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TRANSFORMER TECHNOLOGY MAG

Impact of the Next Generation of Design

Interview with Luiz Cheim, Senior Principal R&D Engineer at Hitachi ABB Power Grids

Design for the Future. Design for Success. Design for Safety.

Interview with Khayakazi Dioka, Corporate Specialist - Transformers and Reactors, Eskom Holdings SOC

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Designed to detect and diagnose problems at the earliest stage, the TOTUS Bushing Monitor uses integrated intelligence and analytics to provide reliable and intuitive information to asset managers about bushing health.

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- Capacitance
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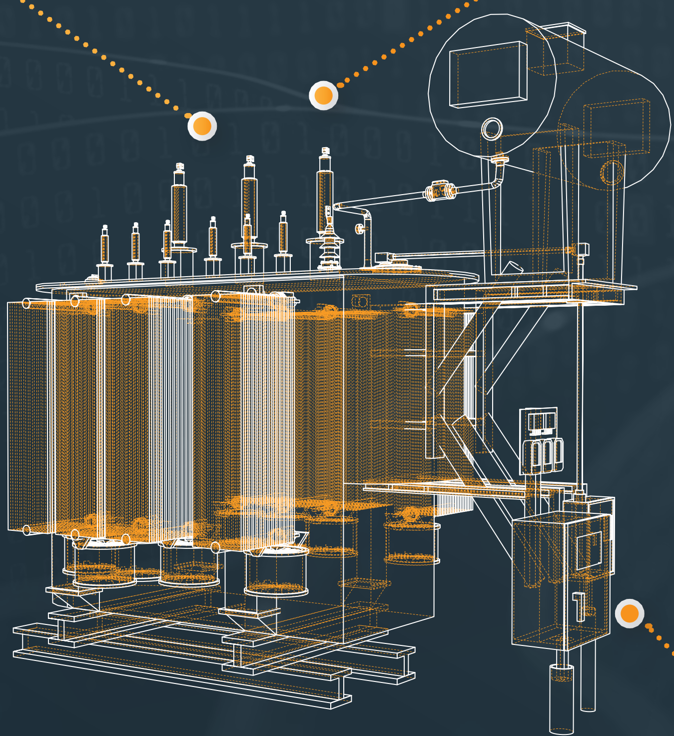
- Load



1 DETECT

Anomalies under real operating conditions

2 DIAGNOSE

Risk, condition & failure mode

3 DECISION

Quick and actionable insight

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Impressum

TRANSFORMER TECHNOLOGY MAG

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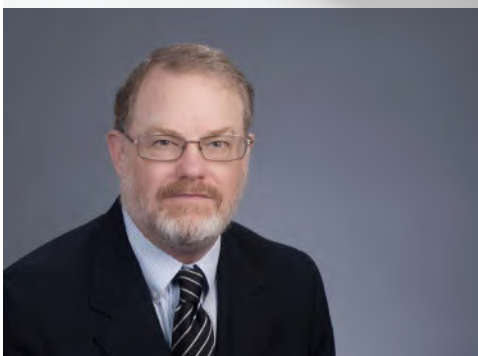

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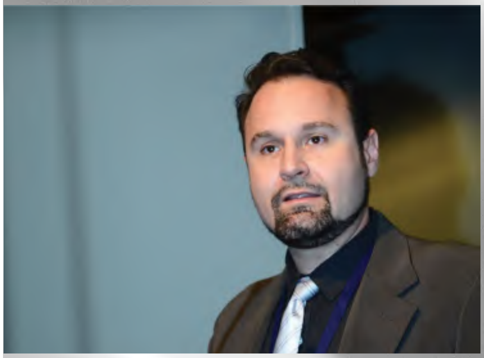

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Design for the Future. Design for Success. Design for Safety.

The reliability of electrical power creation and distribution must be continually safeguarded and improved. This does not happen by chance or through reactionary-maintenance tasks. This must be focused on from the early design stages and continued through the life of the assets tasked with these functions.

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Sometimes, a technical advance comes along that is both simple, elegant and effective. This article brings us the Sen Transformer, a solution that offers a plethora of power flow control features all in one unit and uses time-tested components proven to be reliable, cost effective and portable to meet today's needs for a smart grid.

TRANSFORMER INSULATION SOLUTIONS

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RESINS AND VARNISHES

PRODUCT	CHEMISTRY	APPLICATION / FEATURES	OIL FILLED	DRY/CAST	TRACTION
Dolphon CC-1180	Epoxy 1k	Impregnation resin, excellent mechanical and chemical resistance, VOC free, EN45545-2 approved		X	X
Dolphon CC-1118	Epoxy 1k	Impregnation mainly for traction transformers, excellent mechanical and chemical resistance, VOC free, thixotrop, EN45545-2 approved		X	X
Hi Therm BC-346A, BB-346A, BR-346A	Polyester	Impregnation and coating, hot curing		X	
Dolphon BC-359, BB-359	Polyurethane	Low temperature curing, flexible impregnation and coating		X	
Dolphon CC-1305	Polyester in DAP	Flexibilized impregnation resin, low VOC		X	
Permafil 724CT	Polyester	Special non-greening polyester resin, low weight loss during heat aging		X	
Permafil 709T	Polyester	Unique semi-rigid solventless polyester with excellent tank stability		X	
Dolphon CC-1105	Polyester in DAP	Industry standard, high reactivity, low viscosity, low VOC		X	X
Dolphon XL-3102	Polyester	For high thermal properties, 100% label free impregnation resin, high reactivity, low viscosity		X	
Synthite AC 41	Polyurethane	Coating varnish, air drying		X	
Synthite AC 43	Polyester	Coating varnish, air drying		X	
Dolphon CW-1081	Epoxy 2k	Coating varnish, best protection		X	

BANDING

PRODUCT	DIMENSIONS	APPLICATION / FEATURES	OIL FILLED	DRY/CAST	TRACTION
Poly Glas® 76830	up to 1“ width 300, 750‘ length	Core leg support, Bandage, standard duty material	X	(X)	X
Poly Glas® 76843	up to 1“ width 300, 750‘ length	Core leg support, Bandage, moisture resistant formulation	X	(X)	X
Poly Glas® 76870	up to 2” width 300’, 750’, 1500’ length	Core leg support, Bandage, moisture resistant formulation	X	(X)	X
Poly Glas® C155	50 mm (2“) width 100, 200 m length	Electrical shielding and mechanical banding of core columns	X		

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PRODUCT	DIMENSIONS	APPLICATION / FEATURES	OIL FILLED	DRY/CAST	TRACTION
KMK	up to 36“ wide	Kraft paper / Polyester film	X	X	
DMD	up to 72“ wide	Polyester mat / Polyester film	X	X	
NMN	up to 72“ wide	Aramid paper / Polyester film		X	
NKN	up to 36“ wide	Aramid paper / Polyester film		X	X
Special laminates	up to 36“ wide	Pre-insulated copper or aluminum foil laminate for strip winding		X	
Coated Nomex	up to 72“ wide	Epoxy coated for layer insulation		X	X

COMPOSITES

PRODUCT	STANDARD
Durapol F200	UP GM 203 GPO-3
Durapol M600	UP GM 205
Vetronit G11	EP GC 203 G-11
Vetronit G11 T	EP GC 22 G-11
Treillis 64330	

NEW CONDUCTIVE POLY GLAS® C155 – TWO JOBS AT ONCE

At high voltage, the lamination stack need to be electrically shielded to avoid local increases of the electrical field at sharp edges.

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PROPERTY	VALUE
Thermal class	F (155 °C)
Thickness	0.33 mm
Base weight	550 g/m2
Resin Content	26%
Curing conditions	3h @ 150 °C or 5h @ 135 °C or 14h @ 120 °C
Tensile strength after curing, at 20 °C	2500 N/cm per layer
Tensile strength after curing, at 155 °C	1800 N/cm per layer
Specific surface resistance after curing	5 - 25 kΩcm/cm
Specific volume resistance	20 - 500 kΩcm

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Dear Readers,

As a reliability professional, I see things from a unique engineering perspective. Reliability is defined as *the ability of an asset* – and I would include a system – *to perform its designed function for its useful life*. We could also safely add: *If designed properly and with proper maintenance and operations, the lifecycle of that asset or assets in a system can extend the life of the asset or the system*. But that would be for another theme and another time. For this issue, we are focusing on the impact of current technology on the design of transformers.

When you consider the impact of the next generation of design, then when considering the design of assets like transformers you quickly realize that they are also greatly impacted by the design of the components that make up the asset. As components change to meet the needs of the asset, to meet the needs of the system, you can see how the next generation of design can actually take on a life much greater than originally anticipated.

When we originally came up with the idea for this issue of Transformer Technology, we did not anticipate how the unlimited ability for component design could impact overall transformer design. What we did find was that the component designs have to be considered, especially when those designs actually increase the reliability of either the component or the component within the asset structure. I know! Only a reliability geek would think this way, right?

Let's look for instance at the design of bushings and what's happening with the next generation of bushing design. Resin-impregnated bushings and new fluids within oil-filled bushings, and in general the whole idea of the design of bushings, is allowing for a more reliable transformer, which means that we have to decide how those changes in bushings will impact the overall reliability of the system. This also impacts the lifecycle of the transformer.

One of the things we did not expect was to be able to look at the design of fluids and the impact that that design has. For instance, Corné Dames in her article on natural esters highlights the changes that are taking place in the oils and fluids design as part of transformer reliability.

Further down the line, in our September/October issue we will delve even more deeply into oils and fluids, and then in the November/December issue we will look at bushings and other component parts. But for this issue we just wanted to focus on the plethora of component design changes that are changing transformer design.

I mentioned that I tend to view things through the lens of reliability, which starts with a high-level view of asset reliability:

Design for reliability
This means avoiding unplanned outages and operating in a way that is the normal operation of the asset in a system. For instance, we know that GSUs need to run at over-rating during highly demanding times.

Operational parameters
Same as above. Also, we know the abuse a furnace transformer takes in any industry like metals, glass, paper and food products and more.

Maintenance protocols
This might be one of the areas where changes need to be made. How do you maintain a transformer when it has already exceeded its planned life by decades? As I presented at the most recent IEEE-ESW event, preventive maintenance is often the cause of unplanned or lengthy shutdowns, as is predictive.

Lifecycle planning
It's not just transformers that have aged well beyond their planned life. Cable systems, bus-work, generators and so many more electrical system assets have lasted far longer than expected. Given that studies indicate that only 11% of failures are due to age, this means we have a lot of life left in billions of dollars of assets.

> Coming in June is something all of us at APC Media are tremendously excited about, so expect our announcement soon. Not only is it the theme for a June issue - it is the basis for a New Community we will be starting and supporting.

So, enjoy this issue and once you enjoyed it, share the entire issue or just one article or interview with someone you know can benefit from it. A thousand do every month and for that we are grateful.

Coming up next for May is the theme: **From Specification to Commissioning: Better Practices for Better Outcomes.** We already have a great issue lined up but because it is a two-month issue, we might be able to squeeze in another article or an interview. If you have an idea, then connect with me at Alan.ross@transformer-technology.com.
I'd love to hear from you.

Finally, coming in June is something all of us at APC Media are tremendously excited about, so expect our announcement soon. Not only is it the theme for a June issue - it is the basis for a new Community we will be starting and supporting.

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

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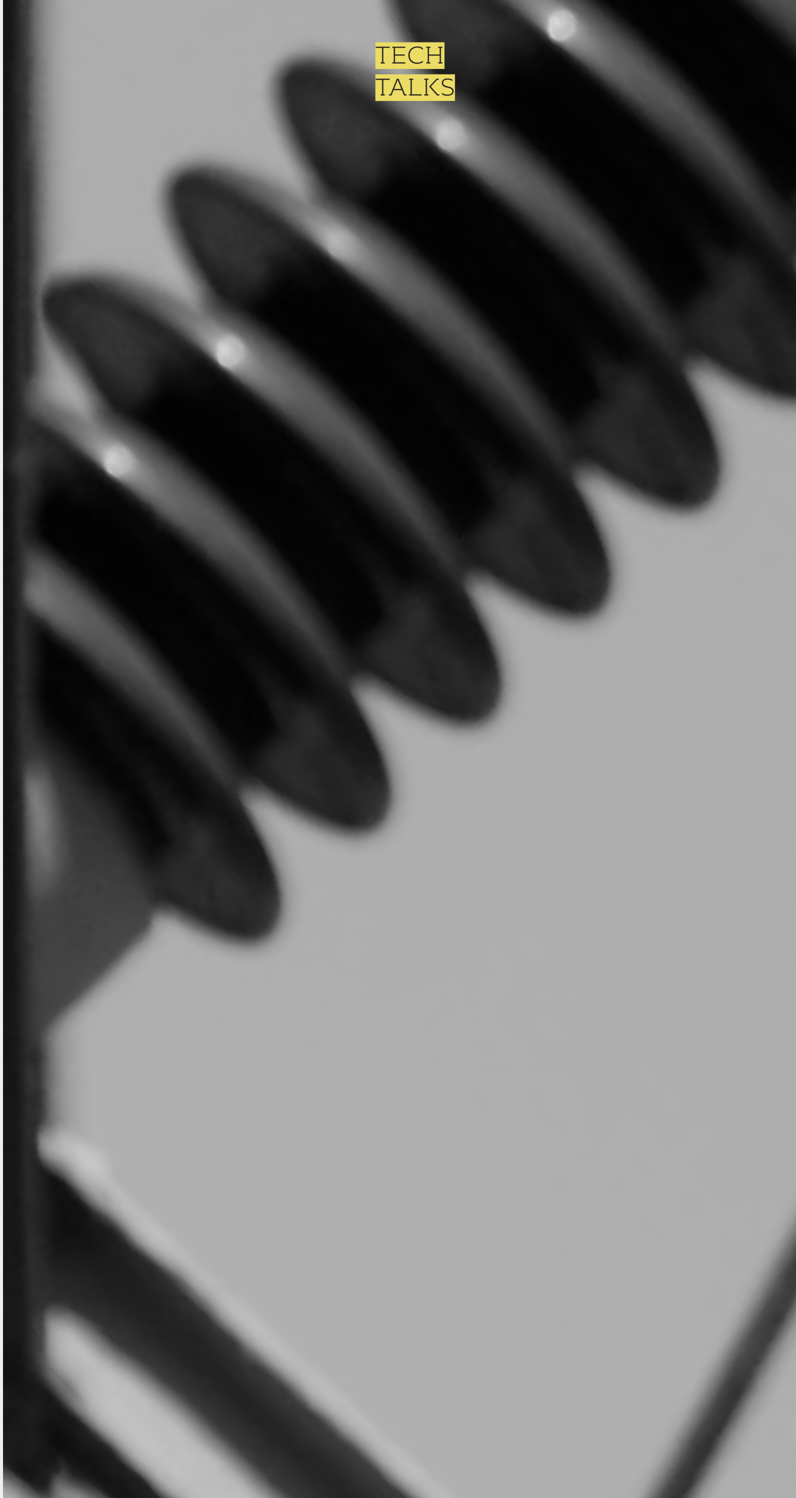

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Luiz Cheim

Senior Principal R&D Engineer at
Hitachi ABB Power Grids

Interview with **Luiz Cheim**

HITACHI ABB

"I think research is in my DNA, as it is for Hitachi ABB Power Grids. We are never satisfied with the world as we see it and are always thinking of better ways to do things based on innovation and technology.

Photo: Hitachi ABB Power Grids

The story behind the submersible transformer inspection robot

Photo: Hitachi ABB Power Grids

Alan Ross, the Editor in Chief of Transformer Technology magazine, spoke with Luiz Cheim of Hitachi ABB Power Grids about TXplore™, a service that utilizes a submersible inspection robot to inspect and detect problems inside fluid filled power transformers. Luiz was Alan's guest on a recent Tech Talk, and this interview is an edited excerpt from that.

Alan Ross: I first saw a demonstration of the submersible robot service for transformers - TXplore™, at the Doble Conference in 2018 by the now retired ABB engineer, Craig Stiegemeier. Before we get into the TXplore™, Luiz, could you tell us a little about your background and career?

Luiz Cheim: I am originally from Brazil and my career has been a long journey. I received my electrical engineering degree in Rio de Janeiro in the 1980s and a master's degree while working at a research institute in Brazil. I then moved to England where I worked at the Electrical Engineering Department of Nottingham University for a number of years, and obtained my PhD, before I decided to go back to Brazil, where I worked with the same research institution for another seven years. I then worked for Siemens for eight years, before I moved to Canada to join ABB and finally to the US, where I now work with Hitachi ABB Power Grids. I have also been heavily involved with CIGRE, serving as the head of the CIGRE Transformer Committee in Brazil from 2000 to 2006.

Professionally, I have always liked research. I think research is in my DNA, as it is for Hitachi ABB Power Grids. We are never satisfied with the world as we see it and are always thinking of better ways to do things, based on innovation and technology.

I have contributed to multiple patents in the US and globally. The plaques you can see behind me at my office are gifts from Hitachi ABB, in commemoration of those patents. The submersible robot will add fifteen more to the collection, hopefully.

As for the robot, robots have been used for many years, but they have never really been applied to transformers - so that was my thinking as well.

AR Let's talk about the robot. I presume you were doing your research and saw a problem relating to transformers. What was the problem that you saw and decided you were going to solve?

LC This is quite interesting. At that time there was no product development on robotic submersibles. There was nothing of that kind. So, I was not looking for a solution to a problem. I actually witnessed a situation on site where I thought to myself: There must be a better way of doing this.

I was invited to a customer meeting that took place in a very large substation. I met the customer and the group of engineers, and they thought I might be interested to know there were my colleagues at the site doing transformer inspection. I didn't know that because I was not involved in that activity at that time.

They invited me to meet my colleagues and see what was going on. We walked around the substation to see an internal inspection of a power transformer on a very hot day. The oil had already been drained from the transformer and I saw my colleague Eric standing there ready to start the inspection.

Eric came out sweating from the transformer. As I stood there, he would go back in and come out in intervals of 15 minutes. And I thought to myself, there should be better ways to do this.

This wasn't the first time I had seen that. I had seen inspections before and even took part in a couple of them with my previous employer. But for some reason that day, because of the circumstances and the hot conditions, I went back to the office and thought, we have to do this differently.

Internal inspections of transformers are difficult tasks in confined spaces, you need well trained people and complete compliance with required procedures to manage certain HSE (Health and Safety) risks.

Internal inspection of a transformer takes place in a confined space where you enter through a manhole, there is not much room inside and it is dark, with an oily smell and oily surfaces and with the oxygen content being monitored to make sure the atmosphere inside is breathable, with dry air typically pumped in.

And this is how the idea was born. I started searching online asking myself: Is there a rulebook on how to solve this problem? Is there a camera that we can send into transformers? I started digging, looking at pictures. The first thing I found was a submersible 360-degree camera, and I thought, maybe we can use this.

I started brainstorming, and this is one of the reasons why Hitachi ABB Power Grids is first class. The company has what is called The Innovation Database. So, I started sketching the idea of innovation because I knew we had to do

> The robot can dive and go deep into places a human cannot reach and send a very good image of what it sees. The spectrum of views can be observed and jointly analyzed by the designers of that very same transformer, as the inspection is happening, anywhere in the world.

this differently. We need to send a machine, not a human, inside the transformer. What would be the advantages of that? Obviously, we don't risk the health of an employee. Maybe, if we do it successfully, we could save time so the customer would benefit from having a much lower downtime.

I then took the idea of a submersible camera to a few very experienced colleagues, and they thought that customers and transformer owners would never allow a foreign object to be inserted into their five-million-dollar asset. You should forget about it, some said.

What was needed was a change of paradigm because there was no idea like it before. But one colleague from Switzerland had a vision and he said, Luiz, I think we have something here that is a paradigm changer!

Photo: Hitachi ABB Power Grids

He started discussing it internally and asked me how I was planning to do this. I said I had no idea; I am just a transformer guy! I am heavily involved with R&D working with algorithms and machine learning, but I don't know how we are going to do this. We then planned to bring the expertise we had in-house from our robotics team, who had nothing to do with transformers, but they were looking for internal projects they could apply their know-how to.

We brought them to the St. Louis factory in the US, presented my proposal and they said, Wonderful, let's do this together!

At this point I have to say, yes, I was the generator of the idea, but I had a huge support from our entire organization bringing together the transformer knowledge from the TRES group - now called Transformer Components and Services (TCS). Craig Stiegemeier, for example, was in that group and he was very supportive all the way, as was the robotics team.

Obviously, we needed the material support, but without the robotics team, this would just be a good idea stuffed in some drawer somewhere. They embraced the idea and put a lot of energy, people and money into it. Our two groups worked together for the first time ever. We created a steering committee that included a few people from the robotics team and a few from our team, myself and Craig Stiegemeier included.

The steering committee was there to make sure that the resources allocated to the project were properly distributed and that we had the right people for it, as we were on a journey to develop a technology. Yes, robot technology was available, but not for transformers. There was no robot that could navigate inside mineral oil and clearly see things that are designed by electrical and mechanical engineers.

It took us four years from the day I saw Eric at that substation to develop the first prototype that we started to test on real transformers.

AR The fact that ABB at the time allowed the persistence and spending of time, money, and human resources for four years to get there speaks volumes about the company's commitment to a new future.

If I were a customer with a five-million-dollar transformer that I was planning to shut down and open up, and spend thousands or even hundreds of thousands of dollars, bringing in all these people, what would you tell me after your four-year journey?

Don't do what you've been doing for a hundred years just because that is the way you have always done it.

Photo: Hitachi ABB Power Grids

> In the next decade I do not expect to see a single transformer being inspected in a conventional way because I believe that this technology is here to help people and companies to reduce and minimize risks and costs, and to optimize downtime.

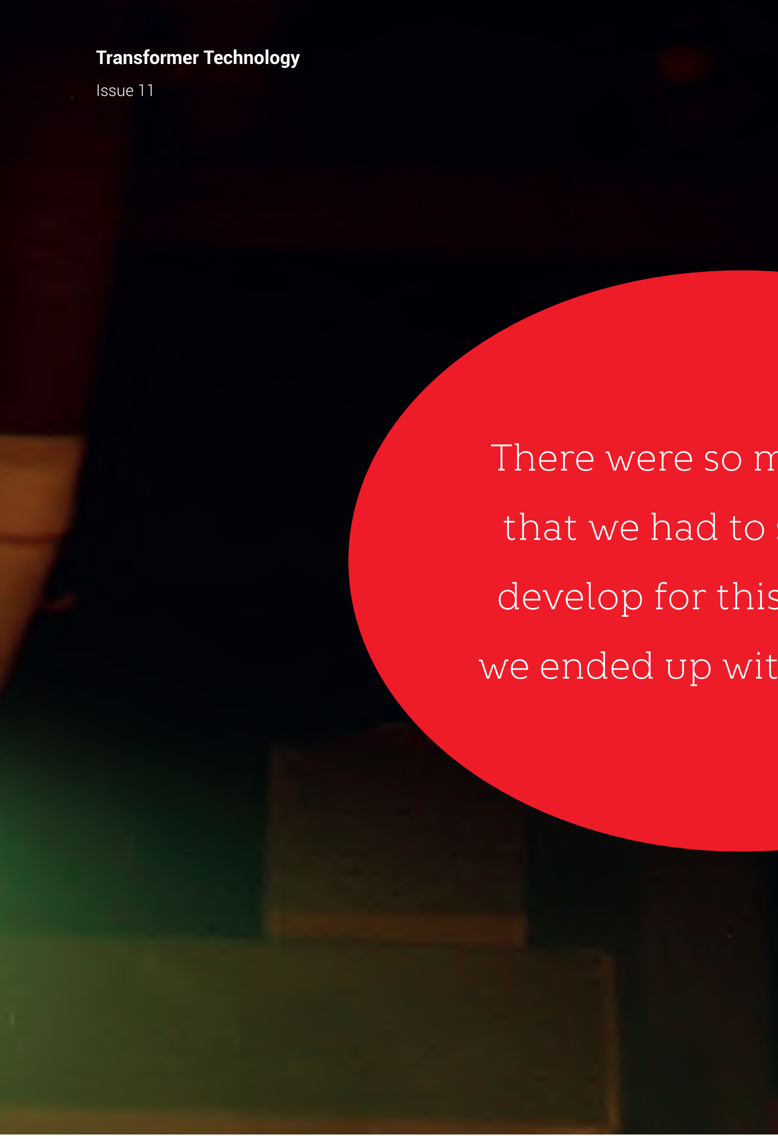
LC Don't do what you've been doing for a hundred years just because that is the way you have always done it. Always ask yourself: What is a better solution? This is almost academic. You don't need to send people to such an inhospitable environment for 15 minutes at a time. During the inspection, the expert also has to take nice pictures. He has to go in with a camera and take a good shot even if the lighting is poor. And these shots have to be of high quality so that people like you and me can clearly see if there is a problem or not. It takes a very skilled person to do that, which is what Eric was.

Obviously, the expert also needs to understand the transformer, the design, and what we are looking for. You also might need to get a permission from the planners or operators to disconnect the transformer. Then you have to count on a downtime of three to six days.

The number of variables and the costs can be huge. If you can do all this in a matter of hours instead of days, that makes good sense, doesn't it?

In the next decade I do not expect to see one single transformer being inspected in conventional ways because I do believe that this technology is here to help people and companies to reduce and minimize risks and costs, and to optimize downtime. You can do it properly and the robot can get to places that no human can.

The robot can dive and go deep into places a human cannot reach and send a very good image of what it sees. The spectrum of views can be observed and jointly analyzed by the designers of that very same transformer, as the inspection is happening, anywhere in the world. The robot is able to communicate all the images - which was one of the 15 patents of this project. The processing of images and the speed of communication between the robot and the outside were one of the difficulties we had to overcome.



> There were so many factors that we had to specifically develop for this robot, that we ended up with 15 patents.

AR What were other problems the team had to overcome?

LC There were a number of technical problems that took us a while to solve. We know that oil and gas companies around the world use robots for inspection and repair, but the transformer robot is going into mineral oil, not water. So, the material used to build the robot had to be compatible with oil to avoid any interaction with the oil that would create a chemical reaction. We had to search for ideal materials to utilize.

Another very important issue is that if anything happens to the robot, you need to be able to recover it. If, for example, there is a part of the robot that comes off, it will stay hidden somewhere inside the transformer. This part has to be easily recoverable, so the robot needs to be able to capture and contain its own parts if they become loose and fall off.

Another problem was navigation through the oil, which has to be highly controlled to avoid creating any bubbles in the transformer. The propellers on the robot cannot generate bubbles of any kind.

And, finally, high-quality vision. This was one of the most difficult issues as the oil can get really dark with age, so the robot needs special vision and special lighting.

There were so many factors that we had to specifically search for or develop for this robot, that we ended up with 15 patents. Everything we designed for navigation in mineral oil had to be new, created from scratch. One new idea generated many other ideas, which made the entire process particularly interesting.

AR Nowadays OEMs are trying to reduce the size of transformers, making it harder for operators to get inside for inspections. Once the robot was born, how did you get it to the market?

LC After the robot was developed it was down to our marketing people, the sales force and the strategic minds behind the organization to decide how to use it. The robot is used as a service offered by Hitachi ABB Power Grids, TXpert™ Services, part of the TXpert™ Ecosystem; it is not sold as a product. Several of our Transformer Service Centers now offer this Service across the world. We already have successful cases reported in Australia and other parts of the world.

AR Tell me a little bit about how it was used, what the problem was, and how using the TXplore™ solved that problem.

LC There are many cases, but this particular case in Australia was interesting because the transformer owner suspected that the load tap changer (LTC) had an issue due to the DGA (Dissolved Gas Analyzer) data, so they decided to do an inspection. We used the TXplore™ and it took some four to five hours to complete the entire process.

The robot found nothing and was able to provide very good pictures of all the accessible parts of the LTC. Since nothing was detected, the client just placed the transformer back in service. So, this was a positive case, where there was no need for further inspection.

AR An LTC inspection can be expensive. Also, we know that often when you try to do maintenance or inspections on something that doesn't have a problem, many times we create a problem. So, it is brilliant to be able to say, the unit is not broken, put it back into service.

LC When our two teams, the transformer services group and the robotics team, decided to work together, our service team operated as the customer who needed a solution. We gave them the constraints because we understood transformers, and they knew robotics.

For example, we told them that when the robot moves around, it can cause damage. If it touches the solid insulation, we don't want it to scratch the paper. So, ideally, the robot would be a sphere. And the first model actually was a ball. But then, if the robot is too big, it might not be able to navigate properly. So there were several steps in the development of the ideal prototype.

Once the prototype was completed, I was no longer involved in the product development, which was a very important phase as well. The robotics team completed the job of designing and manufacturing the product. They needed drawings, components, spare parts, whatever electronics was needed and a place for the robot to be built. So, the robotics team turned it into a real product which they supplied to us.

AR I was impressed with the ability of the light and camera function, regardless of the color of the oil. I applaud whoever figured out how to do that.

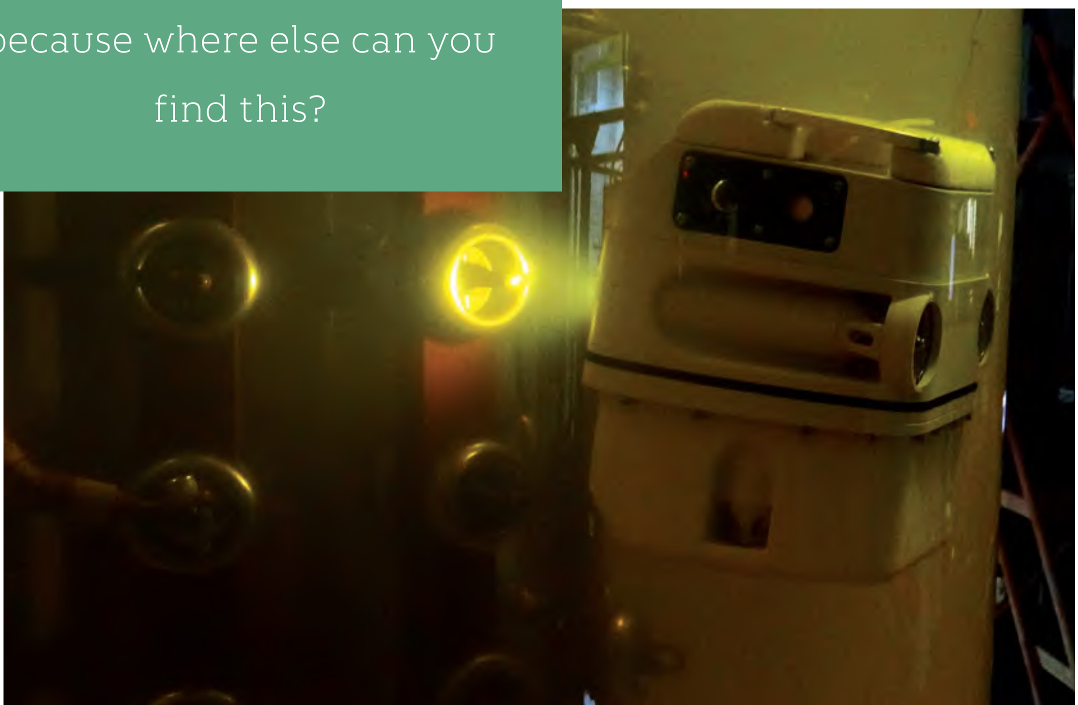
LC It's a special camera, yes. The quality of the images is impressive. Whoever has seen the robot in action, as you have seen it, they must admit it is impressive. I learned a lot from the robotics team, and they learned a lot from our business as well, in the process of working together for the first time.

This is why I am so grateful for a company like Hitachi ABB, because where else can you find this? You can have a brilliant idea, but if you don't have the resources, or you don't have the people, or the support; or even if you do, it is not so easy to make everyone work together if they are totally independent and different businesses as we were and still are.

AR Luiz, over your career you have made a commitment to the advancement of knowledge through IEEE, CIGRE and to the next generation, so on behalf of all of us at Transformer Technology, thank you. You have been a great guest. Thank you so much.

To find out more about TXplore™, visit the official webpage.

> You can have a brilliant idea, but if you don't have the resources, the people, or the support; or even if you do, it is not so easy to make everyone work together. This is why I am so grateful for a company like Hitachi ABB Power Grids, because where else can you find this?



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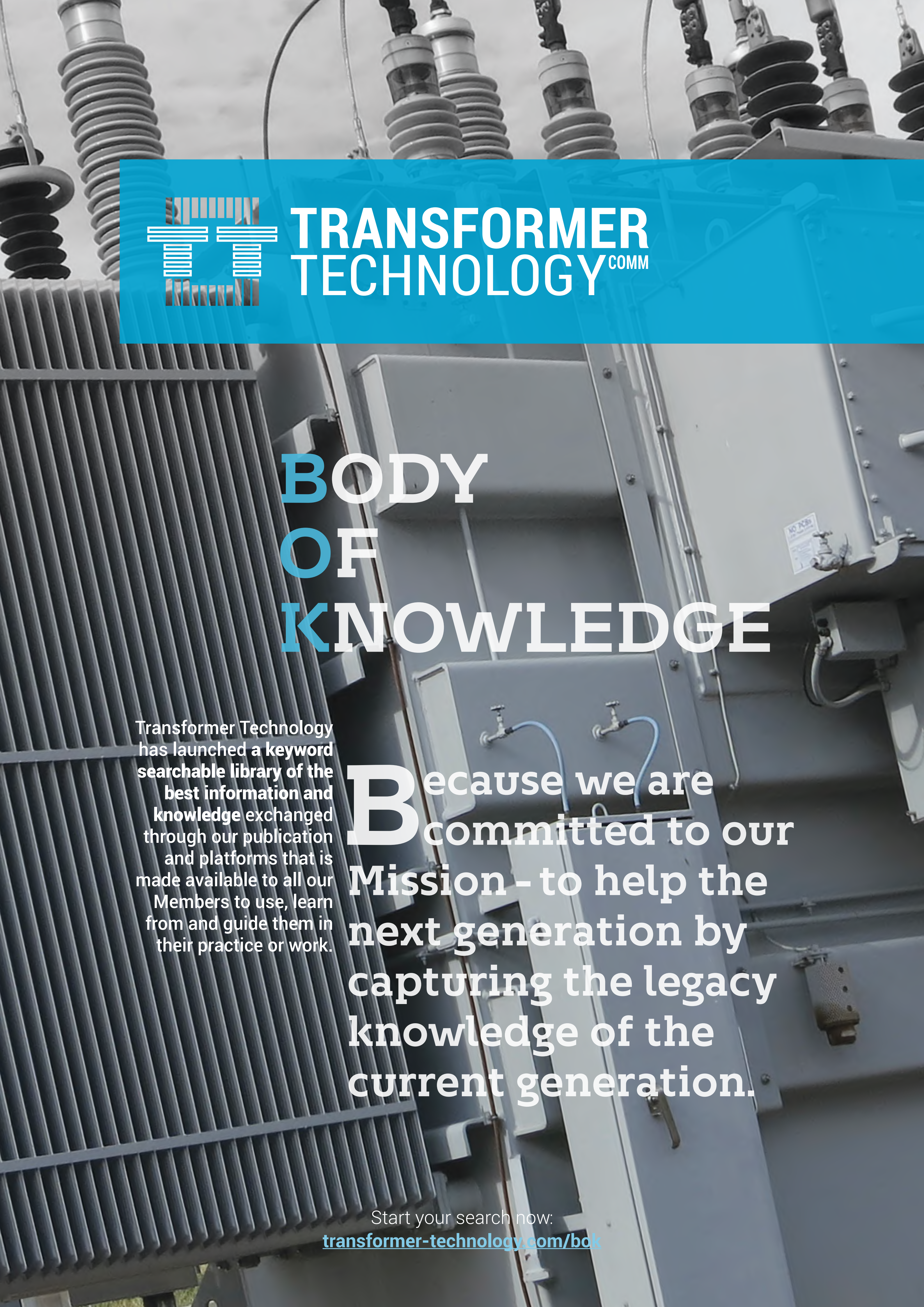
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A Critical Evaluation of Natural Esters for Application in Transformers

Due to the depletion of the mineral oil source and environmental impacts, the transformer industry has shifted its focus from petroleum-based mineral oil to natural and synthetic esters. Ester fluids have been present on the scene for quite some time now, and the environmental advantages and availability have the industry moving towards this avenue more strongly as time passes. The gradual move to the use of natural and synthetic esters is additionally supported by more data that is forthcoming from industry-based studies that are focused on using these fluids in electrical equipment.

This article will focus on environmental concerns, fire safety, physio-chemical properties, and thermal and dielectric performance of natural esters.

Finally, we will discuss the fundamental properties of natural esters and material compatibility related to electrical design.

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Due to the depletion of the mineral oil source and environmental impacts, the transformer industry has shifted its focus from petroleum-based mineral oil to natural esters and esters.

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 are part of the transformer system. Coupled with technical insight, her knowledge and experience help customers optimize their reliability maintenance and electrical asset lifetime.

Introduction

In a transformer, the liquid-cellulose system forms the main component of insulation. This system has a trifold role as the dielectric barrier, mechanical support and heat dissipation route. The insulating liquid is the backbone of the entire system, as this part will have a tremendous impact on the transformer's achieved lifetime [1]. The insulating fluid in a transformer has three functions — to electrically insulate the active parts, to transfer heat from the conductors to the radiators, and to provide a diagnostic medium which enables engineers to assess the equipment's health through regular monitoring and analytical means. Additionally, the insulating liquid is used for arc quenching (in tap changers, for instance) and as an acoustic dampener. Both arc quenching and acoustic dampening are essential for lifetime optimization.

One of the significant concerns related to the use of mineral oil is its flammability. A dramatic escalation of power demand over the past few years has led to overloaded electrical grids, resulting in failures, fires, and consequent oil spills, for which government regulatory agents are imposing stiff penalties due to their environmental impact. Mineral oils may have a toxic effect on the environment that will impact that area for many years to come. Having poor biodegradable properties, serious mineral oil spills can contaminate the soil and our waterways. Additionally, fire hazards are a real threat when using mineral oils, especially in densely populated areas.

As petroleum sources are depleting, the threat of shortages is becoming a reality. To ensure that ester fluids are used continuously and across many applications, we need to guarantee the reliability and safety of electrical equipment.

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Chemistry and the Emergence of Insulating Fluids

Natural esters are extracted from crops like soybean, sunflower, rapeseed (canola), flax, olive, poppy, etc.

International Standards

There is an increase in the use of natural esters in the transformer industry. They are currently used primarily in distribution and medium power transformers, in new units, and for retro-fill units. The first large power transformer of 420 kV voltage class was filled with natural ester fluid back in 2013, in the south of Germany, nearby Stuttgart. Currently, there are around 30-40 units in this voltage class that are already energized or in the process of production, including projects in Spain and Italy.

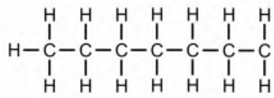
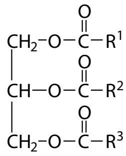
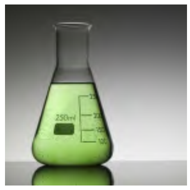
Properties	Standard	Mineral Oil	Natural Ester
Material used	-	Petroleum crude oil	Crops, sunflower, soyabean, etc.
Principle components	-	Complex mixture of hydrocarbons	Plant based natural ester
Chemical composition	-		
Visual examination	ASTM D 1524	Clear and light	Clear and light
Color	ASTM D 1500	Pale Yellow	Pale Green
Color	IEEE	0.5	</=1
Appearance of liquid			

Table 1. Basic properties of insulating liquids: mineral oil and natural ester [2-6]

Physio-chemical Properties

Acidity accelerates the oxidation process in mineral oil and in cellulose systems. In the presence of moisture, the acid can cause rust on the iron components in the transformer. The acids in mineral oil are mostly short-chain carboxylic acids that are formed during the degradation process of mineral oil. These acids are more aggressive, having an essential impact on paper lifetime.

Natural esters have a higher inherent acid content, but they are long-chain free fatty acids that are very mild for other materials and soluble in the natural ester. For instance, the formed acids include the well-known “omega-3”, which is used as a medicine for reducing cholesterol levels.

The interfacial tension (IFT) of a liquid is defined as the measure of the force required to break through an interface between water and oil, thus related to the molecular attraction/repulsion forces between them. Interfacial tension is a significant indicator of polar contaminants and oil decay products in mineral oil. New mineral oils generally have a relatively higher interfacial tension than new natural ester fluids. The lower variation of the IFT in natural esters does not affect the fluid performance, but it limits the use of IFT as an indicator of fluid degradation.

Fire Point and Flashpoint

The fire point and flashpoint are the measures of the resistance of the liquid to catching fire.

The flashpoint is defined as the lowest temperature at which the vapor pressure is sufficient to form an ignitable mixture with air near that liquid’s surface.

The fire point is the lowest temperature at which a liquid in an open container will attain a vapor pressure sufficient to continue to burn once ignited.

Mineral oil has a much lower flashpoint and fire point than ester fluids. A fire point of more than 300°C is required to classify a liquid as “less flammable”.

Up to date, no cases of transformer fires have been reported involving natural ester liquid.

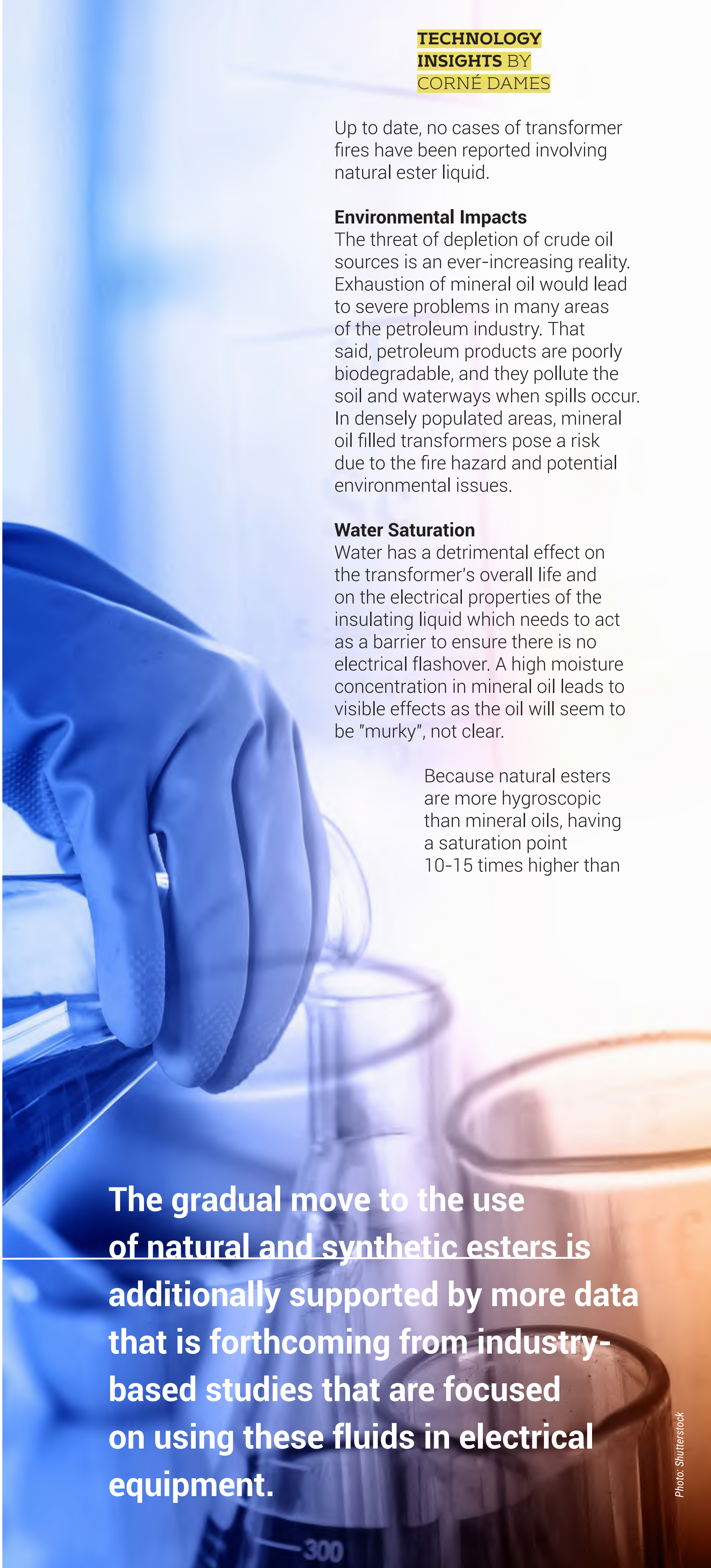
Environmental Impacts

The threat of depletion of crude oil sources is an ever-increasing reality. Exhaustion of mineral oil would lead to severe problems in many areas of the petroleum industry. That said, petroleum products are poorly biodegradable, and they pollute the soil and waterways when spills occur. In densely populated areas, mineral oil filled transformers pose a risk due to the fire hazard and potential environmental issues.

Water Saturation

Water has a detrimental effect on the transformer's overall life and on the electrical properties of the insulating liquid which needs to act as a barrier to ensure there is no electrical flashover. A high moisture concentration in mineral oil leads to visible effects as the oil will seem to be "murky", not clear.

Because natural esters are more hygroscopic than mineral oils, having a saturation point 10-15 times higher than



The gradual move to the use of natural and synthetic esters is additionally supported by more data that is forthcoming from industry-based studies that are focused on using these fluids in electrical equipment.

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Mineral Oil	Natural Ester
IEC 60296 - Edition 4 -2012-02, Fluids for Electrotechnical Applications – Unused Mineral Insulating Oils for Transformers and Switchgear	IEC 62770 - Edition 1.0 - 2013-11, Fluids for Electrotechnical Applications – Unused Natural Esters for Transformers and Similar Electrical Equipment
ASTM D3487-09 – Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus	ASTM D6871-17, Standard Specification for Natural (Vegetable Oil) Ester Fluids Used in Electrical Apparatus
IEEE STD C57.106-2006, IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment	IEEE STD C57.147-2008, IEEE Guide for the Acceptance and Maintenance of Natural Ester Fluids in Transformers

Table 2. List of available international standards on different insulating oils [4, 5, 7, 8, 9, 10]

that of mineral oil, we cannot apply the same moisture content limits. Even with significant amounts of moisture, the ester fluid can still retain its dielectric properties. It should be noted that the effect of water content on dielectric strength as a function of percent of saturation is the same for mineral oil and natural ester fluids [11, 12].

Oxidation Stability

An insulating liquid is prone to oxidation due to the presence of carbon-carbon double bonds. In natural esters, there is a higher concentration of carbon-carbon double bonds in each molecule. Therefore, natural esters are more prone to oxidation than mineral oils. This oxidation process is irreversible but inhibited by the use of antioxidants in the product formulation. In this process, oxygen will be consumed and incorporated into the product of the chemical reaction. When natural esters are continually exposed to oxygen, complex molecules will be formed, increasing their viscosity. This can also lead to oxygen formation containing byproducts such as alcohols, aldehydes, ketones and acids. Therefore, it is vitally important to minimize oxygen exposure during the manufacturing process and while the liquid is used in a transformer. Using sealed units will prevent exposure to oxygen. A diaphragm barrier is required for large transformers with conservators between the internal and external venting or a nitrogen headspace barrier.

Density

The relative density is stipulated as the ratio of the weights of equal volumes of liquid and water at 15°C. Mineral oil (<0.91 g/ml at 15°C) has a lower relative density than natural esters (<0.92 g/ml at 25°C) as per the IEEE standard method.

Pour Point

The pour point of standard mineral oil is typically lower than -40°C, while the pour point of natural esters is in the range of -15°C to -25°C.

Dissolved Gas Analysis (DGA) and Stray Gassing

Stray gassing is defined as the formation of gases when insulating oils are heated at relatively low temperatures (90-200°C) [13].
A substantial quantity of stray gasses, like hydrogen and ethane, is observed in natural ester for some time after energizing a transformer, which can last for months. The susceptibility to stray gassing can differ from batch to batch [14].

Natural esters have a lower gas generation in partial discharge phenomena (hydrogen and methane formation with traces of acetylene) than mineral oil at the same voltage level.

Effect of Concentrated Heat Flux

The insulating fluid is heated to ensure an increased impregnation rate of the cellulose insulation. The insulating liquid is prepared in the heat exchanger chamber of the filtration unit. Excessive heat flux harms the dielectric dissipation factor. Natural ester has a higher thermal limit than mineral oil to initiate phase change. Due to their higher viscosity, ester fluids will remain in contact with the heating element for a more extended period than mineral oil. This means that the maximum allowable watt density for exposure is lower for natural esters. A solution to this would be to limit the maximum watt density or heat flux density, or to avoid immersion heaters instead of turning to plate-to-plate heat exchangers to increase the heating surface and reduce the concentrated heat flux.

Change in Fluid Properties

The application of natural ester fluids is monitored in a wide application range in order to track the changes in the fluid properties under actual service conditions. These results compare well with those found in the accelerated aging experiments done under laboratory conditions. Natural ester exhibits changes during the aging process similar to those seen in mineral oil.

As the natural ester ages, the dissipation factor as well as the acid value will increase, while the interfacial tension and resistivity will decrease [15].

Conclusion

Natural ester has been available for decades. In the transformer industry, it has been established that natural ester is safely applied in distribution transformers and other transformer applications. More than 10,000 distribution transformers using vegetable ester fluids ranging from 10 kVA to 10 MVA are currently in service. As we gain more practical data and case studies from the industry, this fluid application will be used more widely.

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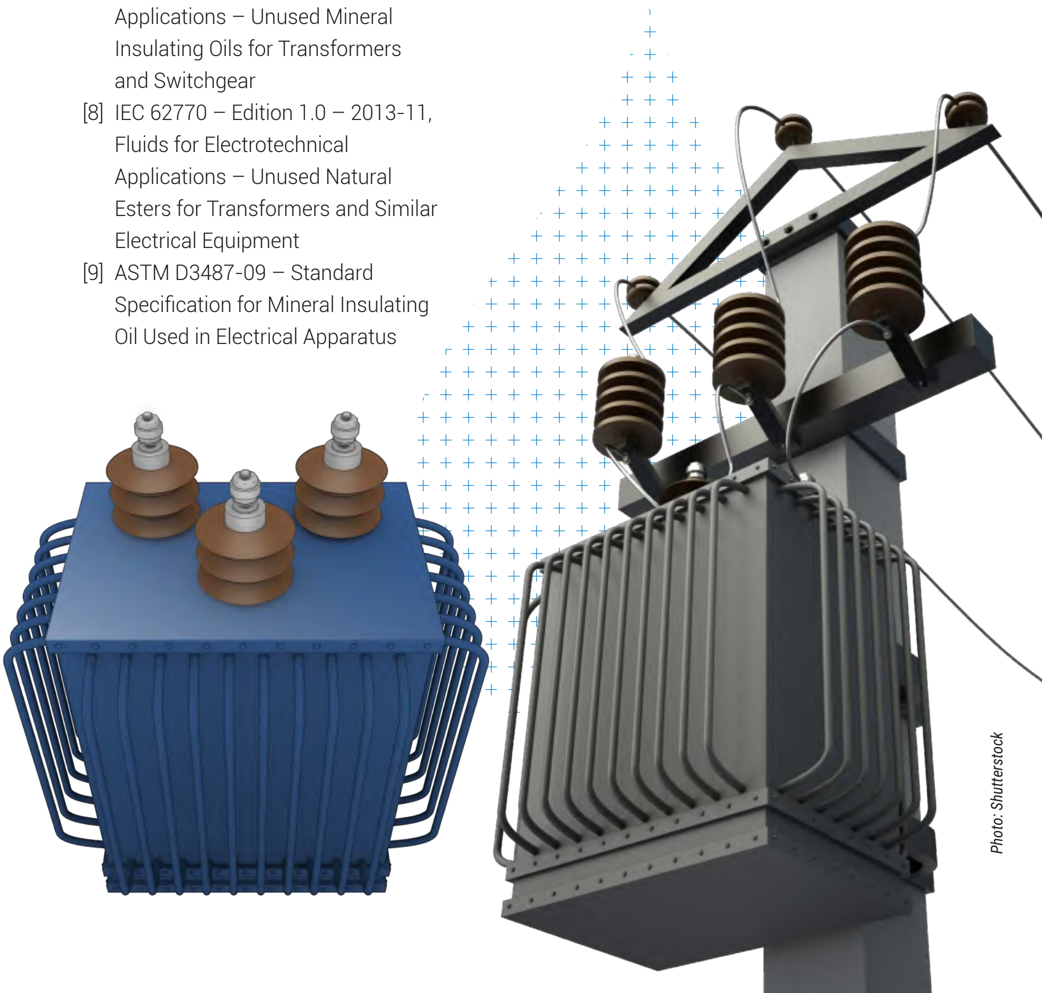

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NEW OPTIONS FOR INSULATION SYSTEMS IN POWER TRANSFORMERS

by **Radoslaw Szewczyk** and **Jean-Claude Duart**

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Dr. **Jean-Claude Duart** has been employed at DuPont de Nemours in Switzerland since 1995. He currently works as Business Development Leader for the Nomex® Electrical Infrastructure segment, in charge of technical development in the area of power and distribution transformers. Dr. Duart received his PhD in Electrical Engineering from the University of Toulouse in France while working as R&D Engineer for Jeumont Schneider Transformers from 1990 until 1994. Dr Duart has published several international papers in both electrical insulation field as well as electrical arc ash protection. He is part of IEC TC112 and TC10.

Introduction

The development of new insulation materials has been critical in the evolution of the design of power transformers. **Insulation systems for liquid filled power transformers are a combination of materials that are aimed to provide the required electrical, mechanical, thermal properties together with a full chemical compatibility for successful operation of the transformer for several decades under defined operation conditions.**

Materials enabling innovative power transformer solutions

The offering of solid materials like papers or pressboards as well as dielectric fluids has been in constant evolution in the 20th century as the use of transformers was expanding through the development of electrical networks around the world. As the timeline in Figure 1 shows, several materials have played important role in the design of the transformers over the past century.

Insulation systems for liquid filled power transformers are a combination of materials that are aimed to provide the required electrical, mechanical, thermal properties together with a full chemical compatibility for successful operation of the transformer for several decades under defined operation conditions.

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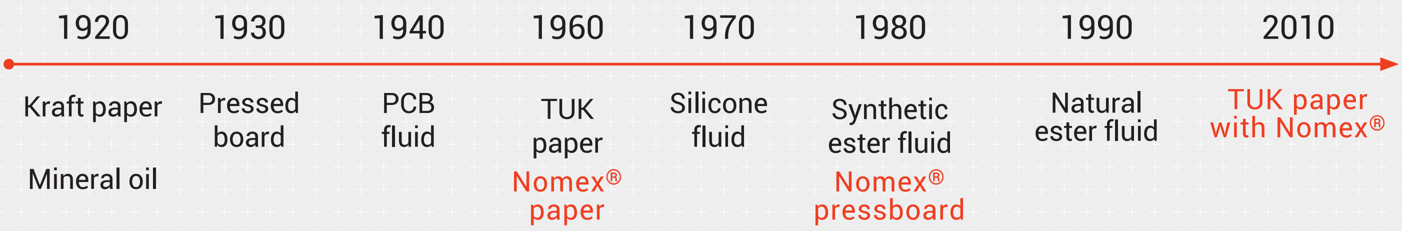
While the first half of the 20th century has seen the development and combination of cellulose based materials for the solid insulation [1] and mineral oil for the fluid, the second half of the century has seen the arrival of new materials based on synthetic polymers.

Figure 1.
Timeline of main insulation materials for liquid filled power transformers



The options offered by the combination of various insulation materials allow more flexibility for the designers to develop transformers that will be able to operate in environments where new constraints have been evolving, whether they are related to space and weight restriction, loading profiles or ambient temperatures.

With the introduction of high-quality cellulose pulp, the production of cellulose paper with improved performance has seen tremendous progress initiated in the late 1920s making it the main choice of insulation combined with mineral oil. Another step was the introduction of thermally upgraded Kraft (TUK) papers in the 1960s. Already at that time the aim was to improve the thermal stability of the paper insulation, a limiting element when transformers have to overcome challenging load profiles or need to meet more stringent size and weight constraints.

About the same time, and in line with the interest of the chemical industry for developing products that featured advance characteristics, a 100% synthetic paper was developed based on the known polyamide polymer, most known under the name of nylon. Here again, in order to overcome the thermal limitation of the nylon, the polymer was modified to integrate aromatic rings that would provide improved thermal performance (Figure 2). The DuPont™ Nomex® paper, an aromatic polyamide, also called aramid, was born. With its thermal class of 220 in the air it was initially used in insulation systems for dry type transformers and rotating machines. It took less than 10 years for the electrical industry producing oil filled transformers to consider it as an insulation for the conductors. An advantage was taken of its significant thermal capabilities combined with excellent electrical and mechanical characteristics, although applicable temperatures had to be reduced due to limited thermal capability of dielectric liquids.

In the area of insulating papers, no other comparable technical steps were achieved in the 20th century and it was only in the beginning of the 21st century when another paper combining the benefits of thermally upgraded cellulose ingredients and aramid was developed. A new generation of thermally upgraded paper was introduced, taking advantage of DuPont™ Nomex® to reach an improved thermal stability compared to regular thermally upgraded Kraft paper (Figure 3).

Figure 2.
DuPont™ Nomex® meta-aramid, poly(meta-phenyleneisophthalamide)

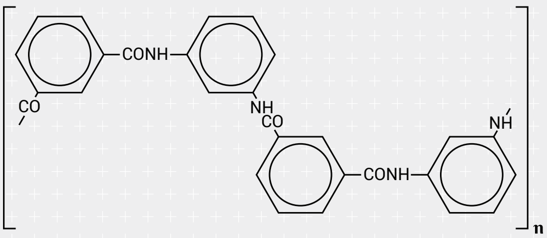
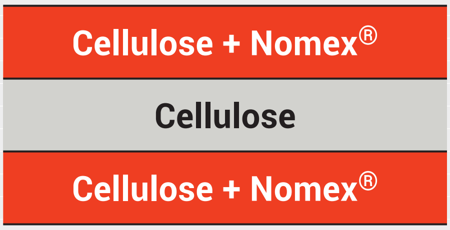


Figure 3.
DuPont™ Nomex® 910 structure



In parallel to the paper evolution the insulating fluids have also seen major developments in the 20th century. First, fluids like PolyChlorinated Biphenyl's (known as PCB) introduced in the 1940s as dielectric coolant and then replaced by silicon oil in the 1970s as they were found harmful to people's health. Then, the upraise of ester fluids, synthetic in the 1980s and then natural in the mid-1990s. It has been a constant search for solutions that could provide additional benefits like fire resistance or, more recently, biodegradability. However, still today mineral oils remain the main insulating fluid for liquid immersed power transformers.

It is also important to indicate that another major material was critical to the development of advanced insulation systems, particularly with the increase of operating voltages that power grids have seen. Almost 100 years ago Kraft pressboard was invented allowing for development of insulating components that would become critical in high and extra high voltage transformers. About 50 years later another pressboard type important for the development of advanced insulation system for power transformer was invented: the aramid pressboard. The DuPont™ Nomex® pressboard followed a similar principle as Kraft pressboard, i.e. combining specific known ingredients dedicated to electrical applications and a manufacturing process involving press capabilities that still remain unique today. This aramid pressboard also offers improved thermal capabilities as compared to the Kraft pressboard.

While these materials development may not describe the only changes than occurred over the last 100 years in insulation materials for liquid filled transformers, they indicate important categories that are used in transformers today to meet the evolving constraints to which transformers are exposed.

Developments in insulation systems

In recent years it could be seen that transformer designs have evolved to not only reduce the size and weight of units, but also improve their operating flexibility. Many modern design techniques or available state-of-the-art technical solutions drive designs to be smaller and more optimal. However, the use of aramid-based materials allows a step change in the ability to make designs significantly more compact, when compared to "conventional" designs that are based on cellulose insulation and mineral oil. These transformers may also benefit from longer lifetime as the new insulation systems are more thermally robust. They also offer more resistance to overload conditions that may result from planned maintenance periods or unplanned demands due to summer heat waves or other operational circumstances.

Industry standards, both IEC and IEEE, define such insulation systems available for use in power transformers. The standards define typical constructions and provide guidance on how the "high temperature insulation materials" shall be used. For example, Tables 1 and 2 present the temperature limits according to IEC 60076-14 [2]. Similar guidance can be found in IEEE Std. C57.154 [3].

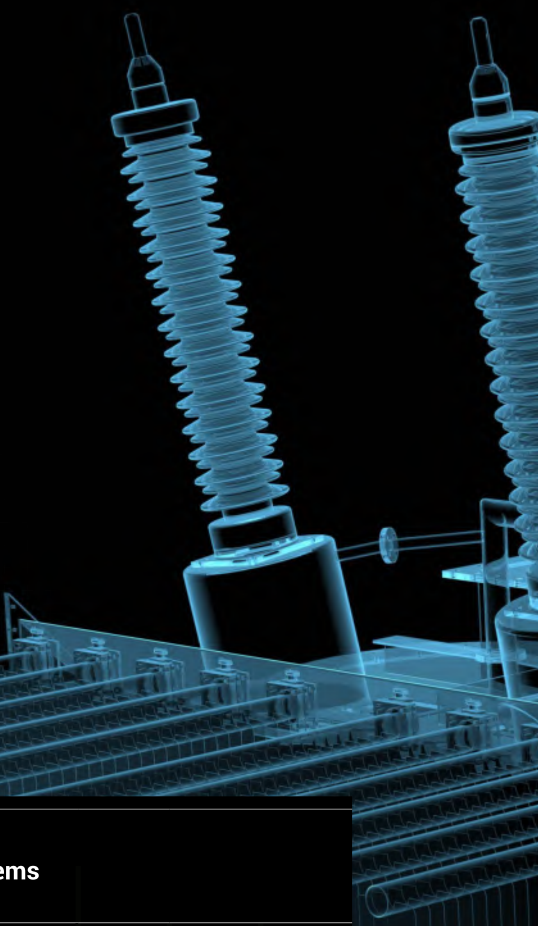
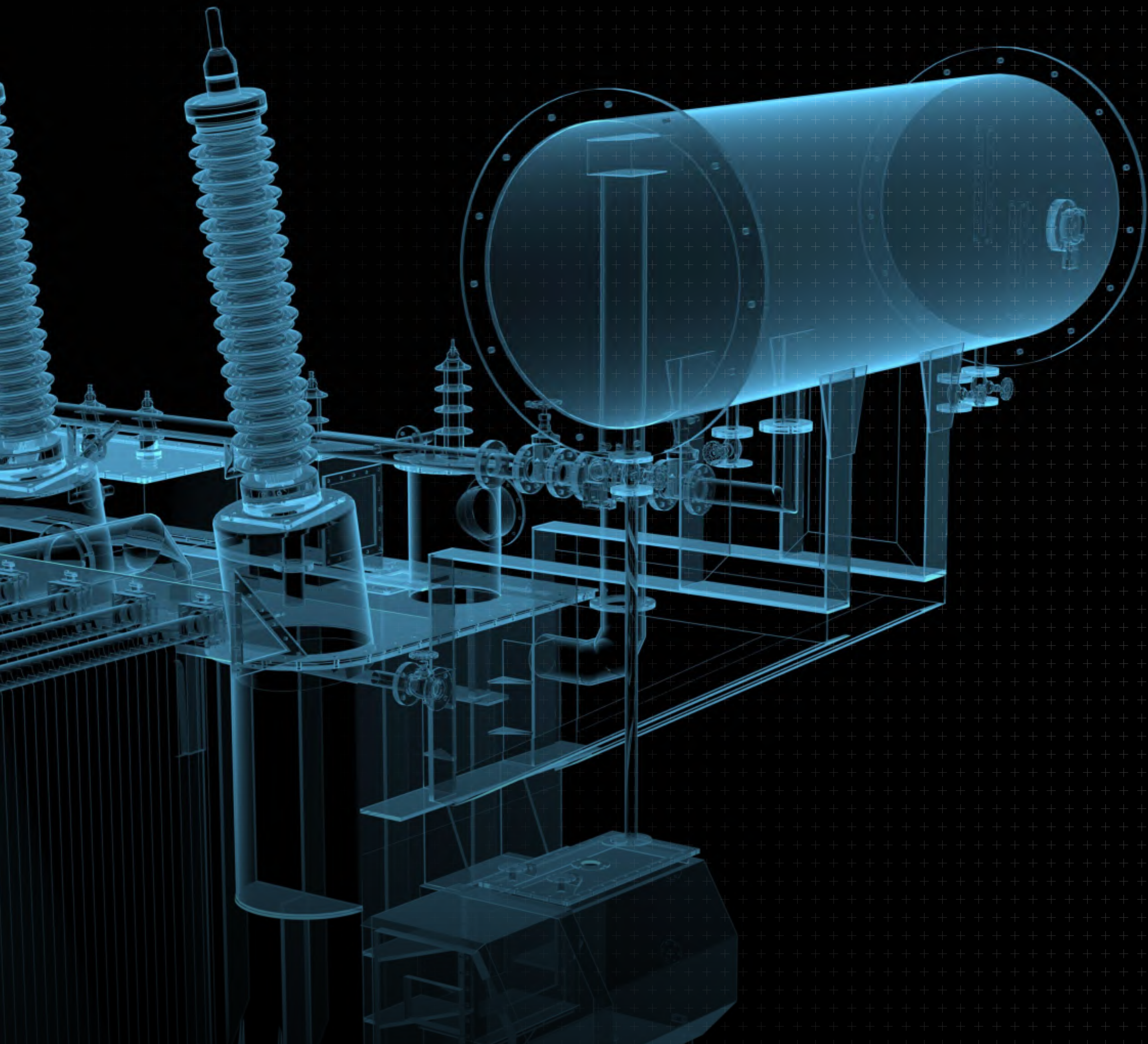


Table 1.
Hybrid insulation windings - thermal limits as per IEC 60076-14 [2]

		Hybrid insulation systems				
	Conventional insulation system	Semi-hybrid insulation winding	Mixed hybrid insulation winding	Full hybrid insulation winding		
Minimum required solid high-temperature insulation thermal class	105	120	130	130	140	155
Top liquid temperature rise (K)	60	60	60	60	60	60
Average winding temperature rise (K)	65	75	65	85	95	105
Hot-spot temperature rise for solid insulation (K)	78	90	100	100	110	125

Table 2.
High-temperature insulation windings with ester liquids - thermal limits as per IEC 60076-14 [2]

Minimum required high-temperature solid insulation thermal class	**130**	**140**	**155**	**180**
Top liquid temperature rise (K)	90	90	90	90
Average winding temperature rise (K)	85	95	105	125
Hot-spot temperature rise (K)	100	110	125	150



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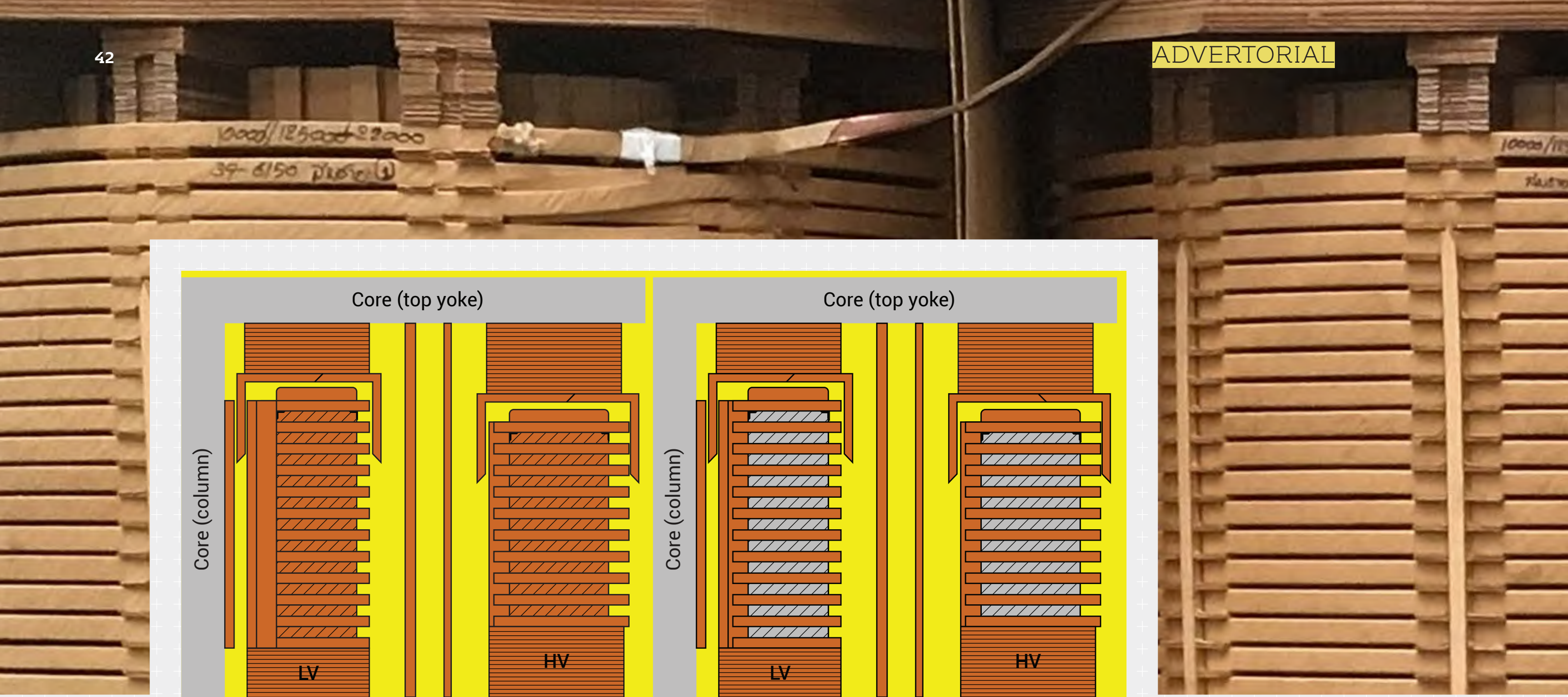
Materials remain one of the critical elements to allow for the transformer designs to continue their evolution to meet end-user requirements.

An example illustration of insulation systems is shown in Figure 4. While few decades ago the Kraft insulation in mineral oil system was vastly used in liquid immersed power transformers (Figure 4a), we have seen over the last five decades the arrival of different insulation systems. One recently developed system consists of the thermally upgraded Kraft paper enhanced with Nomex® on the conductors (referred to as Nomex® 910 paper) combined with cellulose pressboard components and mineral oil (Figure 4b). This system gives the benefit of longer insulation system lifetime when used at conventional operating temperature but also help mitigating a load increase that can be due to planned demand or due to climatic events, generally unplanned.

Another system that has recently emerged is a hybrid system where aramid materials are used for conductor insulation, spacers and strips, while other materials remain in cellulose pressboard. Recently, these systems are combined with ester fluids (Figure 4c). This system is a response to increasing fire and environmental constraints that power utilities can see, e.g. in large cities [4]. Historically the solid materials of this system have been associated to mineral oil since the 1980s in applications for mobile transformers.



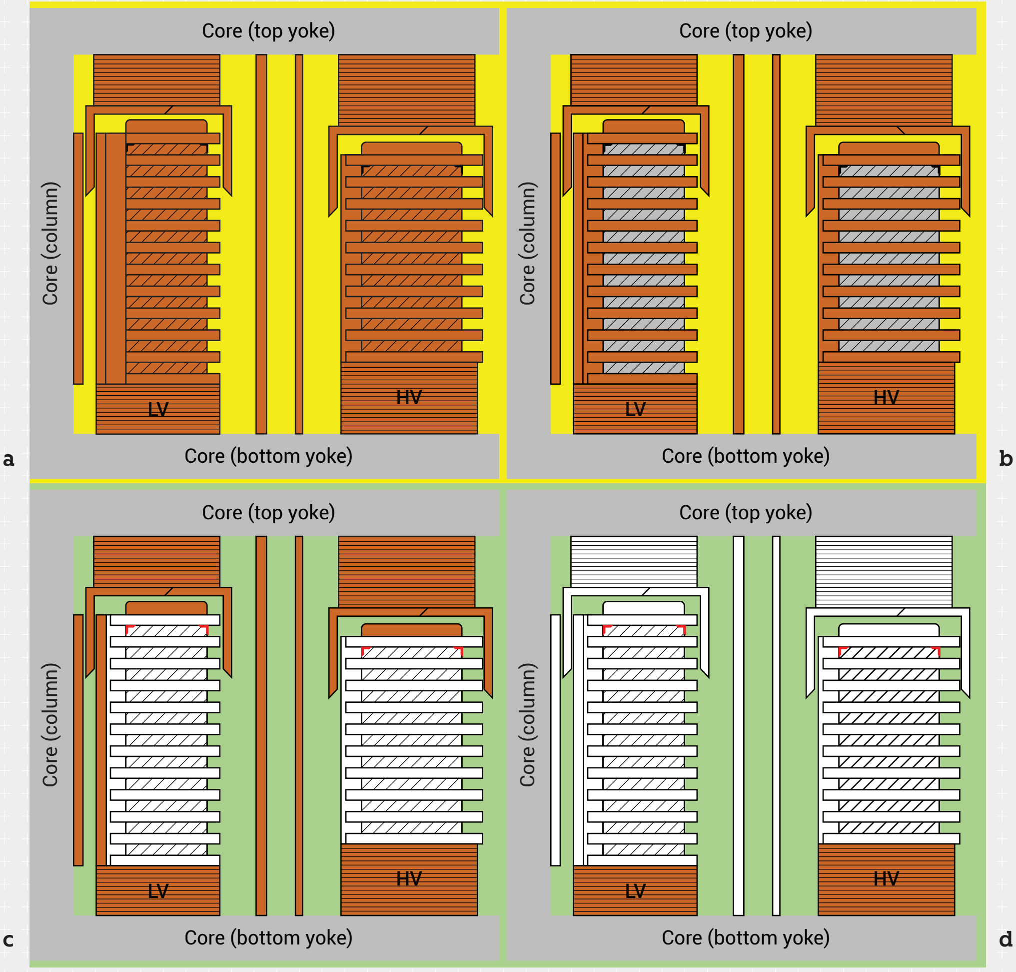


Figure 4.
Example illustration of various insulation systems for power transformers:
a - Kraft with mineral oil (conventional)
b - semi-hybrid with Nomex® 910 conductor insulation
c - hybrid system with ester fluid
d - high temperature system with ester fluid

Recently, an increasing number of developments focus on the use of ester liquids, due to their fire safety and environmental advantages. The thermal capability of ester liquids would allow using them at higher temperatures (although the test methods for more precise evaluation of thermal capabilities of ester liquids are only under development). Then, transformer designs can shift from hybrid systems (Table 1) towards more advanced high temperature insulation systems (Table 2). These systems will require more extensive use of high temperature materials in the transformer construction as illustrated in Figure 4d. The combination of aramid insulation and ester liquids has already been used for many years in smaller transformers, e.g. on-board traction units for rolling stock and compact wind turbine step-up transformers. Nevertheless, the research is continuing for better characterization of these systems and proving their high performance.

New aramid-based insulation parts

Plans for more extensive use of aramid insulation in power transformer high voltage insulation systems drives new developments for innovative insulation parts. One example is the development of formed 3-dimensional end insulation components, such as angle rings, lead exit snouts, and edge protectors. For some of these components there is a need to use a wet formable aramid board.

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The development focused first on identifying the grade of wet aramid material most suitable for forming the required 3D shapes of typical insulation parts. Then, the materials were evaluated for the two typical processes of forming:

- machine forming for more regular angle ring sectors (caps and collars),
- hand molding for more complex combined shapes, e.g. winding exit snouts.

Process optimization led to development of parts that matched the benchmark mechanical and dielectric performance of conventional cellulose based components.

The development of new insulation components also included laminated aramid board for producing thick insulation blocks, e.g. for clamping rings and associated structures. Steps have been made for producing larger sheets of high-density aramid pressboard. Comprehensive studies were performed for adequate glue selection and the process for laminating such boards, and proper characterization of critical properties. The testing included mechanical, dielectric and thermal properties. The dielectric test confirmed the partial discharge inception in the laminated board not happening below the required threshold of 9 kV/mm (Figure 5). This included tests on the laminated board samples aged in synthetic ester at the temperatures up to 155°C. Another test program analyzed dielectric strength and the partial discharge behavior of the laminated board when dielectrically tested at elevated temperatures up to 120°C.

Figure 5.
Test arrangement for partial discharge measurement on laminated aramid board after aging in synthetic ester (photo: DuPont/Siemens Energy)

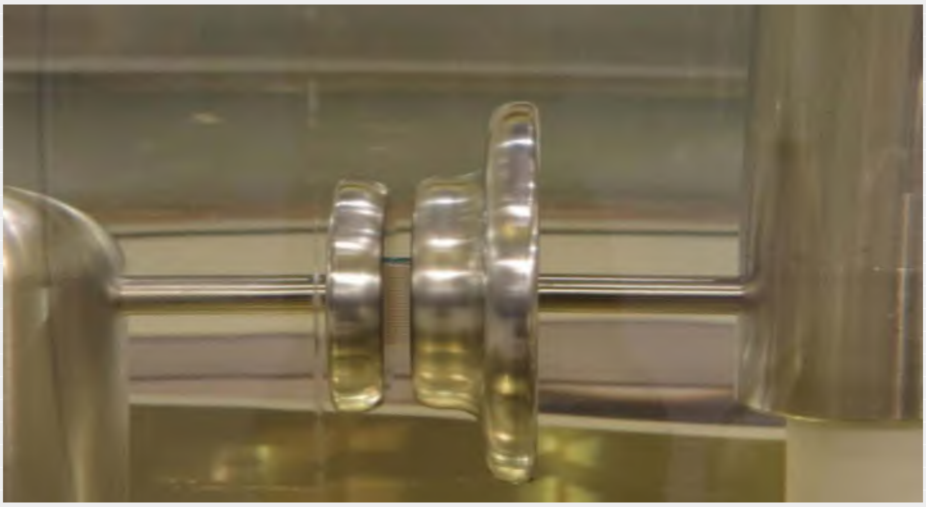

Figure 6.
Example of insulation kit with winding cylinder shaped from high-density aramid pressboard Nomex® 994 PSB (Photo: DuPont™)

Aging in hot synthetic ester liquid was part of the research to ensure the appropriate long-term performance of the laminated material in service. Compatibility with the selected synthetic ester liquid was confirmed.

Additionally, the development was made for large winding cylinders. For producing them, two aramid pressboard options have been evaluated:

- high-density aramid pressboard - in large sheets like those used for the laminated board, or
- lower density aramid pressboard - available in even larger sheets and more flexible but requiring more attention in the processing due to the air humidity impact on dimensional stability.

Figure 6 shows assembly of various insulation components mentioned previously in an innovative insulation kit for advanced power transformers.

Photo: Shutterstock

Summary

The options offered by the combination of various insulation materials allow more flexibility for the designers to develop transformers that will be able to operate in environments where new constraints have been evolving, whether they are related to space and weight restriction, loading profiles or ambient temperatures. Materials remain one of the critical elements to allow for the transformer designs to continue their evolution to meet end-user requirements.

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Khayakazi

Interview with **Khayakazi Dioka**

Corporate Specialist – Transformers and Reactors at **Eskom Holdings SOC**

“In our fleet, we have over 600 transmission transformers, more than 5,000 distribution transformers and over 400,000 units of pole-mounted transformers.

Dioka

Photo: Eskom

Transformer Technology hosted Khayakazi Dioka, Corporate Specialist – Transformers and Reactors at South Africa's electricity utility Eskom Holdings SOC, on a recent TechTalk anchored by Alan Ross, Editor in Chief. This interview is an edited excerpt from that.

Alan Ross: My guest, Khayakazi Dioki, is with Eskom, a company in charge of the transformer fleet for the national transmission and distribution grid in South Africa. As Eskom's Corporate Specialist – Transformers and Reactors, she is responsible for more transformers than any woman that I know.

Congratulations on that Khaya and welcome! It's great to have you.

Khayakazi Dioka: Thank you so much, Alan. It's a pleasure and honor to be interviewed by you.

AR People need to know that when you and I first met, the teddy bears were behind you and I couldn't let go without asking about that. While you are a smart professional female engineer who has tremendous responsibility for transformers, and are heavily involved in CIGRE, the teddy bears are also part of another role that you play as the mother of two daughters. Tell us a little bit about your daughters.

KD Thank you, Alan. I have two daughters and I think they are very brilliant young ladies. They take after the mother; the father agrees.

One is almost twelve now and the other turned eight. They want to do a lot of things, but engineering is not one of them. I took them to work one time when we were doing design reviews and one of my colleagues gave them a calculation to do. We wanted to calculate the stress between the windings. My daughter got the distance correct, and then she said, "I want to be a transformer!" I think she was five.

AR When I told my two sons when I first got involved with transformers some twenty years ago, the youngest one said, "Dad, I love transformers. I mean, Optimus Prime and all that!" When he learnt it wasn't that kind of transformers, he lost interest and became a movie producer.

Let's talk a little bit about your role at both Eskom and CIGRE. At Eskom, you have an enormous number of transformers that are your responsibility, both power and distribution transformers. Obviously, you have a team of people that support you, but how do you go about managing such an incredibly large fleet of transformers?

KD It's quite an interesting task. It is one of the things that make me stay in this field because I am not doing the same thing every day. I'm in the engineering environment, so we own the technology. We look after all these transformers, from specification to finding the transformer, ensuring that whatever we purchase as the organization is according to the need of our network. So, the specification is where it all begins.

We also specify according to the climate and the South African need – not just the need of the network, but also the environment that we are in as these transformers could be procured from anywhere in the country and they are of different sizes. We have power transformers ranging from 10 MVA, or even 2.5 MVA, to as high as 800 MVA. You can really appreciate the fleet size and the ranges that we have.

This also makes the fleet lifecycle management a little bit different because the specification needs to define what we need for all ranges, from the small power transformers to large power transformers. An example are the requirements for condition monitoring, where the implementation of some condition monitoring devices would not be cost-effective for smaller transformers.

Another interesting aspect of this role is that one minute there is a transformer that has failed and we are involved in failure investigations, which requires a different approach. If the incident requires severe investigation and a specialist, this is when we get involved. It is this kind of feedback that we use to monitor the transformer throughout its lifecycle. We can take that information and feed it back into the revision of the specification if there is a need for that.

This is one of the advantages that we have, we get to see the whole lifespan of the transformer, i.e what causes the transformer to fail, if that is in any way linked to the design, how it was specified some 10 or 15 years ago. This then helps in making improvements in the specification and ensures the reliability of the transformers procured going forward. Sometimes this involves the introduction of new technologies.

In our transmission network fleet, we have over 600 power transformers and over 100 reactors. Over and above that, we have over 5,000 power transformers in the distribution network, ranging from 1.25 MVA all the way to 160 MVA. We also have pole-mounted and ground-mounted transformers, which are known as distribution transformers. That fleet alone is over 400,000 units.

We are responsible for the specification of those transformers as well, selecting the suppliers and ensuring that the designs are in accordance with our requirements. We conduct design reviews and perform all factory acceptance tests. But the actual asset management and the maintenance of the operation belongs to the field staff and their management.

AR The scope of what you do is as broad as anything here in North America. You mentioned the difference between the things you would do to monitor and do the diagnostics on an 800 MVA unit as opposed to what you would do on a 4.5 MVA unit. Obviously, there is a growth of monitoring and that's something that is happening in South Africa and the Eskom network. But you will not use a monitor that costs $10,000 or $20,000 on a pole-mounted transformer, which, if it fails, it fails. So, from a reliability perspective, it is about an asset operating as it was designed to operate for as long as it was designed for, which means lifecycle costeffectiveness is critical.

Most transformers in North America are way beyond their expected reliable life. I imagine that you have some over 50 year old transformers and some brand new ones in your fleet as well. How do you go about deciding a monitoring program, a program

Photo: Eskom

as opposed to monitoring, for an individual transformer? Does age matter? What conditions do you take into account when you start looking at getting data from a transformer?

KD Monitoring for us is more related to the size of the transformer. What we use is what we call the Asset Health Appraisal (AHA). In the AHA, we know the condition of each and every transformer, and this is updated every two to three years. The input from the report gives us an indication of which transformers are healthy and which need attention. That attention could mean replacement, immediate maintenance or any repair work that needs to be done.

Based on the AHA report, we have recommendations for replacement and critical transformers are put on a replacement project. Our projects department then starts the procurement process for the transformers set for replacement. The rest of the transformers are categorized according to the maintenance that is required. For instance, for a transformer that is in a bad condition, but that condition resulted from gassing of the transformer, we know that this indicates that the unit has a developing fault. And from there, that can be rectified. We investigate the developing fault, rectify it, and the transformer is back in service. This is generally how we categorize the transformers or how we prioritize replacement. We do not replace according to age; we replace according to condition, because then the condition will determine whether the transformer needs replacement or not.

AR This is brilliant because there are too many places where we see transformers being replaced because of age. They are actually replacing transformers that are good, but just old, and they are not replacing much newer ones that are not as good.

It must also be an enormous task to continuously get the data and update it. For example, DGA can happen instantaneously, it does not happen over two to three years unless the unit is overheating. You must have a very robust asset health program. Is that something that you have developed at Eskom or you use outside vendors? How do you manage that vast amount of data that is coming in?

KD Within Eskom we have a database for our maintenance activities.

When it comes to DGA, there are two ways we deal with that. Some of our transformers are fitted with online gas monitors and as soon as the gas value goes up, a message is sent to the asset owner indicating that there is something going on with the transformer, so an immediate action can be taken. But historically, we have


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been doing manual oil sampling for all our larger transmission transformers every six months. This information is then stored in our database, at our research laboratory.

All of that data, for each transformer that has been sampled, is readily available and I can access it from my computer. The data is then recorded in our AHA program that I mentioned, where we feed all extracted data, and this information gives us the trending data.

I think this is key to DGA - trending the data to see whether a failure is developing on a given unit.

Also, every two years we do life assessment for each transformer, looking at paper insulation. This is all recorded in the same database where we have records on every transformer at Eskom. So, by monitoring insulation, we can calculate the asset health, check the status, and determine whether it is in good or bad condition. The insulation, which is what the life expectancy of your transformer depends on, carries more weight than the rest of the data.

When we detect a transformer has a DP (degree of polarization) value of around 200, for example, meaning it is nearing the end of its life, do we replace it immediately? No! If everything else is fine with that transformer, it basically becomes a critical unit that is awaiting replacement. We don't switch it out. If there is any work that needs to be done on that transformer, you don't want to switch it on and off and drain oil from it because you might not be able to get that insulation back. So, you handle the unit with care while it is in service. In most cases when there is no human intervention those transformers can still stay in service for a little longer.

We then look at major components such as bushing and tap changers. We then need to zoom into the condition of these components to ensure that their condition is also good. An example of an unfortunate case is when a very healthy transformer suddenly fails due to a bushing failure. Unfortunately, the old technology of bushings, oil-impregnated bushings, has resulted in many transformers catching fire. This is very heartbreaking, to see a transformer that is healthy suddenly fail due to a component that could have been replaced cost-effectively.

AR Khaya, it has been a delight talking to you. You are a wealth of knowledge, and that knowledge is something that we want to share with our community and our marketplace, so thank you very much.

Khayakazi Dioka: Thank you very much for having me.

Photo: Eskom


Eskom
KHAYAKAZI DIOKA

Photos: Micafluid AG

21 ADVANTAGES OF USING MICAFLUID TECHNOLOGY IN 2021

Driven by Swiss technology since 1913 to give a longer and better life to transformers.

Headquartered in Switzerland and with operation centres in the EU, MICAFLUID is the sole beneficiary of a century-old heritage of extensive knowledge and experience in the power industry, making it a world leader in the engineering and development of insulating oil treatment, regeneration and integrated systems.

Electricity is one of the most crucial discoveries in human history, providing comfort, encouraging inventions and having a huge importance fuelling our everyday life. The most important enabler of all these possibilities are transformers, located on all branches of the powerline. Yet, a great number of transformers in use are already at, or close to, the end of their lifecycle. The ongoing integration of renewable energy-systems are causing fluctuations to occur more strongly and more frequently, endangering the stability of the system [1].

Essential to the life expectancy of any transformer is the state of its **insulating oil**. Not only is it an integral part of the oil and paper insulation system, but it also serves to provide cooling and health indicators through oil analysis.

However, over time, the aging rate of transformer oils beside temperature is accelerated by water, oxygen and gas content as well as acids derived from oil degradation. These along with other contaminants adversely affect the dielectric strength of the oil resulting in a lower Breakdown Voltage (BDV), propagating into a series of operational issues which shorten the service life of the asset.

CRP regeneration plant inlet and outlet oil colour change

Insulation oil types and how to treat them

It is well known that the main oil types in use today for insulations fall within the following categories:

- **Naphthenic based mineral oil**
- **Paraffinic based mineral oil**
- **Synthetic ester oil**
- **Natural ester oil**
- **Silicone oil**

Each fluid has a different set of characteristics which make them better suited to certain applications, conditions, and cost.

Mineral oil is the most widely used insulation oil despite having some disadvantages due to its limited biodegradability and low fire point. It is important to avoid light fractions in vacuum and thermal cracking during treatment.

Synthetic ester is chemically derived and optimized to have a higher fire point as well as better water solubility and higher viscosity in comparison to mineral oil. Treatment therefore requires a higher process temperature, increased vacuum capacity and specific process cycles to avoid poor treatment results.

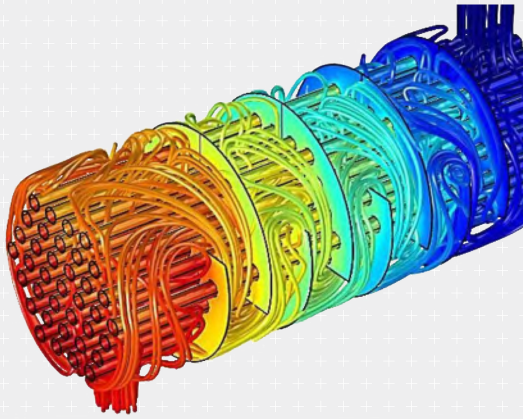
Natural esters are vegetable based fluids which appear to satisfy the growing trend towards "greener" more biodegradable fluids while presenting high flash and fire points. Its higher viscosity also calls for a higher vacuum capacity and more specific treatment parameters.

Silicone is a synthetic fluid which has self-extinguishing characteristics with good thermal stability. It also requires increased heat and vacuum for treatment due to its extremely high viscosity. Furthermore, due to its non-compatibility with other fluids, treatment systems have to be dedicated to silicone oil treatment only, to avoid contamination of other oils.

MICAFLUID VOP treatment systems are prepared to treat **all types of oils** and we are committed to deliver high quality oil purification systems which keep up with the latest developments in the world of insulation oils.

Furthermore, due to an array of technical features which guarantee effective vacuum tight treatment without the risk of microbubbles or contamination, MICAFLUID systems ensure process integrity without any compromises to the asset whether in a production line or substation.

21 Advantages of using MICAFLUID technology in 2021



CFD VOP baffle heating system [2]

1. Efficient degassing with single stage vacuum

MICAFLUID plants require only the smallest suction capacity from the vacuum pumps as the operating pressure for effective degassing is between 1-9 mbar.

2. Optimized electric heating system with horizontal configuration

The oil is indirectly heated and automatically regulated to within 1°C of the setpoint while ensuring a thermal flux of <1 W/cm^2 which prevents hot spot cracking of the oil and guarantees its integrity.

3. Complete system is vacuum tight

The entire system is vacuum leak tested with a guaranteed leakage rate of <0.025 mbar•l/s thus eliminating any entry of air into the process. No inlet feeding pump is therefore required for normal oil treatment.

4. Variable flow-through

Due to a oil level control system especially developed by MICAFLUID, the oil flow is automatically adjusted to the flow-throughput set point without the risk of flooding. MICAFLUID systems are designed to ensure laminar flow on the outlet which prevent the creation of microbubbles usually caused by turbulence.

5. Thin film degassing

The patented oil distribution system for **maintenance free** thin film degassing over the Raschig rings packed columns is known to be the most efficient method of dehydrating and degassing insulating oil. This had been proven in a study performed at the ETH Zurich.

6. Automatic froth control

All VOP plants are equipped with an Anti-Froth Control System. In case of unexpected foaming, the system detects and automatically reduces suction and flow through in the degasser **without breaking vacuum**. This aids the treatment of **high viscosity oils**.

A competent and experienced partner to the Electrical Industry!

7. Filtration with clog detection and automatic control

Three options for fine filters are used in MICAFLUID systems, namely Nylon, Polypropylene and Fiberglass with varying characteristics depending on the final application:

- **Beta X from β1000 to β5000**
- **Nominal fineness from 0.35 µm to 5 µm**
- **Temperature range up to 120°C**

Furthermore, clog detection allows for early warning of a required filter change which can then be performed safely during treatment without stoppages or the introduction of air into the system and process.

8. In-line gas and water content measurement

VZ212A applied on a VOP plant to measure water and total gas content

9. In-line Tan Delta measurement

VZ220A applied on a VOP plant to measure Tan Delta

Photos: Micafluid AG

MicaSonic™ applied on a VOP plant to measure
- Breakdown voltage [kV]
- Moisture content [ppm]
(@ 20°C and actual temperature as per IEC)

10. In-line breakdown voltage measurement with MicaSonic™

11. Process supervision

All MICAFLUID plants are controlled by PLC which automatically control and supervise each operating step and provide process trend data and alarm history.

12. Alarming

Essential to process supervision is diagnosis and alarming. MICAFLUID systems generate information alarm dialogues both on the HMI and via SMS for immediate operator notification and action.

13. Safety functions

Adhering to safety standards such as ISO/DIS 13849-1, MICAFLUID takes the safety of the operators, process and system very seriously and therefore have standard features such as over pressure and temperature protection for the entire installation. Further features such as leak or flood detection, dry run protection and phase sequence control ensures continuous fail safe operation.

14. Operator friendly

With an intuitive touch screen interface, operation of any MICAFLUID system is child's play, reducing the time needed for operator training.

MICAFLUID is committed to delivering highest quality oil purification systems and our team is fully dedicated and continually innovating a wide range of products, instruments and services focusing on the customer's requirements.

Our range includes:

VOP - Variable Oil Purification
CRP - Conventional Regeneration
VPU - Vacuum Systems
OFP - Oil Filtration
HOS - Hot Oil Spray
ODS - Oil Distribution Systems

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15. Industry 4.0

With the use of smart communication protocols and sensors, MICAFLUID systems are prepared for full client-side integration embracing the Fourth Industrial Revolution.

16. Online treatment process on energized transformer

MICAFLUID plants are prepared to perform on onload treatment of transformers using the adaptable onload kit which ensures a completely vacuum tight process from start to end.

17. IEC compliant & energy efficient

All units are IEC compliant thereby achieving the required performance with efficient energy consumption.

MVA Support Platform

18. Low maintenance

The robust plant design requires minimum intervention, limited to vacuum pump oil and filter change. Furthermore, since MICAFLUID units are vacuum tight long term storage even in high humidity corrosive environments.

19. Spare parts guarantee

Micafluid offers an outstanding spare parts and after sales service during the lifecycle of the plants.

20. Retrofittable accessories

Retrofit of all supplements or optional accessories, offered by MICAFLUID, can be installed by the customer without additional mechanical works on the plants.

21. Cost and travel reduction with MVA Support Platform

By subscribing to Micafluid's Machine Virtual Assistance **(MVA)** Support Platform, users have instant access to remotely control and supervise their machine as well as direct Micafluid technical support and online diagnosis via Secure Sockets Layer (SSL).

MVA quickly enables companies to remotely view and act on the oil treatment operation, reducing downtime, as well as travel and operator costs.

Furthermore, having the possibility to perform site or factory acceptance tests and as well as training remotely, MICAFLUID is able to drastically reduce its carbon footprint.

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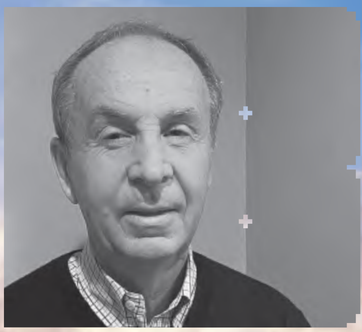
Insulating Oil Field Fill: Challenges and Remedies



by **Chris Kenney** President
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Chris Kenney spent the majority of his time in the refining industry in the sales and marketing of specialty hydrocarbon fluids, more specifically in transformer oil sales. Chris has worked in sales and sales management with Ergon Refining, Cross Oil, Petro Canada and most recently, Calumet Specialty Products. In all these assignments, he was at the forefront in business development roles dedicated to developing net new transformer oil market share. Chris is an expert in the technical aspects of both naphthenic and paraffinic transformer oils and has established worldwide contacts in the power transformer industry and US utility industry. Chris holds a Bachelor of Arts from St. Joseph's University, and currently resides in Acworth, GA with his wife Karen. Chris is available for either full, or part-time consultation arrangements regarding the sale and marketing of transformer oils.

Starting in the mid-1970s, yearly installment of large, extra high voltage power transformers in the U.S. began to drop precipitously.

Photo: Shutterstock

Since the early 2000s there has been an explosion of LPT (large power transformer) and EHV (extra high voltage) transformer installations across the whole of the North American landscape. A 2011 report from an antidumping investigation by the United States International Trade Commission (USITC) defined LPTs as "large liquid dielectric power transformers having a top power handling capacity greater than or equal to 60,000 kVA (60 MVA), whether assembled or unassembled, complete or incomplete" [1]. The 2011 NERC Spare Equipment Data Task Force defines LPTs as follows [2]:

Transmission Transformers: the low voltage side is rated 100 kV or higher and the maximum nameplate rating is 100 MVA or higher.

Generation Step-up Transformers: The high voltage side is 100 kV or higher and the maximum nameplate rating is 75 MVA or higher.

In 2002, the same demand for large power transformers which seemed to evaporate starting in the mid-1970s, robustly returned.

In the United States, starting in the mid-1970s, yearly installment of LPTs and EHV transformers began to drop precipitously. This continued into the late 1990s with a record low point in 1994. This decrease in demand led to a decline in the domestic LPT manufacturing base in the U.S. and Canada. There were simply not enough orders to keep plants in North America busy making large power transformers.

As I discussed in my most recent article in Transformer Technology [3], the same sort of winnowing out of the refiners who produced transformer insulating oils was occurring among domestic LPT manufacturers. The transformer oil marketplace, as it had been in years past, seemed to have disappeared. Consequently, many of the refiners who had previously supplied the mineral oil marketplace were shutting down these lines of business.

The subject relating to the globalization of the LPT manufacturing base with its resulting dislocations is a subject for another article. In 2002, the same demand for large power transformers, which seemed to evaporate starting in the mid-1970s, robustly returned.

We are now in one of the highest-demand LPT markets in recent memory. All of this could be loosely categorized as "the modernization of the grid," also an article for another day.

What does all this have to do with insulating oil field fill? The latest figures I could gather up as to current demand for mineral oil-based field fill would be based on a 2014 U.S. DOE Homeland Security study [4] which looked at the U.S. based LPT manufacturing base coupled to the modernization of the U.S. electrical grid. In 2015, over 500 large power transformers were imported into the U.S. market from overseas manufacturers. This number included only the units imported into the market, not the entire U.S. macro market for LPTs. Needless to say, the insulating oil field fill market is a serious market considering the insulating oil volume and distribution requirements.

What are the challenges facing the specialty refiners who attempt to fill this market demand? There are many. Insulating oil field fill may be one of the most difficult markets to satisfy on a consistent basis compared to other specialty oil delivery requirements. This is due to the very nature of the product application. I can think of no other specialty oil, when delivered, that undergoes the scrutiny insulating oils must pass. There are a number of tests that are performed right off the truck, namely dielectric, moisture and sometimes power factor testing.

An oil must pass these tests before the truck is accepted for delivery. Often these tests are performed in challenging environments that neither the operator nor the refiner has much control over. Some customers want the truck to be sampled; have the sample sent to an independent lab, and wait for the results while the

We are now in one of the highest demand large power transformer markets in recent history.

truck and driver sit. In an era of a tight supply of line haul equipment and drivers, this is never a welcome request. Often, a 25-50 gallon dump from the truck tank manifold will disappear as an "off spec" oil, usually with regards to dielectic. Often a truck will return to the refinery having been declared "off spec" and will test "on spec" by the refinery lab.

Some large LPT OEMs are chronic in their placing an order and then calling the truck back after the truck has left the terminal or refinery. Others place orders which necessitate the procuring of a truck and trailer and then abruptly cancel because of technical issues with the transformer setup at the site.

These are just a few in a long list of reasons that lead to loads being refused, called home or deferred to a later date. They all cause frustration and cost money on both sides of the transaction. Some are the fault of the OEM; some are the fault of the refiner marketer, and some are the fault of the truck carrier. By far the most irritating is when the OEM customer's customer inserts what I call "rouge" specs on the oil delivery. This often manifests itself in asking for PPM water content far below the standard ASTM 3487 industry standard for moisture in product.

Lastly, in order to lessen delivery risks, proper logistical support must be provided by a remote terminal infrastructure. Shipping these products over long distances is expensive, ties up trucks for an unacceptably long periods of time, and heightens the possibility of late shipments – and off-spec product. Many of these issues are communication issues that can be solved by a quality customer service department, preferably one with dedicated insulating oil customer service representatives.

Refiners must also ensure they are aligned with trucking companies that have at least some trailers dedicated to only carrying transformer oils. Construction site crews must provide trained oil test operators, testing to ASTM standards on both method and containers. In short, everyone must do their job, take quality seriously and commit at every level to follow best practices when handling the product.

To oil suppliers who understand the risks and rewards of engaging in this particular piece of the insulating oil supply chain to the LPT market, there will be an adequate financial return, ratable business, and growing revenue. To the OEM manufacturer and utility, there will be timely deliveries, lower construction setup costs, and a quality product with which to energize their new transformer.

Insulating oil field fill may be one of the most difficult markets to satisfy on a consistent basis due to the very nature of the product application.

Photo: Shutterstock

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WHY DO SOME BUSHINGS FAIL?

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

A failed transformer bushing can thus cause a lot of trouble in the field. Not only is there a significant cost to replacing the bushing, but also the resulting transformer failure can incur additional costs, much higher than the cost of the failed bushing, and lead to downtime resulting in more costs to the operator.

Additionally, there is the question of the reputation of the transformer supplier, as well as a possibility to be subjected to penalties for power interruptions and failure to deliver electricity to customers.

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

Let's look at the most common causes of bushing failures, specifically in regard to polymer transformer bushings.

Part Design

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

Things to look for in this area include the following:

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

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

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

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

Polymer

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

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

These properties can be verified by standard test procedures.

Most Common Failures

The most common failures in the material include:

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

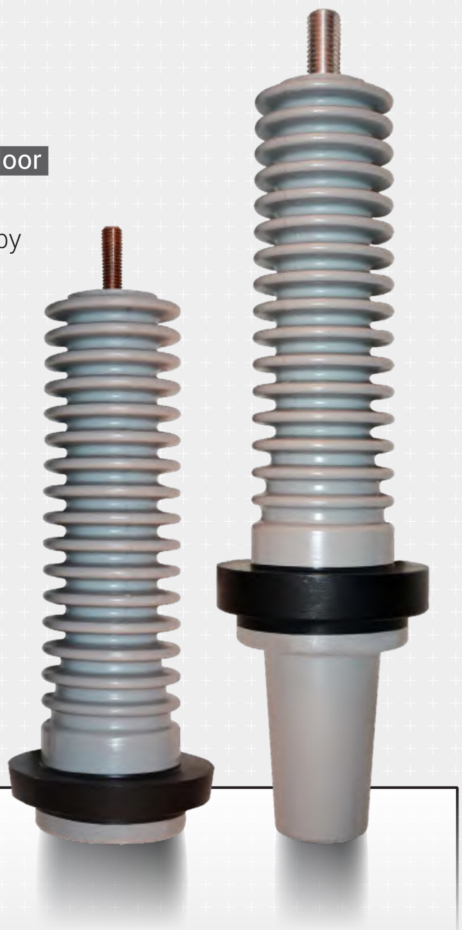

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Photo: CrossLink Technology Inc.

Manufacturing

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

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

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

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

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

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

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

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

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

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

Most Common Failures

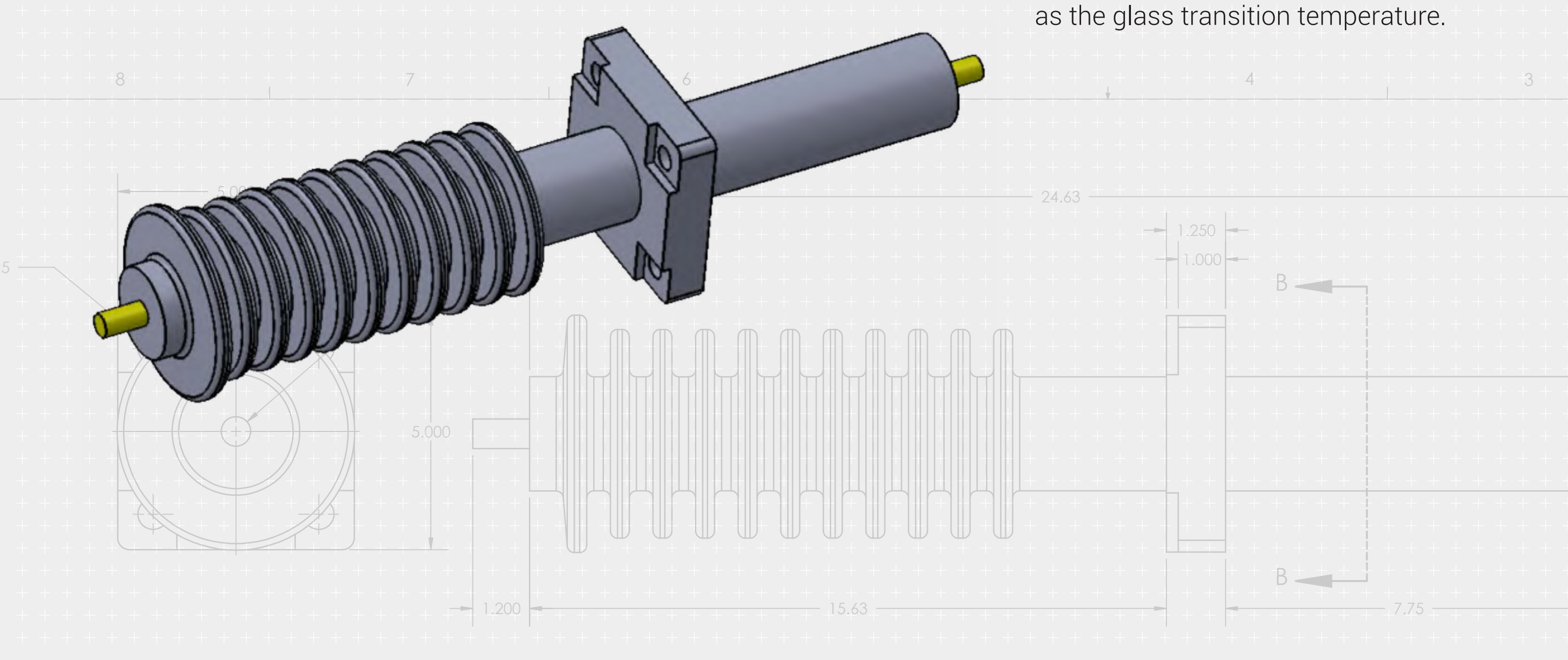
The most common failures that develop as a result of improper processing include:

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

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

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

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



Selecting Your Supplier

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

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

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

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

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

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

Our Epoxy Transformer Bushings are manufactured to the highest quality standards

Epoxy bushings also have:

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

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

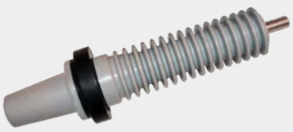


Photo: CrossLink Technology Inc.

Design for the Future. Design for Success. Design for Safety.

by **Martin Robinson**

Photo: IRISS

Martin Robinson is the founder, owner, and CEO of IRISS Inc., a leading manufacturer of infrared inspection windows. Robinson focuses on innovation and is a pioneer of Electrical Maintenance Safety Devices (EMSDs) that help protect technicians from harm while protecting their companies' bottom line. He holds several patents for condition-based maintenance devices and has designed multiple maintenance programs that include infrared, ultrasound, partial discharge testing, nondestructive testing (NDT) and energy management strategies. He holds a NEBOSH certificate in Occupational Safety and Health, an IAM Certificate in Asset Management, is a certified Level III Thermographer, a Certified Maintenance and Reliability Professional (CMRP) and a Certified Reliability Leader (CRL). He is a member of IEEE, NFPA and is a standing member on the technical committee CSA Z463 guidelines on maintenance of electrical systems.

The critical importance of electrical power to every aspect of our world cannot be exaggerated. Electricity must be generated and distributed effectively to end-users, and any disruption in that process means loss of operations, money, and in extreme cases, life. Therefore, the reliability of electrical power creation and distribution must be continually safeguarded and improved. This does not happen by chance or through reactionary-maintenance tasks. This must be focused on from the early design stages and continued through the life of the assets tasked with these functions.

THE RELIABILITY OF ELECTRICAL POWER CREATION AND DISTRIBUTION MUST BE CONTINUALLY SAFEGUARDED AND IMPROVED, WHICH DOES NOT HAPPEN BY CHANCE OR THROUGH REACTIONARY-MAINTENANCE TASKS.

Adopting a "Monitor, Inspect & Manage" approach is a proactive way to avoid the concerns at hand by maximizing the value of workforce time and skill. Scalability is no longer an issue when, instead of going through the time and cost of expanding their workforce, they can apply condition-based reliability technologies to maximize their available workforce skills and availability. These reliability technologies can be specified with the specification engineer and original equipment manufacturer at the initial design/build stage or retrofitted into existing equipment through a simple and inexpensive process.

Additionally, by taking the Reliability Engineering by Design (RED) approach espoused by the Electric Power Reliability Alliance (EPRA), coupled with the Monitor, Inspect and Manage approach as detailed in this article, we will create a practical system approach to asset reliability.

Monitor

With the use of a monitoring system on transformers and throughout substation electrical equipment, asset conditions can be continually collected, trended, and assessed. Monitors feed data through a gateway to software and applications, allowing the information to be continuously accessed from workstations and mobile devices.

When the new equipment arrives from the manufacturer with these monitors built in, customized parameters can be set for the specific operating and environmental conditions the asset is exposed to, which keep it within a "safe zone" to maximize functional reliability. When the asset condition data exceeds the custom parameters, alarms can notify electrical technicians of a possible issue that may require inspection. Keeping human interaction with equipment to only instances where confirmation inspections of potential faults are deemed necessary minimizes risk to workers and eliminates the human-error threat to asset functionality.

As stated earlier, if we, as practitioners, connect reliability and safety, we will gain much more momentum, access more resources and create an environment where we can make sure our transformers are reliable, which also leads to increased safety. And safety continues to play a more prominent role in relation to electrical systems.

Inspect

Once the wireless monitoring system notifies technicians of a possible issue with a transformer or other piece of electrical equipment, the use of pre-installed inspection windows on the asset allows a safe, efficient method of inspecting and assessing any possible issue during an energized condition. Once solely designed for thermographic inspections using infrared cameras, advancements in manufacturing have led to the inclusion of ports that allow for ultrasound and partial discharge technologies to be incorporated into the inspection. Visual, infrared, and ultrasound inspections can be done simultaneously by a single employee.

Additionally, this design protects inspectors from arc flash/electrocution risk, removes the need for bulky and expensive PPE, and allows the inspection to be accomplished more efficiently. Not only does this represent a significant process improvement driven by original design, but it also falls in line with the most recent NFPA 70E updates and continues to protect critical assets from human interaction/mistakes that may cause failure.

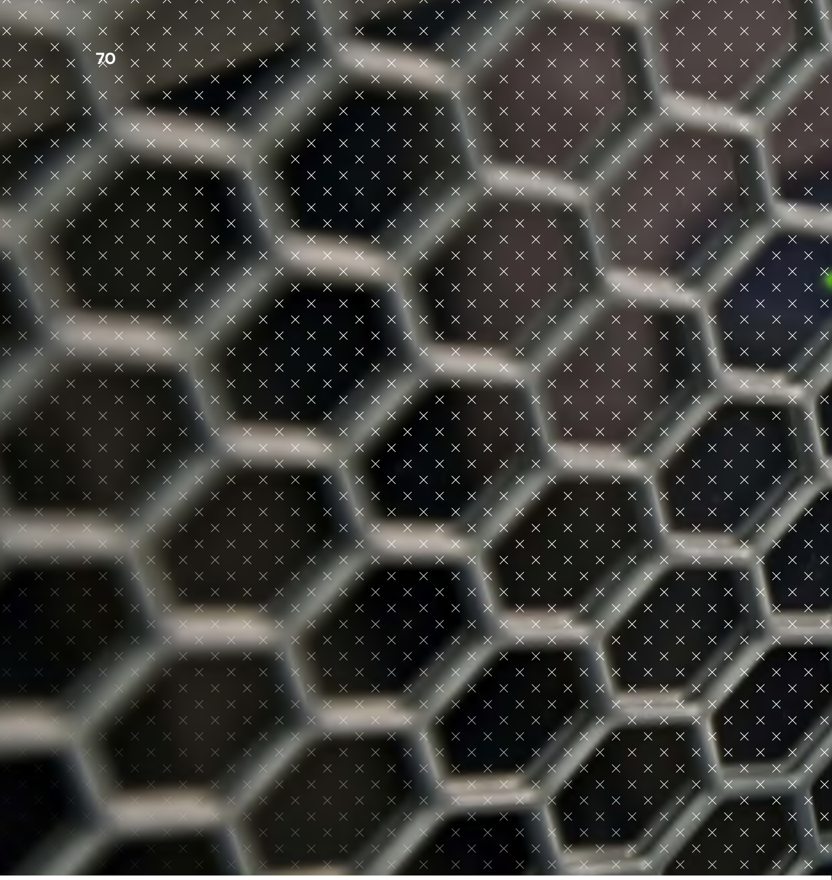
Manage

The data collected during inspection can be stored through intelligent asset management tags attached to the pre-installed inspection windows. From the asset location, information can be transmitted into a dashboard system accessible from workstations and mobile devices.

Customizable routes can be established before, and condition reports generated after data analysis to further increase efficiency. These designed aspects allow managers to assess operations and decide how best to increase Mean Time Between Failure (MTBF).

IF WE, AS PRACTITIONERS, CONNECT RELIABILITY AND SAFETY, WE WILL GAIN MUCH MORE MOMENTUM, ACCESS MORE RESOURCES AND CREATE AN ENVIRONMENT WHERE WE CAN MAKE SURE OUR TRANSFORMERS ARE RELIABLE.

Photo: IRISS



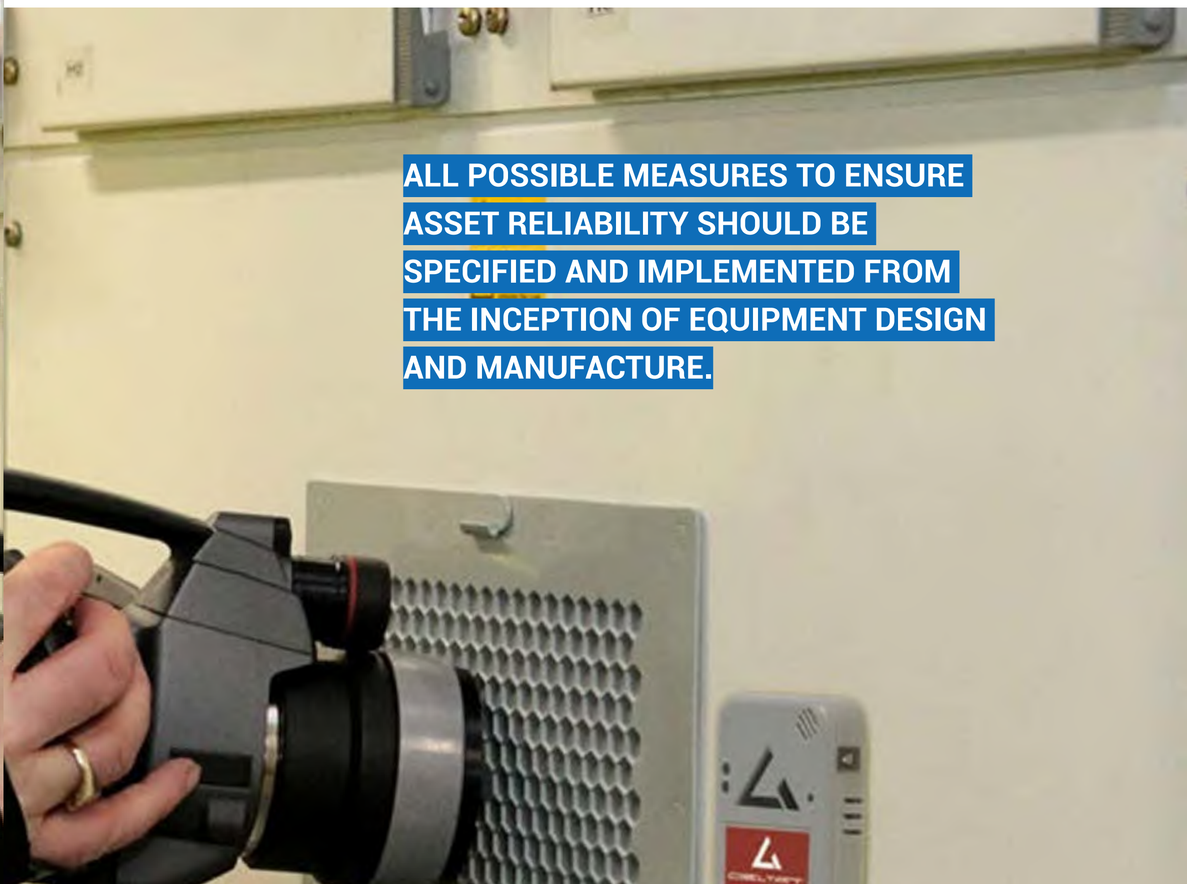
Proper Training

One major issue facing the industry is a coming wave of retirements from the workforce, with fewer new workers entering the industry than the pending need created by this exodus. As the electrical industry expands worldwide, creating the need for a larger workforce, the problem is multiplied. The only way to succeed is to capitalize on reliability technologies designed into the system that allows the industry to do more with less.

While designing for safety and reliability from the equipment-side should drive the overall process toward continuous improvements, the proper tools are only as useful as the hands wielding them. Hardware and software designed/specified by the engineer and constructed by the OEM are ineffective if the people responsible for their oversight are not adequately trained.

Shifting to an engineered reliability system for the electrical maintenance team means training new and veteran staff alike. With "Monitor, Inspect & Manage" the use of technology allows single individuals to accomplish inspection tasks with minimal training. Specialized skill sets of electrical-focused staff can be used for actual necessary maintenance/repair activities.

Another Covid-era issue with learning is that most educational institutions have transitioned to online models. The electrical world can benefit from adding this type of education and certification to on-the-job training programs. These online systems offer on-demand educational and training resources that teach the use of these specific reliability technologies. The workflow is streamlined meaning that the skill-set requirements can be minimized to particular tasks.



ALL POSSIBLE MEASURES TO ENSURE ASSET RELIABILITY SHOULD BE SPECIFIED AND IMPLEMENTED FROM THE INCEPTION OF EQUIPMENT DESIGN AND MANUFACTURE.

Photo: IRISS

Conclusions

As the old saying goes, "if you fail to plan, then you should plan to fail." From the inception of equipment design and manufacture, all possible measures to ensure asset reliability should be specified and implemented. These measures should prove themselves to be learnable, repeatable, and continued throughout any workforce changes to cement the successful practices into the very culture of the role requirements.

Transformers and other critical electrical power assets being monitored remotely cut down on technicians' routine tasks focused on engineering and electrical operations by providing around-the-clock coverage. When an alarm notification is received, correctly designed and installed inspection windows allow an individual technician to easily do visual, infrared, ultrasound and partial discharge assessments of the energized equipment. The data collected on the asset can then be stored, trended and analyzed through the management software. This process increases the Mean Time Between Failure (MTBF) by allowing for planned shutdown and maintenance only when it is necessary.

Staffing issues brought about by the combination of an expanding market and a shrinking labor pool can be overcome by streamlining operations through technology. Both hardware and software involved can be easily integrated at minimal expense, while the employees responsible for their use can be trained through a combination of online and on-the-job training.

STAFFING ISSUES BROUGHT ABOUT BY THE COMBINATION OF AN EXPANDING MARKET AND A SHRINKING LABOR POOL CAN BE OVERCOME BY STREAMLINING OPERATIONS THROUGH TECHNOLOGY.

Photo: IRISS

The Sen Transformer

by **Roy W. Alexander**

Photo: Shutterstock

We are all familiar with power transformers – the workhorses that make transmission and distribution of AC electric power possible. When we think of transformers, we normally think of units that change voltages from for example 12 kV distribution voltage to 120/240 V household utilization voltage. With the addition of a load tap changer (LTC) under load, transformers can easily regulate voltage.

Roy W. Alexander received a BSEE summa cum laude in 1972 from the University of Pennsylvania, Philadelphia. From 1972 to 2010 he was an engineer at PPL Electric Utilities; from 1995 a Sr. Staff Engineer/Scientist. He Received the "Young Engineer of the Year" award in 1985 from the Pennsylvania Society of Professional Engineers. He and his wife own a power engineering consulting firm RWA Engineering LLC in Cranberry Township, PA. He is a distinguished member of CIGRE, having served as USA delegate to Study Committee A3 Electrical Equipment from 2002 – 2008. He was Chair of the PES Switchgear Committee 2001 – 2002 and served as working group chair on numerous Standards Development working groups. He is also a member of the PES Capacitor Subcommittee, the Insulated Conductors Committee, and the IEEE Power Electronics Society.

Special transformers can also regulate phase angle. But imagine a transformer which can independently regulate voltage and phase angle. Imagine a transformer that injects a compensating voltage ($V_{S'S}$) in series with the line, as shown in the single-line diagram in Figure 1, to act as a series-connected emulated impedance of all kinds – inductive, capacitive, resistive, or negative resistive while these real and reactive components are independently variable. The ratio of the compensating voltage ($V_{S'S}$) and the prevailing line current (I) through the line reactance (X) results in a virtual four-quadrant emulated impedance.

Imagine a transformer that injects a compensating voltage ($V_{S'S}$) in series with the line, to act as a series-connected emulated impedance of all kinds – inductive, capacitive, resistive, or negative resistive while these real and reactive components are independently variable.

Figure 1. Single-line diagram of the Sen Transformer

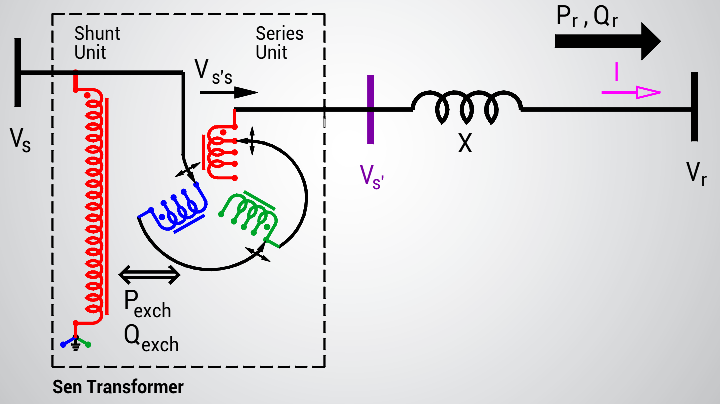
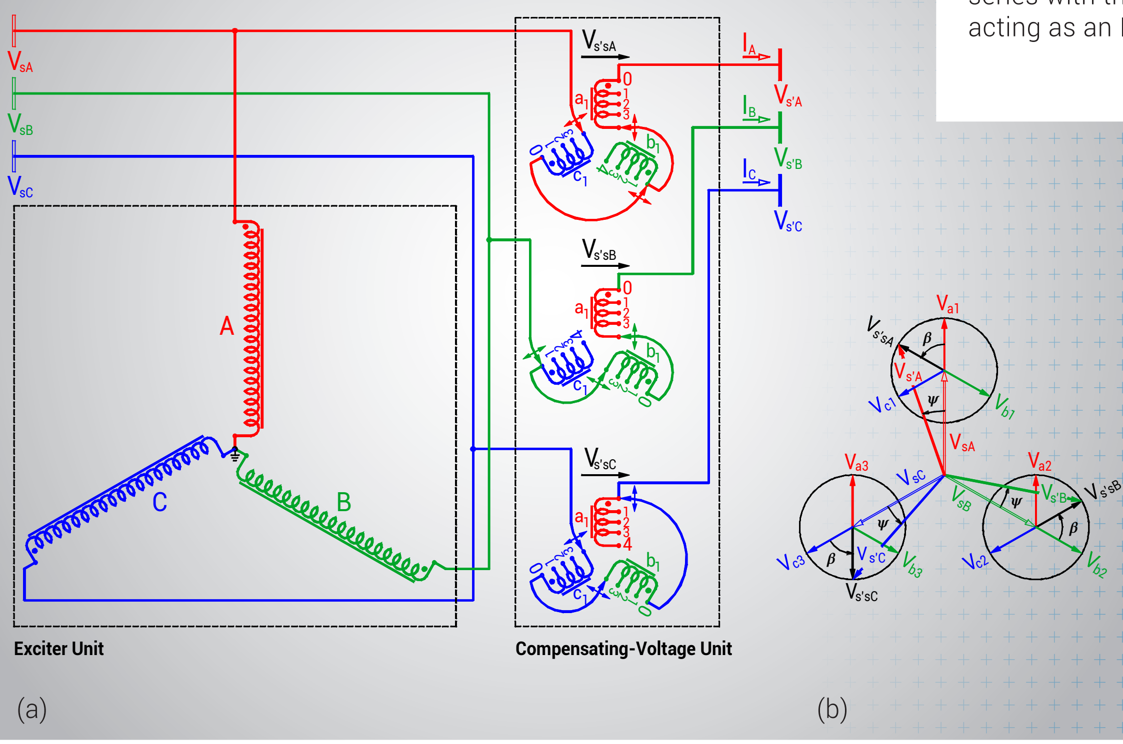


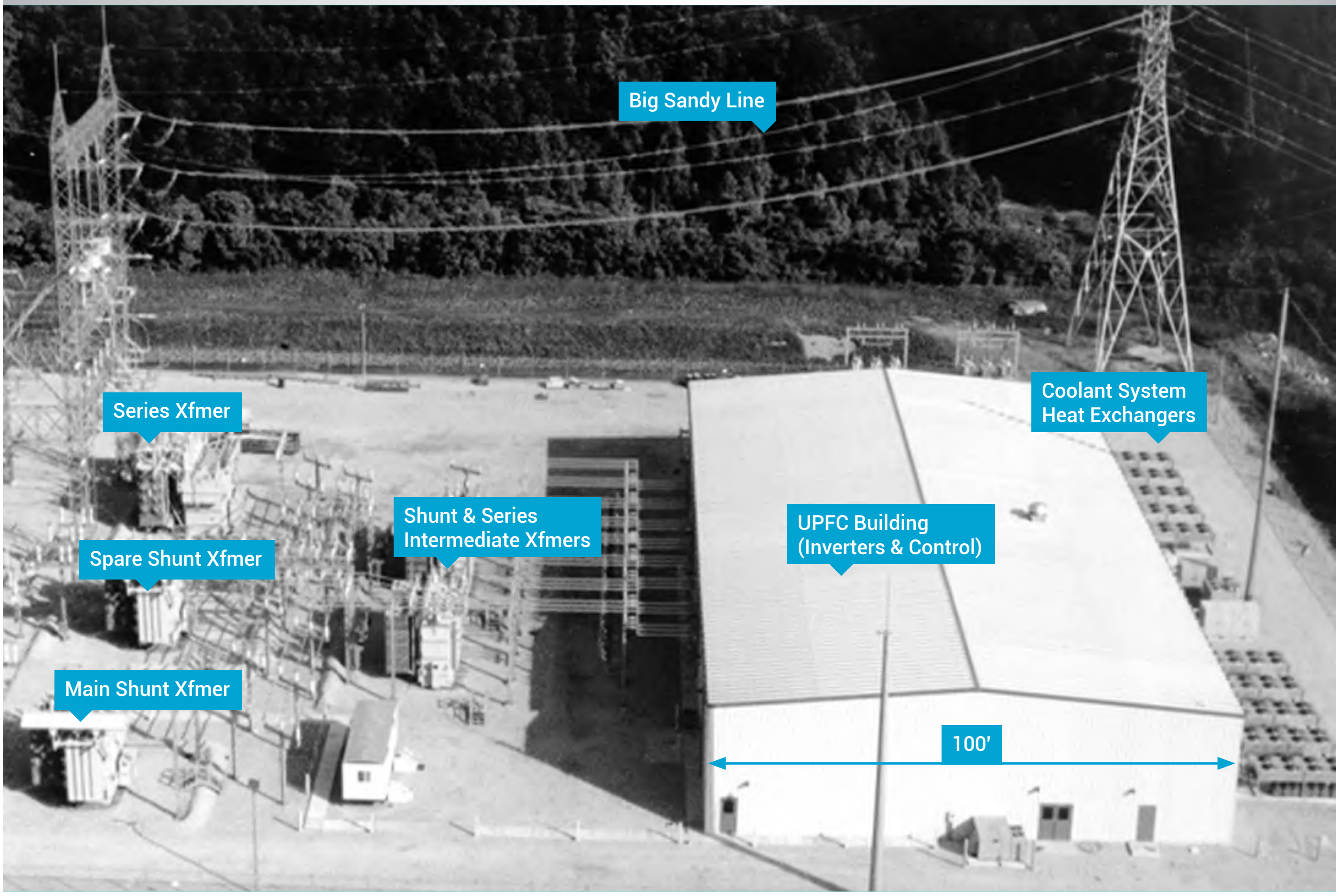
Figure 2. (a) Schematic winding development of the Sen Transformer; (b) Phasor diagram in power flow control mode



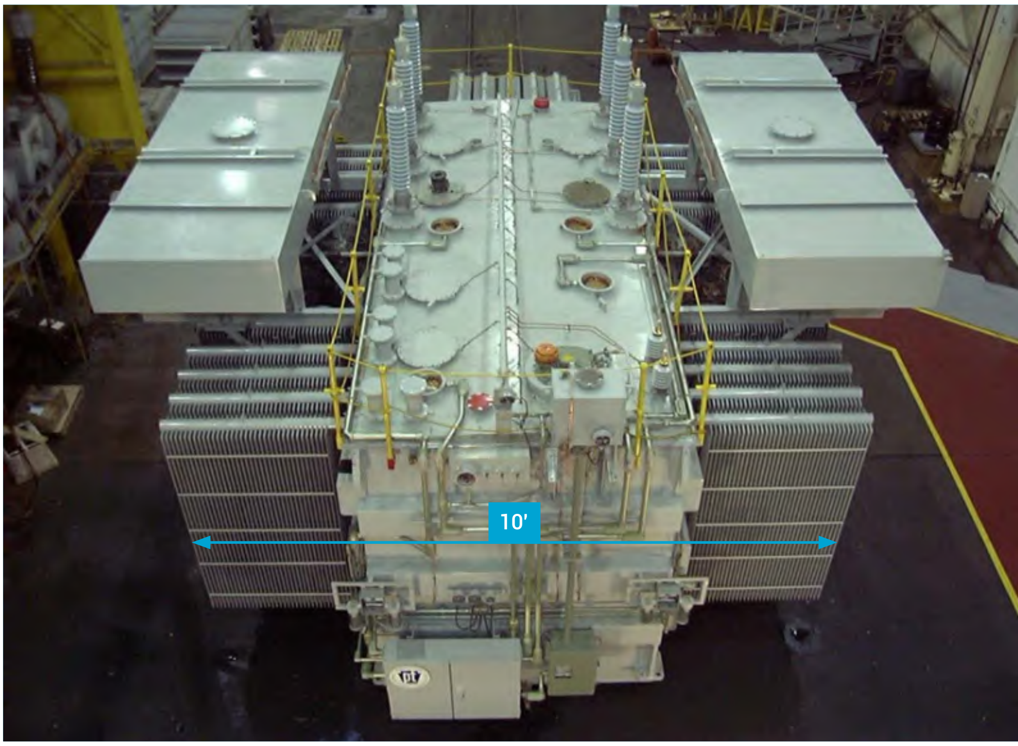
The Sen Transformer uses a Shunt Unit, referred to as Exciter Unit, and a Series Unit, referred to as Compensating-Voltage Unit (Figure 1 and Figure 2). The Compensating-Voltage Unit creates a series-connected compensating voltage ($V_{S'S}$) that is variable in magnitude and phase angle to modify the sending-end voltage (V_S) to the modified sending-end voltage ($V_{S'}$) with desired magnitude and phase angle, needed for desired active and reactive power flows (P_r and Q_r) at the receiving end of the line with voltage (V_r). The compensating voltage ($V_{S'S}$) is also at any phase angle with the prevailing line current. Therefore, it exchanges active and reactive powers (P_{exch} and Q_{exch}) with the line, which is equivalent to emulating an inductor (L) or a capacitor (C) and a positive resistor (+R) or a negative resistor (–R) in series with the line and, thereby, acting as an Impedance Regulator.

Photo: Sen Engineering Solutions Inc.

Figure 3. (a) Westinghouse-made power electronics inverter-based FACTS Controller at AEP's Inez substation; (b) Sen Transformer of comparable rating



(a)



(b)

As you can see from Figure 2(a), the Sen Transformer is a three-phase transformer with a shunt wye primary winding that provides the input energy to the transformer. The series-connected secondary windings induce the compensating voltage, using LTCs. Physically, consider a three-legged core. All four red windings are on one leg, all four blue windings on an adjacent leg, and all four green windings are on the third leg. Therefore, three windings, one from each core leg, are placed in series on each phase of the Series Unit of the Sen Transformer (see Figure 2(a) Compensating-Voltage Unit). Each core leg will have one shunt winding, connected phase to ground on the input side (Exciter Unit) and three series windings to be connected in series – one from each leg on each phase of the output side (Compensating-Voltage Unit).

To reiterate, in total there are three shunt windings, one per phase on each core leg of a three-leg core transformer (Exciter Unit); and nine secondary windings, three in series, one from each core leg connected on each phase of the Series Unit (Compensating-Voltage Unit) of the Sen Transformer. There are nine LTCs, so the nine series windings can each be controlled separately.
The Series Unit of the Sen Transformer can be made to look like an inductor or a capacitor, and a resistor or a negative resistor with respect to the phase under consideration. With the series winding of a Sen transformer placed into a network, the line which it is connected with can have its real and reactive impedance controlled independently. Thus, active and reactive power flows can be varied independently as desired. The switches for the tap changer are preferably mechanical vacuum or oil switches. These can respond in seconds, which is usually fast enough for utility power flow control needs.

If faster response is needed, the switches can be based on power electronics thyristors which, once turned on, commutate naturally. This will move response time from seconds to 50 ms, a 100-fold increase in response speed.
This would increase cost and decrease reliability significantly. Almost never is such a faster response time needed.

The response time can even be reduced further to a few milliseconds if a power electronics inverter-based FACTS controller is used, as shown in Figure 3(a). These inverters use force-commuted switches such as gate-turn-off (GTO) thyristors.

The Sen Transformer can provide the same power flow control functionality as the more expensive, high maintenance, and non-mobile power electronics inverter-based FACTS controllers does. Compare the sizes and footprints of the two similarly capable power flow controllers in Figure 3.

The power electronics inverter-based solution offers a response time that is several orders of magnitude (several seconds verses several milliseconds) faster than the Sen Transformer, but this superfast response capability goes unused in most utility applications. The Sen Transformer uses time-tested, readily available, highly reliable power transformer components. It is inherently more efficient because the mechanical switches in LTCs do not suffer from the high conduction loss from on-state voltage drop and

even higher switching loss from transitioning on-to-off and off-to-on several thousand times every second. These two losses the semiconductor switches cannot avoid.

Another drawback of power electronics inverter-based solutions is that the semiconductor devices, such as GTO thyristors, used in the first-generation FACTS controllers, are not available. The industry moved on to using Insulated Gate Bipolar Transistors (IGBTs).
The upcoming switches are based on Gallium Nitride (GaN) and Silicon Carbide (SiC) due to their inherent advantages of high-speed operation, which results in lower losses, high-temperature operation, lower cooling requirement and smaller gate drive and smaller snubber circuits.

Therefore, FACTS controllers become obsolete in a relatively few years so that one-for-one component replacement becomes impossible in less than 10 years. In the utility world where 40-year equipment life is the norm, this means the entire power electronics inverter-based FACTS installation may need to be replaced several times in that 40 years. Simple maintenance of the power electronics requires highly skilled personnel that are not readily available. The global standard and interoperability do not exist due to a limited number of manufacturers. The inverter-based power electronics FACTS Solution is a highly expensive proposition, perhaps two orders of magnitude more expensive than a long-lived and easily-maintained Sen Transformer.

The Sen Transformer is an obvious winner for power flow control needs for the utilities worldwide.

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Photo: Sen Engineering Solutions Inc.

From Specification to Commissioning: Better Practices for Better Outcomes

specifications, design, transportation, commissioning

As a reliability subject matter expert, I am convinced that all reliability starts at the design stage, and the design stage is more than just how a transformer is engineered, configured and designed, but also how the specifications are created and how it is transported and commissioned. There are so many considerations that will lead to either a reliable asset or one that could fail unexpectedly or even catastrophically.

The roles of design engineering, operations, procurement and purchasing are all impacted by and have an important hand in the design phase of creating a reliable asset, as part of a reliable system. With great contributions from Jon Trout of First Energy, Diego Robalino of Megger, Dan Smith of LCRA, Jason Varnell of Doble and Randy Williams of NASS, this will prove to be an important addition to the Transformer Technology Body of Knowledge.

Finally, there is still room for a few articles or interviews from our Community Members so please drop me a line and let me know what compels you to add to this topic; what you believe will be a contribution that will have long-lasting value to the members of the TT Community. We'd love to hear from you.

Alan Ross,
Community Moderator and Editor in Chief

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