



TRANSFORMER TECHNOLOGY^{MAG}

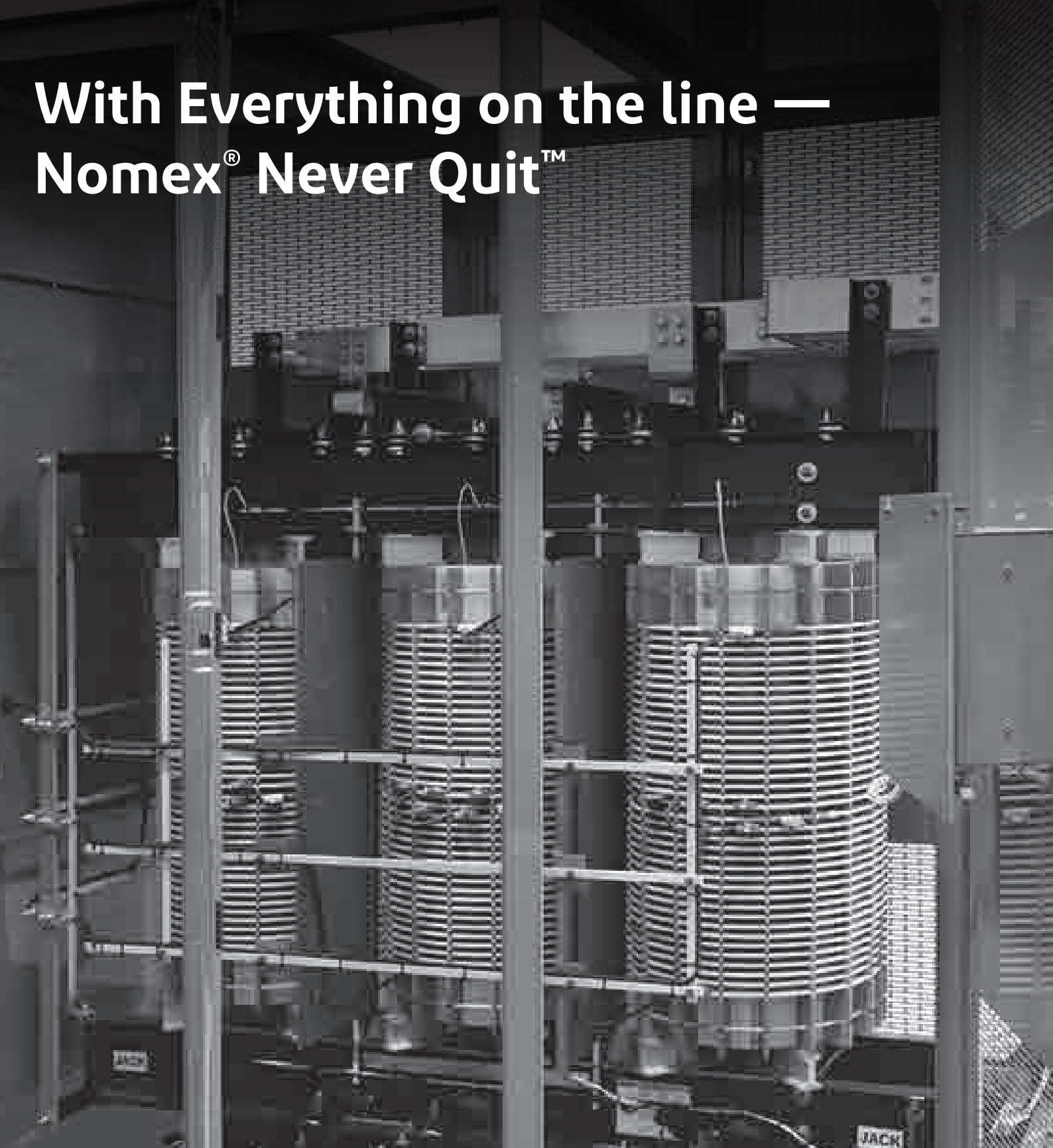
The Dry-Type Revolution

Dry-Type Transformers: Everywhere But Unnoticed

Interview with **Wayne Bishop Jr.**
VP Meetings at IEEE Power and Energy Society

Interview with **Martin Robinson**
CEO of IRISS

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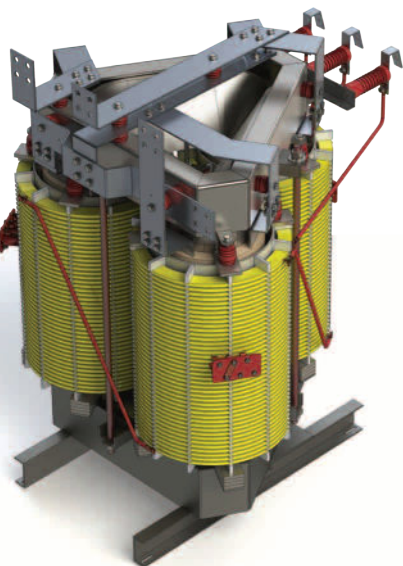


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One of the main focuses of the ongoing technological development of cast-resin transformers is their exceptional operational reliability and fault tolerance, while also increasing their sustainability and economic viability. Digitalization is creating new possibilities for optimizing availability and service life.

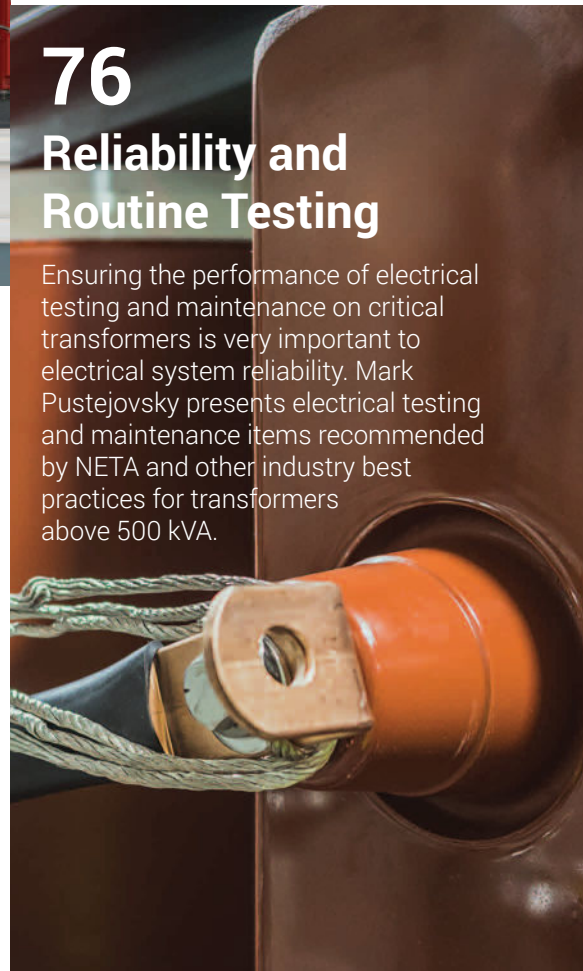
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Ensuring the performance of electrical testing and maintenance on critical transformers is very important to electrical system reliability. Mark Pustejovsky presents electrical testing and maintenance items recommended by NETA and other industry best practices for transformers above 500 kVA.



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Kevin Eaton presents the difference between a conventional, three-legged stacked core against a symmetrical triangular (wound) core used in dry-type transformers, discussing the manufacturing process and providing further insight to the improved characteristics and physical advantages of the triangular-wound core transformers.



Dear Readers,

One of the things that has impressed me the most as Editor in Chief of Transformer Technology magazine is the quality and variety of the people in this industry; people who I have approached to contribute to the magazine, or people who have recommended authors or articles. Our industry seems to have a significant share of professionals who have two things in common.

First, they are “lifelong learners.” They never seem to settle for what they’ve already learned. They seek out knowledge. They have a passion for it. Whatever it is that sparks that curiosity, we are all better for it. For the September issue, I had the privilege of hearing from Craig Stiegemeier from ABB. Craig is a professional’s professional. He is the epitome of a lifelong learner. I believe that you will agree when you get a chance to read his interview in September or listen to our Legends Podcast online when his interview is broadcast.

Second, these professionals are willing to share their knowledge to make the next generation better prepared and better equipped than they would be otherwise. I imagine it might drive our companies a bit crazy with all that sharing, since we live in a world of “proprietaryization,” where creating a unique advantage is prized over a shared advantage. Thank goodness for organizations like IEEE, NETA, IEC, CIGRE and others who level the playing field. Wayne Bishop of Omicron, the new vice president of meetings and events for IEEE, makes a great case for this in his interview in this issue and during his interview on the Legends Podcast.

It has humbled me to have the opportunity to connect with so many “legends” and future legends. That is what we at Transformer Technology hope to deliver to our readers over the coming years: access to professionals, both young and old; technical articles and articles that are accessible to a broader audience; and a forum for these lifelong learners to share their knowledge.

On to the Revolution

This issue was harder to produce than I thought it would be. The more I have learned about dry-type transformers, the more it seems like a story of two teenage brothers. One who is bigger, older and stronger, and one who is smaller, younger, less athletic. The older brother picks on his little brother, but nobody else can... they are family after all. The older brother gets all the attention. The little brother...? Not so much.

That is the analogy I imagined as I researched who should be writing for this issue. The bigger, liquid-filled transformer brother condescendingly asking: Why would you want to know about my little brother? He isn’t really all that unique, or press-worthy, is he?

Since this issue is the Dry-Type Revolution, we are going to focus on the little brother. I think you might find he has more muscle and more to offer than big brother thinks.

So, What’s the Difference?

It is my hope that our magazine reaches not only a technical audience, but also one that wants to be informed about transformers and to learn what has been and what will be. When I thought of the theme, the Dry-Type Revolution, I was hoping to change the way people in the industry think about how dry-type transformers are designed, their application, and where technology is taking them.

Since the differences between a liquid-filled transformer and a dry-type are evident in the names, this issue will focus on the uniqueness of the dry-type and not on comparisons. I used to think that it was a simple issue of location—dry-types were used indoors, where it is dry, and liquid-filled were used outdoors, where it might be wet. Of course, that is not a distinction since liquid-filled are used indoors where there is a need for more power, and dry-types are used outdoors where there is an environmental or safety concern.

Are there advantages to using dry-type transformers beyond location? Of course. Casey Ballard discusses these in his article “Dry-Type Transformers: Everywhere But Unnoticed - A Broad Range of Design and Application”. Kevin Eaton focuses on the “Reshaping of the Dry-Type Transformer”, and Marie Hirzel looks at “Performing a Failure Modes and Effects Analysis on a Dry-Type Transformer”. As a reliability guy, I love her approach. Well done Marie.

Hassan Zaheer shares research on the “Dry-Type Transformers Market: A Growing Niche,” and Mark Pustejovsky presents “Electrical Testing of Dry-Type Transformers.” Heinz Raithel focuses on operational reliability and sustainability of cast-resin transformers, and there is something unique from one of our contributing editors, Corné Dames.

Finally, I believe you will enjoy our interview with Martin Robinson, CEO of IRISS, as he discusses Condition Based Monitoring (CBM) for electrical assets, including dry-type transformers. His interview will also appear on the Legends Podcast page on our website. Martin is a CBM guru and is someone I think you'll enjoy hearing from.

I am looking forward to our September issue dedicated to Transformer Testing, Maintenance and Monitoring: Best Practices. We have lined up some of the best in the industry to share their knowledge and advance the cause.



A new feature we plan on introducing is Future Legends, a forum for the next generation of engineers as we seek out college juniors or seniors who can contribute to the magazine.

If you know someone you think could write an article on something they have learned and are passionate about, please connect them with me at **alan.ross@transformer-technology.com**. I would love to feature our future legends in an article or an interview.

Thank you for being part of the revolution.

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



Alan M Ross



Impressum

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At a Glance

Recent report shows utilities doubling down on modernization

A recently released Black & Veatch's 2019 Strategic Directions: Smart Utilities Report surveyed hundreds of U.S. utility operators and found that utility business models are changing to accommodate the growing volume of renewable energy coming onto the grid.

The report explores how grid modernization efforts like the greater integration of renewable energy and distributed energy resources (DER) are reshaping the market, fueling the grid modernization push.

The report found that roughly one in five survey respondents say their utility plans to allocate more than \$200 million into modernization investments over the next three years, while an additional 26% say they will devote \$100 million to \$200 million.

Distributed energy is by far the top application that utilities plan to support in the immediate future, with nearly three-quarters of survey respondents citing DER in general as shaping their distribution infrastructure in coming years.

The report finds that smarter grids, which rely on interconnectedness, will require active network management, better monitoring, control and automation capabilities.

Utilities continue to recognize the critical role of cybersecurity in ensuring the future health, reliability and resilience of the electric grid.

Source: Black & Veatch

TIRONI opens new oil testing laboratory

With the installation of the latest dissolved gas analysis (DGA) measurement tool, the Italian transformer manufacturer TIRONI has officially opened its new oil lab in Modena.

The laboratory will allow in-house testing and performance of all of the most important tests on insulating oils used in transformers and other electromechanical equipment, the manufacturer said in the release.

The new instruments will allow testing on all commonly used insulation liquids, including new and recycled mineral oils, as well as natural and synthetic esters.

Source, Photo: TIRONI





E.On maps its first substation in virtual reality

German electric utility company E.On has mapped its first high-voltage substation in virtual reality (VR), which will allow its partner companies to conduct substation training at any location by wearing appropriate VR glasses.

After a project phase of several months, the new technology will be used in practice by Bayernwerk, a German network operator within the E.On Group which has around 750 substations and switching stations in its network area, reports Electric Light & Power.

The use of VR for training and instruction purposes on such a high number of substations is estimated to create an annual saving potential of around 800 to 1,000 hours of travel time when the transformer stations are fully digitized.

The first transformer station shown in virtual reality is located in Gebelkofen, a small town in Lower Bavaria, Germany. Bayernwerk assumes that the complete mapping of all its sites in VR will take another four years.

VR elements or comparable technology are also used by other German E.On network operators such as Avacon, e.dis and HanseWerk, as well as E.On Hungary and the Czech Republic.

The new technology offers recruiting and training benefits, without any safety risk.

Source: Electric Light & Power

Georgia Power's Vogtle 3 plant reaches key milestone

Vogtle plant expansion in Georgia has reached a significant milestone with plant equipment for Vogtle Unit 3 now energized, or permanently powered, to perform all subsequent testing for the unit, Georgia Power announced last week.

Previously, the plant had been running on temporary construction power.

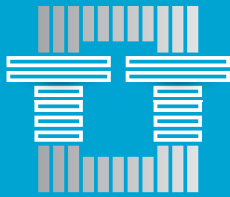
"Initial energization is a major first step in transitioning the project from construction toward system operations," Vogtle 3 and 4 Construction Senior Vice President Glen Chick said. "With energization complete, we can continue moving into the actual testing phase for Unit 3."

The project is now approximately 77 percent complete. With more than 7,000 workers currently onsite at Vogtle 3 and 4, it is presently the largest jobs-producing construction project in the state of Georgia. Once it is up and running more than 800 permanent jobs will be created.

Georgia Power filed an update with the Georgia Public Service Commission (PSC) to affirm that the schedule is on-track for in-service dates of November 2021 for Unit 3 and November 2022 for Unit 4.

Source, Photo: Georgia Power

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Megger acquires Power Diagnostix

Electrical test equipment company Megger has acquired Power Diagnostix of Aachen, Germany, a developer and manufacturer of high voltage diagnostic equipment, and provider of diagnostic services for high voltage installations.

This acquisition will enhance Meggers' capabilities in the field of Partial Discharge (PD) testing and diagnostic solutions for MV and HV electrical assets, including transformers, bushings, switchgear and GIS/GIL installations, the company stated in a press release.

Dr Detlev Gross, the founder and former owner of Power Diagnostix, will remain as Managing Director of the business.

Source, Photo: Megger

Ameren Missouri announces \$5.3b grid modernization plan

Ameren Missouri plans to invest \$5.3 billion on more than 2,000 infrastructure improvement projects across its service area over the next five years.

The Smart Energy Plan includes deployment of new technologies to develop self-healing power lines; installation of infrastructure specially fortified to withstand severe weather, and creation of a pilot portfolio to test microgrid and other technologies, reports T&D World.

The utility also plans to increase its generation capacity through the addition of at least 700 MW of wind generation by 2020, and 100 MW of solar generation by 2027.

Ameren's grid modernization program comes as utilities around the country seek to incorporate new technologies and revise their existing business models.

Source: T&D World

New Arctic grade transformer oil launched

A new Arctic grade transformer oil has been launched that complies with one of the world's most advanced standards regulating the use of mineral oils in transformers.

The new oil is an Arctic grade oil that withstands the toughest climate conditions and complies with the Canadian Class A CAN/CSA-C50-14 specification, one of the world's most advanced standards regulating the use of mineral oils in transformers, Nynas stated in a press release.

Class A oil is recommended for use in power transformers, especially those subject to cold start-up or that have forced oil cooling, including associated on-load tap changers, all of which operate in ambient temperatures below -25°C.

Source: Nynas

Growing Chinese transformer exports – a cause for concern or not?

In the U.S. energy sector, China's emergence as a maker of large power transformers has grabbed the attention of industry executives and U.S. officials. Transformers are the backbone of America's power grid, which are often sourced outside U.S. borders.

"There have been over 200 Chinese transformers that have come into the U.S. energy sector in the last 10 years," said Charles Durant, deputy director of counterintelligence at the Department of Energy. "Before that, there were zero," E&E News reports.

Karen Evans, DOE's assistant secretary for cybersecurity, energy security and emergency response, said her office is looking at the supply-chain threat posed by transformers, being aware of the risk associated with that.

In the U.S., security planning for the power grid has centered on threats to the approximately 2,000 extra high-voltage transformers that carry 345 kV of power or more, since these units cannot easily be replaced.

About 85 percent of new utility transformer orders have come from abroad in the past decade. Since 2010, domestic production has increased, but DOE reported in 2017 that only one U.S. manufacturer produced the special-grade electrical steel required for transformer cores.

Instead, he indicated that components added to transformers, especially smart devices, such as digital monitoring devices and remote sensors are those that could be tampered with and lead to a significant cyber impact.

Source: E&E News





EU prohibits proposed merger between Tata Steel and ThyssenKrupp

The European Commission has prohibited the creation of a joint venture by Tata Steel and ThyssenKrupp under the EU Merger Regulation.

The merger would have reduced competition and increased prices for different types of steel, while the parties did not offer adequate remedies to address these concerns, the EU Commission stated in the press release.

"Steel is a crucial input for many things we use in our everyday life [...] Millions of people in Europe work in these sectors and companies depend on competitive steel prices to sell on a global level. Without remedies addressing our serious competition concerns, the merger between Tata Steel and ThyssenKrupp would have resulted in higher prices. So we prohibited the merger to avoid serious harm to European industrial customers and consumers," Commissioner Margrethe Vestager, in charge of competition policy, said.

This decision follows an [HYPERLINK "http://europa.eu/rapid/press-release_IP-18-6255_en.htm"](http://europa.eu/rapid/press-release_IP-18-6255_en.htm) in-depth investigation by the Commission of the proposed joint venture, which would have combined the flat carbon steel and electrical steel activities of ThyssenKrupp and Tata Steel in the European Economic Area (EEA).

The decision preserves effective competition on European steel markets and the competitiveness of this industry, EU Commission added in the release.

Source: EU Commission; Photo: Shutterstock



ABB and Siemens test world's first subsea substations for underwater factories

As oil- and gas-drilling technology is migrating from floating platforms to the seafloor, some oil and gas companies aspire to build subsea factories that would extract and process oil and natural gas directly on the seafloor, all of which requires electricity.

Industry suppliers ABB and Siemens are now in the final stages of developing competing versions of the world's first subsea power-distribution stations, reports IEEE Spectrum.

The subsea models consist of a transformer, a medium-voltage switchgear, and a variable-speed drive.

Once installed, these stations would connect through a single line to an above-water generator, wind turbine, or power plant, and redistribute electricity to underwater equipment.

Both projects have been in the works for more than five years.

Source: IEEE Spectrum; Photo: ABB (top), Siemens (bottom)

Siemens spins off power business and creates a new company

Siemens intends to spin off and give up majority stake in its Gas and Power business, which comprises power generation, power transmission, oil and gas, and related services, and transfer its majority stake in Siemens Gamesa Renewable Energy (SGRE) to a new company.

The spinoff was unanimously approved by the Supervisory Board on May 7.

Through spinoff of Gas and Power and transfer of Siemens' SGRE stake "a new major player on the energy market" will be created with business volume of €30 billion (\$33.6 billion) and over 80,000 employees, Siemens said in the press release.

"This move will create a powerful pure play in the energy and electricity sector with a unique, integrated setup – an enterprise that encompasses the entire scope of the energy market like no other company," explained Joe Kaeser, president and CEO of Siemens AG.

The new company will have a stock exchange listing by September 2020.

Siemens said the move would help the company meet its medium-term growth and profit targets by focusing its portfolio on "dynamic growth markets and efficiency gains".

The future industrial core of Siemens will be the growth markets of automation, industrial digitalization and smart infrastructure.

Source: Siemens; Photo: Shutterstock

Brazil's 2019 transmission tender expected to attract \$1b investments

Brazil's power regulator Aneel expects to attract \$1b investments in a tender with 13 lots, due to take place on December 19.

The contracts will be offered for a total of 2,380 km of transmission lines and 7,900 MVA in transformation capacity, and include construction of 25 transmission lines and 18 substations, according to the announcement on ANEEL's website.

The projects on offer are located in 12 states, mostly in Bahia and Goiás states.

The final tender documents will be published on November 14. The winning companies will have between 42 and 60 months to execute the projects.

Brazil's most recent transmission tender was held in December 2018, when contracts worth \$3.4 billion in total were closed for the construction of 7,152 km of new lines and 14,819 MVA of transformation capacity. These projects will be implemented across 13 Brazilian states.

Source: ANEEL





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Saturday night early bird venue TBD — details on all to follow.

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Canadian utility applies controlled switching technology for energizing large power transformers

Manitoba Hydro investigated the application of controlled switching, also known as Point-on-Wave (POW) switching, a technology that can safely energize large power transformers using standard circuit breakers.

The utility used this relatively new technology to resolve the issue of residual magnetic fields that can make energizing power transformers difficult, and also, to enhance the standard approach of using capacitor voltage transformers for measuring remnant flux inside the transformer.

The technology was thoroughly tested in the case of two parallel HVDC converter transformers, which were safely energized using controlled switching.

According to the utility, this is also a cost-saving solution, as it doesn't require using special circuit breakers with pre-insertion resistors, which are quite expensive and require frequent maintenance.

Source: Canadian Electricity Association



TVA to invest \$2.2b in transmission system over the next five years

The Tennessee Valley Authority (TVA) said it will be investing \$2.2 billion in transmission system improvements Valley-wide over the next five years in an effort to provide low cost, reliable power, reports Murray Ledger.

As part of these efforts, TVA is planning the construction of a new transmission line that would provide power for growing load and increase power reliability in the Kenlake area of Calloway and Marshall Counties, Kentucky.

The project would include building a proposed 8.7-mile transmission line which would supply power to a new substation operated by West Kentucky Rural Electric Cooperative Corporation (WKRECC), located south of the Kenlake State Resort Park in Calloway County.

TVA is expected to begin surveys in summer 2019 and start acquiring easements in summer 2020. Construction is scheduled to begin in winter 2020-2021 and be completed in summer 2021.

Source: Murray Ledger





Siemens and Iraqi Government sign roadmap implementation agreement

Joe Kaeser, President and CEO of Siemens AG, and Luay al-Khatteeb, Iraq's Minister of Electricity, signed an implementation agreement paving way to full execution of a roadmap for rebuilding Iraq's power sector.

The agreement signed in Berlin in the presence of Adil Abdul-Mahdi, Prime Minister of Iraq and Angela Merkel, Chancellor of the Federal Republic of Germany, builds on the exclusive Memorandum of Understanding signed between the ministry and Siemens in October last year, outlining the specific projects, associated budgets and timelines for the execution phase for all essential elements of the electrification of Iraq, Siemens said in a press release.

This includes the addition of new and highly-efficient power generation capacity, rehabilitation and upgrade of existing plants and the expansion of transmission and distribution networks.

Also, three contracts valued at approximately 700 million euros (\$786 million) have been awarded for Phase 1 of the Roadmap.

These include the EPC construction of a 500 megawatt gas-fired power plant in Zubaidiya; the upgrade of 40 gas turbines with upstream cooling systems; and the installation of 13 of 132 kilovolt substations along with 34 transformers across Iraq.

Source, Photo: Siemens



Trafosur launches new transformer factory in Limpio

In the presence of the President of the Republic of Paraguay, Mario Abdo Benítez, Paraguay's transformer manufacturer Trafosur has officially opened its second manufacturing plant in the country, located in the city of Limpio.

The investment in the new facility will expand Trafosur's production capacity by 40 percent, reports the news agency IP.

Trafosur is mainly focused on the manufacture of distribution transformers for the needs of the National Electricity Administration (ANDE).

Between the manufacturing facility in Asunción and a new facility in Limpio, the company is expected to increase its production capacity from 745 distribution transformers per month to 1,000 units per month.

Source: IP

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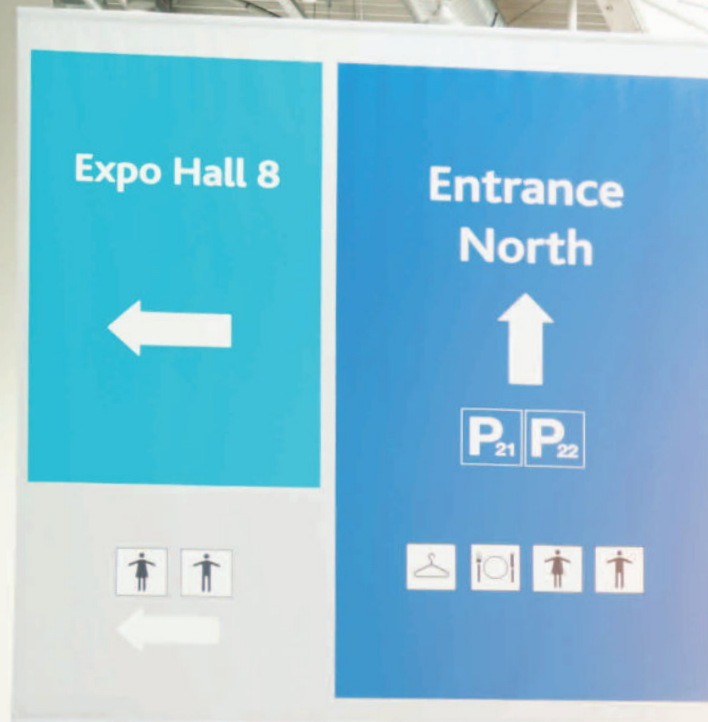


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ATLANTA, GA



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September 17-18, 2019
CHICAGO, IL



COILTECH 2019
September 25-26, 2019
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October (6)7-9, 2019
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IEEE PES
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Meeting
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Wayne Bishop Jr.

Vice President Meetings at IEEE
Power and Energy Society

Interview with **Wayne Bishop Jr.**





For me, and for all
of us, it's really an
exciting time to be
part of the electric
power industry.

Wayne Bishop is Vice President of Meetings at IEEE Power and Energy Society and Head of Marketing, North America, for OMICRON Electronics.

Wayne Bishop is Vice President of Meetings at IEEE Power and Energy Society and Head of Marketing, North America, for OMICRON Electronics. Alan Ross spoke with Bishop about OMICRON's unique structure, the value of R&D, changes happening within the industry, and how IEEE PES is preparing for the future by investing in the most important asset of all – people.

Transformer Technology: OMICRON seems to have a unifying culture. How does an international company like OMICRON keep that unifying culture?

Wayne Bishop Jr: OMICRON is very much a unique organization. We have employees from 45 different nationalities working for the company. We have 28 offices around the world and customers in more than 160 countries. It's very much an international company, but we're very connected.

It's definitely a unique culture with a flat organization; we really don't have any hierarchy. In fact, even though I'm the head of marketing for North America, I'm referred to internally as a coach. All of our managers are referred to as coaches. The word boss is never used. We don't even have a headquarters for the company. Our main office, if you will, in Austria, is called the OMICRON Development Center, but we feel as a company that no matter where you work for the company, that's your office. So, there's no sort of mothership or headquarters.

TT OMICRON spends an inordinate amount of money on R&D. Why? What you've seen from all of that expenditure in R&D?

WB One of the things that really attracted me to OMICRON is their dedication to research and development. We put close to between 18 and 20 percent of our revenue every year into R&D, which is really bucking the trend for the industry. Most companies maybe put 2 or 3 percent of their revenues into R&D, but OMICRON is constantly coming out with new products, new software, new hardware, new solutions, all to the benefit of the electric power industry, and to make it more reliable in the future.

TT What changes are you seeing in the area of testing instrumentation?

WB There have probably been more changes in our industry in the last five years than the last 100 years. When I first got involved in the industry back in the early 1990s, customers of utilities were referred to as "rate payers." When you got your monthly bill, it was the "light bill." That's all changed. There's a huge push toward customers at the utility level, and it's no longer the "light bill," it's the "electric bill." The paying customers are actually driving a lot of these changes that are happening.

Of course, a lot of it is regulation, and political changes as well. There's obviously this huge need to reduce our carbon footprint. So, for the very first time last year, the United States saw a greater generation from gas than coal. We've seen a huge influx of solar and wind, and electric vehicles are really taking off, as are micro grids and energy storage. For me, and for all of us, it's really an exciting time to be part of the electric power industry.

Some would say that back in the early 1990s, it was sort of boring. We had generation, transmission and distribution. And now you have a very dynamic thing that's happening in the industry where suddenly people are putting rooftop solar on and plugging in electric vehicles, so this is affecting the industry, obviously.

There could be reliability issues. A lot of our apparatus is just not made or set up to support these new distributed energy resources (DERs) that are being put on the grid.

A small example: I was just recently at a utility out in California. They told me that the load tap changers on their transformers are normally made to change position maybe four or five times a day. That's what they're manufactured to do. What's happened as a result of putting all these DERs on the grid is that their load tap changers are now changing over 100 times a day! It's just unbelievable.



Wayne's recent visit to a local substation

A lot of our apparatus is just not made or set up to support the new distributed energy resources that are being put on the grid

There are generational changes happening too. What's happening at the utility level is load growth is flat, or negative in some cases. Look at Massachusetts where I live. As a result of energy efficiency and distributed energy resources, we've actually seen a negative load growth.

Energy storage is really going to be the game-changer for our industry. Once we can effectively and efficiently store wind and solar, that will be a game-changer.

TT What will be the biggest change we'll see over the next decade?

WB It's going to be the electrification of our cities and our transportation system. This will make that load growth go up when you have buses and trains and transportation systems electrified. This will also help the environment, so it really has so many positive effects. But again, I just think it's a great time to be part of the industry. We see this at the IEEE Power and Energy Society (PES) where new standards are being put in place to handle these DERs on the grid. Lots of great discussions happening.

TT What can we expect from OMICRON's June Transformer Diagnostic Workshop?

WB One of the reasons why the Transformer Diagnostic Workshop is unique is that it won't be OMICRON giving the presentation. Instead it's going to be outside expert speakers; some of them with 40, 45 years of experience. We'll look at the whole lifecycle of a transformer from specification and factory inspection right through maintenance and testing. Greg Anderson, who has over 40 years of experience in our industry, will be talking about how to write a transformer specification, and what should be included: the good, the bad and the ugly.

Then we will look at acceptance testing of the transformer, transportation of the transformer, and what tests you should be doing. Transformers that are manufactured in, say, Korea, and then shipped to California, for example; they undergo a tremendous amount of stress. We'll talk about some of these tests that utilities are doing on their transformers.

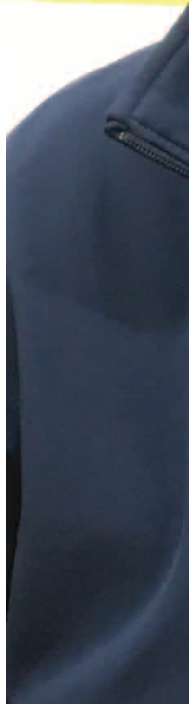
And then once the transformer arrives, the commissioning of the transformer and then of course, the testing and maintenance of that transformer.

We will be talking about the different oil and material test that should be done in the transformer, specifically what happens to the paper of the transformer and maybe some information on dielectric frequency response, which is looking at the moisture content of the paper. We'll also cover the reliability of transformers, and reliability in general, and how that's an important part of our industry.

We'll have a bushing expert come in and also a load tap changer expert.



One of the things that I'm really proud to be involved with is the PES Scholarship Plus program established as a result of the knowledge loss they saw coming in our industry. It offers our electrical engineering students not only scholarships but also a paid internship in the electric power industry.





My Dad Wayne Bishop is my greatest mentor and first introduced me to the electric power industry where he worked for 47 years. He is now retired.

TT What is your involvement in the IEEE Scholarship Plus program?

WB One of the things that I'm really proud to be involved with is the PES Scholarship Plus program. They established this program as a result of the knowledge loss that they saw coming in our industry. IEEE PES wants to offer scholarships to our electrical engineering students who are interested in power, but we want to take that a step further. That's where the word "plus" comes in. They offer a paid internship in the electric power industry.

They've teamed up with some great companies like Schweitzer Engineering, ABB, OMICRON,

and Beckwith Electric and others in the industry, along with utilities that have supplied money to this fund. They also agreed to supply paid internships. And so, as a result, a student might get a \$3,000 scholarship, but more importantly they're able to see firsthand what it's like to work in a utility, and to be assigned a mentor and move around that utility. So far, the response has been tremendous. Hundreds of scholarships are awarded each year and the industry has really gotten behind that. So much so that when I went to the general meeting last year, I looked around and I thought, wow, there's a lot of youngsters here. People in the industry are excited about it. I really see them as the next generation.

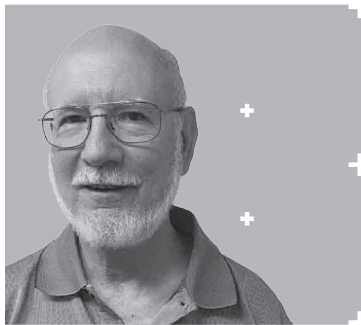
Dry-Type Transformers: Everywhere But Unnoticed

A Broad Range of Design and Application

by **Casey Ballard**
and **Richard Marek**



Casey Ballard received his BSEE with a focus in Power Systems from Virginia Polytechnic Institute and State University in 2003 and works in Application Development for DuPont Nomex®. His previous work experience in the transformer industry includes roles of design engineer as well as research and development where he led testing on the evaluation of insulation systems. He is a senior member of the IEEE Transformers Committee and IEC TC14 delegate for the US Technical Advisory Group with active participation in various working groups.

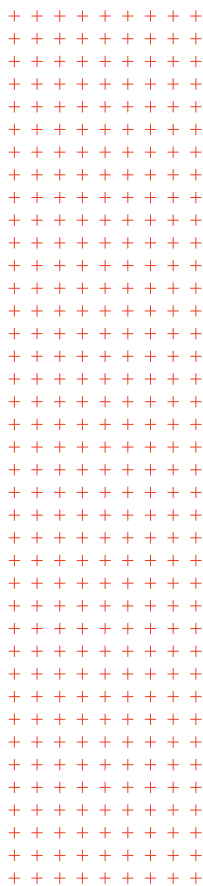


Richard P Marek received his BSEE from Purdue University and has been employed with DuPont since 1998. His previous work experience includes a total of 28 years as a transformer design engineer. He is a senior life member of IEEE where he has been active in the Transformers Committee since 1982 and he was chairman/convenor of the high temperature liquid immersed transformer standards IEEE C57.154 and IEC 60076-14. He is also an IEC TC14 delegate for the US TAG.

Dry-type transformers were among the first electromagnetic devices created in the very early days of developing electricity applications. They were easily studied and then manufactured by the pioneering power engineers. According to the Edison Tech Center, the name “transformer” was created by Ottó Bláthy. He and two other Hungarian engineers, Miksa Déri and Károly Zipernowsky formed a company called ZBD, which comes from the initials of their names. In 1885 the ZBD model alternating-current transformer was invented as a crude prototype. That same year, William Stanley Jr. working for George Westinghouse built his

prototype which eventually became the production version. George Westinghouse, Albert Schmid, Oliver Shallenberger and Stanley then made the transformer inexpensive to produce.

Now they look quite different than they did in the late 1800s. Today dry-type transformers mostly operate in obscurity, in the presence of most of the general public, but hidden in electrical rooms and light gray boxes. However, they serve an important function in the distribution systems of today’s power distribution grid serving to transform the utility voltage to levels where it safely interacts with the general public.



Today dry-type transformers mostly operate in obscurity, in the presence of most of the general public, but hidden in electrical rooms and light gray boxes. However, they serve an important function in the distribution systems of today’s grid transforming the utility voltage to levels where it safely interacts with the general public.



*Low and medium voltage distribution transformers
(Photo: Hammond Power Solutions)*

Originally, they were only operating at relatively low voltage and kVA ratings. The dry-type transformers in use today come in a wide variety of sizes, voltages, and applications.

Their power ranges from a fraction of a kVA up to over 30 MVA and typical voltages up to 72 kV and are used anywhere humans are typically present. Since they only rely on solid insulation and air, they can be placed inside of buildings as they carry a lower risk of collateral damage to people in the event of a catastrophic failure, compared to a liquid immersed transformer using mineral oil. While high fire point liquid immersed transformers are used in indoor applications, a dry-type avoids the need for liquid containment walls and leaking liquid issues. With the

inclusion of a protective enclosure or tank, these dry-type transformers can be used in virtually any location and environment from clean electrical rooms to dirty manufacturing environments to even partially submerged. Outdoor weather resistant enclosures are quite common, even as pad mounted enclosures that are tamper resistant. The absence of any liquid makes these outdoor units inherently environmentally safe. Dry-type units are also used in hazardous locations such as refineries or explosive dust atmospheres where they are installed in hermetically sealed enclosures.

However, using air for both its dielectric and thermal properties does lead to some constraints – especially since air

has relatively poor thermal conductivity and lower dielectric strength compared to dielectric liquids. This has led to the need to operate at higher temperatures to increase energy density and reduce the physical size which has in turn driven the demand for thermally stable and reliable insulation systems. These high temperature insulation materials, such as DuPont™ Nomex® papers have been used in the industry for over 50 years and there are insulation systems capable of continuous operation up to 230°C hottest spot temperature for Class 240 insulation systems. The larger sizes of dry-type transformers are commonly used in larger power systems for customers such as industrial, commercial, research, hospitals, and alternative energy.

There are two main categories of dry-type power and distribution transformers in use today and are categorized based on their insulation system. The first is the original resin-encapsulated transformer that has an open winding structure that is coated in a resin/varnish/epoxy to enhance its mechanical strength and to offer some environmental protection. These transformers are typically used in applications of up to 36 kV and 15 MVA with average winding temperature rises of 150°C using aramid insulation. Resin encapsulated transformers are common in North America and have growing adoption rates in Asia. Another variation of the resin encapsulated construction is vacuum pressure impregnation (VPI) and they come in both low voltage (<1000 V) and medium voltage (1.2 kV to 36 kV) segments. In the low voltage segment there are custom designs and general purpose equipment that is more likely to be stocked in a regional warehouse.

The second category of dry-type power and distribution transformers in use today is the vacuum/solid cast coil construction which uses a molded epoxy to completely cover and seal the windings. This epoxy becomes part of the major insulation system and creates the mechanical structure of the windings. These cast coils have lower average winding temperature rises of 115°C with a maximum of 145 kV operational voltage and power ratings that can exceed 30 MVA. Cast coil transformers are produced globally and are more common in regions outside of North America. This type of transformer has found broad application as step up transformers for on shore wind turbine generators and are often incorporated inside the nacelle or tower.

Low Voltage Distribution

The low voltage general purpose dry-type transformer is the most common type by number of units installed. These transformers typically operate at less than 1 kV and less than 500 kVA. They are used to perform the final transformation of voltage to use at a dedicated

equipment or receptacle load. Due to their flammability resistance and cost effectiveness they are also the transformers that take us in closest proximity in our daily interactions. When serving receptacle and lighting loads they are commonly installed in electrical rooms or closets and when connected to a dedicated load they are mounted close to the equipment to which they are providing service. By installing the transformers as close to the point of consumption the energy efficiency of a building's infrastructure can be optimized. These transformers are often lightly loaded, but typically capable of large overloads as they use high temperature Class 220 insulation systems for the winding construction.

Medium Voltage Distribution

These dry-type transformers serve to step down the distribution voltage from the utility to a usable voltage inside of buildings. They do not require containment or the same level of fire suppression/protection, so they are cost effective in areas that are focused on people and equipment safety. They are also installed in environmentally sensitive areas where any leaks would have detrimental impact to the local ecosystem.

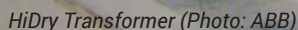
Dry-type units need to operate at higher temperatures to increase energy density and reduce the physical size which has in turn driven the demand for thermally stable and reliable insulation systems.

The VPI transformers are most likely to be found at system voltages at or below 20 kV with the vacuum cast being more common at 20-36 kV.

Some OEMs have taken the medium voltage dry-type into a realm that was previously reserved only for liquid immersed equipment. ABB's HiDry transformer based on VCC technology has pushed the limits of the technology up to 145 kV nominal system voltage and 550 kV Basic Impulse Level (BIL) with hundreds installed globally. The first 550 kV BIL dry-type transformer will be installed in the USA in early 2020. This design has also driven development of accessories such as oil free bushing wells.

Data Centers and IoT

Today we are voluntarily sharing an ever-increasing amount of personal data in electronic format. This data processing and storage is fueling the industry growth in the data center market. The transformers feeding the servers are a combination of MV and LV with a focus on safety and reliability. The MV dry-type transformers are commonly installed indoors to reduce losses and are used to transform the utility distribution voltage of 5 kV to 36 kV down to 600 volts for



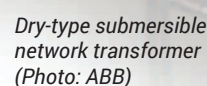
Many installations also require very low inrush requirements for energizing the transformer's core since the transfer switches are protected by instantaneous overcurrent breakers and nuisance tripping of the critical data center loads are to be avoided. The LV transformers in the PDUs must be designed to require minimal maintenance and for optimal reliability in the interconnections and the major insulation system. A commonly used insulation system is rated at 240°C using DuPont™ Nomex® 410 materials which offer extended life and reliability.

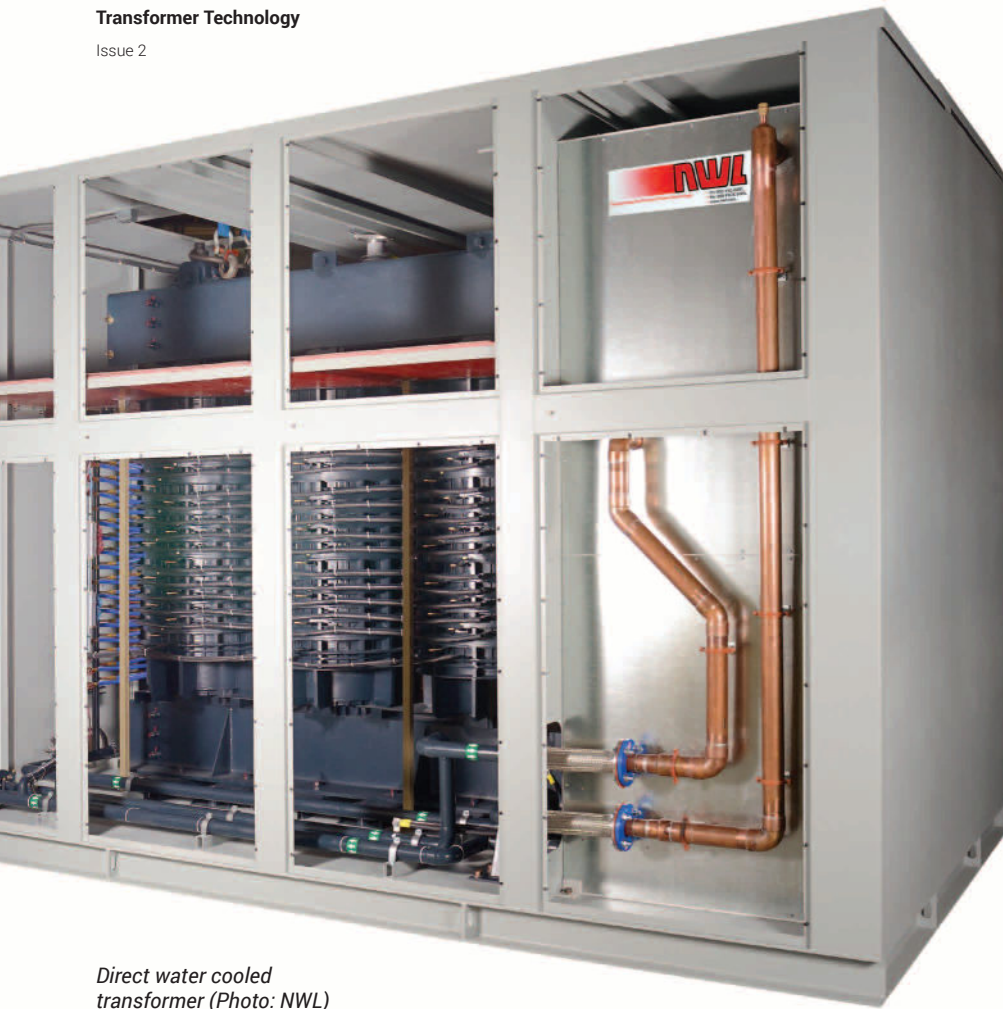
The first 550 kV BIL dry-type transformer will be installed in the USA in early 2020. This design has also driven development of accessories such as oil free bushing wells.

Data Center PDU
(Photo: Power Distribution Inc.)

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Several hundred dry-type transformers installed at the 57-km Gotthard Base Tunnel distinguish themselves by low energy loss, high efficiency, high overload protection and short circuit strength, as well as low maintenance needs over years of active operation





Direct water cooled transformer (Photo: NWL)

footprint, light weight, outdoor compatibility with integrated high and low voltage bushings and corrosion protection on all steel parts. This outdoor dry-type transformer should also be qualified for environmental and fire resistance.

Rectifier and Direct Water Cooled

High current rectifier transformers are used in many different industrial applications, such as electroplating and where high-current dc is needed for electrochemical processes like chlorine production. Furnace applications for melting glass and for producing fiberglass are also processes that use high current DC. Water cooling of the secondary windings allows increased current and can also reduce the transformer size.

Mass Transit for Trains and Subways

The inherent fire safety of dry-type transformers has long been the draw for applications in mass transit such as track side traction for above ground trains. Trackage power transformers step down the overhead

high voltage to usable voltages for the railway network. The duty cycle of traction transformer supplies is particularly difficult, with overloading up to twice full-load current and frequent short circuits on the system. Dry-type transformers with high temperature insulation systems are well suited to this continuous overloading. Subway systems have similar loading patterns and since these units are located underground, the fire safety is even more important. Lighting and ventilation systems for tunnels fall into this same safety category and they are often powered by dry-type transformers. One recent example is the Gotthard Base Tunnel. At 57 kilometers in length, it is the world's longest railway and deepest traffic tunnel and the first flat, low-level route through the Alps. It lies at the heart of the Gotthard axis and constitutes the third tunnel connecting the cantons of Uri and Ticino, after the Gotthard Tunnel and the Gotthard Road Tunnel. ABB was hired as sub-contractor to provide the medium-voltage supply for the tunnel's infrastructure in addition to delivering transformers that provide the power needed to maintain the 50-Hz grid. Several hundred vacuum-

impregnated dry-type transformers ensure the 50-Hz energy supply in the tunnel as well as the energy supply for the emergency backup system. The transformers distinguish themselves through low energy loss, high efficiency, high overload protection and short circuit strength and their low maintenance needs over years of active operation. Demonstrating the magnitude of the application, the lighting system in the tunnel consists of more than 10,000 orientation lights and 450 escape route lighting systems.

Electric Vehicle Charging Infrastructure

The recent and quick rise of electric vehicles (EVs) has driven the dry-type transformer into charging stations. As EVs become more mainstream there is a want from drivers to have more access points for quick charging just like we are all used to with gasoline/diesel powered vehicles. A quick stop to refuel/recharge is expected to take less than 15 minutes using much faster charging stations than are available for residential use. These quick charge stations are now rated at 350 kW and will continue to climb. This high power transfer can put a large load on a dry-type transformer that was previously at a no-load condition. This thermal stress and large variances in load are easily supported by the inherent overload capabilities incorporated into most VPI transformers.

Conclusion

Dry-type transformers have been a key enabler to our current lifestyle starting in the early 19th century and are a key part of a cleaner, digital world tomorrow. The ability to install them in areas frequented by humans with minimal risk of fire or no risk of leaking dielectric fluids fulfills a key niche in our power consumption today. While the use of dry-type transformers is not new, the applications developed recently enhance the reliability of our digital infrastructure, enable the demand for green energy generation and consumption, support environmental awareness, and assist the need for efficient transportation.

Martin Robinson

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For me the biggest challenge is change. Change management is the hardest thing we can ever do. If I had five bucks for every time someone said to me “We’ve always done it this way!” I could retire

CEO of IRIS

Interview with **Martin Robinson**



Martin Robinson is CEO of IRISS, Inc., a global leader in Electrical Maintenance Safety Devices (EMSDs). IRISS manufactures industrial-grade infrared windows using a durable transparent polymer lens that allows visual, UV, and infrared inspections.

Martin Robinson is CEO of IRISS, Inc., a global leader in Electrical Maintenance Safety Devices (EMSDs). IRISS manufactures industrial-grade infrared windows using a durable transparent polymer lens that allows visual, UV, and infrared inspections. Alan Ross spoke with Robinson about safety on dry-type transformer inspections, global skills shortages, the glaring disparity in frequency between time-based and condition-based faults, and the challenges involved with overcoming the deeply held beliefs that accompany the phrase “We’ve always done it this way.”

Transformer Technology: What is an Electrical Maintenance Safety Device?

Martin Robinson: An Electrical Maintenance Safety Device (EMSD) is not just an inspection window; it is any device that enables you to get data or test samples—or anything that you require—in a safe condition.

The Japanese have a great term called Poka-Yoke—that means “mistake proofing.” What we do is find a way of making sure that necessary tasks are designed in such a way that you can’t hurt yourself or hurt the equipment. That leads to a number of things; you can take regular samples, you can do it safely, and the quality of the sample is excellent. When you start to look at what an infrared inspection window is, you start to think of it more as a way of completing a necessary maintenance task, but in a safe, efficient, more cost-effective way.

If you’ve only got a hammer in your toolbox, every problem looks like a nail. You need multiple tools in a condition monitoring subset.

TT What tools do EMSDs enable you to use when inspecting a dry-type transformer?

MR When you look at condition monitoring, you start to break it down to what are the failure modes on the equipment that you’re looking at. What can break? What tools do you have in your arsenal that enables you to find those faults? They say that if you’ve only got a hammer in your toolbox, every problem looks like a nail. You need multiple tools in a condition monitoring subset.

The technician really is your number one asset because the tools are only as good as the person that’s using them. When I look at a transformer, the infrared shows me overheating. The ultrasound would let me pick up arcing, tracking, and corona. A PD scan with transient earth voltage would give me any insulation defects. If I was using motor current analysis, maybe I’ll be picking up stuff on the circuit. If I was using a digital multimeter, I might be picking up issues with current resistance.

But the guy who’s doing the inspection can hear things that are going on and can smell things that are going on. An infrared camera can’t pick up dust or dirt, but the technician who’s looking in can see if there is anything that has encroached in there, such as rodent nests, spider webs, or a whole host of things.

Having an EMSD solution such as a window or inspection system fitted means that the technician can walk up, open up, plug in, take all the data, and move on.



The technician is your number one asset because the tools are only as good as the person that's using them.

TT The industry is experiencing skill shortages on a global scale. How do you see EMSDs helping with those skill shortages?

MR Unfortunately, we've seen a huge impact on skill shortages globally. We just can't find skilled engineers. What that really means to us is that the risks involved with using unskilled engineers is thought to increase exponentially.

By utilizing condition monitoring techniques in a closed panel system, it's all about data. Having a technician that can go up to an inspection system and plug in ultrasound equipment and write down a number, then take an infrared image and write them the maximum temperature, then and look at the PD results and any visual verifications... we can get technicians doing that relatively simply, and then they're just going to react to alarms.

Believe or not, I've got places in London where I've got security guards doing condition monitoring inspection. They just plug in the instruments and write in the numbers, and if those numbers exceed a given alarm level, then they get on the phone and call the technician down.

EMSDs allow us to protect the equipment and the personnel. We can reduce the skill level required for data collection and bring in the skilled engineers when needed.

It's not one-size-fits-all, but it's a myriad tests and skill sets that we can adjust to match the risk.

TT When you look at the future of high voltage electrical systems for data centers, what do you see as the coming challenges?

MR For me the biggest challenge is change. Change management is the hardest thing we can ever do. If I had five bucks for every time someone said to me "we've always done it this way," I could retire.

The challenge is trying to get people to understand that you have to change. We've always had this time-based, calendar-based mentality. Trying to get people to understand that, if you look at failure curves, literally 12 to 15 percent of failures are time-based, but the huge majority of failures are condition based. Then we have to have condition-based protocols to find the majority of failures. The biggest challenge is getting people to understand where we are. And then you have some people jumping on the IoT bandwagon where they're going straight for sensor technologies and are ignoring the use of the biggest resource they have—staff. Staff are not part of the problem. They're part of a solution.

So, for me, the biggest challenge will always be change, and trying to get people to understand that.



We've seen a huge impact on skill shortages globally. What that really means is that the risks involved with using unskilled engineers is thought to increase exponentially



EMSDs allow us to protect the equipment and the personnel. We can reduce the skill level required for data collection and bring in the skilled engineers when needed. It's not one-size-fits-all, but it's a myriad tests and skill sets that we can adjust to match the risk

Dry-Type Transformers Market: A Growing Niche

by **Hassan Zaheer**
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Dry-type transformers are ideal for applications requiring transformers to withstand extreme conditions, and where fire safety is a concern. These are compact, lightweight transformers compared to traditional oil-based alternatives, and are able to withstand high short-circuit current while requiring minimum maintenance. These features make them ideal for use

in industry where fire-safety and compactness of equipment is often highly valued. There are two main types of dry-type transformers: Cast-Resin Transformers (CRT) and Vacuum Pressure Impregnated Transformers (VPI), both having their own pros and cons. Today, however, cast resin transformers are the more common of the two in the market.

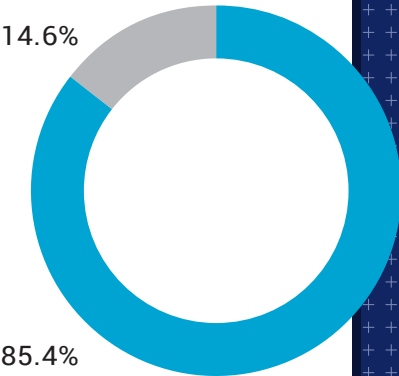
Global Market Opportunities

Dry type transformers are a growing market globally. Primarily being used in industry across the world, their use in utility applications is also growing, where utilities are increasingly using dry-type transformers in compact substations used in urban settings. However, this is still a small segment of the installed base compared to the industrial segment. Another growing sector is renewable generation, especially wind and solar farms,

which are using more and more dry-type transformers. It is estimated that **globally around 85% of dry-type transformers are installed in industry and only ~15% in utility applications** as shown in Figure 1.

Figure 1. Dry-type transformers - global installed base

- Industrial Applications
- Utility Applications



Hassan Zaheer is a Principal Consultant at Power Technology Research and an expert on business development and market entry strategies in T&D business. After starting in the T&D field in early 2014, Hassan has rapidly developed his expertise working on custom analysis projects for Tier-1 T&D manufacturers (among Fortune-500), assisting them with global market studies and market entry strategies. As part of his current role, he provides analyses for clients both as tailored research reports and custom consulting work.





Globally around 85% of dry-type transformers are installed in industry and only ~15% in utility applications

Within the industrial sector, based on their technical features, following industries are the key end-users of these transformers. The growth in these industries pretty much dictates the growth of dry-type transformers:

Chemical Plants:

Fire safety is a huge concern for chemical plants. Hence, dry-type transformers are ideally suited for secondary distribution network inside the factory.



Underground Mining:

Due to very strict fire safety requirements and compact space, dry-type transformers are well suited for electrical distribution in underground mining.



Commercial Buildings:

Shopping centers, business parks and hospitals prefer the use of dry type transformers, due to strict fire-safety requirements.



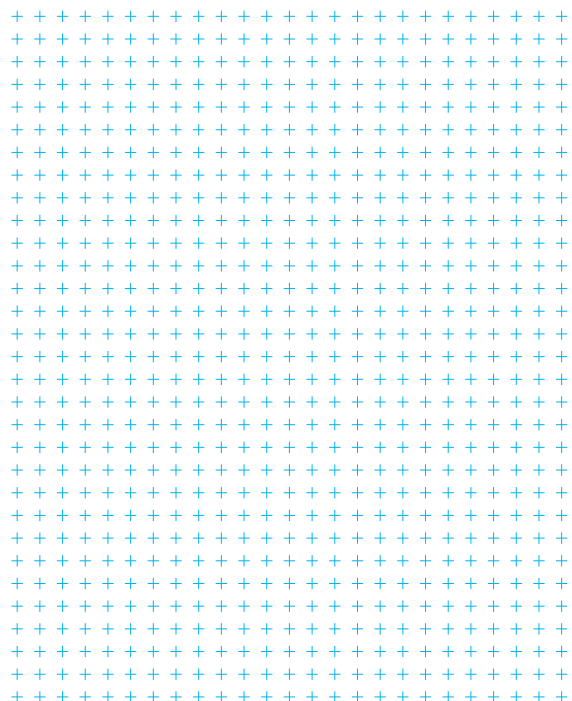
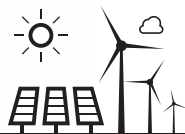
Oil & Gas:

Safety is a big concern in Oil & Gas industry, even more so in off-shore exploration than on-land, where space is limited as well.



Renewables:

Wind turbines require compact LV and MV transformers to be placed inside the housing. Solar farms are sometimes located in harsh conditions requiring more robust transformers which can fit inside inverter installations.



Global market size for dry-type transformers in 2019 is estimated to be around US\$2.39B, with APAC at US\$1.07B, Americas at US\$0.91B and EMEA at US\$0.41B

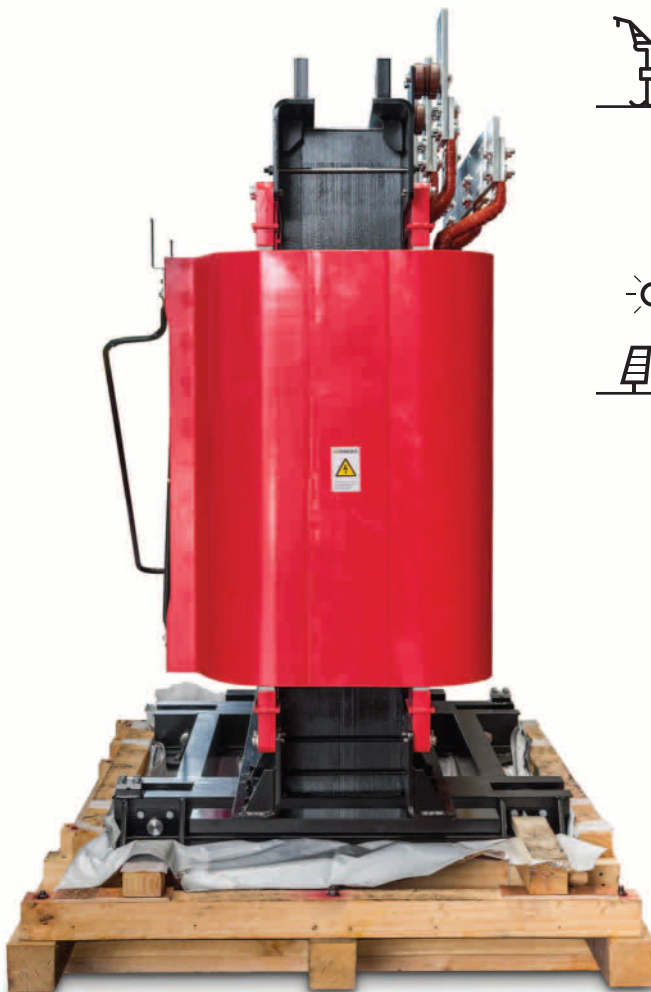
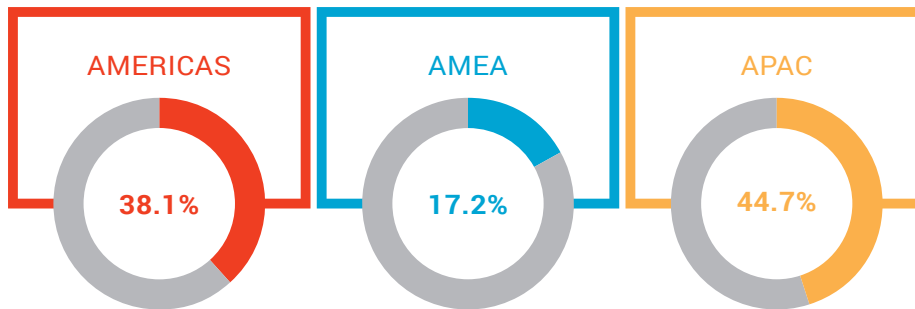


Figure 2. Regional market for dry-type transformers, 2019



Globally, these industries are well distributed in all regions across the globe: APAC, EMEA and Americas. However, it is easy to identify demand centers based on the high concentration of one of these industries. Global market size for dry-type transformers in 2019 is estimated to be around US\$2.39B, with APAC at US\$1.07B, Americas at US\$0.91B and EMEA at US\$0.41B, see Figure 2.

Utilities are now more inclined than before to use alternatives to mineral oil-based transformers with higher safety



Figure 3. Important country markets for dry-type transformers, 2019-2024



Due to rapid growth in APAC region, it is the largest market for dry-type transformers, followed by Americas and EMEA. APAC being the largest market for these transformers, is driven primarily by countries like China, India and Indonesia. Second largest region is Americas, where USA, Chile and Brazil are the demand centers for dry-type transformers. In EMEA, countries with huge industry like Germany, France and Italy, followed by Saudi Arabia and UAE are small yet important markets. On a country specific level, based on the concentration of one or more of these industries, following are the countries which are the key markets for dry-type transformers in the coming years, see Figure 3.

Key Demand Drivers and Trends

The demand for dry type transformers is increasing globally. Following are the factors shaping a growth in demand and market trends of these transformers:

- Natural disasters including forest fires, causing an increased pressure for fire safety on utilities as well, resulting in an expected increased demand from this segment. Utilities are now more inclined than before to use alternatives to mineral oil-based transformers with higher safety.
- Increasing demand from utilities using these transformers in compact substations, especially

in urban settings. This is not only valid for established markets, but also for some developing markets e.g. South Africa.

- Slow, albeit steady, growth in industries like Chemical, Mining and Oil & Gas, especially in APAC region, where these transformers have high use.
- Addition of renewable energy generation, with countries around the world having plans to implement large scale wind and solar farms, resulting in an increase in demand for dry-type transformers from this segment.

With these trends, it is expected that the share of dry-type transformers vs mineral oil-based transformers will also increase in the next five years. However, another alternative on the market, which needs to be taken into consideration is the ester oil-based transformers. These transformers, like dry-type transformers, provide high fire safety, and can be used in applications like chemical plants, mining and even utilities where they provide higher protection against transformer blow-outs. This could in coming years have a negative effect on the growth of dry type transformers. However, at this stage, ester oil-based alternatives are still establishing a foothold in some markets and are not as well positioned as dry-type transformers.

Manufacturer Benchmarking

Table 1 is a subjective analysis comparing top five manufacturers of dry-type transformers with each other on a set criterion for their product positioning. This is based on understanding of the market through interviews with stake-holders in various countries.

Conclusion

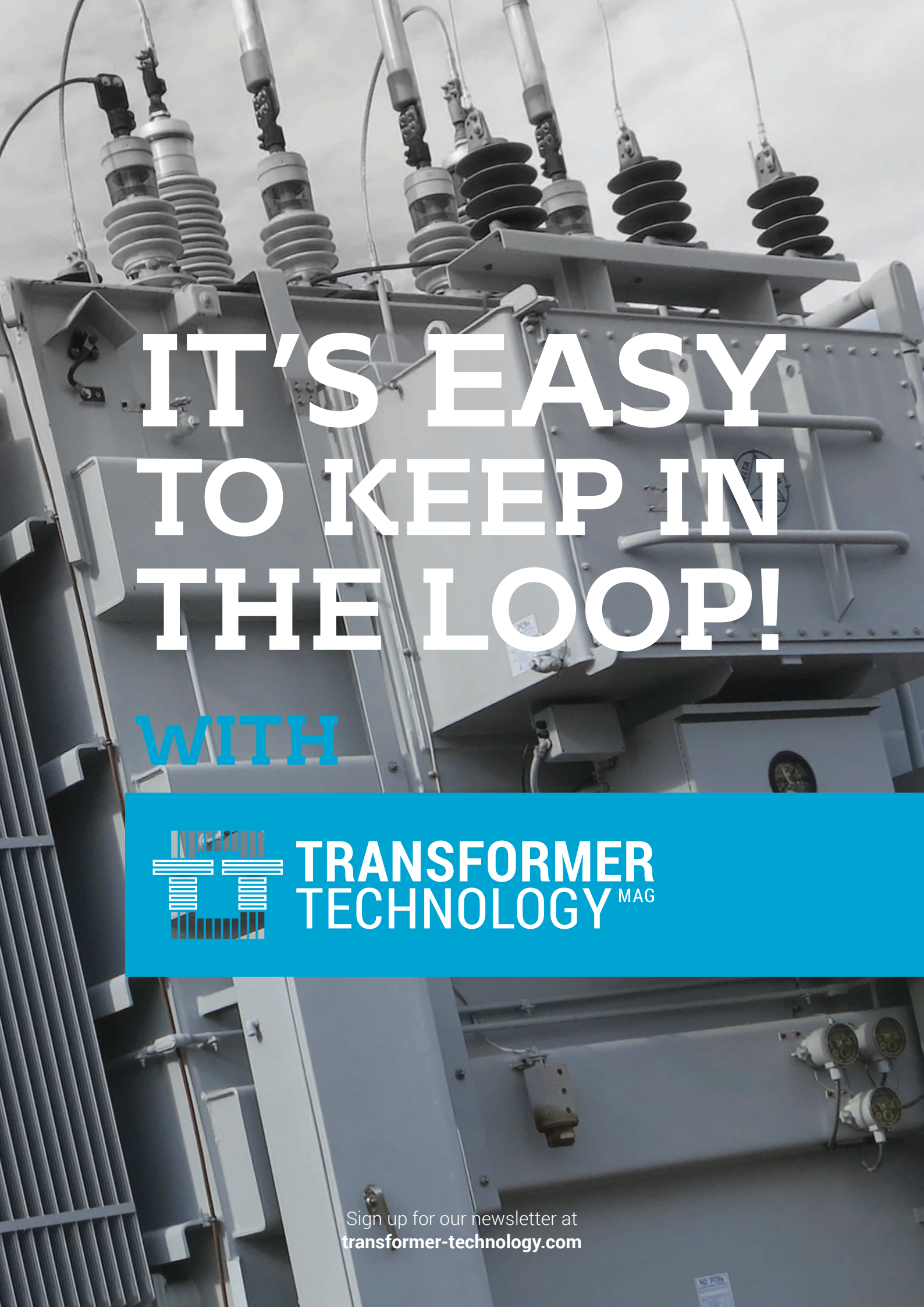
Distribution transformers market, even though saturated, has been seeing a lot of movement with regards to development of various technologies. Dry-type distribution transformers, ester fluid-based distribution transformers and digital transformers are slowly taking a bigger share of market from mineral oil based conventional transformers. This shift means manufacturers need to streamline their strategy for the next 5 years in a different way than before, closely tracking these technological changes, and their relative market shares. Only then would they be able to sustain and grow their position in the market.

It is expected that the share of dry-type transformers vs. mineral oil-based transformers will also increase in the next five years

Table 1. Qualitative manufacturer benchmark

Manufacturer	Product range (Voltage/ Capacity Ratings)	Applications Served	Market Share	Brand Awareness	Geographical Presence
ABB	●	●	●	●	●
Siemens	●	●	●	●	●
Schneider Electric	●	●	●	●	●
Eaton	●	●	●	●	●
Hammond Power Solutions	●	●	●	●	●

- High score; Leading position in the market
- Good score; Average position in the market
- Average score; Market position not very strong



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Dry-Type Transformer Protection and Monitoring Systems

by **Corné Dames**

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Constant monitoring of transformers is vital for ensuring a reliable electrical reticulation network, so any device that can assist in the protection and monitoring of the transformer system is extremely valuable. Monitoring dry-type transformers can pose quite a challenge as there is no oil to test to determine the condition of the unit. An out-of-the-box approach is needed to ensure safe operation, reliability, and lifetime optimization.

Optical fibre sensors are used as an online overheating protection tool, triggering an alarm as soon as local overheating appears. Combining this with acoustic emission partial discharge monitoring will ensure the transformer is reliable and problems can be identified almost at the onset. Once this happens, an offline analysis of the transfer functions of the transformer coils is done to identify inter-turn short circuits, or similar destructions, that might be the cause of the local overheating. This system is efficient, cost effective, and easy to install on almost all categories of dry-type transformers.

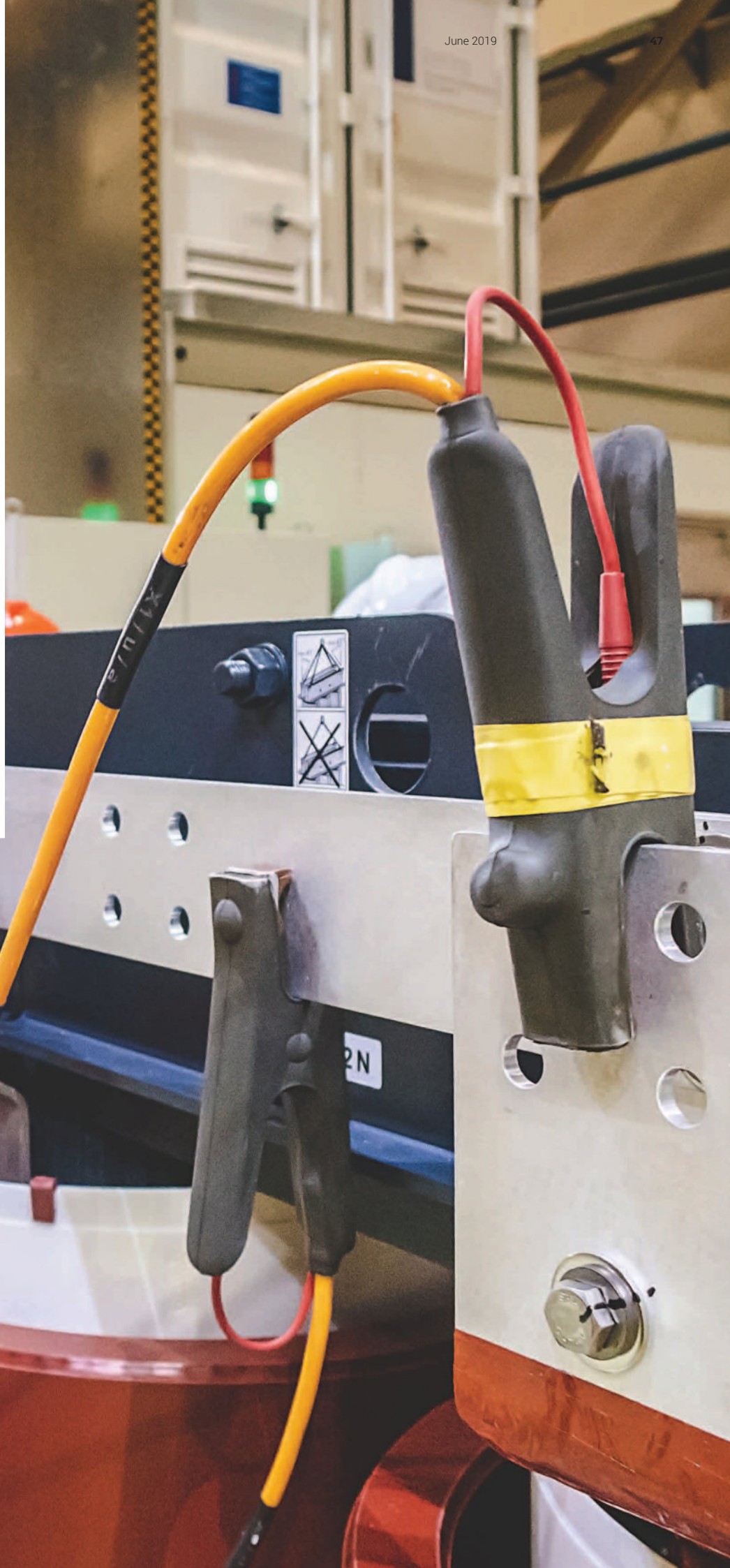
Optical fibre sensors are used as an online overheating protection tool. Combining this with acoustic emission partial discharge monitoring will ensure the transformer is reliable and problems can be identified almost at the onset.

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

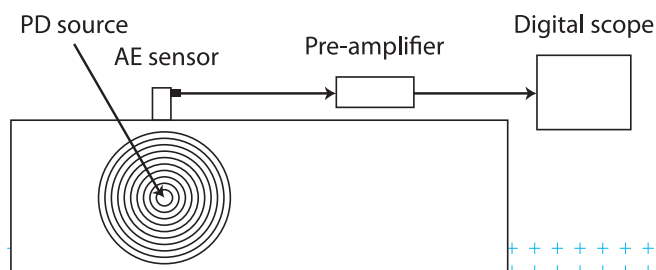


Cast coil transformers assume the epoxy resin will fill all the gaps.

Introduction

Dry-type transformers with epoxy resin insulation have the advantage over liquid-filled equipment in that no environmental precautions are required. There is almost no fire hazard associated with epoxy resin cores. Dry-type transformers also need less frequent maintenance, resulting in extremely low maintenance cost and minimized downtime. However, the poor thermal conductivity inside the dry-type transformer will accelerate the aging of the insulation and reduce its reliable life. Dry-type transformers are extremely sensitive to different destructive phenomena due to the characteristics of their solid insulation. That's why it is extremely important to analyze the remaining life of the dry-type transformer – to ensure safe and reliable operation of the power grid.

Figure 1. The propagation of the acoustic wave



Partial discharge (PD) can be a reason for failure. Because there is no insulation medium like oil or gas present, the effects of partial discharge in these units are severe over the long term. Partial discharge can lead to inter-turn short circuits resulting in local overheating, which again enhances the partial discharge due to the rise in temperature.

Once this chain reaction has started, the breakdown of the insulation is unavoidable if it is not picked up at an early stage. This may cause loss of production as well as the transformer.

I will now discuss the different possibilities for monitoring dry-type transformers and the introduction of new systems which can be used to identify malfunctions at the onset.

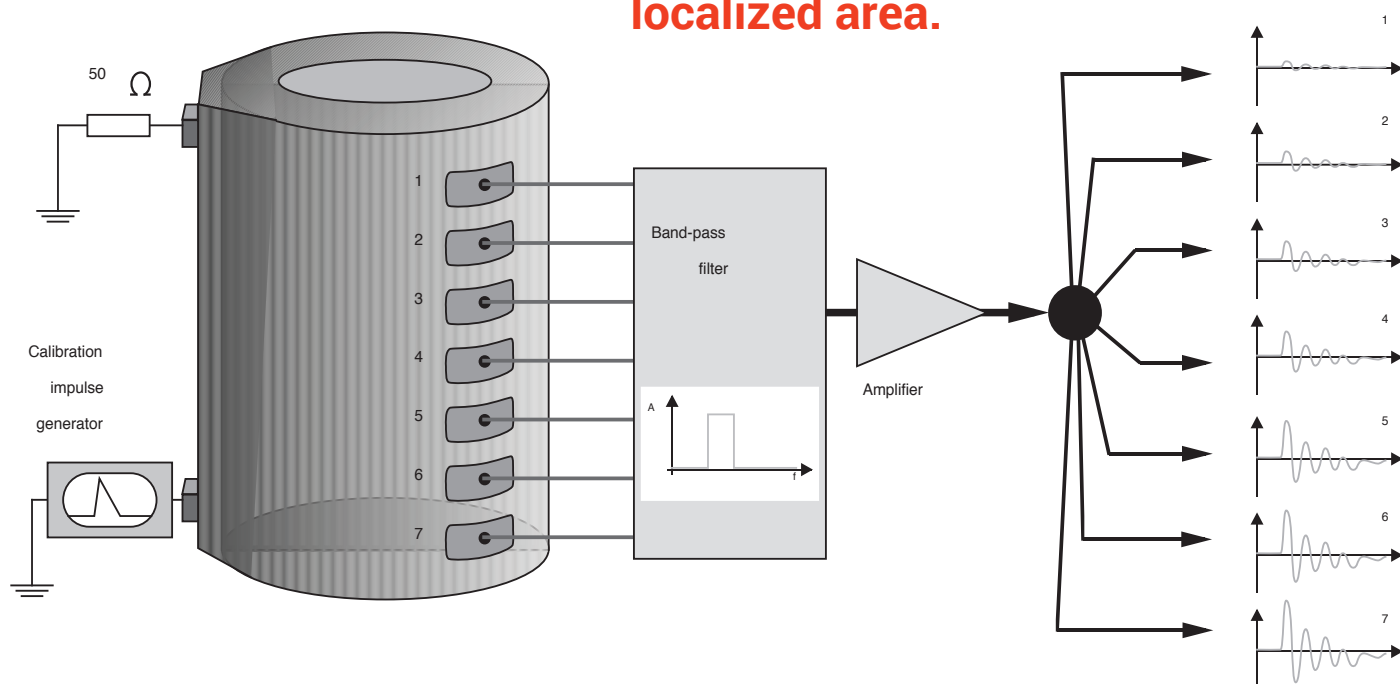
Cast resin dry-type transformers are moisture resistant, anti-flammable, low noise, and have characteristics that eliminate hazards to the public. To raise the power transmission efficiency, manufacturers usually step up the voltage, forcing the transformers' insulation materials to bear an even greater electric stress; in case the insulation performance deteriorates, a Partial Discharge (PD) will follow. If a correct diagnosis cannot be furnished at this time, the insulation in the high-voltage winding of a cast-resin dry-type transformer will break down, consequently causing breakdown and losses. When an internal PD occurs, it will form an acoustic source and emit an acoustic wave (a mechanical elastic wave) which will propagate around the inside of the facility as shown in Figure 1.

Partial Discharge Measurements

Cast coil transformers assume the epoxy resin will fill all the gaps, and design for epoxy dielectric assumes that the unit will be airtight. If air bubbles appear, there will be high stress and the potential for partial discharge develop, which may cause insulation breakdown resulting in transformer failure.

Localization becomes possible because the sensors closest to the PD source return a higher voltage signal on the sensors in the localized area.

Figure 2. Functional principle of new PD detection system



The PD measurement is a well-known quality control tool for the insulation which has been researched, investigated, and improved over time. This gives a highly accurate report of the state of the insulation. Measuring PD in dry-type transformers is mainly done using acoustic, ultrasonic, and electrical techniques. Acoustic and ultrasonic measurements are based on the same principle, but with differing frequency ranges. These methods are not sensitive enough, however, because determination of the apparent charge is usually not possible. These tests can only show if PD activity exists or not.

Electrical PD measurement, with which the apparent charge can be detected, is preferable because it allows appraisal on the extent of the damage inside the insulation. But this

method also has various practical limitations and is not accurate and sensitive enough.

A new PD detection system, which allows the determination of the apparent charge as well as the localization of the PD origin, needs to be examined. Sensors are placed on the surface of the transformers coil, and the electromagnetic radiation caused by the partial discharge can be detected. Localization becomes possible because the sensors closest to the PD source return a higher voltage signal on the sensors in the localized area.

The wave with the highest amplitude, in this case 7, is closest to the PD origin. The acoustic sensors can acquire signals with a frequency scattering between 30 k to 200 kHz [2].

The cost for this type of online continuous analysis is quite high and can in some cases exceed the cost for a new transformer unit, which makes it not viable. A solution for this problem would be to monitor the PD online at intervals, but this won't deliver satisfactory results as PD activities in the solid insulation can be interrupted for a certain period. PD phenomena produces gas due to the destruction of the insulation material, therefore in the defect void the pressure increases, enhancing the breakdown strength and suppressing temporarily partial discharges until the gas diffuses into the solid insulation. After this, the pressure inside the cavity decreases, resulting in the reduction of the breakdown strength and in the renewed appearance of PD activities. This cycle continuously repeats itself until a breakdown appears.

The advantages of the AE method are:

- This method can be used to pinpoint which high-voltage winding has a PD source.
- It produces fewer false alarms, which are frequently encountered by the electrical method due to oversensitivity.
- Since this is related to acoustic signal processing, the cost for the latter stage computer's signal processing is rather low.

The disadvantages of the AE method are:

- Fiberglass will be added in the resin during the manufacturing process of the high voltage winding. The fiberglass holds apparent absorption effect toward acoustic waves, resulting in severe attenuation to the propagating acoustic wave signals inside the high voltage winding.
- The installation of the AE sensor right on the high voltage winding surface will set off the windings discharge phenomenon toward the AE sensor.
- It is not easy to install and replace the system.



Overheating Protection

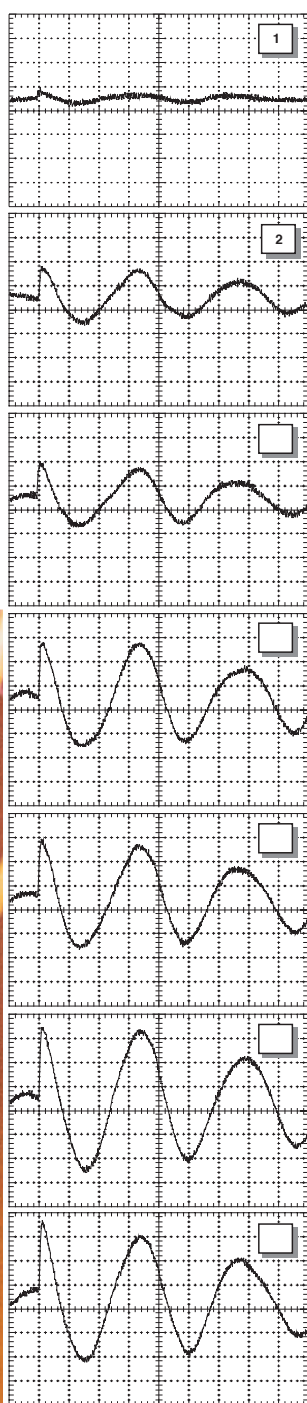
A Positive Temperature Coefficient (PTC) fuse is integrated in the low-voltage coils for signaling a temperature extension due to an excessive current. Local overheating can also appear at the high-voltage coils due to inter-turn short circuits caused by the destruction of solid insulation by partial discharges. The PTC fuse cannot be used in the high-voltage coils, but it would nonetheless be useful to monitor the temperature in the high-voltage coils as this can offer the possibility to disconnect the transformer in time to avoid loss of the unit.

A new fibre optic system with a sensor and control unit would be able to process the measured data and signal an alarm to the control center of the power supply station if an overheating appears. This application is dependent on the modification of the optical transmission properties of a fibre optic cable; thus, the optic sensor does not cause any electromagnetic interference or influence the operation of the transformer in any way. If a light signal is injected by an optical transmitter into one

side of the optic sensor, it can be detected at the opponent end with an optical receiver as shown in the figure below. If an extended elevated temperature arises at the surface of the fibre optic sensor, the damping of the light transmission is increased until a certain temperature limit is reached, where the light transmission is interrupted. In this case an alarm is triggered, and the transformer should be disconnected. This can also be automated and controlled by the protection system, if necessary.

The temperature threshold, at which an alarm is triggered can be adjusted over a wide range, from about 80°C up to 170°C or even higher.

Figure 3. Voltage signals of the sensors 1 to 7 (scale 1V/10µs)



A new fibre optic system with a sensor and control unit would be able to process the measured data and signal an alarm to the control center of the power supply station if an overheating appears.

Thermal Modelling of the Dry-Type Cast-Resin Transformer

Temperature affects the lifetime of the transformer insulation. Variation in winding temperature affects lifetime of the dry-type transformer. Load current, outdoor temperature, and atmospheric conditions affect the temperature of the insulation.

The hot spot in cast resin transformers is situated 10-15% lower than the winding top point. Altitude also impacts the thermal stress on the transformer – maximum operation altitude was found to be 1,000 m at 40°C with relative air density identified as a crucial operation influencer.

It was found that 10% transformer overload will accelerate the aging rate of cast-resin transformer, with insulation class of 180°C, to 13 times greater than the normal rate. In the same transformer, decreasing the current load by 10% of the rated value will decrease the aging rate to 7% of rated aging rate, from 1 [h/h] to 0.07 [h/h].

It was found that the impact of ambient temperature was less of an influence on the aging rate in comparison to load factor. For the same class of transformer, an ambient temperature increase of 10°C will lead to an aging rate of transformer that is three times

greater than the rate value. A 10°C decrease in ambient temperature transformer aging is reduced from 1 [h/h] to almost 0.3 [h/h] [3].

The largest impact was made by load currents, but the atmospheric conditions and ambient temperature also have considerable impact on the transformer. Dry-type transformers are more sensitive to operating conditions than oil immersed transformers [4].

Overheating Alarm Analysis

If an alarm is triggered by the overheating protection system, it is necessary to check whether the overheating was caused by a winding short or another reason. The fibre optic sensor must not show any deformations at the local hot spot, otherwise all coils need to be inspected for inter-turn short circuits.

Conclusion

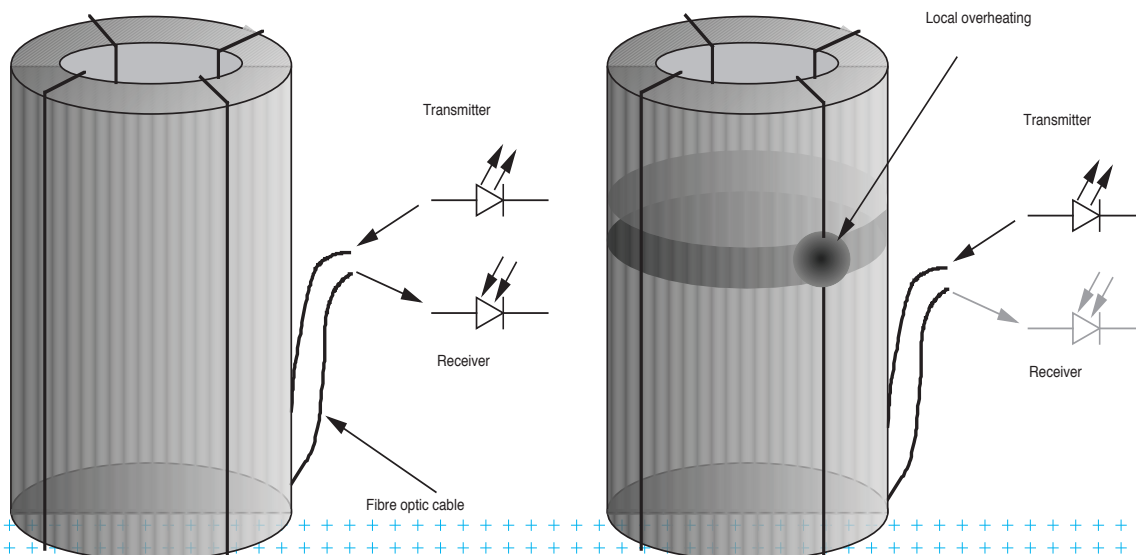
In light of the fact that the dry-type transformer industry is growing very rapidly and taking over a large market share from the traditional oil-filled units, it has become extremely important to find accurate means of picking up on threatening conditions in the dry-type units. The methods as described above give industry a more hands-on approach and greater dependability regarding the epoxy resin dry-type transformers. This ensures a more reliable reticulation system that can be run with greater

confidence than used to be the case previously. As this field is quite unexplored, I view it as an enormous field of opportunities to develop new methods of testing and monitoring these units to ensure growth in the field of reliability, lifetime optimization and cost reduction.

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Figure 4. Scheme of the overheating protection system



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Reshaping the Dry-Type Transformer

by **Kevin Eaton**

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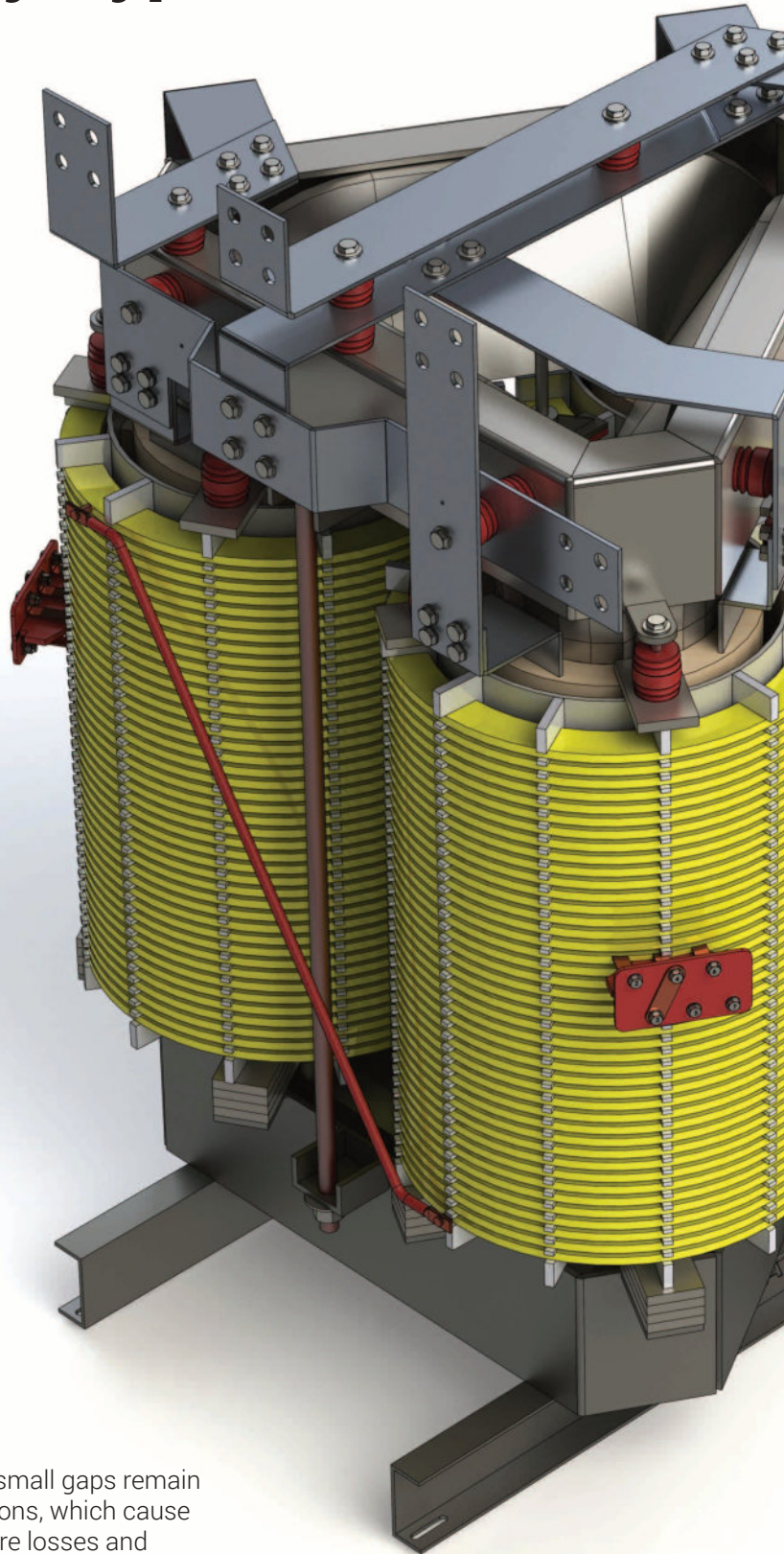
Kevin Eaton is the Marketing and Sales Manager at SGB-USA with more than 20 years of experience within the electrical industry in many different capacities. He obtained his bachelor's degree in engineering technology from Middle Tennessee State University. He is an active IEEE member and author of numerous conference papers, presentation topics, and articles for the transformer industry.

A look back - the conventional stacked core

During the 19th century, when three-phase transformer technology was beginning to come to fruition, it was commonly acknowledged that three identical core legs proved to be the best method for electrical performance for a transformer. The technical challenges in producing a core from a manufacturing perspective—and the impractical cost—made this method not a viable solution for mass supply to the electrical industry.

What evolved during that time, and what is still dominating the market space today, is a linear stacked three-legged core. A linear core for a three-phase transformer consists of essentially five main components that are combined: three individual core legs and the top and bottom yokes which are all made up of stacked straight sheets of electrical steel, Figure 1.

Upon assembly, small gaps remain at the joint locations, which cause an increase in core losses and magnetizing current. The use of overlapping layers (the step lap method) does reduce these effects and is the typical construction style of the linear core provided for the dry-type and conventional distribution market space, Figure 2.



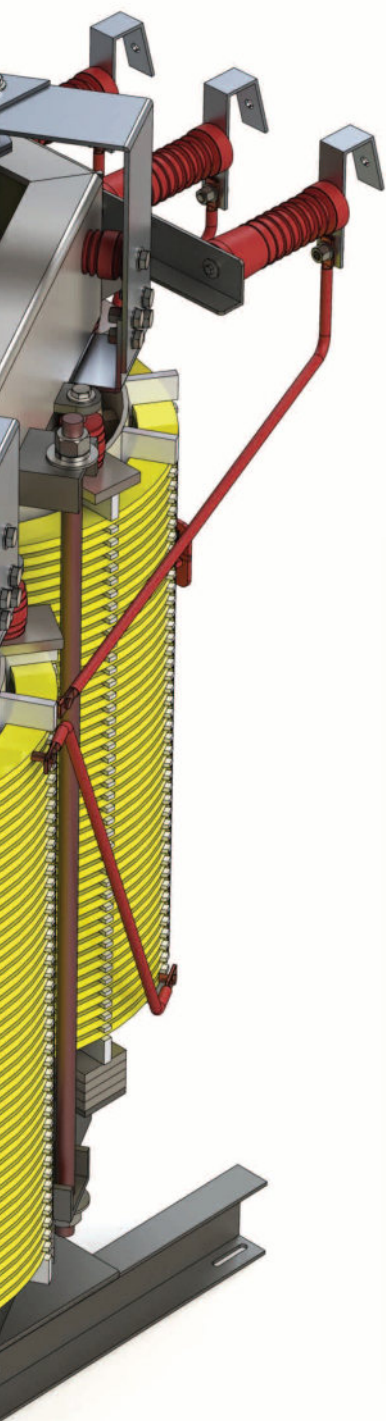
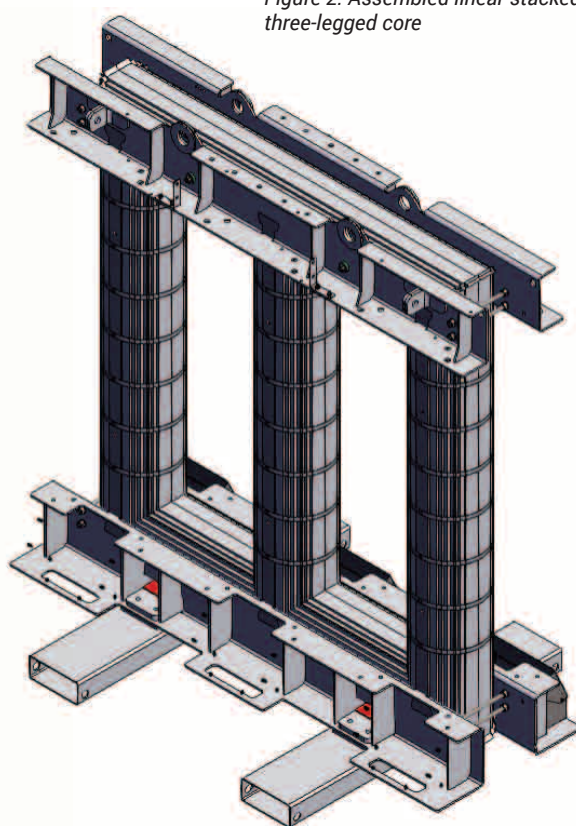


Figure 1. Linear core stacking

Figure 2. Assembled linear stacked three-legged core



Since 2010, the Department of Energy (DOE) has continued to move toward increasing efficiency level requirements (per the Code of Federal Regulations at 10 CFR 431.196) for all distribution transformers, including dry-type transformers rated 2500 kVA or less [1]. The combination of the increase in efficiency level requirements and the advancements in transformer manufacturing capabilities has allowed the original

symmetrical transformer design to become a viable and cost-effective solution for the electrical transformer market space.

How is a wound triangular core transformer even made?

A wound core construction, which produces a symmetrical structure in triangular footprint, consists of only three main pieces. Each of these three core sections is wound from one continuous strip of magnetic sheet steel on a mandrel. Because it is continuously wound, the losses associated with joints are greatly reduced.

The individual core windings are rectangular in appearance with rounded edges. The width of the core sheet varies continuously to produce an almost funnel-shaped cross section. Each leg of this three-phase triangular core contains two core windings: the funnel-shaped cross sections which then meet to form essentially a circular disk. That gives a high fill factor of core material for the coil windings, which is important for a compact and cost-efficient transformer. When comparing the conventional stacked core path via the core legs and yokes, flux is now also possible via the triangular arrangement of yokes. If the magnetic flux in the yoke sections of one of the core windings becomes so great that they become saturated, the flux can pass through the other two windings and back again, amounting to a flux through the three yokes arranged in a triangle.

A wound core construction, which produces a symmetrical structure in triangular footprint, consists of only three main pieces.

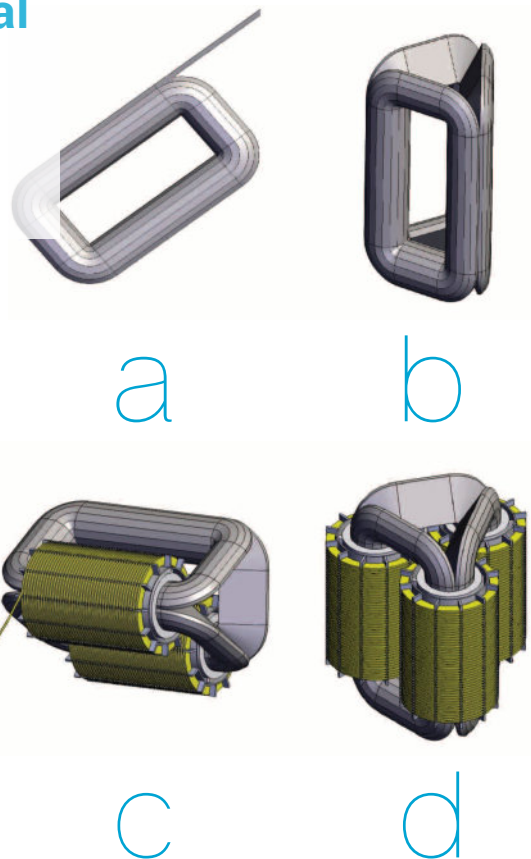


Figure 3. Assembly process for the triangular-wound core:

a – Each core will be continuously wrapped around to form a funnel shape

b – Three core legs are placed together and wrapped with a special insulation material

c – The LV and HV coils are wrapped around the core that is located within a fixed position

d – The entire core/coil will go through the varnish/dipping process

Because the core uses a continuous winding method, this means that it cannot be opened to allow installation of the coils on the core legs. In turn, the coils are wound directly on the core in place. The core assembly is fixed in place on the winding machine while the low voltage coils and high voltage coils are made. The coils produced still utilize the same materials (insulation and conductor) that are employed in the traditional stacked-core method, and they follow the same vacuum pressure impregnation (VPI) dipping process that the conventional stacked method uses for protection from humidity and for mechanical integrity. The assembly process for the triangular-wound core is illustrated in Figure 3.

The triangular design provides a more compact transformer with a smaller overall footprint, with the typical space savings for the triangular construction falling anywhere between 15% and 35%.

The physical advantages that truly make a difference

As an example, let's compare a traditional stacked core and a triangular core construction rated at 2500 kVA, 95 kV BIL, with a voltage rating of 13.8 kV delta primary and 480 Y secondary using aluminum windings and a 150°C temperature rise.

One of the most noticeable differences between the two technologies is also one of the biggest advantages of this triangular design—it provides a more compact transformer with a smaller overall footprint. The typical space or footprint savings for the triangular construction will fall anywhere between 15% and 35%.

Due to the reduced size in core mass and the elimination of joints in the manufacturing process of the triangular core, the sound level of the transformer can be reduced by approximately 5 to 10 dB

When comparing these two 2500 kVA designs, you can see in the layout that the compact design increased in depth by 5% but reduced the length by 25%, which equates to an overall footprint savings of 20%, Figure 4. This creates major advantages from a new installation standpoint, as typical substation lineups are always trying to maximize in space savings where possible.

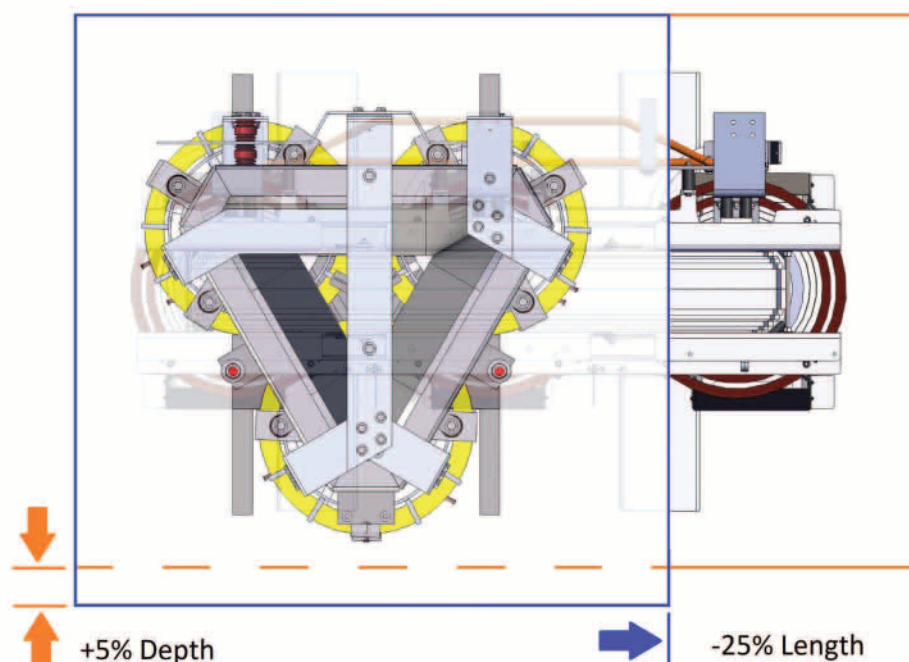
This reduced footprint also creates an advantage in retrofit purposes. Because of the DOE's increased efficiency requirements, it can be a challenge to physically fit the same sized transformer meeting today's efficiency levels back in the same footprint of the existing transformer. The triangular construction may make this task much easier or even provide ability to increase the base kVA rating of the transformer.

The overall weight is also reduced with the triangular construction. When comparing the 2500 kVA conventional design against the triangular design, the weight is reduced by approximately 22%. This may not be quite the advantage as the footprint savings, but in certain installations it could be a decisive factor. Indoor transformer installations, for example, are often limited by the load-bearing capacities of floors, or by limitations in elevator lifting capabilities.

What?! I can't hear that transformer humming?!

Due to the reduced size in core mass and the elimination of joints in the manufacturing process of the triangular core, the sound level of the transformer can be reduced by approximately 5 to 10 dB across the board in all sizes when comparing against a traditional stacked core design. The IEEE Std C57.12.01 [2] requirement for a 2500 kVA transformer, for comparison, should be designed to meet a sound level of 68 dB or lower. By comparing the triangular compact design, it would have an approximate sound level of 46 dB at the same 2500 kVA, self-cooled rating.

Figure 4. Compared to traditional stacked core, triangular design provides a more compact transformer with a smaller overall footprint



What happened to the stray magnetic fields?

In sensitive locations or applications, stray magnetic fields can be a great concern as they could impede the functioning of equipment, especially in areas like research facilities, hospitals, or data centers.

The symmetrical structure of the compact triangular core can cause the stray fields of the individual phases to essentially cancel each other out. The reduced EMC relevant magnetic stray fields decay faster than the required clearance distance, which can benefit the installation within these sensitive areas and eliminate some of these concerns.

Increased efficiency level benefits

The reduction in size and weight of the transformer core, elimination of burrs and seams during the manufacturing process with the cutting core laminations, and the lack of joints in assembly lead directly to a reduction in the no-load losses of the transformer. Transformers produce two types of losses: no-load, which is directly reflective of the core design and is always constant, and the load losses in which the operational losses vary depending on the amount of energy demand required. Most transformers in field operate at a 50% or less load factor. This allows for lower operating costs over the life of the transformer as well as ecological benefit of reduced carbon dioxide emissions.

Other performance benefits

The symmetrical design advantages of the triangular-wound core also assist in reducing inrush currents and the harmonic content of the excitation current. Reducing inrush currents can provide advantages to systems that may be configured with network protection schemes. Some network protection schemes rely on additional sensitive equipment. A reduction in concerns of the inrush current may allow in the elimination to some of these components to the costly protection schemes. In addition, transformer damage could be potentially avoided in the event of a malfunction. A comparison example is shown in Figure 5.

When comparing the conventional stacked core and the triangular-wound core, you can see in Figure 6 that there is improved harmonic behavior in 3rd, 5th and 7th harmonics and reduced 7, 4.5 and 3.5 times. This reduction in transformer harmonics will help in reducing the transformer losses and reduce the potential variability in the transformer output.

The triangular-wound core also has the potential to extend the life of the transformer. When comparing the conventional stacked core, the hottest phase when operating is the middle phase (or B leg) of the transformer. A key factor in determining the life expectancy of the transformer is the insulation and heat absorbed.

The symmetrical structure produces additional savings and benefits in areas such as harmonic content, stray magnetic fields, reduced no-load losses, improved efficiency levels, and life expectancy extension.

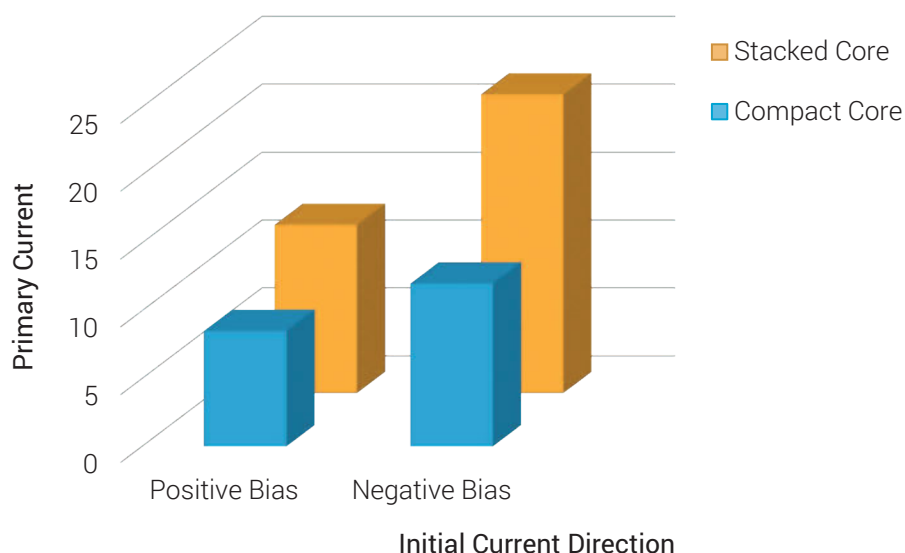
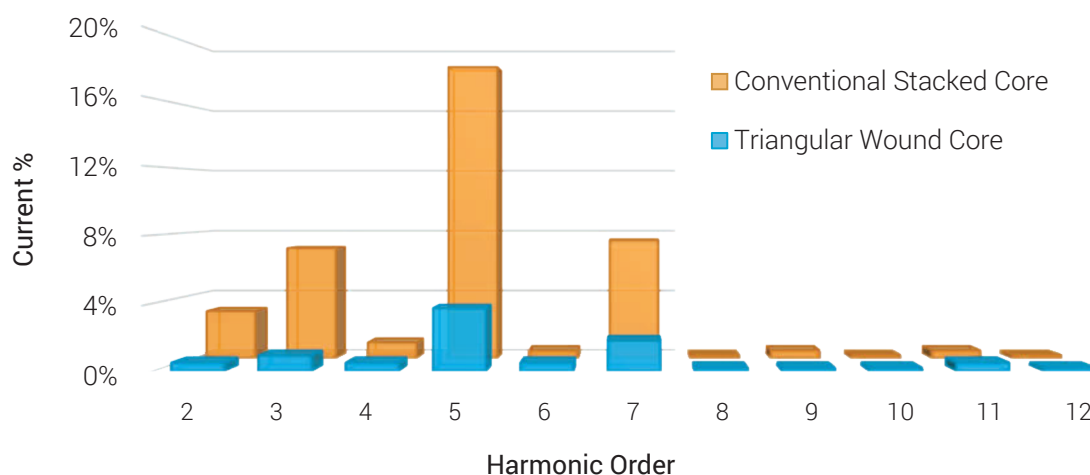


Figure 5. Inrush currents comparison

Figure 6. Harmonics comparison



The middle phase is putting out its own heat during operation and absorbing more heat from both A and C phases. This is why you typically observe the B phase operating at the higher temperature. The triangular core eliminates a middle phase as all coils are evenly spaced symmetrically on the core. Therefore, all coils shall operate at the same temperature with evenly distributed loads.

Conclusion

Advancements in manufacturing techniques and increased performance demands have paved the way for making this cutting-edge triangular-wound technology possible. The symmetrical structure produces great savings and benefits in areas such as footprint, weight, reduction in sound levels, harmonic content, stray magnetic fields, improved efficiency levels, and life expectancy extension.

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Performing a Failure Modes and Effects Analysis on a Dry-Type Transformer

by **Marie Hirzel**

When electrical equipment fails, fires and/or explosions can occur, taking lives and damaging ancillary equipment and structures. These risks make mitigating electrical equipment failure a very high priority. Failure Modes and Effects Analysis (FMEA) can be used to create a maintenance strategy that mitigates electrical equipment failures. This article presents an FMEA on an indoor dry-type transformer for this purpose.



Auxiliary Transfo



Marie Hirzel is a Quality and Reliability Consultant with 35 years of experience in both the public and private sectors. She obtained her BSE in Nuclear Engineering from University of Michigan. She is a Certified Maintenance and Reliability Professional; and is a member of SMRP, ANS, and ASQ.

Table 1. Dry Transformer Failure Modes

Function	Functional Failure	Failure Mode
Provide electrical power at an amperage of 'X' and a voltage of 'Y' from a source 'Z'	Provides intermittent current	Loose cable/connections
	Provides a current less than 'X'	Connection or cable failure
	Provides no current	Transformer insulation failure
	Provides no current or variable current	Transformer winding failure
	Provides a current less than or greater than 'X'	Cooling system failure

To begin the FMEA, I will write a Function Statement for the transformer. Because the FMEA will apply to a wide range of indoor dry-type transformers, I will use variables to create the statement:

Provide electrical power at amperage X and voltage Y from source Z.

This statement specifies what the transformer is expected to do. Next, I will write the Failure Mode Statements and the associated Functional Failure Statements. This produces five Failure Modes, which are listed in Table 1.

The cooling system on this type of transformer consists of ventilation louvers along the bottom and top of the cabinet and may include a fan inside the cabinet. With all the Failure Modes identified, I can now write the Local Effect and End Effect Statements. The Local Effect identifies what can be observed at the unit when the failure occurs. Because the End Effect Statements are facility/application specific, I will use a generic entry. These are listed in Table 2.

Table 2. Dry Transformer Local and End Effects

Function	Functional Failure	Failure Mode	Local Effect	End Effect
Provide electrical power at an amperage of 'X' and a voltage of 'Y' from a source 'Z'	Provides intermittent current	Loose cable/connections	Discoloration, arcing sounds, glowing connection, or fire	Process impact
	Provides a current less than 'X'	Connection or cable failure	Discoloration, arcing sounds, glowing connection, or fire	Process impact
	Provides no current	Transformer insulation failure	Increased operating temperature	Process impact
	Provides no current or variable current	Transformer winding failure	Temperature above or below normal	Process impact
	Provides a current less than or greater than 'X'	Cooling system failure	Increased operating temperature	Process impact

Table 3. Loose Cable/Connections Causes

Function	Functional Failure	Failure Mode	Local Effect	End Effect	Classification	Cause	Detection Method
Provide electrical power at an amperage of 'X' and a voltage of 'Y' from a source 'Z'	Provides intermittent current	Loose cable/connections	Discoloration, arcing sounds, glowing connection, or fire	Process impact	IND	Induced - Incorrect installation	Process indication
					WO	Wear Out - Due to age, heat, and vibration	Process indication

For the purpose of clarity, I will complete the remaining entries together for each Failure Mode. The entries include: Cause, Classification, Detection Method, Control, and Type Statements. The Classification field has three possible entries: Induced, Intermittent, or Wear Out. For the Failure Mode "Loose cable/connections," there are two possible causes: one Induced and two Wear Out. These are listed in Table 3.

I used a generic entry for the Detection Method because it is also facility/application specific. In this case, the Detection Method would be equipment shutting off and turning back on, or the amperes gauge in the control room periodically dropping to 0. Either way, the operator will see the process indication. Proceeding with the analysis, the first Cause has four possible Controls that can be used to mitigate the failure, while the second Cause has three possible Controls, which are listed in Table 4.

Table 4. Loose Cable/Connections Controls

Function	Functional Failure	Failure Mode	Local Effect	End Effect	Classification	Cause	Detection Method	Control	Control Type
Provide electrical power at an amperage of 'X' and a voltage of 'Y' from a source 'Z'	Provides intermittent current	Loose cable/connections	Discoloration, arcing sounds, glowing connection, or fire	Process impact	IND	Induced - Incorrect installation	Process indication	PdM; Electrical Infrared	PdM - Route Based
								PdM; Electrical Infrared	PdM - Online Monitoring
								Training; Precision Maintenance Training for proper wiring connection techniques	Training
								Ultrasonics	PdM - Route Based
					WO	Wear Out - Due to age, heat, and vibration	Process indication	PdM; Electrical Infrared	PdM - Route Based
								PdM; Electrical Infrared	PdM - Online Monitoring
								PM; Calendar or Meter Based transformer inspection	PM - Failure Finding

A preventive maintenance inspection of the transformer's connections and/or cabling must be made part of the maintenance strategy applied to the transformer

I separated the route based infrared Control from the online version to clearly delineate the maintenance strategy to be used. The second Failure Mode, "Connection or cable failure", has three possible Causes: two Induced and one Wear Out. These are listed in Table 5.

Table 5. Connection or Cable Failure Causes and Controls

Function	Functional Failure	Failure Mode	Local Effect	End Effect	Classification	Cause	Detection Method	Control	Control Type
Provide electrical power at an amperage of 'X' and a voltage of 'Y' from a source 'Z'	Provides a current less than 'X'	Connection or cable wfailure	Discoloration, arcing sounds, glowing connection, or fire	Process impact	IND	Induced - Dirt or other contaminant build-up	Process indication	PdM; Electrical Infrared	PdM - Route Based
								PdM; Electrical Infrared	PdM - Online Monitoring
								PM; Calendar or Meter Based transformer cleaning and inspection	PM - Failure Finding
					IND	Induced - Electrical or thermal overload	Process indication	PdM; Electrical Infrared	PdM - Route Based
								PdM; Electrical Infrared	PdM - Online Monitoring
					WO	Wear Out - Corrosion or other age related degradation	Process indication	PM; Calendar or Meter Based transformer inspection	PM - Failure Finding

Once that the FMEA is complete, a maintenance strategy can be created based on the possible Controls

Table 6. Transformer Insulation Failure Causes and Controls

Function	Functional Failure	Failure Mode	Local Effect	End Effect	Classification	Cause	Detection Method	Control	Control Type
Provide electrical power at an amperage of 'X' and a voltage of 'Y' from a source 'Z'	Provides no current	Transformer insulation failure	Increased operating temperature	Process impact	IND	Induced - Electrical or thermal overload	Process indication	PdM; Electrical Infrared	PdM - Route Based
								PdM; Electrical Infrared	PdM - Online Monitoring
								PM; Calendar or Meter Based transformer inspection and testing	PM - Failure Finding
					WO	Wear Out - Age related degradation	Process indication	PdM; Electrical Infrared	PdM - Route Based
								PdM; Electrical Infrared	PdM - Online Monitoring
								PM; Calendar or Meter Based transformer inspection and testing	PM - Failure Finding

Table 7. Transformer Winding Failure Causes and Controls

Function	Functional Failure	Failure Mode	Local Effect	End Effect	Classification	Cause	Detection Method	Control	Control Type
Provide electrical power at an amperage of 'X' and a voltage of 'Y' from a source 'Z'	Provides no current or variable current	Transformer winding failure	Temperature above or below normal	Process impact	WO	Wear Out - Due to age related degradation	Process indication	PdM; Electrical Infrared	PdM - Route Based
								PdM; Electrical Infrared	PdM - Online Monitoring
								PM; Calendar or Meter Based transformer inspection	PM - Failure Finding
					IND	Induced - Electrical or thermal overload	Process indication	PdM; Electrical Infrared	PdM - Route Based
								PdM; Electrical Infrared	PdM - Online Monitoring
								PM; Calendar or Meter Based transformer inspection	PM - Failure Finding

The last Cause has only one Control for it. This means a preventive maintenance inspection of the transformer's connections and/or cabling must be made part of the maintenance strategy applied to the transformer. Also, while Infrared will detect dirt build-up, I recommend scheduling an annual cleaning task. The third Failure Mode, "Transformer insulation failure", has two possible Causes: one Induced and one Wear Out. These are listed in Table 6.

Here, I recommend using Infrared. If that is not possible, the transformer will have to be tested during the PM task. The fourth Failure Mode, "Transformer winding failure", has two possible Causes: one Induced and one Wear Out. These are listed in Table 7.

Again, I recommend using Infrared. If that is not possible, the transformer will have to be inspected during the PM task. The fifth and final Failure Mode, "Cooling system failure", has four possible Causes: two Induced, one Intermittent, and one Wear Out. These are listed in Table 8.

Table 8. Cooling System Failure Causes and Controls

Function	Functional Failure	Failure Mode	Local Effect	End Effect	Classification	Cause	Detection Method	Control	Control Type
Provide electrical power at an amperage of 'X' and a voltage of 'Y' from a source 'Z'	Provides a current less than or greater than 'X'	Cooling system failure	Increased operating temperature	Process impact	IND	Induced - Dirt, corrosion, or other contaminant build-up	Process indication	PdM; Electrical Infrared	PdM - Route Based
								PdM; Electrical Infrared	PdM - Online Monitoring
								PM; Calendar or Meter Based cooling air system inspection, cleaning and/or lubrication	PM - Failure Finding
					IND	Induced - Insufficient fan lubrication	Process indication	PM; Calendar or Meter Based cooling air system inspection, cleaning and/or lubrication	PM - Failure Finding
					INT	Intermittent - Temperature relay or fan motor starting switch failure	Process indication	PM; Calendar or Meter Based cooling air system inspection, cleaning and/or lubrication	PM - Failure Finding
					WO	Wear Out - Age related degradation	Process indication	PM; Calendar or Meter Based cooling air system inspection, cleaning and/or lubrication	PM - Failure Finding

Now that the FMEA is complete, a maintenance strategy can be created based on the possible Controls.

Using infrared on the transformer will detect the bulk of the possible failures. In some cases, infrared will detect failures better than other types of inspections or tests. It also reduces the amount of preventive maintenance that needs to be performed on the transformer. Therefore, I recommend using infrared. Once a hotspot is found, appropriate corrective maintenance must be performed to eliminate it. Transformers can be purchased with infrared windows so that a hand-held infrared unit can be used to collect the temperature data, or an online infrared unit can be installed. Additionally, some transformers can be purchased with online infrared already installed on the transformer.

Even with the application of infrared, the following preventive maintenance will still need to be performed:

- Clean and inspect the busbar, transformer connections, and cabling.
- Clean (vacuum) and inspect the cabinet and cooling system.

Also, if the infrared window does not allow a clear view of the busbar connections, the following task will need to be performed:

- Torque the busbar and cable connections.

That completes my recommended preventive and predictive maintenance strategy for a dry-type transformer.

**Using infrared on the
transformer will detect the
bulk of the possible failures.
It also reduces the amount of
preventive maintenance that
needs to be performed on the
transformer**



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Focus on Operational
Reliability and Sustainability:

Cast-Resin Transformers Meet the Highest Standards

by **Heinz Raithel**

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Heinz Raithel is Vice President of Sales and Marketing, Geafol Cast Resin Transformers at Siemens Smart Infrastructure. He works at Transformatorenwerk Kirchheim/Teck, Germany, the Siemens global competence center for this technology. After his apprenticeship at Trafo Union (now Siemens) as a power electronics technician, he completed his studies in electrical power engineering and earned the degree of Dipl.-Ing (FH). He has approximately 30 years of experience in the global sales of distribution and power transformers.



One of the main focuses of the ongoing technological development of cast-resin transformers (category: dry-type transformers) is the exceptional operational reliability and fault tolerance of these highly available components, while also increasing their sustainability and economic viability. Digitalization is currently creating new possibilities for optimizing availability and service life.

Like other transformer types, cast-resin transformers are mainly used where electricity needs to be transformed from the medium-voltage level down to low voltage, or to another incoming mains voltage. Unlike traditional models, they operate with high-voltage windings fully encapsulated in cast-resin insulation instead of transformer oil or other liquid insulating materials, which makes a tank with insulating and cooling liquid unnecessary.

Thanks to this apparently simple idea, the technology has been successful ever since its market launch in 1966. **The percentage of cast-resin transformers compared with traditional, oil-immersed transformers continues to grow worldwide – with good reason, as they offer characteristic benefits.**

In order to avoid the long low-voltage cable routes that increase transmission losses and to boost the overall efficiency, transformers are usually installed near the electrical loads. This almost always means in areas frequented by people, which is why transformers have to operate extremely safely and reliably. This applies as much to high-rise buildings, hospitals, data centers, metro stations, ships, and oil rigs as it does to paper mills, rolling mills, airports, and other infrastructure with high power requirements. In addition, transformers

often operate in close proximity to passersby and residents, only separated from their immediate surroundings by the wall of a secondary unit substation or transfer substation or by a metal housing. That's why safety is everyone's top priority.

In light of the above benefits, cast-resin transformers are the preferred option wherever distribution transformers have to be installed in close proximity to people, because they ensure users a high level of safety in operation. At the same time, they have excellent electrical, mechanical, and thermal characteristics. Transformers with these features require minimal maintenance and ensure a generally high level of safety in terms of their behavior in fire. Given appropriately high-quality standards in development, design, and production, cast-resin transformers are reliable in operation, environmentally compatible, flame-retardant, self-extinguishing, and non-toxic.



Given appropriately high-quality standards in development, design, and production, cast-resin transformers are reliable in operation, environmentally compatible, flame-retardant, self-extinguishing, and produce no toxic gases.



Their characteristic strengths make cast-resin transformers ideal for applications like onshore and offshore wind power generation. In these cases, cast-resin transformers are used to step up the voltage supplied by the nacelle-mounted generator to the correct level for feeding into the medium-voltage network. Transformers for wind turbine

generators are usually designed for operating voltages on the medium-voltage level up to 40.5 kV.

Transformers installed in wind turbine generators are subject to much greater mechanical, electrical, and thermal stresses than transformers installed in standard secondary unit substations. Due to the limited

space, accessibility is also frequently restricted, which means high demands on design, product quality, and safety. These can be met with mechanically reinforced versions that are easily able to tolerate the strong nacelle vibration. All metal parts must also be painted with a special coating to protect them from the aggressive, salt-laden marine atmosphere.

The high operational reliability of this technology makes it possible to install cast-resin transformers in close proximity to the consumer: for example, at airports, metro stations, in buildings, etc.

The highest quality standards for their development, design, and production satisfy extreme requirements for operational reliability and availability.



Their characteristic strengths make cast-resin transformers ideal for applications like onshore and offshore wind power generation.

The relevant standards are monitored by international testing institutes such as KEMA/DNV-GL in the Netherlands, FGH Engineering & Test GmbH in Mannheim (CESI, Germany), and IABG (Industrieanlagen-Betriebsgesellschaft mbH) in Munich, Germany. As part of an extensive program of numerous complex tests, the cast-resin transformers are evaluated for vibration resistance, lightning impulse withstand capability, and short-circuit strength. To verify their suitability for installation in the nacelle of a wind turbine generator, for example, Siemens transformers are exposed to acceleration of up to twice the gravitational acceleration in all three coordinates in order to assess their mechanical resistance to operationally induced vibration and transportation stress.

In addition to the important aspect of safety, cast-resin transformers also often have a smaller footprint than comparable liquid-immersed or gas-insulated transformers and are extremely flexible in terms of the position of their high-voltage and low-voltage terminals. No fire-extinguishing equipment or oil troughs are required, which means additional space savings.

Designs with reduced no-load and short-circuit losses increase the transformer's efficiency, which in turn reduces its operating costs. This is how appropriately designed cast-resin transformers also meet official efficiency requirements, like the specifications of the United States Department of Energy or the requirements for implementing the European Ecodesign Directive 2009/125/EC. Epoxy resin-insulated transformers are also practically maintenance-free – a key criterion for remote offshore wind farms.

Cast-resin transformers must be classified according to verified environmental, climate, and fire classes. Geafol transformers satisfy the strict requirements of environmental class E2/E3, climate class C2/C3, and fire class F1 according to the international standard IEC 60076-11 and are also available in versions that qualify for higher classifications. The MTBF (mean time between failures) statistics for these devices from Siemens are equally impressive: They have a mathematical availability of over 98 percent, even after 30 years of operation.



In wind turbine generators in particular, transformers are subject to extreme stresses; however, thanks to mechanically reinforced versions, cast-resin transformers can easily tolerate the strong vibration in the nacelle.



This type of absolutely reliable solution in a limited space is also required, for example, when supplying electricity to critical and industrial infrastructures and data centers. **It is therefore essential that extremely high requirements for operational reliability and availability be met, based on the highest quality standards in development, design, and production.** In large part, this requires a great deal of expertise and experience, from the selection of materials and their precise processing to the structural implementation of high dielectric and mechanical strength.

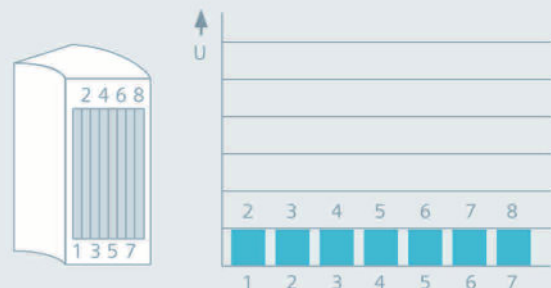
It's often a matter of details, which is perfectly illustrated by Geafol cast-resin transformers from Siemens, more than 150,000 of which have been installed worldwide to date. They've been on the market in their basic form since 1966 and have been continuously refined ever since. Over the past five decades alone, the weight of our transformers has been reduced by more than one-third, with no reduction in output range or adverse effects on operational safety and reliability. However, development isn't limited to just weight reduction: Important changes have also been made to the transformers' active

components. Modern cast-resin transformers have long ceased to be dependent on copper windings, although these transformer types continue to be in demand and are also offered by Siemens. Over the years, however, the use of aluminum foils and strips insulated with high-grade plastic film has prevailed. Similar to the way capacitors are manufactured, this technology has moved to the forefront because the foil winding combines a simple technique with high electrical safety. The insulation is exposed to much lower electrical stress than in other types of winding.



Round-wire winding

The interturn voltages can add up to twice the interlayer voltage.



Foil winding

The interlayer voltage is equal to the interturn voltage.

Whereas turn-to-turn voltages in a conventional round-wire winding can add up to twice the interlayer voltage, the interlayer voltage of a foil winding never exceeds the single voltage per turn.

To guarantee long-term compliance with strict international safety standards, cast-resin transformers – although largely maintenance-free by design – also need to be checked at regular intervals to ensure that they're in good working order.

Whereas turn-to-turn voltages in a conventional round-wire winding can add up to twice the interlayer voltage, the interlayer voltage of a foil winding never exceeds the single voltage per turn. This is because all layers uniquely consist of a single winding, ensuring excellent power-frequency voltage strength and impulse voltage strength. But why aluminum?

Aluminum's coefficients of expansion are very similar to those of the special Siemens formulas for casting resin and result in only minimal mechanical stress, especially in the context of load change-induced temperature fluctuations. Efficiency calculations based on a comprehensive evaluation of conductivity, material price, specific weight, and loss balance have also shown that the aluminum conductor invariably offers advantages.

Modern Geafol cast-resin transformers are manufactured using strip winding machines that enable a number of high-voltage and low-voltage phase windings to be produced in one shift. Once the primary- and secondary-side

windings have been completed, the coils are sealed with special resin mixtures. The quality of the encapsulation of the high-voltage coils plus the electrical advantages of the foil winding are crucial factors in ensuring freedom from partial discharges up to twice the rated voltage. The cast epoxy resin used to encapsulate the high-voltage coils is applied under vacuum and at high temperature, which prevents harmful gas inclusions. Special high-performance vacuum pumps generate the vacuum required for this process in the casting chamber.

The transformer core is comprised of grain-oriented, cold-rolled electric sheet steel whose thickness and layering are a function of requirements related to no-load losses and noise level.

As in the case of rolling mills and high-tech factories, the market increasingly needs transformers with higher ratings for larger offshore wind turbine generators. The reason is that cast-resin transformers are highly

reliable in operation and are also extremely efficient, which results – beside the lower maintenance costs – in a reduction of the operating costs. With transformers, higher power ratings generally mean higher currents and therefore greater heat loss. The solution to this problem is special cooling ducts – and not just for the low-voltage winding but also for the fully encapsulated high-voltage winding. To achieve extremely high MVA ratings, additional cooling ducts must therefore be incorporated both on the high-voltage side and in the core.

Transformers are the key operating elements at hubs in the distribution system. In terms of winding technology, transformers have to be designed to reliably handle overvoltages caused by switching operations without additional, external protective devices. Extensive trials using a combination of Siemens Geafol cast-resin transformers and vacuum switches have proven that the medium-voltage windings can easily handle switching overvoltages.



A great deal of effort is invested in producing cast-resin transformers that not only conform to familiar international standards according to UL, CSA, or TÜV but that can also be aligned with GOST, SABS, or ANSI/IEEE on request. Specifications according to UL1562, ANSI/IEEE C57.12.01, and CSA C22.2 must be taken into account for the North American market in particular. For companies active in European and European-influenced markets like Asia and the Middle East, the most important standards for the transformers used in these areas are IEC 60076-11 and DIN EN 60076-11.

To guarantee long-term compliance with these high standards, cast-resin transformers – although largely maintenance-free by design – also have to be checked at regular intervals to ensure that they are in good working order and, if necessary, cleaned or repaired. Models like the Geafol transformer that comprise multiple components

If the response temperature of a sensor is reached, the resistance rises sharply and the trip relay switches over immediately. If the winding cools down by about 6 K below the operating temperature, the relay coil in the trip relay is fully energized and the contact switches back. The highest permissible ambient temperature for the trip relay is limited to about 60°C, making it suitable for installation in medium- or low-voltage distribution cabinets.

As an alternative to conventional PTC thermistor detectors, Pt100 temperature sensors can be used to continuously measure temperature. Additional sensor types for recording other operational safety- and service-related parameters with appropriate analysis devices will be available in the near future.

As the amount of operational data obtained from the transformer increases, it stands to reason that this data should be used for tasks like

are located at the hub of the power grid with access to all information on the energy flow, which makes them ideal sensors for detecting grid status. As “Sensformers,” formerly simple transformers have now become information hubs. The data allows conclusions to be drawn about the status of the units and the power grid, enabling more flexible, optimized operation of the entire grid. Existing transformers are being equipped with an IoT gateway for this purpose. Every operator is given access to a cloud-based platform application that visualizes the data collected and enables conclusions about the status of the transformer and its output on the different voltage levels. If operators know the exact status of their transformers, they can address their current challenges: for example, integrating the growing proportion of renewable energies and distributed power generation into the power grid while still operating the grid as cost-effectively as possible.

The transformer becomes a sort of information interface, in that it records the latest measured values and operating parameters in real time and transfers them to the cloud.

offer advantages in this context because individual parts can be replaced relatively easily, quickly, and inexpensively for maintenance and repairs.

Geafol transformers are equipped with temperature sensors to protect them from thermal overloading. The most cost-effective monitoring solution is the PTC thermistor detector in the low-voltage windings combined with a trip relay. In the case of converter transformers, the core temperature is also monitored.

If two PTC thermistor detector systems are used to monitor temperature, one is wired to give an alarm and the other to switch off the transformer. The nominal operating temperatures of both systems differ by 20 K. A third system can, for example, take over the task of controlling the fans. The temperature sensors function as PTC resistors.

making predictions about the plant's future output or developing schedules for preventive maintenance. Real-time performance data can also be processed in the cloud, and this creates numerous possibilities for integrating transformers into networked IIoT (Industrial Internet of Things) environments. This idea is especially interesting in the case of transformers with higher ratings. Specific benefits include more efficient maintenance models and longer service intervals as well as evaluation and analysis options that extend over longer periods of time, thereby enabling reliable run-time predictions and, as a result, longer operating cycles.

In view of these factors, Siemens has been gradually equipping its transformer portfolio with digital intelligence since 2018. The fact that transformers – along with low- and medium-voltage switchgears –

Conclusion

The percentage of cast-resin transformers compared with traditional, liquid-immersed transformers continues to grow worldwide – with good reason, because their high operational reliability and long service life have been allowing operators to install this technology in close proximity to the consumer for over 50 years. Ongoing technological developments have focused on their exceptional operational reliability and fault tolerance while also increasing their sustainability and economic viability. Relatively new application areas in particular – like onshore and offshore wind turbine generators and data centers – require absolutely reliable solutions. The same applies to the supply of electricity to critical and industrial infrastructures. Once again, digitalization opens up new possibilities for further optimizing the availability and service life of cast-resin transformers.



The weight of the Geafol transformer has been reduced by one-third over the past five decades with no reduction in output range or adverse effects on operational safety and reliability



Electrical Testing of Dry-Type Transformers

by **Mark Pustejovsky**

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Mark Pustejovsky graduated with a Bachelor of Science in Electronics Engineering Technology from Texas A&M University in 1993. He has worked in the electrical testing field since graduation. Mark has 15+ years of experience in electrical testing, power quality, arc flash evaluations, and protective relaying. In his role as Senior Vice President of Workforce Development at Shermco Industries, he helps train, retain, and, recruit Shermco employees to continue to be a leader in the most technical workforce in the industry.



Dry-type transformers are a large part of the electrical infrastructure for many industrial and commercial sites. Therefore, ensuring the performance of electrical testing and maintenance on critical transformers is very important to electrical system reliability. This article covers electrical testing and maintenance items recommended by the InterNational Electrical Testing Association (NETA) and other industry best practices for transformers above 500 kVA. NETA has two standards, one for acceptance testing of new units (ANSI/NETA ATS-2017, *Standard for Acceptance Testing Specifications for Electrical Power Equipment & Systems*) and one for maintenance testing of service-aged units, (ANSI/NETA MTS-2019, *Standard for Maintenance Testing Specifications for Electrical Power Equipment & Systems*). We will focus on maintenance testing specifications in this article. Also, the recommended testing of dry-type transformers is very similar to liquid-filled transformers, with a few key differences.

For large dry-type transformers (500 kVA and above), ANSI/NETA MTS-2019 recommends visual and mechanical inspections and electrical tests similar to the tests recommended for liquid-filled transformers. However, determining the health and reliability of a dry-type transformer can be much harder than that of a liquid filled unit. In liquid-filled transformers, oil typically makes up a large part of the insulation system. Being that most insulating oils have relatively similar dielectric values, expected insulation values are very similar in most liquid-filled transformers. For dry-type transformers, however, the primary insulation is made up of different types of dry insulation, depending on the manufacturer and specifications. Since dry-type transformers do not have oil to cool them during operation, they must be constructed of materials that can withstand higher temperatures without sustaining damage. Dry-type transformers can be constructed of Insulation Class B (130°C), Class C (220°C), or Class H (180°C) materials. The typical oil-filled transformer has a rated temperature rise of 65°C and Insulation Class A materials are used.

There are various construction methods for the manufacturing of dry-type transformers, and each type is suited for different environments and applications. These various construction methods include Open Wound, Vacuum Pressure Impregnated (VPI), Vacuum Pressure Encapsulated (VPE), and Cast-Coil Resin.

Insulation Tests

When testing a transformer's insulation integrity, there are two main types of tests recommended:

- 1) Insulation-resistance tests and
- 2) insulation power-factor (or dissipation-factor) tests.

Because of the different types of materials and methods used, the

test results can vary greatly between different types of transformers. Moisture or humidity can also influence the test results, as the insulating materials of dry-type transformers are exposed to the atmosphere and can be greatly affected by the surrounding environment. When the transformer is energized, it will be elevated in temperature, and as it cools, it will absorb moisture. Therefore, it is best to test soon after it is de-energized.

Per Table 100.5 in ANSI/NETA MTS-2019, insulation resistance values for windings of dry-type transformers (greater than 5,000 V) should be 25,000 Megohms or greater.

There are various construction methods for the manufacturing of dry-type transformers, and each type is suited for different environments and applications

Insulation power factor results vary depending on the material and construction, and it is recommended to compare to similar units and previous base line tests results. Capacitance should be recorded whenever a power-factor test is performed. The capacitance is dependent on the shape of the windings, and if the transformer ever feeds a high-level fault, these readings can be compared to previous results to determine if there was damage to the transformer due to winding movement during the fault.

It is also worth noting that it is difficult to correct power factor readings to a base temperature on dry-type transformers.

Temperature may influence the power-factor results, but there are too many different types of insulation to assemble a "standard temperature correction factor" chart, and for the most part the temperature characteristic curve should be relatively flat. If power-factor results are questionable at high temperatures, allow the unit to cool and retest when the temperature is closer to 20°C.

When performing power-factor testing, a "tip-up" test should also be performed on all windings greater than 2.5 kV. This will aid in determining the presence of partial discharge (PD) anomalies.

In dry insulation, partial discharges can occur within voids in the insulation. Partial discharge is a localized dielectric breakdown of a small portion of the electrical insulation. Over time, a series of these small insulation breakdowns will eventually lead to an insulation failure. Therefore, it is important to detect when PD is occurring, before it leads to failure. A tip-up test is conducted at two voltages; a lower voltage (something below the PD inception point) typically 2 kV or below, and then at operating voltage.

If no PD is occurring, the power-factor values at the two voltages will be similar. If PD is occurring, the power factor at the high voltage will be higher than it is at the lower voltage. ANSI/NETA MTS-2019 recommends that this difference be less than 1.0 % for an acceptable test. A tip-up test can be performed on an oil-filled transformer, but it is much more important with dry insulation.

Visual and Mechanical Inspection

When performing acceptance or maintenance testing on dry-type transformers, visual and mechanical inspections are very important. Transformers are shipped with shipping bolts that keep the

Winding resistance is another test recommended by ANSI/NETA MTS-2019. A winding resistance test injects a DC current through the winding to be measured, and then reads the voltage drop across

It is difficult to correct power factor readings to a base temperature on dry-type transformers

Excitation testing is performed by energizing one phase of a transformer at a time and measuring the amount of current drawn. A

typical excitation current test pattern for a three-legged core is two similar readings and one lower reading.



The aim of this test is to find poor electrical connections, inter-turn short circuits, abnormal core faults and winding problems. It gives information for an electrical and mechanical assessment of transformer conditions. The test is performed on each phase by exciting the transformer with all other windings being open-circuited. Excitation tests must be performed before any other DC tests (such as winding resistance) are performed, as DC testing can magnetize the core and cause erroneous test results during the excitation test. If a pattern of two similar readings and one low reading is not obtained, one possibility is core magnetization. The core should be demagnetized, and the test performed again to see if the results change. Many manufacturers of electrical test equipment offer stand-alone test sets for this function, or have this function built into the winding resistance test set.

Core Ground Test

The transformer core, which is effectively a conductor that is not intended as a current-carrying path, may develop potential [voltage] due to capacitive coupling with the innermost winding when the transformer is energized, resulting in partial discharges that may damage the transformer and induced potential when the transformer is carrying load. This can occur and be detrimental to the transformer's useful life unless the core is solidly connected to earth ground. The core ground also assures protective device operation in the event of a winding to core insulation failure. For such a fault to be

recognized by the protective system of the power supply/line (and quickly disconnect the line), the transformer core must be grounded to provide an electrical (fault) path back to the source. A core is typically grounded at a single point only, as multiple core grounds may result in circulating currents and overheating in the core. The core ground test is performed to ensure that the core is only grounded at the grounding point. Not all dry-type transformers have the ability to lift the core ground, but when available, the grounding bond to the core should be lifted and an insulation test of 500 Vdc should be performed. The core insulation-resistance values should not be less than one megohm.

When performing acceptance or maintenance testing on dry-type transformers, visual and mechanical inspections are very important



Many transformers have surge arresters on the high side to protect the windings from transients that might occur from switching or external sources such as lightning. The proper voltage rating of the arrester is critical and should be verified during testing. Metal-oxide varistor (MOV) type arresters have two voltage ratings: maximum continuous operating voltage (MCOV) and rated voltage. The MCOV rating is chosen by what type of grounding is used on the electrical system. When the system is solidly grounded, the MCOV rating of the arrester can be lower than if the system is a Delta or ungrounded system. On an ungrounded system, the phase voltage on one phase can become as high as phase-to-phase voltage during a fault on another phase. Therefore, ensure the proper MCOV rating was selected based on the

On-line Inspection and Test

With liquid-filled transformers, it is very easy to pull oil samples and get a very cost-effective analysis of what is going on inside the transformer. Since it is not possible to sample the air in a dry-type transformer in the same manner, regular off-line maintenance is important. However, you can

perform on-line partial discharge scans and thermographic (IR) scans of the electrical connections at regular intervals as a cost-effective means to monitor the health of the transformer. The temperature gauges, cooling fans, output voltage readings, and loading should also be monitored regularly.

In Summary

There are many tests that can be performed routinely on dry-type transformers to keep the electrical system at your site safe and reliable. Since there are many different transformer construction techniques and materials used, trending test data can be very valuable. No one electrical test can tell you if a transformer is in overall good condition, but performing the battery of tests outlined in this article can give you reasonable confidence about the health of the transformer.

When performing acceptance or maintenance testing on dry-type transformers, visual and mechanical inspections are very important



Testing Maintenance Monitoring: Best Practices

The September issue of Transformer Technology will focus on best practices for testing, maintenance, and monitoring, with articles from leading practitioners in the field of transformer maintenance.

Jason Dennison, manager of the largest transformer oil testing laboratory in the world, will take us deep into the practices and processes for lab testing. Diego Robalino, our Contributing Editor from Megger, will explore the area of electrical testing. Bob Rasor, a 34-year veteran of transformer maintenance services, will share common best practices for transformer maintenance.

We will also have articles from experts from Southern California Edison, Doble, Weidmann, Delta Star, Reinhausen (MR), and others who are committed to advancing and sharing our knowledge.

We have interviews with Craig Stiegemeier of ABB, who is retiring after 30 years of service, and John McDonald of GE, who is likely to never retire. Their unabridged interviews will soon be available on our website as part of our "Legends" podcast. A Legend is defined as someone who is a lifelong learner, a teacher willing to share their knowledge openly and freely and finally someone who has left it better than they found it. Both of these men deserve the legends label.

Finally, I realize the incredible blessing I have been given to be able to connect with all of these professionals who are dedicated to taking their time and energy to share their knowledge with us. My hope for Transformer Technology is that we become a "collaborative community" of excellence that leaves a legacy for future generations. Join the movement.

Alan Ross, Editor in Chief

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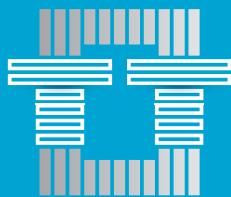
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