it enjoyable, shareable and challenging to become part of our community online and in print. As I just wrote this I thought, "and you thought this would be easy?" It is a testament to the amazing support I get from my team that we can attempt to pull this off. Thank you to all of you.

3. The future of information exchange is going digital and moving away from print. How can I even think that when we are the publishers of a printed magazine? I don't want us to become Blockbuster in the face of Netflix or Sears in the face of Amazon, so accept the change and embrace it for the opportunity it creates. Every printed issue is what we aim at to complete a theme. The first three have been New Technology, The Dry Type Revolution and now this edition themed, Best Practices of Testing, Maintenance and Monitoring.

   I'd like to challenge you to help us deliver the best themes of the future by contacting me at alan.ross@transformer-technology.com and let me know what themes you would like to see for 2020 and beyond.

How will we make this change from a print publication to an online collaborative community? We have already begun with the addition of our news feed and commentary on important news items. We don't want to just bring you the important news but also want to go behind the press releases to what it means. For instance, Siemens announced layoffs. We went behind the scenes to look at what that means as they adjust their business to new realities. It's opinion, but well informed and well intentioned.

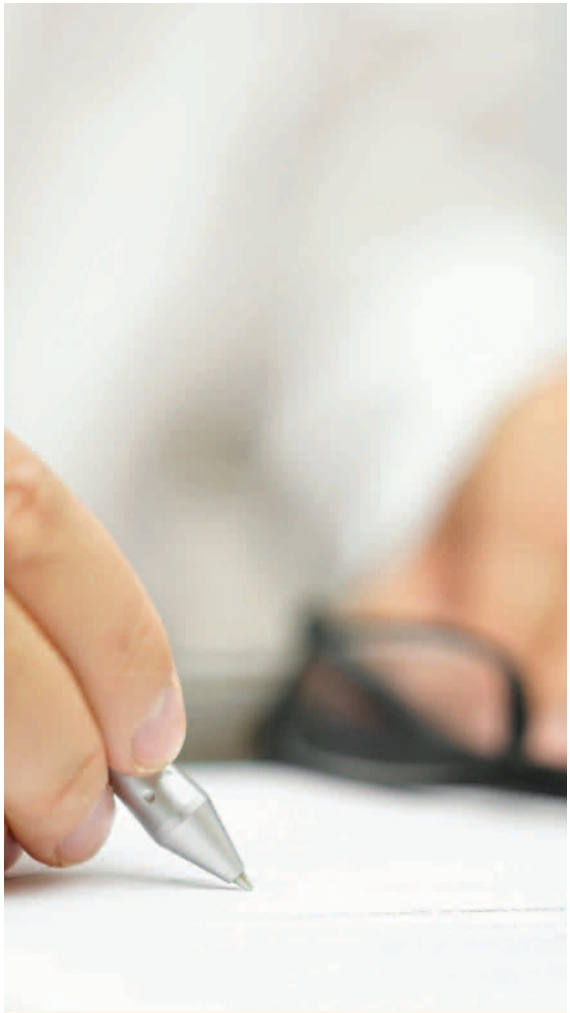
We also added two podcast features: One on Transformer Technology and one called Legends. Podcasts might also show up as written interviews in future issues. You will see many more posts, sharing insights into the articles and podcasts we publish, and we welcome your feedback.

Please let us know when we meet or exceed your expectations, but also when we fall short. Engage with the community. Collaborate. Share your thoughts, ideas and technology of the future. I promise, we are listening... and learning.

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

Alan M Ross

At a Glance



Pioneer Power Solutions closes sale of transformer business

Pioneer Power Solutions, Fort Lee-based manufacturer of electrical transmission, distribution and on-site power generation equipment, completed the sale of its liquid filled and dry type transformer businesses to Mill Point Capital, a middle-market private equity firm, for a base purchase price of $68 million.

Pursuant to the transaction, Pioneer sold all of Pioneer Transformers Ltd. and the companies comprising its Dry Type Transformer Group, which included Jefferson Electric Inc., Bemag Transformer Inc. and Harmonics Limited LLC.

Pioneer Power manufactures, sells and services electrical transmission, distribution and on-site power generation equipment. Its transformer businesses make specialty electrical transformers for utility, commercial power, industrial manufacturing and construction users. It has locations in the U.S., Canada and Mexico.

Mill Point executive partner Antony Besso will become chairman of Pioneer Transformers.

Source: Pioneer Power Solutions

Sunbelt Transformer merges with Solomon Corporation

Trilantic North America, a private equity firm, has announced the merger of Solomon Corporation, a provider of maintenance and repair services for electrical transformers, with Sunbelt Transformer.

The combined entity will address a critical segment of the electrical power equipment and services market, serving the transformer and related needs of commercial, industrial and electric utilities customers throughout North America.

As part of the transaction, Tom Smith, CEO of Sunbelt, has been appointed Chairman and CEO of the combined entity, with key leaders from both organizations remaining on board to guide the business' next phase of growth.

"Sunbelt and Solomon are both companies with entrepreneurial roots that have grown through an emphasis on delivering quality solutions, superior customer service and cultures of collaboration and rigor," said Mr. Smith.

Tom Hemmer, former CEO of Solomon Corporation, will serve as Group President of Solomon going forward.

"I am tremendously proud of Solomon's growth to date and look forward to partnering with the team at Sunbelt in order to more effectively serve our customers as a joint platform," said Hemmer.

Source: BusinessWire; Photo: Solomon Corporation

Georgia Power to rebuild 380 substations over next 3 years

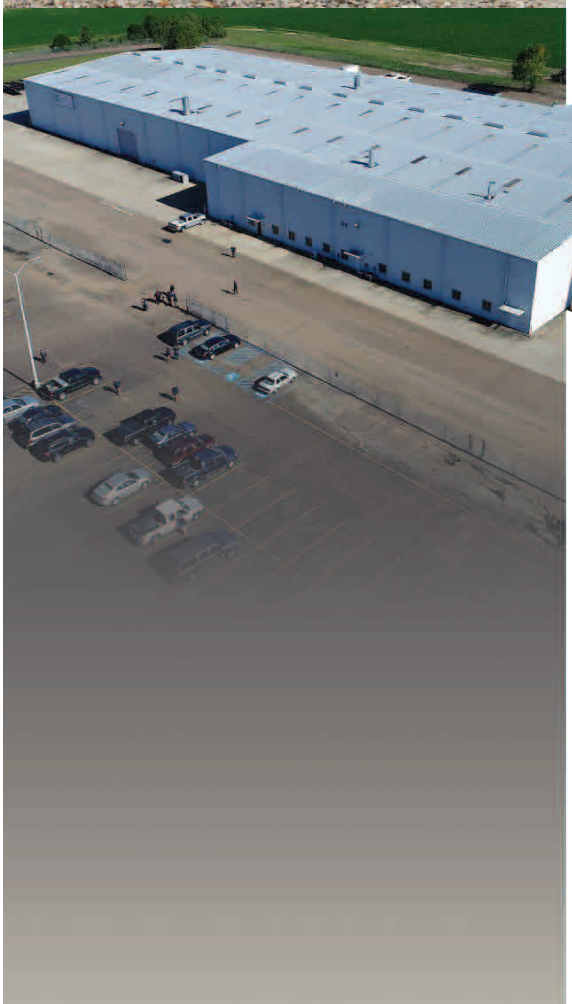
Georgia Power filed a request with the Georgia Public Service Commission (PSC) to increase customer rates by approximately 7% in 2020 to enable the company to continue making investments in Georgia's energy future.

In the filing, the company highlighted nearly $18 billion in recent and future investments that are made to strengthen the reliability and resiliency of the state's electrical system and to comply with federal regulations.

Since 2013, Georgia Power has invested more than $4.1 billion in expanding transmission and distribution infrastructure, replacing aging transmission assets and strengthening the reliability and resiliency of the electric grid, and plans to invest an additional $1.3 billion in a grid investment plan over the next three years.

This plan includes rebuilding 380 substations to continue strengthening transmission and distribution infrastructure.

Source: Georgia Power



Emerald Transformer names new GM of Lexington plant and announces expansion

Emerald Transformer (Emerald) has named Jim Palmer as the company's new general manager of the Lexington, Mississippi, plant.

Palmer brings over 30 years of experience in organizational development, operations management and safety and environmental protection within multi-state and multi-plant production.

As general manager, Palmer is responsible for overseeing the performance, compliance, productivity, efficiency and profitability of Emerald Transformer.

The company also announced it is increasing its footprint in the Mississippi region and expanding its primary service territory from four to eight states.

"Emerald Transformer is fully committed to growing our business and creating new jobs in Mississippi," said Stuart Prior, CEO and president of Emerald Transformer, adding that the company plans to "further enhance and expand our customer relationships in Holmes County and throughout the southeast."

Source, Photo: Emerald Transformer

US DOE selects companies to develop transformer sensor technology

The U.S. Department of Energy's Office of Electricity Delivery and Energy Reliability (OE) has selected three companies to develop, prototype, and demonstrate TRANSENSOR, a low-cost optically based smart monitoring system.

PARC, Con Edison and General Electric will cooperate to develop and test TRANSENSOR (Transformer Real-time Assessment INtelligent System with Embedded Network of Sensors and Optical Readout), which will increase reliability and safety by providing real time asset health.

"It's been predicted that the smart grid sensor market will reach $39 billion by 2019," said Ajay Raghavan, PARC research area manager and principal investigator leading the effort. "We are working on innovative low-cost embedded fiber-optic sensors that can reliably monitor conditions in a broad variety of harsh environments, including those seen in smart grids, so that we can understand the real-time state of critical systems."

Con Edison personnel will lead the final field demonstration of TRANSENSOR.

GE personnel will play a support role in the testing for qualifying TRANSENSOR on its Safe-NET network transformers leading to the planned field demonstration with Con Edison.

Source: Printed Electronics

GRID 20/20 releases new distribution transformer monitoring technology

Richmond, Virginia-based provider of distribution transformer monitoring solutions, GRID20/20, announced the release of its latest monitoring technology designed to facilitate grid modernization within the US, Ontario Canada, and abroad.

"Advanced Transformer Infrastructure is the required next step to improve grid reliability and resilience," said Alan Snook, President of GRID20/20.

"As our insatiable desire to adopt clean (renewable) energy accelerates, and related mandates continue to be enacted, Distributed Energy Resources (DER) is growing rapidly. The undeniable problem is that our aging transformer fleets were never designed, nor even conceived to handle reverse energy impacts commonly introduced by DER. This reality sets the stage for a series of costly grid reliability, safety and resilience concerns," added Snook.

According to the press statement, the new IoT turnkey solution with sensors and a suite of robust analytics capability provides operators with intra-grid information enabling them to reduce power outages, lessen serious fire/wildfire risk, and avoid damaging financial liability.

Source: GRID 20/20

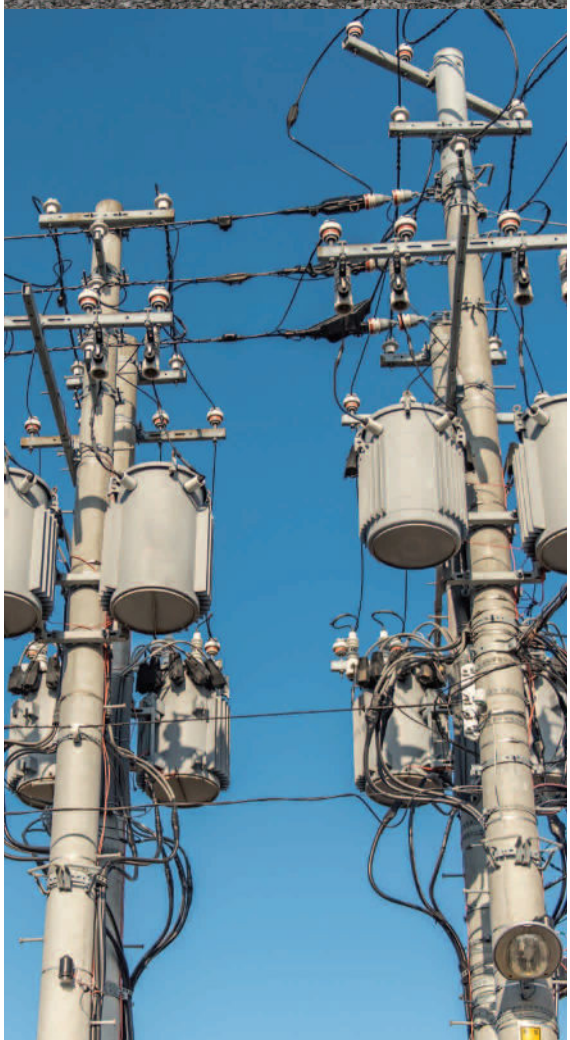


ABB names Björn Rosengren as CEO

The Board of ABB has appointed Björn Rosengren as Chief Executive Officer.

He will join ABB on February 1, 2020 and succeed CEO, Peter Voser, in this role on March 1, 2020. At that time Peter Voser will revert to his position at ABB solely as Chairman of the Board.

Björn Rosengren (60), a Swedish citizen, has been the CEO of Sandvik, a high-tech global engineering group, since 2015. Prior to that, he was CEO of Wärtsilä Corporation, and spent some thirteen years (1998-2011) in a variety of management roles at Atlas Copco.

"The Board is pleased that Björn Rosengren will be taking the lead at ABB, bringing with him a proven track record of value creation and exactly the managerial skills ABB needs during the next stage of its transformation," said ABB Chairman and current CEO, Peter Voser. "After undertaking a thorough search, the Board is convinced that Björn Rosengren is the best candidate for the role."

CEO-designate, Björn Rosengren, said: "I am honored to have the opportunity to join ABB, a truly global technology leader, after I have completed my current commitments. At such a pivotal time for manufacturing industries, ABB must continue to best serve the needs of global customers with a unique technology and digital solutions portfolio to help enhance their productivity."

Source, Photo: ABB

New research substation opened for testing and online monitoring

Electric Power Research Institute (EPRI) has designed, constructed and commissioned a full-scale, three-phase, outdoor 138 kV substation at its High-Voltage Laboratory in Lenox, Massachusetts.

The research substation includes all the key components of a utility substation: transformer bushings, an SF6 circuit breaker, a disconnect, buswork, arresters, post insulators, and composite poles.

The substation is now operational, with the transformer bushings both energized and subjected to high current.

The substation is a tool for rapid and cost-effective knowledge gathering on how new substation components (such as new, oil-free bushings) perform over time and how on-line monitoring technologies (such as on-line bushing monitoring and on-line partial discharge detection) respond to a wide range of scenarios.

The Lenox location provides conditions for the assets to experience cold winters with ice and snow, warm springs, and summers with fog from the adjacent river. A spray system has also been installed to increase the wetting rate.

Source: T&D World

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

Coming Events

CWIEME Americas
September 17-18, 2019
CHICAGO, IL

Electric Power Reliability Summit
September 17-18, 2019
AUSTIN, TX

COILTECH 2019
September 25-26, 2019
PORDENONE, ITALY

Advanced Research Workshop on Transformers - ARWtr 2019
October (6)7-9, 2019
CORDOBA, SPAIN

EuroDoble Colloquium 2019
October 20-23, 2019
PORTO, PORTUGAL

IEEE Transformers Committee - Fall Meeting
October 27 - 31, 2019
COLUMBUS, OH

The Transformer Experience - Weidmann 18th Annual Technology Conference
November 5-7, 2019
SAN ANTONIO, TX

Photo by Shutterstock

TIRONI successfully completes short circuit test on ester-filled 400 kV transformer and a new 400 kV autotransformer

Italian transformer manufacturer TIRONI has successfully completed the short circuit withstand test on its first 400 kV prototype filled with natural ester.

The 250 MVA, 400 kV autotransformer was tested at the CESI lab in Rondissone, Italy. The company will now start a series production of these autotransformers that will be in service in the Italian transmission network.

The manufacturer has also successfully short-circuit tested their first prototype of the 250 MVA, 400/135 kV autotransformer that was manufactured for the Italian transmission system operator Terna.

The test was performed at the lab in Rondissone and the transformer, once the final checks at the factory are complete, will be certified according to client's requirements.

Source, Photo: TIRONI

Siemens to cut 2,700 jobs and optimize power transmission products business

Siemens has informed its employee representatives about further long-term measures related to the establishment of Siemens' Gas and Power (GP) Operating Company that has led to significant synergies and optimization of support functions.

The plans, as they have now been presented, call for reducing approximately 2,700 jobs worldwide over the course of several years, with around 1,400 of these jobs being in Germany.

At the same time, Siemens highlighted that the growth-oriented Vision 2020+ strategy concept will also be reflected in workforce development, with an expected net increase of around 10,000 jobs worldwide within the same time period.

Other new measures also address the power transmission products and systems business.

Siemens says the transformers and switching technology markets are burdened by excess capacities, requiring measures for optimizing cost structures and capacities at all locations. Doing so will help preserve the competitiveness of these locations, the release said.

In addition, across the GP Operating Company, bundling and optimization has reduced the need for some of the services provided by support functions.

Source, Photo: Siemens

China's longest 1,100 kV transmission line goes online

China has launched its longest extra-high voltage (EHV) power transmission line, connecting the far western region of Xinjiang and the eastern province of Anhui.

The 2,065-mile (3,324-km) transmission line with voltage of 1,100 kV is designed to transmit 66 billion kilowatt-hours (kWh) of electricity a year.

Most of the electricity transmitted by the line will come from the Zhundong coal-fired power plant in northern Xinjiang.

This project will help meet increasing power demand in industrialized eastern regions and reduce the amount of wasted electricity in the west.

According to the State Grid Corporation of China, by the end of June the country had 18 EHV lines with overall transmission length of 17,131 miles.

Source: Reuters

Manitoba Hydro completes one of the largest HVDC projects in North America

A provincial Crown Corp., Manitoba Hydro commissioned the Bipole III project, completing its third HVDC transmission line that will deliver renewable hydroelectric power produced in northern Manitoba to customers in southern Manitoba, Canada.

This 860-mile (1388 km), 500 kV HVDC transmission project took five years to construct and it was one of the largest construction projects in North America.

The new line interconnects two new converter stations – the Keewatinohk converter station located on Fox Lake traditional territory, northwest of the town of Gillam in northern Manitoba, and the Riel converter station, just east of Winnipeg. The design and construction of the converter equipment was completed by the consortium of Siemens Canada Ltd. and Mortenson Construction.

With temperatures in Manitoba nearing 40°C (100°F) summertime and going as low as -50°C (-58°F) in winter, all equipment used within the converter stations had to meet these challenging temperature extremes, including the large HVDC converter transformers, which were manufactured and delivered from Germany.

Source, Photo: T&D World

Brazil transmission companies start removing GE current transformers

After an unusual number of explosions involving the same transformer model, several Brazilian power transmission companies started removing transformers made by General Electric.

Brazil's grid operator ONS recommended replacing the CTH-550 transformer model after registering 53 explosions, saying the equipment showed "a failure rate that is superior to what is expected" for this equipment, reports Reuters.

There are approximately 700 pieces of these units in Brazil's grid. Power transmission companies have already launched tenders to buy replacement transformers as they discuss the costs and a schedule for the changes with GE and regulators.

GE is investigating what caused the equipment failure in Brazil. In a statement to Reuters, GE said: "GE Grid Solutions performed a series of checks in the equipment with its clients and, as of this moment, there is no evidence that the problems were caused by the design, components or production processes."

Brazil's electrical energy regulator Aneel said that, after conducting a detailed analysis, it has determined the problem is with the manufacturer.

Taesa, one of Brazil's largest power transmission companies, and Colombia's ISA ISA.CN already started replacing this model of transformers in their networks. Due to the changes and lead times, the process is expected to take one year.

Source: Reuters

ABB to supply 100 transformers for offshore wind project in North Sea

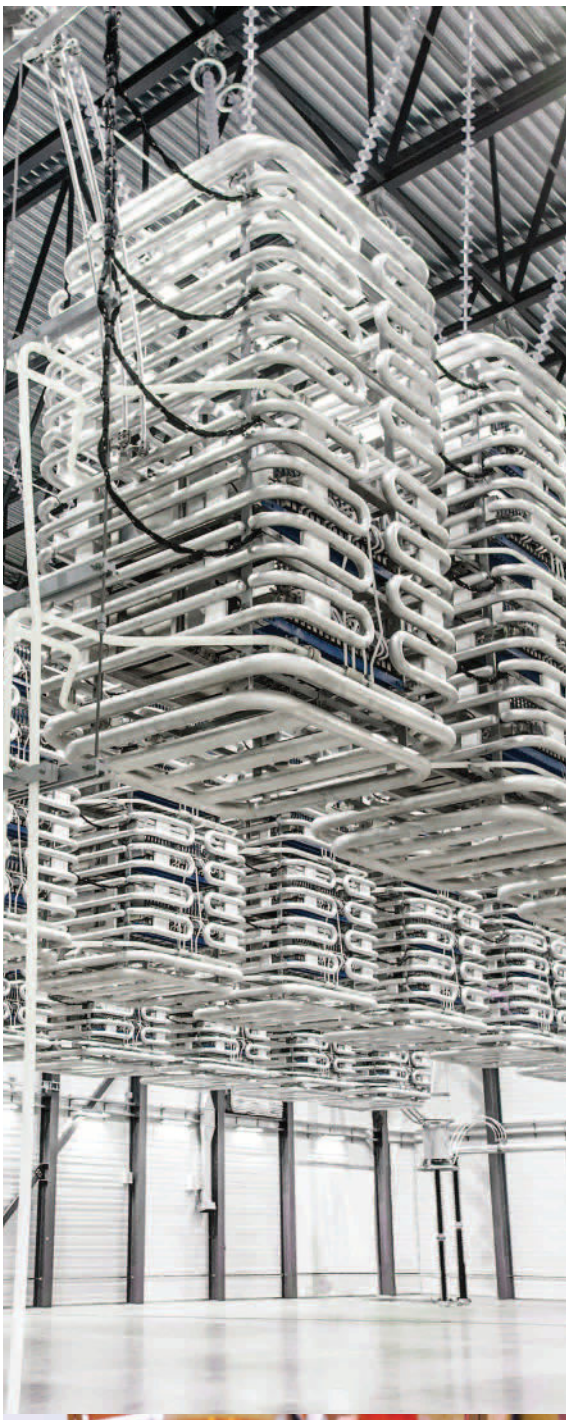
ABB has won an order from MHI Vestas Offshore Wind for the supply of its compact WindSTAR transformers for installation in wind turbines in the North Sea.

Under the project, 100 transformers manufactured in the transformer factory in Vaasa, Finland, will be supplied for Moray Offshore Renewable Power's Moray East offshore wind project.

The 295 square kilometer windfarm will contain wind turbines up to 670 foot (204 meters) tall to the turbine's blade-tip, each with the capacity to generate 9.5 MW of electricity at 66 kilovolts. This will be made possible by the transformers that are compact enough to be placed inside the wind turbine.

The windfarm will have a capacity to generate 950 MW of renewable wind power in Moray Firth (an inlet of the North Sea) off the coast of Scotland, and be capable of providing enough clean energy to power up to a million households.

Source, Photo: ABB



South Korea awards large HVDC order

Korea Electric Power Corporation (KEPCO), South Korean largest electric utility, awarded ABB Power Grid's business with an order to build two new HVDC converter stations.

One substation will be located on the mainland to convert the power from alternative current (AC) to direct current and transfer the electricity by undersea cable with almost no losses to Jeju Island, South Korea's largest island, where the other substation will convert the current back to AC for distribution.

The high voltage direct current (HVDC) converter stations will provide an additional 200 MW of power to Jeju island, enough to provide electricity to 500,000 homes.

Additionally, the voltage source conversion (VSC) technology will also be implemented to help the utility to operate the island's existing interconnections more efficiently by providing additional stability and by minimizing the risk of power outages.

Source, Photo: ABB

MPF Weidmann paper factory increases production of transformer board

Weidmann Malyn paper factory (MPF Weidmann), Ukraine's only producer of electrical insulating board for power engineering machines including transformers, announced it increased production by 8.6% in the period of January-May 2019.

According to the UkrPapir association, the paper mills' output of transformer board rose by 29.7% to 2,190 tonnes.

MPF Weidmann is a member of the WICOR international group, and it is the only company in Eastern Europe that can supply almost all kinds of electrical insulating paper and cardboard that meet regional and international standards.

Source: Open4business.com

Qualitrol appoints new President

Qualitrol announced that Andrew McCauley has been appointed president.

With over 20 years of experience in leadership across multiple industries and with Qualitrol's parent company, Andrew McCauley has a proven track record of being a trusted leader with a commitment to the customer experience which will be an asset as Qualitrol continues to accelerate growth, the company said in the press statement.

Prior to accepting the role of President of Qualitrol, Andrew held senior roles at Pacific Scientific and Kollmorgen in addition to his most recent position as the President of Specialty Products Technologies Company in Elizabethtown, NC.

Andrew has a BS in Electrical Engineering from Virginia Tech and an MBA from the University of North Carolina, Chapel Hill.

Source: Qualitrol

PFIFFNER International acquires Swiss high-voltage test systems developer

HIRSCHTHAL, SWITZERLAND – PFIFFNER International AG, a solution supplier for customers in the sectors of electrical energy and rolling stock, announced the acquisition of HAEFELY TEST AG, member of the HUBBELL Group prior to the transaction.

HAEFELY is a Swiss high-voltage test systems and instrumentation producer and developer based in Basel, Switzerland, whose customers are electric utilities, industrial manufacturers of products for the electric energy sector and general industrial manufacturers.

HAEFELY will remain active on the market under the HAEFELY brand.

„I'm very pleased to welcome all employees at PFIFFNER International. Both companies share the passion for current and voltage as well as for innovative technology and products for the electric energy sector what will ease the integration of HAEFELY in our Group" said Fritz Hunziker, the chairman of the board and the owner of the PFIFFNER Group.

With this acquisition, four Swiss brands – PFIFFNER Instrument Transformers, MOSER GLASER, ALPHA-ET and HAEFELY are now aligned under one roof.

Source: Pfiffner Group; Photo: HEAFELY

Siemens successfully tests one of the world's largest autotransformers

Siemens has successfully short-circuit tested and certified a single-phase 500 kV autotransformer with a power rating of 300 MVA.

The tested unit is one of the largest short-circuit tested autotransformers in the world and has been certified by a third-party testing laboratory in the Netherlands.

The 225-ton autotransformer was manufactured in Siemens Transformers factory in Guangzhou, China from where it was transported to the Netherlands for testing.

After the initial test in the Netherlands, the transformer was shipped back to China for further customer acceptance tests and visual inspection of the active part, before it received a certificate of short-circuit performance.

The design and service application for this type of transformer is to be typically used for areas with large transmission distances, such as those in Asian and South American countries.

Source, Photo: Siemens

Shermco Industries acquires Electrical Manufacturing and Distributors

Shermco Industries, Inc., an independent provider of electrical testing, maintenance, and repair services in North America, announced that it has acquired Electrical Manufacturing and Distributors, Inc. (EMD).

EMD is a provider of process controls services including automated control systems design, systems integration, electrical engineering, custom programming, and fabrication of power distribution centers, electrical racks, and control panels.

Shermco is majority-owned by San Francisco-based Gryphon Investors, a middle-market private equity firm. Terms of the transaction were not disclosed.

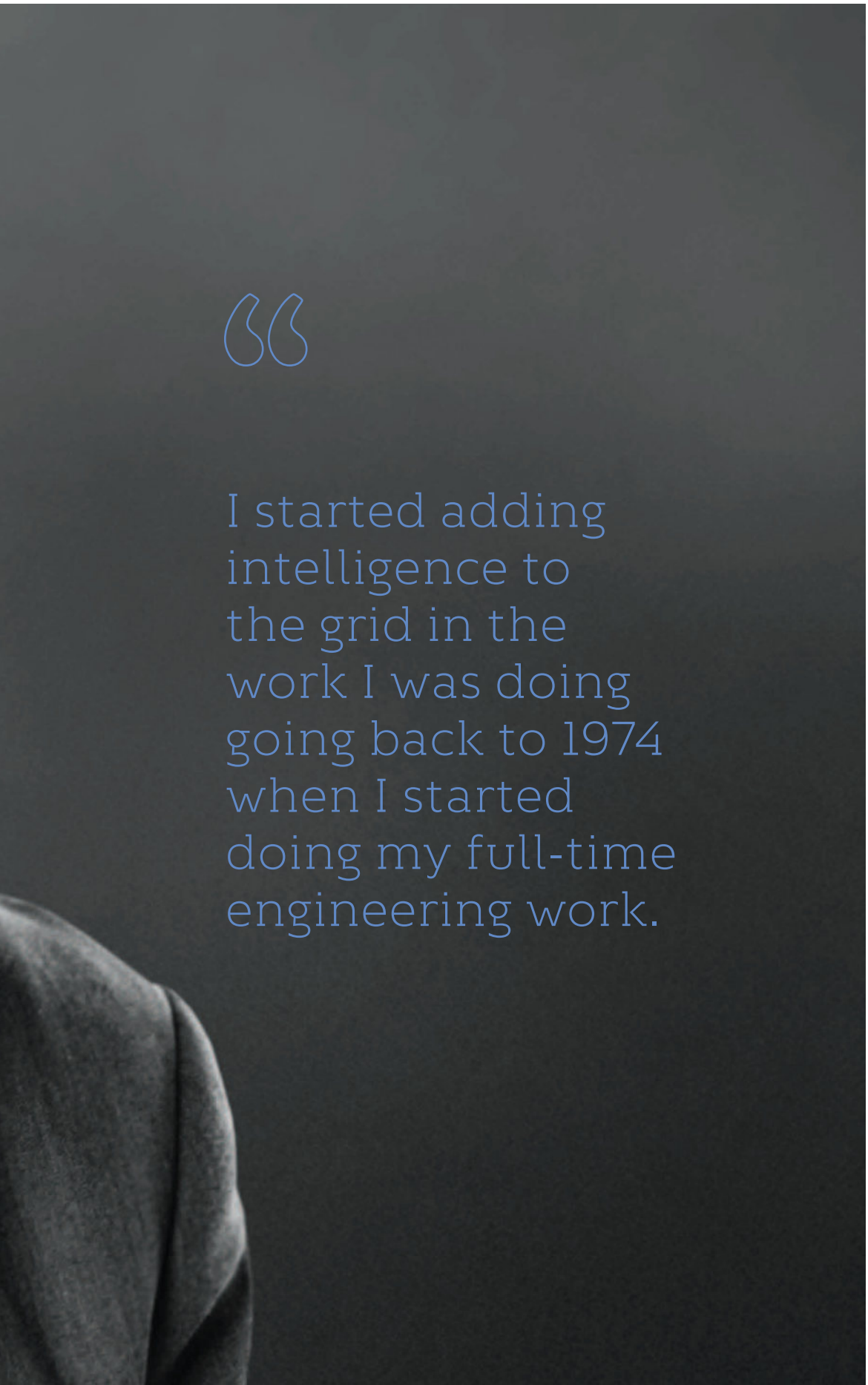
Source: PR Newswire

John McDonald

Smart Grid Business Development Leader at GE Grid Solutions

Interview with **John McDonald**

Photo: GE



John McDonald was in sixth grade when he realized he wanted to be an electrical engineer. A half century later, he is a legend in the industry.

John McDonald was in sixth grade when he realized he wanted to be an electrical engineer. A half century later, he is a legend in the industry. McDonald is an active member of the IEEE Power & Energy Society, a subcommittee chair of the society's Long Range Planning Committee, and a mentor to young professionals entering the field. McDonald has authored and co-authored more than 100 technical papers and articles and five books. Alan Ross spoke with McDonald about the smart grid (both past and present) and what seasoned professionals can do to help young generations enter the ever-changing field of transformer technology.

Transformer Technology: What are your thoughts on the Smart Grid, and how have you seen technology progress towards that goal recently and in the past?

John McDonald: About 12, 13, or 14 years ago we started hearing the term "Smart Grid," but a lot of us that had been in the industry a long time initially kind of took offense to it, because this wasn't new. I started adding intelligence to the grid in the work I was doing going back to 1974 when I started doing my full-time engineering work.

I actually call it the "Smarter Grid." I differentiate what intelligence we have been adding to the grid over the past 20 to 30 years, and what is so different [now]. The biggest difference is that we have a lot of new technology that is being developed much more quickly than ever before, and it gives us much more functionality. There are many, many more things that we can do on the grid than we were able to do before.

TT What are some examples of the advancements that define the "Smarter Grid?"

JM For a long time, we were getting data from the field every two to four seconds. And that's what we call the scan rate of the SCADA master station—the Supervisory Control and Data Acquisition system. But now, with synchrophasers, we can get 40 to 50 samples per second compared to one sample every two to four seconds. We get so much more insight into how the grid operates and it just gives us much more capability to do more.

TT I have a personal passion against proprietarization—when software or equipment sellers say "buy my thing, it's the only thing, and I control it; you have to work with me and I don't work with others." We will not have a smart grid with proprietarization. How have you been able to bring more of an integrated approach to it through your involvement with IEEE?

JM The days of standalone devices are long gone. But it only works if the different vendors with their technology components all comply with the same set of standards. There's much more emphasis today on industry standards and that's why IEEE is so important as a standards development organization. Even though there are 39 societies, and 7 councils in IEEE, the Power & Energy Society writes over 50 percent of the standards. It just shows, with respect to the grid, how important standards are.

I have chaired the substations committee, and we have 500 experts writing all the standards for the substation. Up until about the mid-90s, everything was proprietary. The communications and automation were all proprietary, because we didn't have standards that we could point to that were accepted for the industry and that were mutually agreed upon. That changed in the mid-90s, and from then on, the industry requires industry standards that are not proprietary.

TT In what ways do you help young professionals and students in IEEE enter the field?

JM I tell students and young professionals the three things that you can really benefit from when you are involved with IEEE. One is technology. Two is your network. Three is leadership experience.

First, the best way to learn technology, and to truly learn in depth, is to volunteer to write a standard on that technology.

I differentiate the intelligence we have been adding to the grid over the past 20 to 30 years from the technologies that we have now. What we have now I call the "Smarter Grid".

Photo: GE

You don't write a standard about what you've done in the past, or what you're doing today—but you do have to have a vision for the future.

You are in a room with lots of industry experts from different organizations. You're learning from everybody and everybody is learning from you. When you write a standard you can get that input from all the people there. It is so valuable and so rich—it's information that you would never get just by going to work every day at your own company. You really learn the technology in depth and you also learn where the technology is going because you're writing the standard for the future.

Second, you expand your network with really key industry context. These people that you're working with become lifelong friends, and if you ever get into a situation with your work where you're stumped and you're not sure what decision to make, or you need some more information, you have a vast network of industry people that you can always talk to.

Third, IEEE is a volunteer organization and in my 48 years being an IEEE member I've grown as an engineer and industry leader, gaining valuable leadership experience through many leadership positions I've held.

> Up until the mid-90s, everything was proprietary because we didn't have standards that we could point to that were accepted for the industry and mutually agreed upon. That changed in the mid-90s, and from then on, the industry requires industry standards that are not proprietary.

TT How can IEEE help you grow as an engineer and an industry leader, and do so at your own pace?

JM You really cannot do it in your own company, because it takes time to advance in a company. But at IEEE you could do it instantaneously. Volunteer for leadership positions. If you're interested in developing a particular standard, find out where the next meeting is, attend the meeting, and volunteer to write a part of a chapter for a new standard.

I started in the substations committee in 1987 as a working group member, but within one year our working group chair moved on and we had an opening to chair that working group and I volunteered. Within a year I was the chairman of the working group, and I had just joined the year before. There are unlimited opportunities to get really good leadership experience.

TT Many of the Legends I have spoken to as part of this series are Eagle Scouts, and so are you and your son. Tell us about that part of your life.

JM My father went through scouts himself and he really, really enjoyed the benefits of it. My grandparents were active, and my dad took my [younger] brother and me and made sure we were in Cub Scouts. My mom was our den mother, so my mom had the den meetings in the afternoon. My dad was Scoutmaster for a while in Boy Scouts. We went through Boy Scouts with a lot of support from our parents. I'm a kind of a very driven person, very competitive. I'm the type of person who always wants to see things through. The challenge of getting the ranks and the merit badges... that was important to me.
I became an Eagle Scout and I found that it really helps. [It] not only helps you with your resume, but it also helps you. In Scouts you're not only managing peers, but you're also managing adults, the leaders of the troop. I said that when I hopefully got married and had kids of my own, I'd hopefully have a son, and I would make sure my son had the same opportunities [my parents] gave to my brother and me.

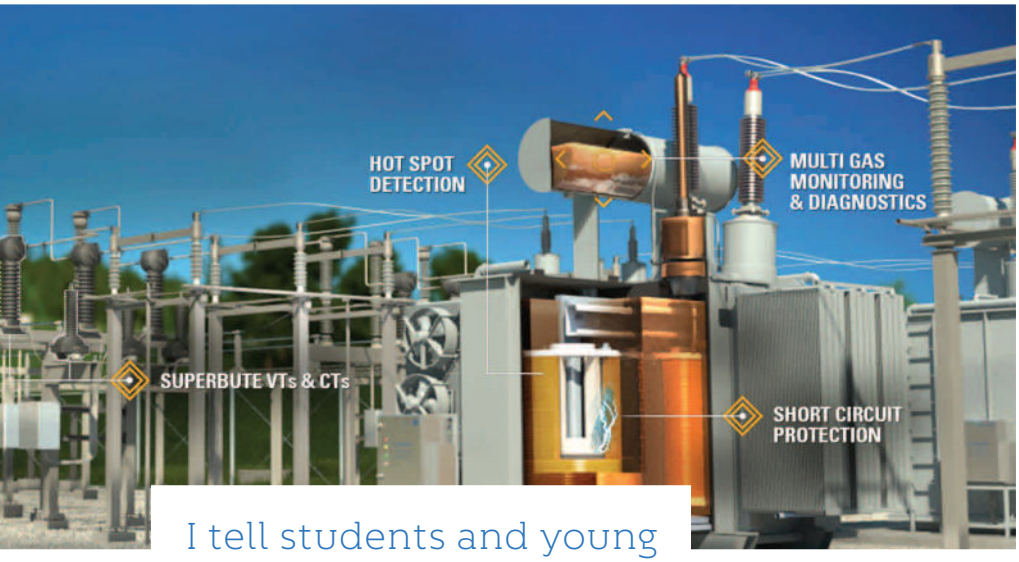


Photo: GE

I tell students and young professionals the three things that you can really benefit from when you are involved with IEEE. One is technology. Two is your network. Three is leadership experience.

TT You've run a program called Key Insights in Career Management for IEEE PES student members and young professionals. How did you do it, and why?

JM I was going to be talking to all of the IEEE PES student members in the US and Canada at the IEEE PES student congress. We always have technical talks on different technical subjects, but it is very important for students and young professionals to get some mentorship and some guidance in their career. I went through 45 years of my full-time engineering career and thought about key decisions and key things that really influenced the rest of my career, and I found that there were 12. I laid out those 12, but I wanted to present them in a way that was fun and entertaining, but still impactful, so I used a lot of family photos, business photos, and some photos from IEEE PES meetings and trips. The impact has been great both within IEEE and with my own company, as a webinar or in person. There's a link on the IEEE PES Resource Center so that anyone in the world can access it and hear what I had to say.

Best Practices for Transformer Testing and Maintenance

by **Jason Dennison**
and **Bob Rasor**

A well-maintained transformer can last more than 50 years. If you catch a fault condition early, there are corrective actions you can take to prevent further damage to the transformer and avoid costly downtime from catastrophic failure.

Why do transformers hum?

Because they don't know the lyrics.

Most of the time the transformer "just sits there and hums like it always does" behind a fence, out of sight, out of mind, which can give a false sense of security of just how much risk resides in the transformer should things goes awry and in terms of business expense and production loss.

Photo: SDMyers

Sampling and Inspection

Liquid sampling and visual inspections are crucial parts of any effective transformer maintenance program. It's most efficient to schedule inspections at the same time as liquid sampling because the person pulling the sample is already on site. After taking a fluid sample, the technician can inspect and record the vital pieces of information about the transformer, such as:

- **Gauge readings** – Record temperature and liquid levels.
- **Preservation system** – Check gas pressure, desiccant condition, and pressure relief devices.
- **Radiators** – Check for corrosion, fan operation, and pumps.
- **Surfaces** – Check for corrosion, assess the condition of the paint, and check the seals.
- **Bushings** – Check for corrosion and issues with connections and coatings.
- **General area condition** – Observe and record vegetation control, check for pests, and assess the condition of the substation fence.

A thorough inspection should also include infrared (IR) scanning of key areas such as the bushings, connections, radiators, cables, the transformer tank, and the preservation system to look for inconsistencies in the thermal profile of the unit. Infrared scanning is not as cost prohibitive as it once was. The cost of IR equipment has dropped dramatically over the past several years, and there are many service companies that provide IR scanning as a service, with some also offering diagnostic information.

When pulling the liquid sample, it is crucial to do so in a manner that ensures the sample is representative of the entire volume of liquid in the transformer. This is key to ensuring the quality of the liquid analysis. ASTM D923 provides basic instruction on proper sampling practices, and most labs will provide sampling instructions on how to draw accurate samples.

Jason Dennison is the Senior Manager of Diagnostic and Analytical Services at SDMyers, LLC. Dennison leads the world's largest transformer liquid testing laboratory with a team focused on safe operation while generating high volume data analysis and diagnostics. He obtained a bachelor's degree in Chemical Engineering from the University of Akron with Polymer Specialization and is a Lean/Six Sigma Black Belt with project management experience spanning industries such as rubber processing, metal machining, petrochemicals, compliance, software development, laboratory chemical hygiene and processes, and data analytics and diagnostics. He is a member of IEEE and ASTM and presents nationally as an authority on transformer fluid analysis.

Robert T. Rasor is Director of Transformer Services at SDMyers, where has been a dedicated member of the engineering team for 41 years. Rasor has worked in several positions from a product design and field commissioning engineer to his current role directing field service, operations, and plant management. He supervised global PCB operations facilities in eight countries and led a manufacturing group that designed and delivered hundreds of pieces of custom and production oil process equipment. He is active in technical societies such as IEEE, and is the active chair for C57.106, the Guide for Acceptance and Maintenance of Insulating Mineral Oil in Electrical Equipment. Bob is the Technical Director for SDM.

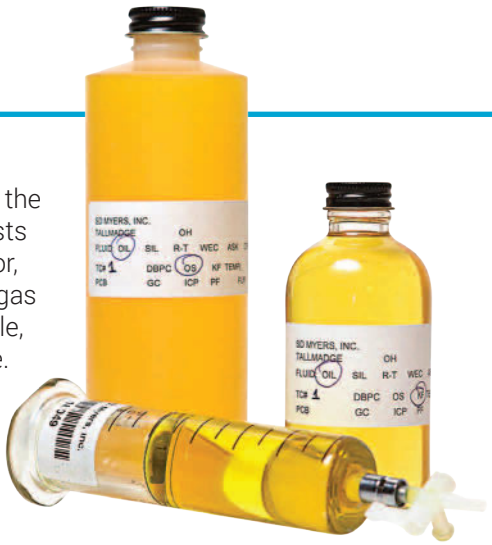
Typically, the sampling process starts at the sample valve , located near the bottom of most transformers. The first step is to flush liquid through the valve in order to clear out stagnant liquid in the valve body that may not be representative of the rest of the liquid inside the transformer. This liquid is waste and must be handled according to regulations from bodies such as the EPA, and according to your organization's spill containment plan.

Transformer oil sampling

Did you know? Convective and conductive forces inside the transformer play a key role in homogenizing the liquid and its characteristics inside the tank of the transformer. This homogenous liquid is what you want to send as a representative sample to an analytical lab.

Transformer oil testing lab

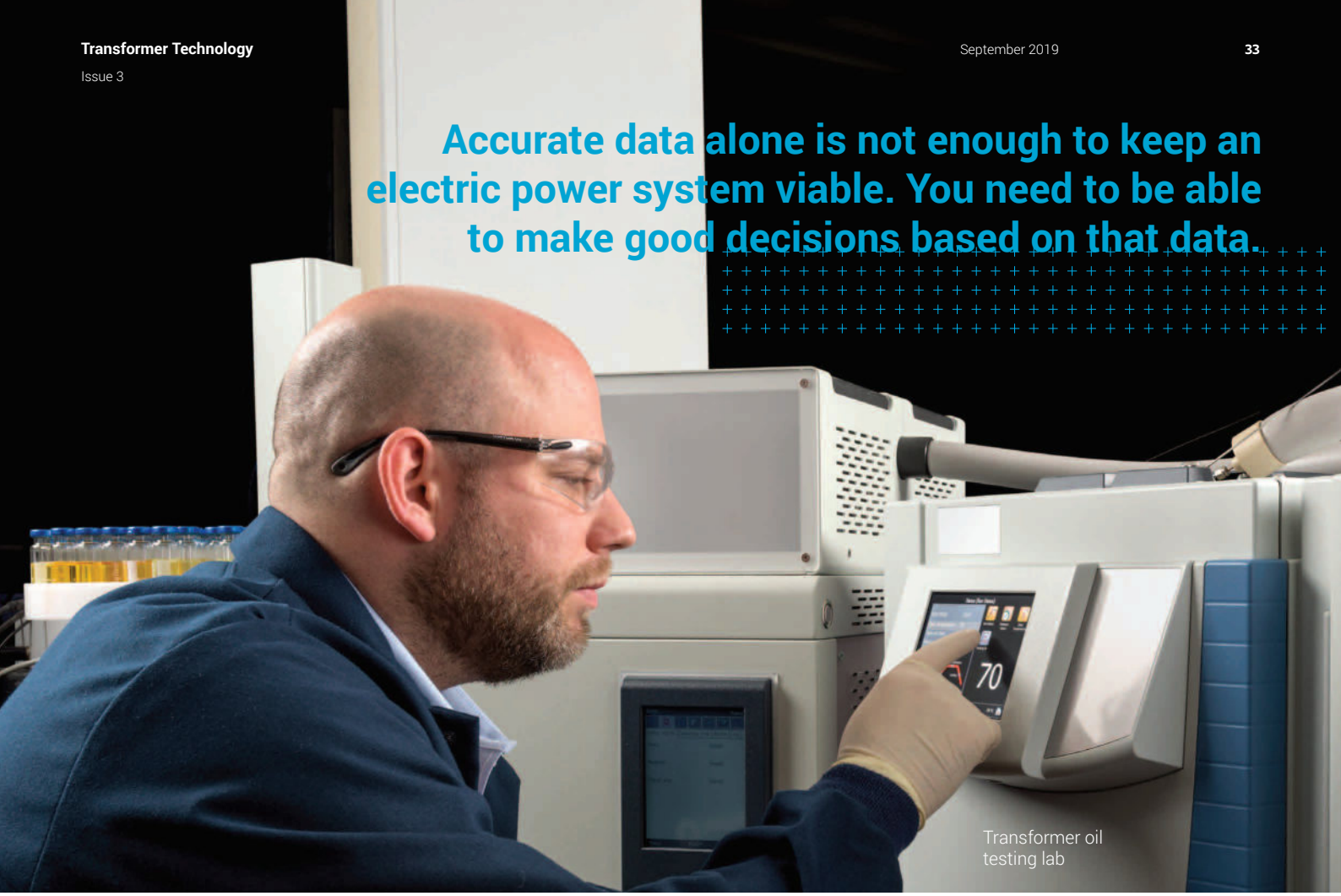
Sample containers vary based on the test performed. Containers for tests such as liquid screen, power factor, moisture analysis, and dissolved gas analysis will include a plastic bottle, a glass bottle, and a glass syringe. It is considered best practice to fill the containers in the order of the sensitivity of the analysis. The container for DGA testing, for example, should be filled last, because it allows as much liquid to flow through the sample valve as possible to get the most representative sample of the liquid inside the transformer. All sample containers should also be clearly labeled to pair the sample with the transformer from which it came.



Oil sampling containers

Photo: SDMyers

Accurate data alone is not enough to keep an electric power system viable. You need to be able to make good decisions based on that data.



Transformer oil testing lab

Liquid Testing

There are a great number of tests that can be performed on dielectric liquids that can help assess the health of a transformer. The most common tests are indicators of general aging and contamination, moisture incursion, and incipient faults. These tests are:

- **Liquid Screen** – A group of tests that looks for premature aging of the dielectric fluid. A liquid screen can also point to contamination from internal issues such as coking or sludge, or external issues such as contamination from other liquids.
- **Karl Fischer** – This test determines the presence of moisture in the dielectric liquid, and the liquid temperature determines the percent saturation of water. This is an important test because moisture in dielectric liquids can lead to oxidation and formation of acids that degrade the solid insulation.
- **Dissolved Gas Analysis (DGA)** – A DGA detects the presence of key gases that can identify incipient faults from low- to high-energy events and can point towards issues with the solid insulation.

This group of tests is the foundation for assessing the health of a transformer. Depending on the criticality of a transformer—the estimated impact of potential loss—further testing may be required. These tests can be performed during routine testing or when diagnostics suggest that an issue is present. Some of these tests include:

- **Power Factor** – This test can indicate liquid breakdown, contamination, and, in some cases, moisture.
- **Inhibitor** – Transformer oil typically includes an inhibitor to help prevent oxidation, which can lead to premature aging of the liquid. The weight percentage can be determined by this test.
- **Furan Analysis** – A byproduct of paper degradation is the formation of certain compounds, called furans, which can be correlated to the tensile strength of the solid insulation in the transformer.
- **Metals in Oil** – By burning off organics in the liquid, this test can determine very low quantities of metals such as aluminum, copper, and iron.

Other specialized tests exist to determine certain impurities or to confirm physical properties of the liquid, such as Corrosive Sulfur, Flash and Fire Point, Particle Counts, and Filming Compounds.

This is not an exhaustive list of tests available, and there are other tests that may be useful too. These tests are typically ordered based upon the results from regularly scheduled testing.

Ultimately, which tests to perform at what interval is a decision that asset owners should make through the lens of maximizing the reliable life of the transformer.

A transformer powering the light in the parking lot, for example, would be considered less critical than a transformer that powers a data center or operating room. It's also important to view the power system as a whole. Performing an impact assessment across the power system can identify opportunities to shore up the reliability in any operation.

Diagnostics

DATA»INFORMATION»KNOWLEDGE»WISDOM

Accurate data alone is not enough to keep an electric power system viable. **You don't need just the data; you need to be able to make good decisions based on that data.** Translating data into insights requires expertise.

While industry organizations like NFPA have standards on manual sampling, and ASTM has standards on sampling liquids and performing tests, many standards are available that can assist in diagnosing the condition of a transformer. IEEE guides such as C57.106 and C57.104, and IEC guides such as 60567 and 60599, pertain to acceptance criteria and result interpretation.

The key to useful diagnostics is in **understanding the actual transformer** so that the guides, standards, and practical experience can be used in concert to assess its health. For example, without practical knowledge of the transformer, the recommendations in the guides might state that the level of acetylene in a DGA of a new oil-filled cabinet transformer is a concern, and recommendations range from "test it again" to "purchase a DGA monitor" to "shut it down immediately." But it is possible that the acetylene inside the new cabinet transformer is left over from the welding process during manufacturing. Pairing the guide recommendations with practical knowledge, it is possible to make an informed decision on whether to perform ongoing DGA to be sure that the result is not indicative of a fault and to establish a baseline for future analysis.

Diagnostics should be action oriented. It is common for experts to see early warning indications of problems in test data, and for them to recommend further action. Often, however, these warnings are ignored. Many failures could have been avoided if they had been addressed earlier.

There are thousands of transformers in our database that are more than 50-years-old. Achieving this length of service depends on the people responsible for maintenance having a reliability mindset and the capability to address warning signs as early as possible. Some issues can be fixed without an outage, though many issues do require planning a shutdown. While inconvenient, a planned outage is much more cost-effective and manageable than an unplanned event that could severely disrupt operations for an undetermined period of time.

The key to useful diagnostics is in understanding the actual transformer so that the guides, standards, and practical experience can be used in concert to assess its health.

Monitoring

The field of remote transformer monitoring devices and services has been developing for many years. However, as our industry better understands the capabilities and as communication technologies become more cost effective, the field is gaining traction. System security is improving but will continue to be a key issue for the advancement of monitoring devices that require connectivity, particularly as more of what is traditionally "Operations work" leans more heavily on IT infrastructure and support.

It is common to test a transformer via laboratory analysis one to four times per year at routine intervals.

DGA monitoring

Laboratory testing and continuous monitoring are both here for the long haul. The best reliability plans will exhibit the flexibility to capitalize on both types of data.

The advent of continuous monitoring changes the landscape on the quantity of data available by orders of magnitude. This volume of data can be a powerful asset for understanding the ongoing condition of a transformer. It does, of course, change some of the skillsets required to care for critical assets. The job market for business and data analysts is exploding as companies come on board with data-rich applications. It is no longer enough to just acquire data; you must also be able to make it understandable and actionable.

Laboratory testing and continuous monitoring are both here for the long haul. Traditional laboratory analysis generates high quality, high integrity data from systems and processes that have been honed over decades against methods that are defined by standards bodies such as ASTM. Continuous monitoring as an emerging technology is going to play an increasingly larger role in helping asset owners make faster maintenance decisions, and the volume of the data can be used for trending and for more sophisticated analysis. The best reliability plans will exhibit the flexibility to capitalize on both types of data; the pairing of all that data with in-depth knowledge will drive an organization toward more intelligent decision-making.

Oxidation, Aging and Reliability

The paper insulation is what gives the transformer its mechanical strength. This remains the most prominent factor in the reliable life of your transformer. The term "reliable life" refers to the transformer's ability to take on expected stresses—load variations, surges, lightning, and temperature variations—and maintain servicing levels and frequency.

How Does the Insulation Weaken?

Short answer: **oxidation and moisture degradation**. Strength is measured by the Degree of Polymerization (DP). DP is a measurement of the average length of the cellulose molecule chains that make up the paper and is directly related to its tensile strength. Shorter cellulose molecular chains mean lower tensile strength and weaker paper.

Oxidation and moisture degradation weaken the paper insulation. Acids are created in transformers due to oxidation and will weaken/age the insulation. Since the insulation strength (DP) is based on the cellulose molecular chain length, damage from acids (created during oxidation) to the chain results in lowered tensile strength for the transformer's eventual inability to withstand original design stresses. The damage is irreversible.

The paper insulation exists in a mineral oil environment. If the oil stays in acceptable condition, the paper has an optimal environment to maximize its life and reliability. However, oil is a hydrocarbon and subject to the chemical laws governing it. Heat, moisture, and oxygen are present in transformers and cause oxidation where acid is formed, as well as other destructive oxidation byproducts, including more moisture.

These acid compounds are polar and are attracted to the paper and absorbed by it — even as they are created. The acid builds up and weakens the paper by breaking bonds and shortening the cellulose chains (lowering DP), meaning the tensile strength lowers. As noted, moisture is also destructive to paper, so keeping moisture levels in acceptable ranges is also important (see IEEE Field Reconditioning Guide C57.140, Section 7.2).

Acid—an oxidation byproduct—deteriorates the paper insulation

Photo: SDMyers

What Are Aging Indicators?

Regular intervals of fluid testing are economical and also still the most commonly used means to monitor transformer reliability. **Aging indicators** include elevated acid, lowered IFT, elevated moisture and Liquid Power Factor along with the creation and presence of furanic compounds. When cellulose paper degrades, furans are liberated. Furans are created from the paper and found in the oil. They are measured in parts per billion. Additionally, there are more chronic aging dissolved gases present, such as carbon monoxide (CO). Electrical testing and the strength of the insulation also correlate to Insulation Power Factor.

Typically, the age of a transformer does not necessarily affect its performance—unless there is a fault condition. Severely overheated transformers can degrade rapidly. It is important to make sure cooling packages are working properly and levels are maintained. If fluid levels drop below the cooling ports, severe damage can happen quickly. Visual inspections of all the mechanical aspects of a transformer must be a part of all sampling and services.

Can the Damage from Acids Be Limited?

Yes, at first. But as time goes on and corrective action is deferred, the acids and other oxidation products eventually form sludge, which leads to localized overheating. Heat is one of the necessary conditions for oxidation. Therefore, additional heat further intensifies the oxidation, and again, results in more water that further intensifies oxidation. Servicing the still reliable paper insulation early will limit damage. The acid, being polar, is quickly absorbed into the paper and leads to detrimental effects, namely small and larger amounts of acid that will eventually cause damage and can be corrected. There are widely accepted stages to this aging process:

1. Acid is usually first generated in the oil by oxidation from the presence of heat, oxygen, and moisture. It is true, however, that the paper can also oxidize independently of the oil.
2. Initial small amounts of this acid are first absorbed by the paper insulation. Oil levels remain in the "acceptable" range. At this point, keeping oxidation inhibitor at the proper levels will continue to retard oxidation.
3. The "questionable" range is when to take action with oil processing. Keeping the acid below the damaging range will avoid loss of the paper insulation's strength.
4. Once the acid has reached 0.1 mg KOH/g, damage has begun, and action is vital. Stop further damage with Hot Oil Cleaning. Despite the name, Hot Oil Cleaning cleans the insulation, not just the oil, by ridding the insulation of destructive acids and sludges. At this stage, furans can be rising and may be 500 ppb or greater.
5. Once furans are over 1,000 ppb, the paper will show significant damage. Any action taken can slow further damage but will not recover what has been lost.

How is the acid in the transformer corrected? Hot Oil Cleaning and absorptive clay treatments can create a solvent-like action to dissolve and remove the acid and sludge. As the oil is heated and cleaned, it also cleans the paper insulation when done with the proper treatment recipes. The controlling factors for effectiveness are heat, dwell time, and adsorbent clay in a vacuum oil purifier.

How can you slow or prevent oxidation? Processing services exist to prevent, slow, or even stop oxidation. Here are a few common approaches in our industry:

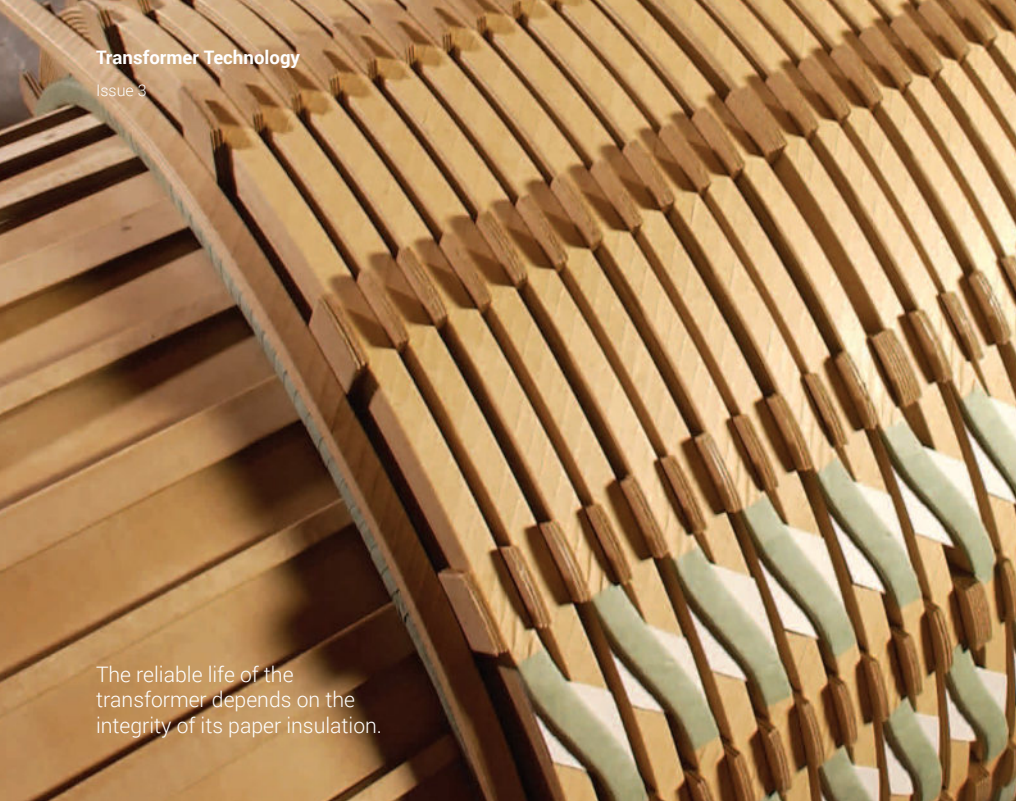
1. Control the moisture. **Moisture reduction is key** to slowing and stopping oxidation. As much as 75 percent of transformers with oxidation issues in our database have an accompanying moisture presence. It can be a little confusing as to which came first, since moisture not only causes oxidation, but is also a byproduct of oxidation.
2. Dry and cool the oil. Where oxygen from the air is present in a transformer, moisture and heat can be reduced. Passive dryers work, but if load and ambient are driving up temperatures, additional auxiliary cooling may also be needed to reduce these components to oxidation.
3. Apply **Oxidation Inhibitor** to the oil. Inhibitor is a primary way to combat oxidation and is supported by IEEE C57.106. As the oil produces free radicals, the oxidation inhibitor will react with and stabilize them, thus stopping the oxidation chain reaction in its earliest stages. Ideally, **oxidation inhibitor levels should be kept at 0.3 percent** or greater.

What about damage already done? Once the cellulose is damaged, insulation life cannot be restored. The damage is irreversible. Here are some points to consider:

- Hot Oil Cleaning improves the condition of the insulation. The smaller the amount of acid in the insulation, the lower and slower is its destructive effect.
- There is a point whereby, looking at the condition of the insulation, the oil, and results from other important indicators such as IR and electrical testing, the best course of action is to replace the transformer.
- Consider the past furan and DP levels prior to oil reclamation. Most oil processing with clay filtration such as Hot Oil Cleaning will strip furans from the oil.

Consider the time and temperatures needed for proper and complete cleaning. Oil can be cleaned in just a few passes in lower temperatures. It takes more passes at a higher heat to provide adequate cleaning of the paper. If the oil only is cleaned and the paper left untreated, within months the acids will come back out of the paper and oil qualities will again move away from the "acceptable" range.

Healthy insulation is promoted by controlling the harmful byproducts of oil oxidation. This optimizes the strength of the paper insulation which is the reliable life of the transformer.



The reliable life of the transformer depends on the integrity of its paper insulation.

Combustible Gas Issues

Combustible gas levels are an indicator of an abnormal condition in a transformer. They are created by excessive localized or general overheating. Extreme temperatures and arcing are identified by a key gas: acetylene. These conditions are typically acute and must be dealt with immediately. The following are typical steps taken to correct them:

1. Retest to confirm the condition.
2. Arrange an immediate inspection and include electrical testing, depending upon the severity. Many issues can be field-corrected. Untanking is rarely done in the field, so there are repairs that require taking the unit out of service and shipping it to a repair facility.
3. Drain and perform an internal inspection.
4. Make repairs in the field, when possible.
5. Refill the transformer. Care must be taken to fill with the proper procedures. Vacuum rated transformers must be vacuum filled if the core has been exposed. UHV units require a complete drain and fill any time the oil is lowered.

If refilling a lower voltage unit, cleaning can be performed with a cartridge filter. Consult with OEM requirements. In this case, the oil will still contain combustible gases and it must be degassed with a vacuum oil purifier. This will reset the gas levels.

Some leach back is expected for the first several months.

Staying ahead of leaks and maintaining the correct level is another important aspect of reliability in transformers. The regular visual inspection assures this. It is recommended to perform a visual inspection no fewer than four times a year. The following are some of the aspects of the inspection:

- **Level in the transformer**. Keep in mind, some training is required to interpret the level gauge with respect to the temperature of the oil. Oil expands 1 percent for every 10 degrees Celsius. A 25-degree Celsius measurement is "normal" or "low" if the oil temperature is significantly higher than 25 degrees Celsius.
- **Leak inspections**.
- **Gauge information**. A consistent "zero" psi on a pressure vacuum gauge often indicates a leak, as the transformer is not holding pressure or vacuum. A transformer with a leak is "breathing" ambient air and, therefore, humidity in and out of the transformer. The moisture is however typically only "in" as the oil and insulation have a high affinity for moisture.
- **Paint and rust condition**.
- **Bushing and insulator surface condition**.
- **Overgrown vegetation in the substation** that could lead to a flashover.

As the oil is heated and cleaned, it also cleans the paper insulation when done with the proper treatment recipes. The controlling factors for effectiveness are heat, dwell time, and adsorbent clay in a vacuum oil purifier.

Photo: SDMyers

Best Practices

Whether you're conducting oil processing, doing transformer repair, or electrical testing, there are best practices that are important to follow for safety and reliability.

It is helpful to define procedures and equipment to optimize the services rendered. For instance, in oil processing, it is important to not just filter oil, but also to address **cleaning the paper insulation**. When oil processing, require pumping records to assure the temperature and passes will achieve the required results. Reaching 70 degrees Celsius is optimal to allow the oil to reach the aniline point where it can dissolve oil generated sludge and acid

Additionally, moisture cannot be corrected by "pumping" on a transformer, as there is approximately 100 times more moisture in the paper insulation than there is in the oil. Instead, use either **vacuum dryout techniques or online moisture dryers**, as defined by the Field Guide of IEEE, C57.140.7. Online dryers are effective in moisture reduction.

Selecting and Working with a Contractor

It is always important to contract with an experienced provider with a proven safety record and a well-documented training program. There are a number of contractor-related criteria to be included in the scope of the project. Always create a written, clear scope of work for any bidding purposes. This will help avoid short cuts and define expectations.

As mentioned, you should require pumping records to achieve the required results when oil processing. When electrical testing, make sure it is defined as who is disconnecting and grounding. When hiring a contractor, you should:

- Define work hours and how to handle changes that are discovered while on site. At a minimum, have the provider control and monitor moisture and the acidity of the oil.
- Define work hours and how to handle changes discovered while on site.
- Ask that the provider have an equipment reliability program to assure excellence in the equipment being sent including safety gear inspection and key calibration records.
- Refer to C57.106, the "Oil Guide," which can be used for oil quality requirements.
- Follow IEEE C57.93 and C57.140 for field drying and vacuum filling. Be aware of the required set times after filling before energizing when the core is exposed.
- Ask that the provider have an equipment reliability program to assure excellence in the equipment being sent, including safety gear inspection (PPE) and key calibration records.

Environmental Considerations

- Be sure the provider has Field SPCC (Spill Prevention Control and Countermeasures) training, including the use of spill berms, and that they have a spill kit on site.
- Process units from lowest to highest so as to never add to the PCB content of the next transformers. If you have PCBs, expect some surcharges—there are legitimate costs to do it right.
- Be aware of the advantages of the new Ester liquids. These are popular for a reason as they hold up well. They are fire resistant (Fire Point of 300 degrees Celsius) and they are eco-friendly. Ester fluids can be processed in most equipment with a pre- and post-flushing adder. Getting some esters in oil is not much of an issue, but too much oil (>6 percent) will lower the flash point.
- Use a filtering clay when oil processing equipment that improves acid. There are environmentally friendly solutions for regeneration that avoid landfill or incineration of the oily waste. In general, you can expect a drum of waste for every 3,000 pumping gallons of oil.

Reliability Outcomes

Data supports the principles and action-related reliability steps in this paper. In a paper published by CIGRE and the IEEE, which considered 1,500 transformers, the transformers with services to combat oxidation and moisture showed more than six years of extended life per service rendering. This doubled the life of the average transformer, which was reported in many studies to be under 20 years.

Additionally, by maintaining frequent visual inspections and regular fluid and electrical testing, the probability of a surprise lapse in reliability is very small. As indicators trend toward aging, plans for contingency and an acceptable timetable for a planned outage will negate further concerns for a lapse in power provision.

There are transformers backed up by spares or double-ended subs. We refer to these more important units as being **system critical**. Units that shut down operations, or huge segments of your operation, are considered **mission critical**. This reality takes the units with the mission-critical rank and looks at condition or monitoring and moves them to the top of the priority list. Meanwhile, a system-critical unit in bad shape will also be

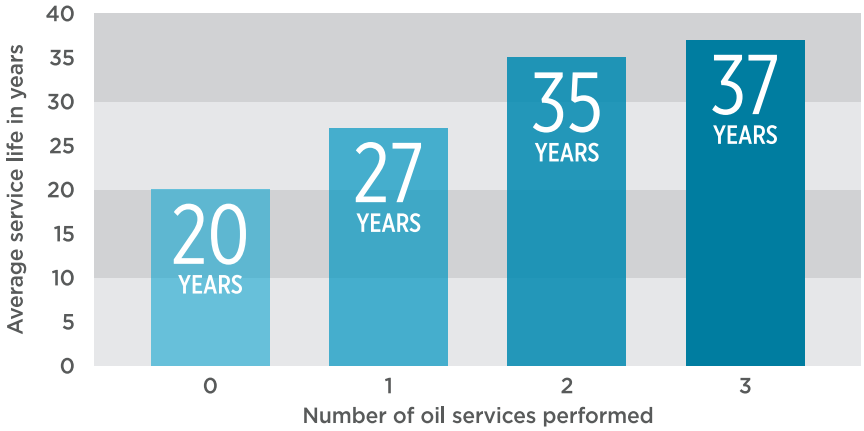
a top priority and warrant a spare or double-ended sub.

When power and people's lives are at stake, a backup electric source might be in order, as well as a backup generator and reliable fuel source. Hospitals and mines are good at this. There are product and service providers who have designed levels of commitment based on non-critical and system or mission-critical transformers.

Even reliable transformers need **contingency plans**. On mission-critical units, the need and timeliness for the required power restoration leads to double-ended subs, spares, and generators — all components of contingency plans. Some main transformers are supported by the power supplier with spares or mobile substations to restore power in four to eight hours. Some operations cannot live with any power interruptions and need a generator and an adequate fuel supply. Production, engineering and finance departments play roles in determining the best fit for a reliability program and the contingency programs for each power system.

Average Service Life Related to Number of Oil Services Performed

An SDM study based on 1,534 decommissioned oil-filled transformers > 500 kVA



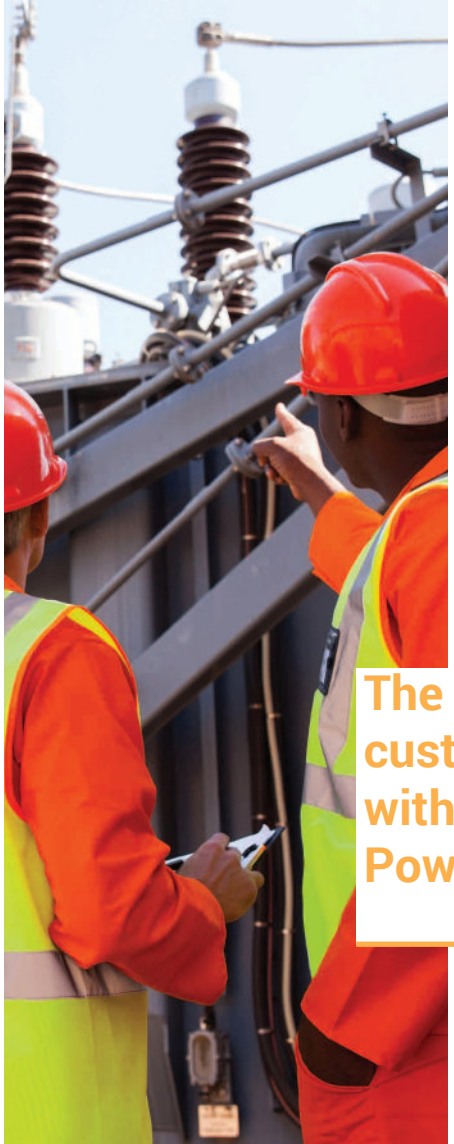
By maintaining frequent visual inspections and regular fluid and electrical testing, the probability of a surprise lapse in reliability is very small.

Photo: SDMyers

Three Tips for Reducing Wasted Time When Testing Transformers

by **Brandon Dupuis**

Brandon Dupuis received a B.S. Electrical Engineering from the University of Maine. He joined OMICRON electronics Corp. in 2013, where he presently holds the position of Regional Application Specialist for transformer testing. Brandon's focus is currently on standard and advanced electrical diagnostics for power transformers and circuit breakers. Presently, Brandon is a well-known OMICRON instructor teaching electrical transformer diagnostic testing theory, application, and test result analysis, which includes both presentations and hands-on training. Brandon is an active member of the IEEE PES Transformers Committee.



The transformer test that customers most struggle with is the transformer Power Factor test.

Review the "Power Factor Checklist" Prior to Testing

Performing offline electrical tests on transformers can be time-consuming, especially when the field measurements are not captured correctly the first time. This article identifies the electrical transformer tests that test equipment users often struggle to perform efficiently and correctly. Three field-testing tips will be provided, to address the transformer tests that are often "time-suckers". By building awareness, test equipment users can better avoid the situations where a significant amount of time is lost due to retesting, troubleshooting, and collaborating with test equipment manufacturers.

Without a doubt, the transformer test that customers most struggle with is the transformer Power Factor test (which includes the Overall Test, the Bushing C1 Test, and the Bushing C2 Test). Unfortunately, the Power Factor test is highly sensitive to the test environment, to the test lead connections, and to the test specimen's earth-ground connection, among other things. Since the Power Factor measurement is highly sensitive, obtaining the correct (i.e. the valid) Power Factor measurements in the field is challenging.

The high sensitivity of the Power Factor test is a double-edged sword: On one hand, the high sensitivity makes the Power Factor test a powerful tool for identifying compromised insulation (e.g. moisture ingress, contaminated oil, a "bad bushing", etc.). On the other hand, the high sensitivity makes the Power Factor test prone to measurement error.

To save wasted time and prevent from retesting, troubleshooting, and collaborating with test equipment manufacturers, the following Power Factor Checklist should always be reviewed, prior to executing any Power Factor measurement:

- **Are the transformer tank and the test-equipment solidly grounded to earth-ground potential?**
  Not connecting the test specimen and the test equipment to a solid earth-ground reference is the most common mistake test equipment users make in the field.

- **Are the bushing terminals of the transformer completely disconnected and isolated from all cable, bus-bar, support insulators, surge arrestors, etc.?**
  When applying a test-voltage of 10 kV, a minimum clearance of 3 in. should be established (between the terminal(s) that is energized and all other surfaces). Avoid using a rubber blanket, insulated gloves, etc. to isolate the bushing terminals from external surfaces – ***the best insulator for Power Factor testing is air!***

- **Are the surfaces of the bushings dry (and reasonably clean)?**
  Moisture on the surfaces of the bushings can significantly influence a Power Factor measurement. In most cases, using a clean, dry rag to dry the surfaces of the bushings is sufficient. In cases where excessive surface contamination on the bushing surfaces is present, using Windex or Collinite may be used to clean the surfaces of the bushings, and thus, may improve the Power Factor measurements.

- **Are the groups of bushing terminals short-circuited together? All primary side (H) bushing terminals must be shorted together, and all secondary side (X) bushing terminals must be shorted together.** Always use NON-insulated conductor(s) to short-circuit the bushing terminals together when performing a Power Factor measurement – Do NOT use insulated shorting leads. If insulated conductor(s) are used, then the conductor's insulation can easily become part of the Power Factor insulation measurement. Also, connect the shorting jumpers as tightly as possible from bushing-terminal to bushing-terminal (in other words, do not let the shorting jumpers sag and/or touch any surface other than the terminal being energized).

- **Remove all in-service grounds from any neutral bushing terminals.**
  For example, remove the in-service ground-connection from the X0 bushing terminal, if applicable.

- **Place the LTC in any off-neutral tap-position.**
  Some transformer Load-Tap-Changers (LTCs) utilize a "tie-in resistor", which has been known to influence the Power Factor measurements, when the transformer is tested in the neutral tap-position. Specifically, Federal Pioneer Electric and Federal Pacific Electric transformers with LTCs have been known to exhibit this behavior.

- **Ensure that the exterior surface of the test equipment's high-voltage cable is not touching any surface of the transformer, at the "far end" where the test terminal is being energized.**
  A conservative approach is to ensure that the last two feet of the far end of the test equipment's high-voltage cable is not touching the transformer tank, the surfaces of the bushings, etc.

- **Be aware that the test environment can significantly influence a Power Factor measurement.**
  - Do not Power Factor test in the rain.
  - Avoid testing in high-humidity situations (where excessive moisture is present).
  - Avoid Power Factor testing when the temperature of the transformer oil is below 0°C.
  - Power Factor test after lunch, if possible (which is typically when the least amount of moisture/ humidity is present).

The Power Factor Checklist is intended to help test equipment users "get the measurement right the first time", which is the most practical strategy to saving wasted time when testing transformers. In conjunction with the Power Factor Checklist, the Variable Frequency Power Factor test can be utilized by test equipment users, to quickly and easily *confirm* that the Power Factor measurements obtained are indeed correct.

Photo: Omicron

Identify Incorrect Power Factor Measurements Before Leaving the Job Site

One of the most common scenarios we encounter as a test equipment manufacturer is when a customer contacts us to review a set of power transformer test results. Often, the data set is provided *after* the test equipment user has left the job site and returned to the office. Upon reviewing the data, we (OMICRON) frequently identify incorrect Power Factor measurements, and recommend that the customer retest, to obtain the correct results.

Regardless of whether the transformer is still offline or has been re-energized, once this scenario occurs, a significant amount of a company's time and resources have been wasted. If the crew returns to the field to retest, then time and resources are wasted testing a second time. If the transformer has already been re-energized, then the company invested time and resources to obtain invalid test-results that cannot be used to assess the condition of the transformer.

To quickly identify and correct "bad" Power Factor measurements *before they leave the job site with the incorrect test results*, test equipment users can utilize the Variable Frequency Power Factor measurement. With a Power Factor measurement at one test-voltage and at one test-frequency (in other words, with one Power Factor percentage value), it is difficult for the test equipment user to verify that the measurement is even valid; however, invalid measurements often become obvious when the Variable Frequency Power Factor measurement is performed and analyzed.

The Variable Frequency Power Factor test involves performing Power Factor measurements at a series of different test frequencies (e.g. 15 Hz, 30 Hz, 45 Hz, 60 Hz, 150 Hz, 200 Hz, 300 Hz, and 400 Hz). The general guidelines used to assess the Variable Frequency Power Factor test (along with several case studies) are provided in the paper titled "The Value of Performing Power Factor Sweep Measurements on Bushings" [1].

Table 1.

Case Study - Lapp POC 138 kV Bushings (1998)

	Measured Power Factor (10 kV - 60 Hz)	Nameplate Power Factor (10 kV - 60 Hz)
H1	0.36%	0.29%
H2	0.24%	0.23%
H3	0.35%	0.23%

Consider the bushing C1 Power Factor measurements shown in Table 1, which were obtained from testing three Lapp POC 138 kV bushings. By only analyzing the 10 kV-60 Hz Power Factor values, it is not obvious that the Power Factor measurements are incorrect; however, notice that the Variable Frequency Power Factor traces for the three bushings in Figure 1 are erratic and jagged. In general, jagged frequency-sweep traces are indicative of invalid Power Factor measurements. In this case, the customer determined that they did not short-circuit the primary side (H) bushing terminals of the transformer, when the C1 Power Factor measurements were performed on the bushings.

"Getting the measurement right the first time" is the most practical strategy to saving wasted time when testing transformers.

Figure 1. Variable Frequency Power Factor results for three Lapp POC 138 kV bushings

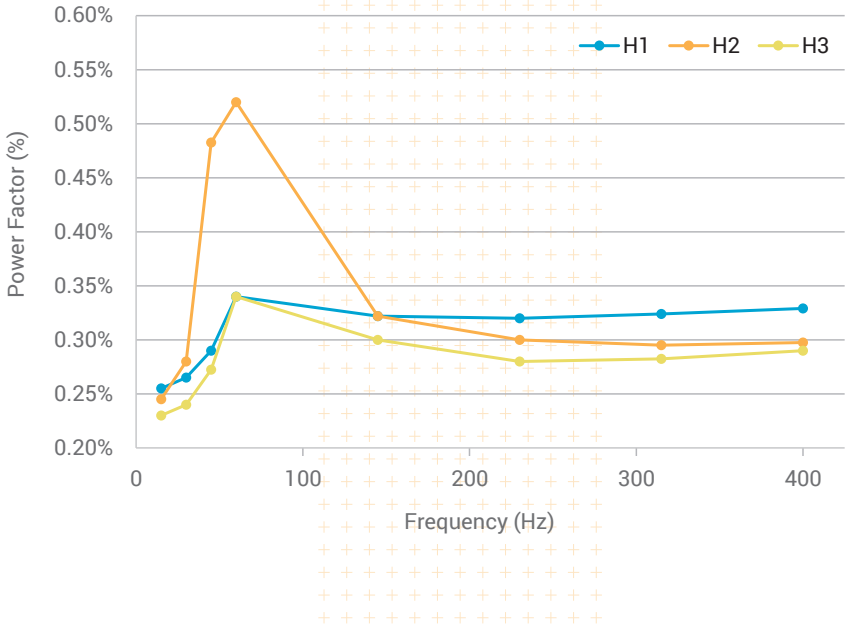


Photo: Omicron

To quickly identify and correct "bad" Power Factor measurements *before they leave the job site with the incorrect test results*, test equipment users can utilize the Variable Frequency Power Factor measurement.

Consider the Overall Power Factor measurements shown in Table 2 and Figure 2, which were performed on a Kuhlman 118 kV oil-filled transformer. The 10 kV-60 Hz Power Factor measurements look "normal" for an oil-filled transformer, but upon reviewing the Variable Frequency Power Factor traces, the customer noticed that the CH frequency-sweep trace looked abnormal. Notice that as the test frequency increases, the CH trace approaches 0% Power Factor, and even becomes negative. Negative Power Factor measurements are typically a tell-tale sign of an invalid measurement.

If the test equipment user only had the 10 kV-60 Hz Power Factor measurements on-hand, then it is conceivable that they would have overlooked the incorrect measurement. In this case, the customer determined that the transformer tank and the test equipment were not connected to a solid earth-ground reference potential.

With the Variable Frequency Power Factor traces on-hand, test equipment users can quickly identify invalid measurements, and can retest before they leave the job site with the incorrect test results.

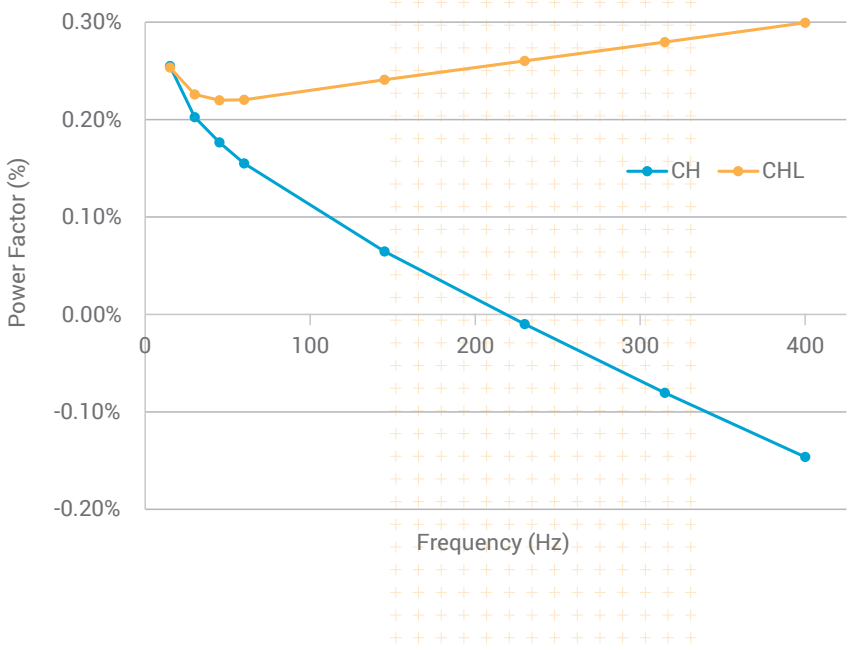
Table 2.

Overall Power Factor Measurements

Kuhlman 118 kV transformer

	Measured Power Factor (10 kV - 60 Hz)
CH	0.16%
CHL	0.22%

Figure 2. Variable Frequency Power Factor results for a Kuhlman 118 kV transformer



Select the Appropriate Test Current – DC Winding Resistance

The field transformer test that test equipment users most struggle with (other than the Power Factor Test) is the DC Winding Resistance Test. The DC Winding Resistance Test is the offline measurement for identifying bad connections and discontinuities along the current carrying path of a transformer winding [2]. Specifically, the DC Winding Resistance Test is an invaluable tool for identifying bad connections associated with tap-changers, which includes both De-Energized Tap-Changers (DETCs) and Load-Tap-Changers (LTCs).

In theory, the DC Winding Resistance Test is a simple concept that relies on the fundamental application of Ohm's Law (V = I x R) [2]; however, in practice, obtaining the correct transformer resistance measurements is challenging, because to obtain the correct measurements, the transformer's core must be saturated. The most common mistake that test equipment users make when performing the DC Winding Resistance Test is not waiting long enough for the core to fully saturate (in other words, the resistance measurements are captured "too soon"). Typically, when the resistance measurements are captured "too soon", the measured resistance values are higher than expected, which makes it appear that there is a bad connection, even when no fault exists.

The best strategy for saturating the transformer core quickly, and in turn, obtaining the correct resistance measurements quickly, is to inject as high of a DC current as possible into the winding under test. The higher the injected test current, the faster the transformer core saturates, the faster the test is performed. The following guidelines are intended to assist test equipment users with selecting the appropriate test current for a given winding resistance measurement:

- The lower the resistance of the winding under test, the higher the test-current should be.
- Typically, when testing winding resistances greater than 100 mΩ, a test current in the range of 5-10 A is sufficient – most resistance measurements performed on the primary side (H) winding of a transformer have resistance values greater than 100 mΩ.
- Typically, when testing winding resistances less than 100 mΩ, a test current in the range of 20-30 A is ideal – most resistance measurements performed on the secondary side (X) winding of a transformer have resistance values less than 100 mΩ.
- Load-Tap-Changers (LTCs) in North America are most often applied to the secondary side (X) winding of a transformer. In cases where the LTC is located on the secondary side, a test equipment user often has anywhere from 57-99 resistance measurements to obtain (that are often well below 100 mΩ in magnitude). In these cases, it is important that a sizeable test-current (e.g. 20-30 A) is available to the test equipment user, so that they may perform the lengthy test-sequence as quickly, and accurately, as possible.
- The test-current should not exceed 10% of the rating of the winding under test.
- The test-current multiplied by the resistance (of the winding under test) should not exceed the maximum compliance voltage rating of the test instrument's DC

Photo: Omicron

The best strategy for saturating the transformer core quickly, and in turn, obtaining the correct resistance measurements quickly, is to inject as high of a DC current as possible into the winding under test.

current source. In general, the more power (VA) the test instrument's DC current source is rated for, the higher the test current that can be injected into a given winding, the faster the DC Winding Resistance Test can be performed.

To summarize, test equipment users often attempt to apply the same magnitude of test current for both the DC Winding Resistance H and DC Winding Resistance X tests; however, since the magnitude of winding resistance is often significantly different when comparing the DC Winding Resistance H and DC Winding Resistance X tests, it is conceivable that two different test currents (one for the primary side test, and one for the secondary side test) should be applied when performing both tests. The most common mistake made is NOT injecting enough current when performing the DC Winding Resistance X test, which often leads to a lengthier core-saturation time, and inaccurate measurements (especially when an LTC is involved).

Again, the best way to reduce wasted time when testing transformers is to get the measurement right the first time.

References

[1] B. Dupuis, "The Value of Performing Power Factor Sweep Measurements on Bushings," *Transformer Technology*, Issue 1, pp. 56-64, June 2019.

[2] C. L. Sweetser, "Obstacles Associated with Winding Resistance Measurements of Power Transformers," *Omicron*.

Bringing Clarity to the Complexity of Condition Monitoring.

DOBLE ON-LINE MONITORING SOLUTIONS

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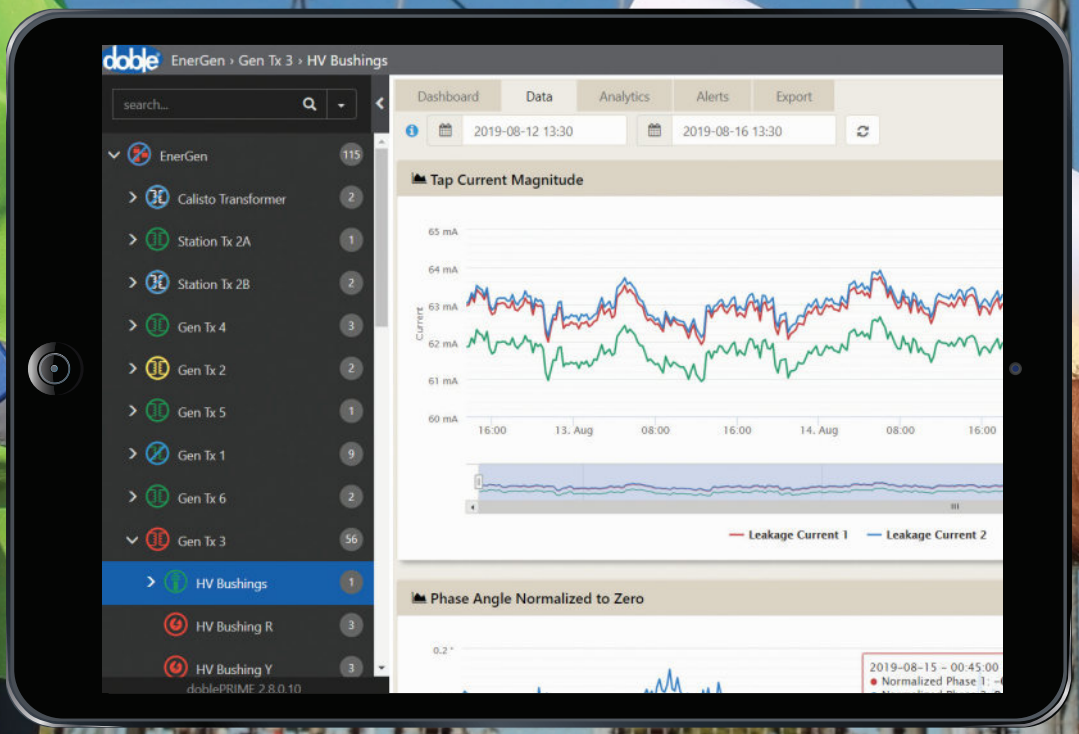

THE CHALLENGE

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.

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

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- Analytics are based on industry standards, best practices and nearly a century of Doble expertise
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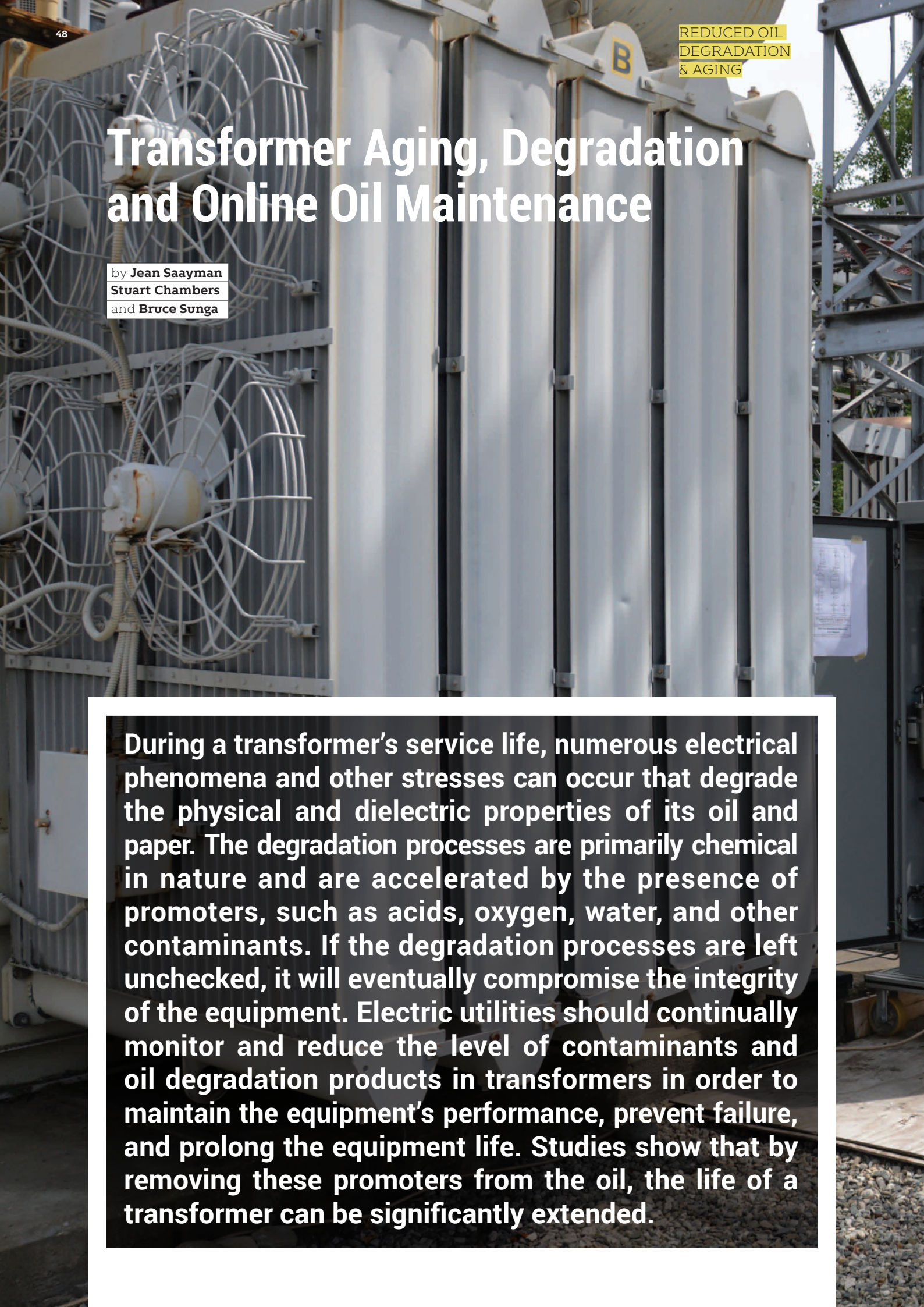
- Support is a phone call away

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.

Transformer Aging, Degradation and Online Oil Maintenance

by **Jean Saayman**
Stuart Chambers
and **Bruce Sunga**



During a transformer's service life, numerous electrical phenomena and other stresses can occur that degrade the physical and dielectric properties of its oil and paper. The degradation processes are primarily chemical in nature and are accelerated by the presence of promoters, such as acids, oxygen, water, and other contaminants. If the degradation processes are left unchecked, it will eventually compromise the integrity of the equipment. Electric utilities should continually monitor and reduce the level of contaminants and oil degradation products in transformers in order to maintain the equipment's performance, prevent failure, and prolong the equipment life. Studies show that by removing these promoters from the oil, the life of a transformer can be significantly extended.

Photo: Powertech Labs

Dr. **Jean Saayman** is a Process Engineer in Powertech's R&D, Investigation & Consulting department, where he is responsible for continued research in online decontamination and reconditioning of insulating oils. His areas of expertise include transfer processes, experimental design, transformer diagnostics, and insulation degradation and aging. He also manages Powertech projects for implementing online oil reconditioning services and conducts failure investigations of electrical utility assets.

Dr. **Bruce Sunga** is the Director of the Substations Technology and Testing sector at Powertech Labs. He brings more than 25 years of commercial, industrial and electric utility experience in areas of stations and system planning, analytical studies, asset management, project management, design, automation, R&D, construction, testing, commissioning and acceptance, failure investigation and maintenance. The Substations Technology and Testing sector is comprised of two world-renowned labs, a prestigious R&D and investigations group, a substations studies group, and field testing services and asset management group.

Dr. **Stuart Chambers** is the manager of R&D, Investigation & Consulting, as well as a lead for the polymer and materials investigation facility in Powertech's Substations Technology & Testing group. His areas of research and development include transformer diagnostics, insulating paper degradation, aging properties of insulating oils, and polychlorinated biphenyls (PCB) decontamination. He has completed substantial research into insulating solids, fluids and gases for the Electric Power Research Institute (EPRI), Canadian Electrical Association (CEATI), BC Hydro and other research organizations.

The benefits of maintaining low moisture concentrations are established knowledge in the electrical industry; however, as a greater understanding of the degradation process has been gained via research and development, the benefits of removing the other contaminants has come to light. Powertech Labs has conducted several laboratory investigations into the formation of these byproducts and the benefits of removing them, and has successfully developed, studied, and implemented novel online purification techniques on operational field transformers. This article provides an overview of the aging process of transformers, the chemistry involved, and which compounds and byproducts further promote aging.

Transformer Aging

There are five prominent contaminants present in transformer insulating oils:

- Moisture
- Acids
- Polar Compounds
- Corrosive Sulfur
- Dissolved Gases

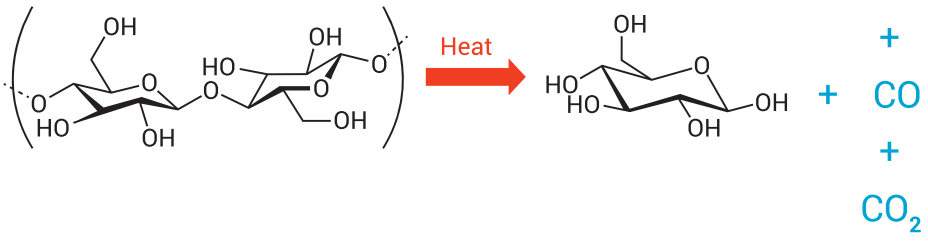
The focus of this article will be on moisture, acids, polar compounds, and corrosive sulfur and the formation of sludge. Dissolved gases can also promote the aging process, however the benefit of gases as a fault tracking method can outweigh this effect. Elevated levels of dissolved gases also present other operational issues unrelated to transformer aging and, for these reasons, there are limits at which the benefits do not outweigh the drawbacks.

The degradation processes are primarily chemical in nature and are accelerated by the presence of promoters, such as acids, oxygen, water, and other contaminants.

Moisture

Furan, moisture and dissolved CO and CO_2 are the main byproducts of cellulose (paper) degradation (Figure 1). Cellulose based degradation typically occurs due to overheating of the paper, which ranges from low energy items such as hotspots to high energy events such as arcing. The resulting decomposition compounds, gases and water from degrading cellulose dissolve into the oil as they are being formed. Oil has a saturation capacity for water and acts as a carrier of the water to the paper where it gets re-absorbed into the paper. This absorbed water "attacks" the cellulose and thus promotes further degradation which in turn produces more water and other contaminants. The process creates a positive feedback effect and can results in a rapid deterioration of the paper's Degree of Polymerization (DP). It is for this reason that the moisture content has been identified as a critical parameter to maintain assets. L.E. Lundgaard et al [1] correlated the life expectancy of a transformer to the Water Content of the Paper (WCP). Figure 2 illustrates the logarithmic nature of this effect.

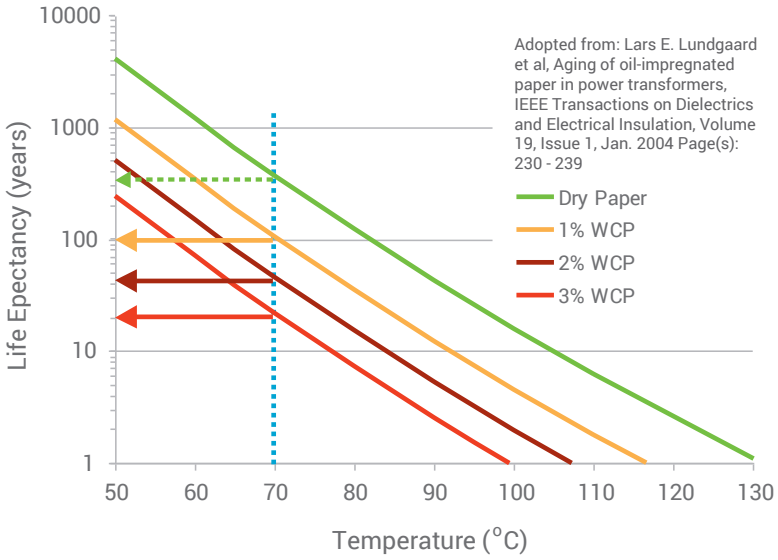
Figure 1. Furan, moisture and dissolved CO and CO_2 are the main byproducts of cellulose (paper) degradation



Not only do these contaminants deteriorate oil quality and promote further aging of the paper, they are also precursors to sludge.

Photo: Powertech Labs

Figure 2. Correlation of the life expectancy of a transformer to the Water Content of the Paper (WCP)

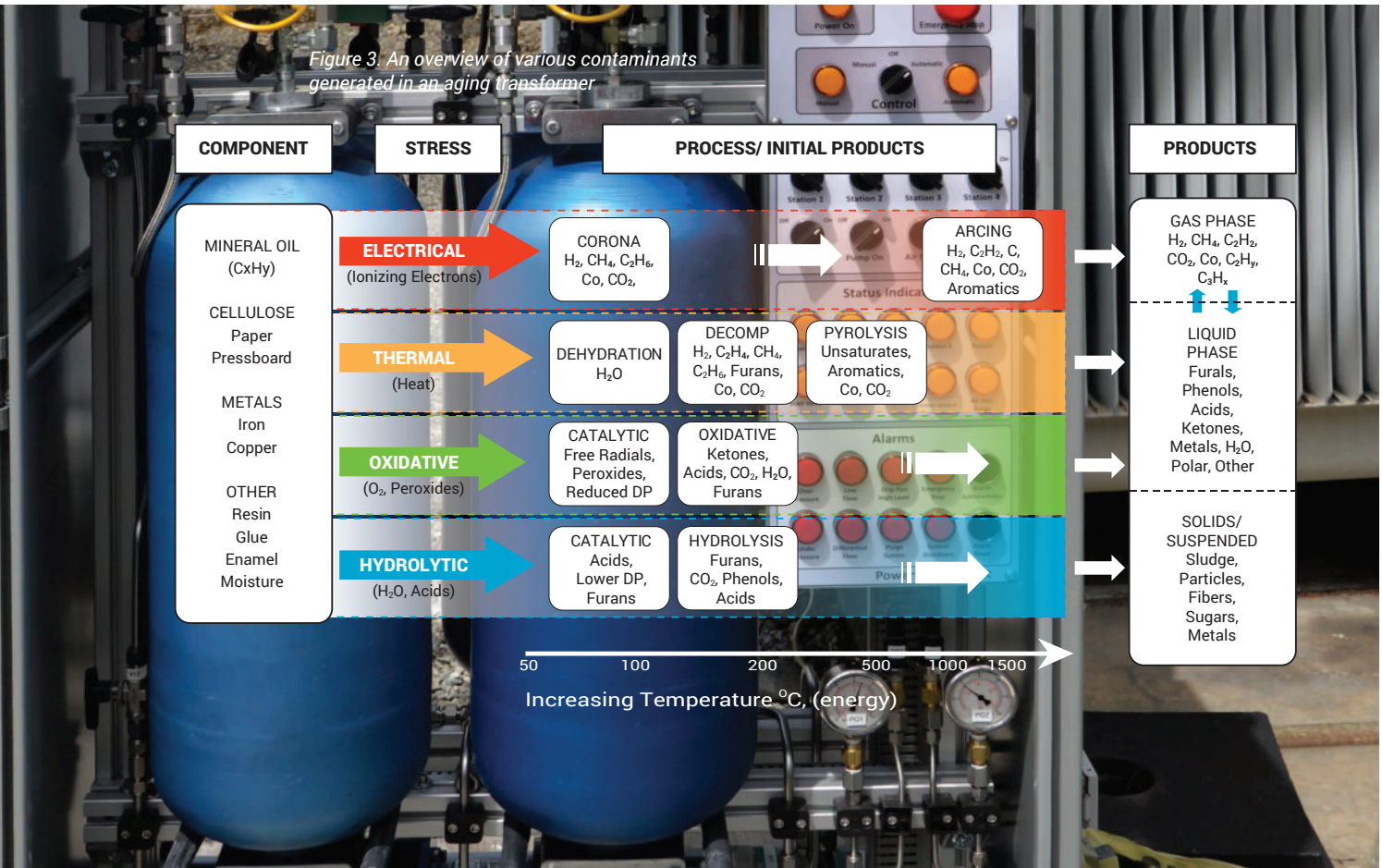


Acids, Polar Compounds and Sludge

Although moisture is a significant problem and well understood, there are other contaminants that are generated in an aging transformer with affects as detrimental, or worse, than moisture. These other contaminants that are generated from paper and oil include; acids, acetone, methanol, polar compounds, and other oxidation products. Phenolic compounds, acids, and additional polar compounds can form from the laminates, spacers, glues, and wood. Like moisture, these contaminants also promote and increase the rate of aging. A simplified yet comprehensive overview of the various contaminants that can form is shown in Figure 3, which includes details on the types of stress and components that generate these contaminants.

Not only do these contaminants deteriorate oil quality and promote further aging of the paper, they are also precursors to sludge [2]. In particular, polar functional groups like peroxides, organic acids, alcohols, aldehydes, ketones, and furans are the culprits. The precursors tend to polymerize to form larger and larger molecules. Eventually the molecules cannot dissolved or suspended in the oil, and crash out as solid deposits, a.k.a. sludge. Sludge in a system can inhibit the flow of oil causing the core to overheat and, in turn, increase the rate of aging. Once sludge has formed, it is impossible to remove without shutting down the transformer, draining the oil and physically removing sludge from the internals. This is an involved, costly, and difficult process and can be avoided by simply managing the dissolved sludge precursors.

Figure 3. An overview of various contaminants generated in an aging transformer



Corrosive Sulfur

An additional contaminant that is harmful to transformers is corrosive sulfur. Certain sulfur species attack copper, creating copper sulfides which dissolve or deposit onto the paper. These deposits cause an increase in conductivity of the paper and will eventually result in a breakdown of the insulation. There are pass or fail (qualitative) oil tests, like ASTM D1275, which identify corrosiveness; however, it gives no information on the responsible sulfur species. It is for this reason that the general term of "corrosive sulfur" is used. Note: not all sulfur species are corrosive.

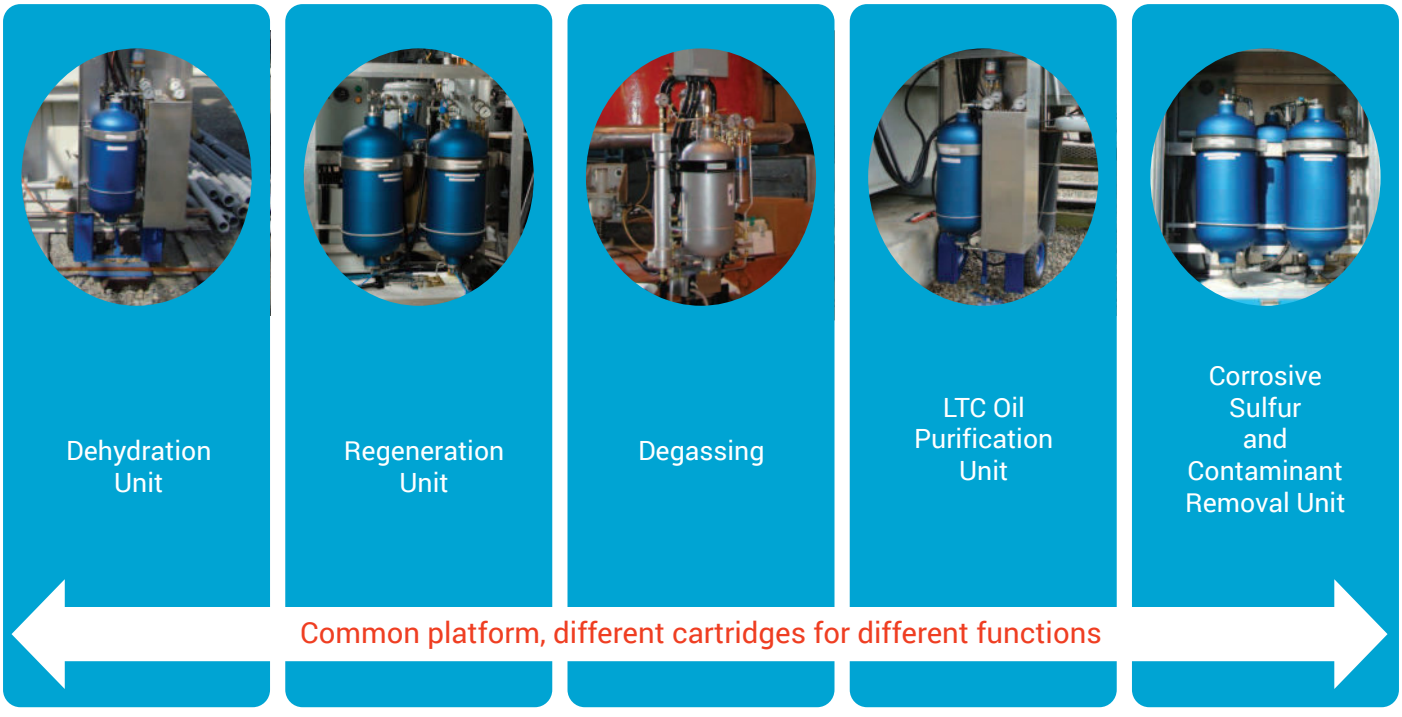
There is one specific corrosive sulfur species that was identified over a decade ago when a sudden increase in transformer failures was observed. The qualitative tests failed to identify problematic oil, and no obvious pattern to the failures could be discerned. Powertech Labs (and several other organizations) performed investigations to identify the corrosive sulfur species and ultimately discovered that Dibenzyl Disulfide (DBDS) was the common denominator in the failures. When referring to corrosive sulfur, the electrical industry typically and historically solely refers to DBDS. This contaminant had significant cost implications for utilities and Powertech Labs proceeded to developed methods to selectively remove DBDS and other corrosive sulfur species from transformer oil. Of all the contaminants which can eventually lead to the demise of a transformer, corrosive sulfur is the only one which doesn't continuously form but can go undetected in standard oil testing programs.

The traditional methodology of maintaining oil quality is to replace the oil, but new online technologies have now been developed, meaning an extended outage is not required.

Extending the Life of a Transformer

As the science behind some of the aging processes has become apparent, methods to slow the process and extend the life of a transformer have become clearer. In practical terms, one of the main methods to slowing the aging of a transformer is to maintain the oil in a good state—

Figure 4. One platform, multiple uses



not only for the purposes of good dielectric properties, but also for the purposes of controlling the promoters. The traditional methodology of maintaining oil quality is to replace the oil, but new online technologies have now been developed, meaning an extended outage is no longer required. Most of these online technologies are comparable to the concept of dialysis—they are devices that are connected to a transformer in a loop arrangement, taking out a small flow rate of oil, processing it, and returning the clean oil to the transformer. The method by which the oil is processed is selective adsorption, which allows it to remove specific contaminants. Removing the contaminants not only reduces the promoters but it also improves and regenerates the dielectric oil quality.

The Online Maintenance Industry

Services and equipment that utilize these online oil treatment technologies to restore oil quality without requiring equipment outages are becoming more prevalent. However, the majority of suppliers offer online options only for dehydration or use a non-selective adsorbent material for removing the contaminants from the oil, requiring significant amounts of time and adsorbent. Newer offerings include online oil decontamination systems which use proprietary absorbent technologies to selectively remove other contaminants from the oil of in-service transformers. These systems selectively remove all oil and paper decomposition products (acids, polar components, furans, moisture, particulate matter, and corrosive sulfur), restoring the oil quality to near new conditions. After restoring oil properties, the units keep the oil clean and dry at all times, preventing the accumulation of moisture and degradation products from reaching harmful levels, thereby extending the life of the transformer.

Powertech has successfully demonstrated this newer technology at several BC Hydro facilities, including Kent substation, G.M. Shrum Peace Canyon, and Stave Falls Generating Stations, as well as several U.S. utilities. These field trials

Photo: Powertech Labs

By eliminating moisture, acids, and polar compounds, the life of the paper can potentially be extend by several decades. By eliminating acids and polar compounds from the oil, the production of sludge can be prevented.

demonstrated results showing that the transformer oil was cleaned to as new condition in terms of dielectric strength, acid content, power factor, color, interfacial tension (IFT), and other oil quality parameters. The advantages of this technology are:

- It can operate online with an in-service transformer, avoiding system shutdown.
- It allows for significantly lower cost than other methods.
- It can be installed in a few hours and left unattended.

Specific benefits Powertech added to their Online Oil Decontamination Unit (OODU) system are:

- Safety features which include leak detection sensors, flow disruption sensors and solenoid valves as ways to safely and automatically shut down the unit.
- Capability to selectively perform one or more functions, including removal of acids, moisture, corrosive sulfur, PCBs, or degassing of the oil.

Conclusions

Many assets were originally designed with a lifespan of a few decades in mind. With aging assets and tighter operational and capital budgets, extending the life of a transformer has been a key topic of research for many electrical utilities. Research has found that by eliminating moisture, acids, and polar compounds, the life of the paper can be extend by several decades. By eliminating acids and polar compounds the production of sludge can be prevented. All these contaminants can be controlled by maintaining the oil in a pure state, and new technologies have been developed to do this in an online and continuous way.

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[2] L. Lewand, "What is sludge," *NETA World Journal*, 2006.

Balancing the naphthenic, paraffinic, and aromatic carbon contents of transformer oils to improve performance and extend transformer life

by **Ronald R. Hill**
and **Zachary C. Patterson**

Although traditional naphthenic oils have provided generally acceptable properties for transformer oils, tests have proven that an oil with a higher paraffinic carbon content can deliver improved performance and extended transformer life.

Photo: ExxonMobil

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Introduction

The composition of transformer oils, in particular the balance between naphthenic, paraffinic, and aromatic carbon contents, can play an important role in determining the performance and lifespan of transformers.

Although traditional naphthenic oils have provided generally acceptable properties for transformer oils, tests have proven that an oil with a higher paraffinic carbon content can deliver improved performance and extended transformer life.

This article highlights the key properties of transformer oils with different chemical compositions and the tests that were undertaken in determining if oils with a higher paraffinic carbon content can deliver enhanced performance versus those with a higher naphthenic carbon content.

These key properties include:

- Oxidation stability which can affect transformer lifespan.
- Gassing tendency which can influence the ability of an oil to adsorb gas under partial discharge conditions.
- Aromatics content which can contribute to SHE benefits and negative gassing tendency.
- Low-temperature viscosities which can impact cold temperature operability.
- Heat transfer capabilities which can determine transformer loadings and size.
- Material compatibility which can affect leak prevention.

The transformer oils being compared

Several typical transformer oils, all with a significant naphthenic carbon content (represented by the blue bars) – see were compared to a new oil with a much higher paraffinic carbon content (as shown by the green bars), see Figure 1. The new transformer oil with higher paraffinic carbon content was developed to provide improved properties versus typical naphthenic oil performance.

Figure 1. Percentage of aromatic carbon content (Ca), naphthenic carbon content (Cn), and paraffinic carbon content (Cp), based on ASTM D2140

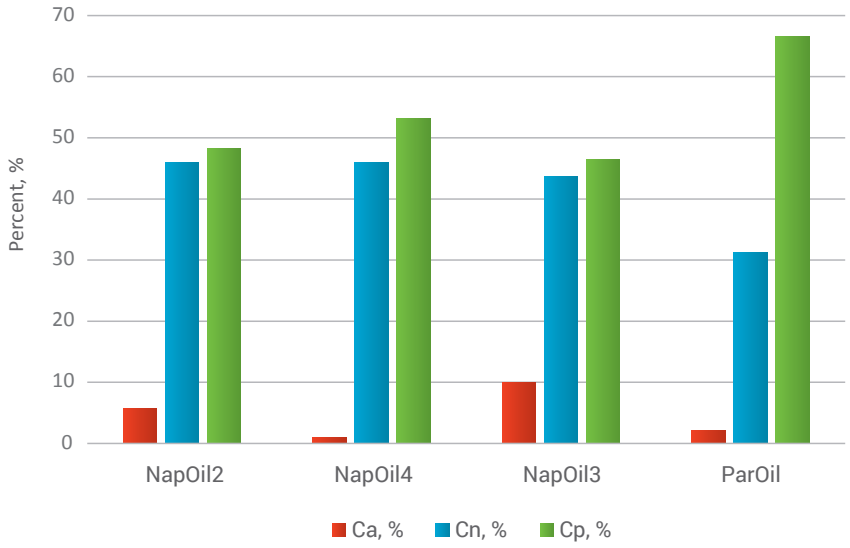
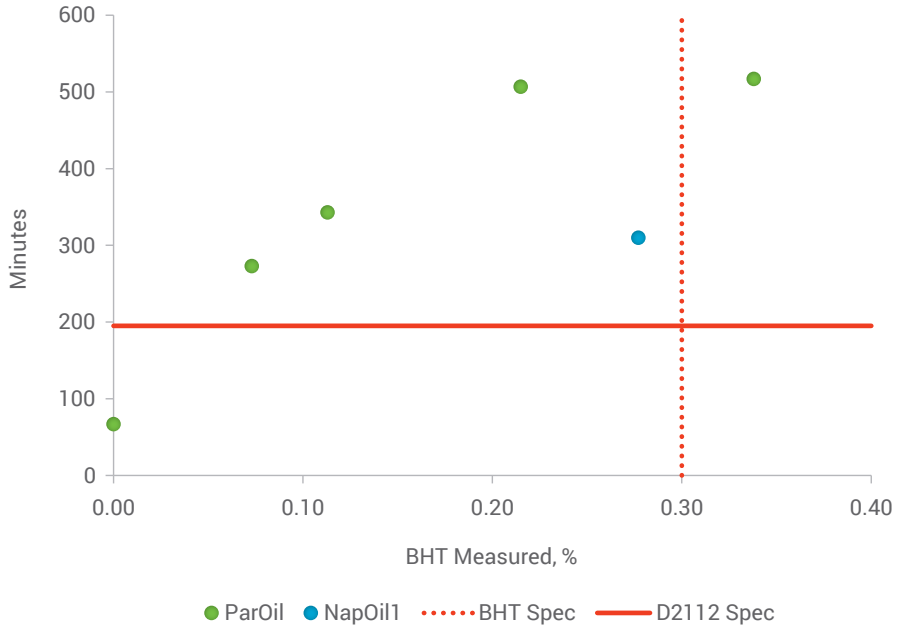


Figure 2. Paraffinic oil response to BHT compared to typical naphthenic oil, based on ASTM D2112



Improved oxidation stability for greater transformer lifespan

An important property of transformer oils, and a requirement of ASTM D3487, is oxidation stability. In testing, the paraffinic oil (illustrated by the green dots) exhibited a very good response to BHT, a common anti-oxidant used with inhibited oils, compared to a typical naphthenic oil (shown by the black dot), as demonstrated in Figure 2. A higher paraffinic carbon content and lower aromatic carbon content can improve the oxidative stability of the oil to help maximize transformer lifespan.

Figure 3 shows that the oxidation stability of the paraffinic oil improved by about 20% to 100% compared to three naphthenic oils with similar anti-oxidant contents.

Negative gassing tendency

Another key requirement of ASTM D3487 is the gassing tendency or "degassing" performance.
A transformer oil with a negative gassing tendency indicates that it can adsorb gas while under electrical stress. A negative gassing tendency is advantageous, therefore, in minimizing the build-up of hydrogen gas because the oil can adsorb gas under partial discharge conditions in the presence of gas bubbles.

The new paraffinic oil has a greater negative gassing tendency than typical naphthenic oils, as shown in Figure 4.

The new paraffinic oil achieves strong negative gassing performance with only a minimal aromatic carbon content, as shown in Figure 5.

A transformer oil with a negative gassing tendency indicates that it can adsorb gas while under electrical stress.

Figure 3. Oxidation stability of paraffinic oil versus three naphthenic oils, based on ASTM D2112

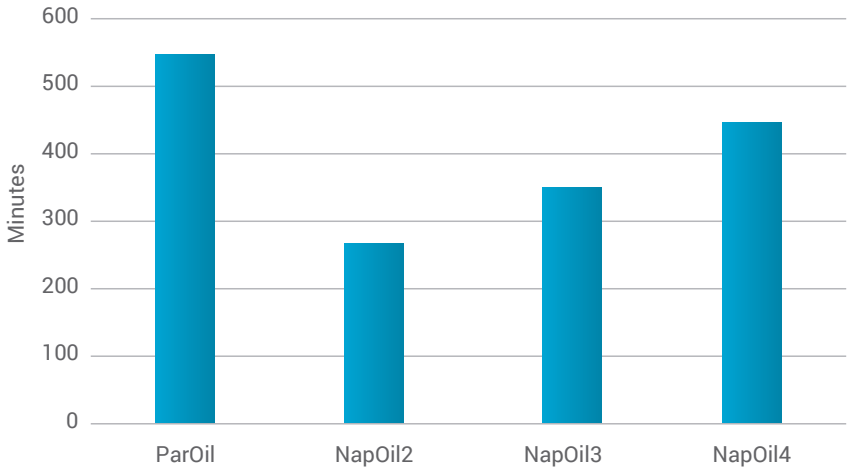


Figure 4. Gassing tendency of paraffinic oil versus typical naphthenic oils, based on ASTM D2300

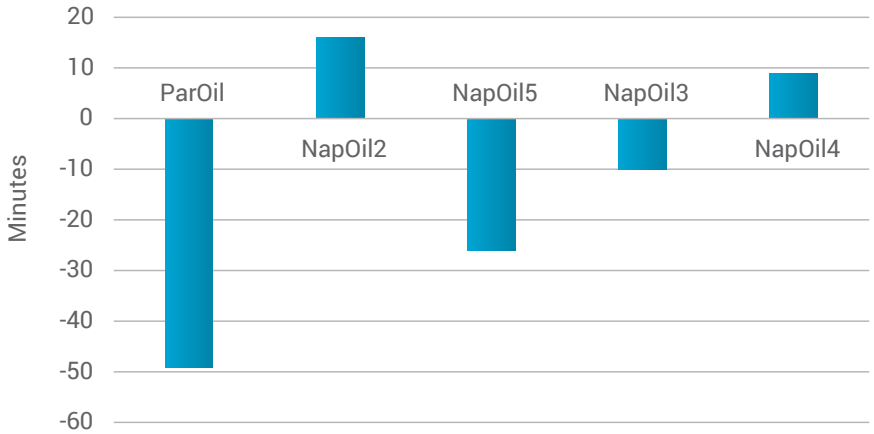
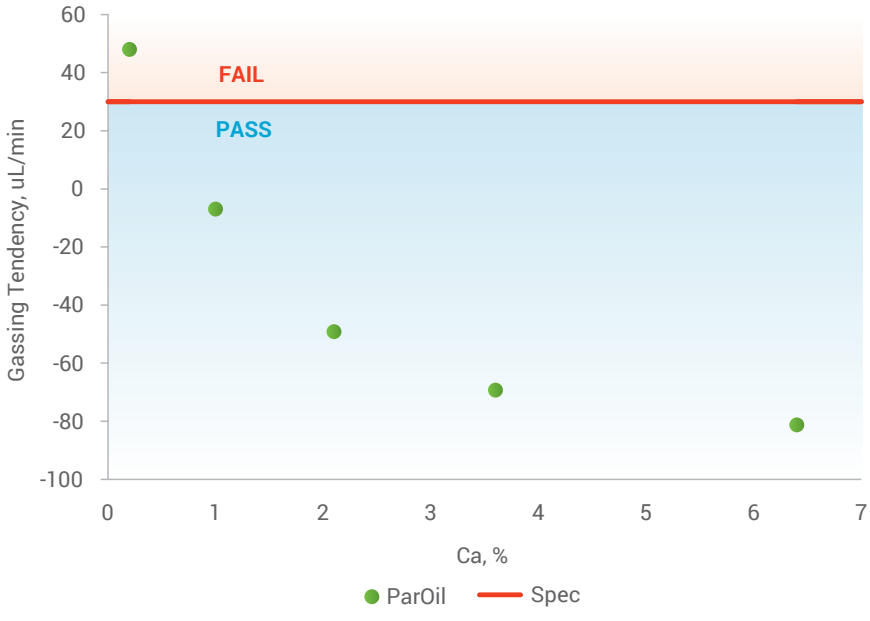


Figure 5. Gassing tendency (ASTM D2300) of paraffinic oil versus aromatic carbon content (based on ASTM D2140)



Low aromatics content for SHE benefits

Naphthenic transformer oils can contain embedded aromatic rings in the molecular chain of the oil, which can lead to a high aromatics content and variability in gassing tendency. Additionally, some naphthenic molecules may also emit hydrogen. As a result, product composition and degassing performance can suffer.

To help counter this, the new paraffinic oil has been developed with a very low aromatic carbon content, as shown in Figure 6. This delivers potential safety, health, and environmental (SHE) benefits due to lower exposure to aromatics. Importantly, the aromatics content of the paraffinic oil is also very consistent, providing a more constant gassing tendency.

Low viscosities for cold temperature operability

Another important transformer oil property is low viscosity at low temperatures. The new paraffinic oil has a very low viscosity at low temperatures, as demonstrated in Table 1. At -40°C (-40°F), the viscosity of the paraffinic oil is about 1,500 cSt, compared to 3,000-5,000 cSt for the three naphthenic oils, based on ASTM D445.

The low viscosity of the paraffinic oil at low temperatures can be beneficial for the cold-start of transformers in cold climates. The higher paraffinic carbon content of the oil contributes to its lower viscosity, while the higher naphthenic carbon contents of the other oils results in much higher viscosity.

Lower viscosity can also improve heat transfer by providing better oil circulation inside the transformer to facilitate effective cooling. Figure 7 illustrates the importance of the Mouromtseff number and low viscosity. An oil with a high Mouromtseff number equates to an oil with a good heat transfer rate. Because viscosity appears in the denominator of the equation, an oil with a lower viscosity exhibits better heat transfer and more effective cooling.

Figure 6. Paraffinic carbon content, naphthenic carbon content, and aromatic carbon content, based on ASTM D2140

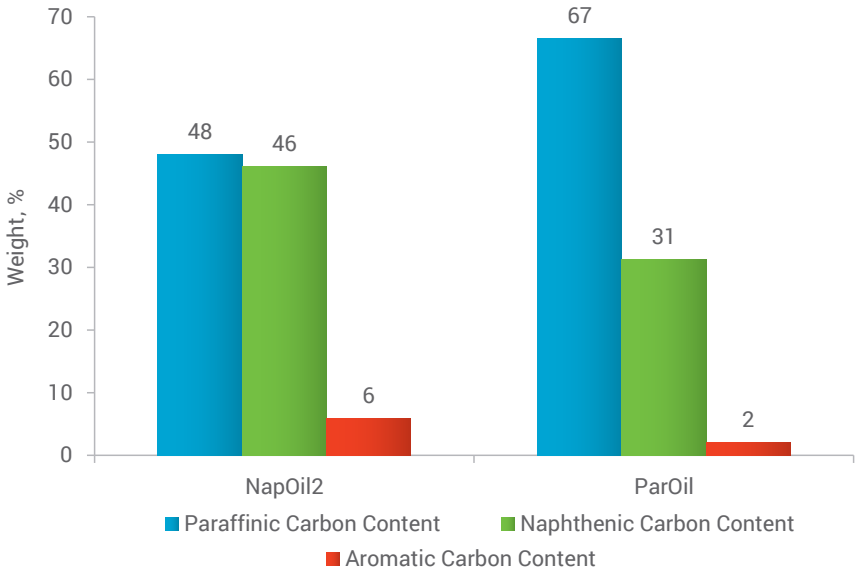


Table 1. Viscosity dependence on temperature and composition

Temperature °C	Viscosity, cSt (ASTM D445)			
	NapOil2	NapOil3	NapOil4	ParOil
100	2.4	2.3	2.6	2.3
40	9.4	9.5	10.4	8
0	63.7	50.7	68.2	40.6
-30	996	713	1,005	371
-40	3,876	3,065	5,300	1,546
	Composition (Based on ASTM D2140), wt%			
Ca	5.8	9.9	0.9	2.6
Cn	46	43.6	45.9	30.5
Cp	48.2	46.5	53.2	66.9

Figure 7. Mouromtseff number and importance of low viscosity

Mouromtseff Number for comparing heat transfer rates of liquid coolants:

$$Mo = \frac{\rho^a K^b Cp^d}{\mu^e}$$

ρ = density
K = thermal conductivity
Cp = specific heat
μ = viscosity

Effective heat transfer for higher loadings or smaller transformers

When considering effective heat transfer, the thermal conductivity (k) and specific heat (Cp) of the transformer oil are important properties that need to be considered. These properties were measured and compared for the paraffinic oil and different naphthenic oils.

The new paraffinic oil exhibited higher thermal conductivity (k) and specific heat (Cp) compared to the more naphthenic oils tested, as shown in Figure 8 and Figure 9. These improved heat transfer properties allow transformers to operate at lower temperatures, run at higher loadings, or allow a smaller transformer size to be used.

Good material compatibility can prevent leaks

Good material compatibility between transformer oils and gasket materials is another important property of oils, as it can help to prevent leaks. The compatibility of different oils with different gasket materials was tested using ASTM D3455. The gasket materials were immersed in the oils and heated to 100°C (212°F) for 164 hours.

Figure 8. Thermal conductivity at 80°C by PLTL-73

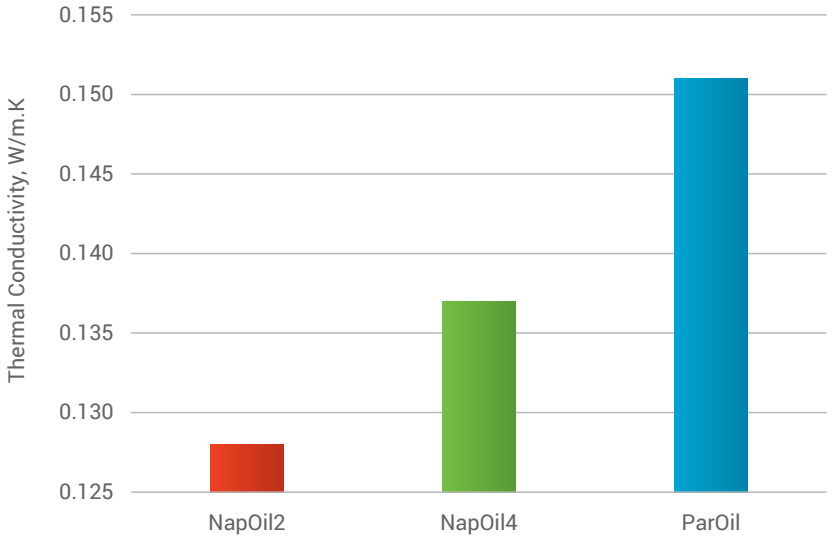
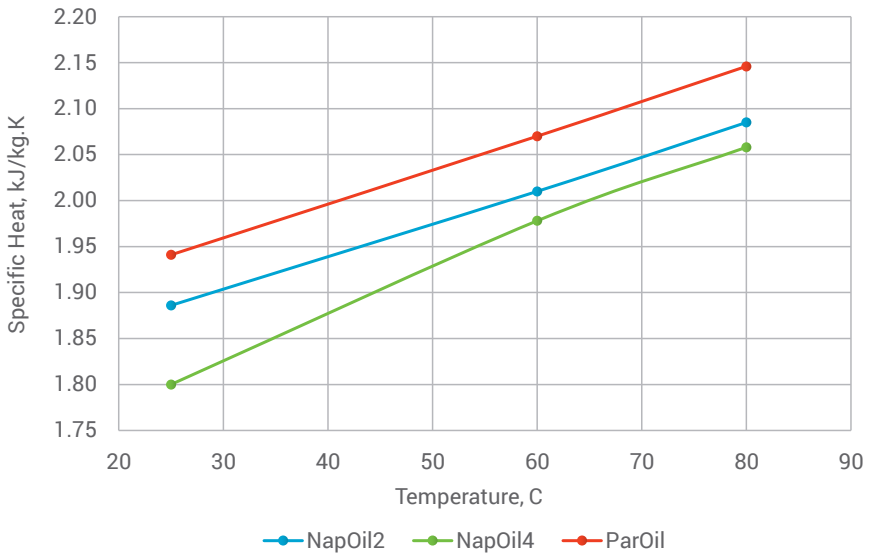


Figure 9. Specific heat versus temperature by ASTM E1269



The low viscosity of the paraffinic oil at low temperatures can be beneficial for the cold-start of transformers in cold climates.

Figure 10. Power factor by ASTM D924 at 100°C (PF100) after gasket immersion by ASTM D3455

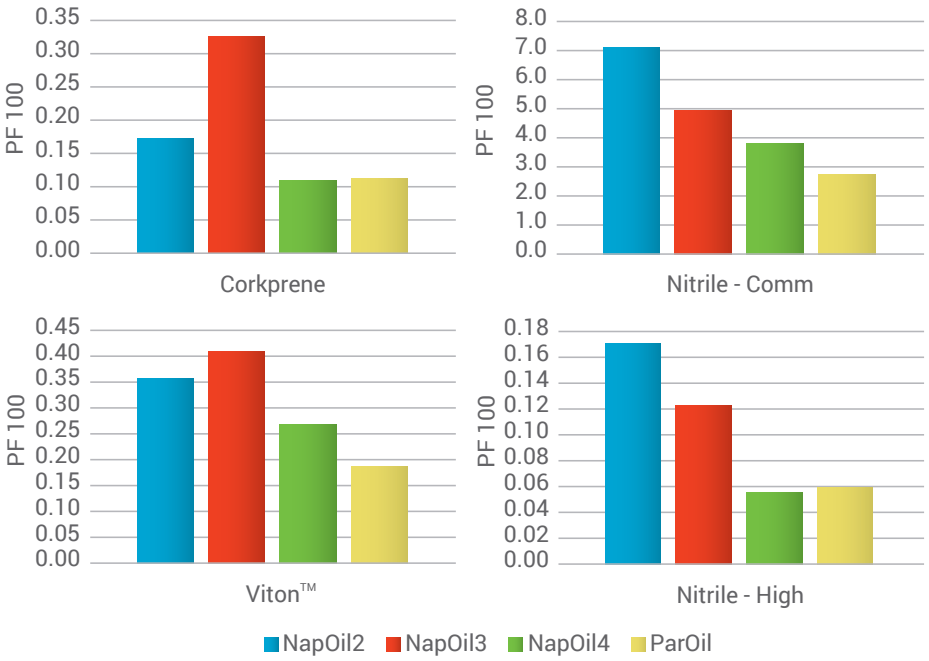


Figure 10 shows the measured Power Factor of the oils at 100°C (PF100) after immersion of the gasket materials. While the naphthenic oils and the paraffinic oil performed similarly in the overall compatibility testing, the paraffinic oil exhibited a similar or lower Power Factor @ 100°C (212°F) after the immersion. A lower PF100 is desired because it indicates lower impurities and, therefore, less attack on the elastomers.

This is a result of the paraffinic oil having lower aromatic and naphthenic carbon contents than most naphthenic oils, which decreases the "solvency" strength of the oil. The lower solvency strength is also reflected by the higher aniline point of the paraffinic oil, compared to the naphthenic oils (which is not shown here). Improved material compatibility is a result of lower solvency strength.

New paraffinic oils have demonstrated the ability to meet requirements of ASTM D3487 and have shown capability of exceeding performance in key tests. As a result, transformer performance can be enhanced and its lifespan extended.

New paraffinic oil for enhanced transformer performance

Traditional naphthenic oils have historically provided generally acceptable properties for use in transformers. A new paraffinic oil has been developed, however, which delivers improved properties compared to those naphthenic oils tested:

- Up to 2x higher oxidative stability for extended service life
- More than 100% lower negative gassing to adsorb gas under partial discharge conditions
- Up to 75% less aromatics, which offers more consistent quality and safety, health and environmental benefits
- 40% lower viscosity at 0°C (32°F) for better low temperature performance
- Over 5% improvement in thermal properties
- Improved material compatibility for less risk of leaks

The composition of transformer oils, in particular the balance between naphthenic, paraffinic, and aromatic carbon contents, can play an important role in determining the performance and lifespan of transformers. New paraffinic oils have demonstrated the ability to meet requirements of ASTM D3487 and as discussed above, have shown capability of exceeding performance in key tests. As a result, transformer performance can be enhanced and its lifespan extended.

Acknowledgements

The author of the paper would like to express gratitude to the following employees of ExxonMobil for their contributions and review of the article: Caterina Tran, Aisha Mehmood, Andrew Broenen, Martijn Burgers and Shaival Mehta.

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President, SDMyers

After 54 years in the transformer business, you could say we've learned a thing or two.

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INTELLIGENT TRANSFORMER MANAGEMENT

By **Marius Marinoiu**
Global Product Manager,
Weidmann Electrical
Technology

Transformer Hot Spot Hunting

Increasing need to monitor transformer hot spot

Transformer owners are increasingly operating under tighter maintenance and capital expenditure budgets. The time has passed when transformers were specified with hefty design margins. Today, to control costs and increase efficiency, transformers are designed in sizes and capabilities closely aligned with operating needs. However, at the same time utilities face an increasing demand for high levels of network reliability and reduced interruptions. There are many situations when the electrical system, along with its most important asset – the power transformer – is subject to stress. For example, with the increasing number of extreme weather events and supplying peak power in emergency situations. In many cases there is no room for error or equipment failure.

It is widely acknowledged that the winding temperature limits the transformer loading capability. Having the ability to accurately determine the winding hot spot is key when operating the transformer close to its design limitations, while also ensuring the situation is kept under control regarding transformer insulation life and health.

As the global leader in transformer insulation design and manufacturing, and a fiber optic monitoring supplier, Weidmann has the capability and expertise to design, produce and test fiber optic temperature probes and insulation assemblies, leading to the lowest fiber failure rate.

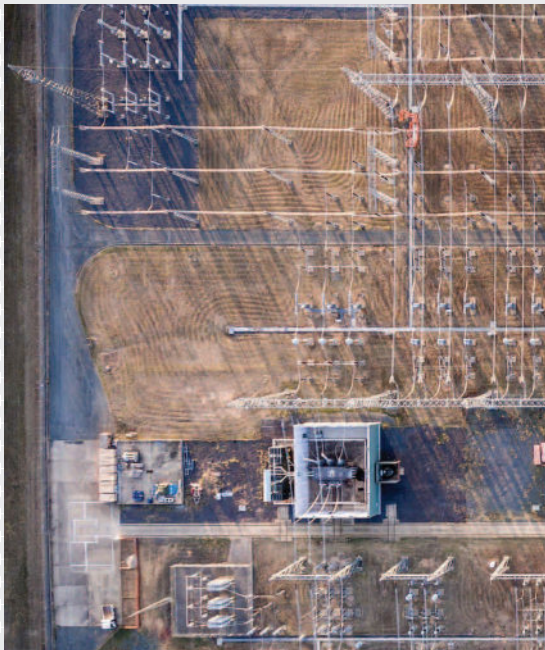
Use of fiber optic sensors in transformers

Fiber optic technology was applied in transformer hot spot monitoring several decades ago and is continually being improved and refined. State-of-the-art design and electronic components are increasingly used in fiber optic monitors and controllers. With appropriate configuration by transformer manufacturing personnel and proper installation in the windings, the fiber optic is capable of operating long after the transformers demise. Therefore today, hot spot fiber optic monitoring systems are proven and trusted to provide real time, accurate information about the temperatures inside the transformer tank, specifically in the transformer windings. However, there are several challenges still to overcome.

For example, a utility ordering transformers from multiple manufacturers and specifying fiber optic monitoring systems may receive transformers with fiber optic probes installed in different ways in the various insulation components, that have been tested in alternative ways and that have passed different criteria. This is valid even across different manufacturing facilities belonging to the same transformer manufacturer. Although the transformer manufacturers do an excellent job in installing the fiber optic monitoring systems on their transformers, how can utilities purchasing transformers ensure that they receive the transformer with fiber optic probes mounted in insulation in the same way, having been tested equivalently and respecting the same criteria?

The answer is consistency.

The SmartSpacer®can be pre-ordered as part of the transformer OEM insulation package ensuring that it is designed specifically for the transformer type, and tested to the highest standards.



A consistent approach

Given the level of standardization applicable to this topic and existent in industry today, the consistency can be guaranteed only if the assembly of the fiber optic temperature probe with insulation component is manufactured and tested by one, specialized entity. This in its turn guarantees that fiber optic-insulation assemblies perform per specifications, in the same way, while being subjected to stressing elements specific to transformer winding, whether these elements are electromagnetic stress or physical.

SmartSpacer®

Weidmann SmartSpacer® undergoes a rigorous design, FEA analysis, and thermal, mechanical, electrical, and for some designs X ray tests to become certified. This reduces the risk of incorrect probe installation and loss of use or potential reduction of insulation system integrity which can lead to premature failure.

As the global leader in transformer insulation design and manufacturing, and a fiber optic monitoring supplier, Weidmann has the capability and expertise to design, produce and test fiber optic temperature probes and insulation assemblies, leading to the lowest fiber failure rate. At Weidmann these assemblies are called SmartSpacer®. It ensures quality and consistency, as well as realizes savings for both transformer manufacturers and operators.

Improper installation of the fiber-optic probes in the transformer windings can result in inaccurate data or can potentially increase localized stresses in the insulation system. Any discontinuity must be avoided during installation, as well as incompatible materials such as some adhesives, and voids that can reduce the integrity of the overall system. Weidmann SmartSpacer® is designed to eliminate all these issues.

SmartSpacer® provides the manufacturer and end user with the confidence to install fiber optic probes in the windings that will not compromise the integrity of the insulation system or transformer reliability in the long term. The SmartSpacer®can be preordered as part of the transformer OEM insulation package ensuring that it is designed specifically for the transformer type, and tested to the highest standards. This minimizes the work required by the OEM and ensures consistency in the probe assembly and installation leading to a lower risk of breakage or failure.

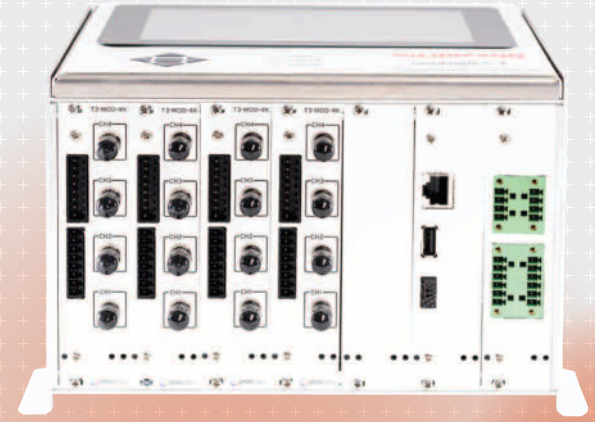
Weidmann SmartSpacer® undergoes a rigorous design, FEA analysis, and thermal, mechanical, electrical, and for some designs X ray tests to become certified. This reduces the risk of incorrect probe installation and loss of use or potential reduction of insulation system integrity which can lead to premature failure.

InsuLogix® T – State-of-the-art monitoring system

The SmartSpacer® is an optional solution that can be supplied along with the Weidmann InsuLogix® T – fiber optic monitoring system. The InsuLogix® T is designed, manufactured and tested to the highest quality standards in one single location at Weidmann's facility in Dresden, Germany. Fiber optic temperature probes, fiber optic cables and the SmartSpacer® are also assembled and tested at Weidmann.

The InsuLogix® T is a state-of-the-art monitoring system, utilizing the latest high-performance processor that increases power and stability to ensure maximum percentage uptime of the device, with minimal maintenance or troubleshooting required. The device combines class-leading configurability with the latest in-built logic and the highest number of configurable relays per channel, all managed through the largest device mounted touchscreen and keypad available on the market today.

The InsuLogix® T is a state-of-the-art monitoring system, utilizing the latest high-performance processor that increases power and stability to ensure maximum percentage uptime of the device, with minimal maintenance or troubleshooting required.



WEIDMANN

Weidmann SmartSpacer® is designed, tested and manufactured as individual components and shipped with a certificate of compliance confirming the component has met the following five-part Weidmann certification process:

Design: The detailed design of the insulation component and embedded sensor are compatible with normal and emergency electrical stress limits typically found in EHV and UHV liquid-immersed power transformer winding designs, as specified by the transformer manufacturer and operator.

Dielectric Analysis: The component, sensor, and connection system have been extensively modeled and analyzed using Finite Element (FEA) numerical analysis techniques to ensure that the SmartSpacer® is compatible with electric field stresses in the winding and support insulation system designs.

Functional Testing: Insulation components and embedded sensors are tested in the Weidmann or equivalent high-voltage laboratory to demonstrate the output metrics and applicable tolerances required for the sensor. They are suitable for use in the transformer internal environment, in both alternating voltage and impulse conditions, applicable to the BIL voltage class as specified by the power transformer operator.

Manufacturing Processes: All components meet strict manufacturing process controls in compliance with drawings and specifications that preclude the possibility of electric field stress concentration or negative impact on the transformer dielectric system or performance.

Quality: Strict conformance to written quality assurance system standards are met for components and matching sensors throughout the manufacturing, assembly, packaging, and shipping stages. The Weidmann Quality Management System is certified to the ISO 9001 Standard.

Marius Marinoiu has almost 20 years technical and sales experience at a global level in transformer monitoring applications and analytical services. He holds an Engineering degree in Industrial Automation and Robotics, and a Master's Degree in Non-Conventional Control Systems. At Weidmann he is responsible for assisting in the development and implementation of strategic sales plans for the Transformer Lifecycle Product (TLP) Market Segments in North America. Previously he managed implementation of turn-key transformer monitoring solutions globally.

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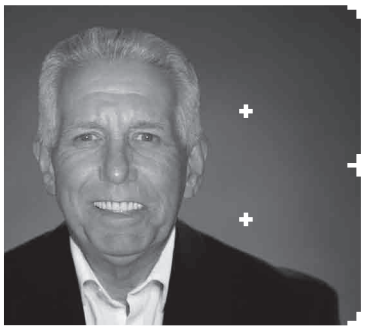
Power Transformers:

Properly Categorizing Developing Faults via Dissolved Gas Analysis

by **Randy Cox**

What we need to know initially is the amount of paper involved in a given fault, if any.

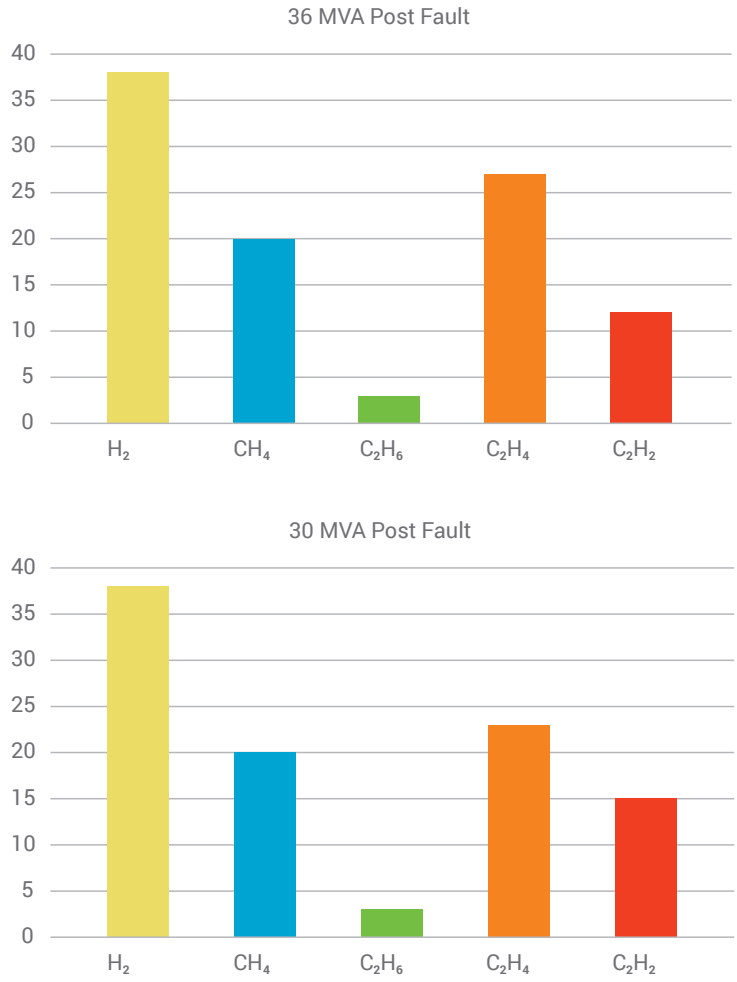


Randy Cox is the Domain Expertise Manager for GE Grid Solutions. His current duties include interfacing with the industry, writing and presenting industry related technical papers, committee work and education of customers on the technical advantages of GE M&D technology, products, software and solutions. Prior to being employed by GE Grid Solutions, Randy was employed by SPX Transformer Solutions, Inc. as the Operations Supervisor for the Texas Service Center, which included staffing and implementing a new service center to perform transformer installations, repair and LTC maintenance. Randy has published many industry technical papers related to substation transformer and circuit breaker diagnostics. He is a current member of IEEE & a Fellow at General Electric.

Operating an electric grid has its challenges, not the least of which is finding additional time locating potential problems before they turn into the evening news. Whether you are a District Manager, Engineering Support, Operations Supervisor or Substation Technician, transformer Dissolved Gas Analysis (DGA) is simply one aspect of a busy day for which you are likely responsible. For this reason anything that can be made easier, should be, and under normal circumstances is most welcomed. While much of the chemistry behind DGA is complex and important for our industry chemists to understand, the day to day review of DGA by the utility need not be complex. In cases where we may struggle to make sense of the information, there's a wealth of industry chemists and experts willing to assist, with regards to further, or a deeper interpretation.

In this article we will identify some simple guidelines that may be applied to assist in identifying what is involved in the fault. What we need to know initially is the amount of paper involved in a given fault, if any. These steps of interpretation will most certainly help to simplify the analytics regarding, what many consider to be, a very complicated subject; categorizing (or distinguishing) developing faults within oil filled power transformers. If these answers can be rapidly obtained, it can mean the difference between a less costly onsite repair versus a total replacement of the transformer.

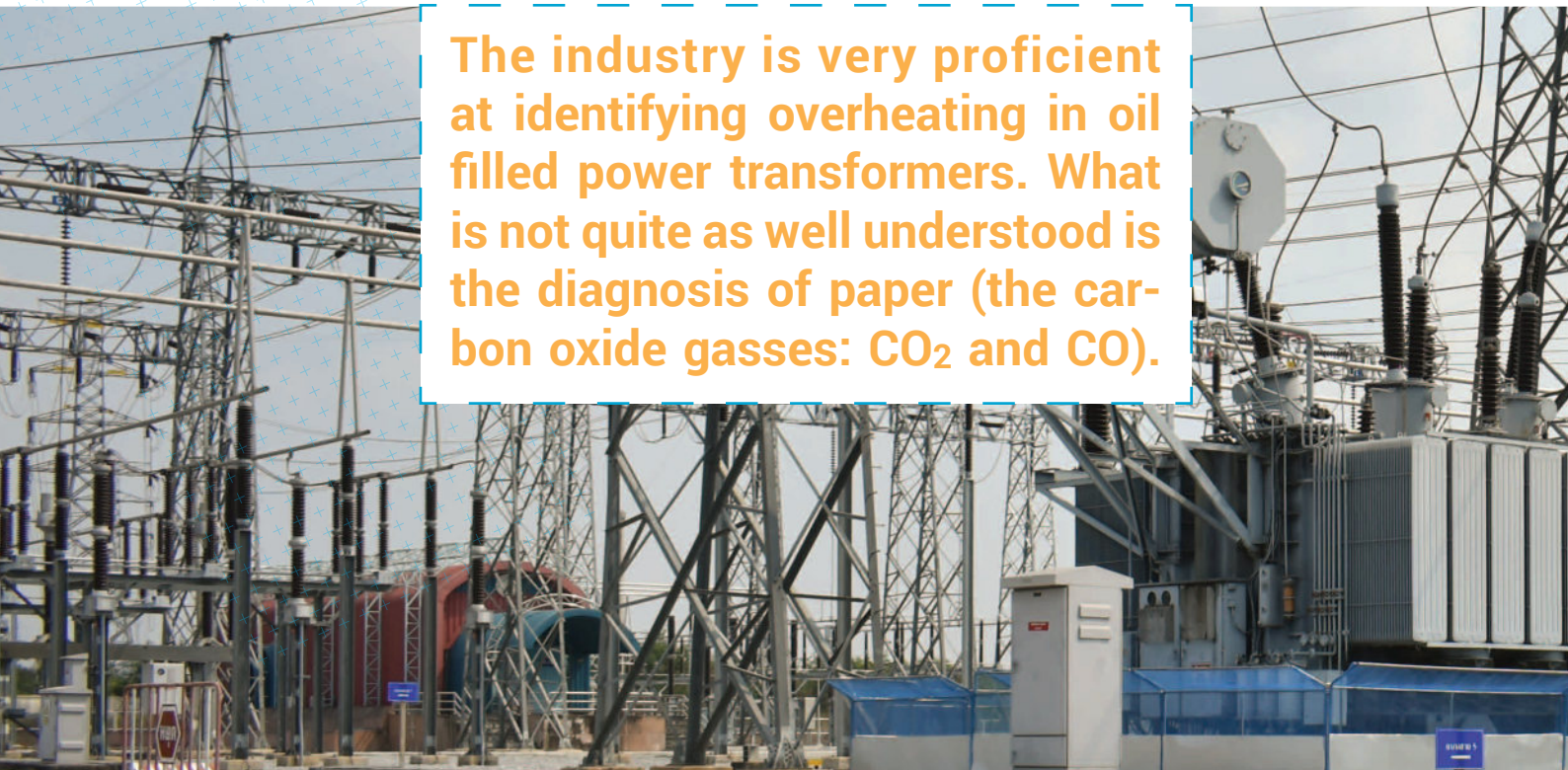
Figure 1. Similar arcing profiles for two transformers that tripped on a transformer differential relay operation



The Facts

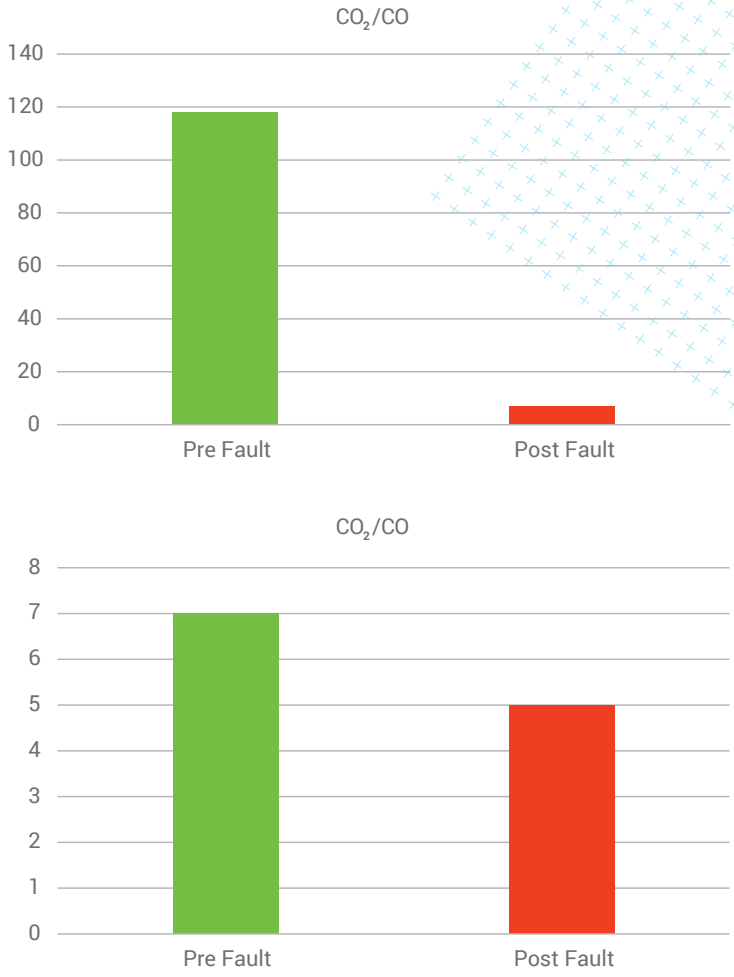
There are "knowns" in DGA. The industry is very proficient at identifying overheating in oil filled power transformers. Measuring the internal oil temperature at 150°C+ temperatures is accomplished by the measurement of what is referred to as the "hot metal gasses." These gasses are, in order of their initial thermal generation, hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4) and acetylene (C_2H_2). What is not quite as well understood is the diagnosis of paper (the carbon oxide gasses: CO_2 and CO). It can be even more challenging if the issue exists on a paper wrapped lead.
To better understand how to arrive at a conclusion regarding an issue, it is important to note that at all working temperatures, CO is less soluble than CO_2 and the higher the temperature, the more CO_2 remains in solution (it will be absorbed from atmosphere if partial pressure of CO_2 in atmosphere is greater than partial pressure in the oil).

This is an important point, since identifying "categorically" where a problem exists, the CO_2/CO ratio must be trended.



The industry is very proficient at identifying overheating in oil filled power transformers. What is not quite as well understood is the diagnosis of paper (the carbon oxide gasses: CO_2 and CO).

Figure 2. Post event impact on the CO_2/CO ratio in the 36 MVA transformer (top) and 30 MVA transformer (bottom)



Trending provides critical data for decision making, as opposed to data that is a simple snapshot in time. In other words, what was it prior to the problem, or where is its norm? This thinking is new to our industry, as this ratio is typically referred to in many technical publications and industry guides as a single value for diagnostic purposes. To demonstrate this more fully, the following transformers both tripped on a transformer differential relay operation with a very similar arcing profile. There's no question that a flashover occurred in both transformers as seen in Figure 1 [1].

These transformers had very different problems, evidenced by the post event impact on the CO_2/CO ratio as seen in Figure 2, maintaining the order of these transformers.

What we now know is that the more paper involved in a fault, the greater the impact on the CO_2/CO ratio.

Where the ratio dropped significantly, a low side winding failure occurred and where a paper wrapped primary lead flashed over (minimal paper), much less impact.

The CO_2/CO ratio trending provides critical data for decision making.

To further illustrate the value of this ratio, Table 1 presents the data of a 10 MVA transformer that tripped on a transformer differential relay operation, to which there was absolutely no impact on this ratio, verifying that there was no paper involved in the presence of the hot metal gas generated, post fault.

As can be plainly seen in the above example, once the hot metal gas generated, it did not have a negative impact on the CO_2/CO ratio. An internal inspection revealed a failed de-energized high side tap changer. Even though there was no paper involved in the fault, when the ratio is compared to generation of hot metal gas, the lack of impact actually tells the story. The issue was in an area that did not support any paper being involved, thus bare metal, such as a de-energized tap changer contact.

Table 1. 10 MVA transformer data

Test Date	Hydrogen	Methane	Ethane	Ethylene	Acetylene	CO_2	CO	CO_2/CO	Nitrogen	Oxygen
9/5/2002	2	0	0	0	0	1820	221	8.235294	68476	9186
8/19/2004	4	o	0	0	0	1875	249	7.53012	80061	7268
6/16/2005	2	1	0	0	0	1951	231	8.445887	79140	7284
8/14/2006	6	3	0	0	0	3450	322	10.71429	82900	7507
8/7/2008	2119	736	44	666	1405	2530	239	10.58577	67189	7881

Testing the Theory

To better understand the effect that thermal, or lack thereof, has on the CO_2/CO ratio, an experiment was conducted by Memphis Light Gas & Water on a 25 KVA transformer with mineral oil and Kraft paper. A thermal well was installed through the wall of the transformer and inserted to a depth of 5" into the windings. A small heating element was then placed into the well and raised to temperatures ranging from 100°C to 180°C over a period of 22 days. The CO_2/CO ratio started at 55.60:1 at 100°C and as the temperature was increased in 10-degree increments, the ratio displayed a steady increase until 150°C was reached. At this point, the ratio was at 78.51:1, but began to decrease as the temperature continued to be raised up to 180°C. The ratio had declined to 48.23:1, and at this point the heating element was moved so that it was no longer in contact with the paper insulation and was only directly heating the oil. The temperature of the heating element was maintained at 180°C. After the element was positioned to only be in direct contact with the oil, the CO_2/CO ratio began to steadily rise, apart from the 11/21/2014 sample, until it reached 52.55:1 at the end of the experiment. The 11/21/2014 sample was determined to be erroneous due to all gas levels being approximately half the value of the samples taken immediately before and after that date [1].

The more paper involved in a fault, the greater the impact on the CO_2/CO ratio.

Why Does It Work?

CO will never remain dissolved in the oil equal to, or more than CO_2. Because CO seeks to leave solution at all working temperatures relative to CO_2, the CO_2/CO ratio cannot drop in the absence of CO creation. Therefore, if both gasses are decreasing relative to prior samples and the ratio drops it must be because CO is being generated more than CO_2, but both are being generated at lower levels than are leaving the oil. Looking at the design of a transformer, we can better understand why the ratio of CO_2 and CO can be used to identify the general fault location. In other words, does the problem that exists have heavy paper involvement, light paper involvement or no paper involvement. The relative availability of oil to contact the paper determines the available O_2. The more oil that is available, the more cooling and O_2 available. In the windings, where paper is tightly wrapped, oil has less contact per volume of paper than a lead [2].

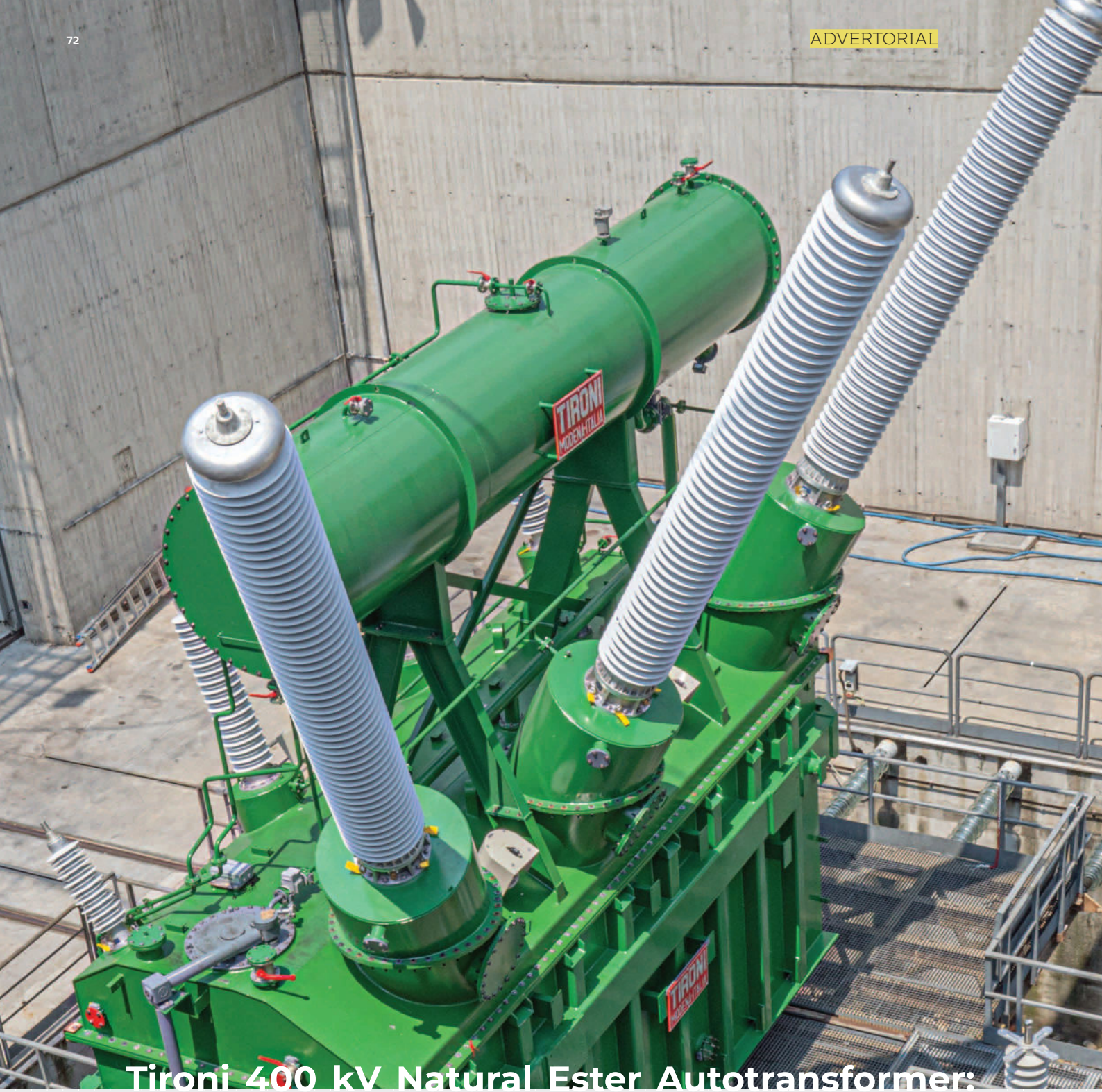
Summary

Transformers have a home as it relates to the CO_2/CO ratio. Additionally, these ratios are not all the same. In some publications it is noted that they should be between 3:1 and 11:1, while other publications say that it should be above 7:1. The truth is that transformers can, for the most part, be just about any value. The key is not "what value" they display when all is well, but rather what happens to these ratios when issues develop proportional to their norm. What we have learned is that where heavy paper is involved (inner-winding), the ratio drops to a minimum value of 65% or greater. Where less paper is involved, such as a paper wrapped lead or even outer-winding, which has greater access to available 02, the value drops to between 25% and 50%. Where no paper is involved, the ratio may actually increase, or it may decrease slightly.

References

[1] C. Rutledge, Assistant Manager, Memphis Light Gas & Water
[2} T. Rhodes, Sr Engineering Technologist, Asset Information & Intelligence, Duke Energy

In terms of CO_2/CO ratio, transformers can, for the most part, be just about any value. The key is not "what value" they display when all is well, but rather what happens to these ratios when issues develop proportional to their norm.



Tironi 400 kV Natural Ester Autotransformer:

The Successful Short Circuit Withstand Test

The summer of 2019 has been a tremendous one for Elettromeccanica Tironi with two very important achievements having been accomplished within a mere 60-day period in June and July.

TIRONI
power transformers

The first accomplishment was a successful **short circuit withstand test** performed on a 400 kV autotransformer, an important step to becoming recognized as one of the few large autotransformers' manufacturers to have done so. But Elettromeccanica Tironi enters into a very reduced elite class with the second consecutive success: **Another short circuit withstand test successfully passed, on the first attempt, of a 400 kV autotransformer filled with Cargill's Envirotemp FR3 natural ester fluid derived from renewable vegetable oils.**

This 250 MVA, 400/135±5x2% kV, KFAF autotransformer, successfully tested at the CESI lab in Rondissone, Turin (Italy), is one of the largest high voltage transformers filled with natural ester. Ordered 20 months before the testing, this unit is the prototype for Terna Rete Italia, the Italian grid management and transmission operator.

In less than two years Tironi – the Italian transformer manufacturer established in 1960 in Modena – was able to design and manufacture the prototype, overcoming several difficult challenges that required both engineering and technological/industrial innovations.

New engineering was necessary to design a completely new unit taking into consideration the characteristics of FR3 natural ester in comparison to the historically used mineral oil. Investment in the Modena plant was necessary in order to have a fully separated and dedicated oil plant for natural ester along with a new Oil Lab.

In less than two years Tironi was able to design and manufacture the prototype of a 400 kV autotransformer filled with natural ester, overcoming several difficult challenges that required both engineering and technological/industrial innovations.

New Design

The main goal for Tironi engineers was to develop a new design of the 400 kV auto-transformer, taking into consideration allof the peculiarities of Cargill's Envirotemp FR3 fluid. Tironi was able to accomplish this by using their internal experience and design skills to produce a completely original Tironi design.

The main design implications that the engineers had to overcome were twofold:

1. The different viscosity and dielectric permittivity of the Envirotemp FR3 compared to mineral oil
2. The different stability of FR3 relative to oxidation

Dielectric design

As to the dielectric design considerations, the main characteristic considered was the greater dielectric permittivity ε_r of natural ester compared to that of mineral oil (typically 3.2 vs 2.2). This leads to a more uniform distribution of the electric field throughout the insulation, with a reduction of the electric field in the oil channels and an increase in the electric field in the paper. This gives different proportions between oil and solid insulation if we compare it with an identical unit in mineral oil.

Cargill FR3 fluid is a natural ester derived from renewable vegetable oils – providing improved fire safety, transformer life/capability, and environmental benefits that are superior to mineral oil and unsurpassed by any other dielectric coolant. Because it is derived from renewable raw materials, it has a neutral carbon footprint – unequalled by any other dielectric fluid option.

A transformer filled with FR3 fluid can operate 20°C warmer than the mineral oil equivalent while maintaining the same life expectancy of the insulating materials. Compared to mineral oil at the same operating temperature, FR3 fluid actually protects the insulating paper up 7.4 times longer than mineral oil.
This high temperature capability enables:

- Increased load capability in about 20% in comparison to traditional transformers
- For space constrained locations, utilities can increase capacity while keeping same footprint
- For growing population areas, utilities have increased load capability to better handle the increasing demand, especially for peak hours
- Design smaller, more efficient transformers that could use less fluid and less construction materials

FR3 fluid has a fire point of 360°C, more than twice the fire point of mineral oil. This greatly improves the fire safety for any transformer, either indoors or outdoors installations. This is particularly important in heavily populated areas such as restaurants, malls, and urban communities.

FR3 fluid not only provides reliable performance and increased fire safety, but it is also an excellent option to help utilities protect the environment in their communities:

- Made from 100% renewable engineered vegetable oil;
- Readily biodegradable as designated by the Environmental Protection Agency (EPA);
- Non-toxic in both oral toxicity tests and aquatic toxicity tests;
- Has a neutral carbon footprint – 56x less carbon emissions than mineral oil.

Thermal design

The thermal design of the autotransformer is considerably influenced by the higher viscosity of the natural ester fluid which reduces the flow speed and therefore the flow rate. This aspect is partially compensated for by the higher thermal conductivity compared to that of mineral oil; but to maintain an equivalent thermal dissipation with the same temperature gradients, it is necessary to dimension the oil channels differently.

Mechanical design

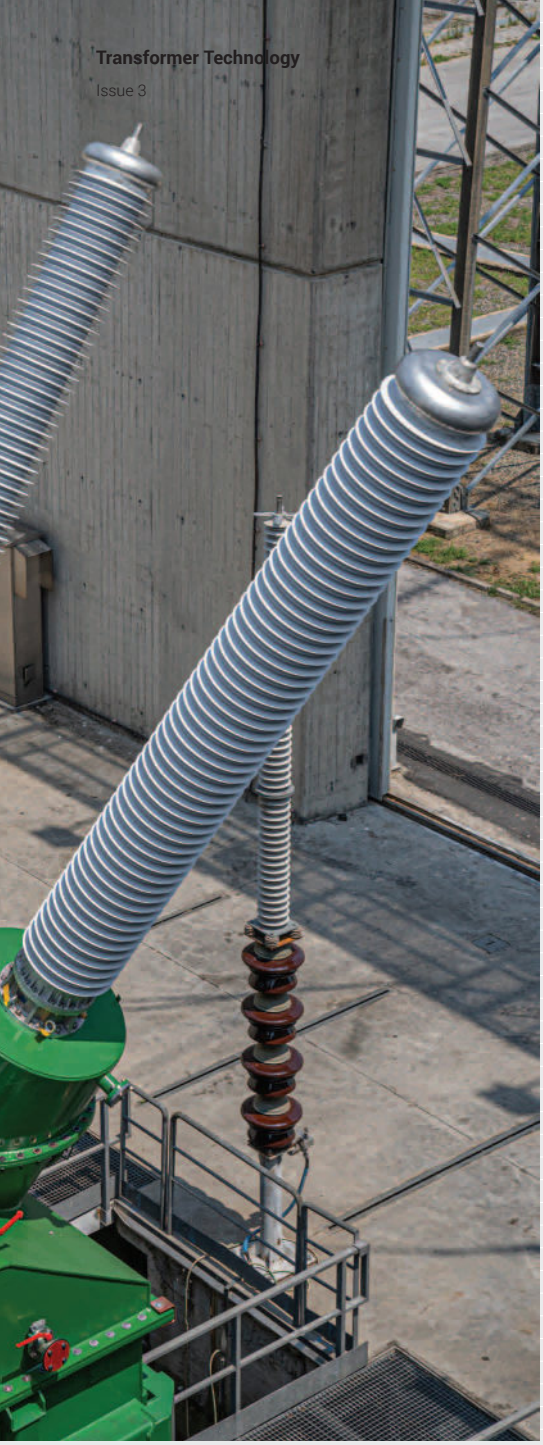
Considering the different stability to oxidation of natural ester fluids compared to mineral oils, it was also necessary to take some precautions in the mechanical design, foreseeing the use of the rubber bag membrane in the conservator or an airtight tank with nitrogen cushion. Large power transformers, like this for Terna, already have the rubber bag but it is also important to remember to install a "membrane rupture relay" with an alarm to the control associated with the urgent intervention signalling (IU).

Compared with the "sister unit" with mineral oil, with the same power and voltages, this new design – which was made with Tironi's own software and also verified through third party finite elements software – shows some minor differences in the oil and overall weights (approx. 55 and 200 tons) while assuring the benefit of using a natural ester fluid like the Cargill's Envirotemp FR3.

Oil Plant

A new important investment allows Tironi to have a completely separate oil plant for natural ester fluids, which allows for a fully independent storage and treatment plant with separate oil pipes to the filling area. The storage is composed of three separate compartments of 25,000 litres each, with heating elements and nitrogen generators. The treatment is composed of an adjustable OTP up to 6,000 lt/h.

This investment has created a duplicate, although of smaller dimensions, of the existing system for mineral oils, which assures excellent conservation of the oil. This in turn avoids any possible contamination between the two oils.



Tironi Lab

Another significant new asset of Tironi is their new Oil Lab, a full capability chemical lab operating within their Quality Management structure. This new lab has been instrumental in testing new natural esters.

Lab tests, including 11 gas DGA tests, are performed in real-time, and results immediately shared and analysed with plant technicians. These tests proved extremely valuable in assisting the decision process during all development phases. Fine-tuning of treatment settings, definition of operational procedures, monitoring dielectric efficiency during each treatment step; all took advantage of the Tironi Lab's readily available data.

This analytical support has proven priceless, resulting in both steady development of treatment practices and straightforward, error free transition from experimental to operational phases.

Finally, analytics performed during the experimental phase turned into first-hand "knowhow", which is currently being applied to production parameter monitoring, ensuring the processes keep within fixed boundaries.

Today, the Tironi Lab has developed fundamental competencies in natural esters dielectric features and has grown into a prominent facility capable of supplying consistent, real-time diagnostics.

Thanks to the accomplishments outlined above, Elettromeccanica Tironi enters into a very elite group of companies capable of designing, manufacturing and testing a 400 kV unit filled with natural ester. With these accomplishments Tironi enters into an even more selective club of companies who are capable of passing a short circuit test for such a high voltage level.

This remarkable success describes very well Tironi's capabilities in engineering and manufacturing and it marks a great starting point for 2020, a year in which Elettromeccanica Tironi will celebrate its 60th Anniversary. That is a remarkable achievement in and of itself.

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Right from the Start:

Best Practices for Transformer Testing & Inspection Upon Arrival

by **Shane Smith**

Shane Smith received his BSEE from Virginia Tech and started his career with Delta Star in 1997. He has worked in the electrical industry for over 20 years with expertise in transformer testing and controls while simultaneously playing a critical role in the development of technical relationships. He is currently employed as the Director of Quality for Delta Star, is a certified Six Sigma Black Belt and a member of IEEE.

Receiving a new transformer is a familiar event in this industry.

However, it is important to remember that decisions made immediately upon a new unit's arrival can affect costs and labor for years to come.

Taking the right steps initially can pay off in the long run through reductions in maintenance costs and downtime.

Here are some best practices to observe as soon as the new transformer arrives.

Photo: Delta Star

A Thorough "Once-Over"

First, did the transformer truly arrive safely? If the unit shipped with an impact recorder, check to ensure that it had a smooth trip. Impacts *on any axis of 4 Gs or greater* may indicate rough handling that could potentially have caused damage to the transformer.

Otherwise, inspect closely for any signs of damage that may have occurred during transit. Scuffs, dents, and scrapes in the paint are obvious clues, but take a careful look at all of the following:

- Tie rods or chains used to secure unit to trailer or rail car
- Tank pressure level – See Slidebar 1
- Signs of leaks on the main tank (for units shipped with oil) and bushings
- Attached fittings, conduits, cabinets, boxes, terminals, gauges, valves and switches
- Condition of all accessories, such as radiators, fans, bushings, etc. (Loose condenser bushings can also undergo power factor testing upon receipt outside the transformer, provided they are properly configured with test taps, and are upright and stabilized.) – See Slidebar 2

Exercising due diligence in the initial inspection and testing process can pinpoint issues that could lead to unplanned outages down the road.

Photo: Delta Star

Sidebar 1

Perform Pressure Check
In order to maximize the life of the transformer, we must keep moisture out of the insulation system. Tank pressure is a critical factor to observe because it serves as an indicator of potential moisture ingress into the winding insulation.

Check the gas pressure in the transformer as soon as possible after arrival. The transformer will have been pressurized at the factory (commonly to approximately 5 psig, but this can vary according to manufacturer)—so if gas in the tank is at atmospheric pressure, there could be a leak in the tank.

When a unit ships empty, the pressure that was initially applied at the factory will vary based on thermal changes, but normally a unit should not arrive at zero pressure or in a vacuum state.

When a unit ships oil filled, there is a much smaller gas space, and the pressure changes relative to the factory benchmark can be more substantial as the oil level varies with temperature changes. The pressure may transition to a vacuum state (if the temperature drops) or increase to the point where the pressure relief device actuates (if the temperature increases).

If there has been no pressure change since the unit left the factory, then there has been no opportunity for moisture to enter the unit, and you can rely on the manufacture's original dew point, which was captured under stable, controlled conditions.

Sidebar 2

Perform Power Factor Test
For units that arrive fully assembled and oil filled, Power Factor testing should be a priority. Performing capacitance and dissipation tests on the bushing insulation can be an extremely valuable precaution.

Capacitance readings from the bushings can show whether moisture acquired during shipment has compromised the performance of the capacitive layers. (A rise in capacitance of more than 10% points to a potentially hazardous condition.)

Looking Deeper

Once the external condition has been assessed, it's time to examine key internal and functional details—all of which further confirm that the transformer is properly fit for service. (Note: Do *not* attempt electrical testing on units in a vacuum state.)

Confirm Core to Ground Insulation Resistance

Using an insulation resistance meter (usually at 1000 Vdc), check the resistance from the core ground bushing or grounding strap. A reading below 100 Meg Ohms should be reported to the manufacturer.

It is also important to identify whether the unit is gas filled or oil filled so the results can be properly compared to the manufacturer's original readings in the same condition.

Verify Moisture Levels

For units shipped without oil and filled with dry air or nitrogen, there is little chance the insulation system has picked up any moisture if positive pressure is present upon arrival. To be certain, check the dew point of dry gas in the transformer and compare it to the factory results.

The factory dew point readings are often taken indoors and therefore in a stable thermal environment. Thermal stability can be difficult to replicate in the field due to constantly changing ambient conditions, but early morning is generally the best time.

For units shipped in oil, it is advisable to take an oil sample in a syringe and have an oil lab measure its moisture content.

Sweep Frequency Response Analysis (SFRA)

For units that arrive with bushings installed (temporary shipping bushings work as well), SFRA testing is another preliminary test that can help determine if there has been any mechanical change or damage during transportation. Sweep Frequency Testing can be performed prior to removal from the truck or railcar and compared to factory results.

If external damage or impacts greater than 4Gs are noted, an internal inspection may be justified to look for signs of movement or shifting. Contact the manufacturer to discuss the findings that led to inspection, and to identify the specific features to inspect.

Before undertaking any internal investigation, remove pressure slowly. Purge the unit with dry air to minimize moisture ingress and verify the air quality inside the unit per OSHA and safety requirements, as some will ship filled with nitrogen.

All of these precautions should be taken before the unit is removed from the truck or railcar, and any concerns should be documented in photos and reported to both the manufacturer and the carrier.

Keep all materials in the shipment together; if components are damaged and must be replaced, be sure to reunite those replacements with the original shipment.

Preparing for the Future

The next steps of the receiving process are determined by the transformer's assignment status. Specifically, is it headed into storage, or immediately into service?

Ideally, the transformer would be completely assembled and filled with oil immediately upon arrival, but if the unit is destined for storage, this may not be practical. In those cases, the methods to employ will be based on the expected duration of storage and will largely revolve around guarding against condensation and rust.

Short-Term Storage
For units that will be stored for one to three months, pressurize the tank with dry gas at approximately 5 psi. Record the initial pressure, then check and log pressure levels at least monthly—with weekly measurements being preferable. Supply power to the control cabinet and energize the heater to prevent condensation – See Slidebar 3.

Long-Term Storage
For storage periods greater than four months, the transformer should be completely assembled (including radiators), vacuum processed, and filled with oil above the 77°F/25°C level, leaving at least 6 inches for oil expansion. Pressurize the tank to approximately 5 psi. Pressure should be checked and logged at least monthly to ensure that this pressure is maintained. (All readings should indicate either positive or negative pressure.) Supply power to the control cabinet and energize the heater.

Leaving transformers empty for an extended period of time is a major risk, due to the threat of moisture damage to the insulation.

Photo: Delta Star

Sidebar 3

General Storage Tips:
- Units stored outside should have their bushings and tank properly grounded to help prevent damage during electrical storms.
- Fill radiators with oil or pressurize with dry gas to prevent rust.
- Remove protective covers from fans and gauges; store accessories in a dry location.

Assemble and Oil Fill as Soon as Possible

Leaving transformers empty for an extended period of time is a major risk, due to the threat of moisture damage to the insulation.

Oil filling and assembling the units promptly not only protects and preserves the solid insulation, it also enables prompt testing such as:

- Baseline DGA
- Oil Quality Testing
- Turns Ratio
- 10 kV Excitation
- Power Factor & Capacitance
- Bushing Power Factor & Capacitance
- Insulation Resistance of Windings
- Insulation Resistance of Core
- Winding Resistance
- Control Functions
- Current Transformer Ratio and Polarity

Keep those points in mind when evaluating storage plans. For many utilities, maintaining a spare transformer fleet has become a top priority. Given the fact that those spares may not be fully assembled, filled and dressed out, careful and consistent testing and evaluation throughout the storage period becomes essential to keep the spares ready for prompt deployment.

Coming out of Storage

When the transformer is removed from short-term storage, measure the empty unit's dew point and compare to the figures obtained upon arrival. If the moisture exceeds the manufacturer's allowable range, follow the manufacturer's dry-out procedures.

Another critical post-storage consideration is tank pressure. Take a final reading prior to installation and compare to the readings compiled over the storage period. All readings should show either positive or negative pressure (or both) but should not have dropped to zero and remained there. A sustained zero pressure level likely indicates a leak, which will have to be repaired before installation.

Careful Installation

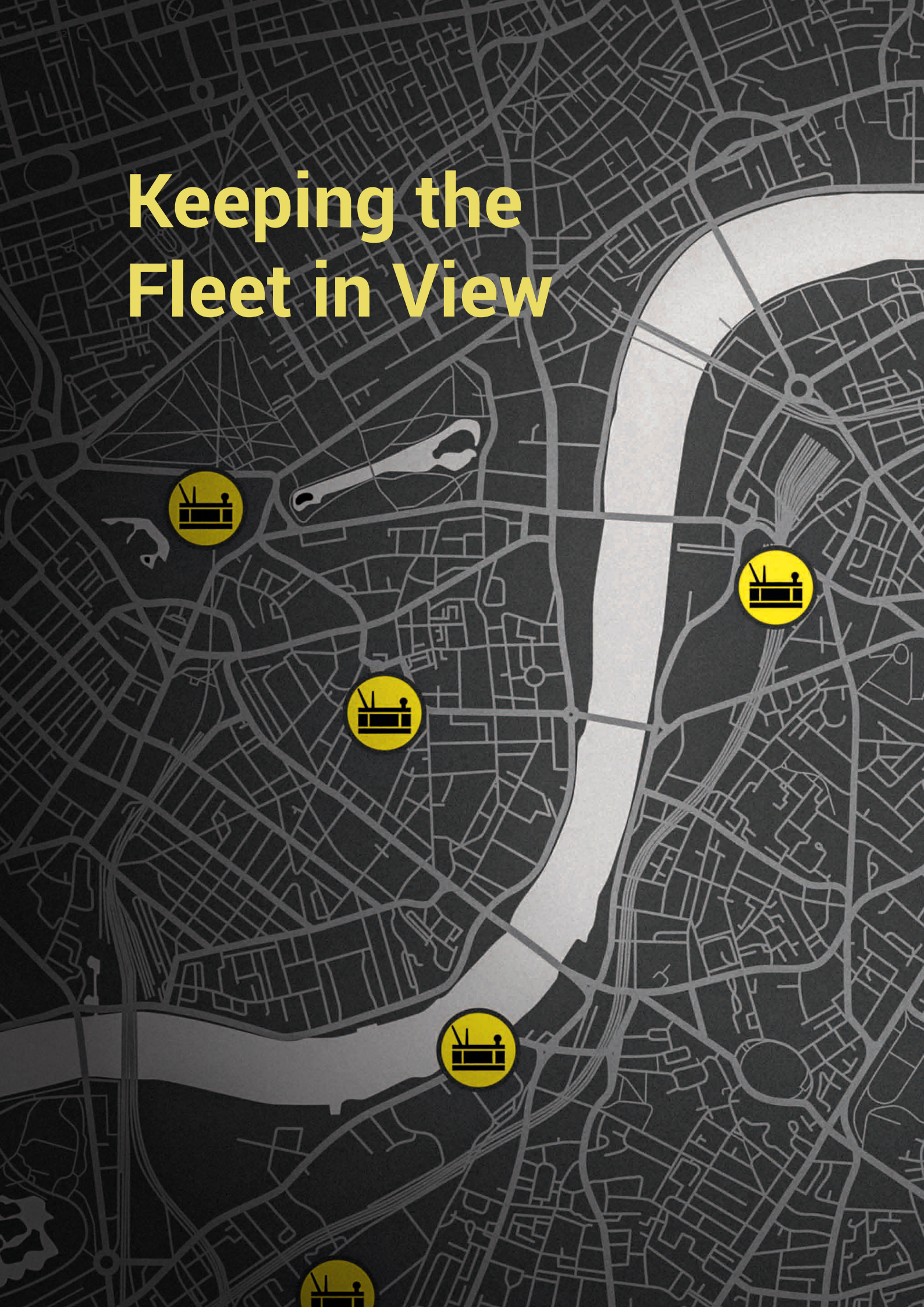
Installation and commissioning can now be accomplished following the manufacturer's instructions.

Repeating the Basics

Exercising due diligence in the initial inspection and testing process can pinpoint issues that could lead to unplanned outages down the road. And when units have to be removed from service unexpectedly, it can trigger a domino effect that impacts secondary assets and systems. Addressing those issues right from the start can help reduce downtime and extend transformer lifespans.
The precautions presented here may not be revolutionary, but even the most experienced industry veteran can sometimes benefit from a review of the basics. Getting the unit inspected, assembled, processed and filled with oil as quickly as possible sets the stage for prompt, thorough testing.

The goal of the entire process is to help ensure that whenever the transformer is needed, it will truly be ready.

Keeping the Fleet in View



All around the world, grid operators are being confronted with the same challenge: the fact that their equipment is reaching old age. It is no longer uncommon to see power transformers with a service life of 50 years or more. One of the questions that every grid operator is faced with is therefore 'What sort of shape is my fleet in?' Finding an answer to this question is becoming more and more urgent: Fluctuating and higher loads resulting from renewable energy sources are increasingly causing the crucial pieces of equipment needed to ensure a stable power supply to reach their limits.

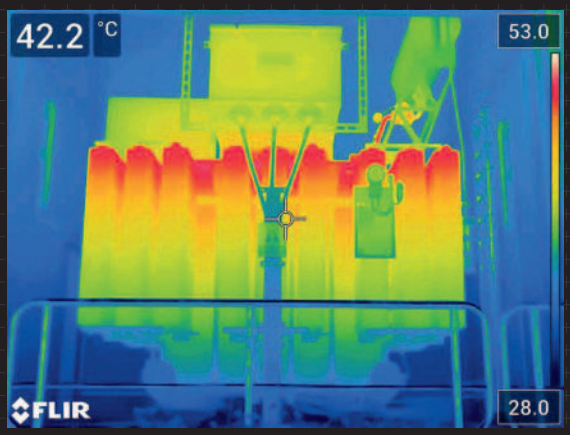
To combat this, Maschinenfabrik Reinhausen has developed a condition-based method to identify critical units at an early stage: FLEETSCAN 2D. The two-dimensional assessment matrix incorporates, firstly, the likelihood of functions failing in order to model the reliability of the fleet. The second dimension then considers the loss-of-life and is important for making long-term investment decisions. The manufacturer-independent evaluation tool is a lean solution on which operators can rely to keep their fleets in shape.

FLEETSCAN 2D

How is my transformer fleet doing?
The fleet management solution from MR provides the answer in just a few steps.

COLLECT DATA

A sufficient database is essential to carry out the condition assessment. To keep disruption times and assessment work to a minimum, FLEETSCAN 2D offers three assessment stages. Depending on how detailed the assessment needs to be, not all three stages have to be carried out. Transformer data is already available in many cases, so the work involved in recording the data is minimal.



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1st stage: existing data

The operator provides the data which is already available. This includes, for example, the master data of the transformers, measurements that have already been carried out, and maintenance history information.

2nd stage: on-site appraisal

The second stage involves an on-site appraisal which is carried out during operation. In a visual inspection, an MR expert uses a checklist to examine the transformer for signs of corrosion, leaks, and visible damage to the bushings and fans. The expert then carries out infrared thermography and a complete oil analysis.

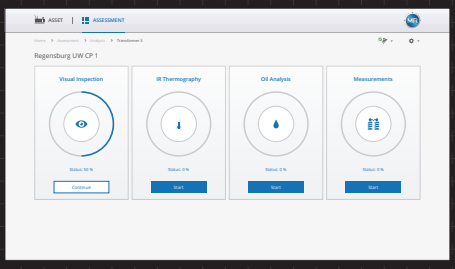
3rd stage: complete testing

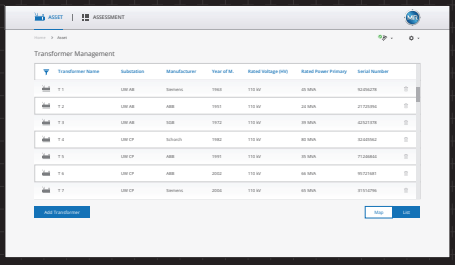
If, after the first two stages, there are any indications of more significant damage, MR performs targeted testing involving extensive measurements. These include dynamic resistance and partial discharge measurements which require the transformer to be taken off the grid.

2

EVERYTHING AT A GLANCE

FLEETSCAN 2D makes it possible to clearly save all collected data using browser-based software. This enables grid operators to retrieve all relevant information for any transformer in the fleet at any time.



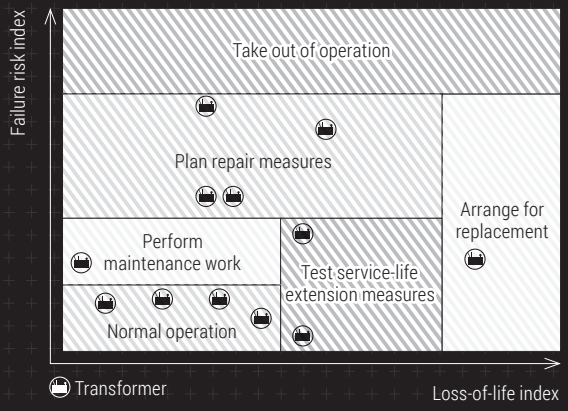


EVALUATION

Following data recording, it is time to move on to the core element of FLEETSCAN 2D: the evaluation. Using an algorithm developed by MR and the University of Wuppertal, the condition analysis is carried out in two indices:

- **The failure risk index measures the likelihood of functions failing.**
  These values provide important reference points for the maintenance strategy, which is crucial for the OPEX budget.
- **The loss-of-life index is a key variable when making long-term investment decisions, and is therefore relevant for the CAPEX budget.**

For the assessment, the results of the two indices are transferred into an XY diagram. The condition of the fleet can thus be visualized simply: The more transformers that are located in the quadrants near the origin, the better the condition of the fleet and vice versa.



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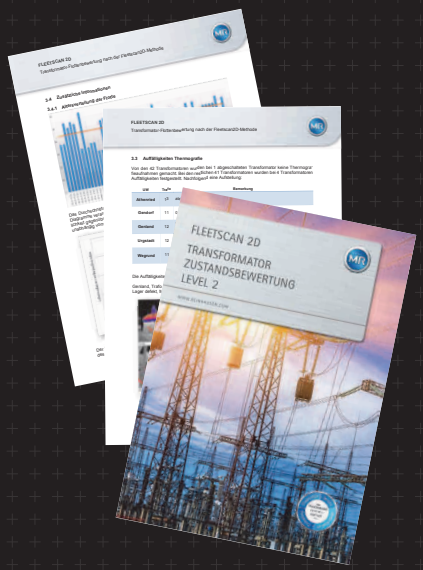


RECOMMENDATIONS

Once the assessment is complete, an MR expert will take a detailed look at the results, check the plausibility of the data, and offer recommendations. The grid operator will then receive a comprehensive report from which the measures that need to be taken, such as maintenance tasks and investment decisions, can be derived. Depending on the condition of the fleet, MR recommends that the FLEETSCAN 2D assessment be repeated every three to five years.

YOUR CONTACT

Would you like to use FLEETSCAN 2D to assess your fleet of transformers? Alexei Babizki would be delighted to advise you:

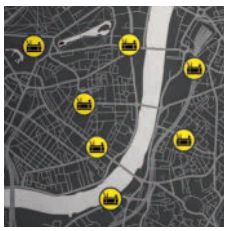
✉ **A.Babizki@reinhausen.com**

Photo: Maschinenfabrik Reinhausen

"The FLEETSCAN 2D method enables us to objectively assess the technical condition of our transformers. The detailed recommendations and the 2D matrix help us to make operational and strategic decisions relating to asset management"

Martin Hentschel, Head of the Power Supply department at Stadtwerke Mosbach GmbH

One System—Many Advantages



OVERVIEW OF THE ENTIRE FLEET

Asset managers obtain a clear overview of the condition of their fleet, enabling them to plan their OPEX and CAPEX budgets effectively. Thanks to the results of the condition assessment, strategic planning can be carried out in a simpler and more structured manner.

INCREASED SERVICE LIFE

Thanks to the detailed, pragmatic, and independent recommendations provided by the MR expert for each transformer, the service life of the fleet can be increased by implementing targeted measures, without large investments necessarily being required.

PRACTICE-ORIENTED

Thanks to a flexible choice of test stages, downtimes are minimal. Only the tests that are absolutely necessary are carried out. Following the assessment, service managers and asset managers are presented with results which they can transfer directly into practice.

ISO 55000 STANDARD

FLEETSCAN 2D and its extensive documentation help grid operators to meet the requirements of the ISO 55000 process. This industry standard structures and assists asset management activities and in many countries is becoming the benchmark for utility and industrial companies.

DIGITAL SOLUTION, SIMPLE HANDLING

Users of FLEETSCAN 2D are able to manage all relevant information about the transformer themselves thanks to web-based software. All of the data that is collected and the assessments that are performed on each piece of equipment are available at any time.

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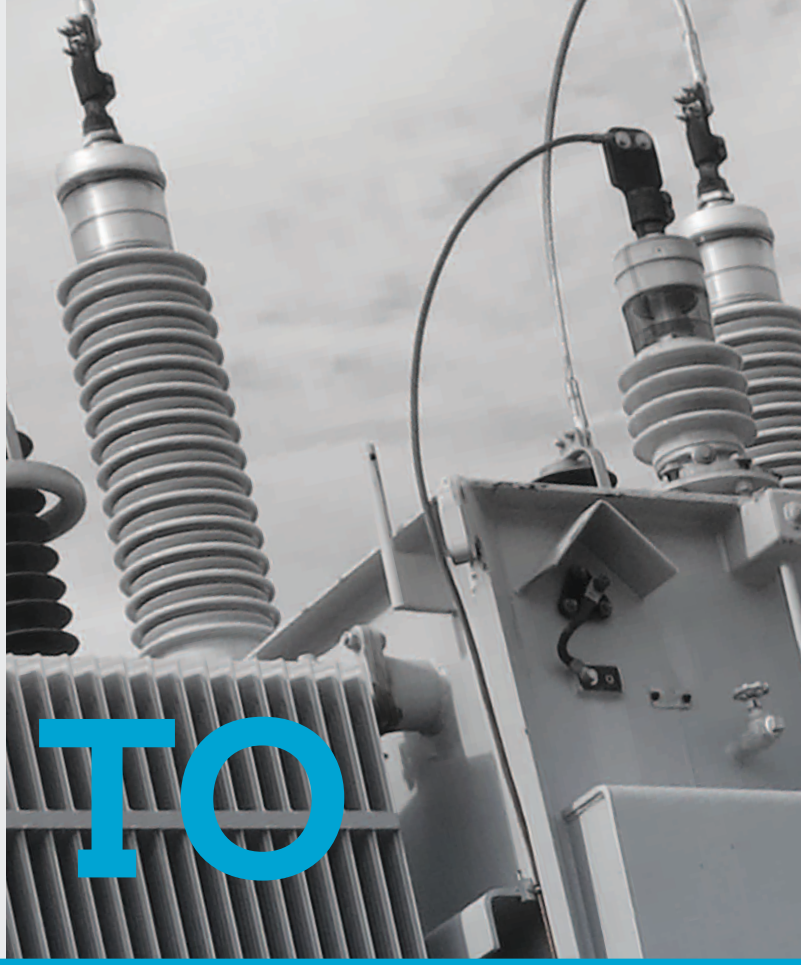

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Risk Management Requires Actionable Insight:

Adding Value with Truly Integrated Transformer Monitoring

by **Marco Tozzi**

Introduction

Power transformers are integral to the flow of energy and dynamic communication and could be viewed as the nerve centre in the era of digitalization of energy systems. However, environmental and operational factors can affect the health of an aged transformer fleet and reduce the capabilities and readiness for the technological change.

Managing and mitigating this increased and changing risk profile requires new methodologies for asset owners. The way to improve the transformer reliability and gain real insight into its condition is to address its critical components in real operating conditions.

A more holistic approach to transformer monitoring can lead to converting data into more actionable insights and, ultimately, optimize the maintenance cost and effectively manage risk.

The concerns of Subject Matter Experts (SMEs) in the electrical energy environment are increasingly devoted to transformer health and maintenance cost optimization. The intention is to extend the lifespan of transformers, but quality and reliability do not always follow this extension as production is often affected by economical constraints due to aggressive competition pushing for reducing material costs. In addition, the integration of renewable energies is creating scenarios where the effects of harmonics, switching transients and intermittent load on the transformer insulation are very often unknown and unpredictable.

Only when monitoring all the key components and parameters, in synergy, can the factors of health, risk and reliability be better understood. It is not enough to perform time based offline measurements as it is important to consider the circumstances and environmental and operational influences that can lead to a defective condition. Many of the crucial phenomena to be monitored are stochastic in nature, meaning online monitoring is essential. A more holistic approach to transformer monitoring can lead to converting data into more actionable insights and, ultimately, optimize the maintenance cost and effectively manage risk.

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

Photo by Camlin Power

The way to improve the transformer reliability and gain real insight into its condition is to address its critical components in real operating conditions.

A Holistic Approach

A 2015 transformer reliability survey published by CIGRE [1] shows that more than 60% of failures in transmission transformers involves one of the following components: high voltage windings, on-load tap changers (OLTC) and bushings. A similar percentage can be found in generation transformers with the difference being that the three main components are: low voltage windings, high voltage windings and bushings. In addition to this, external short circuits have been highlighted as one of the major contributors to failure.
It is clear, therefore, that a more comprehensive approach to transformer monitoring is needed if we are to consider the key components, parameters, external events and operational conditions that can contribute to failure. Figure 1 provides an overall picture of what this holistic approach should be, monitoring bushings, main tank, OLTC, oil conservator and cooling system. In addition, advanced modelling and analytics can be used to aggregate the through fault current events [2], [3], estimate the aging factor, hot spots, overloading capabilities [4], [5] and probability of transformer failure.

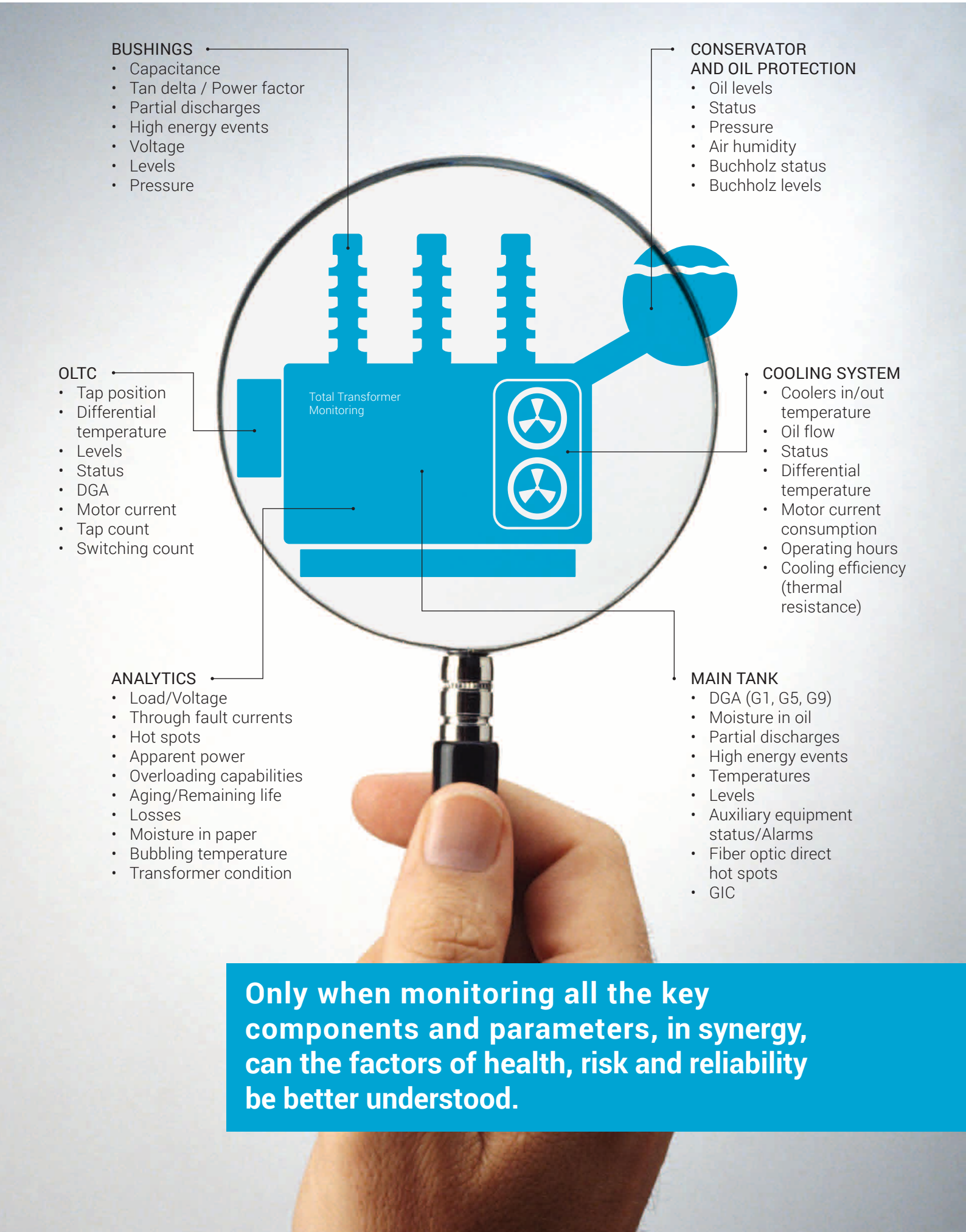
It is important to understand a few key points about the nature and goal of online monitors.

Online monitors must:
- Be reliable in terms of hardware
- Be cost effective
- Provide reliable warnings and alarms
- Provide synchronized, consistent and meaningful data using open standards

Online monitors should be designed to:
- Highlight anomalies under real operating conditions
- Detect anomalies and developing problems at the earliest possible stage
- Provide integrated data to Subject Matter Experts (SMEs) and Operation & Maintenance (O&M) managers that can be easily correlated to extract meaningful information
- Help the SME and O&M manager to plan appropriate maintenance and offline tests
- Contribute to the identification of most probable failure mode by combining online results with offline results and transformer maintenance history
- Reduce maintenance costs
- Ultimately allow the asset owner to manage and mitigate risk

Online monitors are not designed to:
- Replace all offline tests
- Replicate offline testing standards and processes

Figure 1. Example of a holistic transformer monitoring approach



Only when monitoring all the key components and parameters, in synergy, can the factors of health, risk and reliability be better understood.

Case Studies

The following case studies demonstrate successful examples when the utility was able to plan preventive actions and maintenance thanks to the study of the correlation of two or more parameters.

Case Study #1
KEPCO successfully replaces 345 kV bushing thanks to online monitor showing capacitance increase and high energy events

Bushing and partial discharge monitoring was installed in 2015 on a single-phase transformer bank in Ulsan, South Korea. The installed device was continuously monitoring the currents from the bushings and the partial discharges from both the main tank and bushings using properly designed tap adaptors installed at the bushing test taps. The acquisition was continuous (not scheduled) and simultaneous in all phases with the results summarized every hour. The bushings, from NGK, were 30 years old, OIP, 345 kV, around 430 pF of capacitance.

On February 2015, a sudden step increase of the capacitance (C1) in bushing A was detected by the monitoring system, estimating a capacitance change in the order of 1.7% which corresponds to a rough increase of 7 pF. Such a small change could have been caused by a partial short circuit between two layers in the condenser core, considering >60 control layers for 345 kV bushings. KEPCO planned an offline test to confirm the online readings, but the results proved difficult to interpret. Indeed, the absolute value of bushing A capacitance had not changed significantly from the previous measurements, as shown in Table 1.

Table 1. Offline results before (2012, 2104) and after (2015) the online alarm

345 kV NGK Bushing OFFLINE Capacitance C1 [pf]

	2012	2014	2015	Increase since 2012
Bushing A	435	429	438	0.60%
Bushing B	433	430	426	-1.60%
Bushing C	432	NA	430	-0.46%

345 kV NGK Bushing OFFLINE Capacitance C1 [pf]

	2012	2014	2015	Increase since 2012
Bushing A	435	429	438	0.60%
Bushing B	433	430	426	-1.60%
A-B	+2 pF	-1 pF	+12 pF	2.7%

However, it was noticed that while the increase of capacitance in bushing A was quite small, both bushings B and C were showing a decrease of capacitance. This led to the assumption that the test setup was different when readings were taken. In order to take this into consideration, the relative difference between capacitance A and B was analysed over time. It was then possible to spot that this difference was quite constant in 2012 and 2014 (below 2 pF), while it was significantly high in 2015, exceeding 12 pF (roughly equal to 2.7% of capacitance increase).

This offline test was not conclusive but led to further investigation of the online data.

Figure 2. Capacitance increase in bushing A1 and high energy event recorded at the same time

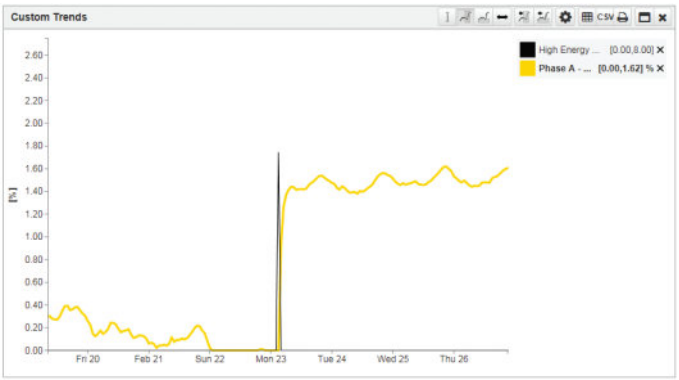


Photo by Camlin Power

It was then found that at the precise moment of the bushing capacitance increase, a high energy event (partial discharge activity with significantly high magnitude, generally equal or higher than 20 V peak-peak [6]) was recorded in the same phase (from same sensor) by the online monitoring system. In this case, the recorded event had just 8 pulses per second and it happened just once. The fact that this event was recorded in conjunction with the capacitance increase was an important detail that prompted an additional offline test: oil sampling from the bushing and Dissolved Gas Analysis (DGA). Table 2 reports the results of the DGA analysis for bushings A and C. It can be clearly seen that the amount of acetylene in bushing A is well above the tolerance values, being 76 ppm; while level of acetylene in bushing C was zero, as expected.

Following the results shown in Table 2, KEPCO promptly planned and executed the bushing replacement within a few months, thus saving the bushing from a potentially catastrophic incident. It must be noted that the repetition rate for both the capacitance change and the high energy event were quite small in terms of absolute magnitude. But being able to detect both these phenomena online and see that they occurred in the same moment provided crucial information enabling KEPCO to take a very successful action.

Table 2. Offline DGA results for bushings A and C

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

KEPCO was able to take a very succesful action thanks to the correlation of online data showing small variations of capacitance and partial discharges.

Case Study #2

345 kV bushing in North America replaced for capacitance increase and high energy events

Bushing and partial discharge monitoring was installed in 2018 on 504 MVA three-phase transformer in North America. The installed device had the same characteristics of the asset in Case #1 and was installed on a voltage tap on Westinghouse 1979 OIP bushings.

Similarly to Case #1, a sudden step increase of the capacitance (C1) in bushing H2 was detected by the monitoring system, estimating a capacitance change in the order of 2.9%, which can correspond to a short circuit between two layers.

By looking at the data it was observed, once again, that a high energy event was recorded in conjunction with the capacitance increase in the same phase. Figure 4 shows the recorded data (not averaged, published every hour) and the partial discharge pattern. The event was characterized by impulses with significant magnitude (60 V peak-peak) and very small repetition rate (just 6 pulses per second), almost describing a sudden arcing activity. Recognizing the same correlation pattern (capacitance change + high energy event) seen in the KEPCO case, it was then suggested to the utility to take an oil sample of the bushings.

Figure 3. Bushing tap adaptor for partial discharge and bushing monitoring

Table 3. Offline DGA results for bushings H1 and H2

OFFLINE DGA results for H1 and H2 bushings

	H1	H2
H_2	20	85
CH_4	8	167
C_2H_2	<2	21
C_2H_4	<2	645
C_2H_6	14	65
CO	75	714
CO_2	1.460	2.790
N_2	51.800	84.300
O_2	7.490	29.600
TDCG	117	1697
TDG%	6,07	11,79

The correlation of partial discharges and bushing monitoring data, along with proper offline tests, was successful in identifying the problem at a very early stage, optimizing the maintenance and ultimately saving the transformer.

Figure 4. Capacitance increase in bushing H2 and high energy event recorded at the same time

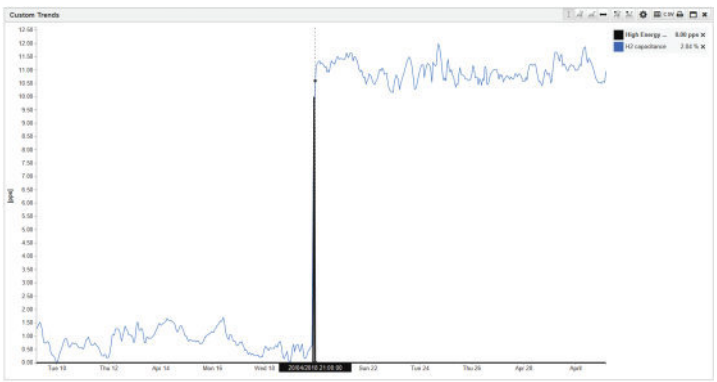


Photo by Camlin Power

Table 3 reports the comparison between the DGA from bushing H2 and H1, showing the acetylene concentration exceeding 20 ppm in the bushing where the capacitance change and high energy events have been detected, confirming the online analysis and enabling the utility to immediately plan the bushing replacement. The correlation of partial discharges and bushing monitoring data, along with proper offline tests, was successful in identifying the problem at a very early stage, optimizing the maintenance (in this case truly condition-based) and ultimately saving the transformer.

Most important:

- The absolute intensity of the capacitance increase and the partial discharges were so small that if they were only considered individually and separately they would cause little concern.
- The combination of the two small deviations/anomalies occurring at the same time, plus the experience from previous similar cases, suggested the choice of the DGA oil sampling as confirmation test.
- It must be noted that DGA on bushings is not a routine test for the utility's policy and it is carried out only in very exceptional cases.

Case Study #3

25 MVA GSU with unknown defect under investigation through DGA, partial discharge, and temperature and bushing monitoring

A 25 MVA GSU transformer was installed in 1986 in a hydro plant in Europe. In 2018 the transformer underwent regular maintenance with the OEM who carried out the following actions:

- Oil degassing. The transformer had a history of abnormal but stable levels of hot gases due to a thermal issue such ethylene and methane. The fact that the gases were stable for a long time indicated that the defect was likely not active anymore.
- Replacement of the glass inspection window in the bushings.

The transformer was originally not equipped with any monitoring system. After the maintenance, an oil sample was taken which showed abnormal levels of H2 in the range of a few hundred ppm. The OEM speculated that this could have been related to the same defect that generated the ethylene increase previously and was likely to be associated with hot spots.

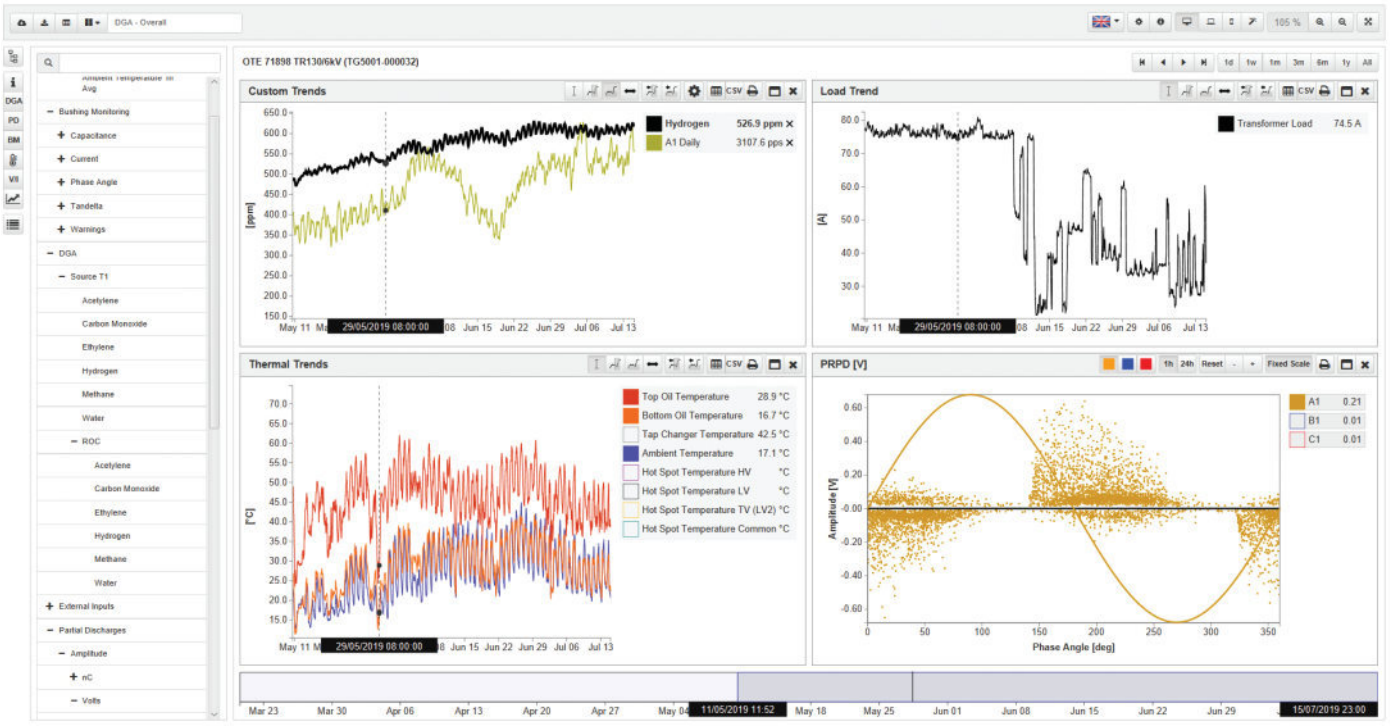
Figure 5. Online holistic monitoring system installed in 25 MVA GSU

Since the new gas pattern was not actually showing “hot metal” gases and considering that the H2 increase was significant and coincidently occurring right after the maintenance, the generation company suspected that the defect was somehow related to the latest maintenance. The utility equipped the transformer with a comprehensive transformer monitoring system that included a five-gas monitor and modules for monitoring moisture, partial discharges, and bushings, as well as analytics capabilities and temperature readings.

After two months of results the following results were observed:

- After a first H2 increase of about 4 ppm/day, the subsequent two months showed that the H2 was still increasing but with a lower rate, at about 1.6 ppm/day, reaching an absolute ppm level of roughly 700 ppm. All other gases had normal concentrations. There was clearly an active defect.
- The partial discharge module immediately detected a persistent active partial discharge source in phase A. This activity had two components, likely indicating two different defects:
  - The first is always present and constant in amplitude and repetition rate (5000 pps) with indirect polarity and typical for defects inside the main tank (including the bushing turrets, i.e. whatever is outside the bushing core). This activity has no cross coupling with the other phases which means that the source is far from the other two phases or very close to the partial discharge sensor.
  - The second is sporadic, with smaller repetition rate (in the range of 1000-2000 pps) and with direct polarity indicating that it could be inside or very close to bushing A.The overall partial discharge activity was increasing over time in terms of repetition rate, indicating that the active defect was in phase A.
- From the phase-resolved partial discharge (PRPD) pattern it was difficult to identify the partial discharge source, however similar shapes of the pattern had been recorded when the oil treatment was not conducted properly leaving small air bubbles trapped, or when small puncturing activities were present in the paper insulation on the top of the winding column (e.g. in the stress ring).
- Looking at all the data collected by the holistic monitoring system, it is possible to see that there is almost no correlation between data. The gas generation and partial discharge activity are not influenced by the load, nor by temperatures and humidity.

Figure 6. Online results synchronized and visualized in a way to enable further investigation on the possible correlation



The first speculative analysis, after having looked at the online data, was leading towards the possibility that the defect was likely to be due to the last oil filling process that apparently had not been carried out under vacuum (due to the fact that gaskets are not suitable for the vacuum process).

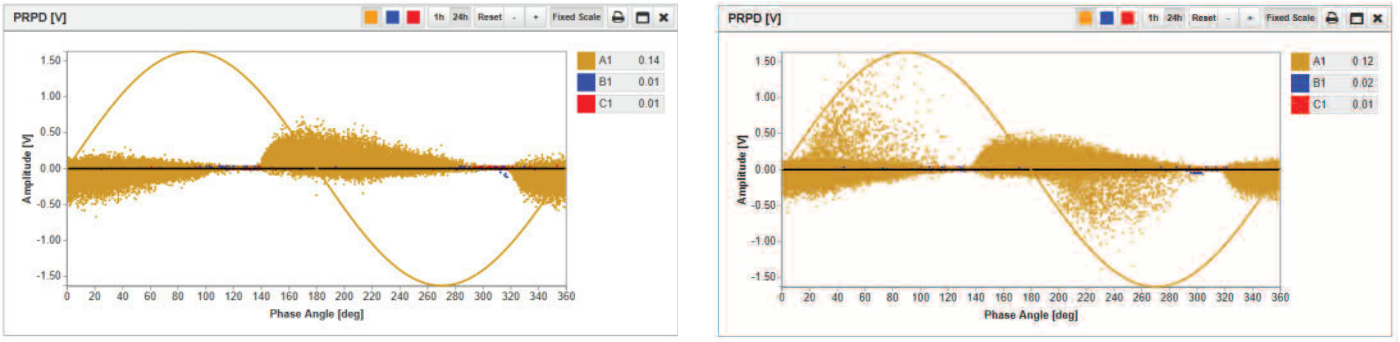
Photo by Camlin Power

Due to an absence of hot and arcing gases, the perfect condition of the bushings (in terms of capacitance and tan delta) as well as the absence of a clear correlation with load or temperature, the utility decided to:

- Keep the transformer monitored and under control in order to analyse the gas and partial discharge development during the next few months.
- Plan the gasket replacements in order to perform a proper oil treatment and refilling under vacuum to remove any possible trapped bubble.
- Agree that maintenance was to be planned. However, this could be deferred to the next stop of the generator considering that:
  - the overall picture provided by the online monitor indicated that the transformer was not in a critical condition, and
  - the transformer was continuously monitored so any unexpected change in the condition would promptly notify the Subject Matter Expert.

In this case (which still under investigation at the time of publication) the use of the total transformer monitoring not only aims at optimizing and deferring the maintenance to the best possible moment (generator annual stop) but is also a means to resolve the controversy between the OEM, responsible for the maintenance and oil process, and the transformer owner.

Figure 7. PRPD pattern of the stable partial discharge activity in Phase A1 (left) and the sporadic activity overlap (right)



Conclusion

The use of a more holistic and integrated approach to transformer monitoring can significantly help to optimize maintenance and mitigate risk. Holistic means the treatment of the whole transformer, taking into account operational data, environmental data, external factors and previous experiences, rather than just a single diagnostic parameter such as DGA. The chances of identifying the failure mode or defect can dramatically increase, allowing asset owners to understand their risk and ultimately make prompt and better-informed decisions. The planning and the use of valuable offline techniques (DGA in bushings, SFRA, DFR, etc.) can be better informed by the information provided by the monitors. The monitor's role is not to replace the offline methods but to optimize their use and effectiveness.

The correlation of the different parameters such as DGA, partial discharges, bushing capacitance etc. plays a fundamental role. However, the key point that has been shown in the case studies is that the correlation and occurrence of these events can sometimes be even more important than their absolute magnitude. A small capacitance increase and a few partial discharge pulses can be easily neglected, ignored, or treated as insignificant if considered individually. The outcome obtained by the correlation of all these small events can have a huge impact on risk assessment process and failure identification processes, and facilitate better decision making.

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With headquarters in Italy and branches in Egypt, China and Brazil, we are positioned in strategic places around the world so we can respond promptly to every need of our local customers. We have created a network of services suitable for accompanying every user in their projects.

Our R&D department designs and implements solutions suitable for all electric machine types with the ability to operate in any application sector (railway, airport, shipping, building, construction, food, subway, alternative energy and others).

Security and reliability are our guidelines, granted by ISO 9001 certification and by specific certification related to each product.

Thanks to the progressive evolution of our temperature monitoring technologies, we are now working to create increasingly digitalized devices that interface easily and immediately with any kind of existing systems.

In this case, digitalization is a technological progress which revolutionizes the approach to parameter control and allows the operator to act remotely, planning maintenance interventions in advance (predictive / preventive maintenance).

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Data flows are immediately usable and manageable in an intuitive and simple way (in some cases even from Mobile or Tablet), thanks to specially designed graphic interfaces.

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In this way the User, ***using the wide range of data in a predictive way***, can work to improve the basic concepts of **Reliability**, **Maintenance and Efficiency**.

At Tecsystem, we are able to keep abreast of the times, and we have developed two product lines which meet the new needs:

- **ETH(ernet) LINE:** equipped ***with Ethernet output with Modbus TCP / IP protocol*** - to display, program and collect temperature parameters. Suitable for systems where wired networks for the acquisition and remote control of information are available: it is a widely used technology for industrial networks.

  Among this LINE we present the **T1048 ETH** * which is UL certified and best features are the following:

- IntelliFan: to reduce the thermal shock of the transformer anticipating partially (one bar at a time) the activation of the ventilation system.

- Voting: this function comes from the concept of redundancy, that consists in duplication of components of a system with the intention of increasing reliability. Taking advantage of this principle, we use the probes installed on the three phases to monitor the operation of the transformer but at the same time ensure the proper functioning of the probes themselves, discriminating any false alarms

- FailSafe: The T1048 has n.o. selection (normally open contact)/ n.c. (normally closed contact) for alarm and trip relays. The selection of the setting n.o./ n.c. introduces functions Fail Safe and No Fail Safe.

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- **WS LINE:** equipped with a simple graphic interface for displaying and analyzing the temperature information detected, as well as a small antenna for ***Wi-Fi connection***, it offers the possibility of intervening for the programming and configuration of the system, without having to install dedicated Apps or Software, ***on any Internet Browser***.

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Automated Substation Monitoring with Thermal Imaging

by **Richard Harada**

Introduction

Infrared technology is widely used by utilities to find heat related anomalies in the electrical system that could indicate potential problems. Portable infrared cameras have been typically used by thermographers to periodically inspect substations and other key areas of the grid. Early detection of excessive heat in the electrical system, or the absence of it in some cases, allows the utility to schedule maintenance and correct issues before an expensive failure occurs. While periodic scanning is useful, it is subject to many changing variabilities including changing environmental and load conditions.

Automating thermal inspections can greatly reduce the costs to utilities through reduction of travel while increasing employee safety and the amount and quality of data that is collected.

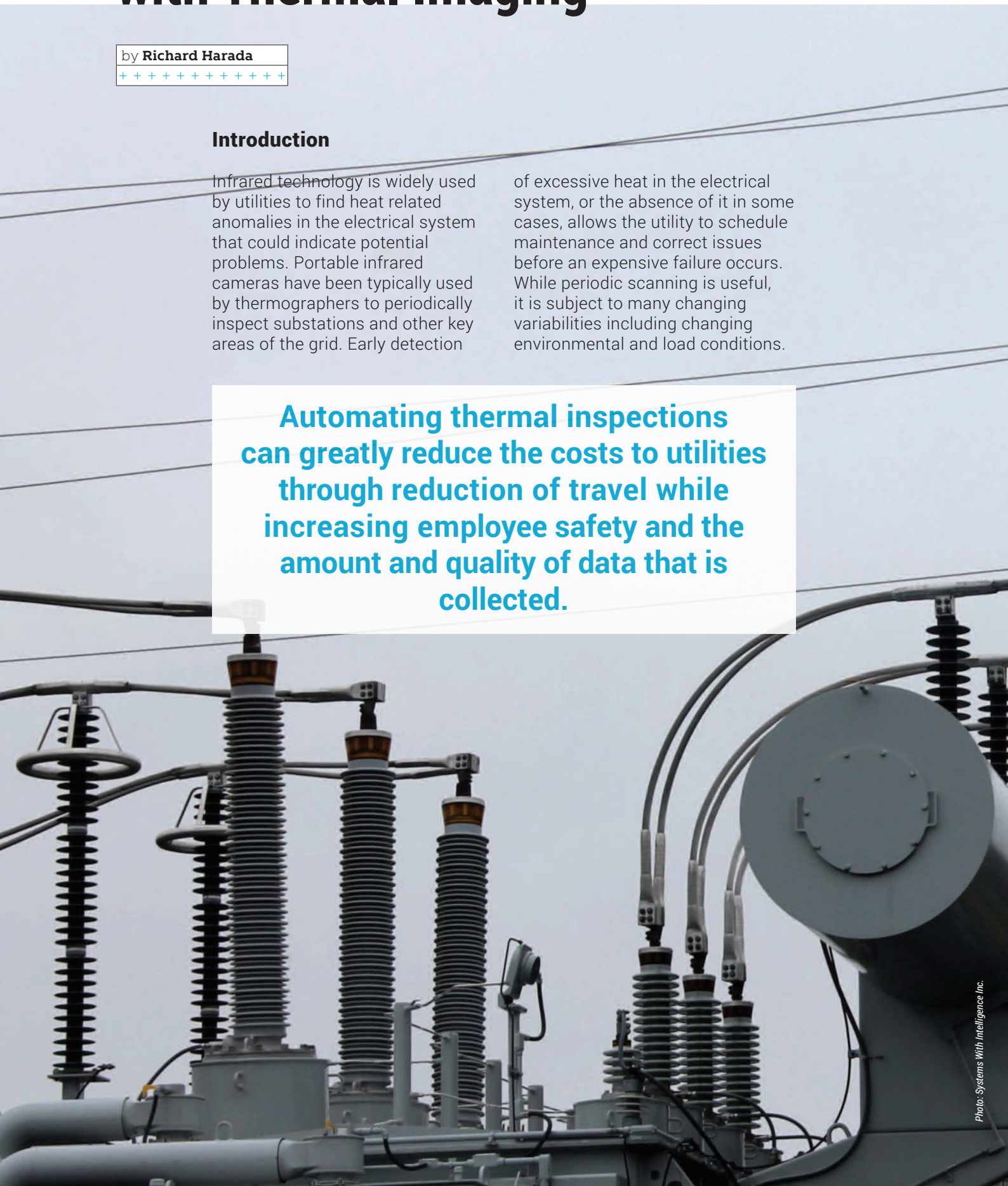


Photo: Systems With Intelligence Inc.

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

Being able to monitor your substation remotely is one of the keys to going touchless.

Automating thermal inspections can greatly reduce the costs to utilities through reduction of travel while increasing employee safety and the amount and quality of data that is collected. Furthermore, the data can be made available to SCADA and asset management applications as part of a condition-based maintenance program to increase the utility's bottom line through improved asset life, efficiency and reduced outages.

Automated and remote inspections can lead to more efficiencies and cost savings for utilities by allowing them to go "touchless."

Figure 1 shows a thermal monitoring camera that can be programmed to automatically monitor equipment in the substation. A thermal image of a transformer shows temperatures of transformer components and allows thermographers to define areas to take temperature readings. The readings are digitized and converted to temperature points.

Utilities such as PPL Electric Utilities and PSE&G [1], [2] are implementing touchless substation projects that involve remote monitoring to gather the health information on substation equipment and condition-based maintenance (CBM) to plan and prioritize service work. Remote monitoring can involve many types of connected sensors such as those that measure current, voltage, temperature, dissolved gas, etc. Some of the key areas to monitor with sensors are transformer components such as bushings, cooling fans and load tap changers.

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

Figure 1. Substation rated, infrared monitoring sensors can be permanently installed on pan-tilt mounts to automate the thermal scanning process.

Photo: Systems With Intelligence Inc.

Background on Thermal Imaging

Thermal imaging is the technique of measuring infrared radiation from an object and converting it into a temperature value. An important feature of thermal imaging is that it is non-invasive — it uses a sensor that can measure temperature values without physically touching the object. It is not required to power down equipment to install the sensor or to make the measurements. The measured value can be affected by many environmental factors including ambient temperature, humidity, wind and emissivity of the target object. With these factors in mind, it is often more meaningful to use comparative measurement; comparing the temperature differences between like components instead of trying to measure an absolute temperature value on each, effectively cancelling out the environmental variables. An advantage in the electric power industry is that the power system runs on three phases, so in many cases inside a substation it is possible to measure like components on different phases, i.e. measuring the temperature difference between the A, B and C phase transformer bushings [2]. In this case, instead of trying to calculate what an absolute temperature value should be, it is simpler and more meaningful to compare temperatures between phases. Typically, the temperature of like components should be within 1°C of each other. If not, there could be a load problem or a component problem in the system.

The International Electrical Testing Association (NETA) has established a guideline of comparative measurements and relative comparisons to ambient temperature.

Thermal imaging is useful to find heat related anomalies in many areas of a substation.

As outlined in Table 1, NETA has recommendations for actions to take when comparative readings reach defined levels.

Thermal imaging is useful to find heat related anomalies in many areas of a substation, such as connection points, disconnect switches, breakers, insulators and arrestors.

Around transformers the key points to monitor are:

Bushings and surge arrestors – Hots spots on the connection point could be due to loose or dirty connections. Hot spots on the body could indicate a breakdown of the insulation.

Cooling Systems – Cool spots on radiators could indicate blockages or low coolant levels. Cool or hot areas in fans can indicate electrical or mechanical problems that require maintenance.

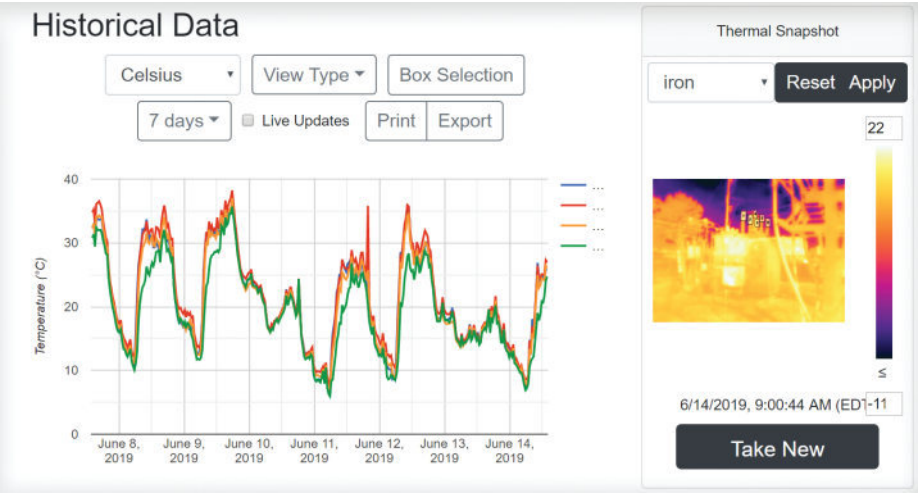
Load Tap Changers (LTCs) – The LTC tank should be the same or lower temperature than the body of the transformer. A bad connection on the tap changer will heat the tank only if it is carrying load. A faulty tap may not show up in a thermal scan if it is not connected at the time of the reading.

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

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

and efficiency. The system analytics automatically detect temperature abnormalities in the system and send alarm messages. The data can be stored locally at the site and communicated directly to the control center SCADA or to asset management systems for real time situational awareness.

Figure 2. Continuous temperature values can be trended over time and correlated with weather and load conditions.
(Source: Systems With Intelligence Cloud Dashboard)



Advancements in Thermal Imaging Technology

Processing Power

Thermal imaging runs on computing power. As advancements in thermal imaging technology continues, the performance of thermal imaging is increasing while the price of the technology is decreasing. An automated thermal sensor can capture high, low and average temperatures from hundreds of pre-set points while cycling and scanning through areas of a substation. Using high resolution imaging and the appropriate lens, the temperature on even a small object can be measured from up to 50 meters away. Data processing can be done at the edge of the network to improve reliability

Communications

Major improvements in network communications have been a huge benefit to thermal imaging technology. In the past, with handheld cameras, the data was stored in the camera and transferred to a computer system manually. Now, with modern Internet Protocol (IP) based systems, the temperature measurements are digitized, stored on solid state memory and transferred to storage and control center systems in real time. Many utilities have high speed connectivity to their substation, but even those with little or no connectivity can still take advantage of the edge processing that minimizes the amount of traffic that needs to flow over the network. Utilities with no wired connection to their remote sites can utilize modern 3G and 4G wireless networks that provide high speed connectivity.

Data points can be trended over time to establish a health index and the graphs and current readings can be accessed via an information dashboard (Figure 2). Visual and thermal sensors can send their data wirelessly to the cloud for remote sites that have limited connectivity (Figure 3).

Reliability

Infrared sensor technology has shifted from analog imaging to digital imaging resulting in improved image quality, more efficient methods for transmitting data, and simpler processes for storing and analyzing the data. The previous generation of thermal cameras used analog communications to transport information making it susceptible to degradation and loss. When used in a substation the interference effect was increased due to the presence of high levels of electromagnetic interference (EMI). New, network-connected imagers now digitize the signal at the source and can transmit the data over fiber optic cable which is immune to the effects of EMI. Storage technology has improved so that data can be saved to solid state drives, eliminating the need for mechanical spinning drives. Substation rated equipment is required to meet high levels of reliability and the components and designs can now meet these requirements while maintaining a high level of performance.

The Advantages of Automated vs. Manual Thermal Scanning

Utilities have been doing manual thermal scanning for years, and they are aware of the problems that can be uncovered with the technology. Utilities have thermographers on staff (or they use professional contractors) to perform thermal site inspections. However, there are many advantages to using continuous, automated thermal scanning given the advancements in thermal scanning technology.

Photo: Systems With Intelligence Inc.

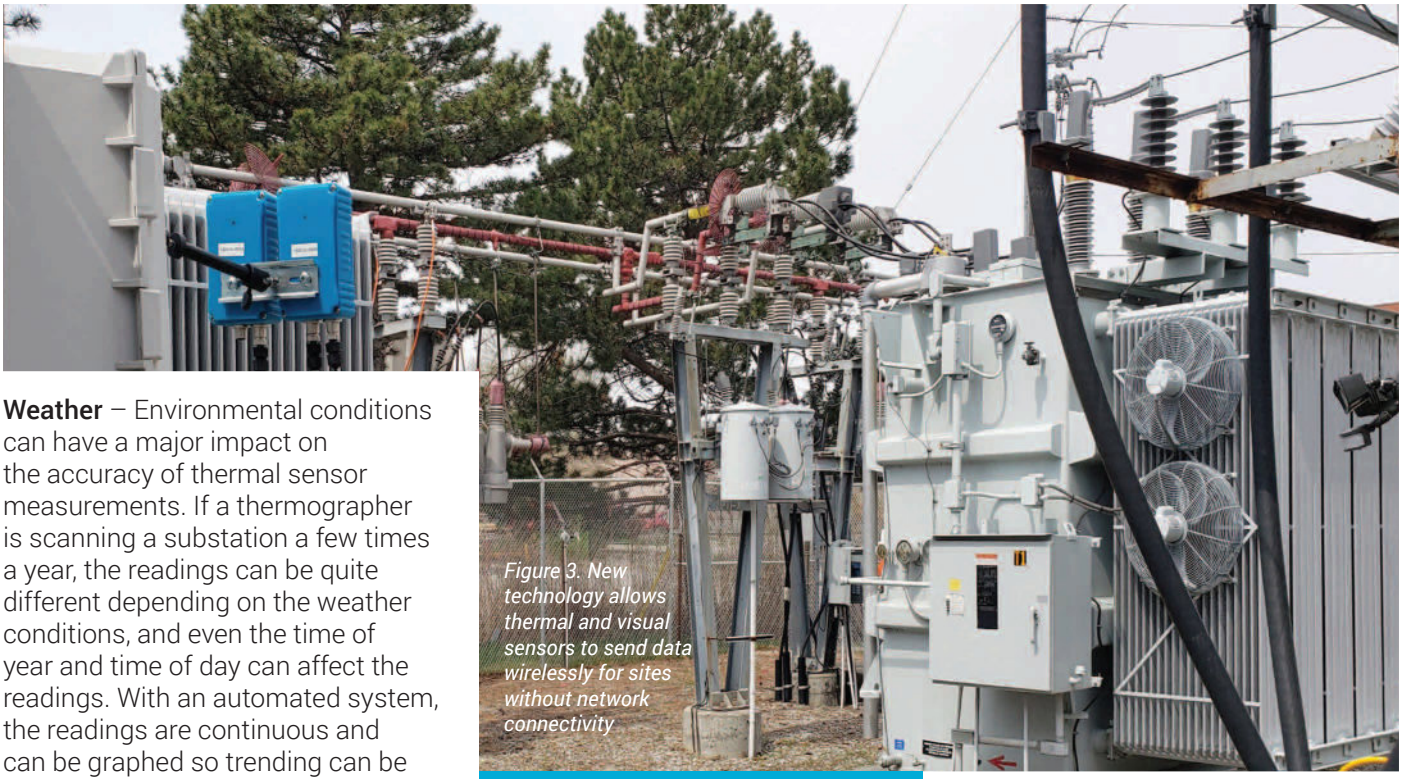


Figure 3. New technology allows thermal and visual sensors to send data wirelessly for sites without network connectivity

Weather – Environmental conditions can have a major impact on the accuracy of thermal sensor measurements. If a thermographer is scanning a substation a few times a year, the readings can be quite different depending on the weather conditions, and even the time of year and time of day can affect the readings. With an automated system, the readings are continuous and can be graphed so trending can be established that will account for weather abnormalities and will even show how temperatures vary daily and seasonally.

Accuracy of data entry – A thermographer using a handheld thermal imager will at some point need to transfer the readings to a computer system. The transfer of data can be prone to error when a manual operation is involved. An automated system records the data to a database and has an interface to send the data in real-time to SCADA, asset management or data aggregation applications, eliminating the possibility of human error.

Consistency and interpretation of results – Thermal scanning results from the substation can vary over time. Aside from the changing environmental conditions, variations in the angle, position and distance to the object may affect the consistency of the readings. Different thermographers may use different imagers and interpret settings and readings differently. An installed thermal imager will be installed in a fixed location and will be programmed by the thermographer to scan the substation at predefined, pre-set positions with high accuracy and consistent parameter settings. This guarantees consistent readings and interpretation of results.

There are many advantages to using continuous, automated thermal scanning given the latest advancements in technology.

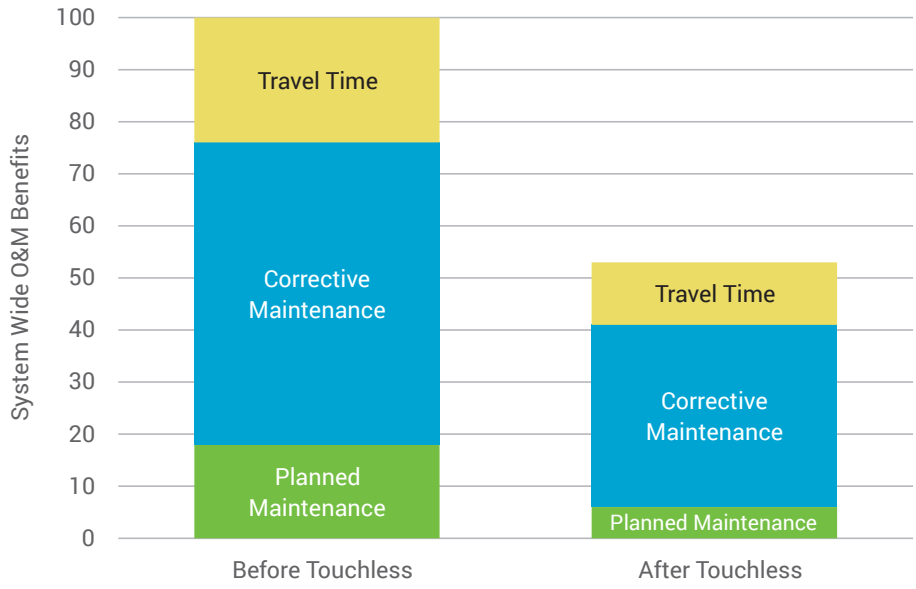
System load – The amount of current being drawn can have a major effect on the thermal scanning results due to the I^2R factor. If current is leaking through an insulator, or if there is a poor or loose high resistance connection, that point will heat up more when there is greater current flow. A faulty tap on an LTC will only show up when that particular tap is connected. Some hotspots may only show up during times of peak load, so if the thermographer is not performing the scan during this time the hot spot will remain undetected. Conversely, the continuous scanning system will find the hotspot during each time the system hits peak load or when a faulty tap on the LTC is connected. This will generate an alarm about the condition.

Continuous thermal data – Manual thermal scanning doesn't provide continuous data. By its nature, data from manual scans is infrequent and can be less accurate unless the same experienced thermographer is doing the scan each time. Continuous thermal data allows for trending of temperature data and relating it to weather, seasonal changes and system load. The thermal data can help asset managers establish asset health indexes for the purposes of condition-based maintenance.

Timing - Periodic inspections are valuable for finding hotspots, but they can miss problems if the timing is off. As and example, a substation that is inspected today may be struck by lightning tomorrow, damaging an arrestor. That damage may not be discovered until the arrestor fails.

Connection to Management Systems – With automated thermal imaging, data transfer happens seamlessly. As the temperature data is collected, it can be uploaded directly to connected SCADA systems, data aggregation systems such as OSISoft, or asset management systems using industry protocols such as DNP, Modbus or IEC 61850. This type of connectivity provides operators with real time data and asset managers with data that can be used to track asset health and condition.

Figure 4. Reduction in O&M costs using condition-based maintenance. (Source: The Future is a Touchless Substation [2])



Condition Based or Preventative Maintenance

As utilities strive to get the most out their assets while making the most efficient use of maintenance resources, they are turning to condition based maintenance to try and achieve these goals. As shown is Figure 4, CBM saves a utility money by reducing trips to the field by alerting crews to equipment problems before failures occur. CBM can extend the life of assets by allowing crews to perform repairs before costly failures occur [3]. With constant monitoring, utilities know the condition of their assets and can schedule maintenance only when required instead of on a time-based schedule. This makes the most efficient use of personnel and materials. Automated thermal monitoring provides a constant source of timestamped temperature data that can be connected directly with asset management databases and correlated with weather, load and other situational conditions in the substation.

Summary

Utilities know the benefits of thermal monitoring, and new technology can now make it automated and more affordable. While there is an initial capital expense to install a continuous thermal monitoring system, there are many benefits that a utility can realize in a relatively short amount of time that can save operations and maintenance costs, help prevent outages and extend the life of high value assets.

Thermographers can set up the system to perform automated thermal scans of the substation. The thermal cameras can be programmed to take temperature measurements on hundreds of points with thresholds set to determine if the readings are within tolerance. The thermographer can also take control of the system remotely for focus on specific areas of interest. Since the system will typically include visual cameras, substation managers can also perform remote visual inspections of equipment and conditions in the substation. Utilities benefit from remote inspections by:

- Reducing the frequency of truck rolls by eliminating the need to be on-site for inspection.
- Increasing safety by reducing the amount of exposure that employees have to hazardous areas.
- Monitoring crews on site, which can influence behaviour and ensure that crew follow safety procedures. If any incidents occur, a video recording can provide valuable evidence and training for the future.
- Increasing the volume of inspections, which ensures that the substation is in top condition, animals are not moving in, and the substation remains a safe environment for the public and for employees.
- Allowing remote troubleshooting and visualization, which informs the crew of equipment condition and failures before going to the site. This may allow them to have the right parts on the truck before rolling out.
- Providing constant and consistent data for condition-based maintenance.

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[1] E. Rosenberger, M. Coyle, *PPL Touchless Substation Project*, 2017.

[2] D. O'Rourke, R. C. Alvarez, M. Khan, "The Future is a Touchless Substation," *T&D World Magazine*, 2019.

[3] D. A. Genutis, *NETA World – Infrared Inspections and Applications*, 2006.

[4] J. Lonneker, B. Baker, "SDG&E Takes a Proactive Approach to Maintenance," *T&D World Magazine*, 2013.

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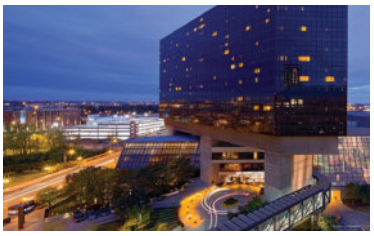

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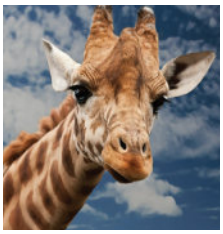

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Face-to-face in a digital world – the value of industry events

In an ever increasing virtual world, where do industry events fit? Can we gain the knowledge we need to do our jobs today and in the future from the digital world alone? Or should we also realize the value of stepping away from the screen? **This article explores the benefits of sharing knowledge face-to face through industry events, investing in people for their personal development and, ultimately, realizing how organizations are reaping the rewards.**

In the March 2019 edition of Transformer Technology magazine, Alan Ross, Editor in Chief, asked the question "What if much of that legacy knowledge isn't worth passing on in the first place? What if things have changed and are changing so rapidly in our field of electrical system reliability that much of that legacy knowledge is outdated, or even worse, what if it is flat out wrong? Would we want to make sure the next generation learned it?"

This question on the surface appears easy to answer. But how do you continue to ensure individuals and organizations gain the knowledge and skills required to be successful?

Choosing and attending the right industry events can be an important starting point.

Photo: Shutterstock

Motivation!

Some events are considered expensive, requiring time away from the office, and the return-on-investment isn't always clear. But they provide opportunities that you simply cannot get elsewhere.

Having the opportunity to learn, meet with experts and peers, and have a bit of fun(!) is a great way to motivate people. From time to time, everyone's motivation dips, especially when facing the same routine and set of challenges each day. An industry event provides a great opportunity to free your mind from day-to-day tasks and experience something refreshing and motivating.

An organization with motivated, proactive employees, contributing new ideas is always more likely to succeed.

Learn something new and imagine new ideas!

Reading industry publications, blogs and whitepapers can certainly contribute to a better understanding of new developments and trends in our industry. However, watching, listening and interacting with experts face-to-face is invaluable. Attending an event allows people to ask questions and make important connections with industry experts and peers. Attendees learn new skills and best practices, leading to practical ways to achieve long-term success as an individual and organization.

Industry events also present the opportunity to meet like-minded people who share similar interests and face similar challenges in the workplace. Stepping away from daily work life and networking with peers can generate fresh, new ways of thinking and learning, translating into ideas and concepts that provide a strong ROI to organizations.

Networking, in person!

In a digital world, networking in person is becoming more and more difficult. We often forget how effective in-person interaction can be.

We cannot expect that an individual has the answer for every challenge today's world throws at them. Having a strong network of experts and peers from within a given industry to call upon can provide a leverage to solve new problems, discover best practice and learn from similar challenges. Events provide valuable time to network and socialize as an industry. Investing in building an individual's network reaps benefits for employers and organizations for years to come when new challenges inevitably present themselves.

Attending industry events should be part of all organizations overall improvement and growth strategy. Understanding industry trends and current developments is key to being successful and competitive. Having motivated, engaged individuals in an organization can only lead to additional benefits, now and in the future.

So referring back to Alan Ross's question, lets equip ourselves and future generations with the knowledge and skills required to ensure our industry of transformers, power generation, transmission and distribution can be successful for years to come - and it is evident industry events play a leading role in confidently knowing that up-to-date research and ideas are being discussed and passed on.

WEIDMANN

Francis Fisher

is the Head of Global Marketing at Weidmann Electrical Technology. Since receiving his bachelor's degree in business from the University of Huddersfield, UK in 2002, he has worked in a variety of commercial roles within the energy sector spanning multiple continents and regions, including Asia Pacific, Americas and Europe, Middle East & Africa

About Weidmann Electrical Technology:

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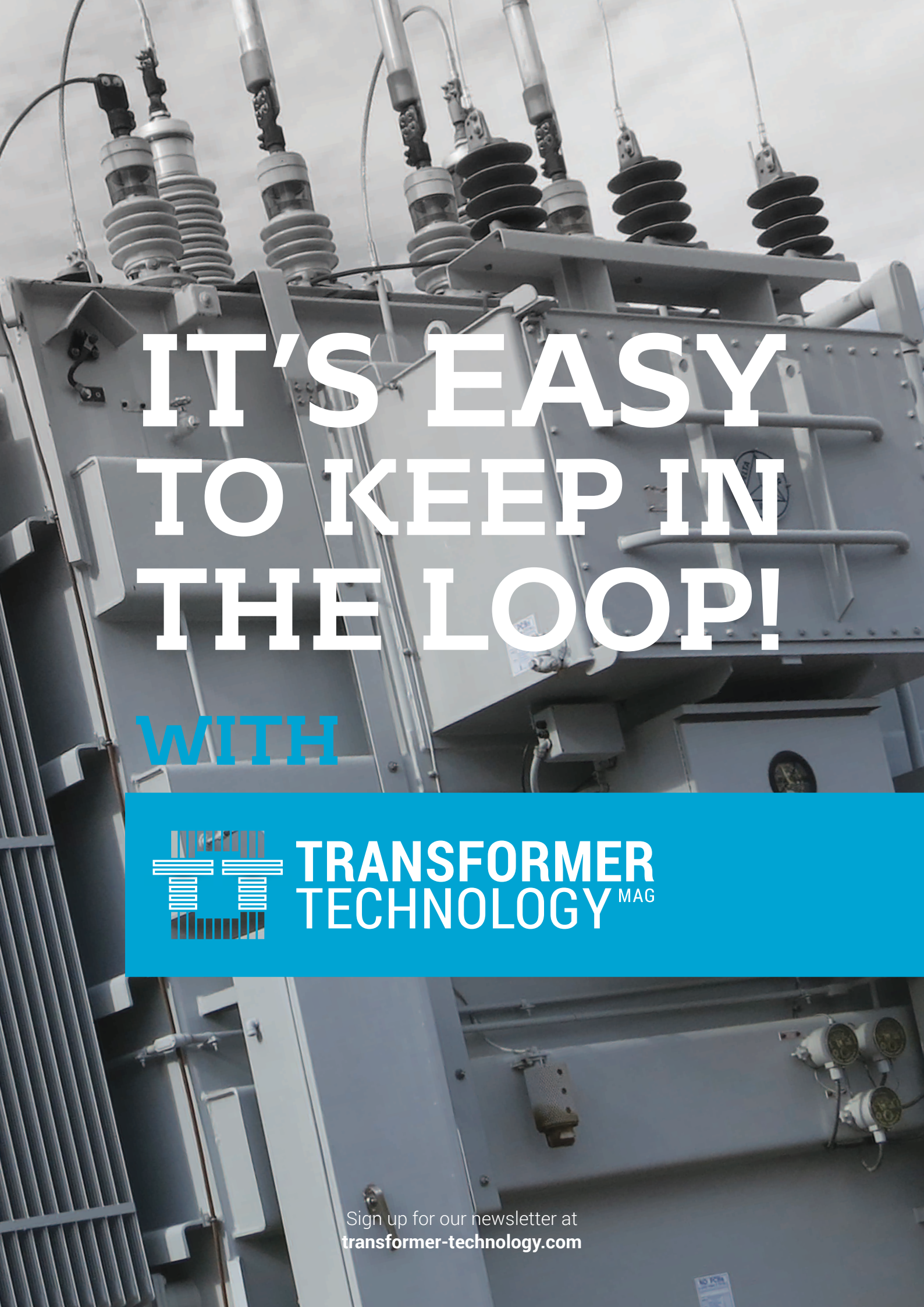
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Discover the latest transformer tech innovations at CWIEME AMERICAS 2019

CWIEME Americas, North America's only dedicated event for the supply chain of coil winding, electric motors, transformers and generators, will be held in Chicago at the Donald E. Stephens Convention Center on September 17-18, 2019.

Amongst the over 90 exhibitors, many will showcase the latest transformer components, materials and process machinery innovations, including Acme Mechatronics, Alliance LLC, Elsan Elektrik, Gorman Machine Corp, Jovil, Metalux, Nishimoto and V&C GmbH - to name but a few.

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Pre-booking required.

Senior industry experts present transformer trends & market intelligence

Besides connections to new and existing suppliers, CWIEME Americas is an all-in-one-place providing visitors with networking opportunities and a highly-curated free-to-attend conference program to boot. The Innovation Talks will focus on how transformer design and manufacturing are evolving, for example in a content session with Saqib Saeed, Principal Analyst - Grid and Power Semiconductors at Power Technology Research LLC, presented by Transformer Technology Editor in Chief Alan Ross.

> For the most part we are redesigning systems, not designing from scratch, adding technological advances while integrating new technology into old systems. ***Transformer Technology***

Presentation by Alan M Ross

The application of Reliability Engineering disciplines and principles provides a unique perspective to a smart grid transmission & distribution system. In this presentation we will look at how technology, UIoT, Machine Learning and Condition Based Monitoring can positively affect the long-term reliability of these critical systems.

While reliability engineering starts at the design phase for asset management decisions, an even greater impact will be on the system those assets comprise. We will look at the best practice approach for a Reliability Centered Maintenance program for transformers as an example of how to apply system approaches to reliability.

As the Editor in Chief of Transformer Technology, Vice President of Strategic Development for SDMyers and active IEEE Power Energy Society and Reliability Society contributor and member, Ross is passionate about reliability of electrical systems. His presentation at CWIEME is sure to engage, encourage and educate.

WHERE AND WHEN?

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Transformer Failures: Causes and Prevention

The factory of the future will have only two employees, a man and a dog. The man will be there to feed the dog. The dog will be there to keep the man from touching the equipment.

Warren Bennis

We aren't quite where Warren Bennis joked we might be in the future, but there is a lot of truth to the idea that equipment is becoming more complex and more automated. With Artificial Intelligence (AI) and Machine Learning (ML) as growing influences, transformers are becoming smarter.

What does this have to do with transformer failures? Given the large aging installed base of transformers in the grid, in industry and in commercial applications, we don't have as many smart assets as we will have in the future; especially as the Internet of Things (IoT) makes real time condition monitoring of transformers and transformer components a reality. So, we are experiencing a growing failure rate, sometimes preventable if the dog had not kept us away from the equipment.

Our December issue is a must read for anyone tasked with the design, manufacturing, testing installation, operation, maintenance, monitoring or life cycle management of transformers. In short, if you have anything to do with transformers, this is a must read and "must keep for future reference" edition.

Alan Ross, Editor in Chief

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