

# TRANSFORMER TECHNOLOGY<sup>MAG</sup>

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# ADVANCED TRANSFORMER TESTING AND TECHNOLOGIES

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Solid State Technology to Streamline Global Transition to Clean Energy  
**Root Causes of Partial Discharge**  
Interview with **Seth Johnson**, Vice President, Powerside

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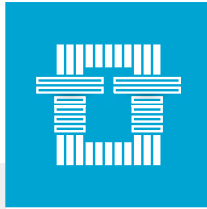
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# Editors

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**Ed Khan**  
Power Systems, Relay protection, Training

Dear Readers,

We are all aware that power transformers are critical components that play a vital role in power delivery systems. They are used to step up or step-down voltage, depending on the needs of the power system. They are also used to isolate circuits, provide galvanic isolation, and protect against surges and over-voltage conditions. Over the years, there have been significant advances in transformer technology, driven by the need for more efficient, reliable, and cost-effective power delivery systems. Just a few of these advances are:

and lightweight than conventional transformers, while still providing high levels of reliability and performance. Gas-insulated transformers are be

coming increasingly popular in urban areas, where space is at a premium. They are also being used in high-voltage direct current (HVDC) transmission systems, where they can provide high levels of insulation and reduce power losses. Even now there is work underway to replace SF6 gas in all applications with new gases that have similar



**Over the years, there have been significant advances in transformer technology, driven by the need for more efficient, reliable, and cost-effective power delivery systems. Here we are naming a few of these advances.**

#### **Growth of Inverter Transformers**

Inverter transformers are used in high-power electronic circuits. They are designed to operate at high frequencies and can handle very high voltages and currents. Inverter transformers are becoming increasingly popular in power conversion systems, such as solar power systems, wind power systems, and hybrid electric vehicles. The development of inverter transformers has been driven by the need for more efficient and cost-effective power conversion systems.

#### **High-temperature Superconducting Transformers (HTS)**

HTS transformers are transformers that use superconducting materials to transmit electrical power. They are designed to operate at very low temperatures, typically below  $-180^{\circ}\text{C}$ . HTS transformers are highly efficient and can handle very high-power densities. They are also very compact and lightweight compared to conventional transformer designs. HTS transformers are being developed for use in power transmission and distribution systems, as well as in high-power magnets for medical imaging and particle accelerators.

#### **Gas-insulated Transformers**

Gas-insulated transformers are transformers that use sulfur hexafluoride (SF6) gas as an insulating medium. They are designed to be more compact

properties but without the negative aspects of SF6. [An interview I conducted with Marcus Heimbach](#) of Hitachi Energy is an excellent discussion of this issue.

#### **Smart Transformers**

Smart transformers incorporate advanced monitoring and control systems. They are designed to provide real-time monitoring of power quality, load conditions, and other important parameters. Smart transformers can also be used to provide real-time control of power flow, voltage levels, and other key variables. Smart transformers are being developed for use in distributed energy systems, such as microgrids and renewable energy systems. They are also being used in data centers, where they can help to improve power efficiency and reliability.

#### **Solid-state Transformers**

Solid-state transformers are transformers that use power electronics to convert power from one voltage level to another. They are designed to be more efficient and cost-effective than conventional transformer designs. Solid-state transformers are being developed for use in renewable energy systems, as well as in electric vehicle charging systems. They are also being used in power transmission and distribution systems, where they can provide improved grid stability and reliability.

# Alan M Ross

### Conclusion:

In conclusion, advances in power transformer technology have led to significant improvements in power delivery systems. With the development of inverter transformers, high-temperature superconducting transformers, gas-insulated transformers, smart transformers, and solid-state transformers, power systems can now operate more efficiently, reliably, and cost-effectively than ever before. These advances have been driven by the need for more sustainable energy systems, as well as the need for better grid stability and reliability. As technology continues to evolve, we can expect to see even more exciting developments in power transformer technology.



Alan M Ross  
CRL, CMRP  
Managing Editor  
APC Media  
Technical Director



# Javiera McGuiggan





“

If we do our job right and people realize how good biobased solutions are for them, there'll be many others that come later and want to participate in the biodegradable biobased products market.

**Global Business Director for Power Systems**  
at Cargill BioIndustrial

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Interview with **Javier F. McGuigan**

**Alan Ross:** My next guest is Javiera McGuiggan. She is the Global Business Director for Power Systems at Cargill. Thank you so much for joining me.

There's something new on the market - rapeseed oil. What is the rapeseed oil thing that you're doing with FR3?

**Javiera McGuiggan:** This week, middle of February, we are launching FR3r, which is like FR3's little cousin made out of rapeseed oil. Rapeseed is exactly the same as canola.

**AR** My next question is, why have another product when we know FR3 works? And it works really well.

**JM** It works fantastic. What is mostly driving this need is that it is pushed by the European market. They have this crop available, so they like the localized oil. That's one of the drivers. It's sort of already embedded in some people's head that soy could be damaging the environment. It doesn't, but we want to make it clear for people that this is not a better product, it's just different crops. Being such a big agent in agriculture, we can make the product out of anything. We know that soy is the best combination of performance and cost that is available right now. But if people


are interested in having a rapeseed version, and other customers in this market are using rapeseed, we don't want people to think they cannot get that solution from Cargill, because now they can.

**AR** That's excellent. I love the idea of a localized crop; everybody would want that.

**JM** Helping your own economy, avoiding moving things around too much, saving on transportation and reducing contamination - if we can do things locally, we will try to do that too. That's why we have so many plants everywhere. This will be produced at a new European plant.

**AR** Cargill has played a major role in decarbonization because you are using plant-based oils as opposed to mineral oils. I heard recently an argument that refining mineral oil now is a green. It's still mineral oil, a carbon-based product. Why would they try to equate mineral oil that's been repurposed to a plant?

**JM** Sustainability is a super important topic. There's no company that doesn't want to achieve that and contribute in some way. We can argue about life cycle analysis and



**We know that soy is the best combination of performance and cost that is available right now. But if people are interested in having a rapeseed version, and other customers in this market are using rapeseed, we don't want people to think they cannot get that solution from Cargill, because now they can.**

numbers and spreadsheets, but can you find anything that would be greener or better for the world than a plant? No.

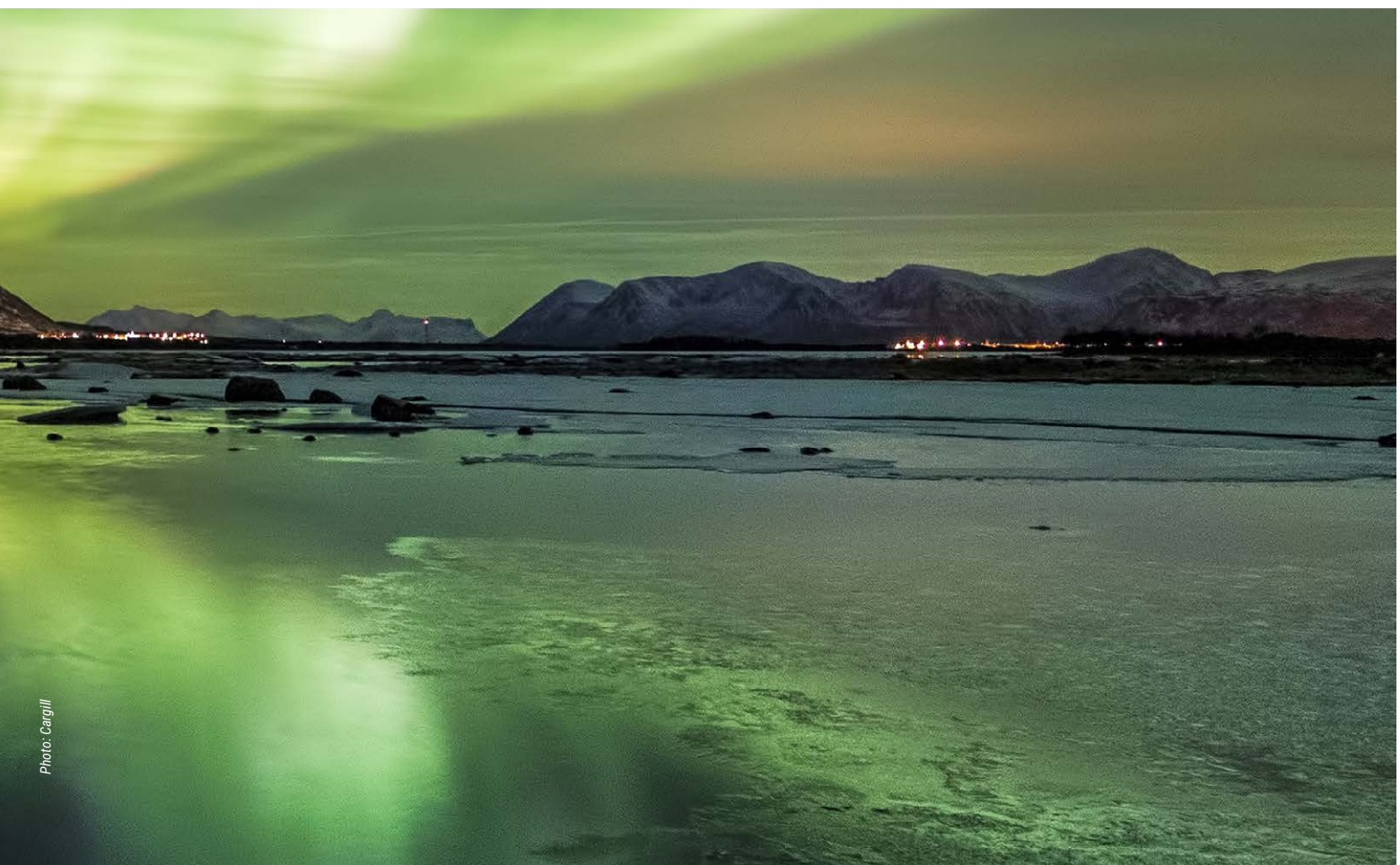
For an LCA analysis, life cycle analysis, where you're measuring the amount of carbon that's emitted to the world, mineral oil as a petroleum-based solution contributes a lot to CO<sub>2</sub> emissions, which then leads to global warming. We want to avoid that, not only to the level of neutral, but hopefully to the level of negative. When you start from a plant, as the plants are alive, they have a biogenic property where they are absorbing CO<sub>2</sub>, so they're literally doing the opposite effect. Some LCAs take in effect, the farming and the whole agriculture, and they ignore the fact that the plant was sitting there, breathing and absorbing CO<sub>2</sub>. Then you consider all the normal farming processes, then the production of FR3, and you get to a number that's much better than mineral oil, because, again, it's a plant. Even negative, if you add the biogenic composition of the plant.

Petroleum solutions are claiming that they can reuse that product for something else, which, don't get me wrong, is fantastic. It's what the world needs, less waste. Reusing mineral oil - great. Can you reuse FR3 for other things? Also true. It doesn't take away from the fact of all the carbon that was emitted at the beginning to produce mineral oil.

I applaud the effort of anyone that makes something that contaminates the world and tries to reuse it for another purpose before it's thrown away. We can also do that with FR3, and that's not the point. The point is, I don't want anyone to get confused to the level of thinking that mineral oils are better than FR3, because we're comparing them to a plant, so there can't be anything greener. That's the end of the discussion.

**AR** You're the global head of Power Systems at Cargill, so you see the world from a different point of view. The world is not the same in adopting all of these things. Who's ahead, who's behind, who is really supporting biodegradables, and who is just nascently getting into it?

**JM** The ones that are the most ahead are linked to the most developed economies. The United States is the largest consumer of biodegradable biobased products. Then there's a very accelerated push in Europe. I feel Europe needed a little more of the proof that it works and how it's going to affect their pockets and if they can financially establish it. But they have aging grids, and a bunch of other benefits that they get from these biobased solutions, so they are in a very much accelerated pace compared to what they have





been before. And then also Latin America has been very much convinced that this is the right solution. In countries like Brazil almost 90% of their distribution grid is now all in natural esters. Those are the three areas that I would say are driving the change. Next to that, there are countries that are making really great efforts. South Africa turned all their grid into natural esters. The Philippines also established that.

Slowly but surely, all the rest are catching up. In Asia, Japan, Korea, China are dipping their toes into the water, but they'll catch up pretty quickly. Once they get into it, they'll go super fast.

I've always said, if we do our job right and people realize how good this is for them, there'll be many others that come later and want to participate in this market. And that, to me, is in general a good thing - having more competition - because at least we're all trying to defend

which is the best natural ester. I can raise my hand - I think I have the best one for sure. But at least I'm not still trying to convince people that it works, or to trust it. It's more of a wave of "we know it works". There's just more activity in the market, and I think overall, for the planet, it's a good thing.

**AR** I was the president of the Electric Power Reliability Alliance, we had a lot of labs that we worked with, and they were doing a lot of testing of FR3. As they began to build up the data, they began to see some benefits to FR3 that weren't there in mineral oil. Speak a little bit about those. Sell me on FR3.

**JM** If it's something related to lab analysis, one of the easiest things you could find is how FR3, just for the pure nature of the science of how vegetable oils work, deals with moisture and free water. The molecules of



soybean oil absorb the water into two separate components, so then it's not free water that can then get attached to your solid insulation. And that's how FR3 extends the life of a transformer. There is a chemical reaction with water that stops it from attaching to the solid insulation.

It's hard to explain, but FR3 is good at aging. It doesn't go brown; it doesn't get burned. You open a transformer with FR3 that's been working for 15, 20 years, and it almost looks exactly the same

At a utility in California, I met an engineer, and he says: "I don't like your fluid, because if I open a mineral oil transformer, I look at the oil, I know exactly what's happened to this transformer. I know what it's been through. I know how long it's been working. I know what could be failing. I open one of yours, and I can't tell anything." And I'm like, exactly. That's why you usually

like it. But he hated it because he would see no change in the oil. It's good with heat, robust.

**AR** I learned just recently that FR3 can withstand overheating significantly better than mineral oil. When you think about where we are right now, the demand on the grid is growing. Everybody is having to produce more. You can't get more transformers. They're three years out in some cases. And we've had a couple of transformer manufacturers here share with us the difficulty they're trying to ramp up. You've got to keep the existing infrastructure working. Therefore, you're going to overheat and overload your transformers.

What is the cost of retrofitting in comparison to the value of retrofitting with FR3? We know the safety issues, the fire retardancy. We know that if you're near water, you don't want mineral oil to spill in water.

**JM** How much value you get versus what the cost of it is a really great question, because when you think of a new transformer, the initial ratio of the price of the oil versus the total cost of a transformer is anywhere between 5% to 8% of the cost of the whole unit. So maybe initially when you're buying the whole unit and you have a fluid that's a bit more expensive than your incumbent mineral oil, you just elevate the cost of the whole unit. And you think, do I want to spend that money when I'm already having to buy all these transformers? After a while, mineral oil transformers either need a refresh, or retrofilling, or adding a couple of additives that have maybe worn out. In the case of FR3, that won't happen. When you just evaluate the cost of oil versus oil, it's such an insignificant cost compared to the labor of even doing this maintenance.

Another engineer in a utility in California said: "I want to just put this oil in there because then I know I don't have to touch it again." Labor cost for the maintenance of a transformer could be four times more, depending on the location of the transformer. You have the crew that has to go there, the time spent on shutting it down, getting it off the grid, doing this maintenance. Then on top of that, if you already have the transformer working and you can extend the life, then again, you have to buy units less frequently, which is another economic factor that is not easy for some people to integrate into their equations. They're just thinking about the initial cost, but it's much, much less significant as a maintenance operation to then do this retrofill compared to all the benefits that you would get out of it, because you get 90% of all the same benefits that you get from a new Transformer with FR3.

People always ask, if there's a little mineral oil left in there, would it still work? And yes, it does.

**AR** Last question. Labor is an issue now, right? You are on the steering committee of Women in Power Systems. Getting more women engineers into STEM, science, technology - you're a real champion for that, and Cargill is a real champion of that. But now there's just a huge problem of getting any staff. Yet, are you suffering from that same thing, is Cargill as a whole suffering from it? Or how do you help industry address it?

**JM** We even struggle with filling some positions in our team that are in a great company and exciting. But finding the right mix of the right energy to sell something that is changing the way people used to think about something is not just sales. It's telling a story. It is getting harder and harder to find

engineers working at our plants for all the capacity increases that that we need at our plants. We are, thankfully, good at retaining. It's a lesson for all of us to learn - treat your employees well and retain them, because it's not as easy as it used to be to just get new talent all of a sudden.

**AR** We did surveys as part of a group I'm part of, and what used to be the number one reason that people look for something new in their career was pay, benefits, job security. Now it is wanting to make a difference.

**JM** This generation wants to feel their job means something. And also, after COVID, they want the freedom that to me is a little scary - people don't even want to go to a work environment, to an office, or to a plant. They just want to work from home. I understand it, and I value the balance of a hybrid situation, but I think the interaction between people, the collaboration in person, and especially for newer engineering graduates, the need to gain that experience from the people that have been there before, is important. There's got to be an adjustment coming, hopefully soon, of people realizing that a hybrid system and a working from home situation are great, but we also have to embrace real life, transferring knowledge, transferring information, and just daily collaboration.

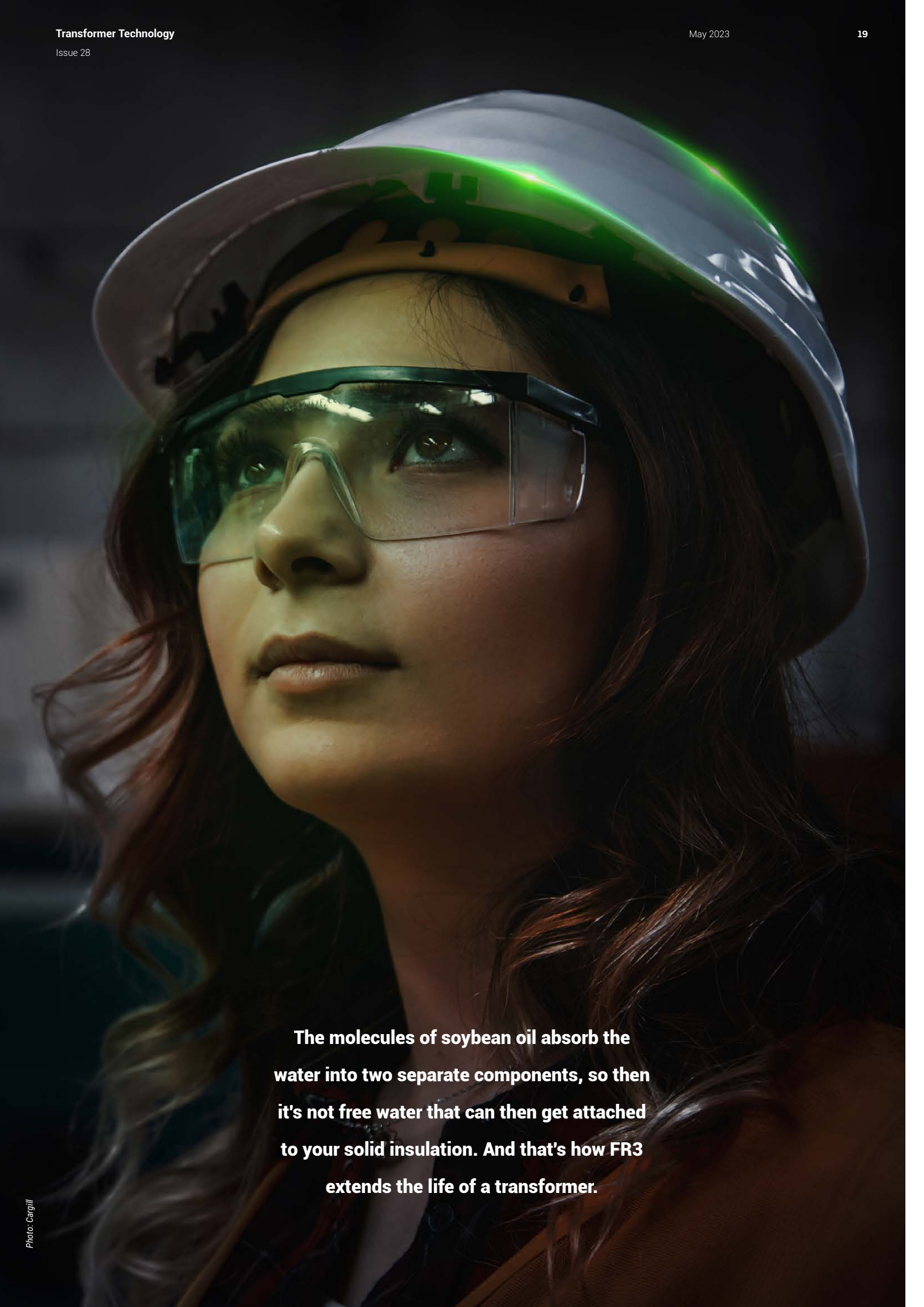
**AR** Another thing is what people want out of a career is community. They want to know they're part of something that does something for society, but they also want to know they're part of a community.

**JM** And you cannot be a part of a community when you're sitting just on the video screen. Especially when people don't turn it on so many times. It's understandable, but it's sad because then you don't get any connection if you don't even turn on your camera.

Sometimes it's hard, especially for women, to find a work life balance. You have your kids at home or you're doing something, and women have to get all pretty to be on camera. There is a lot more social pressure to look okay in front of a camera. I understand it, but when possible, at least that minimum interaction of the video being on is very valuable.

**AR** That's true. It has been a delight, as always.

**JM** Thank you so much.



**The molecules of soybean oil absorb the water into two separate components, so then it's not free water that can then get attached to your solid insulation. And that's how FR3 extends the life of a transformer.**

# Root Causes of Partial Discharge

by **Corné Dames**  
+ + + + + + + +

## Introduction

Power transformers are some of the most expensive components of any power generation system. Reliable operation of all the components within the system is crucial to ensure sustained power delivery. This reliability strongly depends on the ability of the insulation system to withstand the impact of the continued electrical and mechanical stresses on the system during its lifetime. During this service time, all the items forming part of the electrical system undergo deterioration to their insulation systems, this might be due to various contributing factors like electrical, mechanical, thermal, and chemical stresses. Due to this normal deterioration process taking place, some "weak" areas with a decreased capability to withstand dielectric stresses are potential sources of permanent partial discharge (PD) activity. PD measurement is one of the non-destructive methods available which can detect local defects in complex electrical insulation systems.

## What is Partial Discharge?

For more than half a century, it has been a known fact that partial discharge is a symptom of several problems caused by thermal, mechanical (vibration and shock), electrical (voltage), environmental, and chemical processes.

Partial discharges are small electrical sparks that occur within the electrical insulation of switchgear, cables, transformers, and the windings in large motors and generators. Partial discharge is the small electrical sparks that occur when gas pockets exist within the high voltage insulation,

these gas pockets might occur due to thermal deterioration, stator winding movement during operation, or due to other reasons. As the deterioration of the insulation increases, the number and magnitude of the PD will increase. The breakdown of the gas inside the voids creates small voltage pulses that can be detected and measured, and therefore it is possible to monitor the PD. Although the magnitude of the PD pulses cannot be directly related to the remaining life of the winding insulation, the rapid increase in the PD activity or other indicators of insulation deterioration would be a clear indication that the reliability of the equipment is compromised. The testing to determine the presence of partial discharge is a proactive diagnostic measure to ensure the reliability of electrical equipment.

Partial discharge is defined as an electrical discharge that does not completely bridge the space between two conducting electrodes. Partial discharge can occur in various locations in medium and high-voltage equipment. We can differentiate between roughly four types of partial discharge. Each of these types of partial discharge can occur due to different reasons and each with the ability to cause varying levels of damage to the system. A minor defect or deterioration of the insulation encapsulating the conductor might be the cause for the phenomenon of partial discharge taking place. Partial discharge presents as a repetitive sequence of discharges propagating within the insulation and growing over time. Once the insulation is broken down sufficiently to form an unrestricted path for the charge to flow from one conductor to the other, it will result in an arc flash that might be fatal to the equipment.



**Once the insulation is broken down sufficiently to form an unrestricted path for the charge to flow from one conductor to the other, it will result in an arc flash that might be fatal to the equipment.**



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.

There might be various causes for partial discharge. The discharge always starts as a small insignificant scenario that might escalate to ultimate failure at the end of the day. Another definition for partial discharge might be the inability of a portion of the insulation to withstand the electrical field applied to it, or more formally, a flashover of part of the insulation system due to a localized electric field greater than the dielectric withstand capability of a part where the overall insulation system remains capable of withstanding the applied electrical field. [1]

### Types of Partial Discharge

We generally differentiate between two types of partial discharge:

#### 1. PD of the corona type

In a transformer this type of partial discharge will present as gas bubbles in the oil where the gas is ionized in cold plasma of low (ambient) temperature, it will mostly produce Hydrogen gas ( $H_2$ ) together with some Methane ( $CH_4$ ) and will not cause damage or carbonization of the paper insulation. PD of the corona type is also used to describe discharges into air or gas at the terminals of the transformer under test. If shielding electrodes are not used.

#### 2. PD of the sparking type

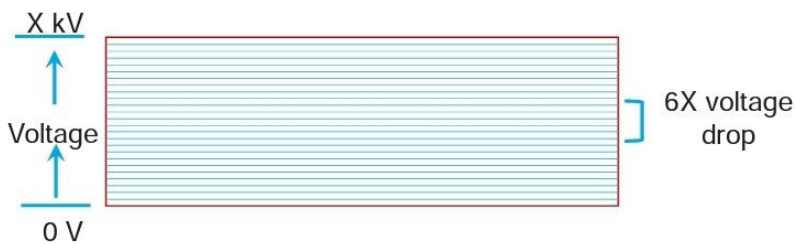
This will occur in liquid (oil) or solid (paper) insulation. These are small arcs and therefore their temperatures are very high (more than  $3000^\circ C$ ). They produce mostly  $C_2H_2$  (Acetylene) and  $H_2$  (Hydrogen) and this will damage the paper insulation (carbonized pinholes, tracking) and the oil will be decomposed, therefore dissolved gases would be present in the oil).

### Defects possibly generating Partial Discharge in transformers. [3]

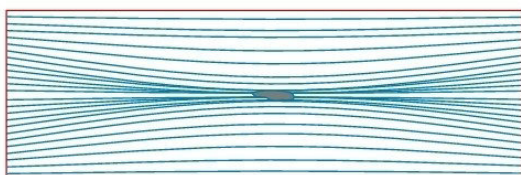
In a transformer with a good design and manufactured to the highest standard, it is very unlikely for PD to initiate during the early life of the transformer unit. However, some discharges might be present as noticed during oil sampling and PD measurement done during commissioning. For these discharges to initiate the has to be some defects present in the insulation system.

- a) Delamination may occur when the thinner pressboard sheets are glued together to form thicker barriers. Voids within these delaminations might remain for a long time.

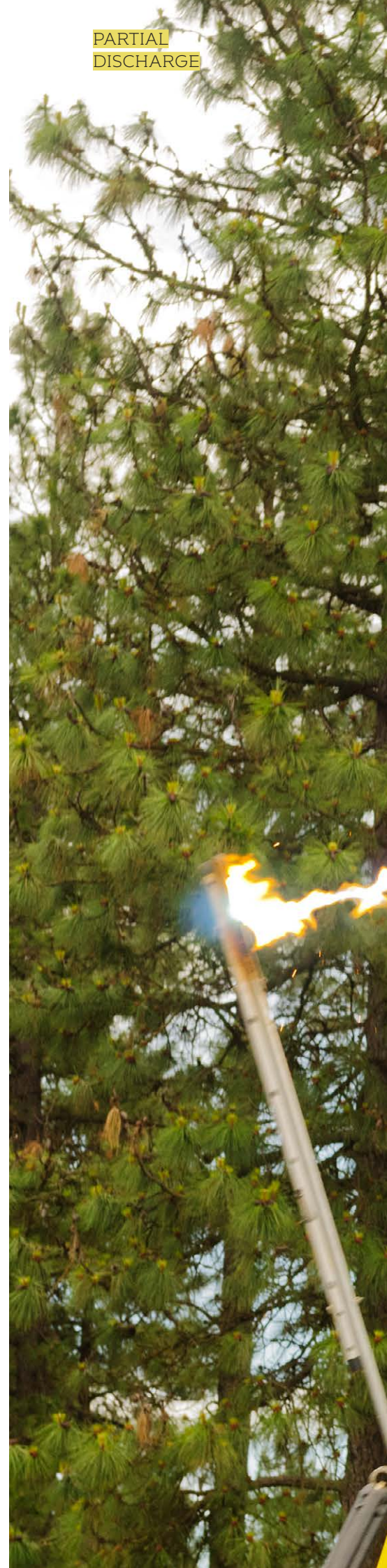
Equipotential Lines [1]



Section through a homogenous insulator showing uniform electrical stress (equipotential) lines. A line indicates where the voltage potential is constant



The same insulator with a void. The lower dielectric of the void causes a concentration of the electrical field through the void high enough to cause breakdown at working voltages





- b) Voids – Voids may occur in glue and Connections with enameled thread, insufficient impregnation of the paper with oil might cause voids to form. It might be possible that these types of voids disappear from one day to the next as the gases are absorbed by the oil and the cavity is filled with oil! Voids might also be present in bushings, a high moisture content in combination with heat and mechanical and electrical fields may create a high local water vapor pressure with a resulting "puffing" effect of boards and winding insulation. Discharges in the "spongy" material may start shortly after this occurrence.
- c) Bubbles formation might be due to gas formation because of the discharges as well as evaporation of water droplets. It has been shown by field studies that a gas bubble in an open oil volume will be ripped into smaller bubbles, which will disappear quickly. Bubbles will therefore only exist in locations Where they are supported by solid insulation.
- d) Free metallic particles- possibly in the wood or stuck to the paper in the windings.
- e) Moisture – This will occur due to the aging of the insulation or might be introduced into the system during commissioning or maintenance work on the transformer. Moisture will contribute in various ways to discharge inception and extinction. During a heating cycle when the transformer is in service (after re-energizing a transformer that has been offline), moisture might be pressed out of the solid insulation. Due to the poor solubility of water in the oil, there might arise a supersaturation of the oil next to the cellulose surface with moisture. This might result in water droplet and bubble formation (2). Evaporation of the water will cause the formation of micro-bubbles and this will lead to discharges. An increase in the moisture content in cellulose paper will make the paper more conducive. Under these conditions, the cellulose fibers will start acting like metallic particles.

Fibers sticking out from the cellulose surface or fibers moving in the oil might initiate discharges. Increased moisture content will also increase dielectric losses. During a cooling cycle, moisture might be absorbed locally by the pressboard. As a result, internal discharges may become prevalent in the cavities within the press board.

- f) A bad connection of electrostatic shields will give large discharges because the capacitance of the defect is large. The "bad" connection will usually have a defined breakdown voltage ( $U_{bd}$ ). The result is the disappearance of charges on the rising flank with voltage-independent amplitudes.
- g) Static electrification – This will give rise to the deposition of local charges. The enhancement of the resulting field may initiate discharges. The discharge tracks due to these types of discharges have been noticed along pressboard surfaces during visual inspection.
- h) Surface tracking – This is a result of discharge propagation and has been found along barrier surfaces and supports. Carbonized tracks can act as conductive protrusions, and may over time increase in length.

### Measurements of PD on transformers

#### 1. Off-line testing in the laboratory

This is used for quality assurance and acceptance testing (Factory Acceptance Testing – FAT) to reveal contamination, manufacturing deficiencies, or incorrect design.

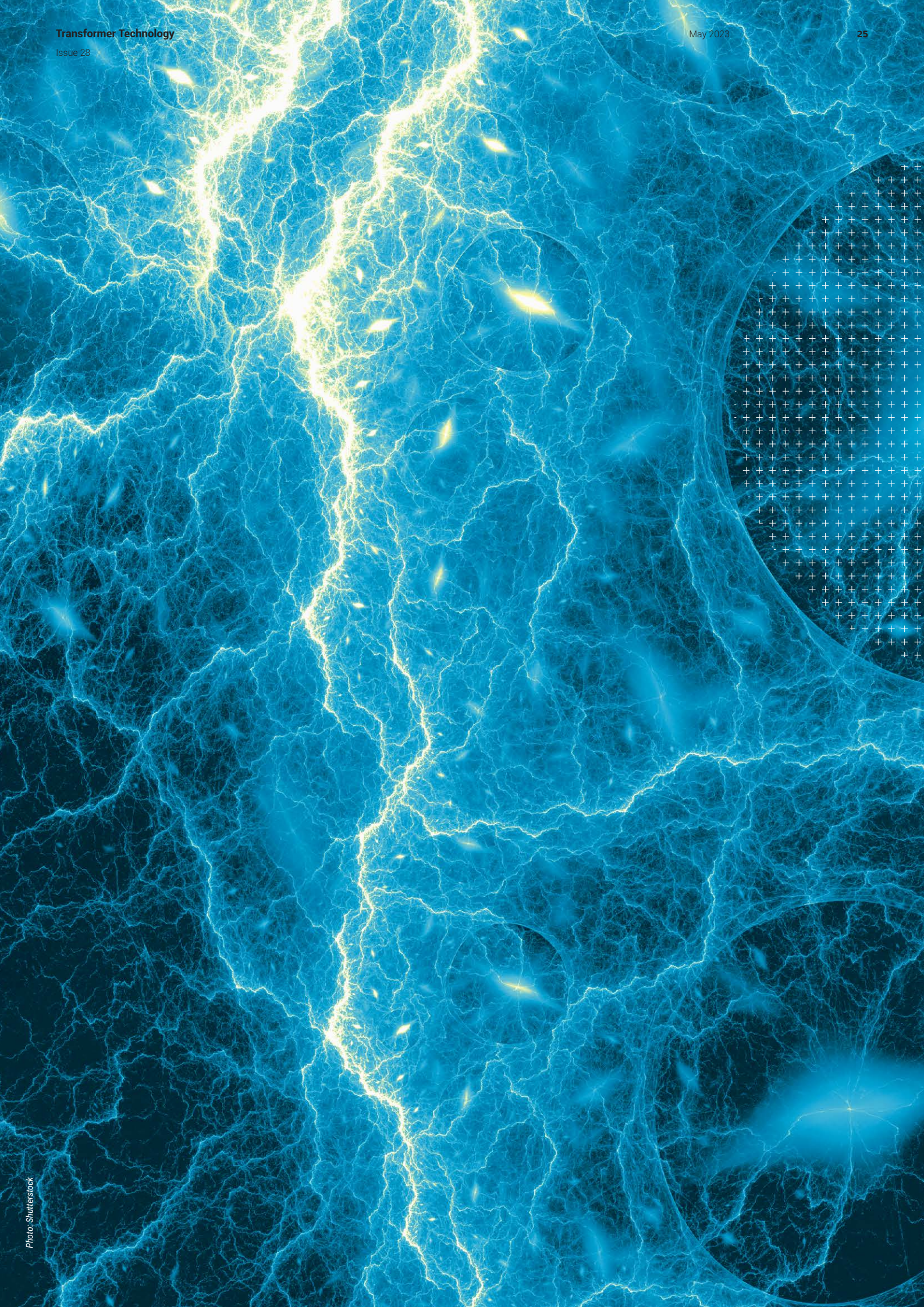
#### 2. On-site PD diagnostic measurement

This could be done online or offline for Site Acceptance Testing. On-line monitoring for new or aged transformers, as a condition assessment tool. This is an on-site test for new or service-aged equipment. This is mainly used for the commissioning of new equipment or after repairs have been done, or for diagnostic purposes as part of the asset management program.

**In a transformer with a good design and manufactured to the highest standard, it is very unlikely for PD to initiate during the early life of the transformer unit. However, some discharges might be present as noticed during oil sampling and PD measurement done during commissioning.**

The application of new diagnostic methods might be due to

1. The movement from a time to a condition-based maintenance strategy
2. The early recognition of insulation degradation
3. Detection of incipient faults
4. Reduction of the cost of outages and unplanned apparatus repairs or replacement.
5. Staff safety
6. The reduction of risk to the environment
7. To identify bad workmanship after final assembly
8. Fleet characterization
9. Optimization of investment decisions



In the past, on-site in-service PD source detection involved dissolved gas analysis based on the taking of oil samples from the transformer tank, using Hydrogen as the key indicator for PD activity in the active part of a transformer. DGA as an indirect measurement is slower to identify a rapidly evolving PD and is usually unable to localize the PD for additional risk assessment. DGA interpretation requires a minimum amount of gas formation to declare a PD activity as significant [Duval 2001]. There are also several practical examples where no increase of combustible gases was recorded despite a PD source being detected by electric and acoustic methods and confirmed through visual inspection of the transformer. It can be stated that electric, acoustic, and electromagnetic PD pulse-based measurements are more reliable in determining PD activity. These methods can be used for the in-depth analysis of PD activity and the assessment of the severity of the threat of PD to the safe operation of the transformer.

In the electrical system, we have the following measurable physical signs that occur as a result of PD.

- Electrical signals are measurable at the bushings of the transformer
- Electro-magnetic transient waves (up to GHz range) are measurable via antennas
- Acoustic sound waves are measurable via acoustic sensors on the tank of the transformer
- The decomposition of the insulating material (oil and cellulose) is detectable by analysis of an oil sample.

**Electric, acoustic, and electromagnetic PD pulse-based measurements are more reliable in determining PD activity.**

## Difference between online and off-line PD measurements

### Advantages of On-line PD measurements

1. Online PD measurements can be performed while the generator is running. They can be performed at any time, while off-line PD measurements can only be performed when the generator is removed from service. This makes online measurements much more cost-effective. Online measurements also provide the possibility to monitor the PD activity of the generator.
2. The operating conditions of the generator influence its PD behavior. Taking the generator off-line

### Advantages of off-line PD testing

1. It is possible to measure the PD activity at different voltage levels. This enables the operator to determine the inception and extinction voltage of PD activity and thereby helping him in the assessment of the stator insulation condition.
2. Generally, off-line PD measurements have a higher signal-to-noise ratio and the influence of disturbance signals is lower. This will result in higher sensitivity, selectivity, and resolution for the offline PD measurements.

## Conclusion

From this information, it is clear that we only touched the tip of the iceberg. So much is left to be said about the test methods and interpretation of partial discharge data which should be addressed in a follow-up article.

It is important to notice that the on-site testing of partial discharge is a delicate science and the practical facts are that we are faced with a lot of "noise" – partial discharge in the background, generated by other equipment in proximity of the test object. The filtering of the signal when determining the partial discharge of the test object is the biggest challenge.

Many companies have equipment with the capability to filter out the background partial discharge originating from outside sources.

On-site it is most important to ensure the accurate and repeatable determination of the partial discharge, to monitor the deterioration as well as the rate of the deterioration. For this reason, it is crucial to use the same equipment for consecutive tests on a specific unit as different test sets might lead to a deviation in results.

The most important test is the initial partial discharge test after commissioning to establish a baseline parameter, or fingerprint, to build on and for future reference. Also, the initial PD reading is extremely important to ensure that no damage has taken place during the transport of the unit and the commissioning steps.

Reference data is crucial to ensure reliability.

**It is important to notice that the on-site testing of partial discharge is a delicate science and the practical facts are that we are faced with a lot of "noise" – partial discharge in the background, generated by other equipment in proximity of the test object.**

### References

- [1] IEEE Alberta Partial Discharge by Tim Erwin of EA Technologies
- [2] V.G. Davydov, O.M. Roizman, W.J. Bonwick, "Transformer insulation behavior during overload." EPRI Substation Equipment Diagnostic Conference. V,TR 111282,1989, pp II -53 to II -72
- [3] Cigre Brochure 226, Task Force 15.11/33.03.02 – April 2003, "Knowledge rules for Partial Discharge Diagnosis in Service."



# Ben Lantz





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Undergrounding has a societal benefit, a long term benefit. Investment decisions should evaluate the "total cost of ownership" of overhead versus underground over the life of the asset. This is how we will get maximum societal benefit.

**Director of Strategy and Development at IMCORP**  
**Executive Board member at PDI²**

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Interview with **Ben Lanz**

**Alan Ross:** My next guest is a friend and a brother, and this is going to be fun. Ben Lanz is the Director of Strategy and Development at IMCORP. He is also an early Executive Board member of PDi<sup>2</sup>. Ben, thank you for being here.

We're going to go on two tracks. One of them is to talk about when you formed PDi<sup>2</sup>, who formed it and why it was formed, and what you think is going to happen.

**Ben Lanz:** While I was very involved in building the organization to where it is today, the original group was a smaller subset. It included Dow and Borealis as material suppliers, some wire and cable manufacturers, and companies like Quanta, who install overhead and underground power systems. We noticed that when we visit with utilities and industrials alike, there's a lot of myths and rules of thumb that people follow when they're making infrastructure investment decisions. Often the conversation went something like this: we thought about underground, but overhead is cheaper, so we went cheaper. The idea of PDi<sup>2</sup> was to form a team including a diversity of companies with expertise in different areas, combine our collective knowledge and best practices, speak to the industry with one voice, and help the industry make better infrastructure investment decisions.

**The idea of PDi<sup>2</sup> was to form a team including a diversity of companies with expertise in different areas, combine our collective knowledge and best practices, speak to the industry with one voice, and help the industry make better infrastructure investment decisions.**

There's a whole set of myths tied to undergrounding. For example, a common myth is that if you're in a floodplain, well, water and cables don't mix, so you can't do that. The facts are that four feet below the surface of the ground, there's 100% condensing moisture. Cables are operating below ground in water or moisture for their entire life and the flooding concern is really a nonissue. People want to make informed infrastructure investment decisions, but myths like these get propagated into rules of thumb which drive poor decisions. We're agnostic as it relates to overhead versus underground, but it is clear that much more education about underground is needed. Another example is related to cost. In many cases, legacy rules of thumb drive people to say the cost of underground is X number of times of the cost of overhead, so the underground option isn't even considered. The reality is the lifecycle analysis of underground may make more sense in many more applications than people would

first realize. We're promoting sound decision making based on the lifecycle cost and giving people case studies they can use to pattern how leading utilities make investment decisions and what parameters to include in the models that they're using to justify costs.

**We're promoting sound decision making based on the lifecycle cost and giving people case studies they can use to pattern how leading utilities make investment decisions and what parameters to include in the models that they're using to justify costs.**

**AR** I have a son, a daughter-in-law and a grandbaby in California. My wife and I spend a good bit of time there. One of the big things in California that we deal with are all of the weather-related things and fires. But I understand there's a hunger within California utilities for that kind of information to make wise decisions. Talk a little bit about California utilities, what's going on there, and PDi<sup>2</sup>.

**BL** There are a number of reasons why utilities are strategically undergrounding assets, and that varies by region.

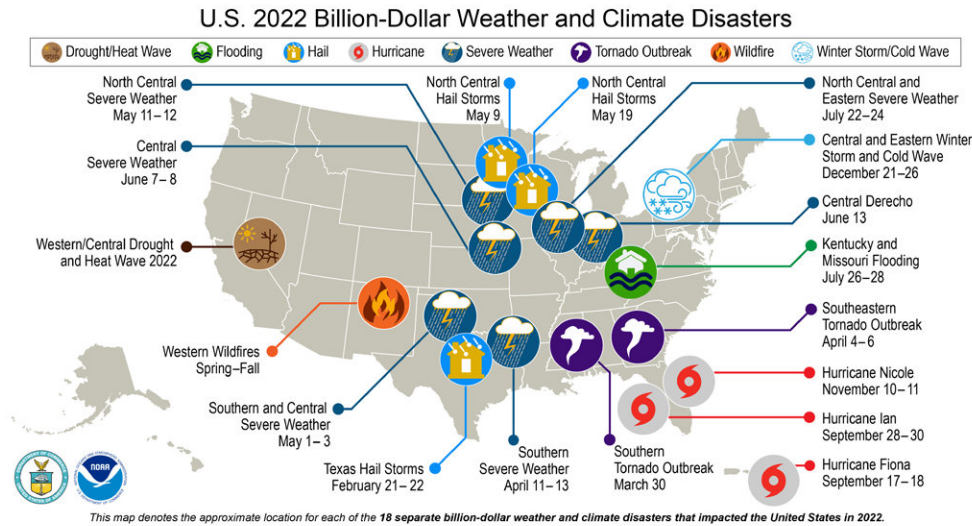


In California, it's the wildfires that are primarily driving decisions.

But if you look at Florida, it's the hurricanes. And Wisconsin, they have the emerald ash borer and other trees. They have 40, 50,

60-foot-tall trees coming down and taking lines out, even if they have trimmed the trees.

More and more, there is a recognition that no matter where you go in the country, if you look at the NOAA website, billion-dollar natural disasters are everywhere.

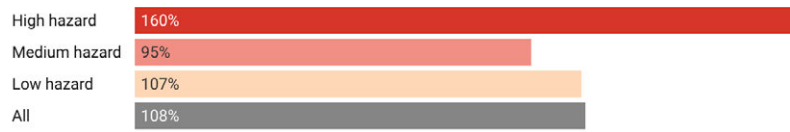


Source: National Centres for Environmental Information



## Population growth in the wildland-urban interface

The number of people in the wildland-urban interface, where development and wilderness meet, expanded disproportionately in areas facing the highest wildfire risk from 1990 to 2010.



Data shows population growth from 1990-2010.

*The Conversation/CC-BY-ND*  
*Source: Krishna Rao 2021*



Again according to NOAA, every year, we spend something on the order of \$20 billion on clean up and maintenance after storms. In California, they may not have the ice storms or the hurricanes, but they have the Santa Ana winds, and they have the fires.

There's even a term for the areas of high risk - the wildland urban interface, the WUI.

Apparently, this is where people want to live. In fact, even after the fires, according to some of the organizations that track this, people are moving back into those areas in droves. In that interface, the growth rate is higher than many other places in the country. Also, about 30% of our population lives in the first county along the coasts, so if you think about that, we apparently want to live in harm's way. It's beautiful - the oceans, the rivers, the mountains, but that's where the danger is.





List of coastline counties: <http://www2.census.gov/library/stories/2018/08/coastline-countries-list.xlsx>  
Source: U.S. Census Bureau

Historically, man has decided to live away from that kind of danger. I believe, as a society, that we're willing to somehow take that risk, because we believe it is a reasonable risk. But all of a sudden, in California you have this large population that's living on that wildland urban interface and they are trying to figure out how best to manage a power system that can ignite fires. So California has a very interesting situation. Right now they are taking counsel from the ratepayers, utilities, consultants, and they are looking for input. Usually their utility rate cases are on a three-year cycle. Now they are talking about a ten-year rate case. An opportunity to make a ten-year investment in underground. I believe California is realizing that undergrounding has a societal benefit, a long term benefit. Investment decisions should evaluate the "total cost of ownership" of overhead versus underground over the life of the asset. This is how we will get maximum societal benefit.

**AR** Is it more cost-effective from a testing and maintenance standpoint for undergrounding than overhead, or is it about the same?

**BL** No, it's dramatically different. Underground is ten times more reliable on average than overhead. That's ten times less call outs. And people will immediately say, oh, but sometimes it takes a lot longer to find the fault. Well, that was our grandfather's grid. There are these things called line sensors that are a technologically advanced and low-cost way to quickly locate underground faults. In fact, I think you had one of the companies on one of your sessions earlier this year, Sentient Energy, that has some rather sophisticated sensors. But there's also fault indicators, very simple devices that can triangulate where the

fault is. You can also use factory comparable PD testing to locate and remove the defects before the cable systems are energized. But even if you have a fault, and you have a crew who is trained to isolate and locate underground faults, you're talking about driving a minivan out there to isolate the fault instead of one of these large bucket trucks and at ten times lower frequency. Think about how that relates to operating maintenance costs. At some investor-owned utilities, they can spend five to ten times more on capital instead of O&M and have the same impact on their stock price. If you think about T&D investment from this lens, utilities want to invest in using capital to remove future O&M. So if you have a solution, albeit potentially more expensive from an upfront cost stand point, investor owned utilities can get excited about this.

**AR** I hadn't thought about that as a case for underground, but it is. Like anything, it's the total cost of ownership over the life cycle. The whole DER thing is - we've been through the problem of making it cheap, and suffering the consequences of not doing it right. People were buying \$13,000 transformers instead of \$16,000, they saved \$3,000. But now you got a gassing transformer that is significantly more costly to replace. Anyway, it's bad decisions and myths [that don't help], as you say.

**BL** And it's a lack of information. So PDI<sup>2</sup> is all about information. Anything that we produce from our research, any case studies that we document, we make that available to the public. We want people to make their own decisions, but based on solid information, and not something that's a myth or a rule of thumb that was made on our grandfather's grid and perhaps by a siloed group of individuals.

**AR** What is your exact role with PDI<sup>2</sup>?

**BL** Well, I'm the immediate past chair, which means I spent the last few years in the Vice Chair and in the Chairman of the Board position. I am thankful to say that during this time we doubled our size. And most of our growth, at least visible growth, has been in the vendor space including consultants, material suppliers, contractors, equipment suppliers, cable manufacturers, and line sensors. We're building this consortium with the companies and individuals who know how to get it done using the latest technology, and even some forward-thinking technologies, like something as exciting as using plasma torches to cut holes in rocks and accelerate trenching, even in the most difficult situations. We have some really forward-thinking ideas, but also some value we bring is just knowing how to do things at scale. For example, some of the utilities who advise us and are building systems at scale are Dominion, I believe they just announced that they hit 1800 miles of undergrounding. WEC Energy Group has installed 2000 miles. PG&E is saying that they're going to install around 10,000 miles and Florida Power and Light says 27,000 miles. There is a trend in certain areas where people see that all of the benefits are lining up. For example, with FPL, they see the gross domestic product of the state as part of the equation.

When you start thinking about the challenge of infrastructure investment from a societal standpoint, all of a sudden, the calculus changes. When several life-cycle factors line up, you're seeing some utilities really jump on undergrounding in a big way. I believe we as a

society need to decide, if we are going to live in dangerous places, are we also willing to deal with the climate and weather as it is and tolerate long grid outages after storms? Also, are we going to have predictable grid investment, or are we going to continue to experience surprise rate hikes, every three years or so because we just had another big storm? Are we going to consider the impact to gross domestic product? When the GDP takes a hit, that's actually tax revenue. If we think of the problem from a tax base opportunity, it is no longer an issue just for the utility and the regulator, it's the legislators that see the impact. For example, Dominion went and got a rider on a bill that's paying for their undergrounding because the legislators are convinced the program helps everybody in the state.

**I believe we as a society need to decide, if we are going to live in dangerous places, are we also willing to deal with the climate and weather as it is and tolerate long grid outages after storms?**

I would say what's exciting about this movement and this trend is that people are seeing infrastructure investment as a societal benefit. It's not just a profitable business scenario, there's a larger societal benefit angle to the whole conversation.

**AR** Next time we're together, I'm going to ask you about all of that as it relates to resilience and reliability. But our time's up. Thank you so much. Good to see you.

**BL** Good to see you again.





PART 2



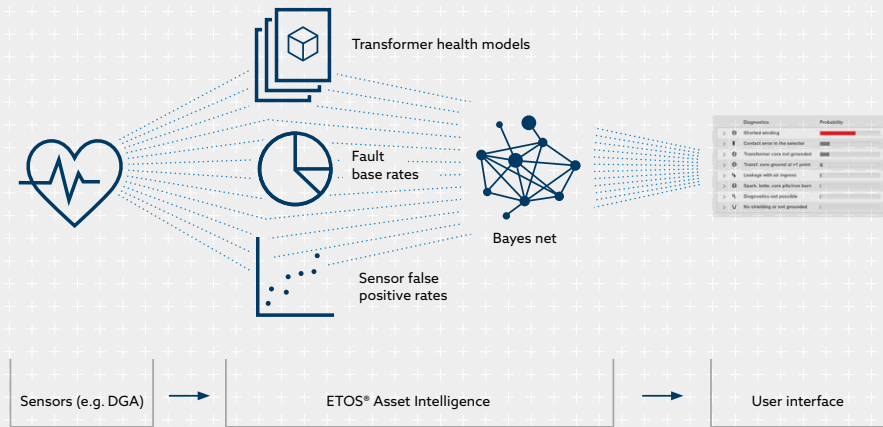
NEW TECHNOLOGIES CAN HELP COMPENSATE FOR THE LOSS OF PERSONNEL KNOWLEDGE AND THE INCREASED DEMANDS ON OPERATING EQUIPMENT

In the last article (March Issue), we described the use and integration of typical sensors with more analysis and inside-view and will now expand the collection and further analysis by edge devices and central solutions.

### Intelligent maintenance of power transformers through ETOS® Asset Intelligence

Monitoring and sensor systems, such as DGA systems, are often installed on power transformers for early fault detection. These can detect operating states and send corresponding messages when limit values are exceeded. However, the mere attachment of various sensors has two decisive disadvantages.

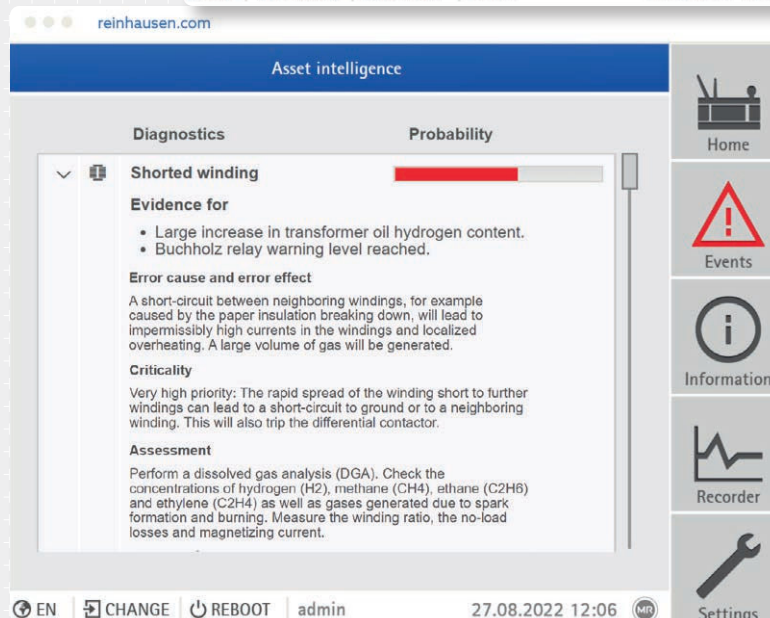
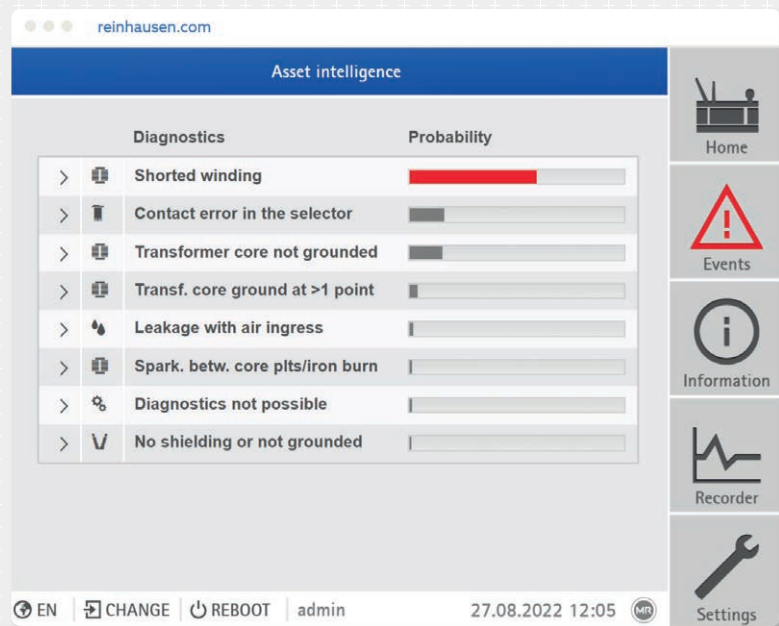
Firstly, the sensors generate a lot of data and messages which are not centrally monitored and evaluated, and multiple events per transformer cannot be easily monitored and interpreted. Secondly, sensor values are not used to comprehensively assess a problem. For example, if temperature, partial discharge and DGA sensors are all capable of detecting winding faults, their statements are not compared with each other. Thus, contradictory statements can occur, and a simple diagnosis is not possible.



The result is a probability estimate for all known transformer problems with the most likely problems being displayed to the customer, along with a list of reasons for the findings. This allows the specialist to interpret the diagnostic results in a simplified way.

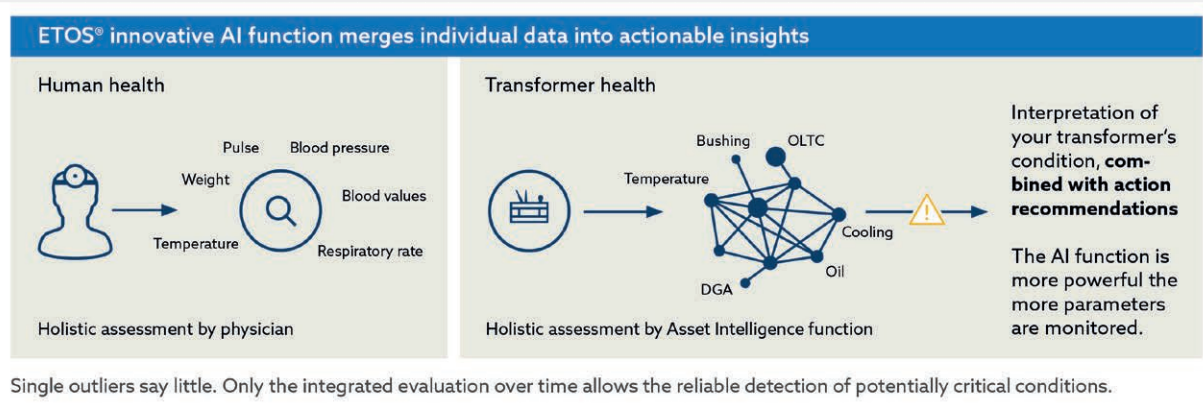
The following example serves as an illustration: The Buchholz relay has tripped and the hydrogen level is greatly increased. Otherwise, there are no further limit violations. ETOS® Asset Intelligence provides the following findings:

**In the central field device (ETOS®), all sensors present on the power transformer are integrated and considered together.**



Like a human doctor who can diagnose through holistic assessment, Asset Intelligence for power transformers provides a guide to minimize risk and take corrective action quickly.

Due to the accurate fault description, the operator knows how to correctly classify the fault, assess its criticality, and initiate the next steps. Qualified fault diagnoses are provided based on the probability of the most common transformer failures as well as the actual measurements and results. The more sensor readings available in the process, the more powerful Asset Intelligence is. Like a human doctor who can diagnose through holistic assessment, Asset Intelligence for power transformers provides a guide to minimize risk and take corrective action quickly.



By using ETOS® Asset Intelligence, the power system operator can compensate for the loss of knowledge due to the departure of qualified personnel and make the asset management of power transformers more efficient.

### Global view of a transformer fleet for efficient asset management

#### Enterprise Asset Performance Management/APM

In times where operative costs must be considered and budget principally shrink, we look for alternative ways of evaluating the physical health of our transformer fleets and adjust strategies to ensure a stable operation of the grid. But how to manage these requirements and how to deal with a fleet of transformers that gets older and mostly consists of different suppliers and several variations over the last years.

We believe in a central solution that covers all online and offline data: no matter if they are measured in real-time by sensors or if they have been measured by hand in on-site inspections or while a maintenance. We call this TESSA® APM and offer a comprehensive system that collects data, checks if limit values are exceeded, use powerful artificial intelligence to recognize trends and give recommendations for your asset- and service-management how to act and what to plan.

We believe in a central solution that covers all online and offline data: no matter if they are measured in real-time by sensors or if they have been measured by hand in on-site inspections or while a maintenance.

To meet your specific requirements and to match your needs, the system is adjustable in its integrated functional modules like online-connectivity, oil-analysis, asset intelligence and so on – those will be described shortly. Important is, that the system also has a powerful interface setting that allows to use TESSA® APM in combination with a existing database solution of your company to exchange necessary data instead of have separated systems in parallel. That ensures a "single-point-of-truth" methodology and reduces efforts of the personnel.

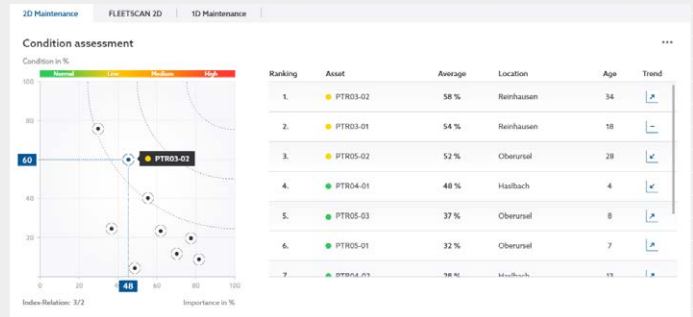




### Condition Assessment

Reliable evaluation standards

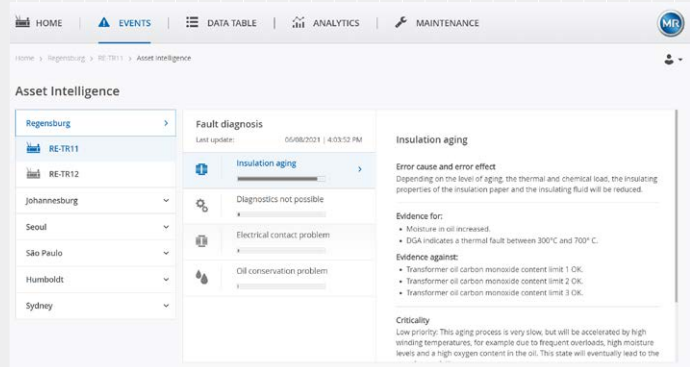
- Combine various data sources (including offline and online data) to gain a clear health index of your transformer
- Configure weighted indices for condition, risks and importance to reflect your asset management philosophy
- Compare to reliable indices defined by MR according to industry standards and expert knowledge



### Fleet Monitoring

24/7 online monitoring of success critical assets

- Connect sensors for continuous data transfer or import sensor data manually
- Apply flexible analysis to sensor data
- Detect critical conditions
- Receive automated interpretation of events



### Summary

#### Customer Statements

"We chose MR's system so we could monitor more remotely.

**In this way, we save resources and ultimately money.**

We also want to understand how components change over time **to better assess service life and necessary maintenance."**

Customer testimonial from a power plant operator in southern Germany/Switzerland



**ETOS®**

EMBEDDED TRANSFORMER OPERATING SYSTEM



**Tobias Gruber** is Automation Portfolio Manager at Maschinenfabrik Reinhausen GmbH, where he has worked for 10 years. He helped develop the current automation systems, i.e., ETOS® for power transformers. He holds MSc. in electrical engineering and is an expert for automation applications responsible for the automation portfolio at MR.

# Marcel Hilgers Hossain





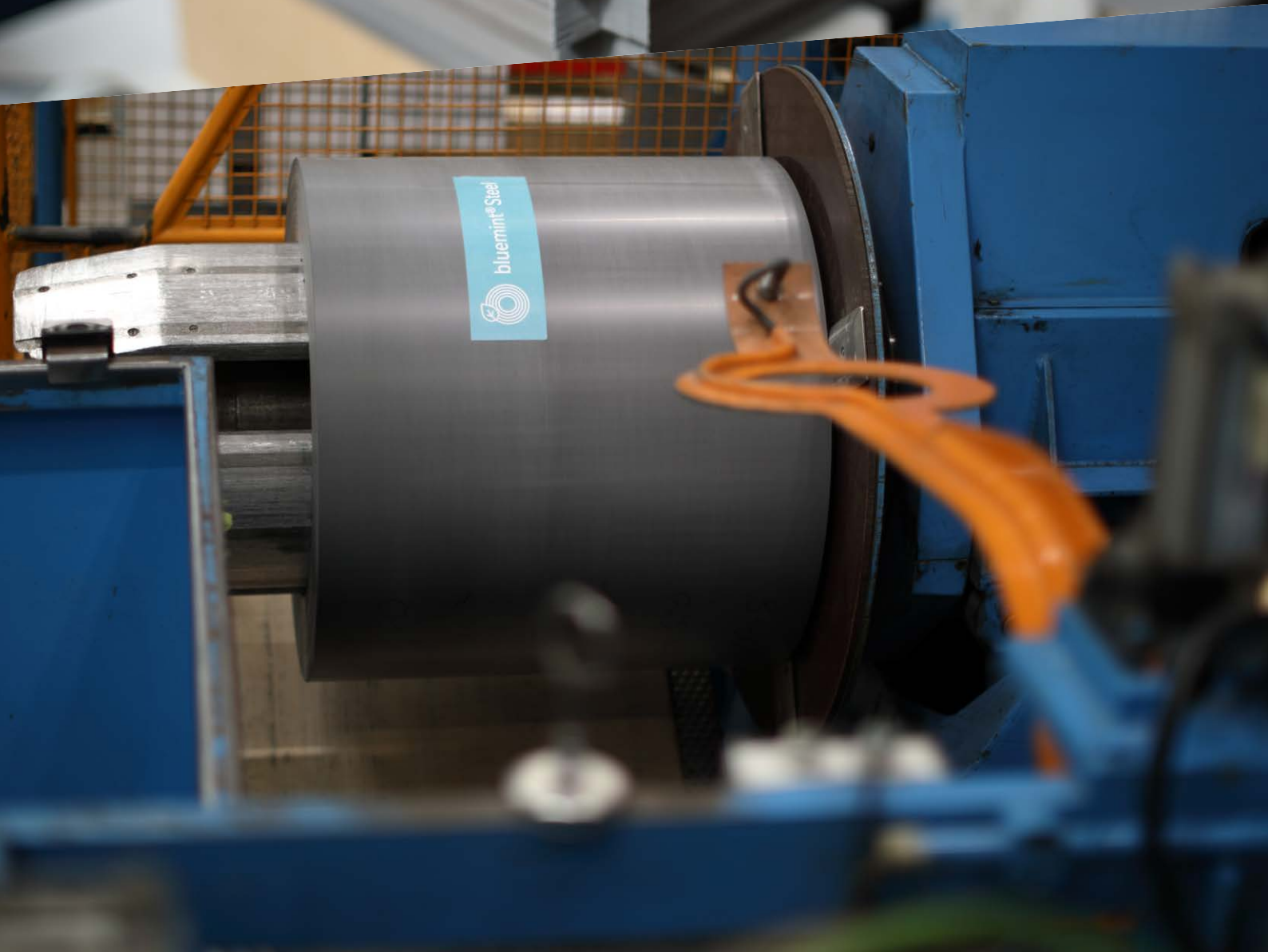
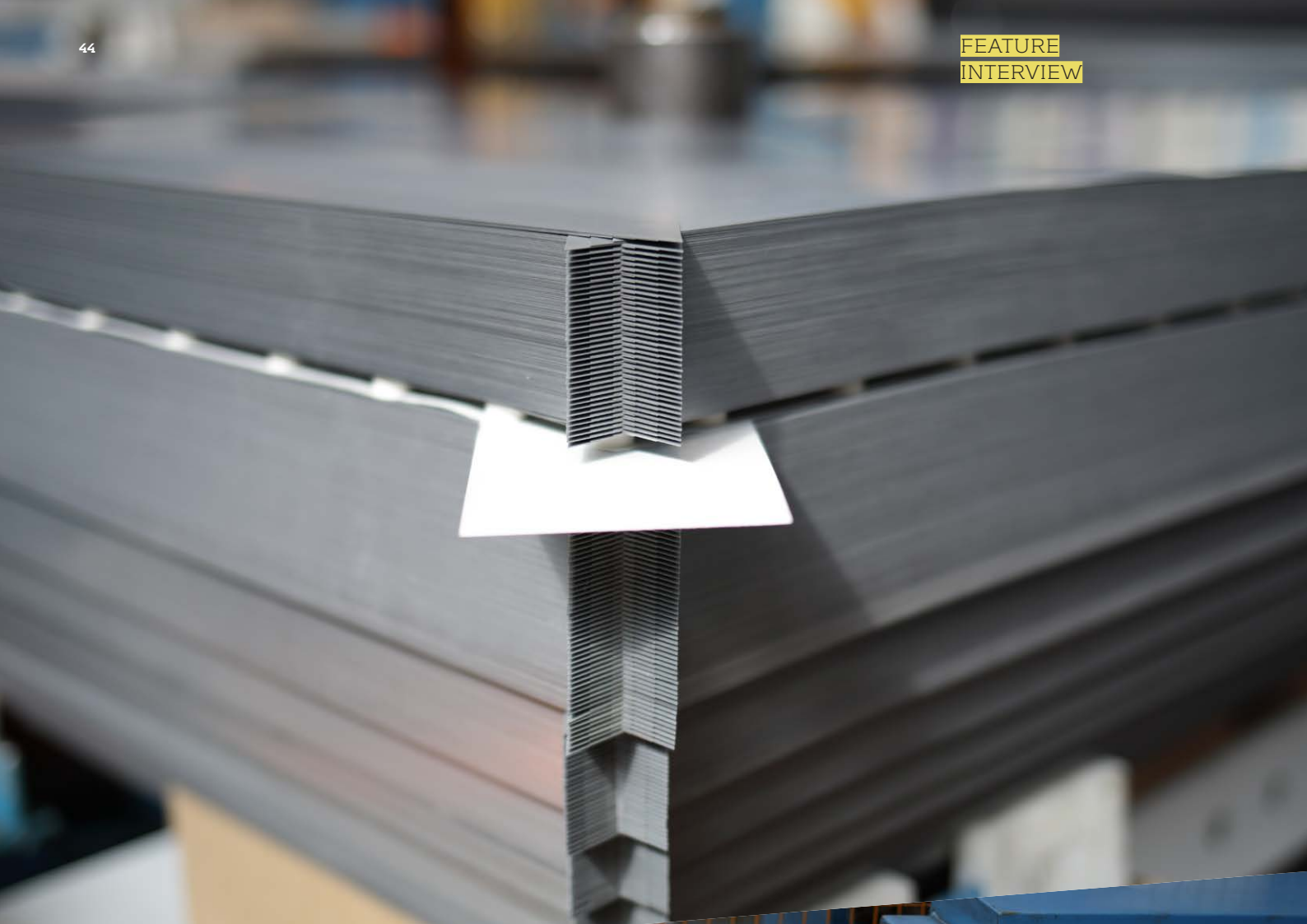
# El Hachhouchi



# Ulrich Voss

**Vice President, Marketing and Sales for Power Transformers at SGB-SMIT**  
**Head of Sales, Technical Customer Service and Communications at thyssenkrupp**  
**Manager of Procurement at Enexis**

Interview with **Ulrich Voss**  
**Marcel Hilgers**  
and **Hossain El Hachhouchi**



**Alan Ross:** I have a delight today. This is not your normal one-on-one because we have three people here. I was looking on LinkedIn and I saw something about a transformer that was made by SGB-SMIT. It was made using steel from thyssenkrupp, and it was made for a company called Enexis. So let me introduce my guests, because we're going to talk about that transformer.

First, this is Ulrich Voss. He is from SGB-SMIT. Ulrich, what's your title there?

**Ulrich Voss:** The official title is Vice President, Marketing and Sales for Power Transformers.

**AR** And this is Marcel Hilgers. He is with thyssenkrupp. Marcel, what's your role there?

**Marcel Hilgers:** Thank you, Alan. I'm pretty happy about my title because it's not really a title. I'm taking care of customers, markets and technology. I am also VP Sales for thyssenkrupp Electrical Steel Group.

**AR** Last, but not least, Hossain El Hachhouchi. Hossain is with the Enexis. What is your role there, Hossain?

**Hossain El Hachhouchi:** I'm the manager of procurement, responsible for the purchase of all the grid components and IT at Enexis.

**AR** I love the story about how we came about with the transformer that you bought. It is very unique: inspirational and aspirational. I want to start off, first of all, with you, Ulrich. SGB-SMIT is a big company. You make a lot of transformers and other electrical components. What in the world caused you all to think you'd like to be able to produce a carbon neutral transformer? How did you get involved in that?

**UV** I would not say carbon neutral, but for SGB-SMIT, sustainability is really one of our key drivers towards the future. And a big part of this is CO<sub>2</sub>. We were thinking a lot about how can we, as a transformer manufacturer, reduce CO<sub>2</sub>. As a manufacturer, we can do a limited number of things. We can produce less waste, avoid waste, use LEDs. But the main drivers are the customer specifications regarding losses, because low losses over a lifetime make a huge impact. And then there are our sub-suppliers. One of our main sub-supplier coal-based materials is core steel, with a portion of approximately 30 - 40%. Therefore, thyssenkrupp is with us here in this talk.

**AR** To get to carbon neutral, you have to get lower CO<sub>2</sub>, so decarbonization is

more where I was going for. We're all moving to try to get to a carbon neutral economy.

Now you're looking at a sub-supply of a major component of transformers, and you talk to Marcel at thyssenkrupp. Marcel, tell us a little bit about how, when you were working with SGB-SMIT, you came up with the idea - we've got to do the same thing, because it's not just what you did in this project, it is a commitment from the whole company to be able to decarbonize, digitalize, and decentralize, right?

**For SGB-SMIT, sustainability is really one of our key drivers towards the future. And a big part of this is CO<sub>2</sub>.**

**MH** I think we are on the same mission in this, the overall electricity industry. But let's have a quick look into the steel industry. In the steel industry, we are a major polluter. So globally, about 8 to 9% of CO<sub>2</sub> emissions are created by steel and iron making. Therefore, we are a big part of the problem, but also a big part of the solution. We as a company have clearly taken commitment right now. Our target is to decarbonize our production completely until the year 2045. But we are doing this in steps. Today we already have decarbonized the steel solutions available. And for this, of course, we need customers, transformer makers, and of course, transformer makers need customers. We are looking for pioneering partners in this big transformation phase. SGB is a dream partner, so to say, because they are really looking forward to decarbonize as well. Naturally, we got together about this for the first steel with a reduced CO<sub>2</sub> intensity to be delivered to them.

**Globally, about 8 to 9% of CO<sub>2</sub> emissions are created by steel and iron making. Therefore, we are a big part of the problem, but also a big part of the solution. thyssenkrupp has clearly taken commitment right now.**

**AR** This is brilliant. If they didn't have a customer, so if thyssenkrupp did not have a customer, SGB, and if SGB-SMIT didn't have a customer, Enexis, none of this would happen. As the procurement expert, you all came along and when they brought the idea to you, adopted it and said, yeah, we would like to work as partners. Talk about when you first heard about it and your role in creating specs and then ultimately saying, we will buy that transformer.

**HE** Let's begin with the credits where they are due, because it's an idea that

actually existed between Ulrich and Marcel. When Ulrich approached us with this idea, we were very enthusiastic about it. To lower our CO<sub>2</sub> impact as a DSO, we focus mainly on lowering the loss of energy during transport. The idea of thyssenkrupp and SGB-SMIT takes that objective a step further. That's quite interesting because as a DSO we do encourage the sustainability production initiatives. But to make a shift, or transition from natural gas or coal to hydrogen, that is a great step and you need you need the industry. I'm very happy to see that these two organisations made this step, especially thyssenkrupp, to be able not only to have a pilot, but to also invest largely in hydrogen production and using hydrogen in the process of melting steel. I hope more will follow, because this is, I think, the only way forward.

**AR** I always love to see where the inspiration came from. As much credit as we're giving to Ulrich and Marcel, the companies that they work for had to make a commitment. Kudos to your bosses and your boss's bosses and the people at the top.

Now let's get down to the basics. How did we get there? I want to talk about the steel first. You said you're a big polluter. We don't want people to know that. We want them to think that steel is made in a garden where flowers grow. Steel is a major component to everything we do and always will be. Talk a little bit about how thyssenkrupp got there. How did you decide that you wanted to make a steel that could be used in a transformer that could be purchased by a customer?

**MH** Thank you, Alan. We are really in the biggest transformation of our company since ever here. Steel has been made for thousands of years, literally, in a blast furnace process using iron ore and coal as a reducing agent. A lot of CO<sub>2</sub> is created by the process itself. To give you one figure here, 3.8 metric tons of CO<sub>2</sub> is created, in our case, per one ton of grain-oriented electrical steel.

Our commitment is replacing all our blast furnaces. We have four of them, and we make around 11 million tons of steel, which creates around 20 million tons of CO<sub>2</sub>. We want to get rid of all of this by applying a new technology - direct reduction technology. In the future we will use iron ore, same as before, however, we will replace coaking coal with hydrogen as a reducing agent. This means water vapor is coming out of the furnace and we have iron sponge coming out of this device. Today we already have "fast track" solutions, such as feeding existing blast furnaces with hydrogen and special scrap as raw materials. And this is what Ulrich is using with SGB.

We have some very, very important news for our company. Earlier this year, we have commissioned the order to engineer and construct the first direct reduction plant with submerged arc furnace smelters. This is an investment of more than EUR 2 billion. And here, Alan, is the answer to your question. This solution needs pioneering because there is no market for this at the moment. But we know there will be a market. Also, in the future gray products will cost more than green products.

***In the future, gray product will cost more than green products.***

**AR** This is happening. It has to come to what I call scale. But scale is people like SGB-SMIT saying yeah, we want to participate in this. And you just spoke about it, Marcel, about the corporate commitment that you made. That's a huge commitment. It also takes a lot of garbage out of the air and hydrogen in itself can be a problem, so you got to do it in a safe way. What is the commitment not just to this transformer, but the commitment from SGB-SMIT to this whole pioneering issue?

**UV** In a way that we really worked with thyssenkrupp and we agreed that they will be the first to bring this to the market. I can only return the compliment - thyssenkrupp is the ideal partner for that. We were the first bringing this to the market and the question was which power transformer customer we should start with. There was no doubt, we selected Enexis. We have a partnership lasting for about 20 years. We supplied so many of these power transformers to them. Therefore, we introduced this idea, and they immediately accepted and welcomed it, and also were willing to continue.

**AR** Hossain, how is the Enexis using this opportunity to express to your market the change and the impact on their lives? I assume your marketing department is getting all over this.

**HE** Well, our situation differs a bit from what is common in certain markets. We are the only DSO in our region. This creates a certain responsibility and cost-consciousness. This means that it's very important for us to keep the prices low. We are very thankful that SGB was willing to deliver the first unit cost neutral.

We are absolutely committed to the partnership that we have with SGB, and we definitely embrace the steps that Marcel and thyssenkrupp are taking towards pioneering in





this area, but it also needs some help from the EU and national governments.

***We are the only DSO in our region. This creates a certain responsibility and cost-consciousness. We are very thankful that SGB was willing to deliver the first unit cost neutral.***

**AR** There's a price to pay at every level. Thyssenkrupp is investing billions of dollars.

We've talked about production and how you're moving to hydrogen. You all are way ahead of everybody. You're the pioneer. And remember what happens to the pioneer. They're the first ones to get shot. So let's put some protection around you and bring some other people to the party. SGB-SMIT, thank you for the fact that you're actually supporting this, because you got the pressure on costs that the consumers and government puts on an excess.

Now it's a matter of scale. And I think scale is coming a lot faster because I know that in the United States we have a thing called the Inflation Reduction Act. It's \$345 billion, of which 40 billion goes to the power industry to reduce carbon. Canada has also stepped up. We're getting Latin America to step up. Europe just passed something on a EUR 58 billion approach to hydrogen economy. Ulrich, do you have any advice for them?

**UV** I wanted to support the statement about governmental support. We as a transformer manufacturer need support from the regulators, from the government. CO<sub>2</sub> needs to find a way into the specifications in a way that it is given clear guidance from the top down.

***We as a transformer manufacturer need support from the regulators, from the government. CO<sub>2</sub> needs to find a way into the specifications in a way that it is given clear guidance from the top down.***

**AR** I think Marcel is the one that ought to end this conversation about the inspiration of what thyssenkrupp is doing.

**MH** I have a very fresh experience here. I'm currently in Italy at a trade exhibition, which is about the electricity industry. And I gave a speech about this topic here - CO<sub>2</sub> reduced steel for this industry. In the audience, there were questions coming which exactly addressed what you just mentioned.

They were saying, we are on board and we want to do this, but we need regulations, and we as an industry need to come together to create this, as there's too much confusion. Of course, we encourage this, because what is sometimes, as a business person first, a bit hard to digest and understand, is that in the end, it's about decarbonization for our future. It's not so much about now, the next business case, competing and so on. Yes, we are pioneering this and we will continue with this absolutely, with our commitment. But we do see, of course, the whole steel industry moving in Europe, as well as elsewhere. We embrace this as well, because that creates credibility for this product, for the industry.

And it's a good thing in the end, as less CO<sub>2</sub> will be emitted. That's what we need.

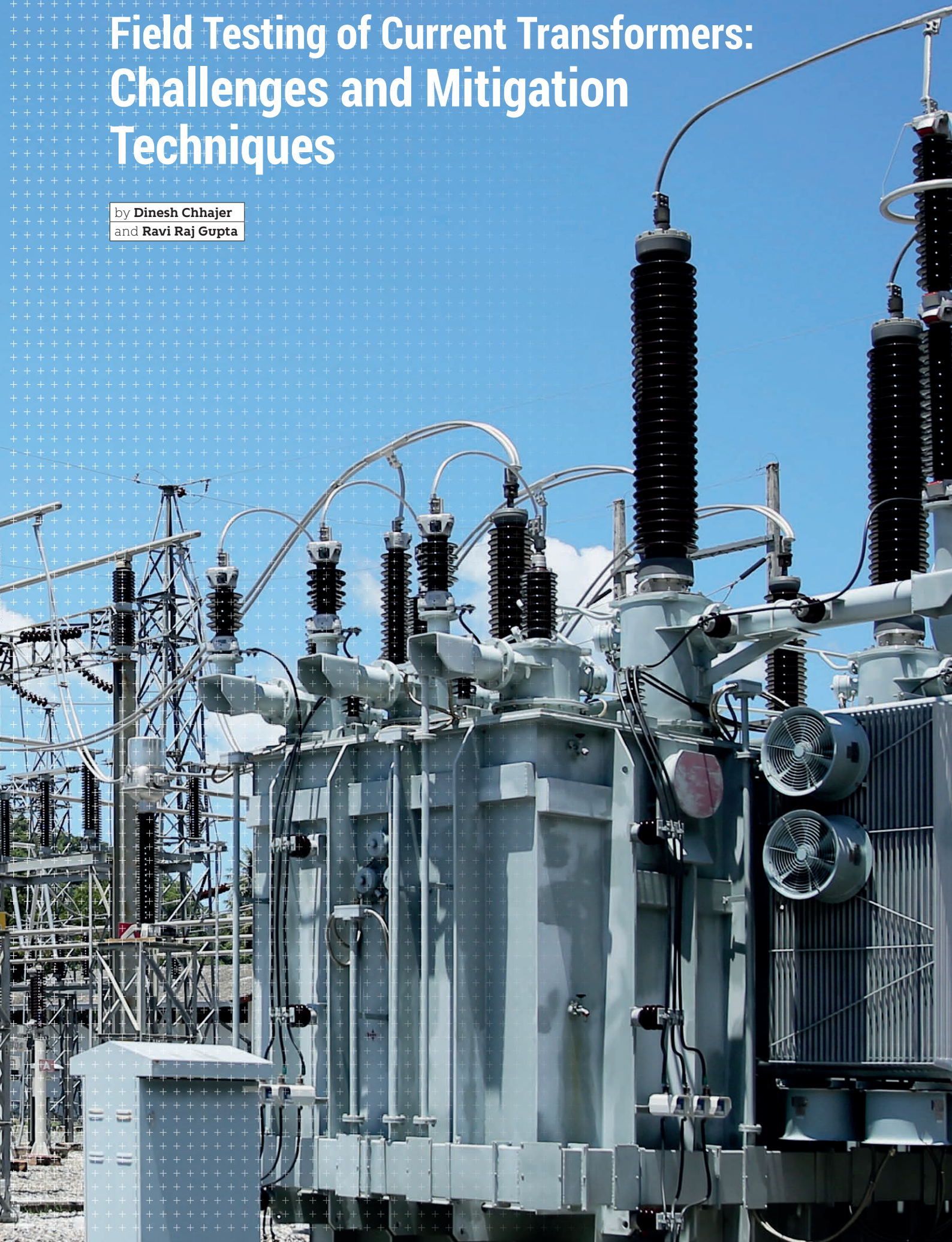
**AR** In the United States, we have an organization called TMAA, the Transformer Manufacturing Association of America. They are a lobbying group to the federal government. I want to give some kudos to them, because they caused this Inflation Reduction Act which has nothing to do with inflation. Steel is going to get some support if they make it carbon neutral. I know we're not there yet, but to get to zero, we have to start here. And you guys have started.

Thank you, Hossain, thank all of your people for what you've done. Thank you, SGB-SMIT and Ulrich and all your people for what you're doing. And thank you, Marcel and thyssenkrupp, for your commitment to this, because you're making the world a better place for my granddaughter.



# Field Testing of Current Transformers: Challenges and Mitigation Techniques

by **Dinesh Chhajer**  
and **Ravi Raj Gupta**





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**Ravi Raj Gupta** received his Master's in Advanced Electric Power Engineering and Electrical Engineering from Michigan Technological University. He is the Substation Applications Engineer at Megger Americas. His responsibility includes providing technical and engineering support for various testing equipment manufactured at Megger. His area of focus is testing equipment that primarily help in testing Transformers, Circuit Breakers, and other Substation assets. He has previously worked with Siemens as a Lead Application Engineer and a Business Development Manager for their Voltage Regulators product line within their Transformers division. He holds an Engineering in Training certification from Michigan.

## Introduction

Current Transformers (CT), circuit breakers and relays are key components of the protection and control systems. Reliability of a protection system depends on the performance of these devices. Periodic testing of these assets ensures that the protection circuit that will operate as needed.

Bushing Current Transformers (BCTs) on power transformers and circuit breakers are tested as per IEEE recommendations to verify their performance and ensure that they meet manufacturer's specifications. Testing BCTs is challenging when they are under overhead energized lines, as induced voltages on these bushing terminals affect measurements, this is more pronounced when testing is performed in EHV stations. This article recommends field practices to overcome this issue and guides in how to evaluate the results.

## IEEE Recommendations for Testing relaying Type CTs

IEEE Power Engineering Society recommends certain field tests to measure relaying type CTs. These tests are designed to verify proper operation, connection, and condition of the CTs. IEEE Standard C57.13.1, "IEEE Guide for Field Testing of Relaying Current Transformers", Reference [1] outlines the intention for the designated tests as well as the test procedures. The recommended tests are: Ratio, Polarity, Insulation Resistance, Winding Resistance, Excitation, Admittance, and Burden Test.

## Field Challenges of BCTs in EHV Environments

EHV environments can compound difficulty of testing BCTs. This is a result of a variety of factors, but the most influential is the elevated level of induced voltage. U.S. electric utilities operate complex transmission systems at voltages up to 765 kV. These EHV power lines interact with

external objects to create capacitive, inductive, and conductive coupling. This results in induced voltage that can reach several kilovolts. This voltage can be calculated using the equation (2) listed in reference [3]:

$$V_{object} = V_{line} \left( \frac{Capacitance_{line-object}}{Capacitance_{line-object} + Capacitance_{object-earth}} \right)$$

When testing a BCT, the bushing terminals can be left open, effectively insulating the tested equipment from ground. When this occurs, the open-circuit voltage that is induced can be calculated using the equation (3) listed in reference [3]:

$$V_{open} = 0.25 * V_{LL} * h_o \sqrt{\frac{h_1^2}{d_{1o}^4} + \frac{h_2^2}{d_{2o}^4} + \frac{h_3^2}{d_{3o}^4} - \frac{h_1 h_2}{(d_{1o}^2)(d_{2o}^2)} - \frac{h_2 h_3}{(d_{2o}^2)(d_{3o}^2)} - \frac{h_3 h_1}{(d_{3o}^2)(d_{1o}^2)}}$$

Where,

- $V_{LL}$  = line voltage between phases (kV)
- $h_o$  = height of the object above ground (m)
- $h_j$  = mean height of phase conductor j (j = 1, 2, 3) (m)
- $d_{jo}$  = distance between phase conductor j and object (m)

This induced voltage makes testing BCTs extremely difficult, especially for verification of ratio and polarity. The addition of stray voltage on any floating bushing terminals will drastically change the voltage on the primary winding, making it impossible to accurately measure voltages on the primary. This has been verified by field measurements that result in ratio errors in excess of 10-20%.

**Interference and Noise**

IEEE recommended field tests on relaying class CTs are mostly performed by the secondary voltage injection method because of the ease of connections and instrument portability. Measurements for tests such as excitation, winding resistance, inter core coupling and burden are primarily taken on the electrically isolated from the primary side, interference negligibly affects these tests, and provides acceptable results.

In Figure 1, ratio and polarity tests are the tests where the test instrument's primary side leads are connected to the bushings of the BCT under test. Since the voltage induced in the CT primary when using secondary test voltage method is just a few volts, it is challenging to measure it accurately under the influence of external electrostatic interference.

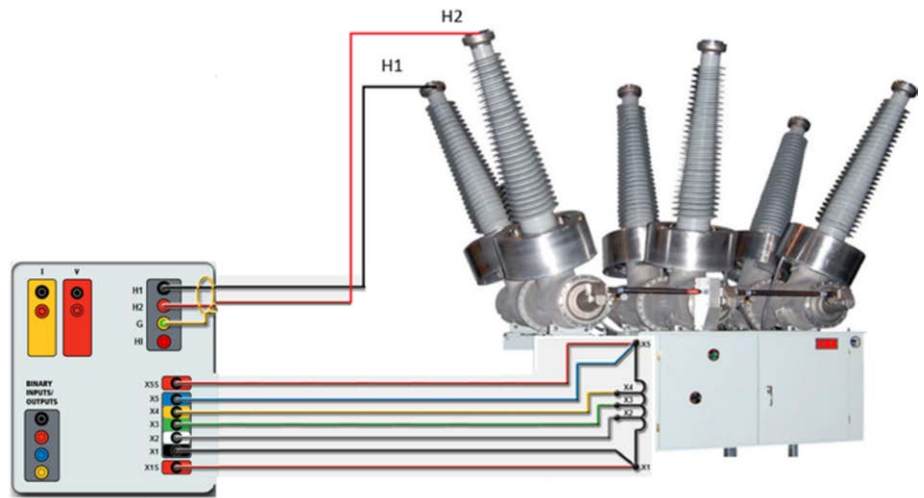


Figure 1: Connections to primary and secondary side of the CT for ratio and polarity test

**Interference Suppression Methods**

Transformer equivalent circuit, as per Figure 3.

Primary winding resistance  $R_p$  and primary leakage reactance  $X_p$

Secondary winding resistance  $R_s$  and secondary leakage reactance  $X_s$

Core loss component  $R_c$  and magnetizing reactance  $X_m$

Secondary winding impedance when referred to primary side can be represented by an equivalent circuit as shown in Figure 4.

Here,  
 $Z_p = R_p + j * X_p$   
 $Z_m = R_c \parallel X_m$   
 $Z_s = \left(\frac{N_1}{N_2}\right)^2 * (R_s + j * X_s)$

For any transformer, magnetizing impedance  $Z_m$  is much larger than primary winding impedance  $Z_p$  and secondary winding impedance  $Z_s$ .

$Z_m \gg Z_p \text{ or } Z_s$

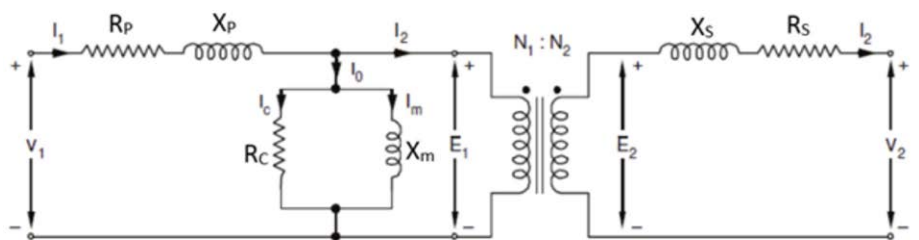


Figure 2: Transformer exact equivalent circuit

To reduce error in the measurement, reduce the impedance or inductance of the circuit. Under an open circuit condition, the impedance seen by the measuring circuit (as viewed from H1-H2 terminals) is primarily magnetizing impedance as shown in Figure 5. Under an induced voltage condition on the bushing terminals, this can lead to an undesired voltage drop in the measuring circuit and can lead to a ratio error outside the tolerances.

To reduce the impedance of the circuit, it is recommended to short the corresponding secondary winding of the transformer as shown in the diagram below.

With the secondary winding short circuited, the impedance seen by the measuring circuit is reduced to the primary and secondary winding impedance. The voltage drop across winding impedance is much lower, and this helps in reducing the ratio and phase angle error.

When working under high voltage energized lines, the induced voltage on the bushing terminals and high inductance of the transformer winding together can create a problem. Any induced voltage would cause leakage or stray current through the circuit and with high impedance it would create a higher voltage drop, thereby affecting the measurements. Therefore, in addition to shorting the secondary winding it is recommended to ground the bushing terminal corresponding to the BCT under test to guard against any induced voltage due to coupling effect. Technicians operating the test instrument should be careful in implementing smart grounding principle and avoid any possibility of ground loops which can create a circulating path and influence the current flow in the measurement circuit. It is important to note that only one terminal should be grounded on high voltage bushing terminals to suppress the interference from overhead energized lines. It is also recommended to connect the unused bushing terminals to the return path H2 lead. This serves two purposes; it reduces the effect

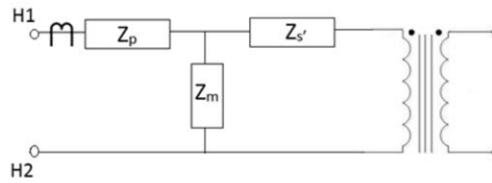


Figure 3: Transformer equivalent circuit as referred to primary

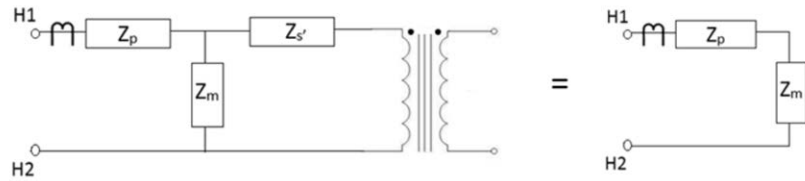


Figure 4: Transformer circuit impedance under open circuit condition

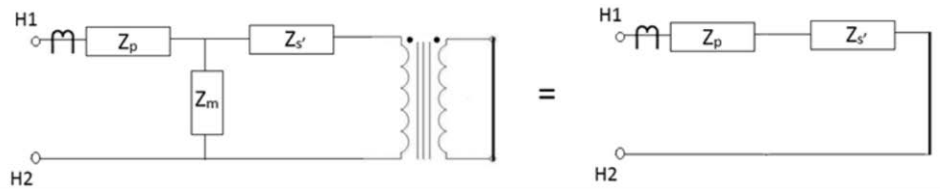


Figure 5: Transformer circuit impedance under short circuit condition

of any induced stray voltage on the floating terminals and depending upon the winding configuration, it would further reduce the overall impedance of the measurement circuit.

The following diagrams depict the recommended connections for

testing BCTs on different transformer configurations:

- 1) Testing H1 BCTs of a transformer with delta winding configuration is shown in Figures 6 and 7. Connection configurations for all the delta winding bushings are given in Table 1.

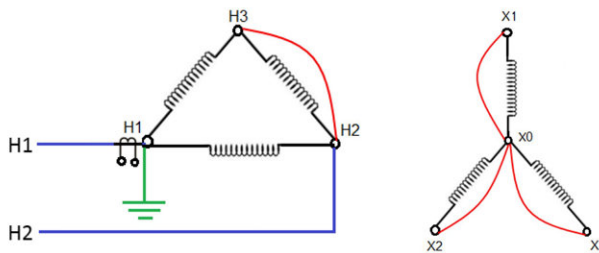


Figure 6: Connection diagram for testing primary side BCTs for a delta-wye configuration

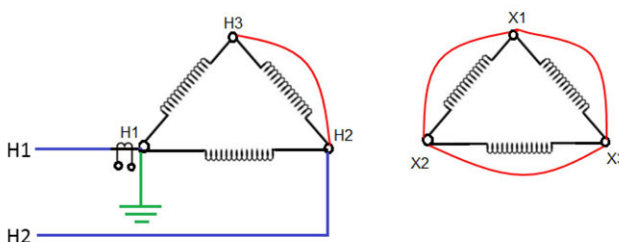


Figure 7: Connection diagram for testing primary side BCTs for a delta-delta configuration

BCT under Test	H1 lead	H2 lead	Ground	Jumpers H side	Jumpers X side
H1	H1	H2	H1	H2, H3	X1, X2, X3 and X0 (if available)
H2	H2	H3	H2	H3, H1	X1, X2, X3 and X0 (if available)
H3	H3	H1	H3	H1, H2	X1, X2, X3 and X0 (if available)

Table 1:  
Connections for each BCT for a delta configuration winding

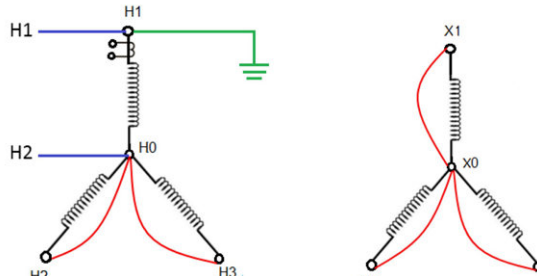


Figure 8:  
Connection diagram for testing primary side BCTs for a wye-wye configuration

2) Testing H1 BCTs of a transformer with wye winding configuration is shown in Figures 8 and 9. Connection configurations for all the wye winding bushings are given in Table 2.

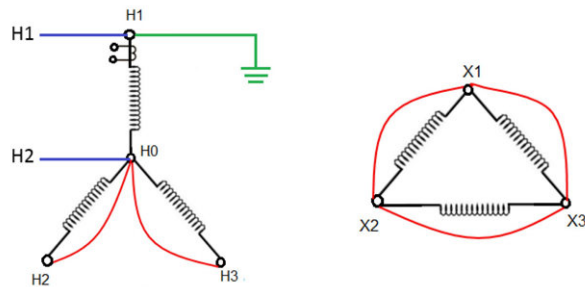


Figure 9:  
Connection diagram for testing primary side BCTs for a wye-delta configuration

BCT under Test	H1 lead	H2 lead	Ground	Jumpers H side	Jumpers X side
H1	H1	H0	H1	H2, H3, H0	X1, X2, X3 and X0 (if available)
H2	H2	H0	H2	H3, H1, H0	X1, X2, X3 and X0 (if available)
H3	H3	H0	H3	H1, H2, H0	X1, X2, X3 and X0 (if available)
H0	H0	H1	H0	H1, H2, H3	X1, X2, X3 and X0 (if available)

Table 2:  
Connections for each BCT for a wye configuration winding

3) Testing H1 BCTs of a single-phase auto transformer with tertiary winding is shown in Figure 10. Connection configurations for all the bushings of an auto transformer with tertiary are given in Table 3.

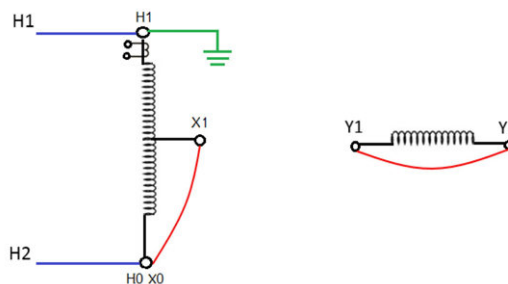


Figure 10:  
Connection diagram for testing high side BCTs on an auto transformer with tertiary

BCT under Test	H1 lead	H2 lead	Ground	Jumpers Primary side	Jumpers Tertiary side
H1	H1	H0	H1	X1, H0	Y1 and Y2
X1	X1	H0	X1	H1, H0	Y1 and Y2
X0	X0	H1	H0	H1, X1	Y1 and Y2
Y1	Y1	Y2	Y1	H1, X1, H0	N/A
Y2	Y2	Y1	Y2	H1, X1, H0	N/A

Table 3: Connections for each BCT of a single-phase auto transformer with tertiary

### Case Study

The company in proximity of overhead energized lines and inductance associated with large windings of power transformers were finding it impossible to test BCTs on transformers in their 765 kV substations. The results obtained were inconsistent and unreliable because of copious amounts of error in the measurements. This utility which owns North America's largest transmission network and operates numerous 500 kV and 765 kV stations, was looking to develop a complete and effective solution to this.

A crucial part of the commissioning process for power transformers in EHV substations is the testing of BCTs. A 765/500/13.8 kV, 750 MVA single phase auto transformer with seventeen BCTs was tested in an energized EHV substation during inclement weather conditions as shown in Figure 11.

As shown in Table 4, a total of seventeen BCTs mounted on different bushings of a single-phase auto transformer with tertiary were tested for all the IEEE recommended tests.

With cloudy and rainy weather conditions along with the nearby energized lines, conditions were not ideal, where a small measurement error (in the mV range) of high side voltage could have easily thrown the ratio readings off. Insulation resistance was first performed as per the recommended connections in IEEE Standard C57.13.1.



Figure 11: Picture showing the testing under energized lines and rainy condition

BCT	1	2	3	4	5	6
H1	3000:5 C800	3000:5 C800	1000:5 0.15S B1.8	3000:5 C800	3000:5 C800	1698:5 C800
X1	3000:5 C800	3000:5 C800	3000:5 C800	3000:5 C800		
X0	3000:5 C800	3000:5 C200				
Y1	3000:5 C800	3000:5 C800	4963:5 C200			
Y2	3000:5 C800	3000:5 C800				

Table 4: BCT with different classes and ratios mounted on different bushings

When performing the primary to ground insulation resistance test, the test instrument detected a presence of live voltage on bushing terminals and gave a "live voltage present"

warning message. The presence of induced voltage and size of the transformer gave indications that test results might get influenced and would pose a challenging situation.

As shown in Figure 12, connections to the bushings were made by bringing a wire from top of the bushing for easy access. The test was first carried out by connecting the leads in a traditional way. Connection, H1 lead to the H1 bushing and the H2 lead to the H0/X0 bushing. All other tests were performed on the BCT without any difficulty. While performing the ratio and polarity tests, readings would not stabilize on high side terminals and manually recording the results gave a ratio error of 20-23%.

To ensure that repeatable and accurate measurements are obtained, three actions were taken:

- Reduce the effect of electrical noise and electrostatic interference from overhead energized lines by grounding the bushing of the BCT under test.
- Short the secondary and tertiary winding (separately) to reduce the circuit impedance.
- Short all the floating unused terminals and connect to the return path (H2 lead).

Using the connections shown in Figure 13, testing was repeated, and consistent results were obtained for all the tests. The following results were on a C800 3000:5 multi-tap CT mounted on the H1 as shown in Figure 14.

Based on the connections applied for the first BCT, the others were tested using the same procedure and accurate results were obtained on all the BCTs. The results obtained on C800 5000:5 BCT mounted on tertiary winding Y1 bushing are shown in Figure 15.

Three other transformers in 500 kV and 765 kV substations were tested with the same concept and all the CTs ratio and polarity measurements were obtained with high accuracy and repeatability. Overall, more than fifty CTs were tested with the same procedure.

It was noted when working with lower inductance transformer windings where there is little or no interference, some of the recommended steps above could be skipped and reliable measurements are still obtainable.



Figure 12: Picture showing the location of each bushing on single phase auto transformer with tertiary

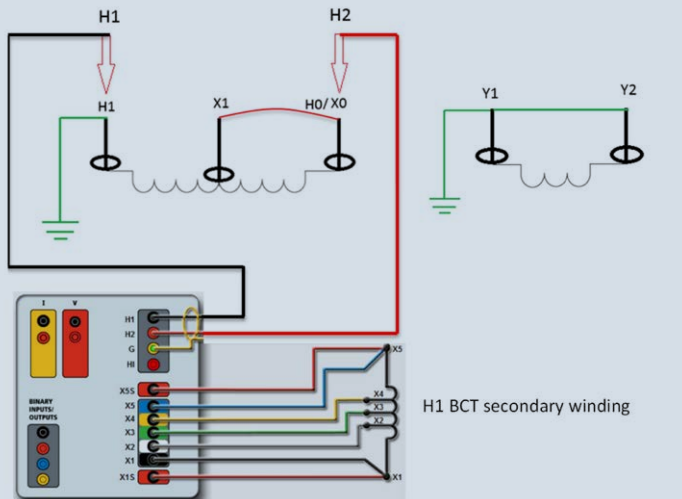


Figure 13: Connection diagram for testing BCTs on single phase auto transformer with tertiary



Tap		X1-X2	X1-X3	X1-X4	X1-X5	X2-X3	X2-X4	X2-X5	X3-X4	X3-X5	X4-X5
R A T I O	Nameplate	1000:5	2200:5	2500:5	3000:5	1200:5	1500:5	2000:5	300:5	800:5	500:5
	Measured	1000.32:5	2200.83:5	2500.68:5	3000.26:5	1200.51:5	1500.37:5	1999.95:5	299.855:5	799.435:5	499.58:5
	% Error	0.032	0.038	0.027	0.009	0.043	0.024	0.003	0.048	0.071	0.084
	Test V (V)	99.530	218.98	248.81	298.52	119.45	149.28	198.99	29.835	79.543	49.708
	Test I (A)	0.1644	0.0747	0.0658	0.0548	0.1370	0.1096	0.0822	0.5485	0.2057	0.3292
	Prim V (V)	0.4975	0.4975	0.4975	0.4975	0.4975	0.4975	0.4975	0.4975	0.4975	0.4975
Phase Dev.		0°29'	0°29'	0°29'	0°29'	0°29'	0°29'	0°29'	0°29'	0°29'	0°29'
Polarity		Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct
Knee	Volt.(V)	196.05	431.26	489.45	587.71	235.22	293.38	391.63	58.422	156.44	98.259
	Cur.(A)	0.2604	0.1186	0.1042	0.0867	0.2179	0.1737	0.1300	0.8603	0.3223	0.5170

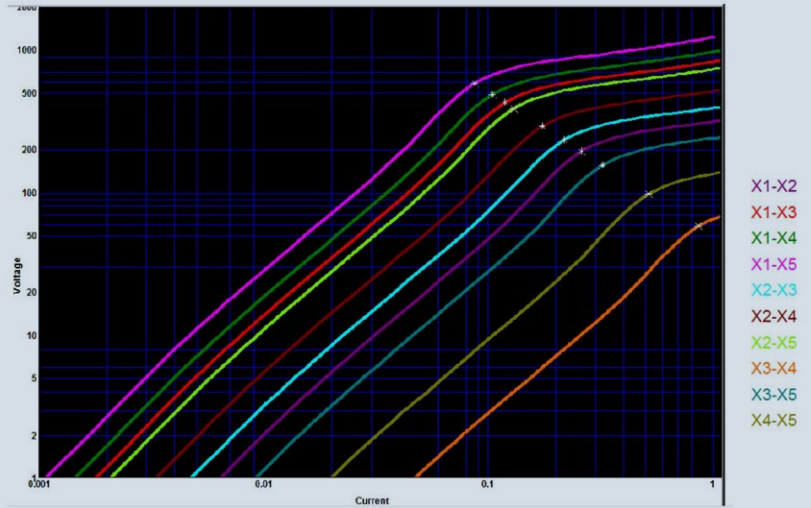


Figure 14: Ratio and Saturation results of H1 BCT

Tap		X1-X2	X1-X3	X1-X4	X1-X5	X2-X3	X2-X4	X2-X5	X3-X4	X3-X5	X4-X5
R A T I O	Nameplate	1500:5	2000:5	4000:5	5000:5	500:5	2500:5	3500:5	2000:5	3000:5	1000:5
	Measured	1495.39:5	1995.21:5	3995.07:5	4995.44:5	499.822:5	2499.69:5	3500.06:5	1999.86:5	3000.24:5	1000.37:5
	% Error	0.308	0.240	0.123	0.091	0.036	0.013	0.002	0.007	0.008	0.037
	Test V (V)	89.405	119.28	238.85	298.66	29.883	149.45	209.25	119.56	179.37	59.809
	Test I (A)	0.0796	0.0597	0.0298	0.0238	0.2383	0.0476	0.0340	0.0596	0.0397	0.1191
	Prim V (V)	0.2989	0.2989	0.2989	0.2989	0.2989	0.2989	0.2989	0.2989	0.2989	0.2989
Phase Dev.		359°58'	359°58'	359°58'	359°58'	359°58'	359°58'	359°58'	359°58'	359°58'	359°58'
Polarity		Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct
Knee	Volt.(V)	123.45	164.86	329.93	412.22	41.430	206.47	288.78	165.07	247.40	82.414
	Cur.(A)	0.1016	0.0762	0.0381	0.0304	0.3053	0.0609	0.0434	0.0761	0.0506	0.1510
Resist. (Ohms)		0.448	0.587	1.187	1.549	0.139	0.739	1.101	0.600	0.962	0.362

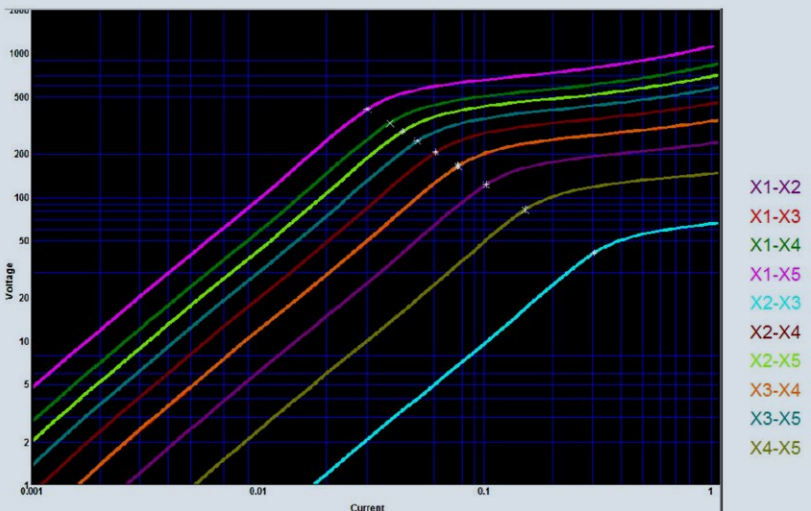


Figure 15: Ratio and Saturation results of Y1 BCT

## Conclusion

Test cases verify effective grounding and isolation techniques can be used to safely obtain highly accurate measurements on BCTs in less-than-ideal environments by eliminating electrostatic build up. This paper outlined measurement techniques for various winding configurations to reduce noise and interference seen in EHV substations. Reduced interference levels provided near perfect accuracy. This allows for precise testing of BCTs as outlined by IEEE.

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# Partial discharge device for more insights



## ICMmonitor Portable Portable Monitoring Device

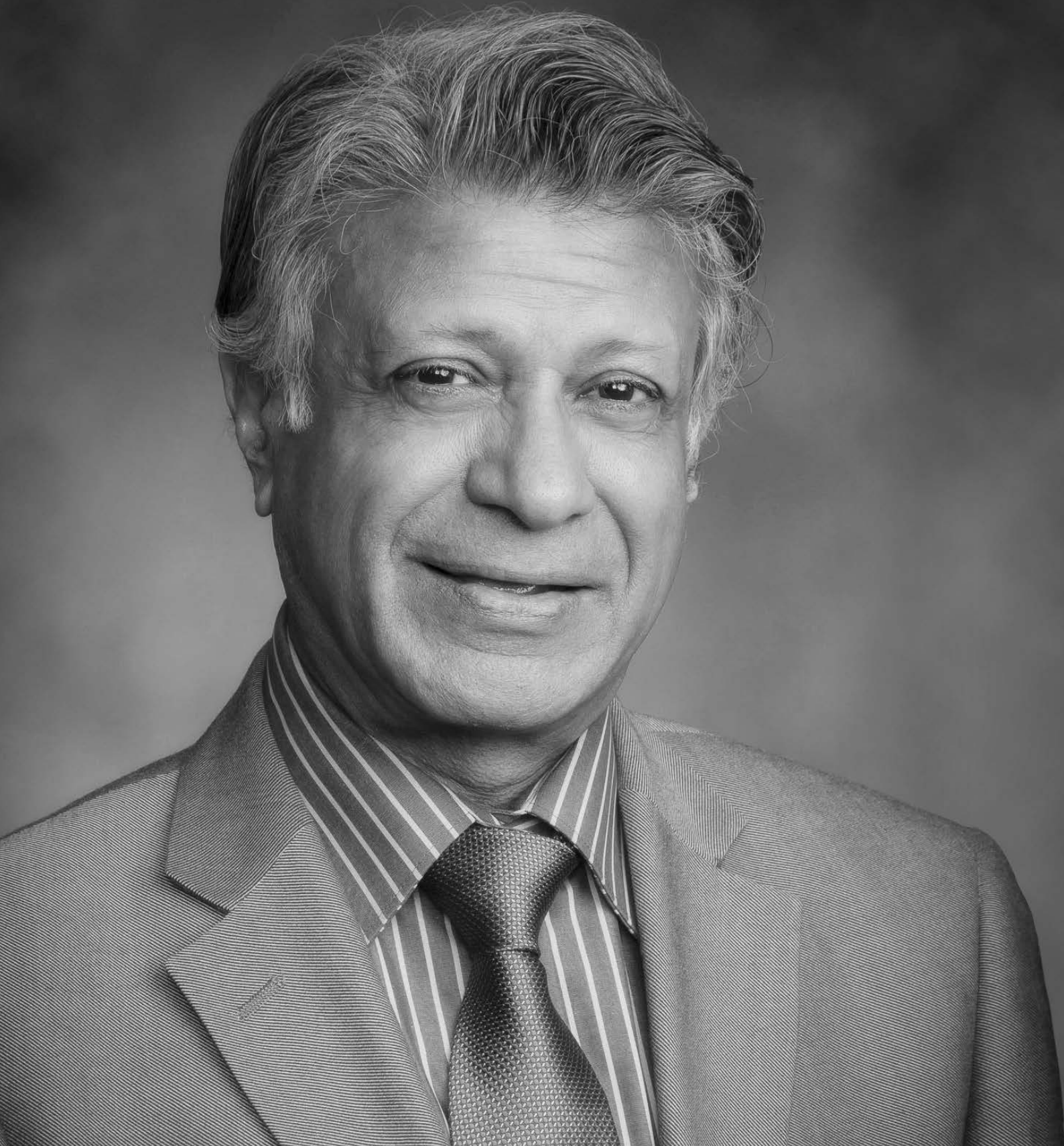
The ICMmonitor Portable is the portable version of our instrument the ICMmonitor. This instrument has been designed for assets that need to be monitored temporarily to detect partial discharge activities. Since it is not fixed installed, you can flexibly monitor one asset after another for a required period. To ensure reliable and precise results of the system under all harsh environmental or weather conditions, it is advisable to use the protective housing the ICMoutlander.

- Flexibility - Portable monitoring solution for required periods
- Visibility - More data insights about the asset's condition
- Reliability - Results under all conditions with the housing ICMoutlander

Learn more about the  
ICMmonitor Portable now



# Prabhat Jain





“

In our country, our biggest challenge is finding people, especially people who have STEM backgrounds. One of the things I have done is hire engineers just straight out of college and then utilize them more on the shop floor. That way, they are able to get their hands on the product.

**CEO-CTO** of Virginia  
Transformer Corp

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Interview with **Prabhat Jain**

**Alan Ross:** I have a guest today is one I've had many times before. Prabhat Jain is the CEO and the steering influencer of Virginia Transformer, Georgia Transformer. Prab, the first time we talked, it intrigued me so much because we were in the middle of the COVID supply chain issues. We also talked about a different approach to transformer manufacturing that was needed for all companies. It involves staffing, it involves technology, it involved a lot of areas that you have implemented at Virginia Transformers. Tell me a little bit about how things have developed since then.

**Prabhat Jain:** Alan, in our country, our biggest challenge is finding people, especially people who have STEM backgrounds. One of the things I have done is hire engineers just straight out of college and then utilize them more on the shop floor. That way, they are able to get their hands on the product. I have also transferred people from our Mexico plant to our plant here in the US. We've hired about 100 engineers from Mexico, and they have come to the US on what we call the TN visa. They are electromechanical engineers and they are working on the winding machines. They do an assembly of 500 MVA transformers and learn about a new state-of-the-art, highly automated, and sophisticated core-cutting machine that requires engineers to run it. We have also hired about 40 local engineers in our three US Plants. And in our Mexico plant, we have hired about 50 new engineers in the last six months. We are bringing more engineers onto the production floor.

At the same time, we started a program that we call EPI Three, which is Equivalent Proficiency Index Three. That means in one year, we get the person to become proficient, equivalent to a three-year person. It works like this: For six months out of the one year, they train full-time. We retrain them, reinforce, educate them, and then we actually have places where we build a transformer in an educational function. We have winding machines and actual transformers which are used for teaching people how to build a transformer. So they build it and we take it apart and build it again. Hands-on crimping and torquing and sealing, on a real product. Not the one that is going to be shipped to the customer, of course, but a practice product.

There are three prongs to this. One is to bring engineers on the floor and bring engineers from Mexico, because there are plenty of engineers available there. They progress from there to become technical leaders of the plant as technicians, quality engineers, process engineers etc. I've established a goal that 20% of the personnel in the manufacturing operation must be engineers and technicians. If I have 500

workers, and operators, I need 100 engineers on the floor. It's a realization after many years of saying, Why can't we improve our quality beyond where we were five years ago, three years ago? We reached a plateau of what we can do with the labor force available and how much we can train them. The next level to rise would be by engineers complementing the operators. This is my solution going forward, to continue to write the increase in our quality first pass yield, doing it right the first time, building the product correctly, and following the prints correctly. It's a huge investment in terms of personnel and in terms of management to oversee these personnel, but that is what it takes to ensure the quality of our custom-built transformers. Because not only does it give you better quality in the plant and a better product for the customer, but it is more satisfying for the people that work in the plant. That is the bigger benefit of this. Because they are successful, we are successful. They feel happy and satisfied. We haven't had a failure for the last hundred units. I started the project last year. This year we'll be getting some output, getting some traction, and making an impact on the quality continuously. And in the next three to five years, we will continue to rise up on that curve of quality. And over a period of time, I'm sure we're going to do even better.

I realized probably about two or three years ago that the demand for transformers with renewable energy battery storage and then data centers are going to be so huge that the supply simply isn't there. And there's going to be about 15 of those all over the world and of course, many others that are happening. There is so much demand for transformers and nobody is building up more capacity. Lead times are growing longer and longer. That's why I launched my plan.

The other project we launched is automation. I'm starting a robotic lab. We launched it last year. We have hired wonderful engineers. They go to school and do robotic engineering and we hire them straight from out of college. And these young people will give you all these ideas and projects to do fun things. We send them to the shop to start trying out stuff and see what

you can automate. So it's really a lab, and it's so exciting. I think in about two years, we would have some robotic applications in transformer making, which will be the first in the world. Very few robots are used in transformer making.

**AR** Everything you're talking about is really cutting-edge. I know transformer manufacturing very well, and we've gotten into this old mindset in the industry that that's the way we've always done it. And maybe they make minor changes here or there but you're talking about major changes. As an engineer, I would love to come to work for you, except I'm retired, so I can't. But we engineers have a passion for making things better.

**PJ** Yes, you certainly do. We have hired six PhDs in the last nine months. And you will be surprised but they are chemistry and physics PhDs. You would wonder why I would need chemistry and physics PhDs, but those are basic sciences. They will help me a lot, and they are solving problems. They are coming up with ideas on how to better cool the transformer, how to better secure the transformer against oxidation and then moisture generation. Scientists can do anything. Engineers can do anything. And you just have to give them a vision, let them loose, and they will go solve problems.

This year we'll be getting some output, getting some traction, and making an impact on the quality continuously. And in the next three to five years, we will continue to rise up on that curve of quality.

**AR** I couldn't agree more. I want to go back to the plant you opened in Mexico, in Chihuahua, and I'm glad you said that it's not just a separate isolated thing but part of this collaborative project you have described. Why Chihuahua? When is it opening?

**PJ** I realized probably about two or three years ago that the demand for transformers with renewable energy battery storage and then data centers are going to be so huge that the supply simply isn't there. And then I estimated one time that we're going to be falling short on the pad-mounted transformers in the world by 20,000 transformers a year. And that's just a narrow estimate from what I could gather. And then nobody is putting up plants for pad-mounted transformers, at least in North America.



Photo: Virginia Transformer Corp

I also realized about a year ago, that we are decoupling from China and that decoupling from China would mean that we really have to do a lot of production at home. And then that production is going to be everything. It's going to be steel, cement, and paper, it's going to be pharmaceuticals, and then cars and batteries and semiconductors. So that's a huge push. This 40 billion semiconductor plant that Taiwan Semiconductor is putting in Arizona alone is going to require roughly \$300 million worth of transformers. There's a brand-new application because it wasn't there three years ago. There is the technology that is coming along on the energy side where they want to electrolysis, separate the hydrogen from water and they're going to combine it with carbon dioxide from the atmosphere and make synthetic fuel. there's. The first project of this going up in Texas, and it's going to require \$500 million worth of transformers in the next three years. Just that one project. And there's going to be about 15 of those all over the world and of course, many others that are happening. There is so much demand for transformers and nobody is building up more capacity. Lead times are growing longer and longer. That's why I launched this plan.

Initially, this plan was only to build small transformers because I saw that 20,000 shortage. However, I started to think about it, meet customers and listened to the energy specials and interviews of the CEOs that they do on Bloomberg. And I started realizing the demand for medium power and large power transformers in our country is going to grow because of the decoupling with China and the energy revolution. So we are really building the industrial infrastructure in our country to support the new manufacturing and the new energy demand. That is why we have launched this plan. It took somewhere around 15-16 months to build. It's amazing what they have been able to do in such a short time.

In addition to this small transformer, I then added a line in there for medium power. This is important because there are seven LNG terminals being built in our country right now, and each one of them requires \$500 million worth of transformers over a period of about seven to eight years.

It's all state-of-the-art: All the wiring is underground, and the piping is underground.

There is nothing overhead. Cranes can run freely everywhere. Everything is lifted by the crane by robotic platforms. You can move them with the remote control, and you can gear them anywhere you want them to go. They carry the transformer from one station to the other station for work. The plant is also fully air-conditioned. And it is only the second plant in North America that can boast that. Our Georgia factory is fully air-conditioned as well. That gives you a very dry, very reliable transformer insulation system. There was a company in Mexico, that was there for 70 - 80 years, and when they closed, we hired all their engineers. These were shop managers and manufacturers with 20 - 30 years of experience and we hired all of them and brought them to our plant.

In addition to this small transformer, I then added a line in there for medium power. We can build up 200 MVA in that plant now. 230 KV, 100 MVA. This is important because there are seven LNG terminals being built in our country right now, and each one of them requires \$500 million worth of transformers over a period of about seven to eight years. That is huge. Our new plant went into operation in October and the medium power line is already backlogged for 50 weeks. In just three months, we have gotten so much demand. So think about one thing: If this plant wasn't there, where would they get those transformers from?

**AR** The lead times would grow even longer.

**PJ** And what does this mean for the country, Alan? As a country, we wouldn't be able to do these projects. They would have to be postponed by one year. That means you hold back the progress for one year. I mean, that's the impact. So that's why I'm doing what I'm doing. So we can give you transformers now, so we can develop synthetic fuel now, so we can build our LNG terminals now to export the gas that we are now flaring in the atmosphere. We can keep that and convert it into liquid and then send it to Europe. They need gas over there.

**AR** Absolutely.

**PJ** This is what I've been able to do with these new plants. And my managers, the leaders of the company, know that it isn't just about building transformers and expanding our business. This is about helping our country to maintain and develop our infrastructure and become more self-reliant. That's so important.

**AR** I'm with you. Now, there's another side effect. You kind of mentioned it.



There was the Mexican plant that closed and all those people lost their jobs. Now they have jobs again. What is this doing in Chihuahua? It's got to be having such a positive impact on that community.

**PJ** The governor of the state, the mayor, and the secretary of the state, they're so energized by our design center. We have 200 engineers in the design center now over there. They say this is wonderful because not only are we giving jobs to the people who make harnesses because that's what most of the American plants do there, but we are building a real product there with real engineers. We do engineering there for us, the Mexican engineers are building products, and designing products for us. So the folks in Chihuahua are so energized. The leaders are saying this gives a big status to them. We created 600 new jobs in Chihuahua in the last six, or nine months. The standard of living in Chihuahua is rising so fast. They have a brand-new district now with shopping areas, cinemas, restaurants, and so forth because the standard of living has gone up so much in such a short time. And not only that, the education is so good. The engineers have respect for the company's process and they follow it. That's one thing I think they have an advantage over Americans. They follow the process. Because they have respect for the company, the managers, and the standard. I find that to be a differentiator.

We created 600 new jobs in Chihuahua in the last six, or nine months. The standard of living in Chihuahua is rising so fast.

**AR** Everything that you said today you are completely right about. It's no longer a supply chain issue. It's a demand curve issue. The demand curve is changing far more

rapidly than we thought it was going to because we've been looking at where transformers are and not where they are going to have to be in the future. EV charging alone is going to change the demand curve. The transformer is the heart of the power system anywhere and we've got heart surgery going on because we have a lot of aging transformers that we've got to take out of service. They're going to fail catastrophically if we don't do something.

You got life cycle planning. You've got this demand curve increasing rapidly. But at the same time the need for quality. It seems to me you're addressing a lot of issues. When is the plant officially going to have a grand opening?

**PJ** We held a ribbon cutting ceremony on 10 February. It was really just to mark the event. Basically, the plant has already produced and shipped its first transformers. But on February 10, about 40 people from Virginia Transformers went down there to see and feel connected and be proud of what the extension of Virginia Transformers is. And of course, the local people were there, the officials like the mayor and secretary. Customers attended as well as our partners across our supply chain.

**AR** Make sure you get some really good pictures because I'm going to do a story on the grand opening and we're going to publish it because I would love to promote what you're doing. I think it's brilliant work.

**PJ** Absolutely. I think it's going to help our country a whole lot.

**AR** Prabhat, I love what you're doing. Everything you've talked about valuing people to create value for the marketplace. You are doing outstanding work.

**PJ** Thank you very much. I appreciate the opportunity to give my thoughts.



# Looking backward to see a way forward

by **Tony McGrail**  
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**Tony McGrail** is Doble Engineering Company's Solutions Director for Asset Management & Monitoring Technology, providing condition, criticality and risk analysis for utility companies. Previously Tony has spent over 10 years with National Grid in the UK and the US; he has been both a substation equipment specialist and subsequently substation asset manager, identifying risks and opportunities for investment in an aged infrastructure. Tony is a Fellow of the IET, a member of the IEEE, CIGRE, ASTM, ISO and the IAM, and is currently active on the Doble Client Committee on Asset and Maintenance Management and a contributor to SFRA, Condition Monitoring and Asset Management standards. His initial degree was in Physics, supplemented by an MS and a PhD in EE followed by an MBA.

As we move towards greater application of, and reliance on, Artificial Intelligence and Machine Learning (AI/ML) systems, it's worth noting that there are some activities where they perform well, and some where they perform poorly. Recent experiences with large language models (LLMs) such as ChatGPT (1) have shown that it is going to be some time before the machines take over from humans in analyzing anomalous condition monitoring data and are able to extrapolate from experience: looking backward to predict the future.

I had heard that AI/ML tools can do all sorts of clever stuff, so I asked ChatGPT if it could help with some bushing data I'd collected from an on line condition monitor: it seemed like a good idea as 'What's the worst that could happen?' The case was a real one, with the data for one bushing plotted below, Figure 1, showing leakage current rms magnitude hourly; the data shows anomalous behavior – but what does it mean?

If you read the limitations for ChatGPT on the landing page it does say:

- "May occasionally generate incorrect information"
- "May occasionally produce harmful instructions or biased content"
- "Limited knowledge of world and events after 2021"

So we proceeded with caution as we are dealing with some HV bushings and 'What's the worst that could happen?' is actually quite bad: catastrophic failure of the whole GSU power transformer with associated consequences: fire, safety and environmental issues, system disruption and so on.

The data in Figure 1 is real, and disturbing: why would a current rise then fall, repeatedly? Could it be a problem with the monitor itself? What does it mean? the question I asked ChatGPT was: "If I am monitoring a bushing and the leakage current rises sharply, but then falls rapidly back to nominal, then rises again, and falls again, then stabilizes close but just above nominal, what should I do?"

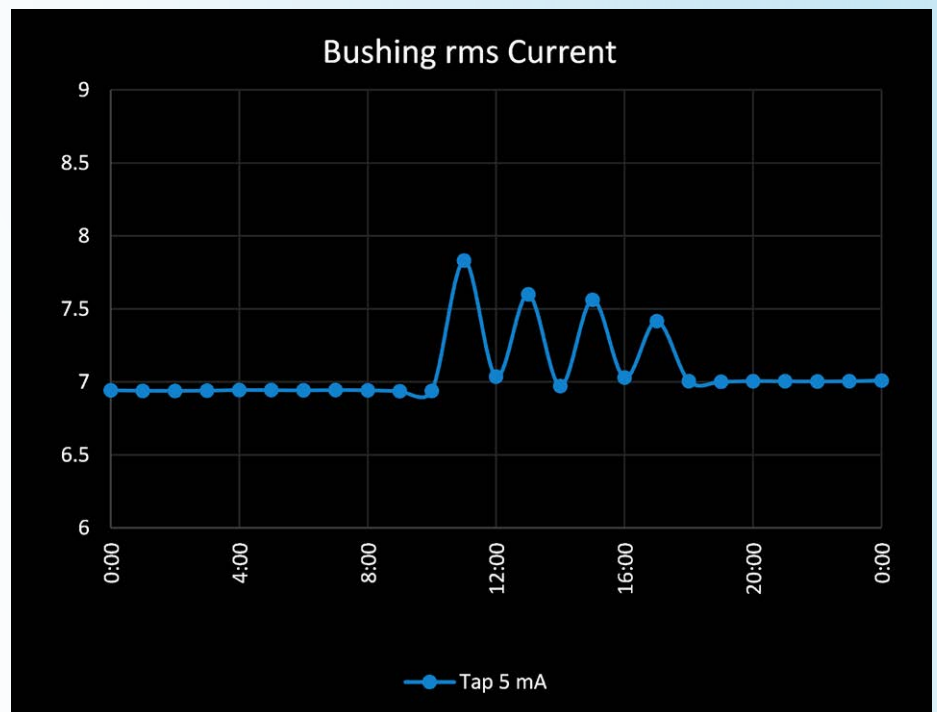
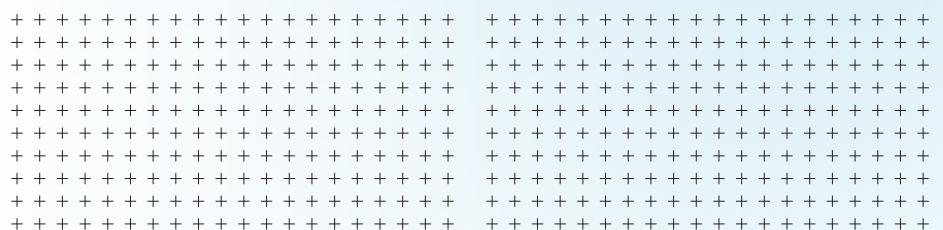
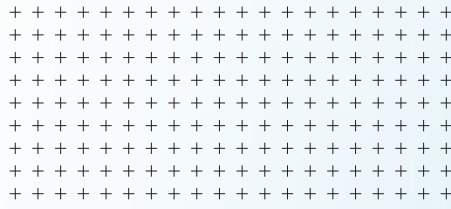


Figure 1: Raw Bushing rms Current Data Recorded hourly



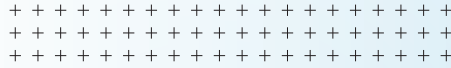
I must admit that I wasn't expecting much in the way of a response and what I got started with the expected generic response that there 'could be a problem which needs investigation' genre, as shown in Figure 2:



It is important to investigate the cause of the repeated pattern of rising and falling leakage current. This could be an indication of a developing fault within the bushing or the surrounding equipment. Depending on the severity of the issue, it may be necessary to take immediate action, such as isolating the equipment, shutting down the system, or conducting a thorough inspection.

Figure 2: Response as expected – broad statements of a possible problem

But what I was not expecting was the caveat that came with it, given in Fig 3.



In any case, it is recommended that you consult with a qualified electrical engineer or technician who is familiar with the equipment and can provide specific guidance on how to proceed. It is also important to follow any applicable safety procedures and guidelines when working with high-voltage equipment.

Figure 3: ChatGPT caveat in terms of condition monitoring data analysis

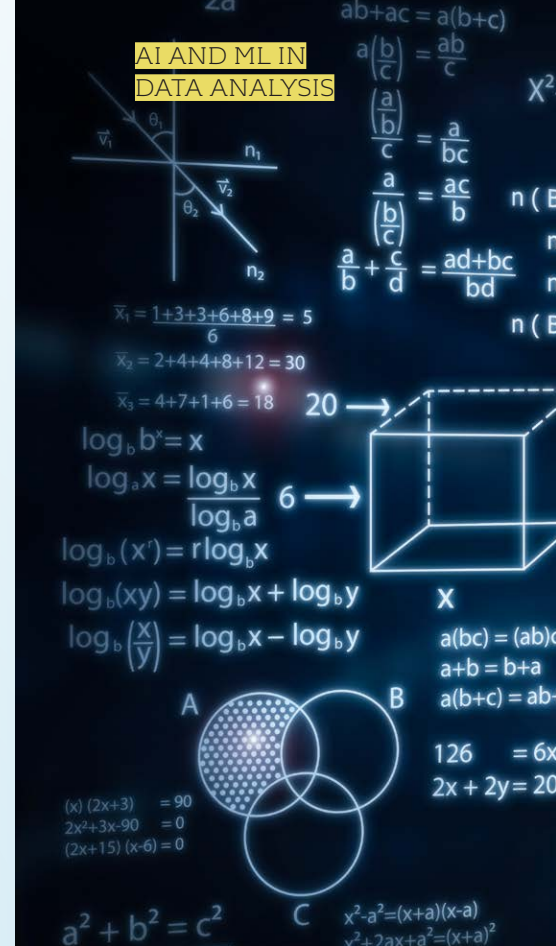
After basically saying "I don't know what this is" in Figure 2, ChatGPT suggests checking with a qualified electrical engineer/technician: this seems to be an eminently sensible idea. Whatever expertise ChatGPT has, it does seem to 'realize' its own limitations. And checking with SMEs is exactly what we did when we reviewed the original data: checking with people who know what they are doing. If you are interested in what the data means, and what happened next, I'd be happy to share: suffice to say it's an unusual case but the bushing remained in service for more than 12 months more.

### Whatever expertise ChatGPT has, it does seem to 'realize' its own limitations.

When successful, AI/ML can look like magic: performing well at picking out faces in a crowd, say, or analyzing lots of data extremely rapidly and consistently, but they can also show bias, make mistakes, and reach unsupportable conclusions (2).

- Problems such as:
- 'Giraffing': where the system detects giraffes in supplied pictures even though there are no giraffes present
  - Bias: usually based on the original data being biased, for example, looking for a reliable transformer and preferring Manufacturer X to Manufacturer Y based on limited failure statistics which don't reflect the real world
  - Misapplication: training a tool to distinguish between pictures of cats and dogs, and then trying to identify a llama...
  - Not having a good indication of why the AI makes the decision it does: it's worth noting the case of an X-ray interpretation tool which performed well, but which made decisions based on the type of X-ray machine that was used, rather than the detailed content of the X-ray (3)

The cause of these mistakes may be through inappropriate 'training', or application to data which is not related to the original data, or which are the result of inflated expectation in the user, and so on. What is common to AI/ML models is that they build on example data – base data, training data, historic data – to identify/classify/analyze 'new' data. And, to quote the language specialist

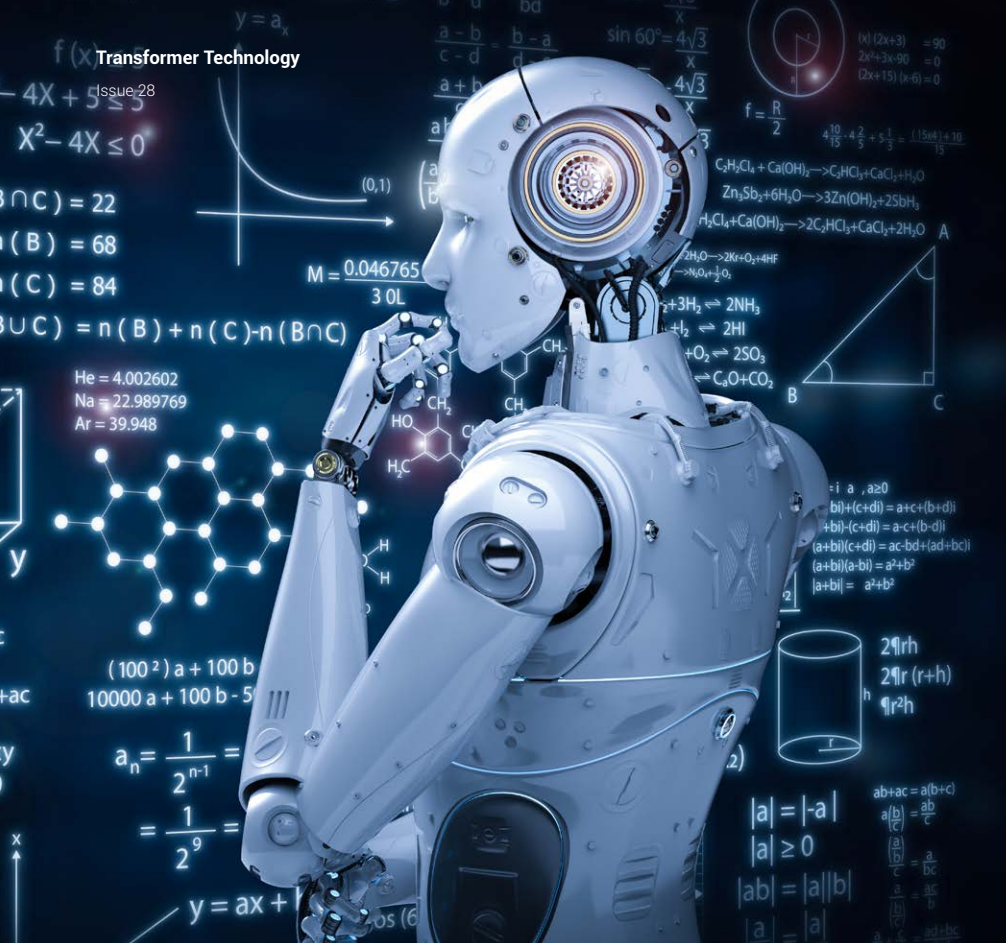


Noam Chomsky who has an insight into the use of language to train and apply AI systems:

*"There is a notion of success ... which I think is novel in the history of science. It interprets success as approximating unanalyzed data."*

### What is common to AI/ML models is that they build on example data – base data, training data, historic data – to identify/classify/analyze 'new' data.

And therein lies the problem – an AI/ML tool is usually very poor at extrapolating from whatever data it has 'seen' in order to make sense of what it hasn't seen previously.



75ppm to >120ppm in a few hours. In the second case, a relatively flat trend suddenly steps up from ~20ppm to almost 120ppm in a few hours.

The two DGA cases, are, in fact, sister transformers: same manufacturer, both 48MVA, both over 30 years old, rarely fully loaded but some indications of overheating in the DGA and FFA levels. The transformer in Figure 4 was taken out of service a few days later, tested using standard tests, and an internal inspection confirmed severe overheating and likely imminent failure of LV lead connections – which had been undersized from the initial manufacture: if it had stayed in service, it could have failed catastrophically.

And the transformer in Figure 5? It was returned to service after a prior maintenance outage, but with



Figure 4: Composite DGA with a rising trend and a sudden step change

It is an interesting side-note that an estimated 95% of the benefits of AI/ML can be achieved through standard statistical and data analyses on the raw data, but that is to miss the point that the other 5% may be vitally important (4). We don't know until we look! BTW, side-note 2: the idea that we just get more data and throw it all at a bigger AI/ML system is usually a bad idea, wasting time and effort and resources: it's best to start with a small system which can grow and build on success (5).

So, we need to understand the data we have available: what did we train the AI/ML on, and does a new piece look at all like that? There are examples of AI/ML classifier tools which, in the first instance, do not

try to classify new data but make a check as to whether the new data looks like previously available data, and calculates an 'out of distribution' (OOD) value (6). If the OOD means it doesn't look like something we've seen before, ask for a relevant specialist to check: that is, ask someone who has domain knowledge, experience and can interpret data.

What else? Context is extremely important, as demonstrated by the following two examples of composite DGA monitors, giving a representative ppm value for combustible gases dissolved in transformer oil. In Figure 4 we can see a gently rising trend over several days, and a sudden rise from about

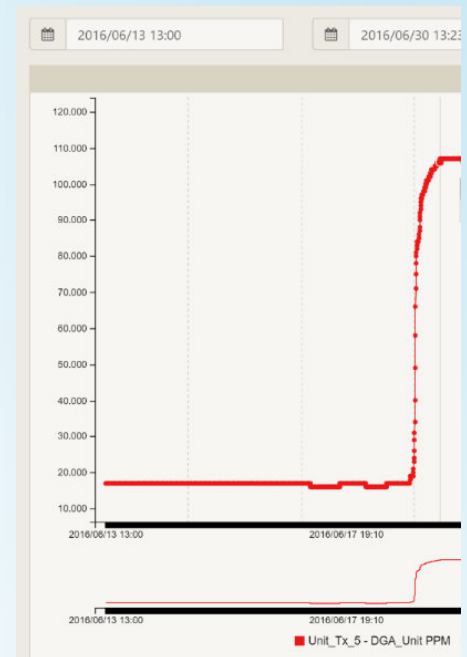


Figure 5: Composite DGA with a 'flat' trend and a sudden step change

the cooler return valve closed: subsequently, there was a temperature alert as the cooling was not functioning, and the rise in monitored DGA was a result of the cooler valve being opened and fresh oil reaching the DGA sensor: the transformer was actually de-energized at the time. How do we get all of that type of information, context, and insight into an AI system? That is going to be a challenge.

At DistribuTech this year, there was a significant number of companies offering AI/ML tools as part of their offerings: OEMs, consultants, service companies, data companies, and so on. What is perhaps most encouraging is that many of them understood quite clearly that while they may find interesting relationships or trends within supplied data, they also need the capability of industry experts to give meaning to the findings. This is a challenge when we are losing capability through retirement or career changes, and have fewer people than needed entering the industry each year. And, of course, new industry individuals will take some years before becoming the SME's of the future. AI/ML can fill some of the gap, but not all of it – over time it may be that AI/ML gets more adept

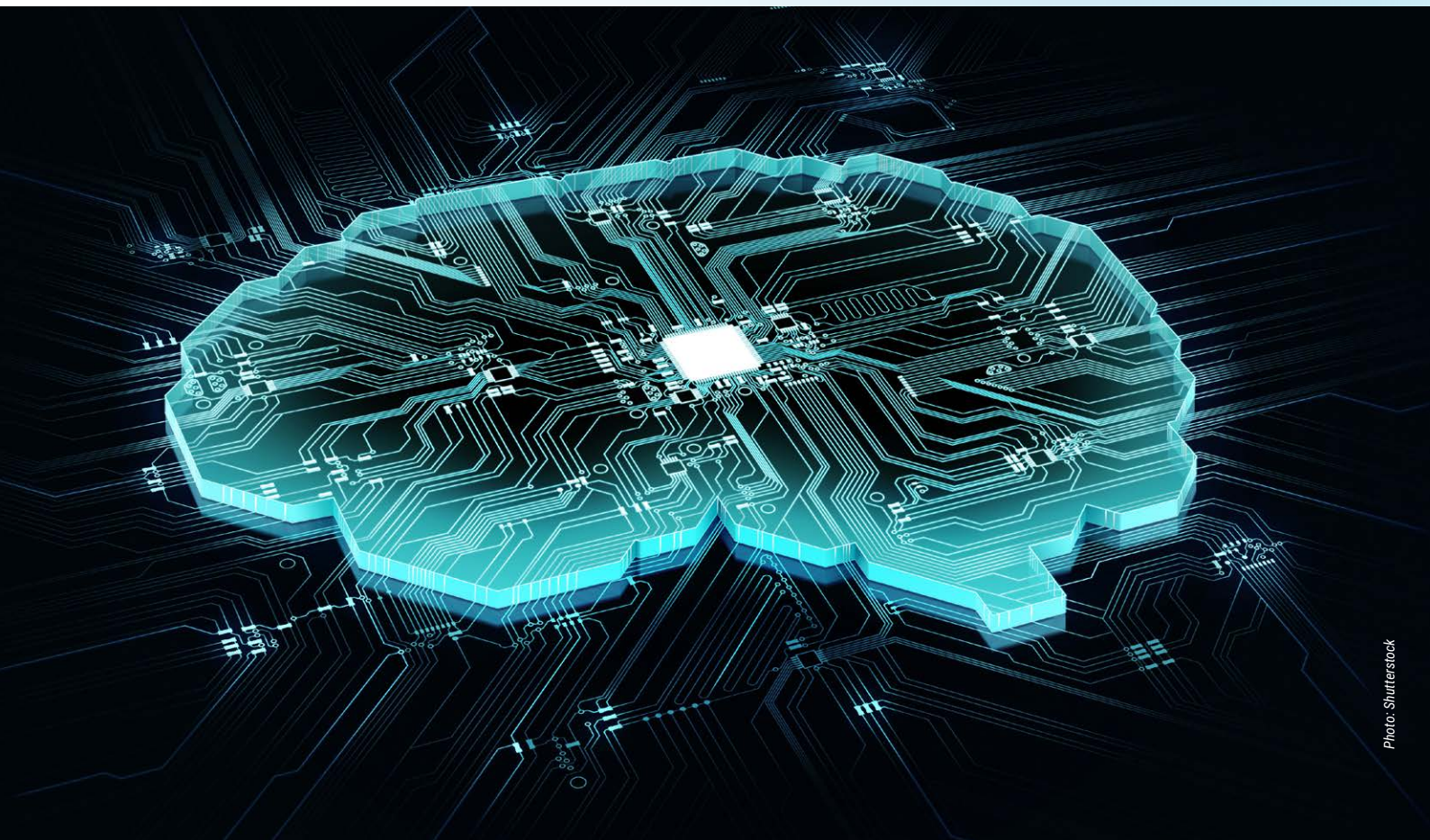
and the cases where real experience is needed are fewer, but the 'edge' cases aren't going away. And with the growth in DERs, and the increase in the need for condition monitoring, there is a corresponding need for humans who understand the data and can look for answers which may lie outside the box: such as would apply to the bushing in Figure 1.

*Over time it may be that AI/ML gets more adept and the cases where real experience is needed are fewer, but the 'edge' cases aren't going away.*

The work of Tom Rhodes and colleagues at Duke Energy is highly relevant – applying AI/ML to support

the engineers, not replace them: use the tools to identify where SMEs can most profitably spend their time. Initially the pure data scientists complained about the data 'It must be wrong as it doesn't fit our models', but after some 'learning' on both sides, the resulting hybrid approach provided great value to the organization (7). And it may be that, over time, the number of cases which the AI/ML passes over to the SMEs reduces, as the AI/ML learns, but that, too, will take time.

So, in the interest of experimentation, I did ask ChatGPT many other questions, but one sticks in my mind: "Can you give me some anagrams of 'Transformer Bushing'?". It shouldn't be too difficult to rearrange 18 letters into something interesting for a system with the language skills of ChatGPT, and it came up with several, but my favorite was "The Grim Buffoons Runes". This may seem pretty good, but it has a couple of extra letters, meaning it fails the basic definition of what an anagram is... sometimes you have to get the simple stuff right, like counting letters, before doing something difficult like rearranging them into new words.



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*The role of SMEs in data analysis is not going to go away in the near future, and we still need someone who knows what is going on,*

*and can look at the data, the context and the details simultaneously to come up with something 'outside the box'.*

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**Conclusions:** AI/ML can only work on what it has been 'shown' and fill in the gaps. It is very poor at generating 'new' knowledge.

is not going to go away in the near future, and we still need someone who knows what is going on, and can look at the data, the context and the details simultaneously to come up with something 'outside the box'.

The role of SMEs in data analysis

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# Seth Johnson



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Ultimately, I believe technology is always going to get better, but is it going to be good enough to maintain the stability required for an optimal high functioning power system?

That's where I think our business plays in, and that's where we have our play in the market.

**Vice President**  
at Powerside

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Interview with **Seth Johnson**

**Alan Ross:** We're at Distributech 2023. My next interview was with Seth Johnson. He's a Vice President at Powerside. Welcome. Thank you.

**Seth Johnson:** Thank you for having me.

**AR** Tell me a little bit about your career, how you got into this industry, and how you got to Powerside.

**SJ** Yeah, it's been an interesting road. I actually never had a desire to get into the Power Systems industry.

I studied psychology and got a degree in psychology and business. And then my goal was to go into neuroscience. I started a PhD program in neuroscience, worked in research for several years and decided it was not for me. I had a family member who worked in the power industry. They were a manufacturer sales rep. in Minneapolis, which is where I grew up, and I spent about four years working for them. They hired me as a technical sales rep, and I got in and just started absorbing everything. I'm in the power business now, and it's addictive.

**AR** You're of the generation, Seth, that wants to know that they're making a difference. That's how we're attracting people now, not because they're about pay and the fact that we're a pretty secure industry. You're making a difference. You probably use psychology when you talk to your customers to understand what they think or how they think or what they do. I want to talk about Powerside, because obviously now you're a VP. Explain what it is that you do with the company.

**SJ** I'm a Vice President and General Manager of our Corrections Business division. At Powerside we have two different divisions, one in Montreal and one in Alameda, California, two different product lines. We're the same company, but I manage everything that happens out of the Montreal business, which is our power corrections business. When we find power quality issues and they need to be corrected, that's where the equipment gets manufactured.

**AR** I was the president of EPRA, the Electric Power Reliability Alliance, before I retired. The changes that are going on that we're trying to adopt or adapt to in this industry, resiliency, reliability, safety, are creating more power quality issues. Talk about the problem and then we're going to talk about Powerside's solution to it.

**SJ** Sure. The problem is it's an ongoing challenge. I mean, we have all these

distributed energy resources now that are contributing power to the grid. We're at a point in time where being able to understand what's actually happening on the grid, how power is being used, how it's being produced, how it's being consumed, and how it's being stored, which is so critical to the infrastructure that we have in general.

**■ We're at a point in time where being able to understand what's actually happening on the grid, how power is being used, how it's being produced, how it's being consumed, and how it's being stored, which is so critical to the infrastructure that we have in general. ■**

The problem essentially is that we're transitioning from coal-fired power plants, high inertia generation, and we're using transistor-based technology, or inverter-based technology to essentially create this AC sine wave back onto the system. Doing this at small scale, people didn't really think much of it because it didn't do a whole lot, but now you're seeing large amounts of it. When you think about how energy is being produced and consumed and then stored, as we get into DC micro grids and



energy storage the problem is that these power sources rely on inverter-based technology. You're using high frequency switching to create this sine wave to bring power onto the network, which is creating noise on the distribution grid.

■ When you think about how energy is being produced and consumed and then stored, as we get into DC micro grids and energy storage the problem is that these power sources rely on inverter-based technology. ■



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**AR** It's interesting, we did some interviews at the Re+, which is a conference in Anaheim, and one of the things that came up was how the whole grid being inverter-based technology is affecting the assets themselves. In addition to power quality, transformers are not lasting as long as they did because they're not used to various power sources, and historically only to step down voltage, right? Not step everywhere! You can give it, you can take it. It's kind of a mess in there. The impact of power quality, let's say, on the end user; whether that is; let's deal with residential first and then I want to talk about how data centers might be impacted, how industrial plants might be impacted, but what is the actual impact of bad or poor power quality in a residential environment?

**SJ** When you think about it from a residential standpoint, essentially, we're losing inertia on the grid, which is what creates the frequency tolerances in which we run the system. When you have all these PV applications that are contributing, you might have enough power available, but if there's a big inrush, or a large motor load, it might not be able to sustain the voltage, and it might also shift the frequency. With the amount of inverter-based technology in the modern electrical system, adding solar increases harmonic content, which is a multiple of the fundamental frequency that is present. This happens with any kind of high frequency switching devices. Harmonic content is dissipated as heat in the system, fundamentally. You think about it from your conductors inside of your home to the conductors going to the transformer, and now you have all of this heat, and then you think, what is the long-term effect of this? If we have, for instance, high harmonic distortion in a residential network, which could also be the same in commercial, or industrial electrical network.

**AR** In the data center market, it's absolutely imperative that they have clean power. A lot of industrial applications now use robotics. Robotics are impacted by bad power quality. We hear that a lot, that the industrial power quality issues are growing. In 2001 EPRI did a projection by the next decade. We've already passed that time. The dollar loss of power quality issues in industrial America was somewhere around \$50 billion annually. It's a lot of money that industry is going to lose, and they have to be competitive. How does Powerside deal with that problem?

**SJ** You made an interesting point there. Go back 30, 40 years, where you have these big induction motors, at heavy industrial facilities doing various production process. It

was all induction-based motors, transformer-based welding. Now it's inverter-based welders, you have variable speed drives, variable frequency drives, DC drives, all of that stuff which is controlling motors. All of that allows the motor to become a little bit smarter. But it creates another issue, which is, again, this harmonic content on the network.

The other thing that's really interesting is high frequency emissions. These are high-frequency noises that are in the bandwidth of 9 to 150 kHz. We did a study at a plastic extrusion facility, and they had a 10 kHz voltage of around 25 volts, so it's this very, very high frequency voltage, which nobody can really pick up.

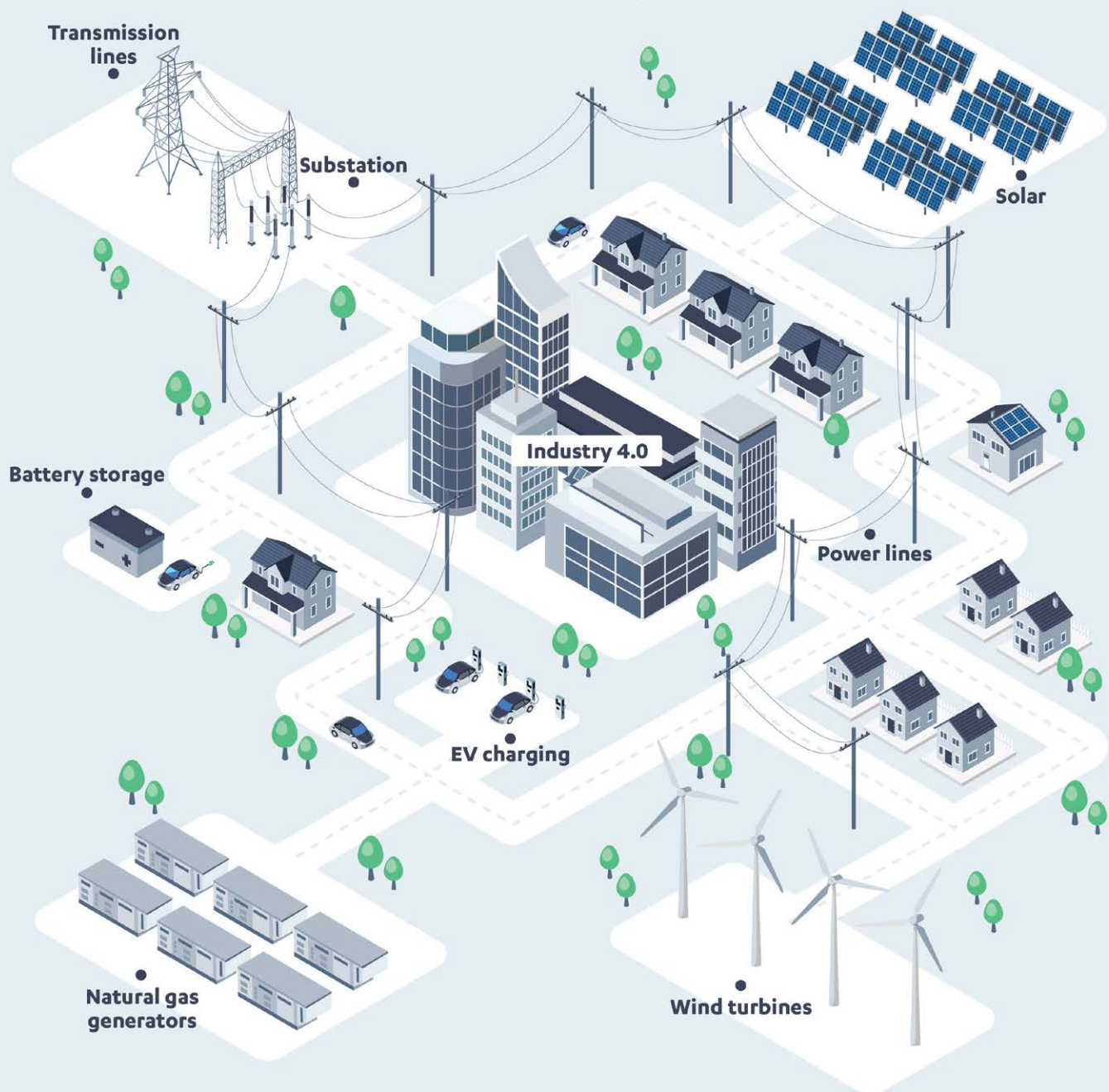
The good news is, in many cases, it gets dissipated. It typically can't flow through the transformer back onto the grid. The downside is that communication and control systems can be greatly affected. The circuit boards are frying, capacitors are blowing up in the control boards. We actually manufacture a very high-end power quality monitoring device, which does waveform capture, waveform sampling. We can do high frequency emission testing, looking at those very high-frequency voltages, and then on my side of the business, we do the correction. We have a power system analysis program where we'll go get data in the field, and then come up with a solution. We're using active harmonic filters, passive filters, and capacitor banks for power factor correction, and we'll even do high pass filters for supra harmonics, these high frequency noises that pose themselves as issues in distribution grids.

**■ We actually manufacture a very high-end power quality monitoring device, which does waveform capture, waveform sampling. We can do high frequency emission testing, looking at those very high-frequency voltages, and then on my side of the business, we do the correction. ■**

**AR** One of the issues that everybody is having, whether you're a supplier to the industry or whether you are the utility industry, is labor. That's from everything, the unskilled technician to the skilled tech, skilled trades linemen. You have the detection and the correction. How can it help the labor shortage or how can it help the people in the company work better, work smarter, work faster? In the detection, you got to be using input from the people in the company. How are you helping them do their jobs better?

**SJ** For general industry, it's about equipment uptime, when we get into the correction

### A modern microgrid



side of things. But we can't do that unless we can detect what the problem is. From a process perspective, our goal is certainly to improve efficiency of these facilities and decrease waste. When we do power factor correction, we're able to decrease current consumption and improve the efficiency of the power system, which will also improve the integrity of the system long-term. When we're talking about harmonics, how they might perpetuate through the electrical system, and how they can be damaging to electrical equipment, you could see how a lot of consumers may not have the expertise to understand this power quality phenomenon.

That plastic extrusion facility I was telling you about, replaces all their drives every three weeks. This is millions of dollars a year! When you can go in with a solution and say: No, this is your issue, this is where it's at and this is how we can fix it; you're a hero in that scenario. We're not an engineering services company, but we provide a lot of very specific knowledge for specific applications.

**AR** You also mentioned something about getting the data from the equipment, to be able to correct, and that's really a part of our passion at APC Technologies - giving the



Photo: Pwyside

operators more of an opportunity to manage their own system, and then they don't have to have a department that comes in and does maintenance.

Lastly, but not finally because we will reach out to you for another edition. Technology is changing rapidly. The use of AI, we've kind of adopted IoT. We accept it in the utility industry. From a standpoint of technology, what is next that we have to accept into the industry?

**SJ** I talked a little bit earlier about energy being produced, consumed and stored. Essentially, this smart grid is going to be the future. For example, the utility is going to know your car is plugged into the wall, so if they need to supplement power somewhere else, they'll have the ability pull power out of your vehicle, or whatever other energy storage device is connected to the grid. I heard from an industry expert that the utility grid in a way is getting smaller. I said, okay, what do you mean? They said, we're going to get rid of all this centralized generation. It's going to be all kinds of decentralized generation, such as wind turbines, solar, and various types

of energy storage. I don't mean it's going to get smaller base solely on capacity, but it's going to become more vulnerable.

**■ Essentially, this smart grid is going to be the future. For example, the utility is going to know your car is plugged into the wall, so if they need to supplement power somewhere else, they'll have the ability pull power out of your vehicle, or whatever other energy storage device is connected to the grid. ■**

Ultimately, I believe technology is always going to get better, but is it going to be good enough to maintain the stability required for an optimal high functioning power system? That's where I think our business plays in, and that's where we have our play in the market. I believe the smart grid in 10, 15, 20 years is going to change the way that we produce, consume and store energy.

**AR** Seth, it has been a delight.

**SJ** What a pleasure.

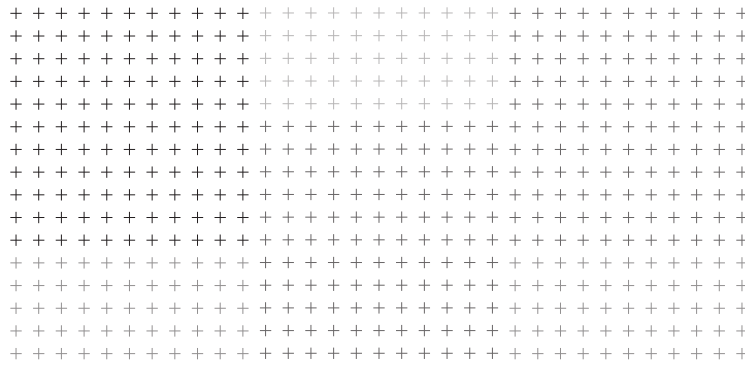


# Solid State Technology to Streamline Global Transition to Clean Energy

by **Tajwer Khanam**  
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- *The electrical power system of a country generally consists of generators, high voltage transmission lines that stretch hundreds of miles followed by distribution lines that span millions of miles in order to serve a range of consumers.*
- *Existing grid infrastructure employs non-ecofriendly equipment that leads to GHG emissions followed by over voltage, phase imbalance and harmonic pollution issues.*
- *Modernization of the grid will utilize the solid-state technologies that in turn are expected to not only streamline the power system operations, but also to assist countries in reducing their carbon footprint.*



Tajwer Khanam is a market analyst at PTR Inc. She supports custom consulting projects related to the power grid and is responsible for data collection and analysis in various areas including the structure of distribution utilities, installed base of transmission & distribution equipment, and future market trends. As a market analyst, she performs in-depth analysis of different equipment markets such as switchgear, substations, and transformers. Tajwer has a technical background and a master's degree in Sustainable Energy from the University of Glasgow.

The electrical power system of a country generally consists of generators, high voltage transmission lines that stretch hundreds of miles, followed by distribution lines that span millions of miles in order to serve a range of consumers. Along with generators, transmission and distribution lines electrical power system comprises of substations as well, and they act as a critical interconnection among generation, transmission, distribution, and consumers.

In a conventional grid electricity is supplied with the help of conventional power plants, for instance thermal,

gas and diesel generators, are not only a costly option at times, but negatively impact the environment as well. However, in recent years we have observed a substantial increase in the deployment of renewables in the generation mix of countries along with the installation of battery energy storage projects and EV charging infrastructure that calls for the grid infrastructure to have the capability of bidirectional flow of electricity and information. This sort of capability that allows bidirectional flow of power and information is absent in the conventional grids, hence modernization and upgradation of the grid is imperative.

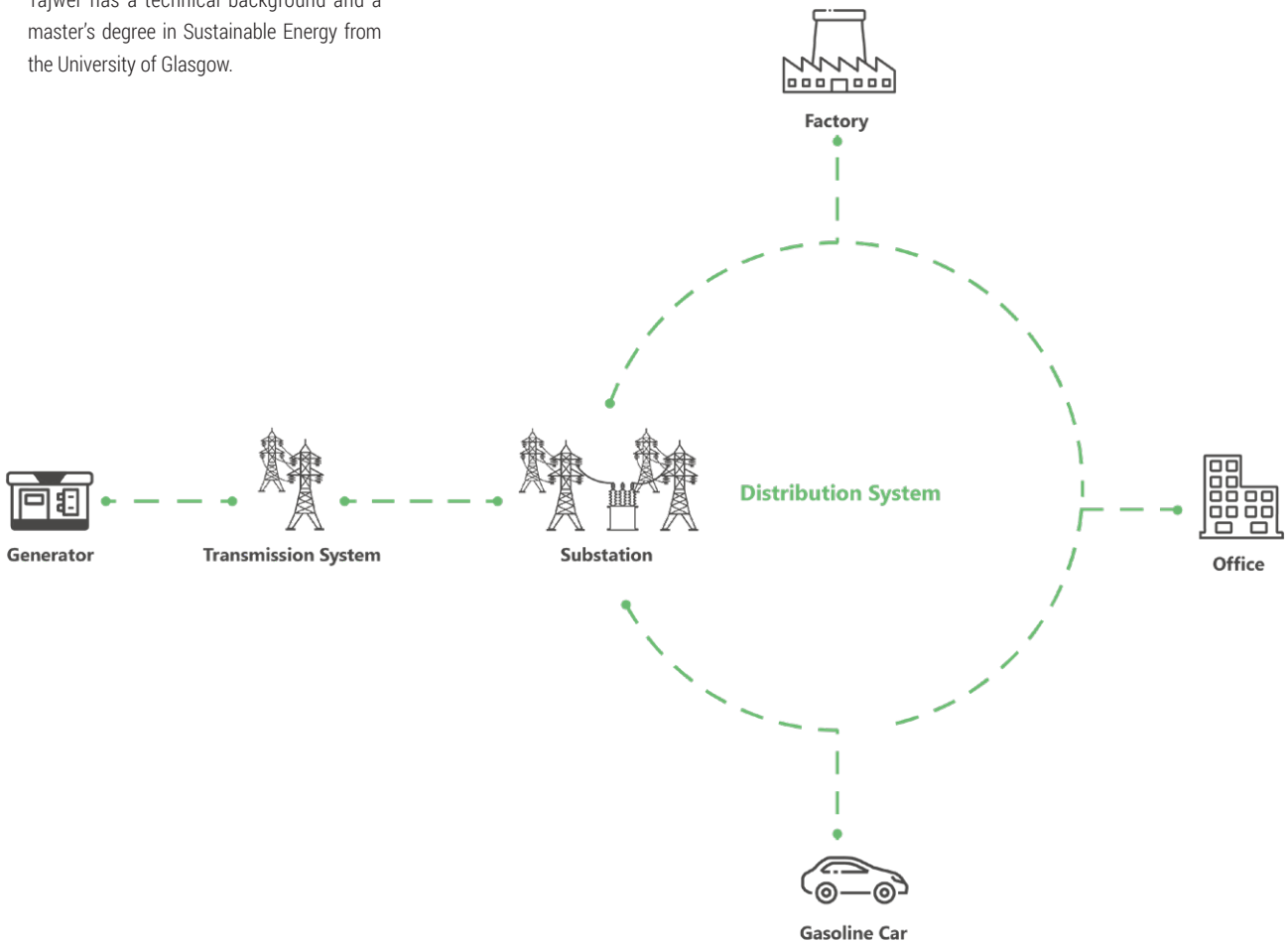


Figure 1: Uni directional power flow in a conventional grid. Source: PTR Inc.

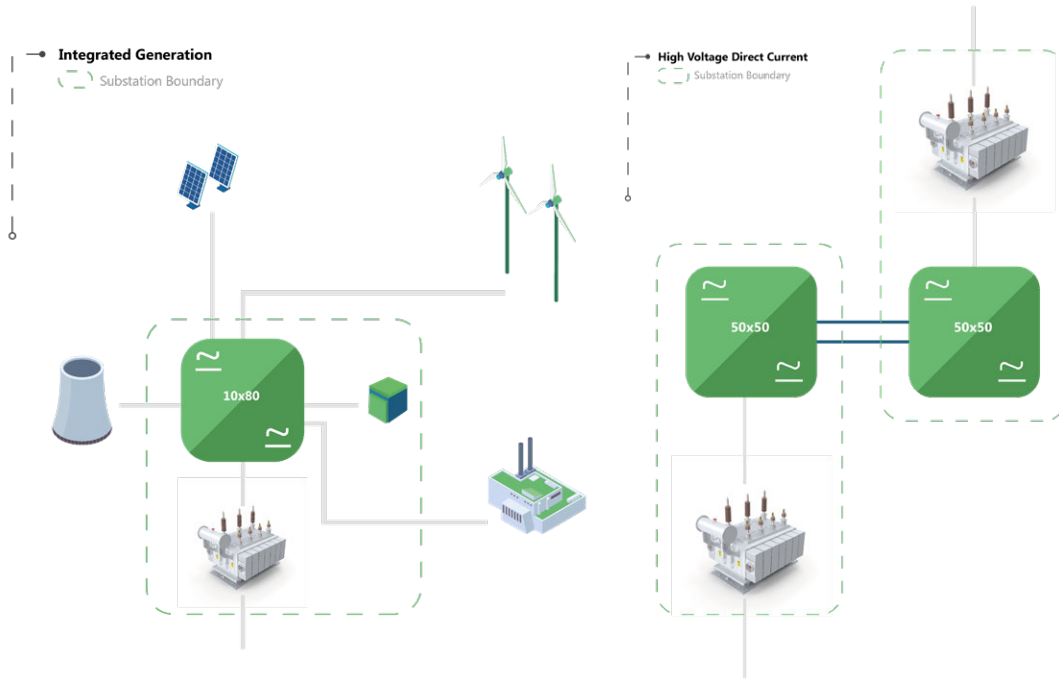


Figure 2: Solid state converter applications within substations. Source: PTR Inc.

**Solid State Technology to Rescue**

As the countries are moving away from conventional generation sources that negatively impact the environment to renewable generation, the need for significant advancements in the substation technologies has increased. Most of these requirements can be met with the solid-state technology, especially after the recent advancements in the technology, that in turn positively impacts the overall reliability and stability of the power grid.

**Solid State Power (SSP) Converters**

The emergence of solid-state converters have radically altered the landscape of power industry in recent

years with their ability to provide dynamic real and reactive power control especially with integrated energy storage in place followed by facilitation of new grid networks, energy dispatch and black start capability. Furthermore, SSP converters have the capability to control the voltage, phase, frequency while allowing bidirectional flow of power.

These converters are efficient as they balance the use of AC and DC topologies which in turn reduces overall system losses. On the other hand, functional control, communication, protection, regulation along with other features that are needed to maintain the reliability and security of future grid are provided by SSP converters. It is noteworthy that the modular and scalable nature of

SSP converters enables them to be used to carry out gradual upgradation of substations whenever required. For instance, if an equipment has failed or has become outdated in a substation, it can be replaced with a SSP converter which can later be linked with another SSP converter in the later stages.

**Solid State Transformers (SST)**

As the countries are moving away from conventional generation sources that negatively impact the environment to renewable generation, the need for significant advancements in the substation technologies has increased. Most of these requirements can be met with the solid-state technology, especially after the recent advancements in the technology, that in turn positively impacts the overall reliability and stability of the power grid.

The emergence of solid-state converters have radically altered the landscape of power industry in recent years with their ability to provide dynamic real and reactive power control.

Additionally, SSTs provide a wide range of grid services for instance reactive power compensation, power quality improvement, current limiting, voltage regulation and power factor correction. It is significant to note that while regulating voltage or carrying out reactive power compensation,

solid state transformers do not use tap changers, which leads to a reduction in the maintenance costs of the transformers.

In the last few years, we have observed that the average cost of battery energy storage has reduced which has resulted in batteries being deployed and integrated with the grid for frequency regulation and back up with the help of SSTs. SSTs also act as power electronic interface between MV AC, and LV AC system as shown in the figure below.

Furthermore, SSTs have the capability to isolate faults in a manner that upstream network faults do not transfer to downstream network, in turn allowing continuity of services to customers.

**Solid State Circuit Breaker**

In a solid-state circuit breaker, traditional moving parts of an electromechanical CB are replaced with the latest semiconductor

technology that has the capacity to not only control the power flow, but also to interrupt and clear the fault in a few microseconds. A conventional CB, on the other hand, takes a few milliseconds to clear the fault. Downtime in case of an internal fault significantly impacts the energy storage systems and related electric grid services (for instance frequency regulation and grid backup). Solid state circuit breakers have the capability to isolate the faulty zone, reduce the arcing probability and let through energy by multiple orders of magnitude.

Advanced power distribution technologies and architectures, for instance DC microgrids, require an improved interruption rate (faster switching frequency), which has also

pushed for research and development in the solid-state circuit breaker technology.

The ABB claims that their concept of solid-state circuit breakers will define the future of energy especially when it comes to electric transportation and battery energy storage solutions. In marine vessels, solid circuit breakers will reduce the downtime, as they have the capability to disconnect the faulty zone while keeping the rest of system in service.

On the other hand, they have also claimed that their CBs will have the capacity to prevent all the rack fuses from blowing up, which leads to a shutdown of the entire system in case of a fault.

These transformers include power electronics circuitry that operates at high frequency, which in turn provides high controllability and bidirectional power flow.

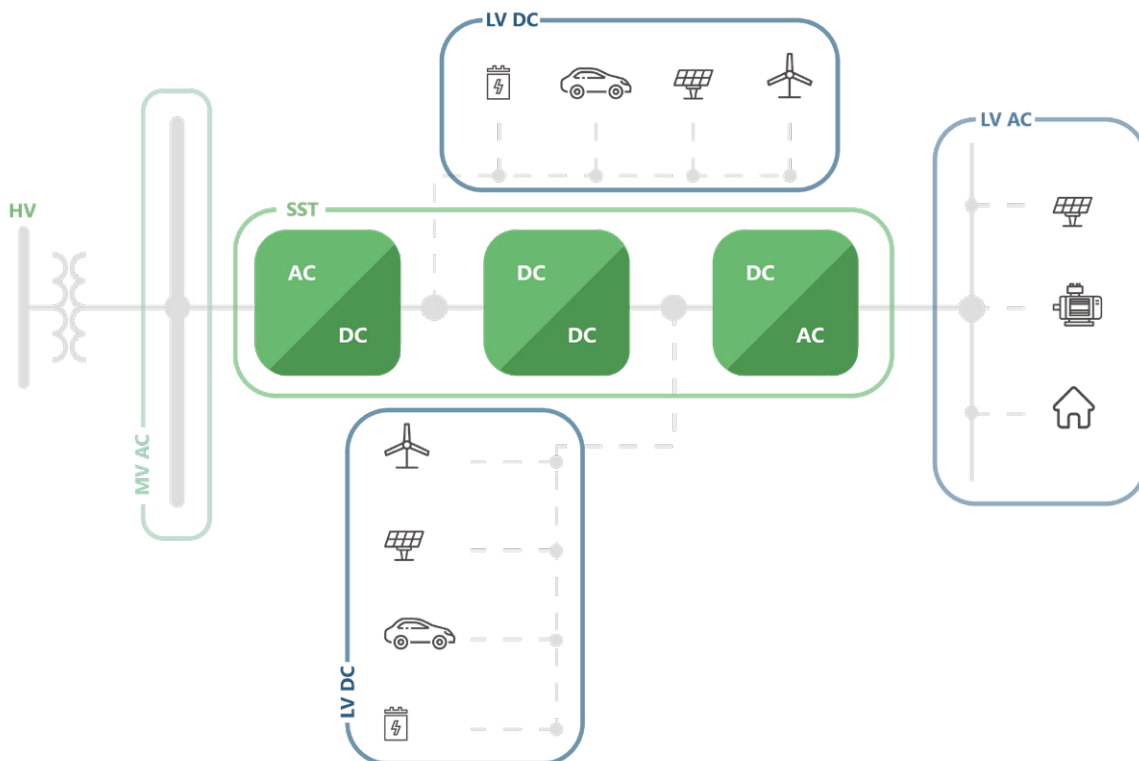
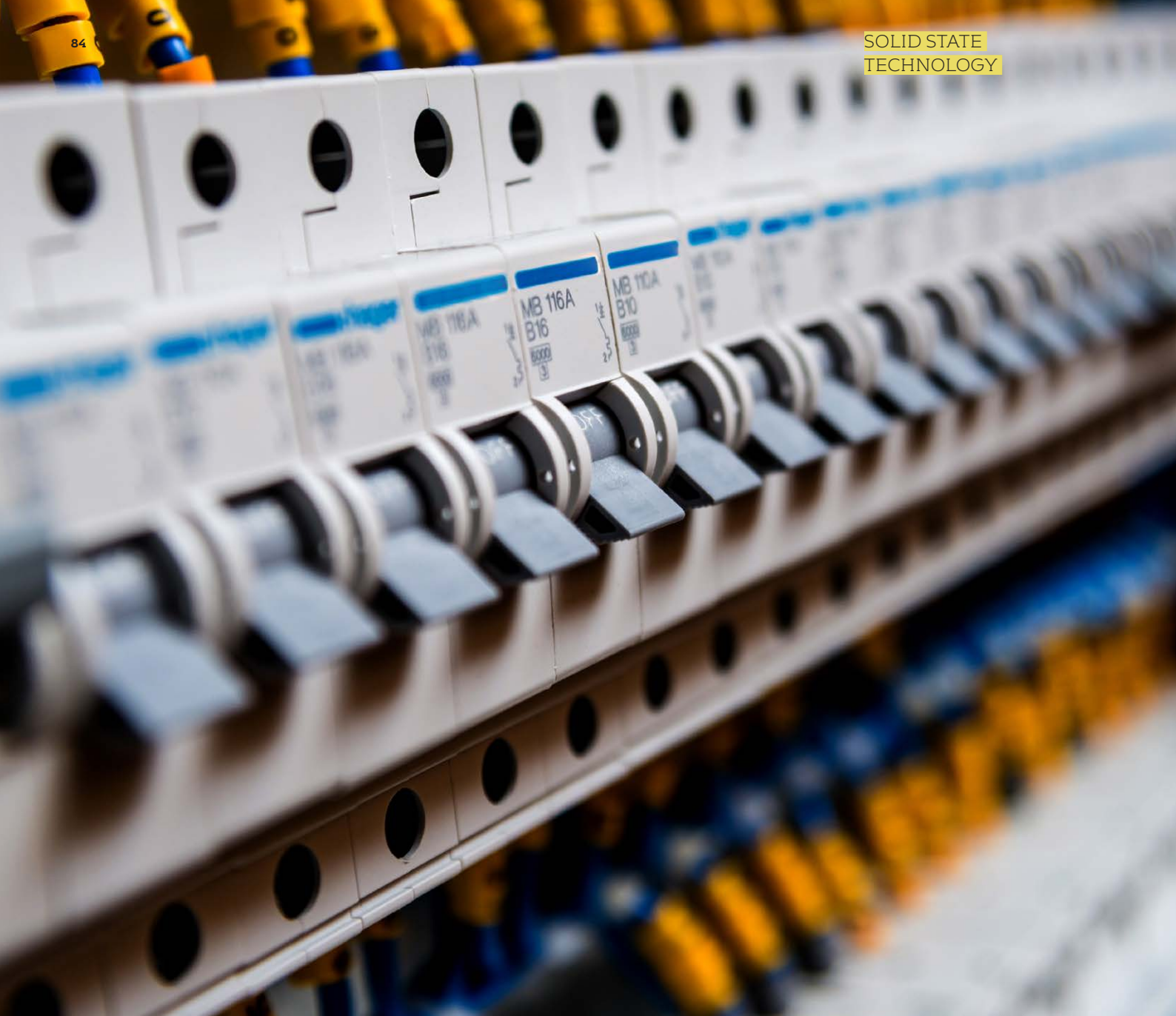


Figure 3: Application of solid-state technology in the distribution network. Source: PTR Inc.



### Hindrance in Adoption of New Technology

Despite the advantages of solid-state technology, there is still a number of bottlenecks in the way of widespread adoption that needs to be catered, especially the challenges linked with the integration and impact on power system operations, maintenance, and existing practices. For the technology

to be adopted widely the improved functionality of the solid-state technology is required to outweigh the costs for each potential application, but this would require significant investment and policy incentives from the regulatory bodies.

In case of solid-state circuit breakers, it is observed that the interruption speed is high, but the on-state losses are

For the technology to be adopted widely the improved functionality of the solid-state technology is required to outweigh the costs for each potential application, but this would require significant investment and policy incentives from the regulatory bodies.

also on the higher side as compared to conventional circuit breakers. However, the emergence of hybrid circuit breakers that employ a combination of classical electromechanical CB technology and semiconductor switches has resolved the problem.

Furthermore, ratings of the solid-state equipment commercially available also plays a significant role in the technology adoption. If a like-for-like in terms of rating is not available in the market, utilities are not expected to consider that alternative.

### Looking Ahead

In recent years, especially after the historic Paris Agreement in 2015, countries (largely advanced economies) across the globe are aggressively pursuing the deployment

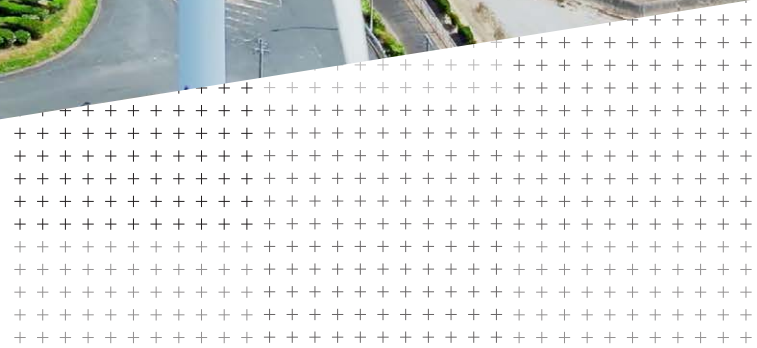
of renewables followed by the adoption of electric vehicles to electrify the transportation sector. Furthermore, we have also observed that the electrical infrastructure has become more vulnerable to not only physical attacks, but to cyber threats as well over the years. This consolidates the case for expansion, as well as modernization of the electricity grid infrastructure.

We strongly believe that modernization of the grid will greatly depend on the solid-state technologies that in turn are expected to not only streamline the power system operations, but also will assist countries in reducing their carbon footprint.

However, costs associated with the deployment of solid-state technology will continue to play a significant role in the decision-making process of utilities and TSOs especially of developing economies with limited

resources. Furthermore, investments will also be required in the research and development of solid-state technology that ensures the availability of a like-for-like alternative in terms of ratings of the equipment.

Modernization of the grid will greatly depend on the solid-state technologies that in turn are expected to not only streamline the power system operations, but also will assist countries in reducing their carbon footprint.



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# Claudia Cosoreanu &

**Chief Technology Officer  
for Grid Automation at GE**

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Interview with **Claudia Cosoreanu**





# Claudia Blanco



**Innovation and customer  
partnerships officer at GE**

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**and Claudia Blanco**

**Alan Ross:** I have two exciting guests that we're here at DistribuTech. One of them is Claudia, and the other one is Claudia. And I am not making that up. They're from General Electric. And first of all, let me start with you, Claudia.

Claudia, tell me a little bit about your background in the power industry and your time at GE.

**Claudia Cosoreanu:** I started with GE 20 years ago in the power industry as an engineer. I graduated mechanical engineering, but with automation and control as the major.

I moved into product management shortly after that. I got my MBA in marketing and today I am the CTO - the Chief Technology Officer for Grid Automation. I also lead the Production Automation and Control Product Line.

**AR** I noticed something. You wanted to save the world when you were an engineer, and then you got your MBA and you wanted to make money.

**CC** I think you need to save the world and make money at the same time.

**AR** Claudia, tell me a little bit about your background in the power industry and your time at GE.

**Claudia Blanco:** I have 25 years in the industry, but I started in automotive business, and I started in the power business twelve years ago when I joined the wind business. I was a global manufacturing director to grow the wind business onshore and offshore at that moment. Then I moved to multiple areas of advanced technology more for a global renewable business. Recently I joined Grid Solutions, in 2018, and today I am the Innovation and customer partnerships officer. I'm an industrial engineer, but I also did computer science. I'm one of those engineers that anticipate the digital world will fit well with mechanical. I did my MBA as well because I wanted to grow that business.

I'm one of those engineers that anticipate the digital world will fit well with mechanical. Claudia Blanco

**AR** We all realize there's a business to be made here. One of the things, two years ago here at DistribuTech, all you saw was IoT. One year ago, all you saw was drones. It's

not that they went away, it's the fact that they're being adopted, they're being brought into the industry. I have never seen the utility industry go through as much change as it's going through right now, which is brilliant for us. Change means need.

Another thing is that you have fewer people because we all have staffing issues. What are some of the other issues that you're seeing as it relates to the problems, the challenges that the utility industry has?

**CC** Before I get into the problems, I just want to recap what is going on. We have decarbonization as a target. We have goals established around the globe by different governments, different companies. They want to be net zero in 2030, 2035. A big part of achieving that is integrating a high level of renewable generation into the grid. The other trend is driving the change in transportation and industry. You see that being pushed.

We have decarbonization as a target. We have goals established around the globe by different governments, different companies. A big part of achieving that is integrating a high level of renewable generation into the grid. Claudia Cosoreanu

So first, talking about problems worth solving, there are more distributed energy resources integrated many times without the utilities even knowing that they're coming. And that becomes difficult for the utilities because they can't operate the grid without having visibility. For transmission, the renewable generation integrated into the grid, because it is variable and intermittent, creates grid stability issues.

Another problem that needs to be solved is that due to variability and intermittency, the grid needs to have faster controls, so digitalization and automation are two big problems that need to be solved. Now you need to be a lot faster with the controls, and digitization and automation are two big problems that need to be solved. And then there is grid resiliency. As you have



extreme weather events or cyber attacks, you need to be able to recover very quickly, so that you minimize the impact on customers, and how many customers are impacted.

**AR** That was really good. Can you add anything to what Claudia has just said, Claudia?

**CB** Something that is very important is to make sure we understand what other problems are to be solved. For what we call the grid of the future, what is now is happening now. To do that, as Claudia said before, we needed to do research, listen to our customers, listen to the industry. That helped us identify those problems that help us prioritize and be complementary to the strategy we were putting in place. We prioritize based on urgency and scalability, because we cannot solve a problem that is just a problem for a place, for a region, for a customer. And collaboration is so important because we think we are ready to collaborate and we are not, right? Collaboration means that, to solve big problems we are going to have soon, we need to do it in partnership.

We talk to our customers and involve them in selecting how to solve those problems. The complexity of that is that if we have a problem, we have multiple ways to solve it, but which one is really the most efficient?

**AR** We already have the problem that the utilities in the United States to a large extent cannot share information by law. Now we're saying to them, share information. So we've got a lot of change going on, policy

changes, the IRA spending billions of dollars, the inflation Reduction. Those are the problems that are exactly what you've just said. Now what's the solution?

**CC** There is no one solution. To comment on what you said, I think there are silos and ideally we would not have utilities do different things.. But the reality is that they will. The grid will evolve depending on the specifics of the region, of the country, of the utilities. It will depend on the government regulations, on the market design. There's a lot at play here that will influence the way utilities adopt some of these technologies. But one solution is digitization and automation. In order to do everything that we want to do with the renewable integration into the grid, while keeping the grid stable and maintaining reliability, you need to have eyes on the grid. So you need to have as much information from the grid as possible so that you know at any point in time what is going on, and you do that with intelligent sensors.

The grid will evolve depending on the specifics of the region, of the country, of the utilities. It will depend on the government regulations, on the market design.  
Claudia Cosoreanu

What we are talking about with some of our customers is the next generation of a digital substation.

We call it next generation because we have been digitizing the substation for the last couple of years. The reality is that it's not adopted, not at the scale that we were expecting it to be. And the reason for that is we haven't really looked at it from an end-to-end solution point of view. It was just not compelling for our customers. We want to offer intelligent sensors as part of the solution. We want to have an integrated digital model of the network within the reach of the substation. We want to have virtualization of some of the functions so you have protection, control automation in the substation, which has its own benefit. On top of that you can add now advanced automation applications, such as wide area protection and control or dynamic system rating.

This is a solution that is flexible, but scalable, and you can apply it to solve multiple problems for utilities.

**AR** One of the big problems you're going to help solve is the people problem. Because Larry's not sitting there anymore, he retired and they replaced him with a kid.

**CC** Absolutely right. We will we will be able to provide a full solution, a full technology stack. We will have the machine learning artificial intelligence technology to help with decision making. Because you're going to have more data, the human brain is actually not going to be able to process it all. We need the technology to help.

**CB** You mentioned the drones, right? New technologies need to also be adopted. So how we prepare the users to adopt those new solutions as well, we cannot miss also this piece of the equation. I remember implementing new technologies like augmented reality some years ago, and we tried to implement that in the factory, just to give a specific example. People were not ready to use that. Those people haven't even used an iPad before, so adoption is going to be something to keep in mind as well, because this is coming now.

Another thing to add to that is how important it is to combine efforts even internally because we have our digital team, we have our experts as well on the physicals, on great automation, but we also have our power conversion. Those multiple areas can add their expertise and solve the problem. If you detect a problem, how do you solve it with grid forming? Detection and problem solving is something that GE brings very well with the technologies we handle.

Detection and problem solving is something that GE brings very well with the technologies we handle. Claudia Blanco

**AR** How have customers you've talked to here reacted to what you're sharing? I love the idea of the stack, the flexibility of it, but at the same time you're trying to create a whole.



You're not here to do pieces and parts because we've done pieces and parts a long time, it hasn't worked. And the utilities are under enormous stress to adapt to all of these changes.

**CC** They're actually very interested. We do have a few customers that want to pilot the solution.

The reality is that I believe the industry is moving. As you were saying earlier, there is no better time than now. The changes are happening, I think we're seeing that in discussions with customers. 15 years ago, it was pretty stable. I would say static. But now you see the interest, you see the challenge, you see the need and the willingness to try. What we're bringing with this next generation digital substation is the end-to-end solution, because we've been talking about piloting virtualization, the sensors, the digital twin of the network. But when you bring it all together, it's the true value. And the reaction has been very good.

What we're bringing with this next generation digital substation is the end-to-end solution, because we've been talking about piloting virtualization, the sensors, the digital twin of the network. And the reaction has been very good. Claudia Cosoreanu

**AR** You're going to be able to create this whole end-to-end, and you're also going to be able to have a digital version of that, right? I love that the world is changing, and they will get there.

Last question I need to ask you. Some countries, some locals can say everybody will do it this way. We are the utility, we have the power. Not so in the United States. We have 50 states regulating all of the utilities. California was one of the first to move to more performance-based rates, right. So as a result of that, they're going to say, hey, is this going to help us perform better? Are we going to be able to keep the lights on? Are we going to be able to be resilient in the case of storms or fires or whatever? Are we going to be reliable? Can we maintain the

existing old assets? Because you're not going to change all the assets overnight. And does your system work with the old system? I think you're going to find that people are going to take a chance to be the first and then a lot of people will be the first to be second.

Globally, what do you see for some of the barriers to adoption or some of the things? You get different geopolitical things going on. What do you see?

**CB** For me, coming from Europe, listening to our customers is important worldwide because, for example, a problem of flexibility is not the same in Spain than as in the US. We were talking with one of our key customers recently, and they said, you need to understand that we are not ready for flexibility because the regulation doesn't allow that in Spain today. But by piloting this in this area, we can demonstrate, and here we talk about proof of concept. Here is how we can help: piloting early enough, giving the value, the results, and demonstrating that the value is high enough to say that the regulation has to be adapted fast.

**CC** I would add to that, especially in Europe, but we've seen a couple of cases in the United States as well, customers are asking us to help them put together the business case for these new solutions and to help them with their seven-year, ten-year plan to really prove to the regulators that this is the way to go. And you did mention the performance-based compensation. It is starting to spread. It started in California. There are other states that are thinking about it. Europe is thinking about it as well. There will be a move towards performance-based, there's no longer just the rate case.

**CB** Something very important I want to add to that, because it's an amazing subject, is how funding from the government can help. Here in Europe, for example, if you want to apply for a call for a governmental funding support, they include you in the collaboration in some way. For example, if you want to work on one area of artificial intelligence, there is a call that obligates you to work with three different countries, and there are areas that you have to meet such as transition, distribution. This is helping to break the silos, as we say, but it also helps regulations to enter into the picture. I think here there are a lot of things that we could do with that kind of support.

**AR** This has been a delight. Claudia, thank you so much, Claudia. It was brilliant. Thank you. We appreciate it very much.

# Chip Angus





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The lead times on buying new transformers and used transformers has really extended. That's really driving the market to maintain the equipment that they have and start implementing these maintenance plans.

**Reliability Account Manager**  
at SDMyers

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Interview with **Chip Angus**

**Alan Ross:** Our next guest is Chip Angus. Chip is a dear friend. Thank you so much for joining me.

Chip and I work together in the reliability world. The reliability of Transformers is kind of where I got my feet wet in terms of electrical systems. And it's where you got your feet wet because you used to be into steel before. So, Chip, what we're talking about is advanced transformer testing and technologies. And one of the things that you and I have been talking about, all of the great testing and technologies in the world only work if they give you data that you can do something with. I know you and I have had some experience with presenting the reliability assessment. I loved your presentation, your discussion with them about how do you use data. So rather than talk about advanced testing, what I want to talk about is how do you use the testing and the technology?

We already have to make better data decisions for our transformer fleet. Explain a little bit about that.

**Chip Angus:** To start off, you must have a robust, CMMS system for all your electrical assets data. If the data is not funneled into that, oftentimes within the plant, it often gets forgotten or ignored. So that's the key to really kicking off a good, robust reliability program.

**AR** But are electrical systems in most CMMS systems for data management, or have they kind of been left out? They house data, but they don't make decisions on data.

**CA** Yeah, I agree, Alan. They've been left out. Historically, I think there's a move to get them in there so they can start generating work orders so the upper management and middle management can start understanding the reliability health of those electrical assets.

You asked me to talk a little bit about our reliability assessment. You must have a robust program that actually categorizes your assets based on the criticality of each line on the plants one line drawing, so your breakers, your relays, your cables, your transformers, they all have to be categorized, whether it's a one-to-four system, a mission-critical system, a system critical or a noncritical system. This is really the first step in starting a reliability program.

...You must have a robust program that actually categorizes your assets based on the criticality of each line on the plants one line drawing, so your

breakers, your relays, your cables, your transformers, they all have to be categorized, whether it's a one-to-four system, a mission-critical system, a system critical or a noncritical system...

**AR** Talk about that. Mission critical, systems critical. What's the difference between those two?

**CA** Well, the mission critical designation would actually shut down the whole entire "mission" of a plant.

You want to put your dollars into mission critical assets to keep your plant running. When you have your shutdowns in September, October, whenever the plants have them, what are you going to focus on first? You want to focus on the mission critical assets and then move down to your system critical. The "System critical" designation would shut down a system of your plant. It might be shipping and receiving, or it might be a smelting line, something along those lines. There'll be some damage there, but it's not going to shut down the entire organization.

...You want to focus on the mission critical assets and then move down to your system critical. The "System critical" designation would shut down a system of your plant. There'll be some damage there, but it's not going to shut down the entire organization...

**AR** I get it. The point being you can overcome it, but it's going to take time to overcome. Even that is damaging.

Let's say I have identified which are mission critical and which are systems critical transformers. Give me an idea of how do I put the right testing into the reliability assessment in order to make great decisions? What are the most important tests I should run?

Everybody says they test their transformers, but they don't. They do DGAs. It's obviously the most important, but what's next?

**CA** You have your liquid screen, which is your acid tests, your color, your



Photo



visuals, your dielectric strength, your furan compounds, infrared thermography, ultrasound, and online DGA monitoring. When you combine all those tests together with a good, robust mechanical inspection, that's going to paint a very clear picture as to what's going on with your transformer. A lot of people don't realize that when labs go to set up their Karl Fischer testing, temperature is important. A robust mechanical inspection to assess the gauges and their function is a must. If they're not functioning properly, they're not getting a good temperature reading from the transformer. You combine all that, and I also recommend doing infrared thermography at the time of your sampling. The reason is that if you get a DGA that comes back and you see high ethane ethylene, maybe some high hydrogen, maybe even the start of acetylene, IR scanning can pinpoint where the problem is. Infrared thermography can also detect low oil level on a transformer, and temperature differences between like bushings to name a few. It gives you an overall picture of what's going on with that transformer.

...A robust mechanical inspection to assess the gauges and their function is a must...

**AR** One of the things that is critically important, the lead time on transformers as we speak in 2023 at the NETA conference is now going to from six months for regular power transformers to as much as three years. Every transformer manufacturer that I know of is sold out. I know that Virginia transformer is just opening a new plant in chihuahua, Mexico. They sold out the day they opened for two years.

People don't realize they can maintain their transformer. You are one of my heroes of helping people take care of the fleet they've got while they're waiting for new transformers to come. We can't solve the lead time, but we can take care of what we've got in order to extend the life of the transformer. How do you extend the life of a transformer through field service?

**CA** That's a great point. The lead times on buying new transformers and used transformers has really extended. You used to, ten years ago, get a transformer in a matter of a couple of weeks. Now it's months and maybe years, depending on the Kva and size. So that's really driving the market to maintain the equipment that they have and start implementing these

maintenance plans. Some of the things that you can do to maintain them is obviously if you start to see acid rising in a transformer, you can hot-oil clean them, reduce the acids, so you don't destroy the paper in the transformer. Again, going back to a robust inspection, if you're finding leaks on a transformer, you're better off to fix them rather than either taking in water, going to negative vacuum, pulling in moisture or atmosphere into the transformer. We're seeing a big shift: people want to maintain their transformers long term. That way they don't put themselves in a position to have to go out and find a replacement transformer, because there's companies out there right now that are suffering because they're trying to catch up on their maintenance and they're years behind.

**AR** That's pretty much the industry as a whole.

We are publishing this in an issue that is called Advanced Transformer Testing and Technologies. What I hear you say is the technology is the data management and the ability to put it into a CMMS. I know that SDMyers has a very robust data management system that is decision dependent. It helps people make wise decisions.

You and I have also had experience where we've told people to stop, they continue to run. And it's a \$50 million loss. I love what you're saying because it's the testing that we do, robust testing that we do using the technology of data management and eventually coming to the point where we're using not AI. We're talking about machine learning.

If I see this often enough, I can start to predict seeing that engineers love extrapolation and interpolation. We want to interpolate data to say what's happening. Give me one point, I can't tell you anything. Give me two, I got a straight line. Give me three, I can tell you where things are going. We want as many data points as we can, but the testing provides data points anyway.

Last comments. How are you doing?

**CA** Doing fantastic.

Doing good. Busier than ever. There's a lot of people out there that need transformer advice and help.

**AR** And that's what the reliability assessment is all about. It is advice, counsel, wise decision making. My friend, thank you so much for joining.

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