



# TRANSFORMER TECHNOLOGY<sup>MAG</sup>

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**PS<sub>T</sub>** POWER SYSTEMS  
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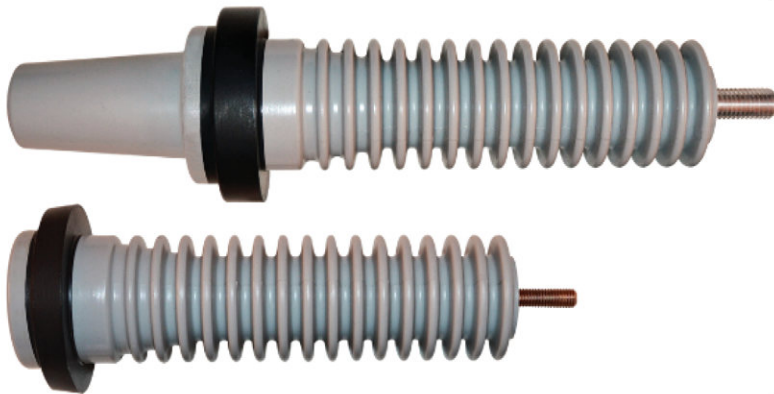
Using Visual Inspections  
of Components to Increase  
Transformer Reliability

Powering Up: **The Latest  
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Interview with **JÜRGEN ACH**  
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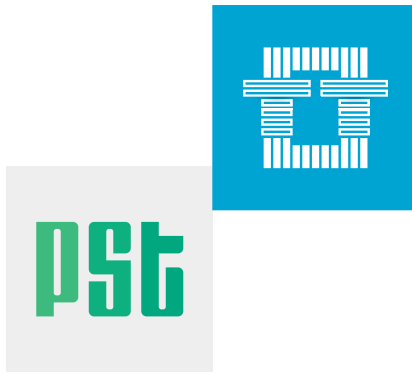
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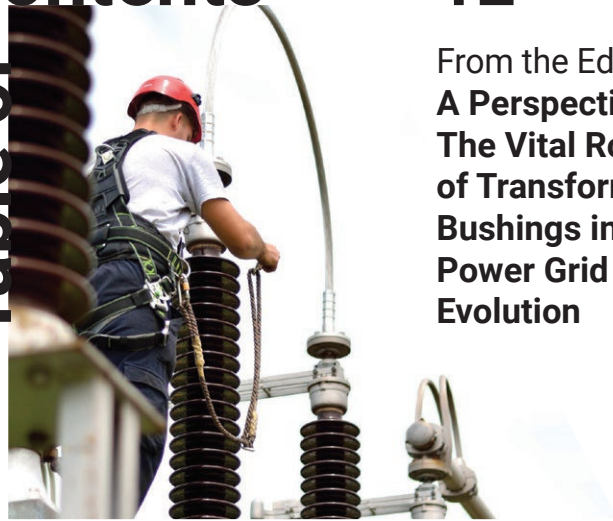
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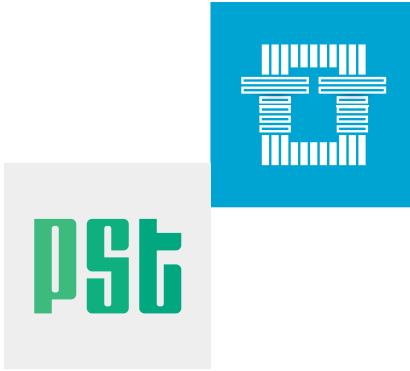
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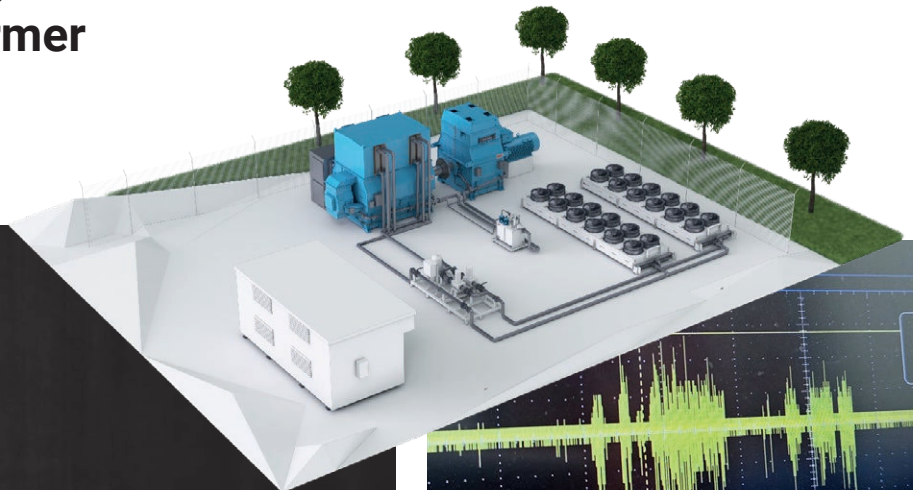
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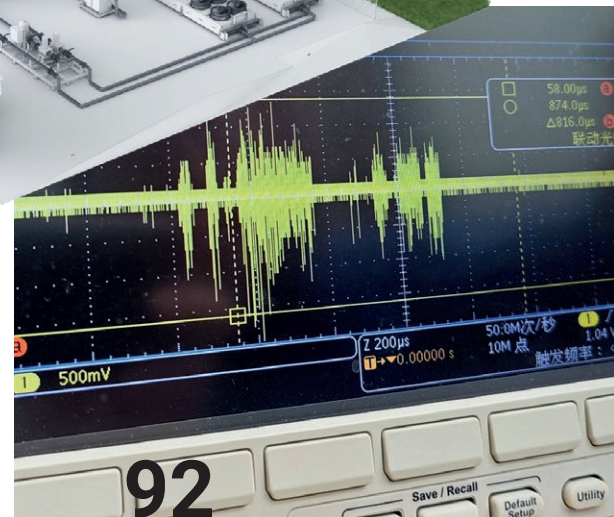
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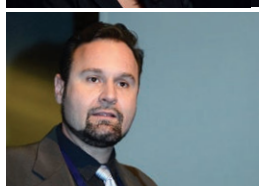
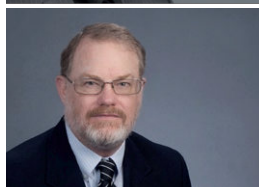
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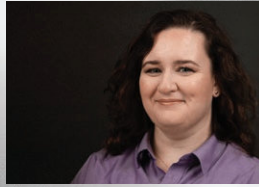
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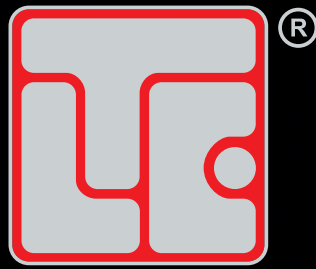
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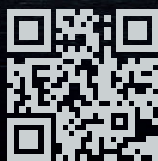
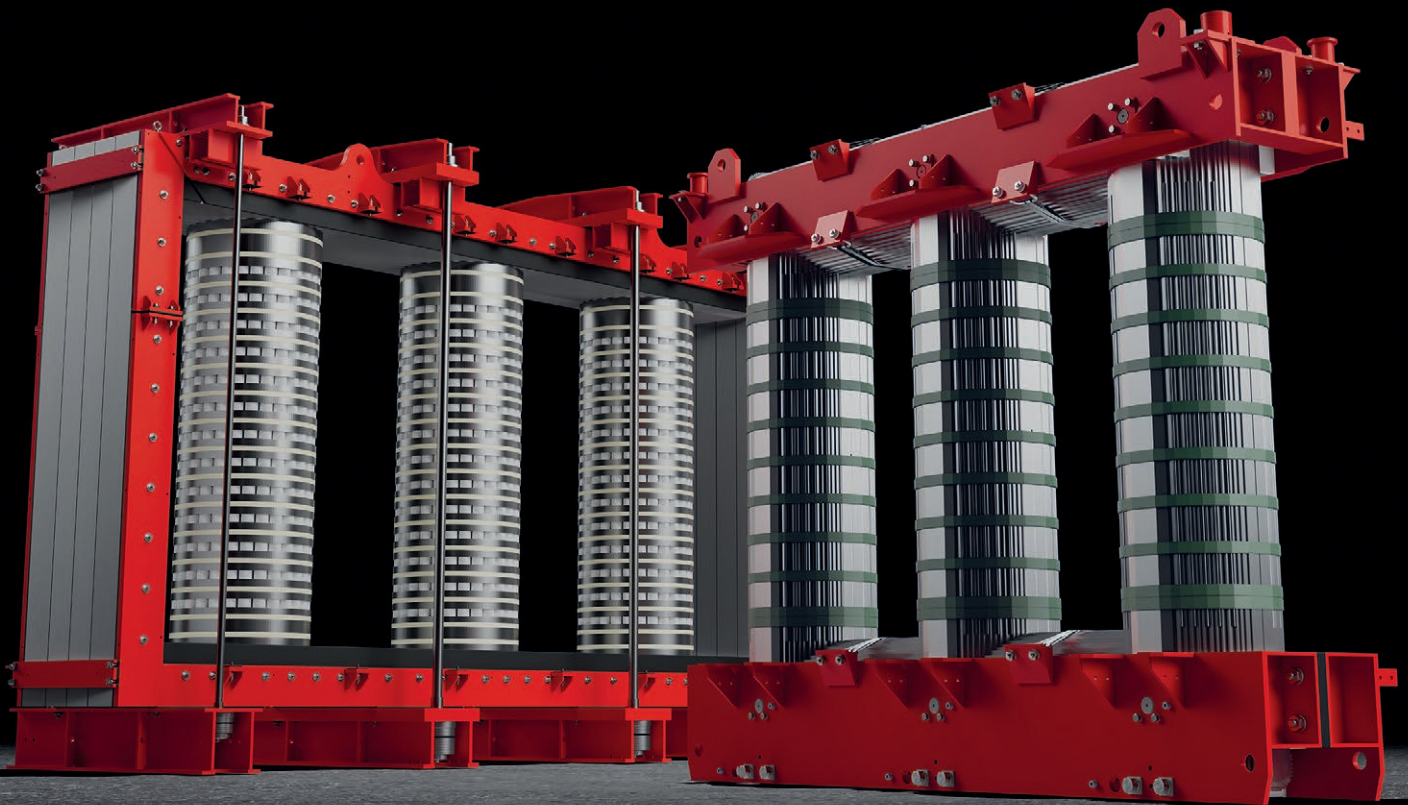
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## The Vital Role of Transformer Bushings in Power Grid Evolution

Transformer bushings and components play a crucial role in the efficient and reliable operation of power grids, especially in the face of a changing energy landscape. As renewable energy sources gain prominence and the demand for electricity continues to grow, the power grid must adapt to accommodate these changes.



### Transformer bushings and components technology is at the forefront of this transformation.

As we make the transition to Power Systems Technology, we will not lose our focus on Transformer Technology. Our strong belief is that transformers are the heart of the power system, a system undergoing dramatic change as we deal with decarbonization, decentralization, digitalization, a warming planet and severe weather events. Transformer bushings and components technology is at the forefront of this transformation.

One of the key challenges in the changing power grid is the need for higher voltage levels to transmit electricity over longer distances. Transformer bushings, which are responsible

for connecting the transformer to the power grid, play a vital role in ensuring the safe and efficient transfer of power. These bushings are designed to withstand high voltages and provide insulation to prevent electrical breakdown.

In addition to higher voltage levels, the changing power grid also requires transformer bushings and components that can handle increased power loads. With the growing demand for electricity, transformers are subjected to higher currents, which can lead to overheating and reduced efficiency. To address this, manufacturers are developing advanced bushing technologies that can handle higher power loads without compromising performance.

Another important aspect of transformer bushings and components technology for a changing power grid is the integration of smart grid capabilities. Smart grids utilize advanced communication and control systems to optimize the flow of electricity, improve reliability, and enable better integration of renewable energy sources. Transformer bushings equipped with sensors and monitoring devices can provide real-time data on temperature, voltage, and other parameters, allowing for proactive maintenance and early detection of potential issues.





**Transformer bushings equipped with sensors and monitoring devices can provide real-time data on temperature, voltage, and other parameters, allowing for proactive maintenance and early detection of potential issues.**

Furthermore, transformer bushings and components technology is also evolving to meet the increasing demand for environmentally friendly solutions. Manufacturers are exploring materials and designs that minimize the environmental impact of transformer bushings, such as using eco-friendly insulating materials and reducing the use of hazardous substances.

Transformer bushings technology is essential for a changing power grid. With higher voltage levels, increased power loads, and the integration of smart grid capabilities, transformer bushings must be designed to meet these evolving requirements. We believe that by embracing advanced technologies and environmentally friendly solutions, the power grid can continue to provide reliable and efficient electricity to meet the demands of the future.



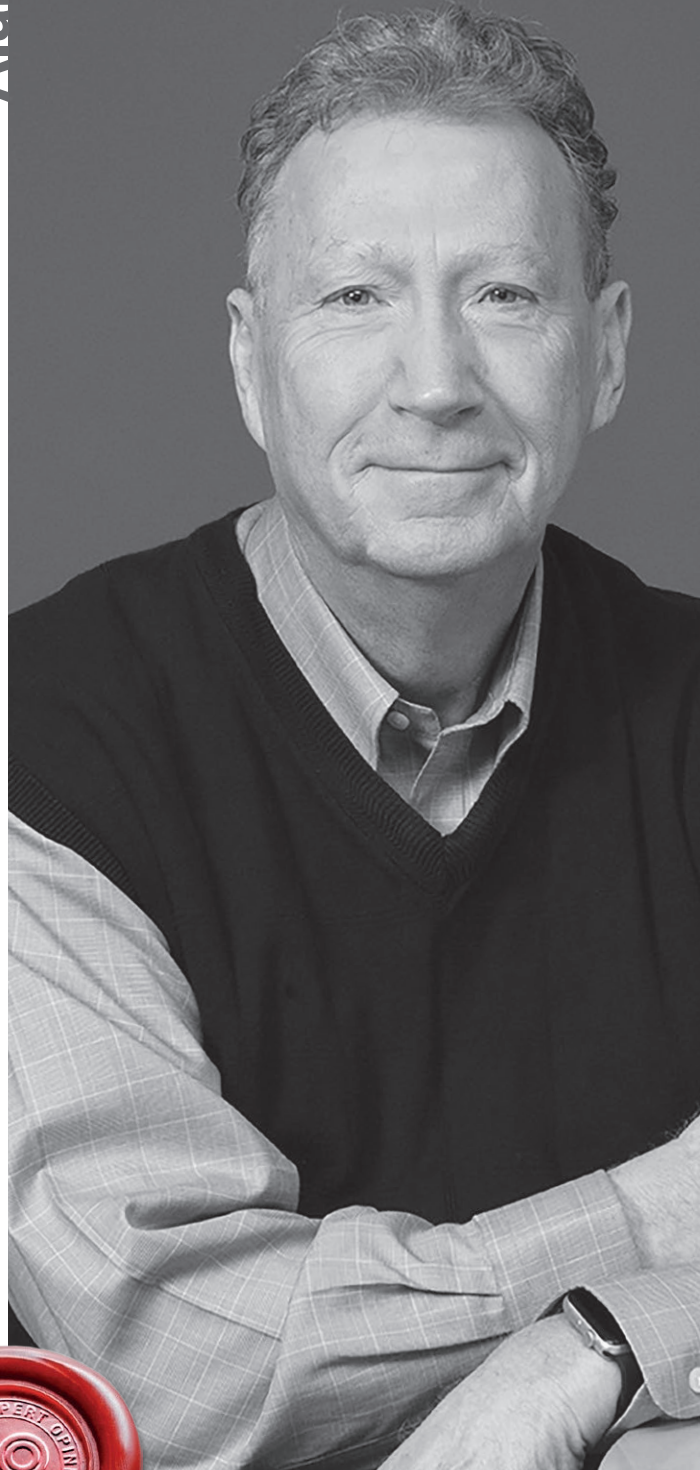
**This issue of the magazine in October has traditionally been, and will in the foreseeable future be focused on the bushing, along with other critical components that help make that important connection.**

As an example, at the recent RE+ Conference and Expo in Las Vegas, it was clear that the industry is adapting to challenges based on the ever-changing demands of the future, modern grid and at the heart of these changes is the transformer. At every connection between generation, transmission, and distribution, down to the final consumer or prosumer, is the transformer, the heart of the system. And the bushing is the most important component making that connection. This issue of the magazine in October has traditionally been, and will in the foreseeable future be focused on the bushing, along with other critical components that help make that important connection. Enjoy!

# Alan M Ross

CRL, CMRP  
Managing Editor  
APC Media  
Technical Director

Alan has decades of experience in the power systems industry and is one of the greatest reliability experts out there.



# Bushing Monitoring: What Were You Expecting?

by **Tony McGrail**

+++++

Well? What were you expecting when you bought a bushing monitor? Let's go through things in stages using a bushing monitor able to give individual bushing power factors and capacitances. Oil DGA, temperatures, PD measurements may also be very valuable diagnostic techniques, and the same approach as discussed here is recommended in those applications.

## Step back...

Ok, let's step back a moment: I'd hope you have a few things in place at the outset after your organization decided to monitor bushings in order to make sure you get value from your monitor.

a) A business case which shows that the benefit of the monitor, or monitors, outweighs the cost of: installation, commissioning, and monitor upkeep over time to ensure good monitor performance. You need data to show that the application of the monitor/s has reduced risk and/or allowed for controlled removal of suspect bushings.

A positive business case for some specific bushings is usually easier to generate as they have specific, possibly accelerated, failure modes.

b) A management plan for the monitor – will it be installed at the factory, removed for shipping, re-installed in the field? Who is responsible for ensuring the monitor is shipped safely and arrives in full working order? If any parts of the system are changed or removed, say for offline testing of the bushing, who ensures that everything goes back together correctly? And the same questions for the sensors

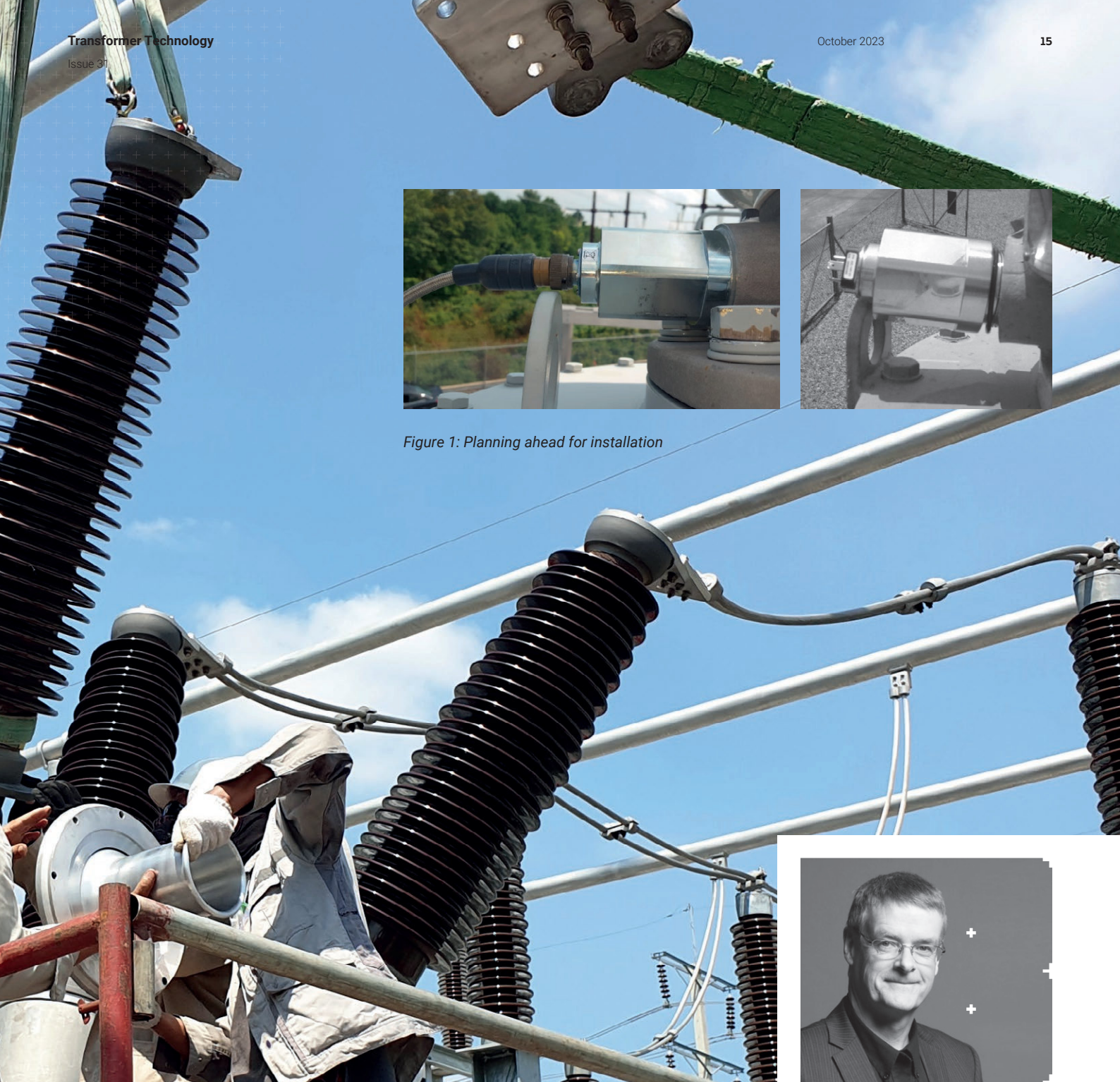


Figure 1: Planning ahead for installation

which attach to the bushings? For example, see Figure 1 where, on the left, there is sufficient space for a bushing tap sensor, which houses the multiple redundant protection components and armored cable, whereas on the right there is insufficient space for the sensor; Figure 2 shows a low clearance adapter for such situations, which allows for some of the protection to be moved away from the bushing tap.

- c) An understanding of what the monitor can do, and what you need to do to allow the monitor to do its job effectively:
- i. What measurements does it make? With what accuracy? How do the raw and derived data values relate to bushing failure modes? How much warning do you get?
  - ii. How is data stored? Where?
  - iii. What are the algorithms used to derive parameters such as power factor and capacitance? How do the algorithms work?
  - iv. How does it communicate alerts? To whom? Locally and/or remotely, what network connections are needed?



**Tony McGrail** is Doble Engineering 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.



Figure 2

d) An understanding of the individual applications – bushing type, location, etc. – which will affect the measurements generated, as there may be different failure modes which apply for GE Type U as opposed to Trench COT(A), for example. At this point we are beginning to look at expectations: what do we see for this particular bushing? For this set of bushings? Do we know what is normal? What is acceptable?

e) Alert management plans:

- i. A set of alert levels for each application based on the bushing type and data available from the monitor which give timely indication of bushing deterioration: three levels at low/medium/high are not uncommon.
- ii. A set of response plans for each alert including what to do, who does it, by when, with appropriate audit details as per an asset management program, including a post alert review

f) Condition monitoring needs to be seen as part of the asset management strategy of the organization and, as such, it's something 'we do' not just something 'they do': 'condition monitoring is not just a box with lights on'(1, 2). A written statement of condition monitoring strategy and policy would be a useful reference.

Condition monitoring needs to be seen as part of the asset management strategy of the organization and, as such, it's something 'we do' not just something 'they do': 'condition monitoring is not just a box with lights on.'

### Step Forward

With everything in place and data being generated and keeping an eye on alert systems, what does your data look like?

As an example, we'll look at a relatively common approach where we use the nominal system voltage and the nameplate bushing capacitance to calculate an expected leakage current magnitude:

- i. simultaneously record the current waveforms for each of three bushings in a set

- ii. Use the waveforms to derive the individual current rms and relative phase
- iii. Compare the derived current values with the calculated expected values
- iv. Set alerts if that current is higher than expected, or lower than expected – by how much depends on the individual application, but a consistent variation of, for example, 2% could be a useful indicator of bushing deterioration, but could also indicate a sustained variation in system voltage

Figure 3 shows the leakage current magnitudes of a set of three bushings recorded over 7 days; note the variability of the individual currents and how the magnitudes vary both individually, with respect to previous values, and relatively compared to other bushings in the set: sometimes the red and blue traces are close together, sometimes they are further apart; sometimes all three change suddenly. What causes these variations?

So, with everything in place and data being generated and keeping an eye on alert systems, what does your data look like?

The causes could include things such as system voltage variation, tap position variation, temperature effects, surface leakage current effects due to contamination on the bushing, bushing deterioration. A small change on all three bushings could well be a system voltage variation; a larger change could be a tap changer operation.

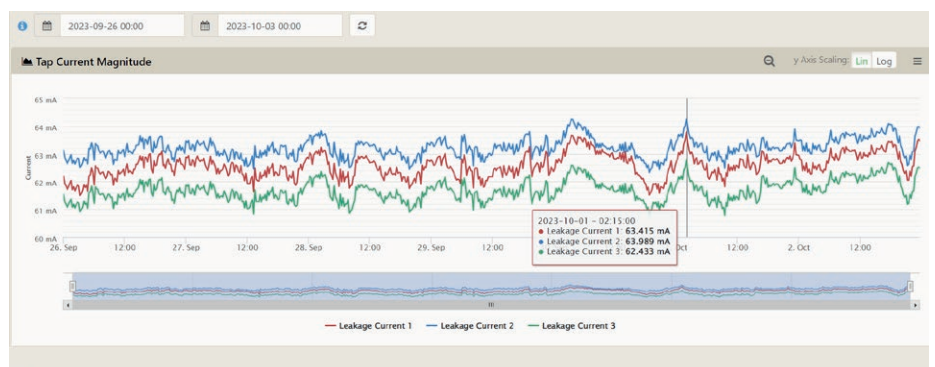


Figure 3: A set of 3 bushing Leakage Current Magnitudes over 7 days

Overall, we need to get to know not only what is expected for a particular application, but also what is normal and acceptable. Then we can tune alerts to be more sensitive to significant variations.

The same approach can be applied for the relative phase angles: we expect them to be 120°, as shown in the left of Figure 4, but this requires a perfectly balanced system and three identical system voltages on three identical bushings.

If one of the bushings in Figure 4 starts to deteriorate and its power factor rises, its phasor will move closer to its driving voltage, which would be a clockwise move, as shown on the right of Figure 4. This results in one relative phase decreasing, one relative phase increasing by the same amount as the other decreases, and one stays the same. However, it should be noted that the 10° variation in phase angle is immense – a variation of 0.5° is not uncommon, but a deteriorating bushing would likely supply only 0.1°.

Figure 5 shows the ‘natural’ variation in phase angle on a set of three bushings over a 4-day period, measured hourly.

The phase angles in Figure 5 vary in a similar way to the currents – they are not constant relative either to their own history or relative to their neighbors. But the fact that Bushing 2 is the one thing common to the two relative phase angles which vary is a strong indication that it is a possible cause of the variation.

We can also use the relative phase angles to work out the power factor of the bushing which seems to have changed. We do have to make some assumptions which we will have to check if an alert comes in:

- i. we expect the system voltage to have a 120° difference between phases, which is not always true, and is affected by, for example, variations in system MVA/MVAR ratios, the proximity of static var compensation and tap position
- ii. we expect, given the relative infrequency of bushing failures, that only one bushing will deteriorate at a time.

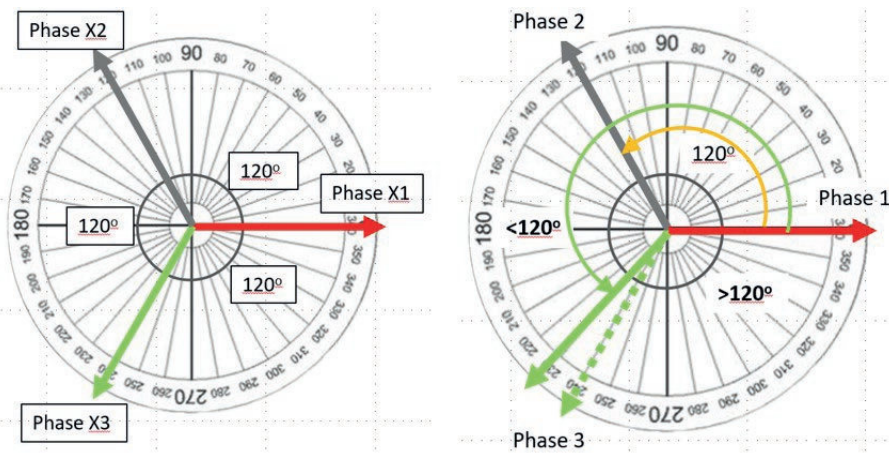


Figure 4: Three Phasors giving relative phase, ideally 120°



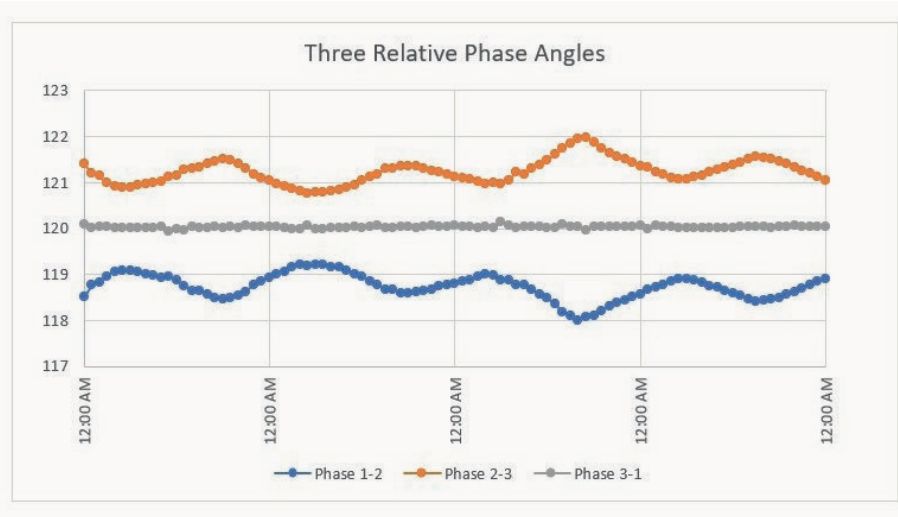


Figure 5: A set of relative phase angles over 4 days

iii. We will use the relative phase angles to calculate a power factor for each bushing and we expect, in general, that the bushing power factor will rise as the bushing deteriorates. This is not always the case and causes of a fall in apparent power factor could include both a rise in surface contamination on the bushing, or a build up in internal contamination providing a resistive path to ground (3, 4)

These assumptions are good in general, but need to be borne in mind as we review data, especially as we work out what is normal. We can set alerts on the relative phase angles to indicate a change of more than a particular value. That value will depend on what is normal for your application: but set an alert level to generate more alerts to begin with, then loosen or tighten the level to provide more meaningful information when we recognize 'normal'.

We use the relative phase angles and the assumptions to derive a power factor for each bushing. Given that the background variability in the phase angle is large, we can add smoothing using averages over a day, a week and a month so as to remove the 'noise' in the resulting power factor values. We can then apply three alert levels to each of the daily/weekly/monthly trends. Figure 6 shows the smoothed values for a single bushing over a 7-day period.

In Figure 6, the monthly power factor is an almost constant value, while the weekly has some low variation, and

the daily much more. This is common, in practice, and reflects the variation on the system plus any variations related to the bushing itself.

In addition, for any measurement that we make, we should also be able to look at not just absolute measures such as picofarads and milliamps, but also percent variations to the value from a baseline, as a change of 1 mA on a 65 mA base is of less interest than a 1mA change on a 7 mA base. In some applications this may give a clearer indication of a possible growing problem.

Finally, it is worth noting that some failure modes can be sudden, from nominally 'good' to failed in a few hours; we have several cases of such rapid onset situations where a likely catastrophic failure was avoided. In such cases we may not have time to see much development in the trends, but we can generate alerts

for the current, phase angles, and instantaneous power factor and capacitances. In fact, we add an alert based on sending out the top-level alert immediately if any monitored value exceeds a preset limit.

### Adding Voltage Reference

If we add a voltage reference to a bushing monitoring system, we can now look at each phase individually as a 'true' power factor between a measured voltage applied and leakage current resulting; we no longer have to assume the 120° difference between phases. A previous article in Transformer Tech Magazine looked at the benefits of the dual relative and true approaches (5), noting that the 'true' power factor is, in practice, addressing the insulation of both the bushing and the source of the voltage measurement, usually a voltage transformer (VT); consequently, the approach is also monitoring the VTs but we would be uncertain as regards which is deteriorating. Relative and true power factor measurements are independent but complementary techniques: if a bushing is identified as deteriorating through relative power factor and true power factor measurements, we have strong evidence that it is the bushing which is in question, and the variation is unlikely to be an artefact of the system voltage variation.

A significant advantage of the dual relative and true power factors approach is that more than one bushing can deteriorate at any one time and we would be able to detect and diagnose that state.



Figure 6: Smoothed Power factor values for a single bushing

### Is this what you were expecting?

The following cases illustrate the need to set expectations. Over 95% of the time you do get what you expect, but the remaining may be somewhat challenging in terms of interpretation and diagnostics; in challenging cases engineering expertise is often needed to fully investigate and come to a conclusion.

#### Case 1: as expected

In Figure 7, on the left, we can see three phase angles for a power transformer, with a sudden change over a few hours of the angles related to the phase 2 bushing. On the right in Figure 7 we can see the variation in leakage current, with a sudden increase in current magnitude for the tap 2 (phase 2) simultaneous with the change in phase angles.

Figure 7 shows what we would hope to see in phase angles and currents in a system which is operating normally, as expected, and then 'sees' a sudden change in one bushing. This data was used to generate an alert and the bushing 'saved'.

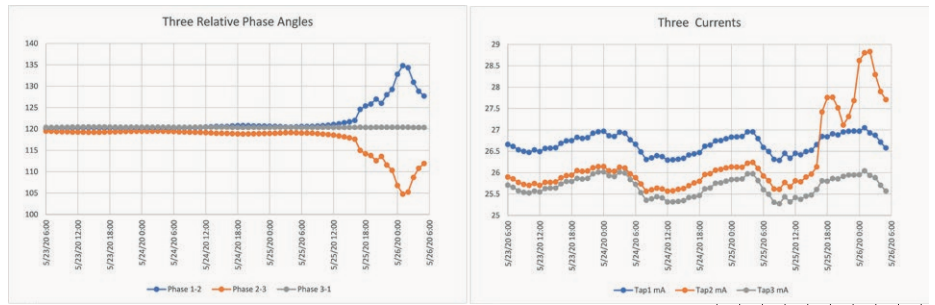


Figure 7: Sudden changes in phase angles and current magnitudes

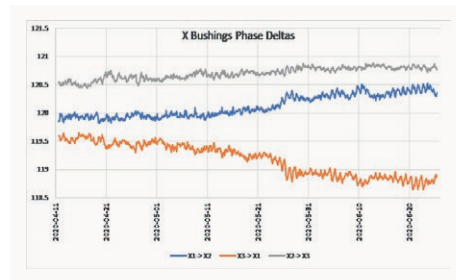


Figure 8: Variations in LV bushing relative phase angles

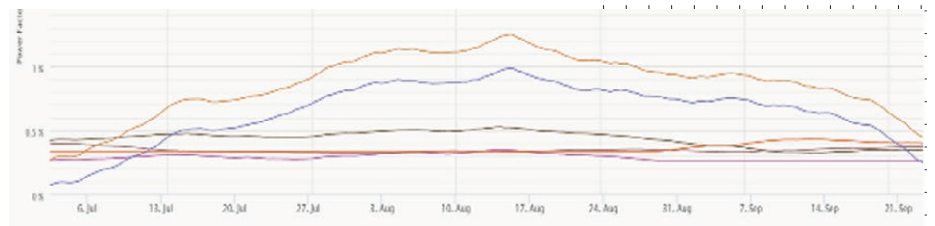


Figure 9: Relative and True Power Factor for 6 Tertiary bushings

Figure 7 shows what we would hope to see in phase angles and currents in a system which is operating normally, as expected, and then 'sees' a sudden change in one bushing. This data was used to generate an alert and the bushing 'saved'.

#### Case 2: not quite as expected

In Figure 8 we can see some interesting variations in the relative phase values for a set of low voltage bushings: none of the traces show a roughly constant value, and the rise in the blue trace is not a mirror in the fall of the orange trace. At the same time, the leakage currents were consistent both over time for individual traces, and relatively between traces.

The cause of the variation in Figure 8 is two bushings beginning to deteriorate – which is unusual.

One of the bushings has a power factor which has risen to almost 2.5%, the other to over 1%. The combination of effects gives the results in Figure 8.

The cause of the variation in Figure 8 is two bushings beginning to deteriorate - which is unusual. One of the bushings has a power factor which has risen to almost 2.5%, the other to over 1%.

#### Case 3: definitely not as expected

It's expected that we would be able to track the deterioration of a bushing which has an increasing power factor, and plan for offline testing and possible replacement. However, what happens if the bushing data indicates that the bushing is no longer deteriorating but 'getting better'?

Figure 9 shows such a case, where a

set of three 23 kV tertiary bushings has both relative and true power factor shown (1).

It is very unlikely that a real bushing would 'get better', but can we come up with a scenario where the power factor decreases? There are several cases in the literature which discuss how reduction in power factor may occur, leading, in some cases, to negative values (3, 4).

In the case here a scenario was identified which could explain the effect – an oil fill gasket at the top of the bushing could leak, allowing ingress of moisture, which would, initially, cause deterioration of oil quality and a rise in power factor. Over time, a consequent build-up of contaminants on the surface of the bushing conductor would build up a resistive path to ground and allow the power factor of the bushing to decrease. A subsequent offline test confirmed the online results.

### Discussion & Conclusions

To get the best from your bushing monitor, it is vital to set expectations up at the outset and ensure the monitor, its maintenance and management are included in the asset management plans of the organization. Then we can expect to get sensible data which can be used to both detect bushing deterioration and subsequently support bushing investigation and diagnostics.

It is important to identify not only expectations, but also what may be considered normal and acceptable for a particular application: then we can set alerts for anomalous data

which may indicate a deteriorating bushing. Both identifying normal/ acceptable and subsequent investigation may need detailed engineering expertise.

To realize the value of condition monitoring in general, and for bushings in particular, it is important to understand failure modes which may apply, their timescales, and the need for written and agreed response plans: what to do, who should do it, by when and with what feedback.

### Acknowledgement

The author would like to thank his many colleagues who provided discussion of practical aspects of bushing monitoring.

### References

- [1] "The Asset Management Context: Condition Monitoring..." J. Beardsall et al, EEA Conference 2023, Christchurch, New Zealand
- [2] "Intelligent Condition Monitoring", T. McGrail, Doble Life of a Transformer Seminar, 2020, Orlando, USA
- [3] "Negative Power Factor of Doble Insulation Test Specimens (An Analysis)", D. Kopaczynski, S.J. Manifase, 55th International Conference of Doble Clients, Boston, USA, 1987
- [4] "Review of Negative Power Factor Test Results And Case Study Analysis", L. Pong, 70th International Conference of Doble Clients, Boston, USA, 2002 Pong
- [5] "Power Factor: Offline Relative and True", Transformer Technology Magazine, Summer 2020, Issue 6



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# CALISTO<sup>®</sup> R9

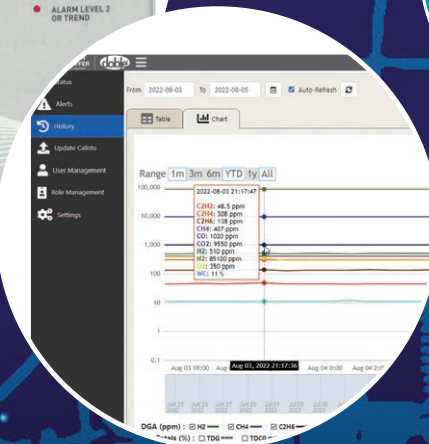
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# Jürgen Ach





Having had a focus on the transformer for many years and working with our customers, we realized that many of them aren't really aware of the actual status of their transformers. There are hardly any sensors, there's SCADA communication, but there is much more potential. We believe that data that is ideally interconnected provides much more information. MR creates a world for the customers where they always have information on everything that is going on in their transformer.

**Alan Ross:** My guest today is Jürgen Ach and he is the Director of Automation for Maschinenfabrik Reinhausen, one of my favorite companies to talk to and do interviews with. Jürgen, thank you for joining me this morning.

**Jürgen Ach:** It's a pleasure to be here, Alan.

**AR** As you may know, I'm a reliability engineer, a member of the IEE Reliability Society, and I used to run an organization called the Electric Power Reliability Alliance (EPRA). So, as you can imagine, I'm very passionate about reliability and MR is entering a "new dimension of reliability". I love that saying. Could you tell us what that means?

**JA** That is a good question, Alan. Having had a focus on the transformer for many years and working with our customers, we realized that many of them aren't really aware of the actual status of their transformers. There are no sensors, there's SCADA communication, but there is much more potential. We believe that data that is ideally interconnected provides much more information. MR creates a world for the customers where they always have information on everything that is going on in their transformer.

The industry looks to the transformer and talks about digitalization but there is a step before, which you have to do. If you'd like to create the industry 4.0 and digitalization, first you have to do the industry 3.0, which is automation.

**AR** That really is a new dimension of reliability, I like that immensely. I believe that one of the big problems we have is the reliability of the grid. We're going to talk about that in a bit but before that, I'd like to hear a little bit about your background. You've been with MR for 28 years. Is that right?

**JA** It sounds incredible but yes, it's been 28 years.

**AR** That's amazing! When you started, what was your first role?

**JA** My first role was as an engineer for order processing. I created diagrams and

production orders for motor drive units and for OLTCs. That was a long, long time ago.

**AR** And now you are the Director of Automation. I want to go into that a little more. What does that mean at a company like MR? That's a unique title.

**JA** Yeah, there is a good reason for this. The industry looks to the transformer and talks about digitalization but there is a step before, which you have to do. If you'd like to create the industry 4.0 and digitalization, first you have to do the industry 3.0, which is automation.

**AR** I love that! And of course, it makes absolute sense!

**JA** In the 90s and in the 2000s, all the other industries rolled out all this automation technology to the factories and built automated processes. Whereas in the transformer industry, our customers didn't do this. Now we have to do it before we can follow through with digitalization. And that is what we at MR are working on.

**AR** Most of our readers, when they think of Reinhausen, MR, they think of the quality of the on-load tap changers. That's what you all have been best known for globally for decades. Highest quality, great research. No one ever got fired for buying a Reinhausen on-load tap changer. Now the company is moving in a completely new direction. Not a different one but a new one, because you're not changing who you are and the pedigree of who you are. But you are changing the direction of your support for the marketplace. What from your experience are the biggest challenges the industry is facing that lead MR to make the decision to take what they've done in the on-load tap changer market and bring it to many other markets?

**JA** When we talk about the end users, we see at least two main fields of new challenges. On the asset management level, we have a lot of people from the old generation retiring and the younger people are not willing to spend a life for a transformer or a bushing. We are losing the know-how of all these technical systems. Hundreds of years of experience that were handed down through these old-school generations are gone. Furthermore, the loads on the transformers are much more volatile than in the past. Our asset managers are finding themselves in this new situation where all the transformers are running at high-volatility loads and a lot of new transformers are needed but there are not enough people to handle them. Digitalization can help to handle this situation.





On the other hand, when you look at the SCADA systems or energy management at least, how should we handle the situation with the load? In Germany, for example, we have many wind farms in the North and a lot of industry in the South, but not enough transformers and transmission lines to connect the two. So currently we have to switch off the wind farms in the North and produce customized energy in the South. Digitalization can also help to bring more energy from one end of the country to the other.

**AR** Variable load management has two parts. One of them is exactly what you are talking about. The other we see frequently in the United States: During the summer everybody is running air conditioning, especially when they get home, the load hits peak and the utilities just don't have enough power. So they tried to manage it by charging a lot to the point where the average kilowatt-hour cost went through the roof. Loads are changing because of weather events and DER with wind and solar. And it's having a negative impact on the transformers. Now you've got all kinds of transients and harmonics that we didn't have before the inverter-based system came into play and the challenges are great. Now, tell us please what MR is going to do to solve them. Pick one challenge and tell me how you're fixing it.

We bring a cloud computer to the transformer and we collect all information on the transformer and all factors. Then you know exactly what's going on in the transformer, exactly what temperature is inside, what the load is, the prognosis from the SCADA system, from the energy management system. You know the status of each component.

**JA** Thank you for this question. Imagine there's a world where you can get the prognosis of wind and sun or anything going on in the energy system, and bring it to the transformer for the next 24 hours. You could know exactly when your transformer needed cooling, and you could manage the cooling control proactively and so enhance the load by using the temperature of the cooling control and managing the oil temperature.

**AR** We call that "running it hot". You allow the transformers to run hot, which allows them to take that variable peak load in there. Is that a product or a service? How does MR bring that into play? Are you using it through the load tap changer?

**JA** Yes, we bring a "cloud" computer to the transformer and we collect all information on the transformer and all factors. Then you know exactly what's going on in the transformer, exactly what temperature is inside, what the load is, the prognosis from the SCADA system, from the energy management system. You know the status of each component.

**AR** Is that the ETOS system?

**JA** Yes, it is a piece of software in ETOS that we call Dynamic Transformer Rating.

**AR** And nowadays it's all about data, data analytics, data diagnostics, and all those things. Where does the data management happen? In the cloud?

**JA** That's a simple answer, Alan: It depends. You can do whatever you like, you can do everything. We install sensors on a transformer, and we bring a CPU, an edge computer on a transformer, and connect it to the energy management cloud and to any other cloud the customer wants. This way you can run all functionality and all the software at the transformer in the edge computer and send them to the cloud. You can also work without using a cloud. Many of our customers do not like asset management clouds, which is their right and their choice. You can also do everything by sending the basic information, the basic sensor data to the cloud and to all the data analytics on the cloud.

If you ask me, the best way is to do the calculation at the edge computer on the transformer and then send the analyzed information to the cloud, only the tangent data of the bushing and the gas from the DGA, not the basic element, tasks and data.

**AR** Alright, you've mentioned two main challenges for the industry customer, now let's tie them together: You've got experienced people retiring, new people replacing them, and having to do so much more than their retiring counterparts. One person replacing three or four because of labor shortage, and everything changing. I'd hate to be that one new person if I didn't have somebody analyzing and giving me not just data, but diagnostics.

Somebody coming to me and saying “This is what's happening in your transformer, you need to do this.” And that is exactly what you do for your customers. Correct?

**JA** That's it exactly.

**AR** Now, let's switch gears for a minute. Here's a company well-known for load tap changers, that is now expanding into the service business. You're doing transformer service throughout the United States. You're providing data analytics, data collection diagnostics, automation, and digitalization. These are big leaps. How do you maintain the quality that MR has been known for in load tap changes and maintain that in a service and digital automation business?

**JA** I believe, Alan, that it is a question of culture. When you have been a manufacturer for 100 years at OLTC, you know the OLTC goes in the transformer and nobody has a chance to go in there and repair it. When we develop something, we work together with sub-suppliers, we take great care of every detail. When we write something on a paper, we double- and triple-check it. For example, when we send the OLTC into the test field, we know that it's more or less one and a half years and one and a half million euros (\$ 1,6 million). We can check that OLTC at once. Some 20 years ago, we decided to reinvent our production department. We have screwdrivers with computers which check every screw and the torque on every screw, and we make sure to test each product before it leaves the factory.

When we develop something, we work together with sub-suppliers, we take great care of every detail. When we write something on a paper, we double- and triple-check it.

Our sales people do not hunt projects. They take care of customers and if there is a problem, they handle it for them. There's really a difference. And I know that it's sometimes really hard work for business unit leaders. It's more or less the same for service. We have a development department for services in Regensburg, and all our service technicians have to come to

Regensburg. They have to complete workshops and tests in our laboratories every two years and only then are they allowed to service our products. The same goes for the electronics department. When we develop software, we make it differently than most and test it and double and triple-check it.

**AR** You said that it was a matter of culture, and that has to be the secret - maintaining the same culture that you have been known for in the new businesses. I almost said core business, but your core business is still load tap changers. However, it sounds like your core business is going to become much broader, much more of a full service to your customers.

**JA** Yes, you're right. It's not a separate business unit. We are talking about the same company and the same people who are doing this automation business. It's the same production department, the same test field. This way we sell a system. We do not sell ETOS and the automation products on one side and then OLTC on the other. Inside this ETOS system, there is a drive for the OLTC and the same people, who work with the customers for both.

**AR** It's a brilliant go-to-market strategy. One of your compadres at MR, Thorsten, was telling us about his 1988 convertible BMW. My son in California just bought a VW ID 4, the electric one and it is definitely not the same as that 1988 BMW that Thorsten is driving. We use the term, “it's not your grandfather's BMW anymore”, as companies evolve and change and MR is undergoing one such change.

We're going to have more conversations in the future about some specific applications, but give me one if you can. Take one application where MR has been able to bring all of it together, or the customer said, “Bring it together for us”.

**JA** It's not easy to pick just one. I will take one from Germany because it's where I am based. We have a project together with one of the biggest German customers. We are working in one of their substations, bringing in all the sensors for bushing monitoring, DGA monitoring, the OLTC monitoring, the cooling control, the OLTC drive, voltage regulation, all in one cabinet. And then we will connect it twice. On one side to the SCADA system. And at the moment, we are discussing together with PSI, one of the biggest EMS manufacturer in Germany, to create this dynamic transformer rating for the aforementioned customer. On the other hand, we will connect the system via a what we call a “data diet” to the asset management system.

We are building quite a new fleet monitoring asset performance management.

**AR** As a reliability guy, I use the term, "Let the machine tell you what's going on". What you just described is exactly that. You're letting the transformer speak. That should be your new slogan: "Let your transformer speak". You don't have to pay me residuals for that, one.

**JA** That's perfect, Alan! I'd just like to add one more thing. We have prepared a new algorithm on the transformer in ETOS. We call it asset intelligence. In this algorithm, we combine all the knowledge from our great technicians and our experts in a base grid and give the customer feedback on what is going on in the transformer and can then recommend and advise on what should be done next.

We have prepared a new algorithm on the transformer in ETOS. We call it asset intelligence. In this algorithm, we combine all the knowledge from our great technicians and our experts in a base grid and give the customer feedback on what is going on in the transformer and can then recommend and advise on what should be done next.

**AR** It is a completely new day for the marketplace. I mean, as you said, we've got the great retirement of people, and add to that that the average power transformer in Europe and the United States is 38 years old. They were not supposed to last 38 years. The future is so bright for MR because you could retrofit the world. I hope you're ready for all of that growth.

**JA** Yes, of course, we are. We are very ready for this.

**AR** Jürgen, you've given us an overview of what the new identity of MR's business is. And now I understand what the Director of Automation for MR does, I can really ask you a lot of the hard questions. So I'd like to right now invite you to do another interview. And when we do that one, we're going to drill down deeper on a couple of areas.

Thank you so much. I think you've positioned MR beautifully for where you're going in the marketplace, and I wish you much success. Thank you for the quality culture that you're creating for the marketplace, because I have transformer oil in my blood and anything you can do to keep those transformers reliable, works for me. Thank you so much, Jürgen, and let's do this again soon.

**JA** Thank you very much, Alan, I look forward to that.



# The Next Generation

of

## Dry-Type High-Voltage Bushings

Nowadays, especially due to increased requirements on EHS (Environmental, Health and Safety), our HSP Hochspannungsgeräte GmbH dry-type epoxy resin-impregnated synthetic (RIS) bushings are the latest development to fulfil these requirements.



High voltage condenser bushings are a key component in AC and DC transmission grids while interconnecting power transformers or shunt reactors to busbars and overhead lines. Insulating high voltage against ground and transmitting the respective currents, bushings must be designed in accordance to the applied electrical field, physical stresses, and impacts such as pollutions, flashovers, seismic events, and others.

In the beginning oil-impregnated paper (OIP) bushings were the preferred technology of choice. Nowadays, especially due to increased requirements on EHS (Environmental, Health and Safety), our HSP Hochspannungsgeräte GmbH dry-type epoxy resin-impregnated synthetic (RIS) bushings are the latest development to fulfil these demands.

Characteristics of those dry-type condenser bushings are:

- Explosion-resistance due to silicone rubber shed instead of porcelain housing and the absence of flammable oil
- No utilization of hazardous and environmental polluting materials and components, such as mineral oil or SF<sub>6</sub>
- Higher currents and overload capabilities
- Suitable for a wide ambient temperature range from -60°C to +55°C
- High seismic resistance

These progressive benefits in the technical design characterize RIS bushings as a key asset of our eco-friendly **REGENERA™** portfolio, created by Trench and HSP. Based on the joint commitment to eliminating harmful environmental impacts, we are driving the sustainable change by delivering high-performance, eco-friendly solutions with disruptive benefits for both our customers and the environment.

Different design and manufacturing methods for condenser graded bushings have been applied and available in the electrical power industry for many years. While oil-impregnated paper (OIP) bushings have been well-known and used for decades in transmission and distribution grids, dry-type epoxy resin-impregnated synthetic (RIS) bushings became a valuable alternative for system operators and utilities. OIP bushings are a mature technology which fulfils the technical standards and requirements. However, over their lifetime, OIP bushings may be exposed to several risks, e.g., the potential loss of insulation media, or accelerated ageing of the paper insulation due to overheating. In these and other cases RIS bushings can be adopted to minimize such risks and increase the safety of the respective transformers and reactors.

**These progressive benefits in the technical design characterize RIS bushings as key asset of our eco-friendly REGENERA™ portfolio, created by Trench and HSP.**



## Principle structure and design of RIS condenser bushings

The main component of a high voltage condenser bushing is the so-called active part, or the condenser core, which, in the case of RIS, consists of a synthetic nonwoven fabric as carrier material impregnated with epoxy resin and concentrically inlaid with aluminium layers forming individual capacitors (see Figure 2).

This condenser core ensures the capacitance grading of the high voltage condenser bushing.

The core is housed in a composite insulator covered with silicone rubber sheds as shown in Figure 1. The gap between the composite insulator and the condenser core is filled with a dry-type nitrogen-based foam. As result, the bushing is completely dry and free of any hazardous fluids and gases, such as mineral oil, SF<sub>6</sub>, CO<sub>2</sub>, etc.

Life cycle Assessments (LCAs) have demonstrated a better environmental performance of RIS condenser bushings in comparison with other established technologies, like OIP or resin impregnated paper (RIP) bushings.

Figure 1: Bushing main components

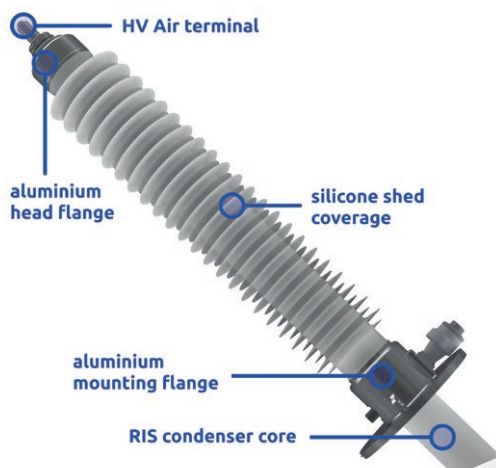
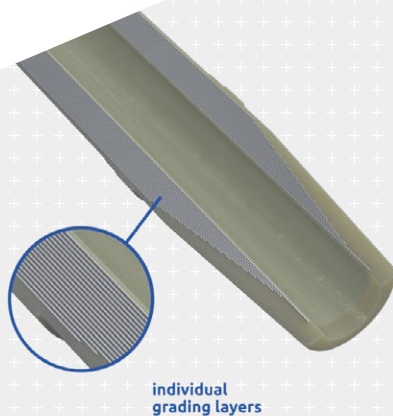


Figure 2: Cross section of RIS condenser core



### Electrical functionality and material properties of the RIS condenser core

In operation, the capacitance graded condenser bushing is capable to distribute the electrical field consistent as illustrated in figure 3. Therefore, the local electrical field stress is reduced and stretched over the entire length of the bushing.

One of the main material advantages of the RIS condenser cores manufactured at HSP is the non-hygroscopic performance. This ensures that no moisture or humidity will enter the condenser core and harm the electrical performance under high voltage, as opposed to paper (used for RIP bushings), which can accumulate humidity easily while exposed to the ambient environment. This aspect is very sensitive in the manufacturing process, but also during storage, installation, and commissioning of the respective bushings. Figure 4 shows the humidity absorption after storage in water, the results after storage at 23°C and 50% rel. humidity are for paper: 6,24% and for synthetic materials: 0,23 - 0,32%.



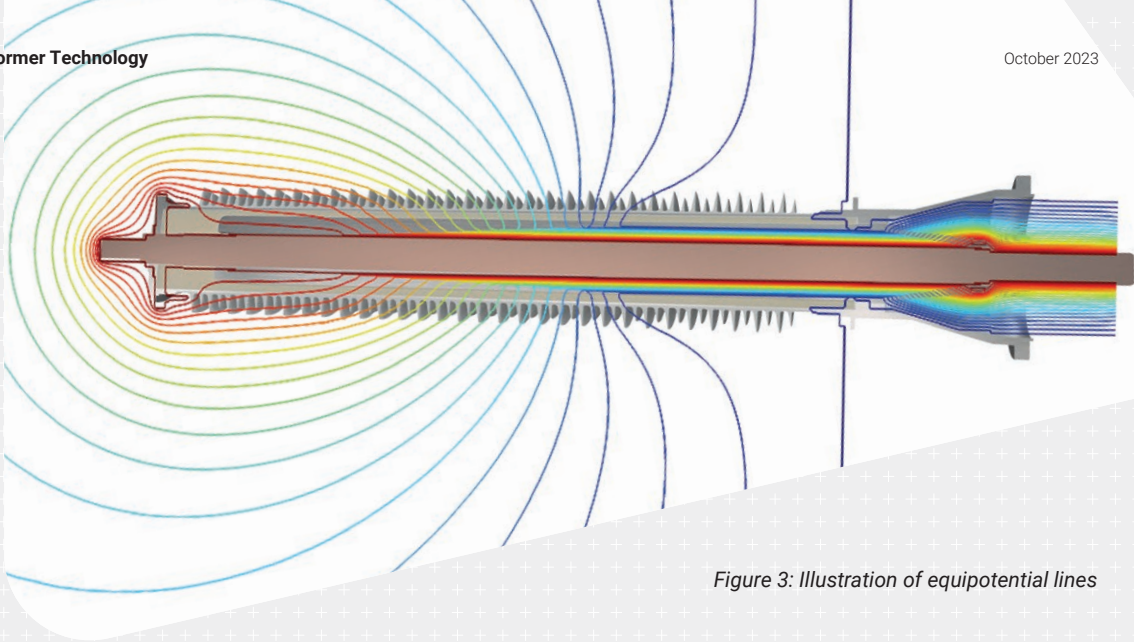
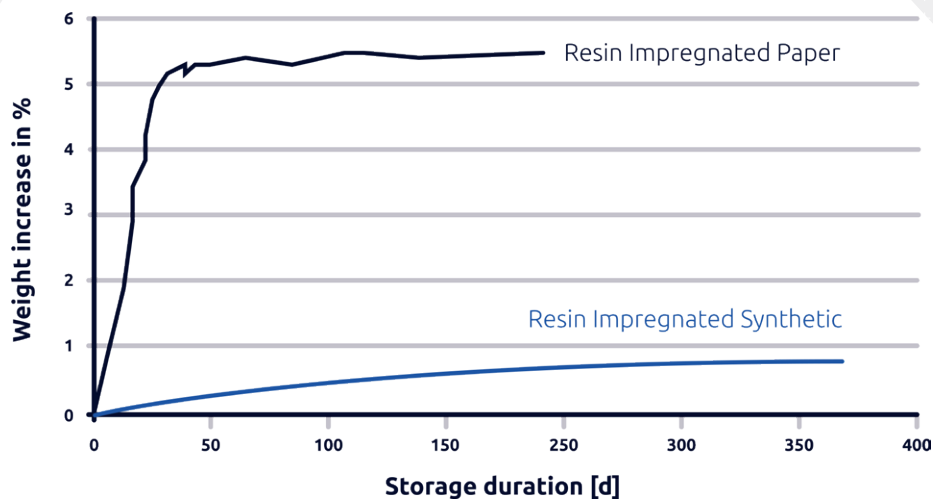
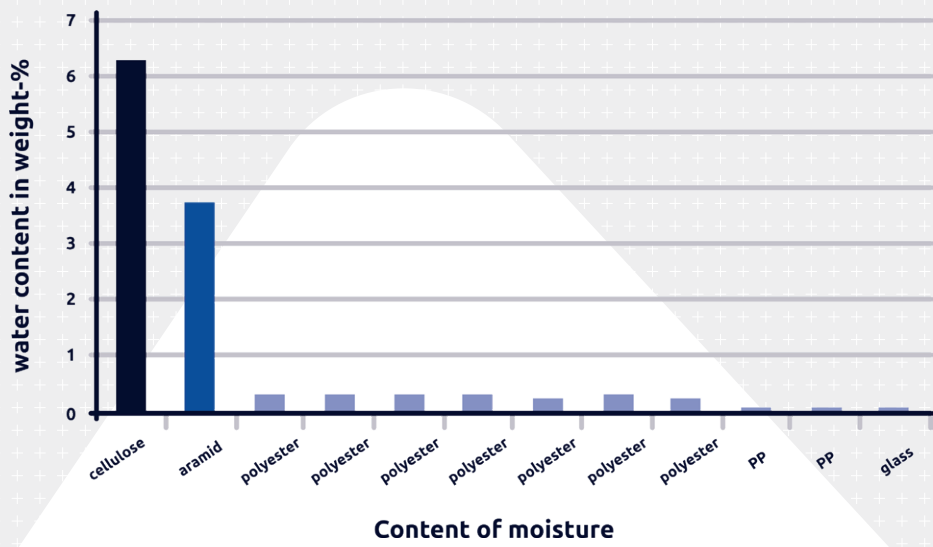


Figure 3: Illustration of equipotential lines

Figure 4: Humidity absorption behaviour after storage in water



Especially in this kind of applications, the DC electrical stress leads to a resistive grading, in addition to the capacitive grading of AC electrical stress.

### Our RIS solution for HVDC grids

HVDC grids and inter-connections need specific equipment, such as shunt reactors and power converter transformers. Condenser core bushings are used for a safe and reliable connection of this equipment to the grid.

Especially in this kind of applications, the DC electrical stress leads to a resistive grading, in addition to the capacitive grading of AC electrical stress. Therefore, design and testing of HVDC condenser bushings is elaborated and defined in specific international standards.

As an example, to demonstrate the capabilities of our sophisticated RIS technology for HVDC applications, we developed and extensively tested a 545kV HVDC converter transformer bushing. To verify the design and testing, the individual test sequences have been performed in parallel with both technologies, RIS and RIP. All applicable type and design tests were finished successfully in 2022. Figure 5 shows the test set-up of the even wetting DC voltage test.

*Figure 5: Type test of the 500kV RIS HVDC bushing – Even wetting DC voltage test*



## Lifetime cycle assessment

The impact of products and services on the environment is becoming more important for TSOs and public utilities, and therefore the use of eco-friendly components and equipment for a more sustainable power transmission and distribution also gains importance. A well-established method to calculate the environmental impact of individual products is the so-called life cycle assessment (LCA). This assessment is used to calculate, among else, the carbon footprint of a respective product from the initial sourcing of raw materials to manufacturing, delivery, installation, commissioning, operation, deinstallation and disposal (Gradle to Grave approach). Figure 6 showcases the comparison of carbon footprint between RIP and RIS condenser bushings under the following base line scenario: Total lifetime of 40 years and a realistic anticipated temperature based on average load of 70% as in-service operation conditions. The result is that RIS condenser bushings have a 45,8% lower carbon footprint than RIP condenser bushings. Also, the operational losses are significant lower for RIS condenser bushings compared to RIP condenser bushings.

Figure 6: Carbon footprint and operational losses of RIP and RIS condenser bushings



**RIS condenser bushings have a 45,8% lower carbon footprint than RIP condenser bushings. Also, the operational losses are significant lower for RIS condenser bushings compared to RIP condenser bushings.**

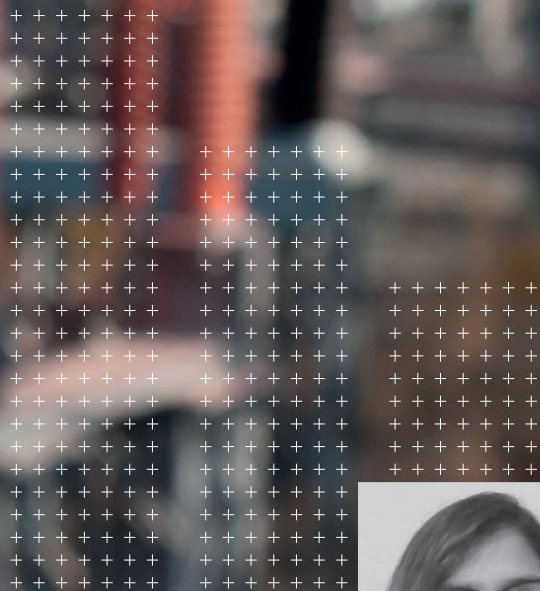
We at HSP are doing our best to create RIS condenser bushings as the best solution for our customers, being the best choice for the application in high voltage AC and DC transmission and distribution grids.

The most advanced development step in the field of manufacturing and materials is the utilization of a synthetic nonwoven as the carrier material for the epoxy resin. Such dry-type condenser bushings in RIS technology offer an even better lifetime performance, especially when it comes to storing, installation and commissioning of high voltage bushings compared to usual OIP or RIP condenser bushings:

- No paper and no insulation fluids such as mineral oil
- Substantially reduced ageing due to avoidance of organic materials
- Higher resistance to humidity -> non-hygroscopic material
- Lower dissipation factor compared to RIP bushings and no partial discharge activities in the electrical field
- Homogenous material characteristics – no voids in condenser core
- Substantially lower carbon footprint in comparison to OIP and RIP condenser bushings

# Powering Up: The Latest Innovations in Electrical Bushings Technology

by **Saifa Khalid**  
+++++



**OTHER THAN PROVIDING CRITICAL ELECTRICAL INSULATION, BUSHINGS PROVIDE SUPPORT TO HIGH VOLTAGE CONNECTIONS AND ASSIST IN MANAGING THE THERMAL STRESSES THAT USUALLY OCCUR IN HIGH-VOLTAGE ENVIRONMENTS.**



Saifa Khalid is a senior analyst at PTR Inc. Her main area of interest is power systems. Currently, she leads the power grid research team in developing PTR's syndicated power grid services and manages custom research projects for Fortune 500 clients globally. The topics under her mandate include HV switchgear, MV switchgear, power transformers, distribution transformers, substation automation, power factor correction, etc. Saifa comes from a technical background and has a BSc. degree in Electrical Engineering.

Over the years the demand for electricity has increased across the globe, which has in turn created the need for a more efficient and reliable electricity grid. The demand for improved reliability and efficiency applies to electrical bushings as well, which has pushed for innovation in bushing technology. Although a bushing may seem like a hollow piece of porcelain that contains a conductor, the task it performs is quite extraordinary. In order to insulate the high voltage conductor, bushings are installed so that flashovers due to ionization of nearby air or gas can be avoided. Other than providing critical electrical insulation, bushings provide support to high voltage connections and assist in managing the thermal stresses that usually occur in high-voltage environments.

PTR Inc. has observed that original equipment manufacturers of bushings have improved the efficiency and reliability of bushings through advancements in materials, design, and manufacturing processes over the years. It is noteworthy that utilities across the globe can prevent

equipment failure, reduce downtime and safety hazards for employees and consumers through investment in high quality bushings.

### Developments in the Bushing Industry

PTR Inc. believes that bushing technology is consistently evolving as OEMs introduce new materials (nanocomposites and silicon carbide), improve design and manufacturing processes with computer aided design and finite element analysis, and embed sensors in the bushings to make them smart.

### New materials for bushings

Bushing manufacturers have introduced new materials, for instance nanocomposites and silicon carbide, which have improved the performance and increased the lifespan of bushing. In nanocomposite materials, embedded nano-sized particles in a polymer matrix increase the strength of materials such that these materials are more resistant to high temperatures.

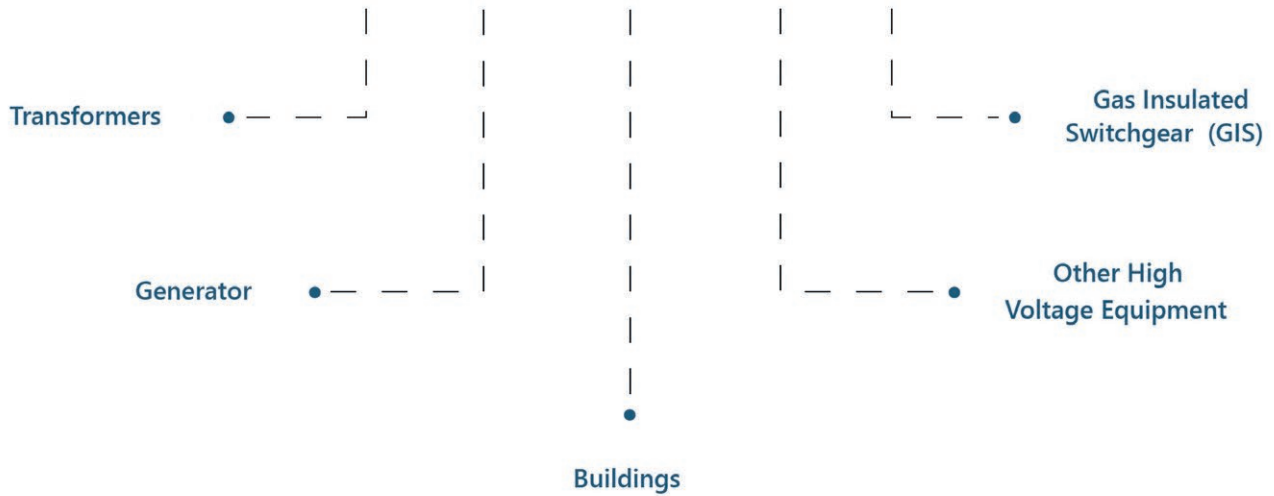
IN NANOCOMPOSITE MATERIALS, EMBEDDED NANO-SIZED PARTICLES IN A POLYMER MATRIX INCREASE THE STRENGTH OF MATERIALS SUCH THAT THESE MATERIALS ARE MORE RESISTANT TO HIGH TEMPERATURES.

On the other hand, silicon carbide has high thermal conductivity which enables improved heat dissipation in turn reducing the risk of overheating and failure. If compared with porcelain, bushings made with nanocomposites or silicon carbide are durable, perform better and are suited for use in harsh environments.

Furthermore, environmental factors such as temperature, humidity, pollution, and corrosive agents in the atmosphere are detrimental



# Applications



**IN ORDER TO OPTIMIZE THE DESIGN OF BUSHINGS, CERTAIN COMPANIES, FOR INSTANCE GE GRID SOLUTIONS AND CTC GLOBAL, USE COMPUTER AIDED DESIGN AND FINITE ELEMENT ANALYSIS.**

for the performance and durability of bushings. The newly developed materials and advanced coatings are significantly more resistant to aforementioned environmental factors. It is worth noting that Tier-1 OEMs are using nanocomposites in their resin-impregnated paper bushings. Also, Siemens' silicon carbide bushings have been installed in renewable energy projects.

### Improved design and manufacturing processes

In order to optimize the design of bushings, certain companies, for instance GE Grid Solutions and CTC Global, use computer aided design and finite element analysis. Use of CAD and FEA has ensured better performance and reliability

**THESE SIMULATIONS ASSIST THE MANUFACTURERS IN GAUGING IF THE BUSHING WILL BE ABLE TO WITHSTAND HIGH STRESSES.**

in bushings. CAD allows the designers to visualize and simulate the electrical bushing in a 3D environment, which in turn paves way for more efficient design and reduces the risk of errors. On the other hand, FEA provides the ability to simulate how the bushing will behave under different loads. These simulations assist the manufacturers in gauging if the bushing will be able to withstand high stresses.

### Smart bushings with monitoring and diagnostic capabilities

Hitachi ABB Power Grids and Trench Group are working to develop smart bushings that are equipped with state-of-the-art monitoring and diagnostic capabilities. System

Figure 1: Applications for Bushing  
Source: PTR Inc.



operators make use of the sensors embedded in the bushing to monitor different parameters, for example temperature, pressure, and vibration. On other hand data analytics is deployed to analyze the data collected through different sensors in turn enabling predictive maintenance and reduce the risk of unplanned downtime. It is noteworthy that this technology is particularly useful in remote or hard-to-reach areas, where carrying out regular maintenance is difficult.

Some bushings in the market are also equipped with advanced cooling and self-cleaning technologies that assist them in managing thermal stresses, detect moisture buildup, prevent buildup of pollutants, and protect against corrosive agents. Such innovations have positively

# Types Of Brushing



Figure 2: Types of Bushing  
Source: PTR Inc.





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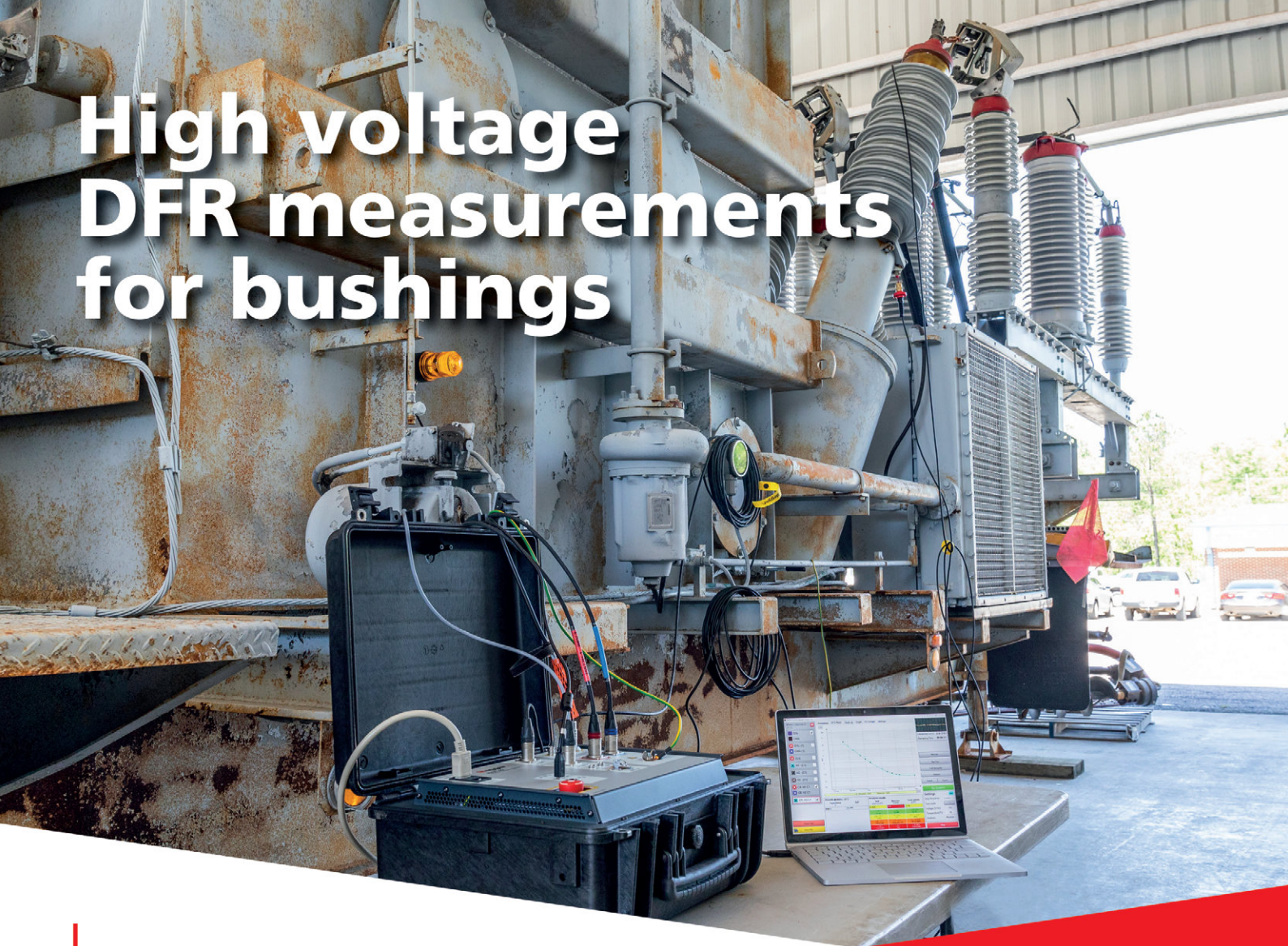
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# High voltage DFR measurements for bushings



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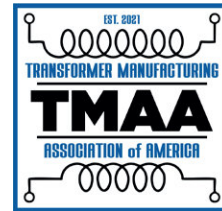
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# Joe Donovan





TMAA's shift from a reactive to a proactive organization involves collaborating with various stakeholders, including policymakers, to address pressing issues.

**Executive Director**  
of TMAA

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Interview with **Joe Donovan**

**Alan Ross:** My guest is Joe Donovan. We've done this a few times, Joe, and you're the Executive Director of TMAA, Transformer Manufacturing Association of America. Welcome, thank you for joining me.

**Joe Donovan:** I'm really excited to be here. It's good to see you again.

**AR** I want to throw a problem out at you. Two weeks ago, at an event that's called Renewable Energy +, 40,000 people from the storage industry, the solar industry and other industries got together in Las Vegas. It was wonderful to see something so unique because we've been talking about it for a long time. It is going to change the generation footprint for every utility out there. Here's the problem, and we're finding this out from utilities and from people who do research in this area. When you create an inverter-based system where the transformer that was a *step-down* transformer now has to be a *step-everywhere*, it's going to take power from my son's house, and when he wants to give power, he needs to be paid for it, and then we need to figure out how to get it through their distribution network to elsewhere. It's a mess out there. It is creating huge amounts of transients and harmonics, which are destroying all electrical equipment at an increasingly alarming rate, especially transformers.

Consequently, one of the things I love about TMAA is you're not just transformer manufacturer. There are service companies, service providers, a whole other group of people, vendors, etc., in the industry that you basically said, Join us, become part of our group, and let's come together to, number one, lobby for what's in our best interest for TMAA. Number two, let's start looking at some of these longer-term problems and see if we can solve them. I throw that in your lap and say: What have you been doing lately, Joe?

**JD** Well, that and then some. It's interesting. When I first started working in the transformer sector 10 years or so ago, we were basically looking at the most unsexy piece of equipment out there. It's pretty much the same thing it's been for 80 years. You've got big step-up, big step-down transformers on the network. It's been carrying the same load, serving the same customers, serving the same interstate system. Kind of boring, right? Ten years fast forward, and all of a sudden, we've got not just issues with supply chain of transformer manufacturers and its vendors, but now you start adding in these renewable generations sources, these bi-directional net metering and other new projects and aspects of the core system, you've got a whole different network

now and a whole different slate of issues that are augmenting not only the need to modernize the grid and therefore increasing the demand on transformers, but also you then add this layer of transition of the grid to a non-carbon based or renewable clean tech, whatever buzzwords you want to use to describe the new generation. That adds a whole other layer of demand onto a pretty static supply, at least on a domestic basis.

That creates a lot of issues. Right now, we're hearing from utilities about problems meeting demand, lead times going from 3 months to 12 months, cost increasing. They're absolutely right. There are important underlying reasons why that is the case. That's going to be different from a distribution transformer than a medium-size or a large power transformer. Some of the same core issues, but the answers are going to be substantially different. That's where I've been spending a lot of my time and where the TMAA has really been focused lately – dealing with setting up communications with other interested trade groups, be it customers, be it utilities, renewable developers, DOE, Department of Commerce, White House. We've been all over the place trying to spread the message and to coordinate a more fulsome response. A lot of that is data-driven, and we, candidly, just don't have a lot of that data right now.

That's where I've been spending a lot of my time and where the TMAA has really been focused lately – dealing with setting up communications with other interested trade groups, be it customers, be it utilities, renewable developers, DOE, Department of Commerce, White House.

**AR** Love when you said that, a *more fulsome response*. That's a great word. It encompasses a lot more – it is both wholesome and full.

Question for you. When you started with TMAA, there was a certain perspective of who you'd be. Share with me where you see it now. Where do things that you didn't expect come from?

**JD** Yes, our birthright at TMAA is from an ad-hoc coalition of transformer manufacturers, domestic-based transformer manufacturers, focusing primarily on medium and large transformers. We were dealing with



Photo: Shutterstock

a lot of ad-hoc issues, particularly tariff issues, Section 232, some anti-dumping issues. We had this ad-hoc coalition, and we'd get together every once in a while, and focus on an issue. It struck me, and more importantly, it struck the founding members of the TMAA that we need to get in front of this issue. We're perpetually in a reactive mode, and we need to get an organization put together that can be proactive and DC-based, because that's where most of the issues we deal with stem. A voice of not just the manufacturers, but also the supply chain that feeds the manufacturers, the customers that buy from the manufacturers, more of a broad approach to address the issues that are impacting all of our members. Where we started out as mainly medium and large power transformer interests, we now have medium, large transformer interests, distribution transformer interests, supply chain vendors that feed into all those transformers. We have customers. We're coordinating quite a bit with utility trade organizations on some of the issues.


Where we started out as mainly medium and large power transformer interests, we now have medium, large transformer interests, distribution transformer interests, supply chain vendors that feed into all those transformers.

By the way, it is our second birthday today. We were founded two years ago today. Within that two-year span, our footprint has increased substantially, particularly here in DC. We can go through some of the projects and initiatives we're working on now that will hopefully mitigate some of the issues that are out there.

**AR** Well, you will mitigate them. And then you know what will happen? There are a whole sea change of issues coming up that you're going to have to, as an organization, deal with. I think you said something that, again, I love about TMAA because I've been around the transformer industry now for about 20 years. As you said, we were always backward thinking because you know what? They were big old beasts that didn't wear out and everybody was happy. Well, we're now wearing them out. The grid is changing more rapidly than most people know. Will we get to a fully renewable energy grid?

Talk a little bit about what's happening in Washington. What are the initiatives that you're involved in? You said you were just recently at the DOE. Talk about what other things are going on there that would interest our readers.

**JD** DC is such a political beast, and the biggest political beast right now that's getting the most headlines is the issue of distribution transformers, and the supply chain issue associated with that. TMAA has been intimately involved in discussions amongst the White House advisors, DOE, DOC, Labor, and



We've got a transformer shortage. What are the causes of that? Labor is one, but the materials and the components that we need to make the transformer is just as important.

I don't know. Maybe not in my lifetime, but we are significantly further along that path than we've ever been. Nobody's trying to open up new coal fired plants anymore, right? There's been a lot of change, and there will be a continuous amount of change that will be affected by the heart of the system, the transformer. That's one of the things I love about it. One of our very first magazine issues had a heart, and the transformer was in the shape of a heart. It said transformer, the heart of the system. It has become more apparent to me today than ever that that's the case. If the system is changing, then you got to look at how the heart changes, how manufacturing has to change.

other organizations that have acronyms, I don't even know what they mean. That is by far the most important thing. One of the conversations I've had recently is with the Office of Electricity at DOE. There's an assistant secretary, Gene Rodrigues, who's doing a phenomenal job of getting out there and trying to understand the underlying core issues that are impacting the distribution transformers. And he's smart enough to know that what's going to impact the distribution transformer sector now very likely will impact the medium and large in the future because the issues will bleed out. He's identified a working group that we've been privileged to

be a part of, consisting of utilities, policymakers within DOE and other agencies, and the manufacturing sector. We've been very pleased to participate in those discussions and look forward to continuing those. That's been a large portion of my time right now. Truth be told, it is a lot of education, both for myself and then trying to educate the policymakers.

It's been very interesting. Everyone in the last four administrations has said transformers are key to national security, right? There are executive orders to that effect, as well as all

with addressing some of your production capacity issues or incentives, the 48C manufacturing incentives, and other programs, we're the interface between you and the federal regulators and administrators when it comes to these issues. A lot of time has been spent on that, and just identifying where the weaknesses are, and focusing attention on how to address those weaknesses, either domestically, by increasing capacity, or finding material sources abroad and making sure we have the right trade policies in place to ensure that we have the ability to meet the demand.

Our message to the supply chain is: TMAA is your face right now to some very senior folks. To the extent that you are needing assistance with addressing some of your production capacity

issues or incentives, the 48C manufacturing incentives, and other programs, we're the interface between you and the federal regulators and administrators when it comes to these issues.

sorts of DOE reports. They're absolutely right. Question is, what does that mean? If it's key to national security, is it just the transformer, or is it all the core components and materials we need to make a transformer that is also key to national security? You can't have one without the other. We've got a transformer shortage. What are the causes of that? Labor is one, but the materials and the components that we need to make the transformer is just as important.

Our message to the supply chain is: TMAA is your face right now to some very senior folks. To the extent that you are needing assistance

**AR** That's a fulsome responsibility. What have you got coming up? What are you looking at in the very short term for future?

**JD** Well, I'm really excited. Actually, in two weeks from this Friday, the TMAA is having its annual meeting here in DC, and all of our members will be all in one spot for the first time since the pandemic. We're going sit down and really think through what the TMAA will look like in five years. What do we need to get there? Who do we need to get involved as members? Who do we need to recruit? And that's going to be a large focus of my 2024.

I'd like to double my membership at a minimum, get more representation from the distribution transformer manufacturers and their supply chains. I would love to have a couple of large utilities come on board so we get their direct perspective as we start to advocate for policies, making sure that what we're saying is consistent with what our customers really need and what our customers really want. That's a big priority for me going into the next year.

**AR** The only problem I have with that meeting is I wish I were able to attend and listen and record and meet some people. It would have been an incredible opportunity for editorial content of the future leaders in the marketplace. When you have the next one, invite me. I'll come.

**JD** I'll get you on the agenda. You can have face time with the full crowd.

**AR** This has been a great catch-up. I want to do this on a more frequent basis. I know you've got a lot going on, and I want to make sure that we can help become part of the voice for TMAA. I keep seeing problems, and I love the fact that you guys are bringing some tremendous solutions to the marketplace. There's a lot of money in Washington right now being spent on electrical systems, and a lot of it will probably be spent poorly. It's not Washington's fault, it's our fault. When we don't give them good direction, or we don't connect the industry with the policymakers, they're not writing policy just to blindly say, *this is stupid*. I know a couple of people at DOE that are brilliant and came from the utility industry and are trying to solve problems, right? I think you guys are an advocate in DC for both the DOE, the White House, all of the acronym-named groups, which is very, very important. Thank you for what you're doing. Let's stay in touch.





**JD** Absolutely. I really do appreciate that, and I appreciate your voice of confidence in the TMAA and myself as its executive director. I look forward to trying to get some answers out there. Unfortunately, you're right. It's a target-rich environment here in DC, because there's a lot of policies being derived based on incorrect assumptions, incorrect political philosophies. I just found out today that there's some discussions about the Buy America percentages being adjusted to require 100% domestic steel in order to qualify for the Buy America credit, which is just physically impossible at this point.

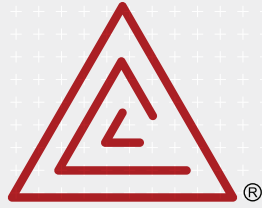
I just found out today that there's some discussions about the Buy America percentages being adjusted to require 100% domestic steel in order to qualify for the Buy America credit, which is just physically impossible at this point.

**AR** It's going to be disastrous to the industry. That is so counterproductive to where the problems are that we're trying to solve, and now I'm with you. But that's your job to fix, Joe.

**JD** Yes, indeed. We're going to try.

**AR** All right. Thank you, my friend. We'll talk later.

**JD** Thank you. I look forward to the next chat.



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## Meeting Demand

## How to Find Reliable Manufacturing Partners in the Transformer Industry

*The global electronic components market is projected to grow by 8.5% annually over the next five years, potentially reaching a valuation of 595 billion by the year 2028.*

*The power transformer sector, meanwhile, is not far behind, with a projected 7% growth rate over the upcoming nine years.*

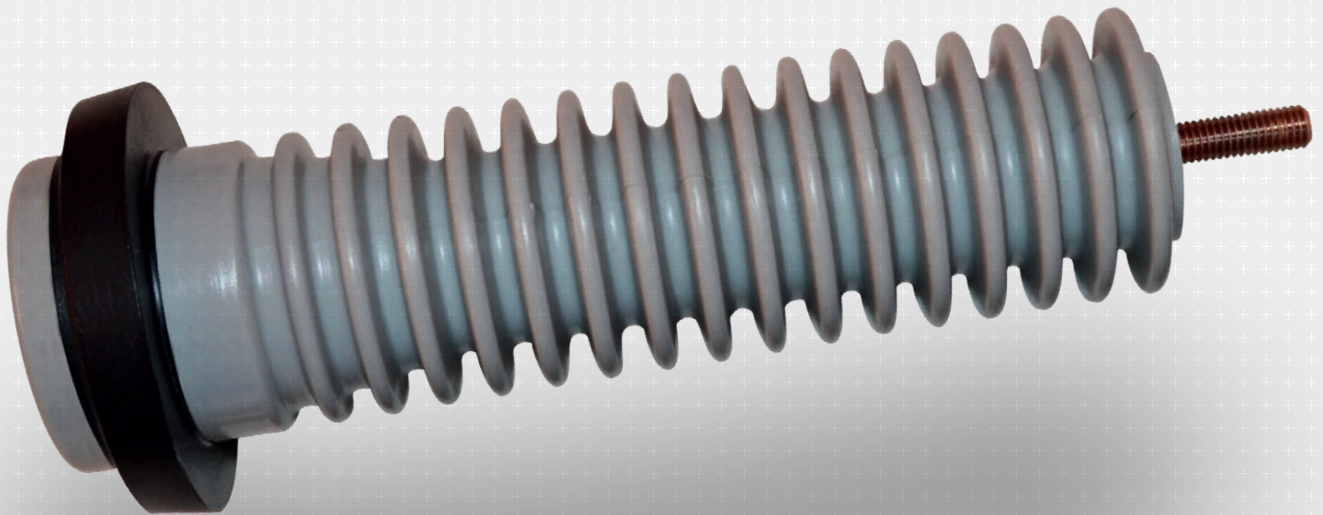


*Demand for electronic components and transformers is surging, and shows no signs of slowing down. The global electronic components market is projected to grow by 8.5% annually over the next five years, potentially reaching a valuation of 595 billion by the year 2028. The power transformer sector, meanwhile, is not far behind, with a projected 7% growth rate over the upcoming nine years, primarily fueled by burgeoning demand in commercial and industrial applications.*

*For manufacturers, these trends are great news, but they may be a double-edged sword – the opportunity they present only benefits those equipped to seize it. Leading manufacturers are now recognizing the need for reliable partners that can help them meet this demand and grow their businesses.*

*How, though, do you find the right partner?*

*Here are some of the key questions you should be asking to find a partner that can help you meet this historic moment and scale your business.*



## **Do They Have Capacity?**

*Capacity has never been more important, and the industry-wide urgency to match supply with mounting demand is palpable. When looking for manufacturing and supply chain partners, the question of capacity should be your first priority. Can a potential partner accommodate your existing production goals? Moreover, can they expand their operations alongside your business growth?*

**Capacity has never been more important, and the industry-wide urgency to match supply with mounting demand is palpable. When looking for manufacturing and supply chain partners, the question of capacity should be your first priority.**

*If the pandemic and geopolitical disruptions taught us anything, it was that relying solely on historic global suppliers has inherent vulnerabilities that can disrupt the supply chain unexpectedly. Manufacturers striving to increase production need to have the peace of mind of a consistent supply of high-quality components and production.*

*A partner with capacity can provide this peace of mind, giving you the bedrock you need to build on.*



## Are They Planning Ahead?

*Selecting the right partner is not just about the present – you have to think long-term.*

*An ideal partner should have the ability to anticipate shifts in demand and adapt to evolving market trends. They need to be a collaborator who is invested in shaping a shared future of sustained growth and innovation.*

*In short, the right partner should be ready to expand with your growth trajectory. This encompasses several crucial aspects:*

- **Facilities:** *Are their facilities appropriately equipped to accommodate an up-tick in demand?*
- **Equipment:** *Do they use the right technology for your applications and needs? Are they investing in cutting-edge equipment to streamline their operations?*
- **Infrastructure and Planning:** *Do they have the infrastructure and strategic plans in place to ensure seamless scalability?*

*Crosslink Technology, for example, has made significant investments over the last few years in a new state-of-the-art manufacturing facility. This strategic investment has enabled us – and by extension our clients – to augment capacity, optimize operational processes, and bolster our workforce.*

**Crosslink Technology has made significant investments over the last few years in a new state-of-the-art manufacturing facility. This strategic investment has enabled us – and by extension our clients – to augment capacity, optimize operational processes, and bolster our workforce.**

## Do They Have In-House Expertise?

*An extension of planning for future growth is a steadfast commitment to skills development and strategic staffing. The most valuable collaborators – those that can help you level up – should always be on the lookout for ways to bolster in-house expertise in engineering, quality control, operations, sales, and customer service.*

*Partners with this approach tend to foster an environment of continuous learning and skill enhancement. These are the allies you should be actively seeking, as they understand that an investment in their workforce not only fortifies their own capabilities but also contributes to your shared objectives – enhanced production quality, efficient operations, and long-term growth and prosperity.*



## Are They Collaborative Partners?

*The best partnerships thrive on collaboration and are built on a foundation of transparent communication and shared objectives. An ideal partner not only understands your customers' market demands but also shares a drive to exceed expectations in service, reliability, and performance.*

**The best partnerships thrive on collaboration and are built on a foundation of transparent communication and shared objectives.**

*Once these fundamentals are established, you can transition from mere transactions and order processing to strategic alignment, paving the way for mutual long-term growth.*

*With a shared long-term vision and a collaborative process, your partners can then go beyond, offering improved planning and assistance for material procurement, manufacturing time, and lead time reduction. They can create customized programs tailored to your unique needs, ensuring delivery dates are met while enhancing reliability and efficiency.*

*It's also worth noting that a collaborative manufacturing partner is likely to have their own partnerships with suppliers, which not only enhance capacity but also guarantee the availability of crucial components, reinforcing operational continuity.*

## Where Are They Located?

*In today's manufacturing landscape, securing timely deliveries and optimizing lead times is crucial. To that end, Crosslink has noticed a shift from traditional sourcing hubs like China and India, which is a reaction to the global disruptions to supply chains over the last three years. More and more companies are now opting for local partners and supply options to have control and reduce concerns about lead times.*

*This strategic move acts as a buffer against disruptions, ensuring components are obtained on time, and enabling smooth production cycles.*

## About Crosslink Technology Inc.

Based in North America, Crosslink has been on the leading edge of technical innovation for close to half a century, designing and manufacturing cast electrical transformer bushings, stand off insulators, and more than 3,000 proprietary formulations for customers in North America, South America, Europe, and Asia.

As part of our unwavering commitment to our partners' success, we have focused on expanding our capacity, with significant investments in a new, state-of-the-art manufacturing facility, which has dramatically increased production capabilities and enabled faster delivery times. It's also allowed us to bolster our in-house skills and expertise, with a dynamic, growing team of sales, engineering, quality control, customer service, and operations professionals.

Adding to our Manufacturing capabilities, we continue to forge key partnerships with global companies that share our commitment to growth, quality, service, sustainability, and reliability. These partnerships have empowered us to expand and diversify our product lines and services in response to market trends, offering customized programs and agreements that meet our client's unique needs.

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QUESTIONS  
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## TRICIA

**WPS:** How did you decide to go into mechanical engineering? Do you think the power systems industry is a good career choice for women and why?

**Tricia Breeger:** While in high school I developed a strong aptitude for math, logical learning, and abstract thinking. As I prepared to enter college my parents, both school teachers, asked me if I wanted to be a teacher. I said no, that wasn't the right profession for me. So, they strongly advised me to pursue engineering. It was my college advisor at the University of Arkansas who guided me towards mechanical engineering. He helped me appreciate that a mechanical engineering curriculum was broad enough to be successfully applied to numerous industries. He felt it was a solid base for a technical career path and also a strong foundation to build upon.

Regarding the power systems industry, when it comes to career choice, I don't often think in terms of what is good for women versus men. I believe it's more important to let your strengths, interests, and passions guide you towards the right career for you. If you are true to your own interests, you'll have the drive and passion to be successful regardless of whether the field is predominantly filled with men or women.

**Q:** Why did you decide to study business as well? How did both of these education paths help you in your career?

**A:** Studying business was an interest that developed several years into my career. Although I enjoyed applying my technical knowledge to my work, once I became aware of the broader responsibilities associated with running a business, I found myself drawn to it. I had begun to develop a strength in leadership and organizational management, but to be excellent I felt I needed a formal education in business. Not long after completing my MBA I ran my first P&L for MEPPI, and I was hooked. When talking about career paths I often counsel employees and colleagues to sincerely recognize their strengths and weaknesses and then put themselves in a position that best utilizes their strengths. Of course, with hard work and dedication, you can improve your weak areas. However, if you apply a similar commitment to your strong areas, the results are exponential. I had a passion and a talent for running businesses, and I knew it was the most impactful way for me to contribute to MEPPI's success.

MEPPI is a company that leads with engineering excellence in products, systems, and services. Therefore, a foundational education in engineering proved to be extremely beneficial in understanding and communicating the technical benefits and differentiating factors in the products and systems we provide. Early in my career I had the good fortune of leading service operations. Nothing emphasizes the importance of customer relationships and customer care like service. My service management role really honed my skills in customer engagement, conflict management, and the importance of the customer experience. I learned that even the most challenging field situations are an opportunity to demonstrate a commitment to your customer that will ultimately strengthen the relationship. In addition to service, running manufacturing operations has been a strong influence in my career. I carry my passion for manufacturing forward as the Vice Chair for Catalyst Connection, a non-profit organization supporting small and medium manufacturers in southwestern Pennsylvania.

*Studying business was an interest that developed several years into my career... I had a passion and a talent for running businesses, and I knew it was the most impactful way for me to contribute to MEPPI's success.*



”

Remaining a student of the business with a sincere curiosity in the markets and industries that you serve is key... Lead by example. Challenge employees to stretch themselves to higher levels of performance.

“

**Q:** How did you start your professional journey in the power Systems industry? Do you have any practical advice for young people at the beginning of their own journey?

**A:** Prior to joining MEPP, I was a design engineer for Westinghouse at their Bettis Atomic Power Laboratory. The move to MEPP gave me the customer engagement experience I truly desired. So, it was really the opportunity to engage customers directly, paired with the opportunity to join a great organization, like MEPP, that resulted in my move into the power systems industry. Today, the power systems industry is undergoing a transformation not seen in 50+ years. The clean energy transition, load growth, resiliency requirements, and federal funding are creating unprecedented momentum and change within our industry making it a very exciting place to be. If any readers are interested in being a part of the clean energy transition and supporting decarbonization, MEPP is a great option and a great place to work. We are driven by deep commitments to quality, integrity, our employees, and the customers that we serve. I am proud to say that we also have a strong and impactful Professional Women’s Program.

*Not necessarily unique to power systems but unique to finding your way in a male-dominated field... Whether you want to build a strong relationship with customers, colleagues, or executives, you need to commit some time to it.*



**Q:** When did you first come into a leadership position? What are your obligations and responsibilities in your current role?

**A:** My first leadership position was the service management role I referred to earlier. I was given the opportunity to build a team from the ground up. We were a small organization with a big responsibility – customer care. The lessons I learned running service continue to guide my decision making today. This includes: a) deliver bad news quickly, honestly, and with transparency, b) do what you say you are going to do, c) every problem is an opportunity, and d) equipment issues don’t kill a customer relationship, it’s how you respond to them that is most impactful to the relationship. In my current role as President & CEO, I oversee business strategy, growth, and development while transitioning MEPP towards digitization and decarbonization. I continue to lead the company’s operating groups with the purpose of creating increasing value for our customers through solutions, systems, products, and services all with the long-standing quality of the Mitsubishi Electric brand.

**Q:** What are the qualities of a good leader? What are the qualities you have that helped you in your journey towards leadership?

**A:** Remaining a student of the business with a sincere curiosity in the markets and industries that you serve is key. I recommend doing more listening than speaking, but then communicating clearly, and also writing things down. Lead by example. Challenge employees to stretch themselves to higher levels of performance. Seeing things through the lens of our customers. Working and collaborating with talented and dedicated colleagues. Standing up for the needs of the business and our employees during difficult times. A sincere passion for the work.

Read the full article in our [September 2023 issue](#) of Women in Power Systems.

# A BETTER ENERGY FUTURE IS A FUTURE OF COLLABORATION

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VERIFY OXYGEN  
CONTENT BEFORE  
ENTERING.

**CAUTION**  
DO NOT USE CONDUIT  
FOR CLIMBING OR  
STANDING



# Three Ways to Measure Transformer Temperature

In the world of power distribution and electrical utilities, monitoring transformer temperatures is paramount for ensuring efficient and safe operation. Over the years, technology has evolved, offering more precise and reliable methods for temperature monitoring.

This article explores three distinct approaches to this vital task: Traditional Temperature Gauges, Electronic Temperature Monitors, and Direct Measurement with Fiber Optic Temperature Probes.

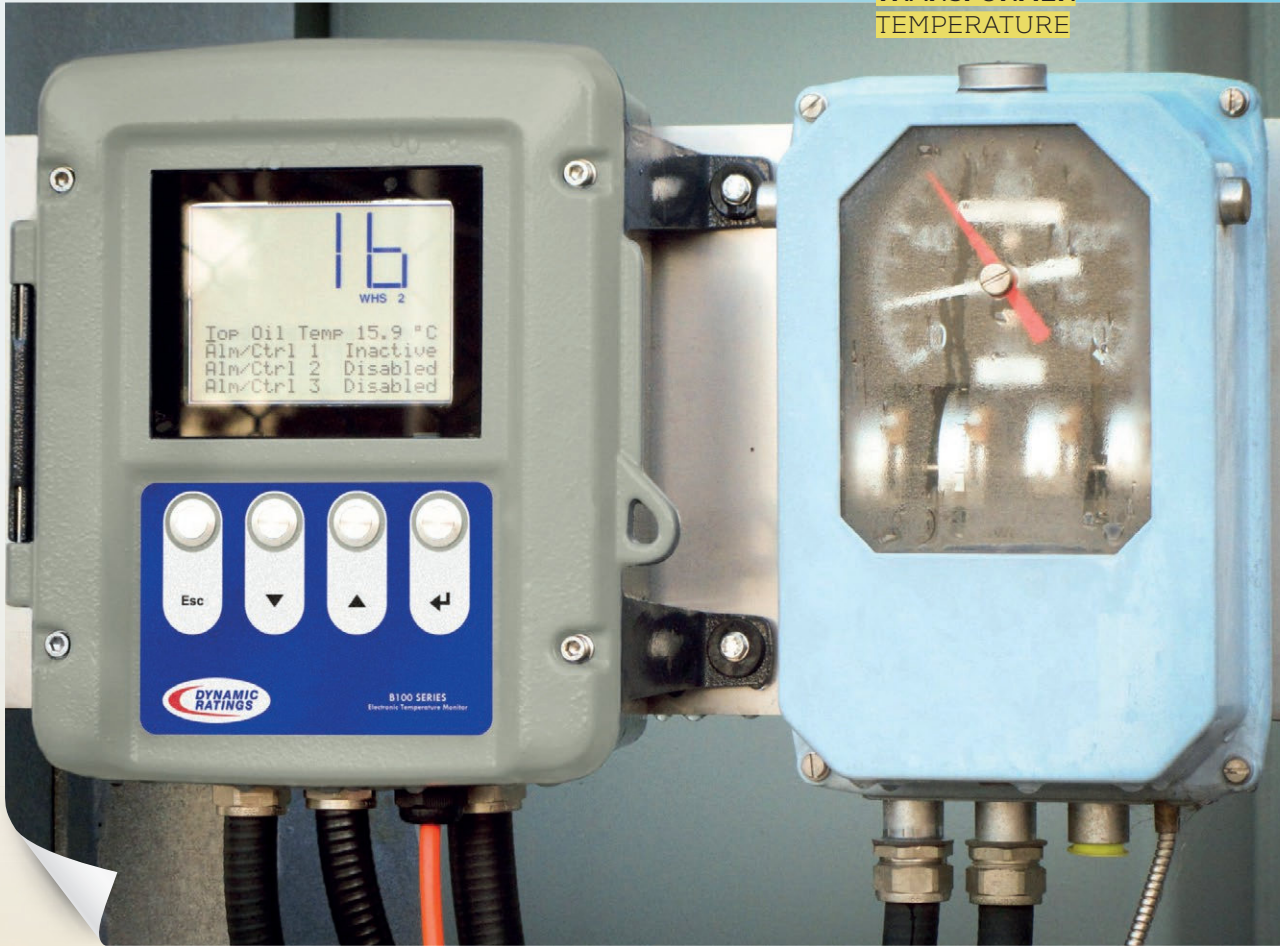


**Tony Pink** founded the North American division of Dynamic Ratings and has since assumed the global management role for the business. He is a recognized leader in electrical power asset control and monitoring solutions with over 20 years of experience in this niche. His professional career began in diesel powered generation equipment with paralleling switchgear design and construction. He then transitioned to SPX Transformer where he managed the Field Service business and subsequently assumed the sales management role for SPX aftermarket parts and service. In 2002, Tony founded Dynamic Ratings, Inc. and built an outstanding team of industry expertise that is enabling utilities to build successful asset health management programs. This business goal was accelerated through the acquisition of Electrical Diagnostic Innovations in 2009 and the acquisition of the iBridge product line from Telkonet in 2011. Tony served as the secretary on the first IEEE guide for monitoring power transformers (IEEE C57.143). He also serves on the University of Marquette Electrical and Electronics Industry Advisory board, helping to ensure the power industry has a continual flow of exceptional engineering talent. He holds a B.S. in Electrical Engineering from the Milwaukee School of Engineering and an MBA from Marquette University in Milwaukee.



Written by

**Tony Pink**



## Traditional Temperature Gauges

Oil Temperature Indicator (OTI) and Winding Temperature Indicator (WTI) Gauge technology was developed in the 1940s and was used to control the cooling system and provide indication of issues to give the transformer thermal protection. They are sufficiently rugged to be used for protection purposes if the recommended maintenance and/or calibration verification is carried out regularly.

However, there are some limitations to this method. Regular on-site maintenance must be scheduled to ensure relative accuracy. WTIs are prone to mechanical damage which may result in an inaccurate temperature reading which leads to inefficient cooling and tripping control. For a deeper understanding, download this white paper.

## Electronic Temperature Monitors

Electronic Temperature Monitors (ETMs) can replace up to three analog gauges and consolidate temperature data and cooling control into a single point of communication. They provide better measurement accuracy than traditional gauges by using transformer design information to calculate winding hot spot temperature both during load fluctuations and steady conditions. ETMs connect to multiple bushing CTs so that all three phases are monitored with one device to identify which one is truly the hottest. Additionally, they calculate the insulation loss of life which helps utilities manage the estimated life of the transformer.

ETMs have electronic communication which provides the data to utilities remotely. It keeps detailed records of data so you are able to download history at any time. ETMs come in robust fail-safe designs to provide additional reliability beyond what a gauge can offer.



**ETMs come in robust fail-safe designs to provide additional reliability beyond what a gauge can offer.**

**Fiber Optic Temperature Probes provide real-time direct winding monitoring. They help validate that the thermal model is truly doing what it is supposed to do.**

### **Direct Measurement with Fiber Optic Temperature Probes**

Fiber Optic Temperature Probes provide real-time direct winding monitoring. They help validate that the thermal model is truly doing what it is supposed to do. Probes are installed in the winding in a modified spacer. The tip is the measurement point which sends a light pulse signal down the fiber. The probe connects to a Transformer Monitor which communicates direct winding data back to the utility. The monitor also has the ability to model multiple windings.

This option is great for critical transformers such as a bulk power transformer because the cost of adding fiber optic temperature probes is reasonable.



# Using Visual Inspections of Components to Increase

# Transformer Reliability

by **Bob Rasor**  
and **Jon Bucciarelli**

Perhaps more than ever before, transformer reliability is of vital importance. It has always been crucial to safety and productivity, but having unreliable electric power equipment is a significant risk for those who rely on uninterrupted power for their operations. Recent changes to essential guides—notably NFPA 70E and NFPA 70B—are more direct in how we must consider and comply with safety and maintenance requirements. This article explores the critical visual inspection of the components of a



**Robert T. Rasor** serves as Director of Transformer Services and has been with SDMyers since 1978, starting as a Product Design Engineer for oil processing equipment. Over decades he has held different leadership roles and reports to the President as the Technical Director for SDMyers. Bob is registered PE and serves on several IEEE Transformers Committee Working Groups, including the current chair for C57.106, the Insulating Fluids Guide.



**Jon Bucciarelli** is President of SDMyers, LLC an electric reliability company specializing in transformer maintenance, fluid testing, field service, and training. In addition to being a company focused on transformer life-extension services, it is a community-aligned company focused on being an advocate for its customers while building a "Good Place" – a common attitude governed by Biblical principles and values.

transformer and how the standards of NFPA 70B affect those who manage and maintain transformers, the most valuable asset in most settings.

**Having unreliable electric power equipment is a significant risk for those who rely on uninterrupted power for their operations.**

Specifically, this article discusses the newly NFPA 70B-directed requirements regarding transformer safety and

reliability. The directives include time-based liquid and electrical testing along with regular visual inspections, which include components such as bushings, radiators, tank condition, gauges, and other accessories.

Visual inspections, perhaps easier to perform as they do not require an outage, are now mandated to be supplemented with regular dielectric liquid and electrical testing. The combination of the two—visual inspections and regular testing—

goes a long way in providing the comprehensive reliability condition of an asset.

**The combination of the two—visual inspections and regular testing—goes a long way in providing the comprehensive reliability condition of an asset.**

First, we will outline a few key definitions referenced below in the discussion of visual inspections and transformer components.



Figure 1



Figure 2

**NFPA 70B** is the document published by the National Fire Protection Agency, often enforced by OSHA, for the standards of electrical equipment maintenance.

**NFPA 70E** is the document published by the National Fire Protection Agency, often enforced by OSHA, for the safety and procedures of workers regarding electrical equipment and its maintenance.

**Partial Discharge (PD)** is a small, localized breakdown of solid or liquid insulation. In oil, it is characterized by the creation of hydrogen. It can be detected by ultrasound.

### Key Definitions

**Accessories** are the components of the transformer other than the dielectric liquid, core/coils, and tank. Generally included are bushings, radiators, gauges, pumps, and fans.

**Bushings** are the conduit by which the electrical energy can enter and exit the transformer. The bushing is a hollow electrical insulator that facilitates the passage of an energized, current-carrying conductor.

**Dielectric Liquid** Mineral oil has traditionally been used in most liquid-filled units. Along with mineral oil, natural esters, silicone, and high molecular weight hydrocarbons make up most of the liquid types found in distribution and power transformers.

**Dissolved Gas Analysis (DGA)** of the dielectric liquid is the standard test method for the analysis of gases dissolved in electrical insulating liquid by gas chromatography (ASTM D3612). Subdivided by what are referred to as combustible gases, the profile gases indicate various conditions in the transformer, from a normal gas situation to one with high energy gases such as acetylene that indicate arcing.

**Infrared Detection**, using an infrared camera, gives a thermal scan with a digital photo that can determine both temperature and temperature gradients on an object.



Figure 3

## Bushing Inspections & Testing

Beginning with the bushings and lightning arrestors, the electrical testing of the transformer includes testing the components with insulators for their proper function and comparing data to OEM or industry standards such as IEEE and IEC. Transformers and bushings sometimes undergo electrical testing (ET) as often as every year, or now, per NFPA 70B, no less than every five years. Every three years, by many, is considered a reasonable goal. ET is, of course, an intrusive, outage-required procedure. There are



Photo: SDMyers

also viable, energized diagnostic procedures such as the informative data provided by infrared scanning, bushing monitoring, and, less commonly, ultrasound diagnostics.

A comprehensive program for the status of bushings would include five different approaches, the first four of which can be performed energized.

**1. Infrared scanning** is an economical procedure and one of the recommended inspections in NFPA 70B Section 9.2. Some of the problems that can be identified include:

- Loose or poor internal connections
- Loose or poor external connections
- Unbalanced loads
- Bushing failure

**2.** After an initial outage for the installation, transformers with bushings that have capacitance taps are candidates for **Bushing Monitoring**. Whether stand-alone or coupled to an online DGA monitor, the data provides peace of mind surveillance, continuously tracking bushing capacitance, power factor, and Partial Discharge (PD) activity.

**3.** The **Visual Inspection** of bushings can be done even from a viewing position outside the substation with magnification. The inspection can notice leaks, discoloration, cracked insulators, and the buildup of dirt.

**4. Ultrasound Detection:** In addition to measuring PD activity within the bushings, bushing monitoring technology allows the user to measure PD activity within the transformer and can tell where the PD is located, whether that be in the bushing or windings, and which phase or phases are affected. The beauty of bushing monitoring is being able to trend these values where alarm setpoints will alert you to potential issues at that time rather than waiting for the next planned maintenance outage. Additionally, corona (when it is at an advanced stage) will produce a heat signature.

**5.** Finally, the outage-driven **Electrical Testing of the Bushings** is carried out via the bushing terminal, ground connection, and fitted C2 test taps. Where a C2 test tap is not available, a hot collar test can be performed instead. This testing is guided in NFPA 70B Section 9.2 and varies based on condition from 1 to 5 years. Capacitance taps are usually found on units 69 kV and higher.

Other visible components on the outside of a transformer can be inspected without an outage, similar to bushing-related visual inspections. These inspections align well with dielectric liquid sampling and can often be achieved while the transformer is energized. Inspections called out in NFPA 70B are, for the most part, required annually, but vary by the condition of the equipment. These inspections include evaluating the state of leaks, liquid level, pressure, temperature, coatings, and the presence of pests or vegetation.

**Other visible components on the outside of a transformer can be inspected without an outage, similar to bushing-related visual inspections. These inspections align well with dielectric liquid sampling and can often be achieved while the transformer is energized.**

The records and trending of these accessories also include common relays such as sudden pressure (SPRs), pressure relief devices (PRDs) and Buchholz relays that may engage alarms designed to de-energize the transformer if an event occurs. A final consideration of an outside-the-transformer perspective can be a dissolved gas monitor. Smart features of some of the above can be posted to SCADA or even transmitted to data-posting platforms.

## Liquid Levels and Overheating

One of the NFPA 70B guidance requirements with a lower budget cost is the "Visual Inspection" called out in Section 11.3.1. The value of this inspection is in catching conditions that can be tied to damaged equipment, safety concerns, or indicators of potential problems.



Figure 4

What are the transformer-related functions related to maximizing reliability and safety that are included in visual inspections?

Perhaps all are significant, but let's look at one of the most common: liquid level and overheating. Transformers are indeed very efficient, but even with their efficient design, the slight inefficiency shows up as heat.

Temperature gauges measure this lost energy that is to be held within design boundaries with radiators, fans, and, on larger units, forced oil pumps. The visual inspection of the temperature gauge plays a role in determining the proper liquid level. The cooling requirement in most transformers is accomplished by radiators or other types of heat exchangers. Although not the case in conservator-type transformers, if a level drops too low, the natural cooling can be affected as the radiator manifolds may not be 100% flooded. Once a liquid level drops, the cooling phenomenon by the radiator—called thermal siphoning—stops, and the transformer will overheat if under enough load. However, be aware that the level could be so low that the temperature gauge may no longer be in the liquid and cause it to appear normal.

When considering liquid level, reading a level gauge is not quite as simple as seeing where the needle is pointing. It is necessary to include the relationship of the liquid level with respect to temperature.



Figure 5



Figure 6

At 25°C, most level gauges have a horizontal pointer position. As the temperature rises, so will the "NORMAL" level position of the pointer. For instance, a transformer running at a 43°C top liquid temperature with a pointer position around the 25°C mark indicates a low liquid level and should be corrected as soon as possible.

**When considering liquid level, reading a level gauge is not quite as simple as seeing where the needle is pointing. It is necessary to include the relationship of the liquid level with respect to temperature.**

Independent of temperature, a liquid gauge with the needle resting on

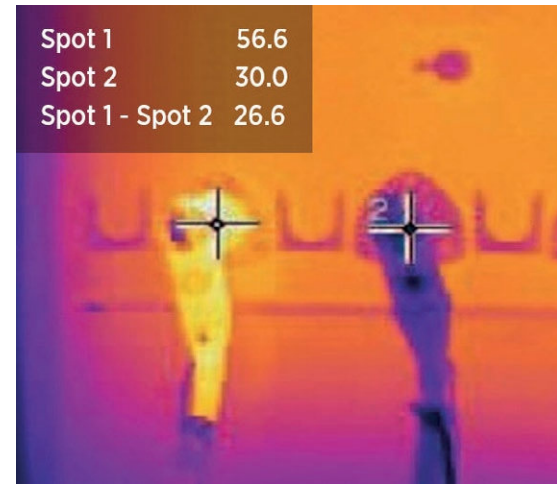


Figure 7

the bottom peg (red arrow) is either very low or the float on the lever has somehow failed. It is important to verify the level in this case. One method is using a long piece of clear tubing on the bottom valve with a vented tank. Raising it to the top of the transformer will show the exact liquid level.

Leaks are common in many older transformers as gaskets age and become brittle. If a leak develops on a radiator flange, repairing just that one radiator is not usually wise—especially on larger units and those subject to vacuum filling where the other gaskets may be well on their way to leaking as well. Scheduling an outage to bring in a field service provider is costly, so replacing all the gaskets in one trip is more economical.

### Thermal Imaging Inspection

It was mentioned that another energized inspection is the infrared scan. This inspection is also reasonably inexpensive and has great harmony with liquid testing and visual inspections. A bushing or internal connection issue can show up on an IR scan. This can also be accompanied by an Ultrasound scan that can detect defects, including those caused by partial discharge.

### Inspection Findings

It is quite helpful to understand how the different diagnostics and inspections correlate. Let's look at the low-level example and see how things tie together.

- The level indicator, when

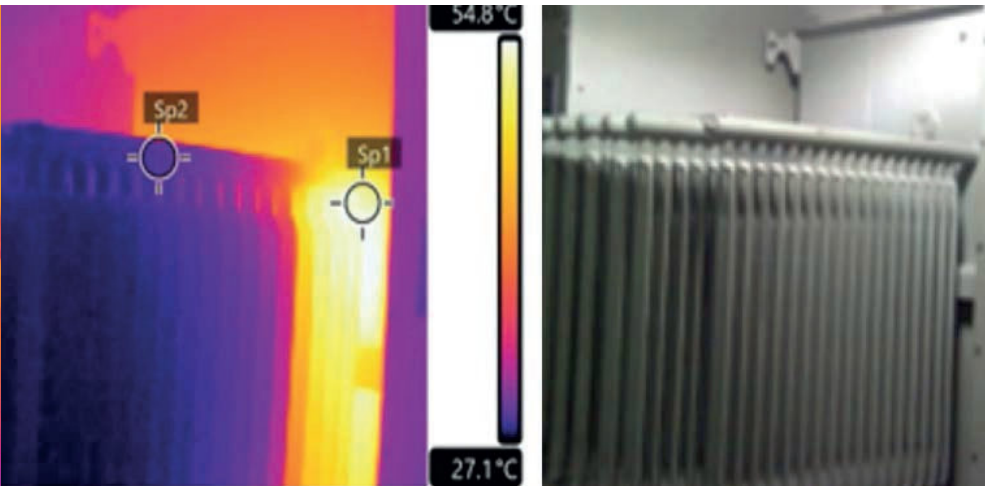


Figure 8

considering the top liquid temperature, is normal to slightly low. If the level gauge were reading 25°C with the 60°C top liquid temperature, this would be a low level.

- As shown above, the infrared scan shows a hotter-than-normal sidewall and a much lower-than-normal top radiator temperature. The top of the radiator and the sidewall at that height should have a similar temperature when proper cooling is present.
- In time, overheating will show up in the combustible gas profile. Low-heating gases such as methane are expected.
- Heat is also a part of the formula for oxidation. Acid and other oxidation byproducts are created over time with the presence of heat, oxygen, and moisture.

The acids created in mineral oil are aggressive toward aging and decrease reliability in a transformer. Furans are indicators that the tensile strength of the paper insulation is under attack.

- Additionally, the temperature of the liquid sample may be higher than the reading on the top liquid temperature gauge. This is due to the level having dropped below the gauge stem.
- With many leaks, the pressure gauge may be at "0". Depending upon where the leak is located, this may be a place for moisture ingress. Excessive moisture in a transformer lowers the dielectric properties of the transformer, aggravates aging, and should be addressed. Vacuum dehydration is not an IEEE-recommended solution unless it includes the vacuum dry out of the emptied tank.

On-line dryers are effective in drying both vacuum and non-vacuum transformers.

- Finally, platforms exist to bring all the data into presentations that show trends and give recommendations. NFPA 70B gives the minimum time-based guidance based on being Condition 1, 2, or 3. The frequency of testing varies based on the condition of the equipment.

**Final Thoughts**

Since the founding of SDMyers in 1965, we have found annual testing and visual inspections to be foundational aspects of stewarding transformer reliability for our customers. Visual inspections of transformer components are fundamental to any comprehensive maintenance strategy. Apart from meeting the basic requirements found in NFPA 70B, these activities help organizations increase the reliability and safety of their transformers—and, more importantly, the safety of workers who interact with them. Prioritizing visual inspections with technical excellence ensures transformers operate as intended for as long as possible and minimizes the risk of significant failures. In this way, organizations spend the least in the short term to get the maximum long-term value for their electrical power equipment.

**Visual inspections of transformer components are fundamental to any comprehensive maintenance strategy.**

DATE	HYDROGEN	OXYGEN	NITROGEN	METHANE	CARBON MONOXIDE	CARBON DIOXIDE	ETHANE	ETHYLENE	ACETYLENE	TOTAL COMBUST.	TOTAL GAS
12/23/19	2	18,069	40,376	4	40	649	1	5	2	54	59,148
02/24/20	22	19,868	56,643	5	114	626	1	5	1	148	77,285
03/08/21	44	13,606	65,353	9	843	1,868	3	5	ND	904	81,731
03/28/22	ND	5,137	48,314	9	710	2,092	3	4	ND	726	56,269
02/24/23	44	7,326	86,426	18	1,759	3,798	5	6	ND	1,832	99,382

**RECOMMENDATION RETEST 1 MONTH**  
 C-ELEVATED LEVELS OF CARBON MONOXIDE AND/OR CARBON DIOXIDE INDICATE THE CELLULOSIC INSULATION MAY HAVE BEEN OVERHEATED OR IS DETERIORATING. POSSIBLE CAUSES INCLUDE OVERLOADING THE UNIT FOR EXTENDED PERIODS OF TIME, INEFFECTIVE COOLERS, AND OXIDATION. IF APPLICABLE, FURAN RESULTS SHOULD BE CONSULTED TO AID DIAGNOSIS.

Figure 9

# Gary Hoffman



## Advanced Power Technologies

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We're looking at the requirement, and what Advanced Power Technologies is doing in that respect is improving the type of monitoring done on power transformers, which are a major asset within the grid.

CEO at Advanced  
Power Technologies

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Interview with **Gary Hoffman**

**Alan Ross:** Hi, I'm Alan Ross. I'm here at the IEEE PES T&D conference. This is the 2020 version that is actually being held in 2022. We're conducting interviews with thought leaders on the future of the power industry.

My guest for this segment of the interview is Gary Hoffman, the CEO of Advanced Power Technologies. Gary, welcome. Thank you so much for joining us.

One of the first things we're asking about is the future. Look at the crystal ball. A lot of change is taking place in a lot of areas. But as it relates to the power industry, what do you see as the major trends, major changes taking place?

**Gary Hoffman:** Well, the significant area of actual improvement is the recognition of the importance of the grid itself and the reliability of the grid itself.

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***The significant area of actual improvement is the recognition of the importance of the grid itself and the reliability of the grid itself.***

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**AR** That's a great thought. We recognize that when the power goes out, the lights go out, nothing works. Texas taught us that.

**GH** They did, didn't they? But on the other hand, it's spurring innovation because let's say everybody on a city block has an EV. But when a major utility in the Northeast has an issue with power delivery, all of a sudden, EVs can't be charged, people cannot go to work. There's a significant impact on the user community, because they don't have electricity. We're looking at the requirement, and what Advanced Power Technologies is doing in that respect is improving the type of monitoring done on power transformers, which are a major asset within the grid. If a power transformer fails, you could lose thousands and possibly tens of thousands of customers because of transformer failure. My business, Advanced Power Technologies, is mainly involved in asset management and the identification using expert system approach to be able to determine when that transformer is about to fail.

**AR** You mentioned two things when you talked about that. I want you

to go a little bit more in-depth with the data, because you got to have that data. If you're monitoring, you've got to be able to send this information somewhere, and you have to have interoperability so that it's got to work together and we're not in an interoperable state today. Talk about that a little bit, about the massive amounts of data that are going to be created by all these sensors.

**GH** Well, the interesting thing in my approach in starting Advanced Power Technologies and running it is to take that burden away from the electric utility. You can have the data, you need the data, but you have to look at all the data. The idea is to develop an expert system that uses known information about how power transformers operate and their potential failure modes to be able to predict when a transformer is about to have an issue, where it needs maintenance. As opposed to doing routine maintenance, you're doing condition-based maintenance. We're moving the industry to condition-based maintenance, even though they don't know it.

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***We're moving the industry to condition-based maintenance, even though they don't know it.***

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**AR** I am a reliability expert. I'm the President of the Electric Power Reliability Alliance, a CMRP certified maintenance and Reliability Professional, Certified Reliability Leader. I have been screaming that for the last 20 years that what we've got to be able to stop doing time-based maintenance, which tends to create more problems than it resolves, and do a lot more condition-based maintenance. Now, going with condition-based maintenance, you need condition-based monitoring. That's what you guys do, right?

**GH** We specialize in that area and we hold, I believe, 13 US patents and foreign patents in the area of condition-based assessment. Advanced Power Technologies has been doing that for 22 years. We became an IEEE fellow in 2015 for transformer monitoring, and we have been a member of the transformer committee for years and years. That's been the exciting part of being involved in IEEE. What sucked me in was being involved in standards development. It's so interesting. You meet so

## ABOUT US

Advanced Power Technologies (APT) was founded in 1999 by Gary Hoffman and since inception has been developing unique product solutions for the transformer monitoring market. Our focus has always been to develop the best and most reliable technology at an affordable price.

As APT moves into its third decade we continue to build on our success by designing simple to use maintenance-free products that **never requires calibration**. We are also proud to be the only manufacturer of transformer monitoring products covered by a **Lifetime Warranty**.

### Product Spotlight: Total ECLIPSE



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- Up to 32 Analog Inputs



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many really smart people, knowledgeable people, and you develop a friendship with these people that will last years.

**AR** Okay, we're going to get more into IEEE. You love it, I can tell.

But I still want to talk about some of this change. You've been doing this long enough to have a voice in it. Demand has been flat for 10-12 years, power demand. Power demand is expected to go,

I've heard, from 30% higher to a double because of electrification and transportation. Because we're bringing a lot of data centers back onshore, because we're bit mining now here as opposed to relying on Chinese mines. There's just a lot of reasons that the North American demand is going up. How do you think that demand is going to impact what you do?

**GH** We're going to sell more product.



**AR** You're going to sell more product? Well, that's a great way to look at it. But specifically, in order to sell more product, what do you have to do, Gary?

**GH** Well, we have to make sure we can deliver product. We all heard of the issues of the supply chain, and they're real. Supply chain issues have created such problems in North America and throughout the world that electronics manufacturers are struggling to solve. We actually

manufacture our own products here in the US. We don't outsource anything. We manufacture even the temperature probes that go into the transformer, but we manufacture them ourselves. The problem is the electronic components, the microcontrollers, the memory chips that are needed, they're in short supply. What we've learned to do when we saw parts just disappear overnight was that we should cover the lead time. Now lead times are more than one year. Instead of just-in-time inventory, we've gone to strategic inventory.



AR I love that. Okay. Talk about that.

GH Okay, so strategic inventory means you live to fight another day. You think about it before you just say, *I'm out*, right? Our director of operations does nothing but watches the parts and makes sure that, as the parts are becoming scarcer and scarcer, he pulls the trigger in time because if we don't pull the trigger now, we won't have parts to deliver our monitors a year from now. We're having to do that and we're spending a lot of cash in order to do that. But it's important to the industry because, in order to continue to provide the product when it's needed, you have to have the material. It's very interesting.

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***Well, we have to make sure we can deliver product. We all heard of the issues of the supply chain, and they're real.***

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AR For most CEOs, the two things that I bring up that immediately get them sparked are supply chain management and labor shortages. What is that doing to your business?

GH Labor shortages is not a problem. We have our own people. They're local people that know how to build electronics, so that's fine. We have production assembly equipment in-house. They're robotic in nature, so they're less dependent on people. Even though people are really important to make sure the process runs as it should, we have automatic optical inspection equipment to inspect everything. It's not like figuring out, Where's Waldo? Where's the defect? It'll spot it right away because it's using an intelligence system to look at the circuit card as it's assembled to ensure that all the components are assembled correctly. We have in place all of the automation tools that we need. We have the people, skilled individuals. We just rock and roll with what we have to do.

I just know I've been fortunate to do a lot of stuff in my career. One of those was as VP of Operations at a major electronics company, where I ran engineering. I ran the factory too, and restructured it entirely. I had this experience. When I started Advanced Power Technologies, it was really simple for me to be able to roll into doing this in a way that made a lot of sense.

AR That is a great background to have. Let's go to IEEE again. You obviously expressed a love for IEEE. You were the past chairman of the Standards Board?

GH In IEEE, we have an organization. We call it an organization unit, OU, and it's called the Standards Association. The Standards Association is responsible for the entire standards development process used by many societies and councils. It turns out PES is the biggest when it comes to IEEE standards. We have in PES more IEEE standards than any other society or council. I was with Jessica Bien today who's IEEE PES President, and we were just talking about that today. This isn't great. We have the most standards than anybody else, even the computer society.

AR That's surprising. I know that you've been involved in many committees. You have people within the company involved in committees. What's the value of them not just coming here, but getting them involved with IEEE on a regular basis?

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***[Involvement with IEEE] enriches [my employees] professionally. They will meet people that will help them. They will find resources that they never knew existed.***

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GH It enriches them professionally. To me, I'm an engineer first and foremost. I run and own a business, but on the other hand, there's an ethical part of what I do. Being an engineer, I believe the profession is of great value. It's almost at the same level as a doctor or a teacher. It's really, to me, a treasured profession that I want to see honored, and I don't want to disrespect my employees by saying they can't be involved in this. They need to be involved; they need to participate. It's really important to me that our people get involved. It helps them do their job better, but also, they can contribute to standards in the way that they think best, not because of their affiliation.

AR This is very important. You mentioned the operating units, the Smart Grid. I'm on the Smart Grid committee, and we have 14 different operating units that actually help promote the program when the program was developed. We are now trying to re-engage many



of those people because many of them just stop working. Once the standards were done, there was an idea that the smart grid is finished, and it really isn't. We're starting to do things. Next year in April in San Diego, IEEE PES will be doing the first Grid Edge conference, which will rival what we do here for T&D at the Grid Edge. It's going to be unique because there's so much change taking place at the Grid Edge. But I'm sure you all will be there.

Last question that I've got for you. From an IEEE perspective, why should a young person come into this industry? Why become part of IEEE when your boss hasn't necessarily said to join, or your company isn't sponsoring it? Why personally should you get involved in it?

**GH** They will meet people in their career. That's really what it comes down to.

**AR** It's a career maker.

**GH** Yes, it's a career maker. They will meet people that will help them. They will

find resources that they never knew existed. If they get into a problem in a design, if they're working on something, hardware or software, or they're working in the field in the utility, they'll have some friends that they can call up and say they having this issue, and maybe that person has had this problem five years ago. It's enlightening. Just the camaraderie of being involved in the organization is just wonderful. I would recommend to all young engineers that they should be involved in IEEE at an early age, but continue to be involved. There are so many student members of IEEE that just disappear.

**AR** Yeah, that's true. We have to do more to encourage them to stay involved. We need their affiliates to say they need to be involved, because it's important. We need their bosses to understand this is not taking time away from the work. This is the work.

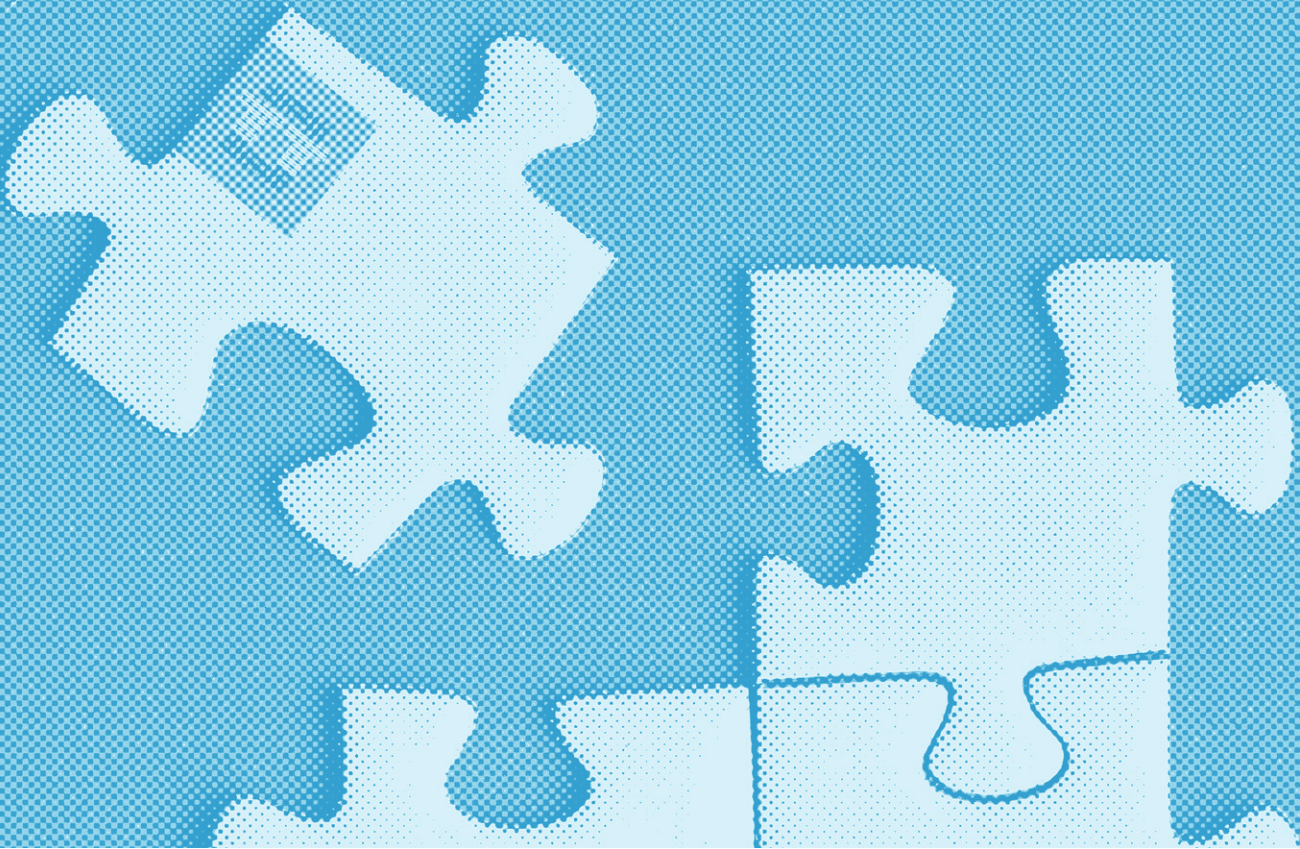
But anyway, that's great. Gary Hoffman, this has been great. Thank you so much for being here.

**GH** Thank you.

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## Digital Technology Solution: The BIIT™ Bushing

## A Bushing with Integrated Low Power Voltage and Current Transformers

This article introduces the reader to the BIIT™ bushing technology; an intelligent HV bushing with integrated low power voltage and current transformers. The BIIT™ bushing with its safety and environmental benefits and its integrated current transformer and voltage transformer measuring and monitoring functions is no longer just an isolation component but an intelligent device that can have a big positive impact on the configuration of a substation.



BIIT™ Bushing

### Background

The BIIT™ bushing was developed as a digital solution for bushing applications in T&D substations. The technologies used for the BIIT™ bushing come from products previously developed by RHM International. The condenser core insulation used is the resin impregnated fiberglass technology which was first introduced to the market in 2003 as a new transformer bushing type, the first totally dry-type paperless bushing in the industry. This bushing type utilizes a finely graded condenser design and a core insulation composed of fiberglass impregnated with epoxy resin wrapped between capacitive screens for a linear surface potential profile from the conductor to the grounded flange. The low-power measurement functions include an integrated Rogowski coil for measuring current and a capacitive voltage divider for measuring voltage. RHM International's low power system combined electronic voltage and current transformer (eVCT), which was developed for the IEC 61850 market, was the first device to use this combination of technologies.

### Some Applications for the BIIT™ Bushing: How this technology can open new and unique configurations to the systems on which it is installed

The BIIT™ bushing with its safety and environmental benefits and integrated monitoring functions is no longer just an isolation component, but an intelligent device. The BIIT™ bushing can replace traditional bushings on a transformer, providing digital transformation of the equipment.

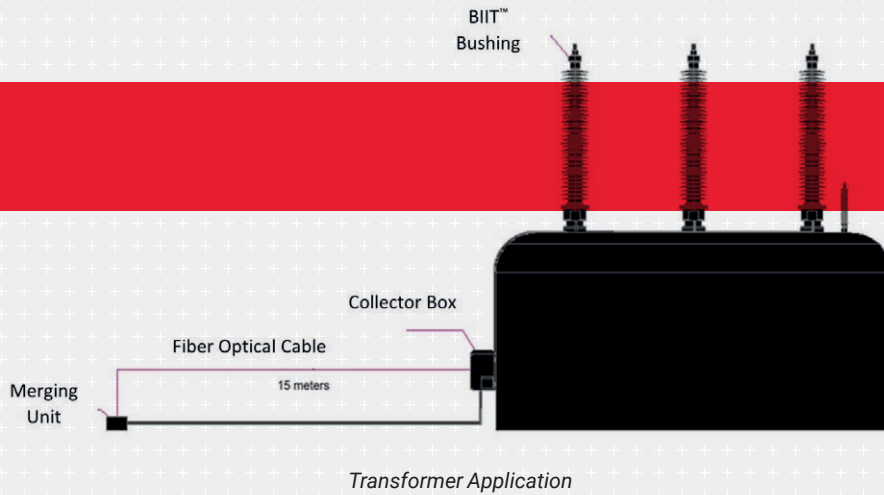
Since no internal bushing CTs are required, there are no limiting dimensions for the bushing oil end to consider, and the size of the bushing turret can be reduced, allowing for better standardization.

**The BIIT™ bushing with its safety and environmental benefits and its integrated current transformer and voltage transformer measuring and monitoring functions is no longer just an isolation component but an intelligent device that can have a big positive impact on the configuration of a substation.**

GIS lineups can be simplified by using the BIIT™ bushing for its incoming connections as the current transformer and voltage transformer compartments in the GIS can be eliminated thereby reducing its overall footprint and SF6 gas volume. This type of miniaturization is particularly important for mobile substation applications, which have strict dimension and weight restrictions.

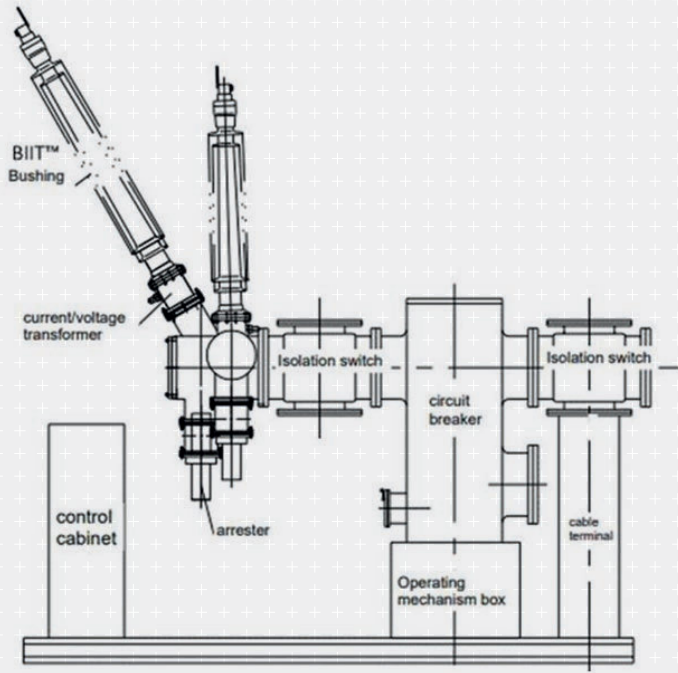
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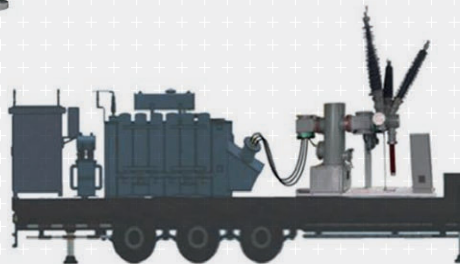
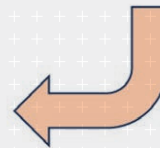


Mini-GIS Component Layout

By integrating voltage and current transformer functions with a bushing design that is explosion-proof, seismic-resistant and free of oil and gas environmental impacts, utilities can now take a forward-looking approach to replacing high failure rate, large power consumption traditional equipment.



Application of 126 kV BIIT™ GIS (transformer) bushing with low-power voltage and current transformers in mini-GIS

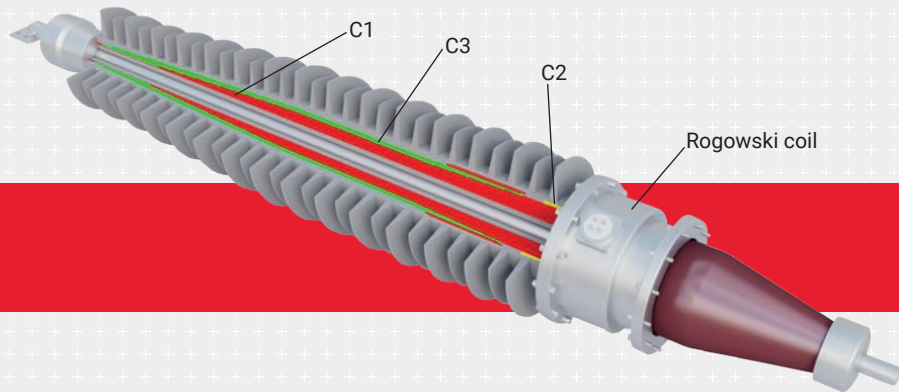


Mini-GIS Application for Mobile Substation

### The BIIT™ Bushing

The BIIT™ bushing utilizes a capacitance-voltage equalizing insulation core wrapped using a trademarked composite insulating material system. The finely graded capacitor design is composed of a main capacitance C1, which withstands the voltage, a low-voltage capacitance C2, which extracts the voltage signal and an anti-interference capacitance C3. The outer insulation are silicone rubber sheds directly set on the core body. Based on the principle of capacitor voltage division, the measurement of the terminal voltage on C2 provides the signal source for the low-power voltage transformer. An anti-interference capacitance C3 effectively improves the precision of terminal voltage signal.

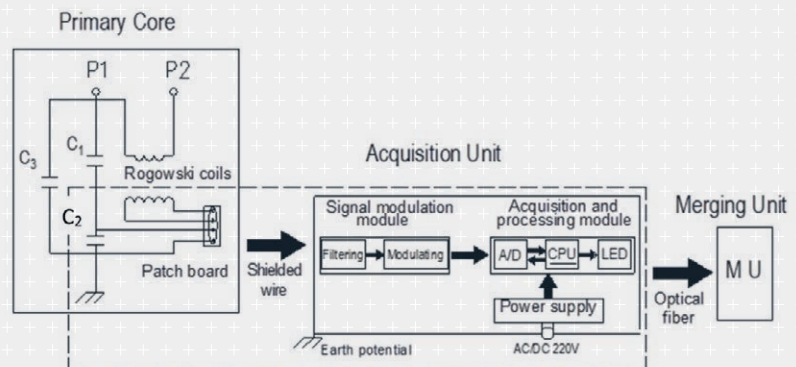
Using Faraday's electromagnetic induction principle, several large inductance hollow coils are set at ground potential inside the ground flange and outside the grounding screen to provide the signal source for the low power current transformer. An acquisition unit composed of a signal modulation module, an acquisition processing module, and a power supply module converts the analogue signals into a digital optical signal, which is sent to the merging unit via optical fiber. The merging unit combines and synchronizes the data from the acquisition unit and transmits the measured current and voltage data in the form of Sampled Values to the digital substation process bus.



Physical Structure of the BIIT™ Bushing

As the power industry prepares for a future digital grid the BIIT™ bushing offers a first step into the implementation of digital sensors in older and new substations. By integrating voltage and current transformer functions with a bushing design that is explosion-proof, seismic-resistant and free of oil and gas environmental impacts, utilities can now take a forward-looking approach to replacing high failure rate, large power consumption traditional equipment. Some application examples for the BIIT™ bushing are discussed further below.

**An excellent example of the cost benefits that can be achieved with the integrated instrument transformer technology is the development of combined equipment designs for conventional AIS substation HV feeder bays.**



BIIT™ Bushing Schematic

### Type Testing the BIIT™ Bushing Design Criteria

In 2021 a full series of type tests in accordance with the IEC 60044-7/8 and IEC 60137 standards was successfully completed on a BIIT™ bushing prototype. The following is a brief summary of the type tests performed.

### Test Object Parameters

Rated Primary Voltage: 110/ $\sqrt{3}$  kV  
 Rated Primary Current: 2000 A  
 Highest Rated Voltage for Equipment: 126 kV  
 Power-Frequency Withstand Voltage: 255 kV  
 Lightning Impulse Withstand Voltage: 550 kV  
 Rated Short-Time Thermal Current: 40 kA, 3 s  
 Rated Dynamic Current: 100 kA  
 Rated Voltage Factor: 1.5, 30 s  
 Current Metering: Rogowski Coil, Accuracy Class 0.2  
 Current Protection: Rogowski Coil, Accuracy Class 5P  
 Voltage Metering: Capacitance Voltage Division, Accuracy Class 0.2  
 Voltage Protection: Capacitance Voltage Division, Accuracy Class 3P  
 Output: Digital

### Type Tests Performed

Test	Requirements
Measurement of dielectric dissipation factor ( $\tan \delta$ ) and capacitance at start and end of tests.	tan $\delta$ at 10 kV, 1.05/ $\sqrt{3}$ and $U_m$ shall not exceed 0.4%  The maximum permissible increase of tan $\delta$ between 1.05/ $\sqrt{3}$ and $U_m$ shall not exceed 0.1%
Dry lightning impulse withstand	15 FW positive impulses/550 kV; 15 FW negative impulses/605 kV; 5 CW negative impulses/666 kV
Wet power-frequency withstand	230 kV, 1 min
Electromagnetic compatibility	RIV shall not exceed 500 $\mu$ V at 1.1 $U_m$ / $\sqrt{3}$ kV
Temperature rise	Tested at 1.2 x $I_{rated}$ Metal parts in contact with insulation 100K/130°C Terminals 75K/105°C
Cantilever load withstand	4000 N, 1 min perpendicular to terminals
Dry lightning withstand	5 FW negative impulses/578 kV
Dry power-frequency withstand	255 kV, 1 min
Partial discharge	< 10 pC at $U_m$ , 1.5 $U_m$ / $\sqrt{3}$ , 1.2 $U_m$ / $\sqrt{3}$ & 1.05 $U_m$ / $\sqrt{3}$
Tap insulation withstand	2 kV, 1 min
Flange tightness	0.15 MPa, 15 min
Accuracy	Electronic voltage transformer: accuracy classes 0.2/3P  Electronic current transformer: accuracy classes 0.2/5P
Short-time current	$I_{dyn} = 100$ kA; $I_{th} = 40$ kA, 3 s
Composite error electronic current transformer	5P20
Temperature cycle accuracy	Electronic voltage transformer errors shall meet the requirements of accuracy classes 0.2/3P under rated frequency, rated voltage and between -40°C and +40°C  Electronic current transformer errors shall meet the requirements of accuracy classes 0.2/5P under rated frequency, rated voltage and between -40°C and +40°C
Visual inspection and dimensional checks	Surface of the bushing is clean and smooth.



**Eric Euvrard** has an extensive international engineering background having held different technical and managerial functions in Europe, USA and China in Commodities, Automotive, Aerospace, Advanced Nanomaterials and Fiber Optics Networks industries, before creating RHM International in 2005 where he presently serves as President. Eric received education in France, in the USA, and in Switzerland.

## Summary

The BIIT™ bushing offers a first step into the implementation of digital sensors in older and new substations. By integrating voltage and current transformer functions with a proven bushing design that is explosion-proof, seismic-resistant and free of oil and gas environmental impacts, utilities can now take a forward-looking approach to replacing its traditional aging equipment, while improving the configuration of stations' environment.

Looking ahead, the BIIT™ bushing's integrated low power instrument transformer technology can reduce the size of equipment for future digital substations. An excellent example of the cost benefits that can be achieved with the integrated instrument transformer technology is the development of combined equipment designs for conventional AIS substation HV feeder bays. Traditional, free-standing equipment like circuit breakers, disconnectors, current and voltage transformers that make up a conventional AIS substation HV feeder bay can be combined into a single piece of equipment, making HV feeder bays more compact and economical.



**Robert L. Middleton** was born in 1948 in Winnipeg, Canada. He received his degree in Electrical Engineering from the University of Manitoba in 1971. He is a registered professional engineer in the Province of British Columbia. He has an extensive background in generation and transmission engineering including quality assurance. He has served on several CSA, CIGRE and IEC working groups and co-authored numerous technical papers. He is presently the Chief of Technology and Engineering for RHM International, a manufacturer of high voltage dry type current transformers, bushings and cable terminations. Prior to joining RHM International he worked over 40 years at two western Canadian provincial electrical utilities.



# Combining Synchronous Condenser and Battery Energy Storage System Technology to Boost Grid Stability

by **Christian Payerl**

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Electric power grids around the world are facing a major challenge due to the steady loss of the spinning inertia, otherwise known as kinetic reserve, that is vital for their stable operation. The main reason for this decline in inertia is that the transition to decarbonized energy is driving the decommissioning of traditional large-scale, centralized power plant based largely on rotating synchronous generators. Increasingly, power is being produced by inverter-based non-synchronous resources such as wind and solar that are not able to contribute inertia to the grid.

Historically, power systems have relied on the inertia inherent in large, centralized generation plant to keep them stable. Inertia acts rather like

a car's shock absorbers smooth the way over bumps in the road. It helps the grid to react to sudden changes in frequency, such as when a generator trips offline, by providing time to respond. This keeps the system frequency within controlled limits around 50 or 60 Hz (depending on the country). In an intact and stable system, the frequency of electricity across the grid network is the same and the system can react to any loss of load or generation and is robust against disturbances.

The impact that reduced system inertia can have on grids in terms of lower stability and resilience is generally well known. It is perhaps less well recognized that the loss of synchronous generation can also

cause a decrease in the available fault current, with a consequent impact on existing relay protection systems.

A further way that the increased penetration of renewables can affect grid stability is by potentially introducing new phenomena such as oscillations. These also have a negative impact on power quality.

The need to mitigate grid stability challenges is driving substantial R&D activity focused on the development of new algorithms and control schemes. There is however an alternative approach that shows considerable promise – this uses a hybrid solution that combines well-proven SC technology for fault current contribution and real inertia with a



Christian Payerl is ABB Sales Manager - Synchronous Condensers and Generators, based in Switzerland. He is an electrical power system specialist with over 30 years of experience in MV/HV transmission projects with FACTS devices such as SVCs, STATCOMs and SCs.

**A hybrid combination of a Synchronous Condenser (SC) with a Battery Energy Storage System (BESS) offers a range of grid-supporting functions, including black-start capability.**

BESS for active power and frequency support.

**Why have Synchronous Condensers made a comeback?**

A Synchronous Condenser is a large rotating electric machine. It is not a motor – it does not drive anything. Equally, it is not a generator – there is no prime mover. There was a time when SCs were ubiquitous in power grids where they were used to provide reactive power to balance out highly inductive loads, like electric motors.

However, over the past 50 years there was a decline in the use of SCs as their reactive power role has been replaced by power electronic equipment.



Figure 1: SC installation at Darlington Point solar farm in Australia

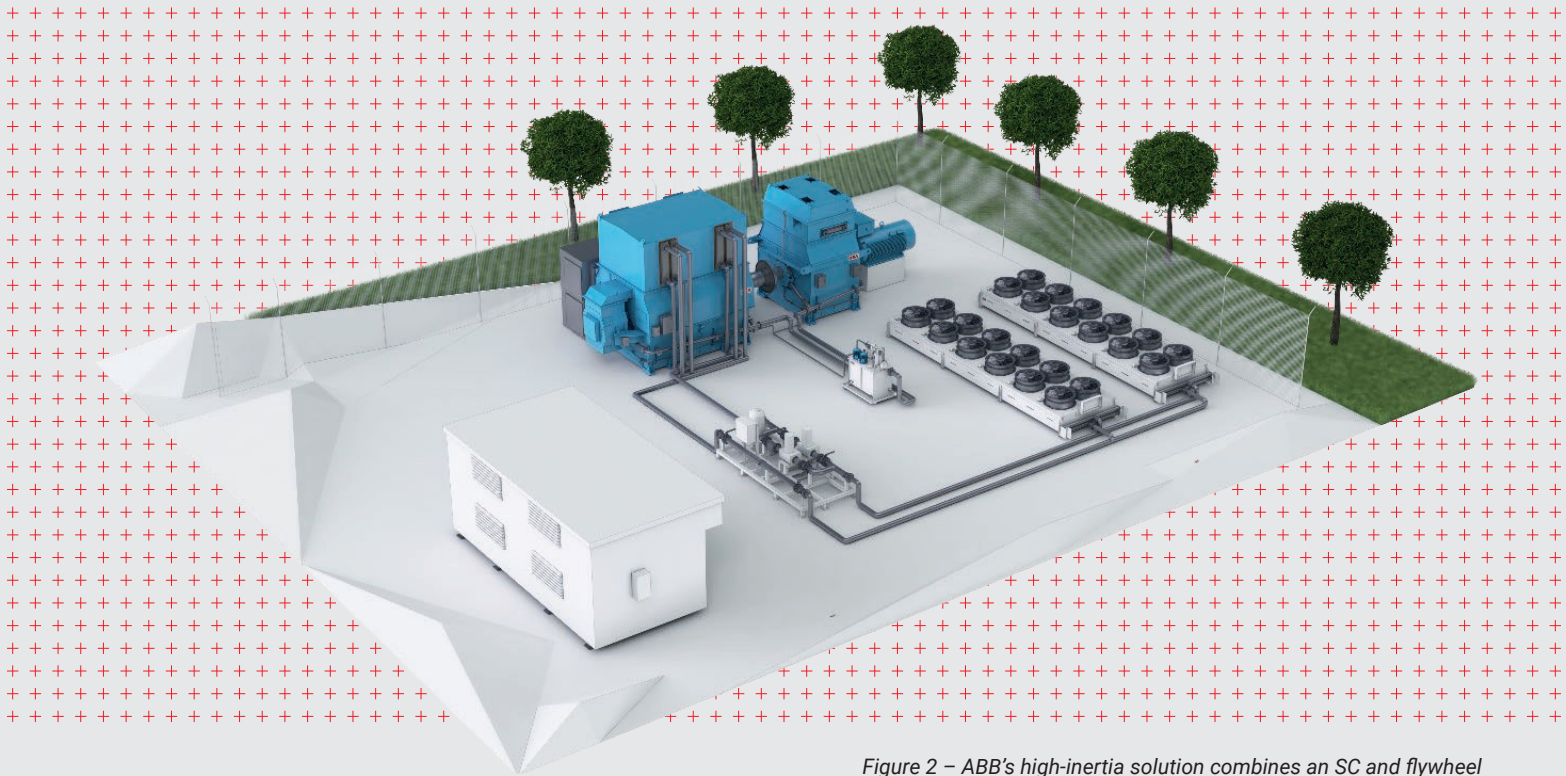


Figure 2 – ABB's high-inertia solution combines an SC and flywheel

They are now making a comeback as the changing nature of grids, and concerns over the loss of inertia, have stimulated new interest. The reason is that SCs can mimic the operation of large generating plant by providing an alternative source of spinning inertia. Because they are large rotating machines, SCs can both supply and absorb reactive power, delivering voltage support and dynamic regulation.

**SCs can mimic the operation of large generating plant by providing an alternative source of spinning inertia. Because they are large rotating machines, SCs can both supply and absorb reactive power, delivering voltage support and dynamic regulation.**

One advantage of SCs is that they are a very cost-effective, scalable and reliable way to maintain power quality. This includes the capability to provide the level of fault current

protection essential to strengthen a weak grid. SCs are therefore a key enabling technology that facilitates the increased grid penetration of renewable energy.

SCs are typically supplied in ratings up to 80 megavolt amperes of reactive power (MVar) and 3 to 15 kilovolt (kV) system voltage to provide a decentralized solution to increase grid strength and stability. It is possible to combine several modules to achieve a higher output, with the added advantage of better redundancy and availability compared to one large unit.

A particularly interesting deployment of SCs is at the Lister Drive Greener Grid project at Liverpool, England. In early 2023, ABB completed a contract for Statkraft, Europe's largest renewable energy producer, to design, manufacture and install two high-inertia SC systems. This innovative project is now playing a key role in stabilizing the local grid to handle more wind and solar power so that National Grid can meet its target of operating a zero-carbon electricity system by 2025.

Lister Drive is the world's first project to feature ABB's high-inertia SC configuration. It couples a 67 MVar SC with a 40-tonne flywheel that increases the instantaneously available inertia by 3.5 times.

Combining a mid-size SC with a flywheel multiplies the available inertia several times, with much lower losses than installing the whole inertia as SC. It is also a cost-effective way of using up to two mid-sized SCs coupled together with the benefits of a high level of redundancy, increased inertia and greater controllability.

A notable feature of the Lister Drive project is that safety has been a priority in the design, installation and operation of the large flywheels. This includes satisfying safety requirements during abnormal events, including containment of a loose but mainly intact flywheel rotor. To achieve this an integrated safety enclosure has been designed to manage the flywheel and provide protection in a single unit.

### **Combining an SC and BESS**

Older, well-established BESS installations feature grid-following inverter technology. This is also a common approach for new installations, especially on a smaller scale. The challenge is that it relies on a stable grid as too much variation in the voltage phasor can cause control problems for the inverter. Therefore, this type of inverter cannot connect to an unstable grid or be used for a black-start.



Figure 3 – Lister Drive is the world’s first application of ABB’s high-inertia SC configuration – housed in the two gray buildings.

There is an alternative solution in the grid-forming inverters that are relatively new and less common, although they are being deployed in larger scale BESS installations. This type of inverter has the advantage that it can stabilize a grid and provide black-start capability.

One potential issue with using inverter-based technologies is that they can cause problems such as power oscillations and opposing control. This is due to the digital nature of their control and measurement systems.

**One potential issue with using inverter-based technologies is that they can cause problems such as power oscillations and opposing control. This is due to the digital nature of their control and measurement systems.**

The advantage of using a synchronous condenser is that its operation is determined by simple physics, making it a stable and reliable method for grid support.

However, it is not so much a case of making a choice between a BESS incorporating power electronics and an SC. Using the two as a hybrid combination is the best solution for the multiple applications we outline here.

**Voltage and reactive power control**

Using an SC will add high overload capability to the grid through its inherent properties as a large rotating machine. It provides instantaneous support during a fault, lifting the voltage and reducing the impact of voltage dip.

When the fault is cleared the SC can create a slight overvoltage since it cannot respond quickly to reduce the excitation current. That is where the quick absorption of reactive power by a power electronic device such as a BESS or STATCOM is useful to reduce this over-swing in voltage. This ensures a faster return to the steady state.

**Inertia and frequency control**

The SC supplies inertia and frequency control as “real” inertia. This is



Figure 4 – Typical BESS installation supporting a solar farm

complemented by fast frequency control, sometimes called “virtual” inertia, by the BESS. Using this hybrid system has been shown to give better system performance and a lower rate of change of frequency (ROCOF).

**Short circuit capacity**

A vital aspect of a power grid is its short circuit capacity (short circuit ratio – SCR) and its relay protection functions. The SC can provide very high short-circuit currents of several times the rated current. Using an SC in combination with a BESS can therefore provide a large fault current contribution, but without the need to over-dimension the BESS inverter to handle the large current that occurs in fault scenarios.

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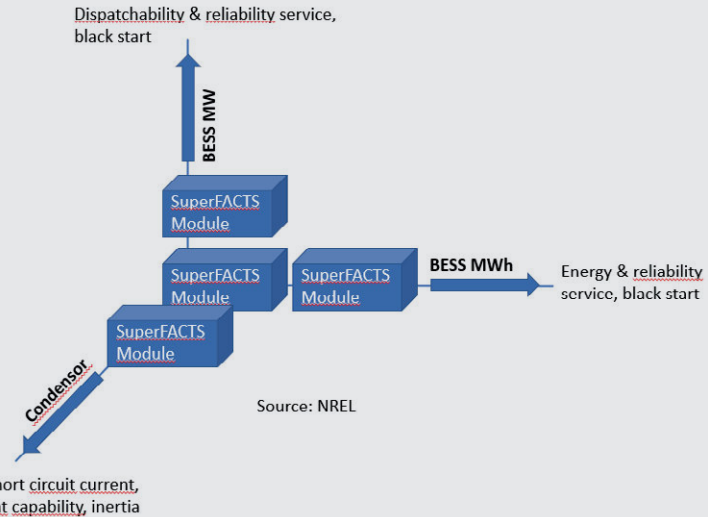


Figure 5 – Combining a BESS and SC is the best solution for multiple applications

**Black-start capability**

A BESS with a grid-forming inverter can provide black-start capability. First, it establishes the local grid to which the SC is synchronized. The SC then adds fault current capability and voltage and frequency stability as the larger grid is restarted and built up by adding additional power generation and loads.

**Oscillation damping**

To improve oscillation damping an SC can be connected to the grid in combination with BESS units. Or a power oscillation damping function (POD) can be added as part of the SC’s automatic voltage regulator (AVR) system.

**Conclusion - A new powerful combination for stable grids**

While SCs and BESS have their individual merits combining them will offer clear benefits in providing grid-supporting functions. These include stabilizing the grid through increased short-circuit current, increased frequency support and system inertia, decreasing ROCOF, and reactive power control. An added benefit is that a hybrid SC and BESS installation can provide black-start capability.

**A hybrid SC and BESS installation can provide black-start capability.**



Photo: ABB

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# Experimental Study on Gas Suppression of OLTC-Generated Emissions in High Voltage Converter Transformer

by Guan Sijia  
Yu Yiming  
and He Chunhong

Tektronix MDO3014 Mixed Domain Oscilloscope

100 MHz  
2.5 GS/s

Tek 预览

M 20.0ms

缩放系数: 100 X

缩放位置: 508µs

□	58.00µs	a	-1.600 V
○	874.0µs		1.390 V
△	816.0µs	b	Δ2.990 V

联动光标

500mV

200µs  
0.00000 s

50.0M次/秒  
10M点  
1.04 V  
触发频率: < 10 Hz

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Default Setup

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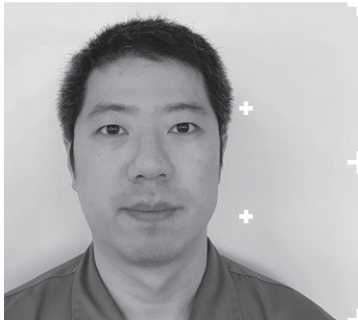
Menu

D15-00

Input Range +30V to -20V  
MSO Capable



**Guan Sijia** started with Shanghai Huaming Power Equipment Co., Ltd. as an engineer for product research and design with special focus on advanced tap-changer application analysis.



**Yu Yiming** having been working in Huaming for more than 10 years, is responsible for product design. Before that, he was the main designer for Huaming CMD tap-changers.



**He Chunhong** is a test engineer in Huaming. His work involves analysis and development of test methods for tap-changers. Prior to that, he was also responsible for controller design in Huaming.

## Experiment Design

Transformers are essential equipment in electric power transmission. In order to ensure the stable operation of transformers and prevent power supply failures due to foreseeable factors in the power system, the smooth operation of the on-load tap changer, which constitutes a vital part of transformers, will mitigate operational risks in the system.

To quantitatively analyze the gases that influence the safe operation of transformers during the functioning of on-load tap changers, a comprehensive set of experimental procedures has been devised.

**Transformers are essential equipment in electric power transmission. In order to ensure the stable operation of transformers and prevent power supply failures due to foreseeable factors in the power system, the smooth operation of the on-load tap changer, which constitutes a vital part of transformers, will mitigate operational risks in the system.**

1. Developed a dedicated experimental platform to facilitate the installation of on-load tap changers and subsequent gas generation tests.
2. Provided a customized large oil tank to immerse the OLTC.
3. Configured a complete set of power frequency withstand voltage testing equipment.
4. Designed a special funnel for gas collection during experimentation.
5. Equipped with motor drive for driving the switch mechanism.
6. Implemented a set of real-time monitoring devices, including Tektronix oscilloscopes, infrared thermal imaging cameras, surveillance cameras, high-speed cameras, multimeters, and real-time voltage monitoring devices at the voltage output terminal.
7. Customized an experimental-specific gas collection bottle, constructed of glass and featuring a three-way valve and a unidirectional valve, along with accessory pipelines for metering purposes.

Position the experimental fixture above the oil tank, and fix the funnel onto the test switch via mounting plates. Then mount the switch onto the experimental platform. After adjusting the voltage divider resistors and inductance, connect the generator and the circuit by conductors. Following this, the output of the voltage divider is led to the positive and negative terminals of the tap selector. Thereafter, after filling the insulating oil into the tank, fasten the measuring device onto the calibration fixture for experimentation using 3D-printed mounting sleeves and adhesive onto the test platform.

## Gas Generation Location

### Equipment Contact System Types

The gas generation position prone to arcing in the on-load tap changer is typically located at the contact points. The contact system is critical for tap changer, designed to carry current, make and break circuits. It functions as an executor within the tap changer assembly. Generally, tap changers can be categorized into two major types based on their operational tasks: load current carrying contacts and arc contacts. Typically, the contact system of the tap selector is designed according to its current-carrying capacity, thus forming a set of load current contacts. On the other hand, the contact system of the diverter switch manages the carrying and transition of load current, including the main contacts and inter-connecting contacts. Another set of contacts is composed of refractory materials to mitigate intense oxidation reactions (combustion) on metal surfaces during arcing and endure the wear that occurs during the making/breaking process.

### Experimental Equipment Configuration

In this case, the arcing gas generation primarily occurs at the change-over selector's moving contact position. The structural design of the experimental equipment for this study is in the shape of "T" and adopts a single-axis design. A single-axis design refers to an insulated shaft, upon which a rotating arm is situated within the cage, allowing this insulated rotary shaft to rotate (incrementally) in order to bring the moving and fixed contacts into making/breaking. The structure is depicted in the Figure 1.

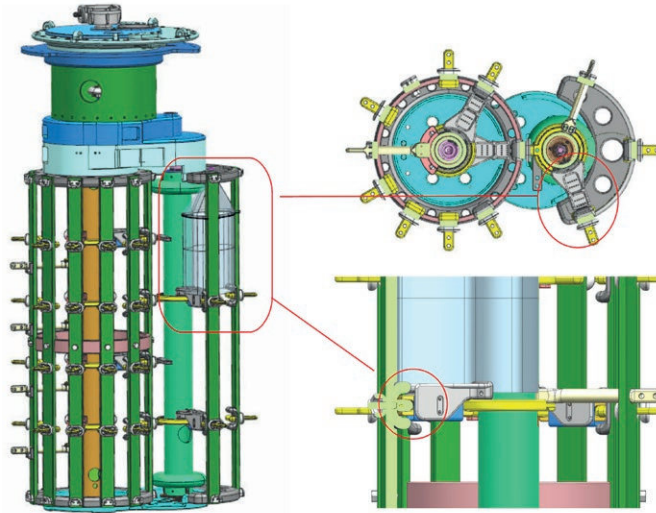


Figure 1: Contact Structure

This structure is widely utilized in various types of tap changers.

### Determination of Experimental Platform and Experimental Scheme

During the experimentation process, the test object are immersed in container filled with transformer oil and placed in a specially designed thermostatic chamber. It is to simulate typical dielectric partial discharges within the transformer by applying power frequency voltage.

Among these components, the material primarily utilized for the simulated oil tank is acrylic, with dimensions of  $\Phi 1,900\text{mm}$  (diameter)  $\times 2,970\text{mm}$  (height). The thermostatic chamber, which utilizes the existing electrical testing lab of the factory, occupies an area of  $3,000,000\text{mm}$  (length)  $\times 200,000\text{mm}$  (width)  $\times 100,000\text{mm}$  (height).

The characteristics of this simulation system are as follows:

**A) Temperature Monitoring of the Tap Changer** – Due to the

non-uniform temperature distribution within the simulated oil tank, the temperature of the upper oil part is higher than that of the lower part. Additionally, the temperatures of various components and the oil will undergo changes upon polarity change-over of the tap changer. To address these variations, a temperature monitoring apparatus is set up.

The temperature monitoring provides the following two benefits:

1. In the power frequency withstand voltage testing, the resistors and voltage dividers in the circuit will bear a load. Consequently, the components' temperature will increase rapidly with the number of switching operations. Given that the resistance endurance temperature is approximately  $250^{\circ}\text{C}$  and the extreme limit temperature is  $300^{\circ}\text{C}$ , temperature monitoring is established to promptly stop the experiment, thus preventing aging and damage to components.
2. Although there is non-uniformity in the upper and lower oil temperatures within the barrel, the oil temperature affects gas solubility. Excessively high oil temperatures close to the boiling point can raise certain issues. Monitoring in real time is essential to avoid such problems.

The resistance endurance temperature is approximately 250°C and the extreme limit temperature is 300°C, temperature monitoring is established to promptly stop the experiment, thus preventing aging and damage to components.

- B) Remote motor drive Control Device – The tested on-load tap changer, while energized, employs a remote control device to rotate the tap changer from safe distance, preventing unnecessary personnel accidents.
- C) Oil Sampling – To facilitate the analysis of dissolved gases in



Figure 2: Motor drive unit model SHM-X

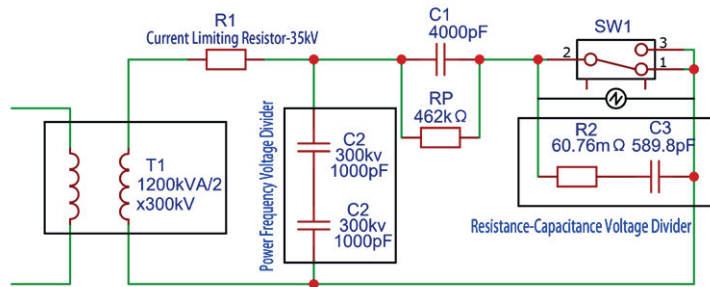


Figure 3: Test Circuit

transformer oil, a specialized collection apparatus utilizing an ultra-irregular funnel design was devised. This apparatus is connected to a customized, pressure-resistant oil pipe that links to a precisely calibrated glass measurement cup fitted with a customized burst-proof double-headed unidirectional valve.

**Partial Discharge Measurement and Acquisition System**

Basic test circuits for measuring partial discharges are generally categorized into two major types: direct circuits and bridge (balanced) test circuits. Direct test circuits are further subdivided into parallel test circuits and series test circuits. In this study, a series test circuit is employed due to its sensitivity enhancement with the increase of the coupling capacitance CK to the sample capacitance CX ratio.

The test power supply consists of an auto-transformer T1 and a power frequency non-partial discharge test voltage divider C2. Its rated voltage is 300 kV, and its rated capacitance is 1000 pF.

The transformer's rated capacity is 1200 kVA, and the voltage is limited to a maximum of 35 kV under the prescribed transformer operating conditions. The limiting current resistor serves to restrict the voltage, providing protection to the experimental setup in the event of test specimen breakdown.

The coupling capacitor C1 has a capacitance value of 4000 pF and can withstand a voltage of 66/√3 kV. It acts as a coupling device in the partial discharge circuit and is parallel-connected externally to a resistive-capacitive voltage divider, which has a resistance value of 60.76 mΩ and a capacitance value of 598.8 pF.

This component simultaneously functions as a voltage divider during the test, allowing for phase correction of the partial discharge waveform. The oscilloscope is connected in parallel to both ends of the resistive-capacitive voltage divider, serving as the monitoring unit for the partial discharge signal. It measures the partial discharge signal, displays, captures, and stores the signal waveform. SW1 represents the partial discharge model within the on-load tap changer polarity switching in the transformer. This component is positioned within a specially designed simulated oil tank to replicate the operational status of the on-load tap changer in the transformer.

## Experimental Procedure

Begin by filling the oil tank with an adequate amount of oil. Install the specialized funnel onto the contact terminals on the change-over selector of the on-load tap changer for HVDC converter transformer. Connect the pipeline and secure the pipeline head to the head flange using zip ties to ensure the pipeline is vertically aligned. Proceed to install the OLTC onto the experimental frame. Subsequently, position the frame with the installed switch over the oil tank, allowing the oil inside the tank to just submerge

the specialized funnel and ensuring the gas collection device's seal. Then, mount the gas collection apparatus at the designated hole on the installation frame and connect the pipelines at each valve port. Following this, install the motorized mechanism on the experimental frame. Finally, connect the test circuit to the OLTC to commence the measurement.

## Experimental Results:

In this experiment, a comparative trial was conducted with the fast contact assembly and detachment methods.

Each comparative trial adhered to the following standards:

The motor drive mechanism was rotated 1800 times, the polarity contacts were switched 900 times (counting method as indicated in the diagram), and the load voltage for power frequency withstand voltage was set at 36 kV.

Wherein, with the installation of the fast contact assembly, approximately 14 ml of gas was collected, and the effective components are illustrated in the table 1.



## Transformer Repair and Testing Branch of Shanghai Jiulong Power (Group) Co, Ltd.

## Transformer Oil DGA Testing Report

Entrusted by:  
Shanghai Huaming Power Equipment Co., Ltd

Submitted by:  
Shanghai Huaming Power Equipment Co., Ltd

Sampling date:  
April 14, 2023

Equipment name: Gas collection equipment for gas production experiment of polarity contact used in converter transformer application

Test date:  
April 14, 2023

Voltage level

Report date:  
April 17, 2022

Detection Result ( $\mu$  L/L)

Equipment Component Gas collection during gas production experiment with polarity contacts for rheological fluids

hydrogen H<sub>2</sub> 1187

methane CH<sub>4</sub> 3.8

ethane C<sub>2</sub>H<sub>6</sub> 0.3

ethylene C<sub>2</sub>H<sub>4</sub> 0.4

acetylene C<sub>2</sub>H<sub>2</sub> 0.3

Total hydrocarbon 8.4

carbon monoxide CO 44

carbon dioxide CO<sub>2</sub> 704


1. Test Method: GB/T 17623-2017  
Determination of componential contents of gas dissolved in insulating oil by gas chromatography method
2. Judgment Criteria: DL/T 722-2014  
Guide to the analysis and the diagnosis of gases dissolved in transformer oil

Conclusion:

## Attention value

Contents	Status	
	Newly put into operation	During operation
carbon monoxide CO	30 ( $\leq$ 220kV) 10 ( $\geq$ 330kV)	150
carbon monoxide CO	0.1	5 ( $\leq$ 220kV) 1 ( $\geq$ 330kV)
carbon monoxide CO	20 ( $\leq$ 220kV) 10 ( $\geq$ 330kV)	150

Test: 

Verification: 

*In this experiment, a comparative trial was conducted with the fast contact assembly and detachment methods. Each comparative trial adhered to the following standards: The motor drive mechanism was rotated 1800 times, the polarity contacts were switched 900 times, and the load voltage for power frequency withstand voltage was set at 36 kV.*

Table 1: Transformer Oil DGA Testing Report

## Transformer Repair and Testing Branch of Shanghai Jiulong Power (Group) Co, Ltd.

## Transformer Oil DGA Testing Report

Entrusted by:  
Shanghai Huaming Power Equipment Co., LtdSubmitted by:  
Shanghai Huaming Power Equipment Co., LtdSampling date:  
April 14, 2023Equipment name: Gas collection equipment for gas  
production experiment of polarity contact used in  
converter transformer applicationTest date:  
April 14, 2023

Voltage level

Report date:  
April 17, 2022Detection Result ( $\mu$  L/L)Equipment Component Gas collection during gas production experiment  
with polarity contacts for rheological fluidshydrogen H<sub>2</sub> 1046methane CH<sub>4</sub> 18.1ethane C<sub>2</sub>H<sub>6</sub> 0.0ethylene C<sub>2</sub>H<sub>4</sub> 0.5acetylene C<sub>2</sub>H<sub>2</sub> 10.3

Total hydrocarbon 28.9

carbon monoxide CO 14


carbon dioxide CO<sub>2</sub> 624

1. Test Method: GB/T 17623-2017  
Determination of component contents of gas dissolved in insulating oil by gas chromatography method
2. Judgment Criteria: DL/T 722-2014  
Guide to the analysis and the diagnosis of gases dissolved in transformer oil

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## Attention value

Contents	Status	
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carbon monoxide CO	30 ( $\leq$ 220kV) 10 ( $\geq$ 330kV)	150
carbon monoxide CO	0.1	5 ( $\leq$ 220kV) 1 ( $\geq$ 330kV)
carbon monoxide CO	20 ( $\leq$ 220kV) 10 ( $\geq$ 330kV)	150

Test: Verification: 

*Through the gas generation experiment, we have observed that in mineral insulating oil, discharges are inevitable during each tap change of the change-over contacts. Discharges induce subtle ionization reactions within the insulating oil, which are proportional to the contact's conductive cross-sectional area.*

Upon detachment of the fast contact assembly, approximately 25 ml of gas was collected, with the effective components illustrated in the table 2.

In the experiment, the moment of contact discharge and bubble generation was captured using a high-speed camera, as shown in the in the figures 4-7.

Table 2: Transformer Oil DGA Testing Report

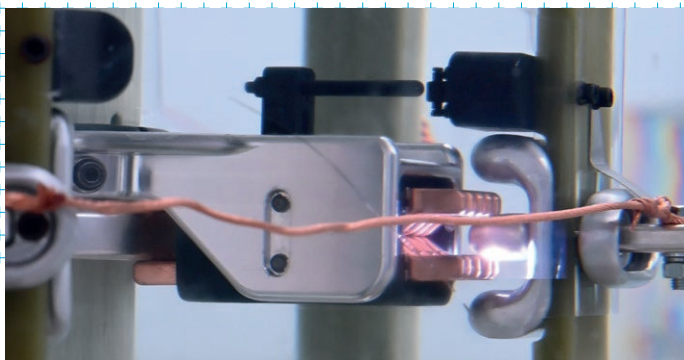


Figure 4: Discharge phenomenon when the tap changer performs polarity switching between the contact boards

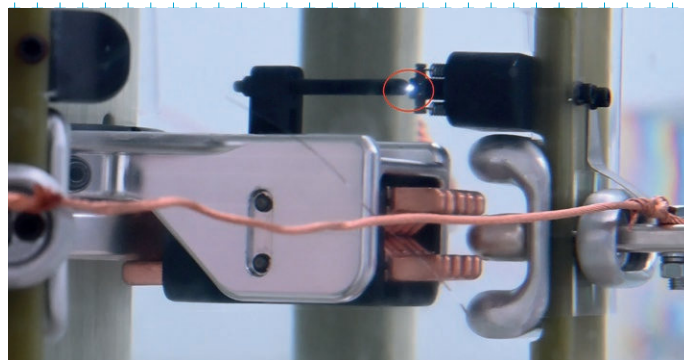


Figure 5: Discharge phenomenon when the tap changer performs reverse polarity switching between the contact bars

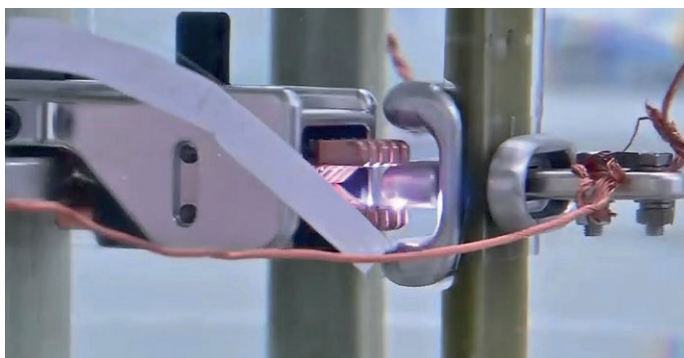


Figure 6: Discharge phenomenon when the tap changer performs polarity switching between the contact bars



Figure 7: Discharge phenomenon when the tap changer performs a change-over switching in reverse phase between the contact bars

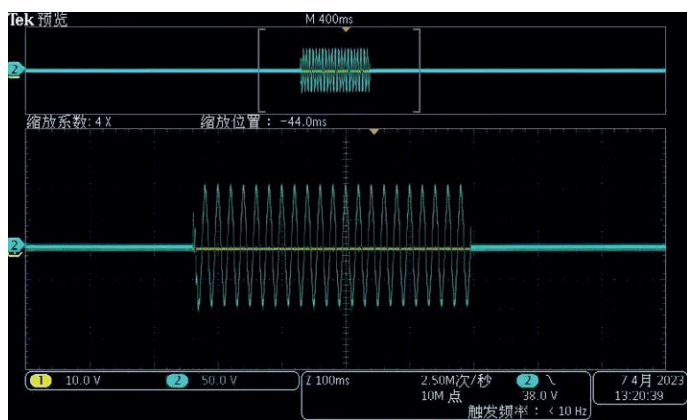


Figure 8: Waveform collected through oscilloscope during polarity switching

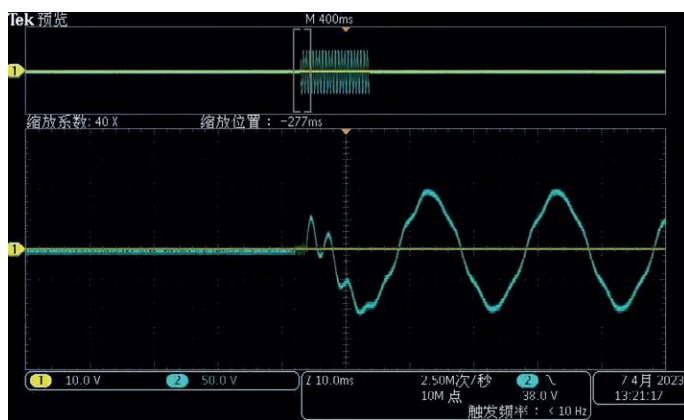


Figure 9: Waveform of Head and Tail Oscillation During Contact Separation -1



Figure 10: Waveform of Head and Tail Oscillation During Contact Separation -2

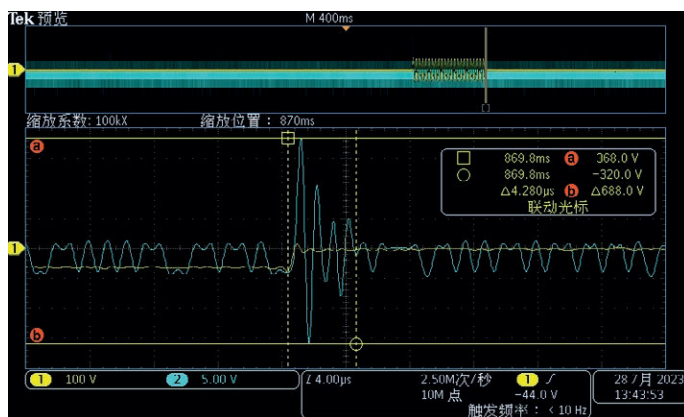


Figure 11: Waveform of Head and Tail Oscillation During Contact Separation -3

## 1. Installation of Fast Contact Assembly Above the Tap Changer's Polarity Contacts:

1.1 When the tap changer performs polarity switching between the contact boards, the moving contact is brought into contact with the fixed contact by the main shaft. At this moment, the discharge phenomenon as shown in the figure on the previous page can be observed.

1.2 When the tap changer performs reverse polarity switching between the contact bars, the moving contact is detached from the fixed contact by the main shaft. The fast contact assembly replaces the main contact and rapidly disengages from the contactor. At this moment, the discharge phenomenon as shown in the figure on the previous page can be observed.

## 2. Remove the Fast Contact Assembly Above the Tap Changer's change-over Contacts:

2.1 When the tap changer performs polarity switching between the contact bars, the moving contact is brought into contact with the fixed contact by the main shaft. At this moment, the discharge phenomenon as shown in the figure on the previous page can be observed.

2.2 When the tap changer performs a change-over switching in reverse phase between the contact bars, the moving contact will be detached from the fixed contact driven by the main shaft. The discharge phenomenon as shown in the figure on the previous page can be observed.

Waveform collected through oscilloscope during polarity switching: Circuit voltage in the typical test circuit.

Waveform of Head and Tail Oscillation During Contact Separation: The oscillation period of the waveform roughly aligns with the discharge duration.

### Experimental Conclusions

Through the gas generation experiment, we have observed that in mineral insulating oil, discharges are inevitable during each tap change of the change-over contacts. Discharges induce subtle ionization reactions within the insulating oil, which are proportional to the contact's conductive cross-sectional area. The designed fast contact assembly method, due to its delayed disconnection and smaller conducting area, effectively suppresses the discharge quantity, thereby reducing the gas generation from the polarity contacts. This approach significantly prolongs the inspection interval of the switch.

Across multiple trials, we have noted that although gas generation is positively correlated with applied voltage, the operational role of the on-load tap changer in a transformer primarily regulates voltage, thereby implying that the number of switches better reflects gas generation under actual operational conditions. Within this experiment, it is observed that, without any gas generation suppression measures, the switch needs to be operated approximately 36 times to produce 1 ml of gas. Considering that the gas volume warning threshold for on-load tap changers is around 250 ml, protection relays capable of monitoring gas volume are sufficient to mitigate the impact of gas over decades of switch operation in power transmission and transformation scenarios. However, for cases of frequent switching, considering voltage levels and switching frequencies, additional gas generation suppression devices should be employed to extend the operational lifespan of on-load tap changers.

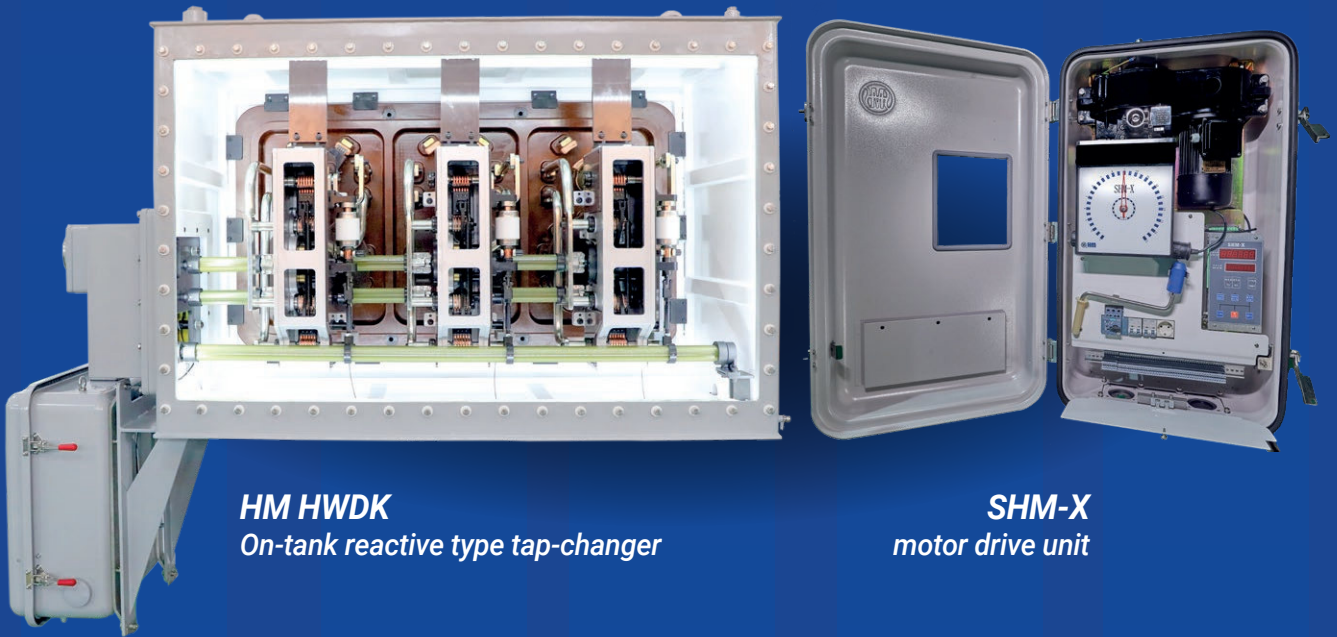
*This structure utilizes an active spring mechanism in conjunction with ultra-fine contact heads to artificially reduce the contact area, thus rendering the conditions for arc breakdown more stringent. The spring's rebound results in rapid separation, achieving fast arc extinguishing. While proven effective in experiments, this structure fails to function during reverse phase switching, compromising its gas generation suppression effectiveness.*

With regard to this gas generation and quantitative experiments, it offers limited benefits to existing OLTCs. But it proves the gas suppression design, validated through experimentation, is effective. This structure utilizes an active spring mechanism in conjunction with ultra-fine contact heads to artificially reduce the contact area, thus rendering the conditions for arc breakdown more stringent. The spring's rebound results in rapid separation, achieving fast arc extinguishing. While proven effective in experiments, this structure fails to function during reverse phase switching, compromising its gas generation suppression effectiveness.



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Shanghai Huaming Power Equipment Co., Ltd.



**HM HWDK**  
*On-tank reactive type tap-changer*

**SHM-X**  
*motor drive unit*

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- **Structure**

Components mounted in a separate and completely isolated oil compartment fixed externally on one side of the transformer's main tank to the side to prevent possible contamination

- **Vacuum Technology with fault detection**

fitted with a switching fault protective module to detect potential vacuum interrupters' failure and lock the tap-changer when critical conditions are detected

- **Superior short circuit performance with up to 30kA peak capacity**

Several features have been combined to reach high short circuit capacity. Vacuum interrupters only transmits current during switching. Both moving and fixed contacts adopt a multi-point contact system to ensure good current transmission and the tap selector's moving contacts adopt bearing springs design

- **Convenient maintenance**

With an internal layout that increases space inside the LTC compartment, it becomes possible to check or replace any LTC component without having to dismantle the LTC

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Brace yourself for an exclusive treat in our upcoming November issue! The world of solid-state technological advances is evolving at an unprecedented pace, with intricate complexities to unravel. To fully capture the magnitude of this dynamic field, we have made the exciting decision to dedicate an entire edition solely to this topic. Get ready to dive into the realm of solid-state advancements like never before.

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NOVEMBER ISSUE**