

TRANSFORMER TECHNOLOGY^{MAG}



Transformers: The **Heart** of the Power System

Interview with **Wilfried Breuer** Managing Director at **Maschinenfabrik Reinhausen**
What is a Transformer Save?
Transformer Condition Assessment: **Moving from Data to Actions**

POWER IN ACTION

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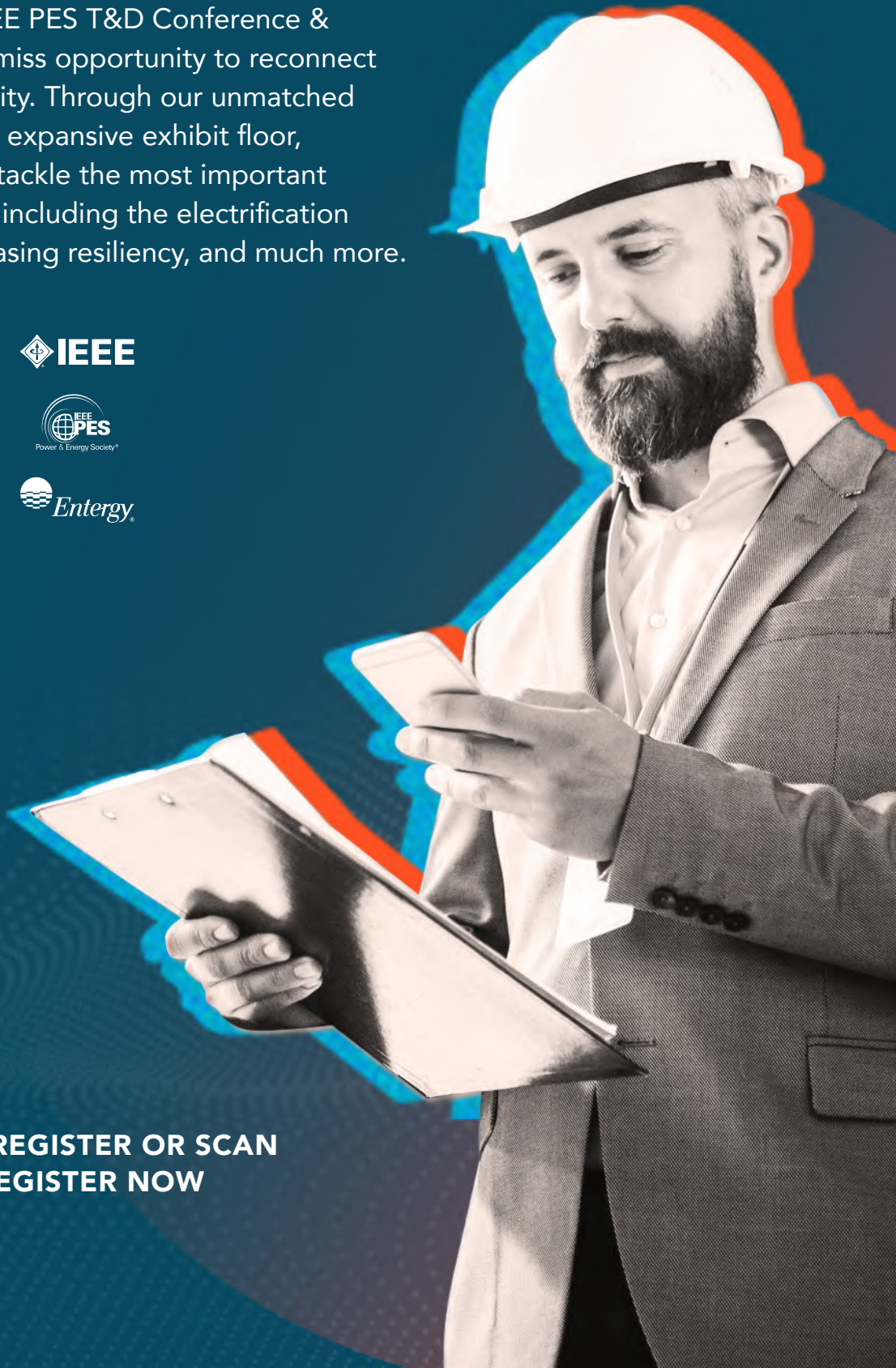
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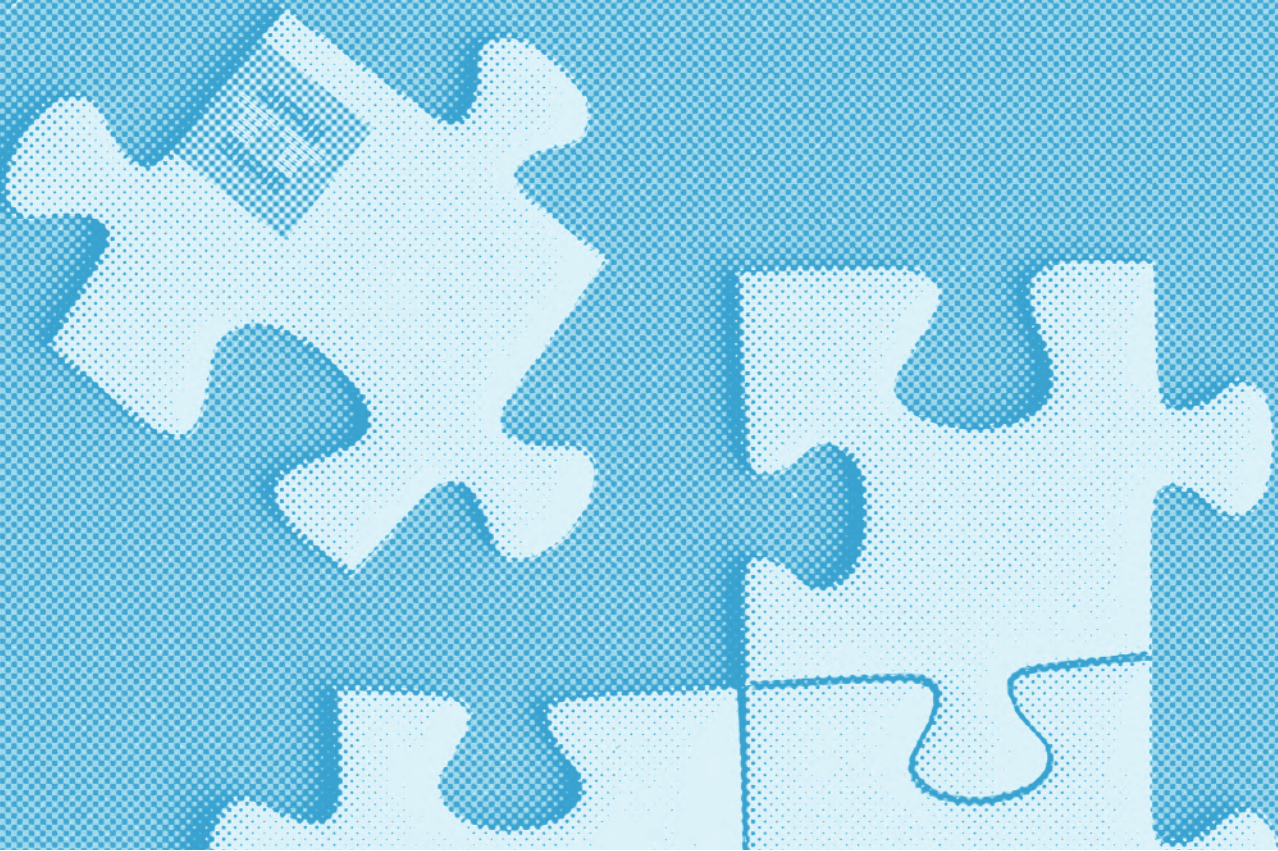
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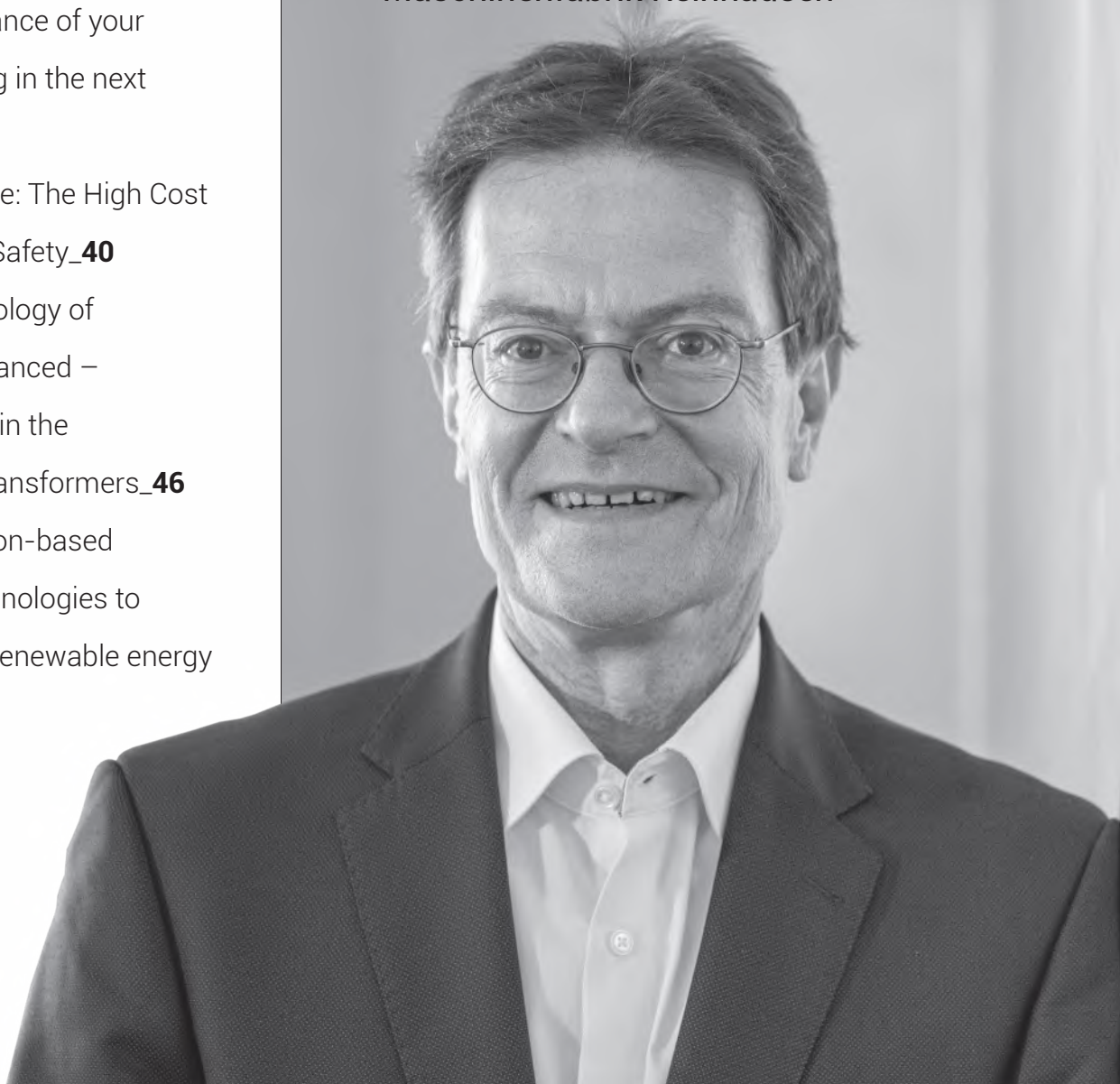
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Managing Director at
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Tragedy & Expense: The High Cost of Low Electrical Safety

The physical environment of any factory is the setting where risk-based behaviors take place, with both machinery and power systems posing the highest threats to worker safety. Structuring out hazards through technology drastically reduces the opportunities for incidents to occur, and as an added bonus, increases the reliability of assets and efficiency of the team.



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By implementing condition-based maintenance technologies into renewable generation, energy providers can offset risk, extend the life of assets, and reduce the cost of repowering a facility.





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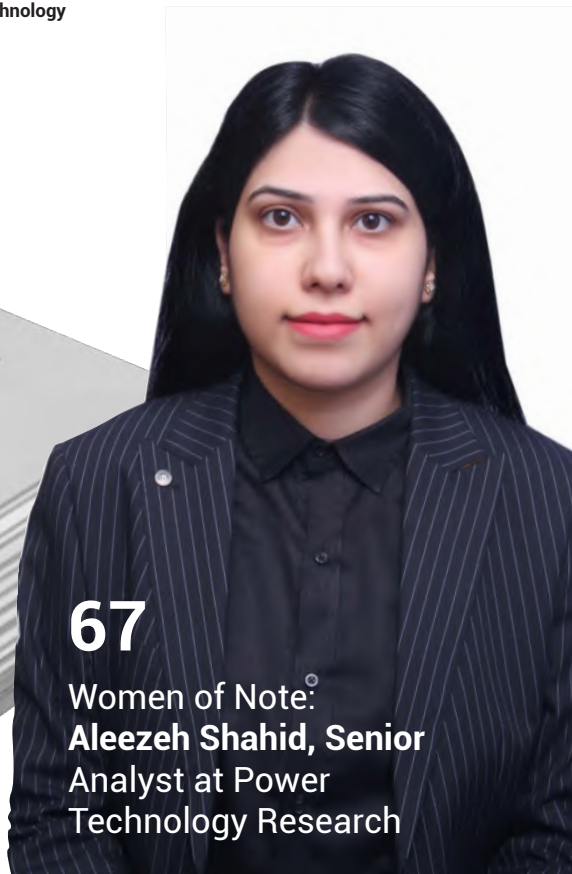
**PTTX Late-model
Eco-friendly Transformer
Core Boosting
Low-carbon Development**

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**Reliability: A Compound
Effect**

What is your definition of reliability? Check your answer against this interesting discussion on critical asset reliability by Traci Hopkins.





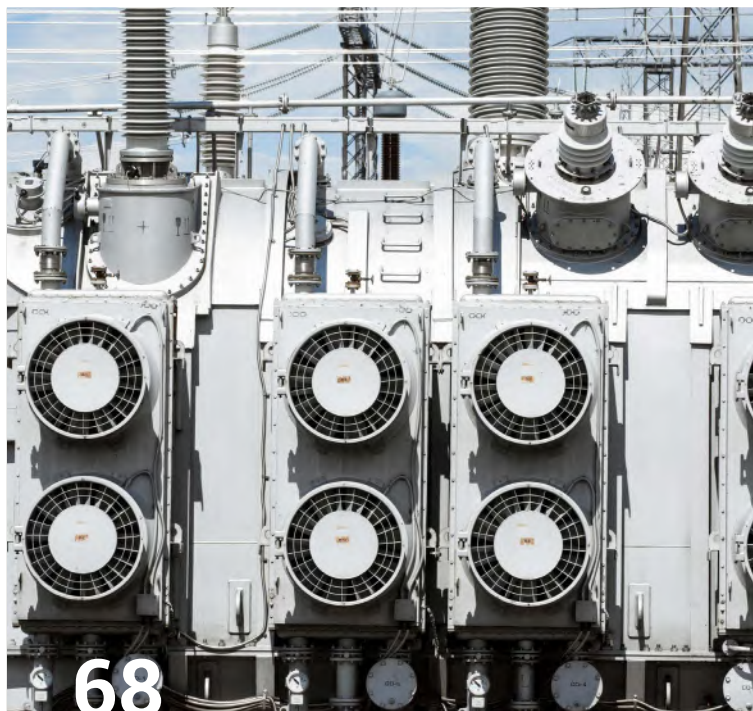
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Transformer Condition Assessment: Moving from Data to Actions

Correlative analyses and data analytics are gaining more importance as they enable users to evaluate the probability of failure by using different parameters, which can be supportive or contradictory to each other in their individual failure mode assessment. Once a potential incipient fault has been identified, a set of actions for rectification can be determined.

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Leading the Charge: Coatings Stand on Front Lines in Protecting Electrical Components

Coatings are the first line of defense to safeguard the critical infrastructure in the face of a variety of conditions. Selecting the proper coating materials to help preserve power generators, transformers, switchgear and more is crucial.



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Detect hotspots, fault damage and temperature trends 24/7, in real time. No need to rely on manual inspections, or periodic oil sampling to determine asset health on demand



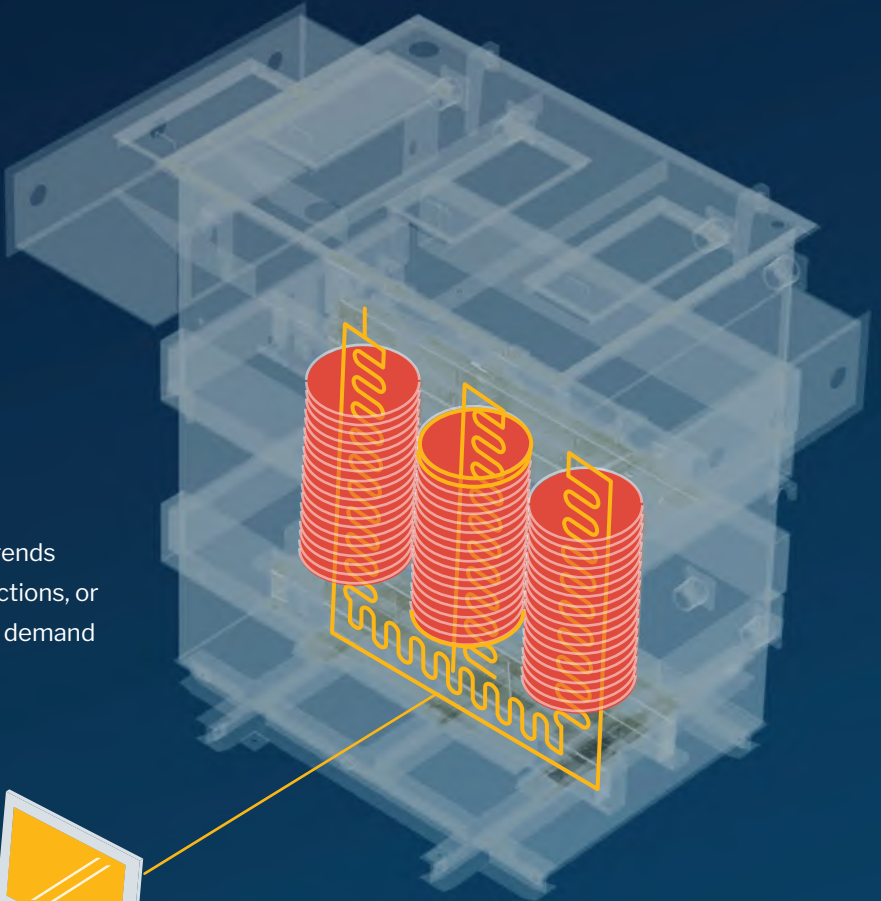
Manage Assets Proactively

Full sensing coverage of windings, core and oil ensures greater operational certainty and prevention of unplanned failures. Operational maintenance is now truly proactive, not reactive.



A True Digital Twin

Real time, comprehensive thermal data from all parts of the asset means you have a true digital twin of the asset. You don't need to rely on assumptions, simulations and extrapolations.



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Dear Readers,



When we were planning the themes for 2022, to provide structure for our weekly Body of Knowledge releases, and for the compiled digital magazine, we believed it was time to expand the themes beyond the *power transformer* and the technical aspects relating to those transformers, without moving too far afield. This February magazine has done that to a lesser extent. Focusing on Transformers: **The Heart of the Power System** begins to formulate the direction for the future in that we address a system not just the heart of that system.

For February we have limited the other aspects of the power system, but in the future, you will see an expansion of our content to include the entire power system, under a new community called Power System Technology (PST). That expansion begins in earnest in April and for the rest of the year. Of course, our Bushings, and our Oils & Fluids issues will remain as stalwarts of October and December issues, as is custom, but even there, we will expand the Body of Knowledge to include PST issues and technology.

As for February, what you will find is an excellent example of the diversity of thought around the heart of the system, the Transformer. Justin Melroy, who I had the fortune of having dinner with at a recent conference, has presented a great article on deploying condition-based maintenance technologies to extend the life of renewable energy assets, which aligns with our sub-topics of green energy, DER, and generation. He covered all three in one article. Great job, Justin!

Tony McGrail of Doble tells us “There’s a 70% Chance Your Transformer Fails”. Yikes! If that headline doesn’t grab you then nothing will. Speaking of uptime, Traci Hopkins presents a great perspective on transformer reliability, also a passion of mine over the past decade. Traci is also a member of Women in Reliability and Asset Management (WIRAM), an organization committed to diversity and inclusion in maintenance and reliability professions. Traci will represent electric power reliability well.

An interview with Wilfred Breuer of MR is a must read as well as articles from members of our Technical Advisory Board: Thomas Linn of Qualitrol and Maria Lamorey of PPG.

With the addition of PST, Transformer Technology will stand front and center in our development of articles and interviews. I particularly love the cover of this month’s digital issue with the transformer clearly identified as the heart of the system.

It is no coincidence that we published this issue on February 14th, Valentine’s Day. A dear friend and leader, Dale Bissonette of Good Place Holdings once said as I entered the world of transformers at SDMyers, “You will find that you will fall in love with transformers before you know it.” He was right. It kind of sneaks up on you; not love at first sight, but a growing understanding of the importance of transformers on pretty much every aspect of modern-day life.



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But the future is clear: Changes in the grid and in the use of power might bring on some technically challenging times for practitioners, as adapting to digitalization, EV adoption, cyber-security, asset management and green energy will be front and center. And while the transformer will still be the heart of these changes, it is certain that adjunct components will also play a critical part of the future, thus the addition of the PST community to our lineup.

For anyone interested in contributing to the theme and sub-topics for April, please let me know at alan.ross@transformer-technology.com. Here are those topics that we will include, but if there is a topic that you think fits with our future focus, please let me know that as well.

Coming in April:

New Design and Advances in Technology

- Dry-type Technology
- Changes in Controller and Instrument Transformer Technology
- Fans & Radiators
- Gauges
- Protection Systems
- Cables and Buss Work

As you can see, the components of electrical systems go well beyond the transformer itself.

Finally, I would be remiss if I didn't also mention that in March, we will publish the third digital magazine for Women in Power Systems (WPS), something we are tremendously proud to have launched in 2021. While there are a growing number of technical associations for women in engineering, and technical professions, WPS takes a different approach. While advancing women in technical roles, we celebrate and profile the complete career woman in our industry, and the reaction to it has been very gratifying. If you would like to find out how to participate in this community, please contact Rachel Linke, Chair of the WPS Steering Committee at rachel.linke@apc.media.

For APC Media, publisher of TT, PST and WPS, 2022 will be the year we will look back upon as the year we broke through the clutter and became the recognized leader within all our communities. The digital revolution is here, and we are proud to have made that part of our DNA. All the staff at APC Media are dedicated professionals who take great satisfaction at being unconditionally excellent, something I am very grateful to share, as a foundation of our values.

Please enjoy this issue and please, as always, connect with us if you would like to be part of any of our communities or to respond to any of our authors. For Rachel Linke and me, our email addresses are above. For any other contact, please use info@transformer-technology.com.

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



Alan M Ross



Wilfried Breuer

**More than Management:
When Excellence and Experience Meet Technology and Innovation**





Managing Director at
Maschinenfabrik Reinhausen

Interview with **Wilfried Breuer**

“

The depth of the knowledge and the personal commitment of MR employees to the product and the company, and their willingness to go the extra mile is exceptional. And it's passionate.

With great pleasure, Transformer Technology is presenting the first part of an inspiring interview with Wilfried Breuer, the Managing Director at Maschinenfabrik Reinhausen (MR). Wilfred joined MR in April of 2019.



Prior to that, he had extensive experience in the transmission and distribution world, including working for Siemens in Thailand and several other countries. Prior to MR he was with TenneT Holdings in the Netherlands, where he served on the executive leadership team.

Alan Ross: Wilfried, welcome and thank you for joining me on this interview.

Wilfried Breuer: It's my great pleasure, Alan.

AR You have an incredible background in technology, especially in the transmission world. When you were asked to join MR, obviously they knew you well and they had an idea of what they were getting. You had an idea of why you would want to take on the role of Managing Director of MR because the company has an incredible pedigree for quality and customer satisfaction, being the dominant player in many parts of the industry they play in. But when you were asked to do that role, what were you trying to accomplish?

WB I would like to give a couple of two points to answer that. One is going way back in my career, when I started to work as a commissioning engineer. In the late 1980s and early 1990s, during some activities I performed at Cahora Bassa, Mozambique, I was introduced to tap changers. I remember the tap changer was something that we were never allowed to touch, even as a senior commissioning engineer, because it was the Holy Grail of the famous MR. In my very early years, I got to interact with it as a special interest of mine. Anything that is special to an engineer, you always keep it as a special interest, so it was always somewhere on the back of my mind.

In the years that followed, and as my career matured, I took a direction into management and leadership. Transformers, as well as tap changers, were always a key part of what I was responsible for in the HVDC business in Siemens. Converter transformers are a key element, if not the most valuable component, of an HVDC system. Likewise, as I moved to TenneT, transformers played one of the crucial roles in connecting offshore wind power to the grid.

In my professional career, I've had the pleasure of working in all three, quite different business governance models: family-owned, mid-size, and global state-owned and regulated, multinational publicly listed companies. I don't know many managers who've had the same opportunity.

When the opportunity to join MR arose, all those memories of tap changers and transformers returned. Joining MR and realizing that now it was my time to "go into the black box" which I had been learning about so early in my career, I must say that was amazing. It's also amazing how much innovative potential is still there once you are inside the company and its expertise.

Another important element for me is that I worked in a variety of business models. When I worked with Siemens, which is a large multinational and public-listed company, I had a great pleasure to work literally world-wide: in Africa, in Southeast Asia, and with many different companies. In China, we did the first ± 800 KV HVDC installation there and accomplished great things with Chinese utilities. We also dealt with a lot of issues around transformers. Then I worked for TenneT, which is a Dutch state-owned regulated utility, and very much between the energy transition, political ambitions and reality of Ohm's law.

And now I work with MR, which is a family-owned, very traditional more than 150-year-old business. I must say, I don't know a manager who had the pleasure of working in all three, quite different governance models: family-owned, mid-size, and global companies that are state owned and regulated, and multinational publicly listed. This was something I only recognized after I signed the contract with MR. Once I did, I really enjoyed it. If you had asked me then what my ambition was, it was to go back to a more technology-centered role, which for me, as an engineer, is more exciting than a grid operator role. With technology driven roles, you are really an inventor, you produce products, type test them, bring them into the market, and you work with customers – that's a different edge. It's entrepreneurial. This is something I learned in my early days and started to miss it throughout my career, so I used the opportunity to go back into the technology area and the opportunity to join MR was highly attractive. I haven't regretted it for a minute.

With technology driven roles, you are really an inventor; you produce products, type test them, bring them into the market, and you work with customers – that's a different edge. It's entrepreneurial.

AR I have never heard anyone relate political reality with Ohm's Law. That's very good. You mentioned the Holy Grail. The Reinhausen company is well known for its culture of excellence and culture of quality, and the load changers are unique in transformers, and they are the Holy Grail. Talk a little bit about that culture. It's been there. It's not that you are bringing a new culture to MR, but tell us a little bit about what you found as you joined the company and the culture, what makes it so excellent?

We have a very high flexibility within our own workforce to adjust to whatever output is needed to fulfil the expectation of the customers. It is not difficult for us to work extra shifts if it is necessary for the market. It is almost a given and that is unique because there is an understanding that everything is paid by the customers who voluntarily decide to use and buy our products or services. They will only do that because we satisfy their basic needs and their expectations, and this is what uniquely unites the company. It makes us feel like a soccer team that has learned to play soccer.

AR Well said, you can put a lot of good players on the soccer field, but they still don't play a good match if they don't play like a team and they haven't practiced. When you joined MR, you obviously felt that they were a well working and managed team. Each and every

one is a global star player. Not only are the Ronaldos there, but they play the game for a long time with a high dedication on customer focus, on technology understanding and on product quality. I love the analogy to soccer/football, the fact that it's not always the best players when it's the best team.

I know that most people in our industry know that product quality is a dominant culture at MR.

WB Yes, clearly the depth of the knowledge and the personal commitment of most employees to the product and the company and the willingness to go the extra mile is exceptional. It was high at TenneT; it was high at Siemens. I wouldn't like to put anyone second, but it's still quite exceptional and passionate at MR. If you ask me what makes it exceptional, it is almost a bit religious. For example, what impressed me is that the demand for tap changers is not continuous and we are not a huge company. We have around 4,000 employees, but still we manage to cope with the fluctuating demand for tap changers very well, almost completely without using external/part-time or hired labor.

You make it your "purpose" to make excellent products. I also know that, especially in North America, you've added a large service arm of the company and your service business is growing. How do you maintain that same purpose in manufacturing as you grow your service business within MR?

WB That's a very good question and point. It starts, as many things do in MR, with the tap changer itself, which is the core of the service business of MR. Very special





things on the tap changer have to be serviced by a tap changer knowledgeable and trained person. In the past, MR only performed the service because it was expected and requested by the customer, not as a profit centre.

The tap changer is the core of the service business of MR and doing service on our own tap changes is something that we are unique for in the industry. But our technicians can do more than just the tap changer because somebody who understands the tap changer also understands the rest of the transformer.

Then we realized that we should be the ones servicing our own products to ensure the quality and long service life. Doing service on our tap changes is something that we are unique for in the industry because no customer, even the highest quality-focused customers, will pay two technicians to work on that changer. Our service techs work typically alone. The customer shows them the transformer, the unit is grounded and switched off from high voltage and then they get the work permit and basically, they are left alone with the job. They are trained in a very unique way as a premium service provider. They must have expertise in the different models of the MR tap

changers, including the vintage models, which they must renew every couple of years.

They must do a practical and theoretical test and prove that they are still capable to do the job. We train them traditionally to take care, by themselves, of the quality because there is no second technician to say, Did you tighten that screw? Did you lose a screw in the tap changer and close your eyes to it because nobody will know about it, because nobody saw it?

The technicians are exceptionally trained to do the job alone. If I made a comparison not using soccer this time, I would say, if you were to fly passenger planes with a single pilot, that's the way we train the people.

Now we also use the same pedigree for doing more on the transformer. We say, once our guy is there who understands the tap changer, he can do more than just the tap changer. Somebody who understands the tap changer also understands the rest of the transformer and he can do a lot of additional things. I know that from working at TenneT, that staffing is more and more constrained at the utilities. They have to do more and more work with less people.

It is a tendency, not only at TenneT, that if they can get one service provider who does more than just a special job, they appreciate that they are not forced due to the lack of own manpower to bundle work. That is exactly where we jump in and that carries a lot of weight for the U.S. market, which is a lot more profit-orientated on the grid operator side. That is our focus coming from the tap changer: doing more running oil rigs and oil treatment because the guys who understand the tap changer understand the transformer as a whole.

AR The first time that I saw Reinhausen going beyond the Reinhausen tap changer was with a friend of mine who worked at a substation area and MR was working on other companies' tap changers. I asked him about it and he said, Well they are cross trained to be able to handle anybody's tap changer. Now the fact that you work on the entire transformer answers the question, why bring in two crews when you can do it with one? You have tremendous growth in North America. You've always been the leader here in the manufacturing end of it and now you've got tremendous growth in the service end of it. My assumption is you've now started in the market. Where do you go from here? What do you think you want the marketplace to know about MR services in North America?

We are number one in servicing tap changers, and not only the tap changers manufactured by MR, and our goal is to be number one in providing higher level transformer service and that is transformer health and condition assessment.

WB Our mission there is very clear. I think we are the number one when it comes to the service of tap changers, not only those manufactured by MR, but of course mostly driven by our large market share of tap changes in the U.S. market, that makes us automatically the number one for specialized service if it's more than just changing the oil and cleaning it a bit. From there, we also want to be the number one when it comes to higher level transformer service. We are not going to aim to be the market leader for washing, radiators or changing the paint. I think that is something where we will also rely on subcontractors. But when it comes to condition assessment, we have developed great algorithms with Fleet Scan 2D and our TESSA Asset Performance Management, which is just being launched, that take care of data analytics which is where we want to be - the first well known practitioner when it comes to transformer health. We want to be the quality-driven transformer experts, as we are known for our tap changers, so that our customers are not under pressure when selling a new transformer, trying to be credible.

That's our pedigree and it is not a hard job internally driving it there, but it is of course



**Embedded
Transformer
Operating
System**

a hard job when it comes to transformer service. You are more exposed to competition. There are more people with similar knowledge, so it is driving us a bit out of our comfort zone in the shadow of the tap changer.

AR That is interesting, because when you go from just the tap changer into the whole transformer, you are still in the maintenance service area. Once you start getting into data management and you get into health management, now you move into the data, the digital area and that's going to be a challenge. But it is also a huge opportunity because of the pedigree of MR. If as a customer you believe the MR pedigree works for manufacturing and now you see it working for service and maintenance, then you can assume that they are going to bring the same quality into the data management and health management of a transformer, and that's where the future is.

As a passionate power reliability guy, I realize that you must have data in order to determine what to do from a service standpoint. That is the exponential growth area within North America.

With ETOS® – our embedded transformer operating system – we are really closing the circle of new tap changers, creating the data and the protocols through the intelligent tap changer drive, which captures all the transformer sensor data. With this we incorporate maintenance, service, condition assessment, and basically a digital twin.

WB Let me switch here to ETOS® – which really closes the circle – our embedded transformer operating system, which we integrate in the tap changer drive. The tap changer drive is an unavoidable part of electrics around the transformer. You have typically three cubicles: the cooling system, the measurements, and the tap changer drive unit. ETOS® combines all the three and enables the operator and the transformer manufacturer to have basically a single digitalization through the modern transformer tap changer drive unit, which you need anyway. In 2021, we sold close to 2,000 of these units. So, it is not just in the pilot phase. We are really closing that circle of new tap changers, creating the data and creating the protocols through the intelligent tap changer drive, which captures all the transformer sensor data. Then what we have is maintenance, service, condition assessment, and basically a digital twin – what amount of the life expectancy of the transformer has been consumed, and what is really the health condition of the asset.

AR We have come to the end of Part 1 of our interview with Wilfried Breuer, which as you just read, is quite amazing. In our April issue, focusing on the Power System Technology, we will share Part 2 of our interview with Wilfried, where he provides his “thought leadership” on the future of the power industry.

I can guarantee that it will be insightful and actionable as we navigate the myriad of changes we are undergoing.



a hard job when it comes to transformer service. You are more exposed to competition. There are more people with similar knowledge, so it is driving us a bit out of our comfort zone in the shadow of the tap changer.

AR That is interesting, because when you go from just the tap changer into the whole transformer, you are still in the maintenance service area. Once you start getting into data management and you get into health management, now you move into the data, the digital area and that's going to be a challenge. But it is also a huge opportunity because of the pedigree of MR. If as a customer you believe the MR pedigree works for manufacturing and now you see it working for service and maintenance, then you can assume that they are going to bring the same quality into the data management and health management of a transformer, and that's where the future is.

As a passionate power reliability guy, I realize that you must have data in order to determine what to do from a service standpoint. That is the exponential growth area within North America.

With ETOS® – our embedded transformer operating system – we are really closing the circle of new tap changers, creating the data and the protocols through the intelligent tap changer drive, which takes care of the entire transformer censoring. With this we incorporate maintenance, service, condition assessment, and basically a digital twin.

WB Let me switch here to ETOS® – which really closes the circle – our embedded transformer operating system, which we integrate in the tap changer drive. The tap changer drive is an unavoidable part of electrics around the transformer. You have typically three cubicles: the cooling system, the measurements, and the tap changer drive unit. ETOS® combines all the three and enables the operator and the transformer manufacturer to have basically a single digitalization through the modern transformer tap changer drive unit, which you need anyway. In 2021, we sold close to 2,000 of these units. So, it is not just in the pilot phase. We are really closing that circle of new tap changers, creating the data and creating the protocols through the intelligent tap changer drive, which takes care of the entire transformer censoring. Then what we have is maintenance, service, condition assessment, and basically a digital twin – what amount of the life expectancy of the transformer has been consumed, and what is really the health condition of the asset.

AR We have come to the end of Part 1 of our interview with Wilfried Breuer, which as you just read, is quite amazing. In our April issue, focusing on the Power System Technology, we will share Part 2 of our interview with Wilfried, where he provides his “thought leadership” on the future of the power industry.

I can guarantee that it will be insightful and actionable as we navigate the myriad of changes we are undergoing.



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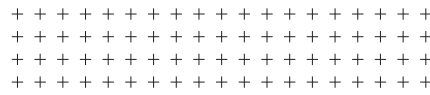


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What is a Transformer Save?

by **John Eastman**





John Eastman, President of ZTZ Services International, has 30 years of experience with substation testing and development of on-line predictive maintenance products. Previously, John was Global Business Manager for circuit breaker monitoring products at INCON and Franklin Grid Solutions when he was named on two US Patents related to new monitoring concepts. John is a graduate of the University of Maine in Electrical Engineering and also holds a Master's in Teaching and Learning for secondary school mathematics. John is a Senior Member of IEEE.

**What is a transformer save?
This is not a trick question.
To most readers of this tome,
the answer is simple. A bona-fide transformer "save" is
when action is taken to protect
a transformer, the action
being motivated by available
information that is predicting
a failure.**

Since the earliest useful microprocessor was available, there have been many types of condition monitors aimed at the utility substation. Most have come and gone and were less reliable than the equipment they were monitoring. Many of these had some merit but in the early days, the communication of the data to people who cared was not possible.

When the SCADA, cell modems, and networks became available, then the problem of data management became an issue. Scanning through data produced by monitors by asset SMEs quickly became very difficult, if not impossible.

**A bona-fide transformer "save" is when action is
taken to protect a transformer, motivated by available
information that is predicting a failure.**

Because the lifespan of the early monitors, and many companies who produced them, was relatively short, the concepts never reached their full potential of usefulness.

recommendation on the condition of an asset was not the value proposition.

There were utility managers who understood the potential benefits of online monitoring yet did not share their operations insight and strategies with maintenance supervisors. This caused the personnel in maintenance to shun the concept of online monitoring. Many field people believed that the monitors would replace them, and their jobs were at risk. Even thirty years ago, online continuous monitoring of substation assets had proven to be an excellent tool in the overall scheme of equipment maintenance, but was not readily accepted.

The early adopters of monitoring quickly learned that monitoring systems do not immediately reduce the maintenance budget, but that the reverse was true. Monitoring quickly showed the "bad actors", requiring them to be moved up on the list for service. Only after the emergent assets were repaired and tested would the O & M expenses gradually decrease. Maintenance managers discovered a "sweet spot" where deployed monitoring and regular manual testing worked together to produce an overall minimum.

With the refinement of the monitoring system over decades, the total operating costs have decreased by monitoring justifying itself and with the forced reduction in manual offline testing. Many renewable energy installations have moved to nearly full reliance of online condition monitoring, thereby making the total expense only the depreciated cost of

**The reality of the reliable automatic system is that
calendar-based maintenance is nearly eliminated and
monitoring intersects at a much lower cost point.**

The end goal for most was to give an actionable signal that an asset was in trouble, with a time margin to intervene and prevent a failure. Continually serving up data for a "panel of experts" to then give a

the monitoring system. The reality of the reliable automatic system is that calendar-based maintenance is nearly eliminated and monitoring intersects at a much lower cost point, as shown in Figure 1.

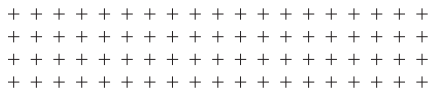
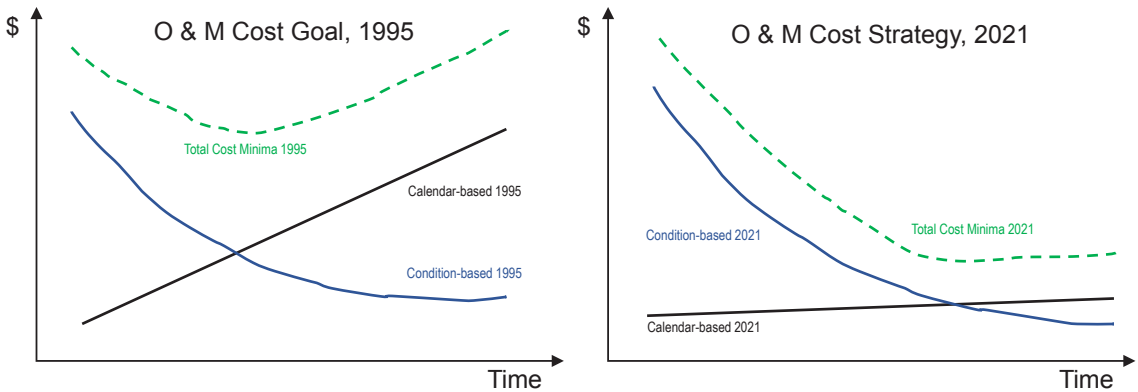


Figure 1. Additive expenses of calendar-based and condition-based maintenance, past & present



Regular offline testing is an expensive program, one that is increasingly difficult to justify as a regular practice. Through long-term development and refinement, a monitoring system for large power transformers earns trust. Industry trust and confidence in the system comes from reliably

transformer at a large solar installation in Imperial County, California in May of 2021. For this system, six signals given by the transformer C1 test taps, three voltage signals given by the low-side PTs (Figure 2), and three voltage signals given by the high-side CCVTs were connected to

replacement transformer would be ten times the value of the transformer itself. With the performance history of over 700 bushing monitors installed within the parent utility, trusting the guidance of the monitor was an easy decision.

Through long-term development and refinement, a monitoring system for large power transformers earns trust. The trust and confidence in the system will come from reliably asserting condition alarms that enable transformer saves.

asserting condition alarms that enable transformer saves. With this trust, reliance is comfortably placed on the automatic system, not the "panel of experts", buttressed by labor-intensive offline testing with expensive equipment.

Below is a tale of two cities. In one city, soon after installation of the bushing monitoring system, a bushing was singled-out as having a power factor of more the twice the nameplate value. With a spare transformer being located 1,800 miles away, a replacement would take at least four weeks. The operator of the solar farm prudently replaced the bushing during a nighttime outage, with no loss of revenue. In another city, the monitoring system clearly asserted evidence, with high confidence, that a bushing was in trouble and the trends indicated an imminent failure was likely. The operator delayed action.

A bushing monitoring system was installed on the main step-up power

the 12-channel monitoring system (Figure 3).

The use of all twelve phasor measurements makes for an extremely robust system with very high signal-to-noise ratio. By using measured system phasor quantities, the bushing attributes can be very accurately known.

Within a few days, it was quite apparent there was a problem with the H1 high side bushing, with power factor nearing three times nameplate (Figure 4). Phases H2 and H3 showed stable power factor, essentially at nameplate values (Figure 5). Because of the heavy load cycle, this transformer was classified as being applied to "rough service". The high power factor reading put it beyond the limit for any "watch list" but was classified as "unstable", in danger of failure.

With "green" renewable energy selling for a premium locally, the revenue loss while waiting for the

In August, the bushing was tested with offline techniques. The test confirmed the high power factor and the bushing was replaced without incident three weeks later (Figure 6). Plots of bushing capacitance and high side imbalance current were stable since the monitor installation, showing the likelihood that the H1 bushing had high power factor when the transformer was commissioned, but was not detected with offline test techniques.

At a power plant in Eastern Europe, bushing monitoring was added to the high-side bushings of a 17-year-old 270 MVA GSU in December of 2015. Six phasor inputs were used; three high side C1 test tap connections and three CCVT inputs. Two months after installation, the data showed the C1 from H2 (blue trace) above the others by 0.5% (Figure 7). The power factor data (Figure 8), shows power factor of H2 peaking at 1.5% (red trace).

Further increasing confidence, the polar plot of the high side leakage imbalance current (Figure 9) shows steady increase, showing strong polarization.

Four months from installation, data shows worsening conditions. C1 at 111% (Figure 10), PF at 8% (Figure 11), and leakage current imbalance of 8.0% (Figure 12).

Figure 2. Bushing sensors installed on low-side bushings



Figure 3. Two six-channel bushing monitors are installed beside the transformer



Figure 4. High-side bushing nameplate showing factory test data

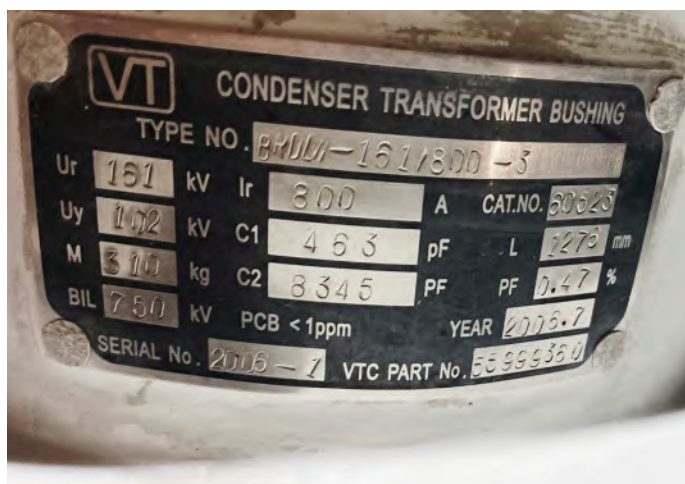


Figure 5. High-side percent power factor for three months since monitor installation

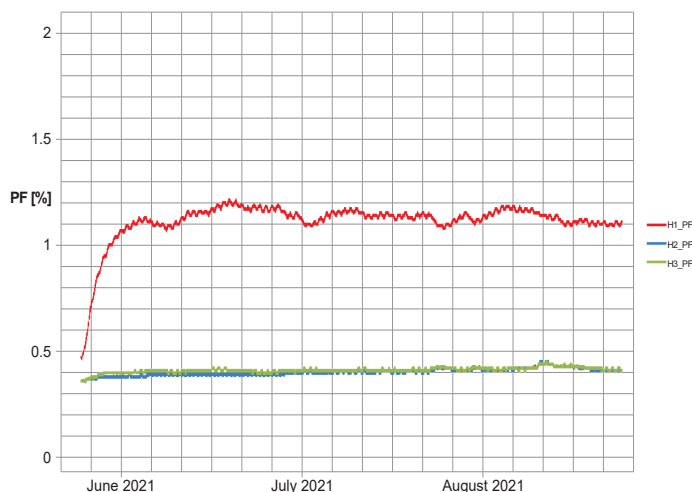
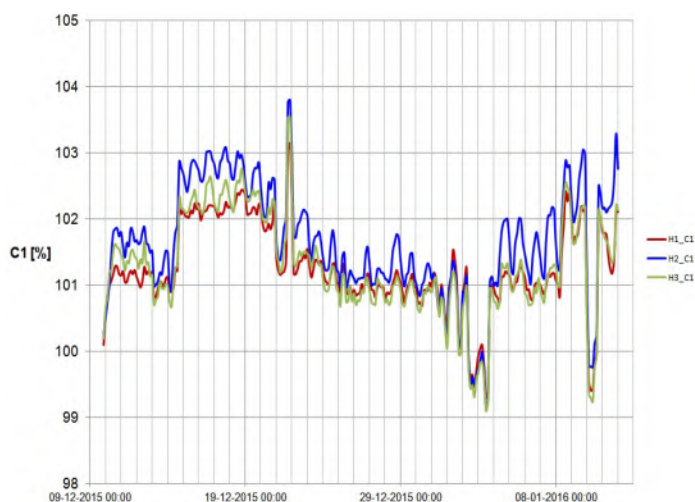


Figure 6. Night time H1 bushing replacement



Figure 7. C1 percentage above nominal of high-side bushings, two month plot



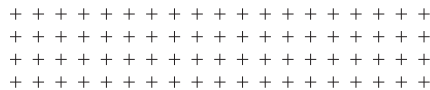


Figure 8. Percent power factor data of high side bushings, two month plot

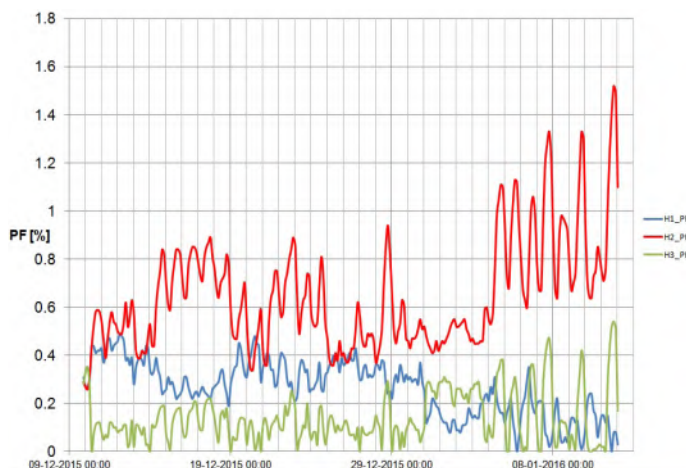


Figure 11. Percent power factor data of high side bushings, four month plot

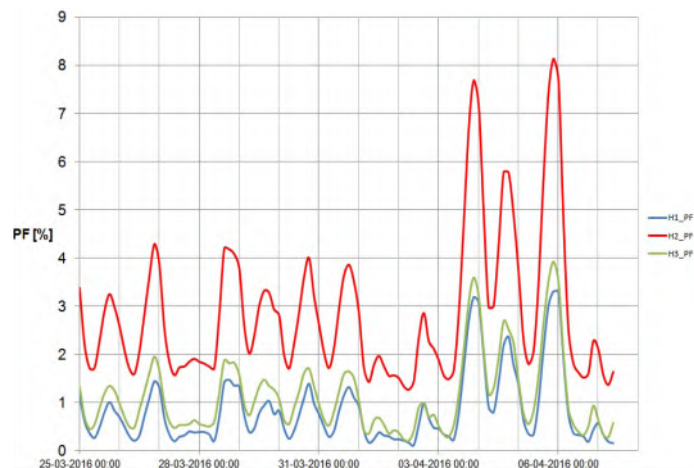


Figure 9. Polar plot of leakage current imbalance, two month plot

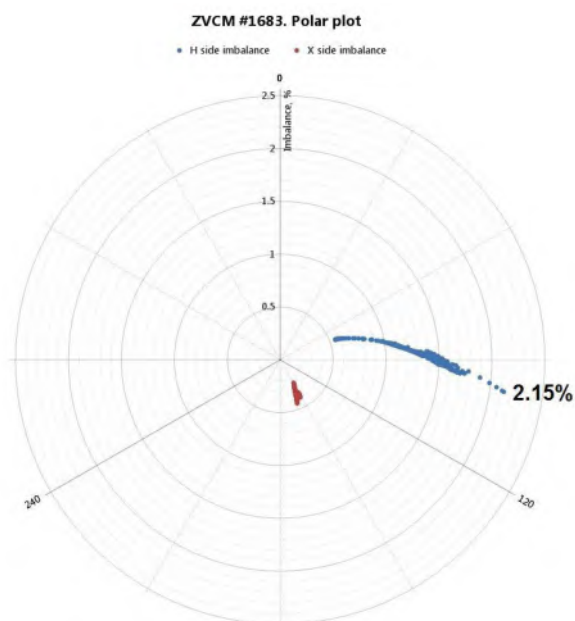


Figure 12. Polar plot of leakage current imbalance, four month plot

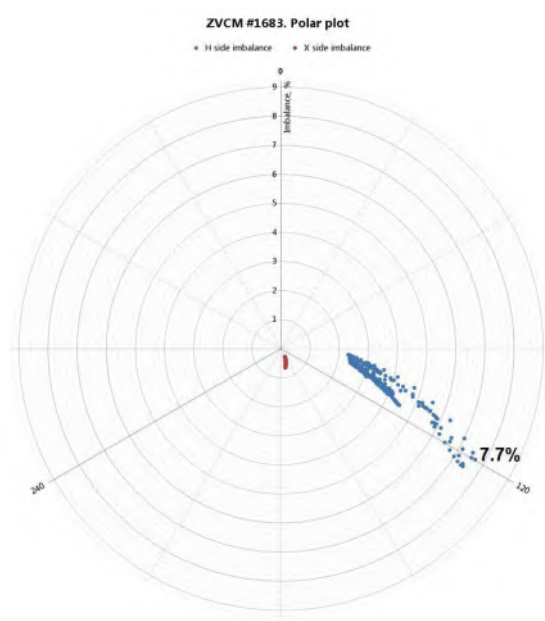


Figure 10. C1 percentage above nominal of high side bushings, four month plot

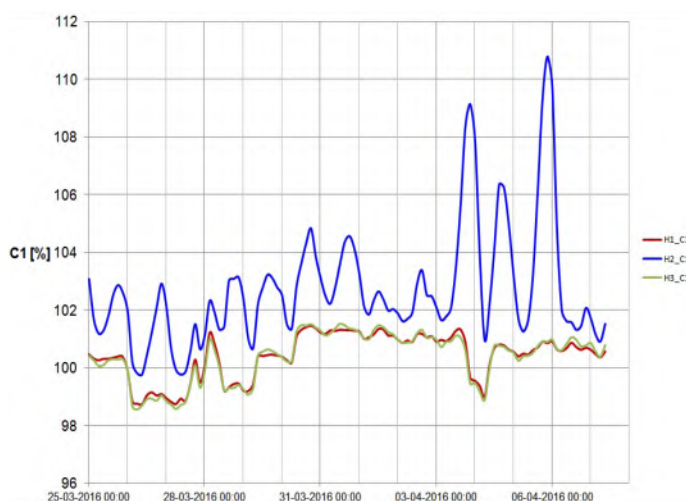


Figure 13. Final death rattle of the H2 bushing, showing last measurement of C1

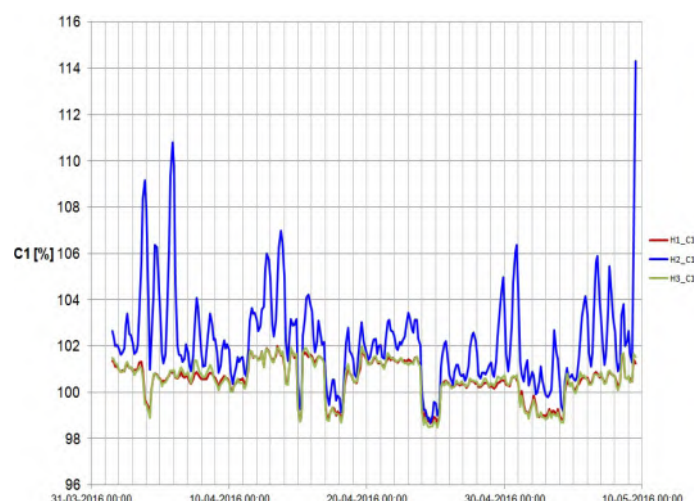


Figure 14. Station security camera view of exploding H2 bushing



Figure 15. H2 bushing debris found in yard showing failed capacitive layers



In May of 2016, it was advised that the transformer be taken immediately out of service for testing. Because an outage was planned within five weeks, the owner decided to wait until then. Two days before the outage, the bushing exploded (Figure 14). The final C1 measurement of H2 was 114% (Figure 13) and 8% power factor. In the last moment before failure, the big increase of C1 can be observed, caused by break of insulation layers between metal foils in bushing condenser core (Figure 15).

A monitoring system giving asset condition guidance with very high confidence is something that is continually improved over decades in thousands of field installations. Sensors and other hardware are required to be made with high precision and material quality, with no system calibration requirement for the life of the system.

Of course, most commercial monitoring systems can be made to work well at time of commissioning, but only the highly developed system, well installed, will last for decades.

The hardware requirements for utility use are different than for consumer electronics. High refinement includes immunity to cyberattack, continuing compatibility as the PC operating system landscape changes, and the continued draw on IT resources for software patches and "updates" made unnecessary.

Improvements applied to algorithms, methods, signal fidelity, and noise rejection give the highest sensitivity to changes and fastest determination of problems. Noise filtering after the measurements are not a panacea. Signal filters with long time constants slow the decision response and hide

valuable nuances. Management of external electrical noise must be in the heart of the system, as part of the wholistic design, not as an afterthought.

The end product is reliable supervision of expensive transformer assets which are becoming more and more valuable as replacements have ever longer lead times.

The failure above was only allowed to happen by human interaction. Waiting for the response from a "panel of experts" is no longer required as an arbiter and can be an expensive liability, especially in the case of a rapidly developing problem.

The actual failure event was captured on video, and you can see it [here](#).

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INTEGRATED SOLUTIONS FROM POWER DIAGNOSTIX BY MEGGER



Power Diagnostix is a provider of instruments designed to detect partial discharge (PD) in electrical insulation before the system is compromised.

FOR FACTORY AND LABORATORY PARTIAL DISCHARGE TESTING

Not only does Power Diagnostix have a large portfolio for such instruments, but it also assists in providing corresponding interpretation and diagnostics of insulation conditions and offers expert technical services.

Power Diagnostix

In 1986, Power Diagnostix was founded in Aachen, Germany to provide solutions for identifying potential defects in insulation systems before a failure occurs. It sought to achieve this primarily by offering partial discharge measuring instruments, as well as with tan delta and high voltage testing equipment.

In June 2019, Power Diagnostix joined the Megger group. Although Megger has had one of the largest product portfolios in the electrical testing industry for over a century, it identified Power Diagnostix as the perfect addition to the Megger team and brought it on board.

PD is a precursor to serious insulation degradation which can lead to failures of electrical components. PD can be caused by imperfections in the insulation system as well as by external factors. Once partial discharge has occurred, it steadily increases over time as the insulation continues to degrade, ultimately leading to irreversible damage and failure. Therefore, it is necessary to detect PD as soon as possible, which can be done using various measurement techniques, such as measuring charge in various frequency ranges or by acoustic detection.

One of the most cherished philosophies of Power Diagnostix by Megger is to be customer-oriented and tackle the issue of PD measurement by working closely with its customers to learn about their challenges and needs.



Power Diagnostix HV test lab in Aachen Germany, used for research, development, training, and test services

One of the most cherished philosophies of Power Diagnostix by Megger is to be customer-oriented and as such, it tackles the issue of PD measurement by working closely with its customers to learn about their challenges and needs. In this way, Power Diagnostix serves, as a partner, to implement solutions, closely cooperating with its customers through consulting, commissioning, and after-sales support. This enables engineers to stay up-to-date on current trends and industry requests to drive the development and improvement of products and services.

Power Diagnostix serves, as a partner, to implement solutions, closely cooperating with its customers through consulting, commissioning, and after-sales support.

From portable testing instruments for field use, to permanently installed monitoring systems for a variety of electrical applications, all solutions are configured specifically based on the customer's needs. This is especially the case when it comes to solutions for high voltage testing laboratories, as each project is custom designed **with** the customer. These solutions are often supplied for use in production line testing, factory acceptance testing (FAT), or quality control after repairs. Given this range of solutions for power transformers and other electrical applications, it is not surprising that Power Diagnostix caters to a wide variety of customer industries, including Original Equipment Manufacturers (OEMs), testing and calibration laboratories, repair shops, and research and education institutions.

Modular concept for laboratory and factory testing applications

Increased testing demands from customers drive the need for time saving, automation, and improved performance and functionality. Modular solutions from Power Diagnostix allow testing laboratories to extend their testing capacity, enhance their technical capabilities, and modernise their equipment to meet customer's needs and to maintain efficiency.

Generally, laboratory applications consist of several main components: partial discharge measuring instrument and associated accessories, high voltage power supply, high voltage control unit, software for control, measurement and reporting, and, most importantly, safety provisions. For each project, components are configured specifically based on voltage level, objects being tested, test procedure, number of measurement channels, noise conditions, desired level of automation, and more.

As an example, a typical testing configuration for PD quality assurance and quality control in the manufacturing of products such as bushings or voltage transformers includes:

- Single PD measurement channel
- Coupling capacitor, quadrupole, and pre-amplifier
- Noise gating
- Optional 4 or 12 channel multiplexer for testing multiple samples
- PD spectrum analysis option

For production line or factory acceptance testing of samples such as bushings or voltage transformers, the ICMcompact is typically the preferred instrument for partial discharge testing. This instrument allows testing according to IEC 60270, easy setup, and can adapt to specific test applications and interference situations through various accessories. Additionally, ICMcompact can be integrated into an automated test bench with other test equipment and automation software as described further in this article.



The ICMcompact shown in two of three available housing versions

A typical configuration for power transformer factory acceptance testing of partial discharge includes:

- 6 to 10 parallel PD measurement channels
- Coupling capacitors, quadrupoles, and pre-amplifiers
- Noise gating
- Phase Resolved Partial Discharge (PRPD) analysis software
- Acceptance test reporting software

Most commonly, when testing three-phase power transformers, an instrument with multiple measurement channels is used. This allows for testing all three phases of the primary and secondary windings simultaneously (6 or 8 channels with neutral bushings). Measuring PD in parallel on all bushings saves the user time with lead connections, accessory configuration and calibration, and total measurement duration. Additional channels can be used for acoustic or Ultra High Frequency (UHF) PD sensors or noise gating (filtering) via a high frequency current transformer or noise antenna, which ensures accurate and sensitive measurements. This saves time and effort and allows better comparison of PD results between phases.

Power Diagnostix is more than a manufacturer of partial discharge testing instruments. We are also involved with the development, design, configuration, and integration of the full system, and provide customer training and commissioning.

For three-phase power transformer factory acceptance testing, a multi-channel ICMsystem is preferably used due to enhanced tools for in-depth analysis. With its true parallel PD acquisition of up to ten channels, the overall testing period is substantially shortened by features such as the automatic calibration cross-coupling matrix. ICMsystem offers both - narrow and wide band PD pattern acquisition, according to IEC 60270. The instrument comes with an embedded spectrum analyser for advanced PD analysis in frequency domain. Moreover, it is an excellent tool to use in case of noisy test environments. Additionally, acoustic sensors can be interfaced with ICMsystem for PD fault localisation.



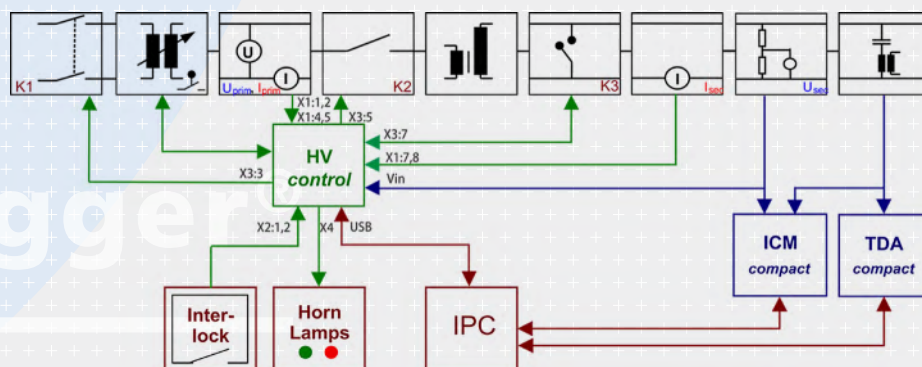
ICMsystem desktop version

Automation for laboratory and factory acceptance testing

Different levels of automation can be provided depending on the test. In the case of full production testing, a high level of automation and a simple go/no-go decision is required. This enables testing technicians to be trained for standardised working procedures during or after production so that in-depth PD knowledge or detailed result analysis is not necessary for daily work.



Alternatively, manual control offers a higher level of flexibility when testing samples or sample variants during development. Automated laboratory solutions typically start with a configuration of ICMcompact (PD measuring device), HVcontrol (High voltage test control unit), a testing transformer, and noise filtering hardware. These components are fully integrated with the HVpilot software so that users can benefit from one automated interface for voltage control including automated ramp sequences, PD measurements, and test reporting. Additionally, TDAcompact is optionally integrated for tan delta testing.



Example functional diagram of an integrated test lab setup from Power Diagnostix by Megger

The system is always integrated with a safety interlock with HVcontrol, horns and/or lamps, as well as manual and automatic earthing discharge rods. These provisions are mandatory in order to prevent exposure of testing personnel to hazardous voltages.

Most customers for this type of application prefer the 19" rack-mountable version for the measuring and control instruments that are integrated permanently into the test bench. This provides convenience for laboratory testing, especially where test routines and samples are repetitive. Cables, instruments, sensors, and other accessories can be fixed installed to prevent loss or damage and to save time with connections and configurations. Optionally, a dedicated built-in computer results in less time spent configuring software or troubleshooting IT issues. An additional advantage for test bench integration is that test sequences and results are stored in one central location.

Users who require portability and field use can be provided with test instruments in rugged portable or desktop enclosures as a suitable alternative.



ICMcompact embedded in a control desk with additional control hardware

Additional integration options

High voltage test chambers (HVTC) can be added to the configuration to provide isolation from noisy conditions and are suitable for PD testing according to international standards. These solutions also allow owners to save space for their testing setup in comparison to an open area where distance, fencing, and isolation are required for safety purposes during high voltage testing.

Tan delta (dissipation factor) measurement is an additional method used to assess the condition of an insulation system for transformers and other electrical equipment. The TDAcompact from Power Diagnostix can be also integrated into such laboratory setups for this purpose. This results in additional convenience and saves time as users can conduct pre-programmed test sequences for voltage step, PD, and tan delta all simultaneously with integrated software from one interface.

Due to the modular approach, customers have the ability to choose many parameters to fulfill their current testing needs. This provides flexibility with voltage levels, type of test instruments, level of automation, and optional hardware and software features. Also, upgrading and retrofitting in the future is possible as needs change.

Supplementing laboratory capabilities with mobile support

Power Diagnostix isn't just a manufacturer of partial discharge testing instruments. Engineers are also involved with the development, design, configuration, and integration of the full system. Additionally, Power Diagnostix provides customer training and commissioning. After the system is installed and in service, the job does not stop there.



Power Diagnostix mobile test system

From portable testing instruments for field use, to permanently installed monitoring systems for a variety of electrical applications, all solutions are configured specifically based on the customer's needs.

Service Engineers are happy to offer consultation, result analysis, and measurement support. If a testing laboratory faces a job that exceeds their hardware or manpower capabilities, experts from the Service Department are available for on-site testing using mobile test laboratories.

Whether it's to support factory acceptance testing for unusual or challenging cases, site acceptance testing at the equipment owner's site, or PD localisation while the equipment is in operation, Power Diagnostix Service is the trusted partner for PD for your power transformers and other applications. We travel Europe-wide to your site with our mobile test systems. Besides PD, we are also happy to offer additional diagnostic tests for your applications, such as three-phase induced tests (up to 90 kV), applied voltage (up to 500 kV), tan delta/loss factor, ratio tests, winding tests, insulation tests, and more.

That's a prediction (or forecast) which can't be wrong!

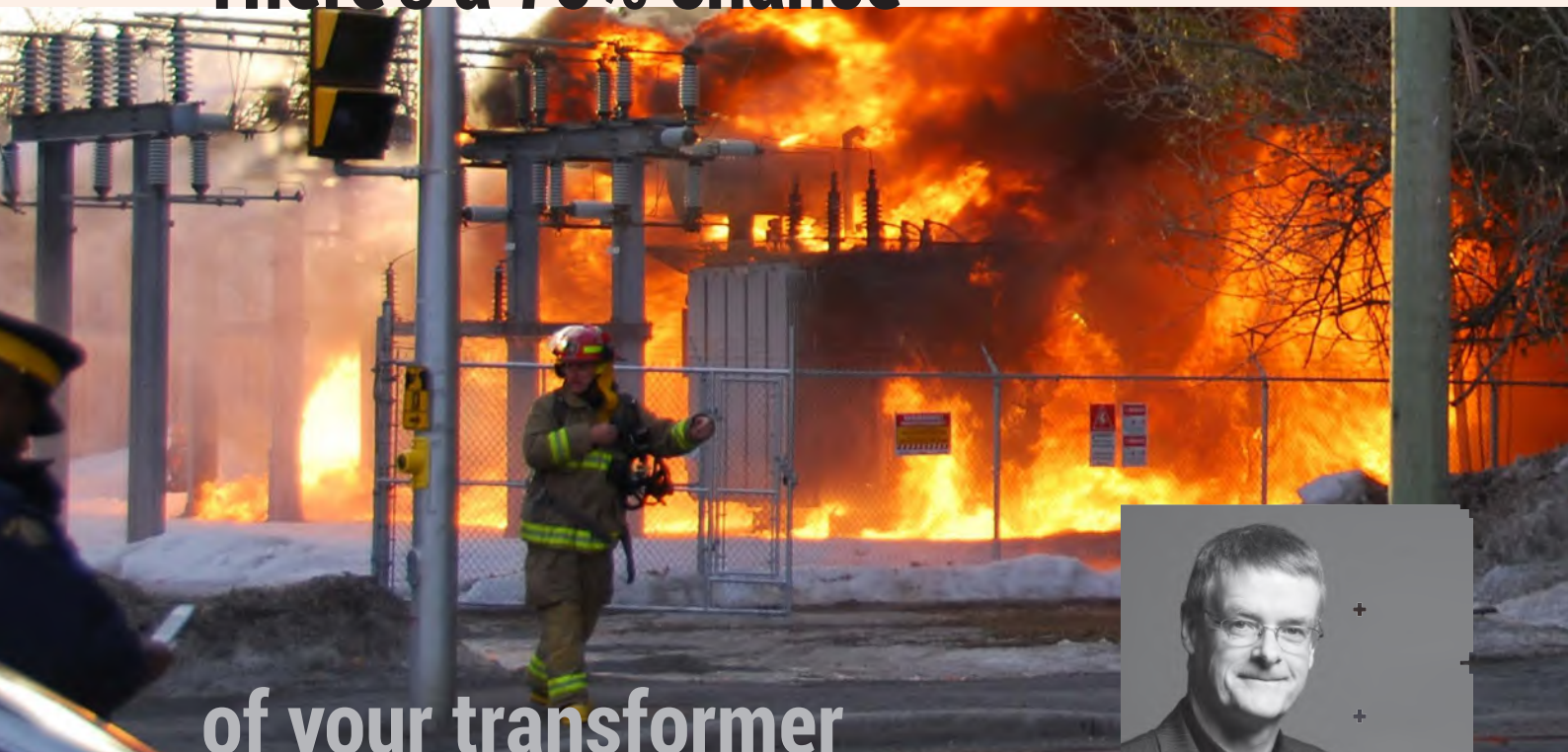
If we say there's a 70% chance of failure as an outcome and the transformer fails, then the outcome falls in the 70%, and if it doesn't fail the outcome falls in the 30%. We're covered come what may.

The *only* ways to get this type of prediction wrong are to say something will *definitely* 100% happen, and it doesn't, or say that something *definitely* 100% will NOT happen, but it does [1]. But avoid the two *definite* statements, and any other version of the prediction cannot be wrong.

How can we check the accuracy of the prediction if the event only happens once? It's not like repeated rolls of a dice, which we can predict with some statistical accuracy. If I roll a standard, fair, 6-sided dice, the chances of rolling a 4 are 1 in 6 (16.67%). If I predict I'll get a 4, say, 50% of the time, that's likely a

poor prediction – which we can check through repeated rolls. We can roll the dice many times, but we can't rerun the year many times. What we can do is look at similar situations, in this case other transformers, and see how well our predictions of failure probability stand up in each case: compare

There's a 70% chance



of your transformer failing in the next year



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

QUIZ?

- What is the expected value of a dice roll - the mean of many throws?
- If there's a 10% chance of an event happening in any 1 year, how likely is the event occurring at least once in a ten-year period?
- How many people need to gather such that two of them are *likely* to have the same birthday (day/month not year)?
- How many need to gather such that 1 of them is *likely* to have the same birthday as you?

QUESTIONS

the estimated probability of failure with the actual outcome at the end of the year for each transformer. If I estimate a 5% chance of failure for a particular transformer and it does fail, I'm out by 95%. But how do we rate the overall prediction accuracy across the population? We can look to weather forecasters!

Some years ago, the weather forecasting folks put together a means to measure the accuracy of predictions or forecasts, called a Brier Score [2]. The score tells you how well your predicted forecast for rain, or failure, or whatever, across a number of locations and times relates to what actually

happened. It does this through a mean square error, with the lower the Brier score the better the set of forecast [2]. The same approach would apply to transformer failure probabilities and can be used to check the accuracy of the forecast; and is something we're working on at present.

If you have an interest in this topic, please contact the author!

When working with probabilities I recommend checking results with an expert as things can get complicated and can sometimes be counter-intuitive [3]. Some quiz questions may help illustrate.



QUIZ!

- a) 3.5, but that's not going to be something you'd actually roll with a fair 6-sided dice
- b) Just over 65% - probabilities don't just add up year-on-year, it's more complicated!
- c) 23 people - which seems a remarkably small crowd for the chance of a birthday coincidence to be greater than 50%!
- d) 253 people - for the chance to be greater than 50%, not the 183 often suggested...

ANSWERS

References

- [1] Barbara Mellers in "Rational Soothsaying", <https://www.bbc.co.uk/programmes/m00132v9>
- [2] https://en.wikipedia.org/wiki/Brier_score
- [3] How Juries are Fooled by Statistics, Peter Donnelly, TED Talk, 2007

Acknowledgement

Thanks to Rhonda, Richard and Vanessa for their suggestions.

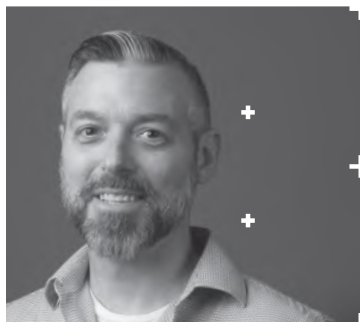
Tragedy & Expense: The High Cost of Low Electrical Safety

by **Michael Riccio**

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The electrical industry is one of the most dangerous work environments for employees. The risk of injuries and fatalities is high due to the nature of the work and the amount of interaction workers have with dangerous equipment and conditions. Electrical incidents happen daily, putting lives and operational continuity at risk. However, there are ways companies can reduce the occurrence of these incidents and protect everyone concerned from the physical, financial, and statutory consequences.



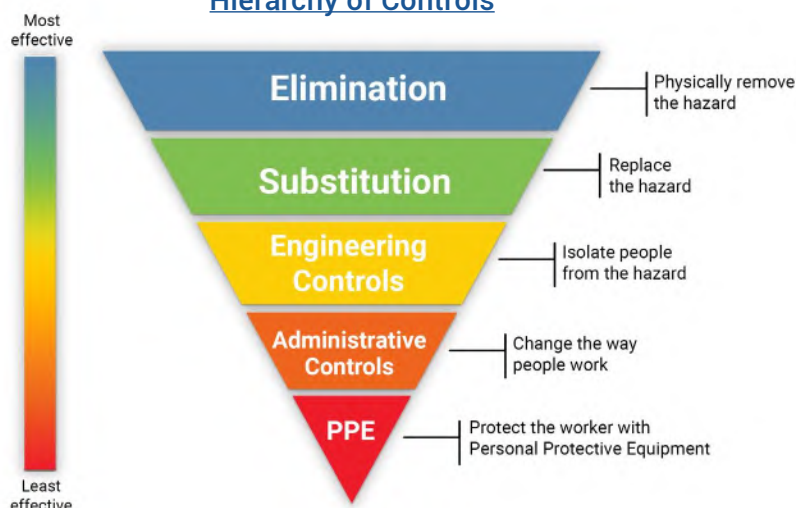
Michael Riccio is the Global Marketing Manager for IRISS Group, providing market/industry analysis, support, and educational insights to customers, distributors, and sales worldwide. He is a Certified Reliability Leader, a CAT-1 IRT thermographer, and is a contributing writer to other industry publications such as the National Safety Council's *Health & Safety Magazine*.

Every year, OSHA puts out their list of top 10 violations, and every year the electrical industry is one of the big "winners". To make things worse, these are not new violations making the list because highlighting the previous year's violations led to vast, industry-wide corrections. It's the same offenses year after year. Patrick Kapust of the National Safety Council stated at the 2019 NSC Expo "these are common violations we're finding – they've been in place for a lot of years. The answers are out there, and employers shouldn't feel like these are complex issues."

Mr. Kapust is correct, the issues aren't complex. But unfortunately, multiple daily news stories reflect excessive failures around the world to keep workers, customers, and the general public safe. A great example of these failures is that during 2021's "National Electrical Safety Month" there were multiple reported injury events every day of the month. These injuries reflect the neglected roles by both management and workers in the safety process.

Under NFPA 70E, both employers and employees have very defined responsibilities as members of a team tasked with keeping safe practices and procedures in mind while accomplishing their tasks. At the heart of NFPA 70E and OSHA initiatives are concepts such as the Hierarchy of Control. This concept attempts to mitigate risk wherever possible, preferring the elimination of hazards as the ultimate goal.

Hierarchy of Controls



Every year, OSHA puts out their list of top 10 violations, and every year the electrical industry is one of the big "winners", with the same offenses year after year.

Whether or not the responsibilities of workers and management alike are strictly adhered to also has major financial implications, not just from an operational and safety standpoint, but from insurance rates and litigation fees/judgements as well. Statistics are heavily studied in the electrical industry, as safety should be the priority for everyone involved. Gambling with this isn't just dangerous, it's expensive.

Recently, charges were brought against a utility company over the death of a power station worker in 2018. During a scheduled routine maintenance, where the employee was found to be doing his job exactly as trained, he was severely burned by an arc flash and later passed away at the hospital, and investigations brought about three separate charges against the utility.

The loss of life is beyond tragic, though not at all a rare case. Unfortunately for companies who have these fatalities and injuries as a result of electrical accidents, this is just the beginning of their problems. OSHA fines can reach deep into the pockets of a company, of hundreds of thousands of dollars in possible costs. The wrongful death cases or lengthy Worker's Comp litigation, as well as associated personnel-driven costs, will most likely lead to a major financial impact on the company. According to Falcon Power Consultants, 5-10 arc flash incidents occur every day in the United States, resulting in 1-2 deaths per day. The average litigation costs for a general industry accident range from \$10M to \$15M.



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Work Comp claims and insurance expenses bring another level of cost. One of the main factors that determines a company's workers' compensation premium is referred to as loss history. This is an analysis of insurance losses associated with workers' compensation claims and plays a key role in causing an increase in premiums. Underwriters calculate premiums using these numbers to determine a company's *experience modification factor* (or *e-mod*). Depending on the results of their assessment, which considers

three years of claim history (not including the most recent policy year), your premium can either go up or down.

With over 3,700 non-fatal electrical accident injuries occurring each year, the average cost of hospitalization for electrical accidents ranges from \$200,000 to over \$1 million (according to the Workplace Safety Awareness Council). Once out of the hospital, as part of the fallout from these claims, the time away from work averages 8-12 months. These incidents will not affect the premium calculations in a positive way, nor will it look favorable for the manager to executive management or help the company's fiscal health.

Operationally, things don't get better in these situations. Unplanned downtime from an electrical incident is expensive on the operational level, such as in a data center where estimates show each minute down averages \$8000 in loss. A study by Aberdeen Research found 82% of companies that experienced unplanned downtime lost an average of \$2 million in revenue. Physical damage resulting from incidents such

as an arc flash add to this with the cost of repair or replacement of the asset(s) involved. Additional costs may also come into play with time required for staff to go through new or refresher safety training and replacing the injured parties with other workers will involve more expense and time.

A study by Aberdeen Research found 82% of companies that experienced unplanned downtime lost an average of \$2 million in revenue.

Not only does it damage a company's operational and fiscal health, but also its reputation and earnings potential with current or prospective customers. What it comes down to is simple: not only does risk lead to great tragedy, but also great expense.

The issue, then, is to figure out how to remove or minimize human error and human risk wherever possible. While that is a difficult task for most industries, the electrical industry faces a much steeper challenge. Risk-based activity is the driver for incident, injury, and fatality. In the electrical world, these behaviors are 30 times more likely to lead to death.

Risk-based activity is the driver for incident, injury, and fatality. By minimizing the interaction between asset and personnel through technology and structure, the odds of incidents occurring drops sharply.

The simple answer is to eliminate the risks completely. The best option is to remove the human factor from as many threats as possible. This is not to say that humans should be replaced with technology, but instead we should eliminate the numerous risk-based behaviors that occur in the workplace through technology. The entire work environment must be approached as “function follows form”. This means the physical environment drives the operational environment, with technology guarding and assisting the worker.

Traditional electrical maintenance practices tend to rely on calendar-based models that include intrusive and dangerous activities that put both workers and assets at risk. From the equipment and operations side, every time an unnecessary time-based task is completed the infant mortality clock is reset and the risk of failure increases. These tasks also increase the odds of a worker experiencing risk while performing their duties. By minimizing the interaction between asset and personnel through technology and structure, the odds of incidents occurring drops sharply. As do the odds of a very expensive outcome.

Switching to a condition-based program leads to asset interaction only occurring when it is absolutely necessary. This involves remote monitoring of asset health, safe and guarded inspections of equipment at full load (overcoming the OSHA Top Ten violation of machine guarding), and the trending/analysis of collected data to create a clearer picture of an asset's operational health.

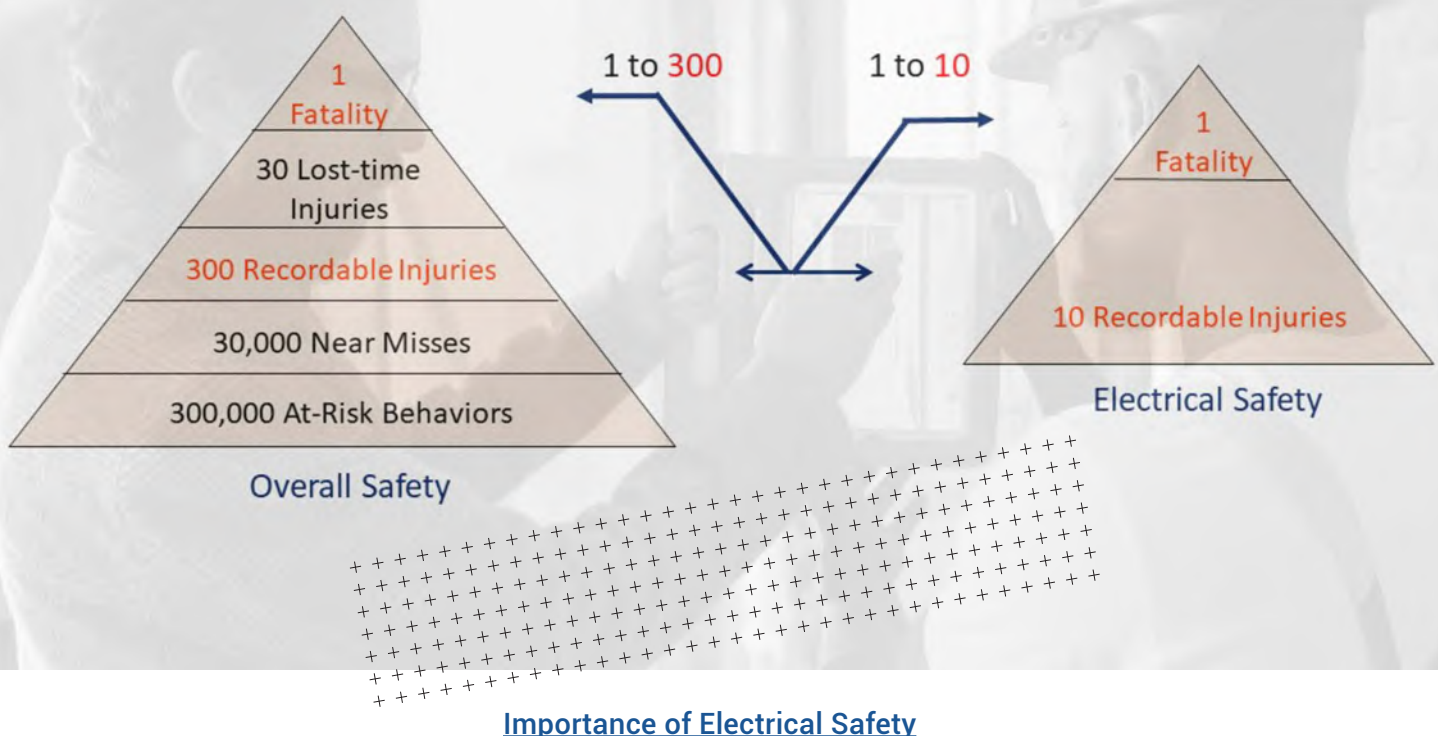
With the use of an online monitoring system on electrical equipment, asset conditions can be continually collected, trended, and assessed. Monitors feed data through a gateway to software and apps, allowing the information to be continuously accessed from workstations and mobile devices. When the asset condition data exceeds the custom parameters, alarms can notify electrical technicians of a possible issue that may require inspection. Keeping human interaction with equipment to only instances where inspections of potential faults are deemed necessary minimizes workers' exposure to risk.

Once the wireless monitoring system notifies technicians of a possible

issue, the use of inspection windows on the asset allows a safe, efficient method of inspecting and assessing any possible issue in an energized condition. Once solely designed for thermographic inspections using infrared cameras, advancements in manufacturing have led to the inclusion of ports that allow for ultrasound and partial discharge technologies to be incorporated into the inspection. Visual, infrared and ultrasound inspections can be done simultaneously by a single employee.

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

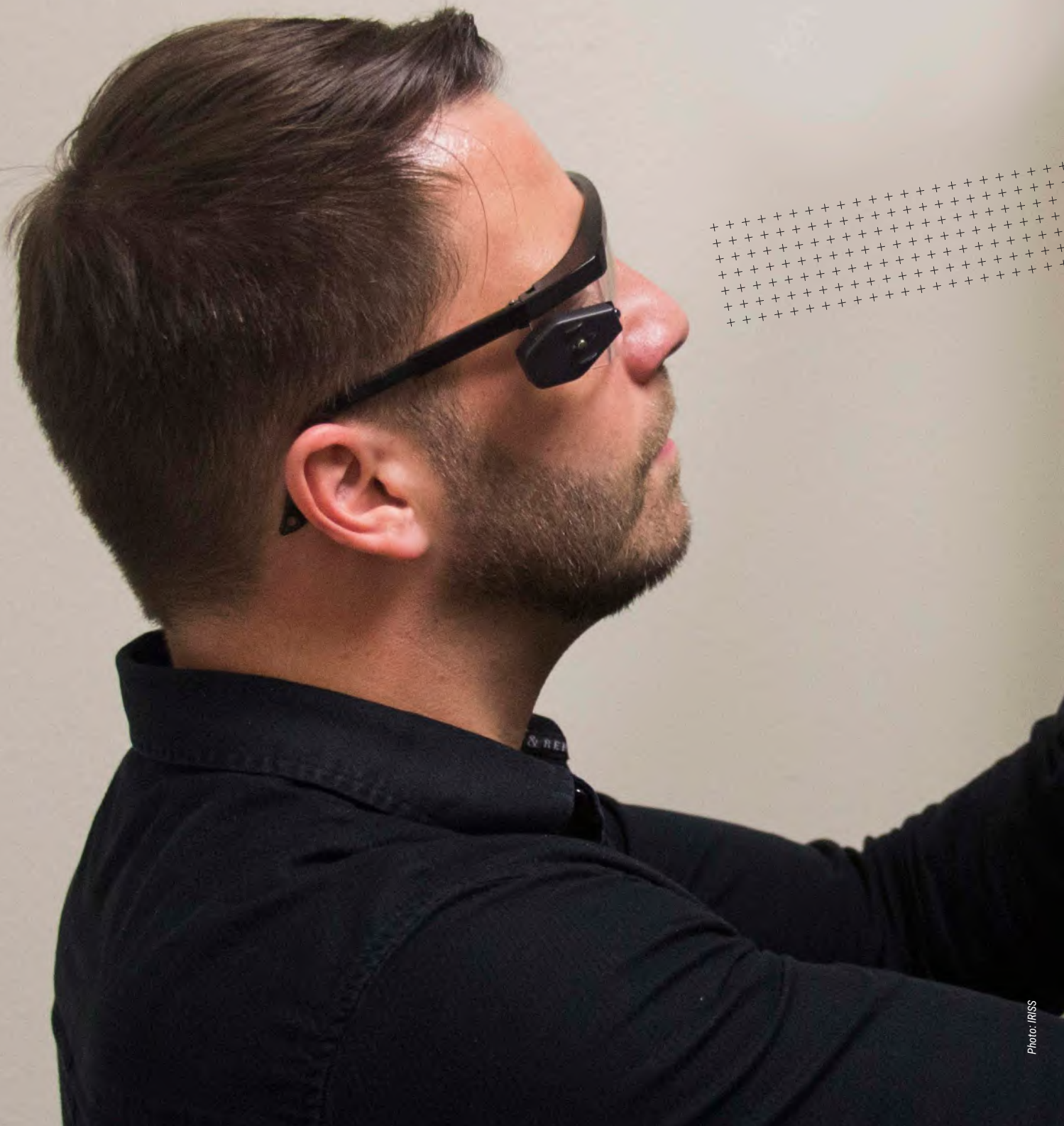
The data collected during inspection can be stored through intelligent asset management tags attached to the pre-installed inspection windows.

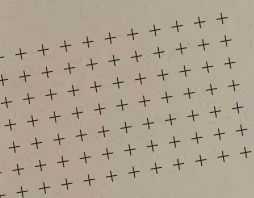


From the asset location, information can be transmitted into a dashboard system accessible from workstations and mobile devices. Customizable routes can be established before, and condition reports generated after, data analysis to further increase efficiency. These design aspects allow managers to assess operations and limit the amount of "scheduled exposure to risk" that so many archaic, yet still employed, systems cause.

The proper tools are only as useful as the hands wielding them. Shifting to an engineered reliability system for the electrical maintenance team means training new and veteran staff alike. The use of technology allows single individuals to accomplish safe inspection and maintenance tasks with minimal training. Online learning systems offer on-demand educational and training resources that teach the use of these specific technologies.

The physical environment of any factory, plant, facility, etc. is the setting where risk-based behaviors take place, with both machinery and power systems posing the highest threats to worker safety. Structuring out hazards through technology drastically reduces the opportunities for incidents/injuries/fatalities to occur, and as an added bonus, increases the reliability of assets and efficiency of the team.





Keeping human interaction with equipment to only instances where inspections of potential faults are deemed necessary will minimize workers' exposure to risk.

DIGITAL TWIN TECHNOLOGY OF SENSFORMER™ ADVANCED

Digitalization of transformers will be a decisive step for grid operators in managing the current and future challenges.

A SIGNIFICANT STEP IN THE DIGITALIZATION OF TRANSFORMERS

First-of-its kind digital twin technology from Siemens Energy offers special advantages compared to conventional solutions.

It enables grid operators to make data-driven decisions, increase the reliability and productivity of transformers and minimize risks using the results of a thermo-hydraulic calculation model.



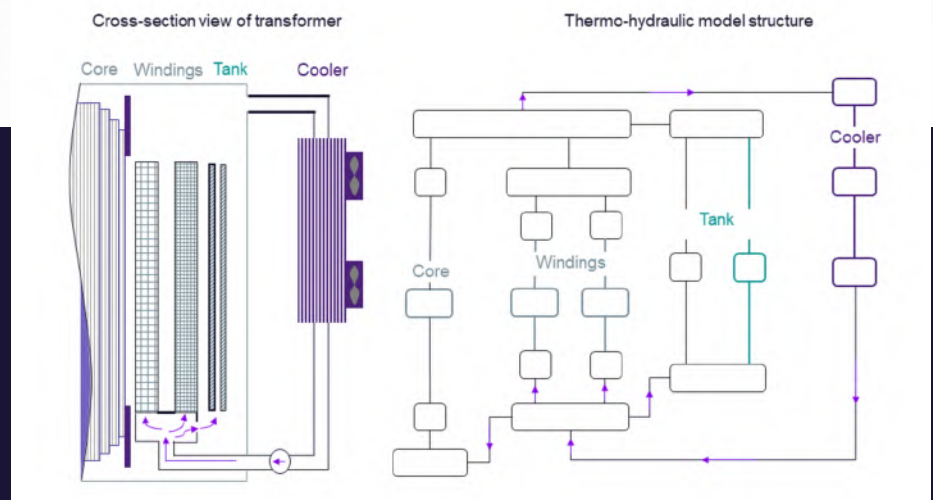
Digitalization helps operators to manage the growing complexity of grids with versatile, intelligent assets, capable of processing large volumes of data and recommending which optimum course of action to take.

Sensformer™ Advanced from Siemens Energy adds a digital layer of operational transparency to power transformers

The world is changing – data has become an inevitable but essential part of everyday life. In 2018, Sensformer™ was introduced as Siemens Energy's first digitally enabled transformer, providing real-time information about the transformer's performance and status. Since then, various other products have joined the Sensproducts™ portfolio (e.g., digitally enabled circuit breakers and gas-insulated switchgears). Challenges, such as the increasing global demand for electricity, which needs to be met with the existing fleet of grid installations, open up opportunities for new solutions. With the aim of increasing transferred energy and optimizing transformer lifetime based on real-time information, Siemens Energy has launched Sensformer™ Advanced with digital twin technology.

The Siemens Energy digital twin technology is also the first of its kind to transfer common technology assets into the new interconnected world, where asset health status as well as dynamic and volatile condition assessment are key and available at any time and any place.

Heat sources of a transformer build a thermo-hydraulic model including the oil flow



Siemens Energy uses a thermo-hydraulic calculation approach which provides an accurate and complete thermal image of a transformer

The digital twin is a virtual replication of each single transformer, established on the basis of its design data. This computational duplication is based on operational data like winding currents, cooling equipment status and ambient temperatures – either in real time to produce an online simulation, or even in advance to simulate potential transformer operation states. The thermo-hydraulic model computes the electrical loss distribution within the transformer's active part. The model takes into account the actual transformer ratio, while considering the tap position. It distinguishes between ohmic and eddy losses with their respective temperature dependency, as a specific feature of the loss calculation. The model is based on real material characteristics like masses and heat capacities of conductive and insulating materials, to allow calculation of the dynamic temperature processes during operation. The hydraulic resistances of certain transformer components such as the core, windings, radiators, etc. are defined as parameters in the model, and the oil flow is determined by the buoyancy forces and optionally additional pump pressures, if pumps are present. Consequently, and contrary to more simplified models, the Siemens Energy digital twin does not use fixed thermal time constants, but can consider the relevant dynamic heat transfer mechanisms in the transformer. Based on this thermo-hydraulic approach, the heat transfer equations can take into account the relevant physical quantities like oil temperature, oil flow, losses, etc. Consideration of the oil flow distribution and heat transfer mechanisms results in a thermal transformer model which covers different cooling modes, as well as the transient behavior between these modes, like xDAF to xNAF or xNAN (note: with x being used for O or K rating). The result is a precise temperature calculation. Moreover, due to the multi-mass approach linked to the oil flow, it is possible to couple the model with other important physical transformer models, for example for a moisture calculation.

Customers can optimize transformer operations based on digital twin calculations

Currently, the digital twin model in Sensformer™ Advanced can be used for three scenarios:

1. for simulating any load and ambient temperature cycle for 24 hours into the future
2. for determining permissible overload with defined boundary conditions
3. for automatically calculating the relative aging of the transformer

This means the customer gains new insights into different transformer conditions. When simulating a load cycle, customers can define values for various operational data for the next 24 hours, which at the same time represent the model inputs (e.g., transformer load, tap position or ambient temperature). The thermo-hydraulic calculation model then simulates the temperature behavior for the transformer top oil temperature, as well as the winding hotspots for the coming 24 hours for the assumed load cycle, starting with the actual thermal transformer condition. Another insight is the continuously determined and visualized maximum permissible transformer's overload capability for the next 30 to 60 minutes. Different boundary conditions such as aging values (loss of life) or temperature limits can be considered in the overload calculation. Finally, automatic calculation of the relative transformer insulation aging is also available. This loss of insulation life is calculated according to the IEC loading guide formulas over the previous 24 hours, the previous 30 days, and since the Sensformer™ Advanced application was commissioned. This provides a real life-time assessment of the transformer and the option of comparing the thermal load of several different transformers.

Design-specific modelling based on customer-specific design

Each transformer has its individual digital twin model. Depending on the design of the transformer (oil natural vs. oil directed, number of windings, colors, fans etc.), a particular model structure is created which is parameterized with specific design information. The required model parameters such as oil volume, heat capacities, insulation thicknesses, ohmic resistances and hydraulic resistances, are determined from the real data of the transformer. Dimensions, materials, thermal data, fan and pump characteristics and many more play a significant role. The thermo-hydraulic calculation is therefore tailored to each transformer design, and it can consequently predict the overload capacity, aging and service requirements with a high level of accuracy.



The main difference between conventional models and Siemens Energy digital twin technology is the use of a multi-mass approach

The main difference between simplified standard thermal models and the Siemens Energy digital twin is the multi-mass approach. Simple models often consider only the thermal behavior of a single winding for a specific tap position and specific cooling mode. It is only possible to simulate for this winding its hotspot temperature for load and ambient changes. However, this is clearly less accurate and not sufficient in terms of real thermal stress within a transformer, as the position of the highest temperature can vary from one winding to another when a transformer is operated at a different tap position. In contrast, the Siemens Energy digital twin covers all windings and the possible cooling modes of the transformer. Depending on the tap position, the loss distribution occurring in the windings is calculated and consequently the hotspot in the transformer can be continuously calculated. The Siemens Energy digital twin is based on a multi-mass model, which also includes the oil flow. In the near future, further other essential physical relationships will be considered, like moisture calculation and insulation degradation. Only these models will really constitute a complete digital twin of a transformer which will allow a very deep insight into the transformer.

The temperature behavior is an essential part of the digital twin technology, where the comparison of measured and calculated values during operation gives an insight into the quality of the calculation model. The diagram on the next page shows such a comparison for an oil natural cooled medium power transformer over a certain period of time. The most accurate correlation between the measured and calculated top oil temperature of the transformer is found in the case of the digital twin, whereas the conventional IEC standard model results in higher deviations and consequently less accurate estimated conditions.

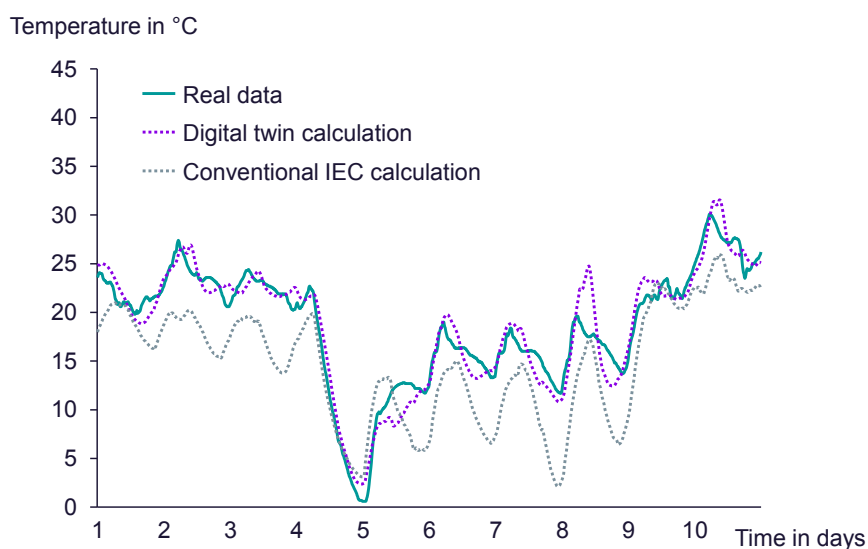
Customer benefits:

- **Real-time information available anywhere and anytime**
- **Notification app to minimize risks and improve environmental protection**
- **Analytics-based and data-driven decision-making**
 - **Improved operational reliability and productivity**
 - **Condition-based maintenance**
- **Data download for reporting**
- **High-level certified security and cyber security standard**

Customers have 24/7 access to Sensformer™ Advanced applications and can use the information provided to cut OPEX

Using the digital twin technology, the Sensformer™ Advanced provides a digitalized solution for different scenarios. The Sensformer™ Advanced web application provides grid operators with 24/7 access and increases transparency in the performance of the transformers. Early warnings and push notifications on mobile devices can further help to alert operators when situations are getting critical (e.g. oil loss, excessive temperatures, etc.). The information provided by Sensformer™ Advanced applications can be used to cut maintenance costs by reducing man-hours at the facility thanks to condition-based maintenance and the prevention of unscheduled outages. Moreover, active load prediction and the aging trending and projection supports the lifetime planning of transformers, which is beneficial for long-term grid modernization. Comprehensive visualization tools support further decision-making in the evaluation of equipment conditions.

Comparison of different calculation methods for transformer top oil temperature



Investing in digitalized equipment is an essential step forward

The worldwide increase in electricity demand as well as the need for sustainable measures to stabilize grids due to an increase in renewable power generation call for digital solutions. Sensformer™ Advanced, based on the Siemens Energy digital twin technology, provides the customer with real-time information on the status of the transformer, which is available anywhere and anytime. A notification app minimizes risks and the information provided allows overload operation, OPEX reduction and enhanced transformer lifetime planning.

The Siemens Energy digital twin is the first of its kind. Further digital twins will follow in the near future, complementing the dynamic condition assessment of a transformer, for example assessing transformer condition when events leading to failures. Exploiting the overall power of digital twins from different sources will complete the transformer operation in future, and will provide a permanent, real-time and independent assessment of asset condition. The holistic twin will be the all-embracing digital re-build of an asset driving the asset reliability and therefore the decarbonization to a new level.

Investing in digitalized equipment is an essential step towards transparent, flexible and reliable grid operation. Better be born connected!

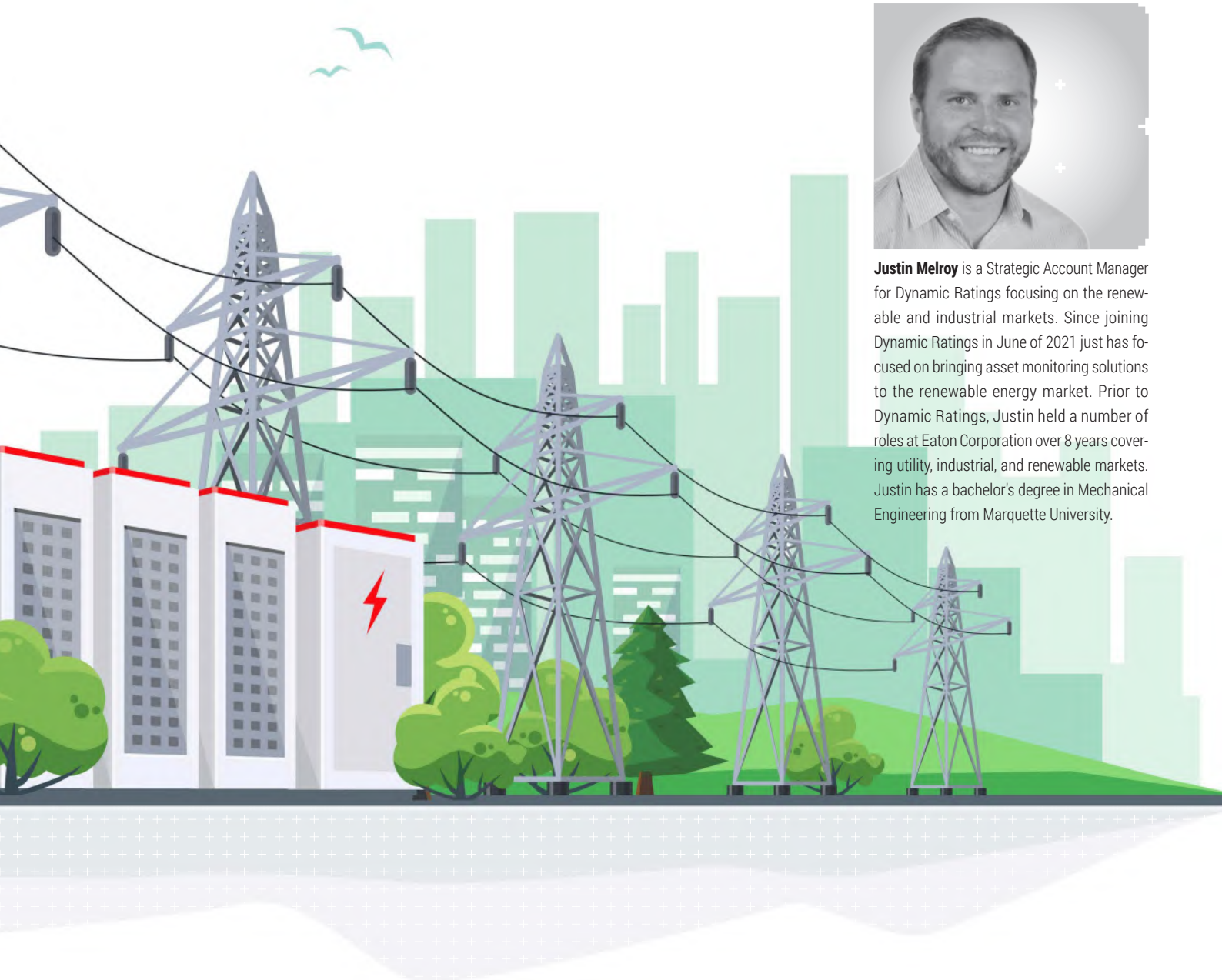
Since the wind and solar facilities were likely designed with a 20-year life in mind, the average age of the installed base is now well into the mid-life span of the electrical assets, which begs the question of what to do now. Owners and operators are faced with options of facility upgrades, replacement all together or abandonment.

Deploying condition-based maintenance technologies to extend the life of renewable energy assets

by **Justin Melroy**

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Wind and Solar energy operations have long been confined to a 15-20-year design life based on turbine and panel technologies, power purchase agreements (PPA) structures and tax incentives. In many cases the decisions to repower or dismantle renewable power operations comes down to the economics of long-term maintenance costs and equipment failure risks. By implementing condition-



Justin Melroy is a Strategic Account Manager for Dynamic Ratings focusing on the renewable and industrial markets. Since joining Dynamic Ratings in June of 2021 just has focused on bringing asset monitoring solutions to the renewable energy market. Prior to Dynamic Ratings, Justin held a number of roles at Eaton Corporation over 8 years covering utility, industrial, and renewable markets. Justin has a bachelor's degree in Mechanical Engineering from Marquette University.

based maintenance technologies into renewable generation, energy providers can offset risk, extend the life of assets, and reduce the cost of repowering a facility. This article aims to shift the status quo of operations and maintenance providers, system designers, and energy users towards a culture of maximizing the lifespan of electrical assets to extend the life of a renewable operation.

The amount of renewable assets connected to the grid has exploded over the last decade, nearly quadrupling since 2011. This has made the renewable energy sector lucrative for investors as well as promising for climate advocates. The onset of renewable generation can be traced back to the 1970s when wind energy began taking off as a response to the oil shortages in the U.S. After a decade of research and development, California saw a great increase of wind turbines being installed. Then throughout the 1990s and 2000s, further developments were inspired by government tax and investment incentives.

Solar power was slower to adopt, as technology limited utility scale projects until the mid-2000s.

In 2008 there was just 0.34 GW of U.S. solar. However, as the cost of solar has decreased and appetite for renewables has increased, the amount of solar in the U.S. today is estimated at 97.2 GW.

Since the wind and solar facility was likely designed with a 20-year life in mind, the average age of the installed base is now well into the mid-life span of the electrical assets. This begs to question of what to do now; owners and operators are faced with options of facility upgrades, replacement all together or abandonment.

Even with the rapid expansion in renewable energy over the past decade, "Renewables need to grow faster than our forecasts to close the gap with a pathway to net zero by 2050 [...]"

For solar PV and wind, average annual additions would need to be almost double what we see in our main case forecast over the next five years," according to a recent IEA study [1]. Owners and operators may be able to close the gap by extending the life of current generation facilities and keeping capacity online beyond original design life. To do so, this would require best in class maintenance practices.

By implementing condition-based maintenance technologies into renewable generation, energy providers can offset risk, extend the life of assets, and reduce the cost of repowering a facility.

The Federal Energy Management Program (FEMP) suggests the following maintenance approaches for renewable energy facilities [2]:

"Modern, effective O&M programs rely on four basic approaches:

1. Reactive/corrective (includes run-to-failure) O&M: Fix/replace when broken
2. Preventive O&M: Time-based actions
3. Predictive O&M: Fix it before it breaks
4. Reliability-centered O&M: A strategic combination of the previous three approaches"

For well supported facilities, operations and maintenance (O&M) practices may have included routine oil samples and dissolved gas analysis, visual inspections and other offline testing of electrical equipment. However, for most of the installed base, the transformers are allowed

to run to failure and substation equipment is monitored on cyclical basis only. As O&M budgets have been trimmed over time, the quality of the maintenance may have diminished.

Best practices for O&M indicate that investments in proactive maintenance are key to the O&M success. Continuous monitoring systems are an efficient means of collecting the necessary data to tackle proactive as well as predictive maintenance goals and keep the power plant running as efficiently as possible.

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Turbine blade and gearbox maintenance are some of the higher maintenance costs associated with a wind facility, leaving the electrical system to often get overlooked or lightly reviewed. However, online monitoring of substation transformers, turbine step up units, and switchgear protecting the substation transformer should be considered since the cost of the system will be absorbed by lower maintenance costs over time.

Online monitoring systems not only provide critical data for assessing the long-term health of the electrical equipment, but they also provide a significant reduction in down time and lower maintenance costs. Online monitoring allows operators to deploy condition-based maintenance and direct maintenance resources to known issues, rather than injecting potential problems by performing unnecessary work. Online monitoring also reduces unplanned outages and maintenance durations, keeping the power and revenue flowing in the right direction.

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In solar applications, the cost of vegetation maintenance and keeping the panels clean can account for as much as one third of the solar O&M costs. It is common that wind facilities require more maintenance and repair activities, whereas the maintenance requirements for solar tend to lean more towards site maintenance. This results in the generality that solar O&M costs are less than wind when viewed on a per kWh basis. However, electrical maintenance costs are relatively similar and provide equal benefit to extending the life of the equipment.

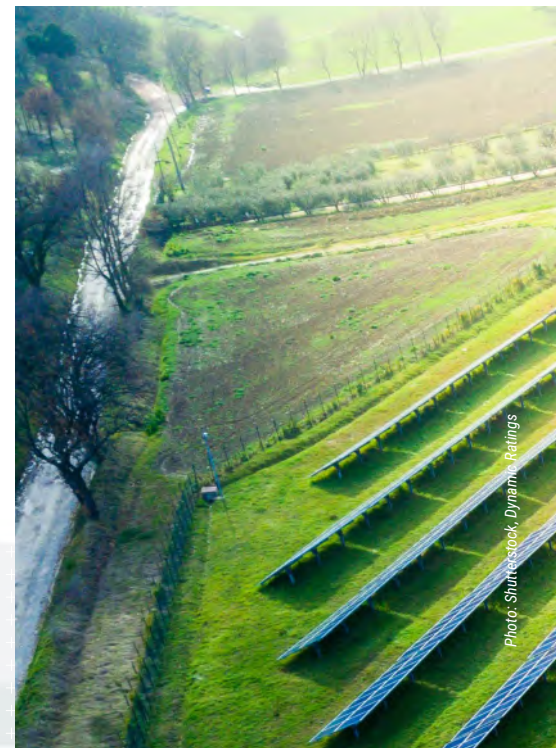


Photo: Shutterstock, Dynamic Ratings

Renewable applications are still the new kid on the block when it comes to the electrical world. In a system that is designed for stepping down power from transmission voltages to distribution levels, a whole host of data is available to determine the useful life calculations for utility transformers. Absent of rich data sets, it becomes important to begin gathering this data early in the life of the renewable asset. Asset owners increasingly rely on independent service providers, OEM provided, or self-performing maintenance work. However, with limited experience in field operations, the cost of maintenance contracts has increased significantly over the years. As a result, investors are increasingly looking for wind and solar farms that have implemented computerized maintenance management systems and asset management systems. Yet, there is still resistance to implement digital solutions as asset owners struggle to justify the up-front capital costs.

This resistance can be eased by considering the loss of production and increased maintenance costs associated with traditional maintenance methods. By allowing an electrical asset to run to failure, the risk of downtime is significantly higher than maintenance guided by an online monitoring system. When planned outages are taken



there is lower logistic costs since parts are not being expedited. Production losses can be mitigated by performing work when generation is at low points and overtime costs can be avoided.

In other industries, the business case for online monitoring can be made based on the impact of an unexpected loss of power impacting production and costing substantial equipment downtime. Similar value propositions can be made for renewable assets.

Failure to protect the substation transformer from partial discharge and bushing failures may result in catastrophic failures that could otherwise have been prevented or mitigated. Since 50% of bushing failures result in fires [3], the entire substation is put at risk. When compared to a total loss of a substation, monitoring costs for

substation breakers and transformers are minor compared to the benefits of the system and the peace of mind in knowing the health of the equipment.

When compared to a total loss of a substation, monitoring costs for substation breakers and transformers are minor compared to the benefits of the system and the peace of mind in knowing the health of the equipment.



Transformer loading conditions leading to premature failures in wind turbine installations are a significant concern for operators. Transformers are typically designed for constant load conditions, but due to the way that wind turbines are operated, the load conditions vary significantly, leading to cyclic loading and harsh operating conditions. These conditions often lead to premature failure making maintenance scheduling difficult. Continuous monitoring of these assets provides maintenance crews critical information on the health of the transformer, and can assist with the maintenance schedules, inventory planning, and operational consistency as transformers and switchgear are able to be removed from service prior to failure reducing the likelihood of damage to other equipment and cutting lost production time. As transformer designs have been improved over time to account for some of the issues faced with early generation designs, new standards have been implemented to address

the required changes [4]. However, it is still recommended to closely monitor transformer performance. Recommendations for transformers include temperature, pressure, liquid level and routine DGA sampling of the oil. When considering the remote location of these sites, it makes sense to transition to digital means of collecting the monitoring data and implementing online monitoring solutions.

When considering the remote location of these sites, it makes sense to transition to digital means of collecting the monitoring data and implementing online monitoring solutions.

Further justification of continuous monitoring systems can be found by reviewing the data collected by transformer and switchgear monitoring systems. With capabilities to understand operating conditions over the life of the asset, owners can make better decisions on whether to replace the electrical equipment when turbine or panel equipment is due for upgrade. Therefore, reducing the cost to repower a facility or extend the life of an existing plant without adding unmanaged risk.

In conclusion, condition-based maintenance powered by continuous monitoring systems will play a substantial role in allowing renewable power operators to maximize the lifespan of the electrical assets on the system. Implementing such systems is a cost effective and proven solution to reduce O&M costs, extend asset life, improve planning cycles, and keep renewable facilities online longer. All these things will shift the culture of renewable operations and maintenance practices towards longevity and sustainability which is needed to address the gap in renewable generation demand and production capacity.

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The benefits and implementation of continuous monitoring systems will shift the culture of renewable operations and maintenance practices towards longevity and sustainability which is needed to address the gap in renewable generation demand and production capacity.

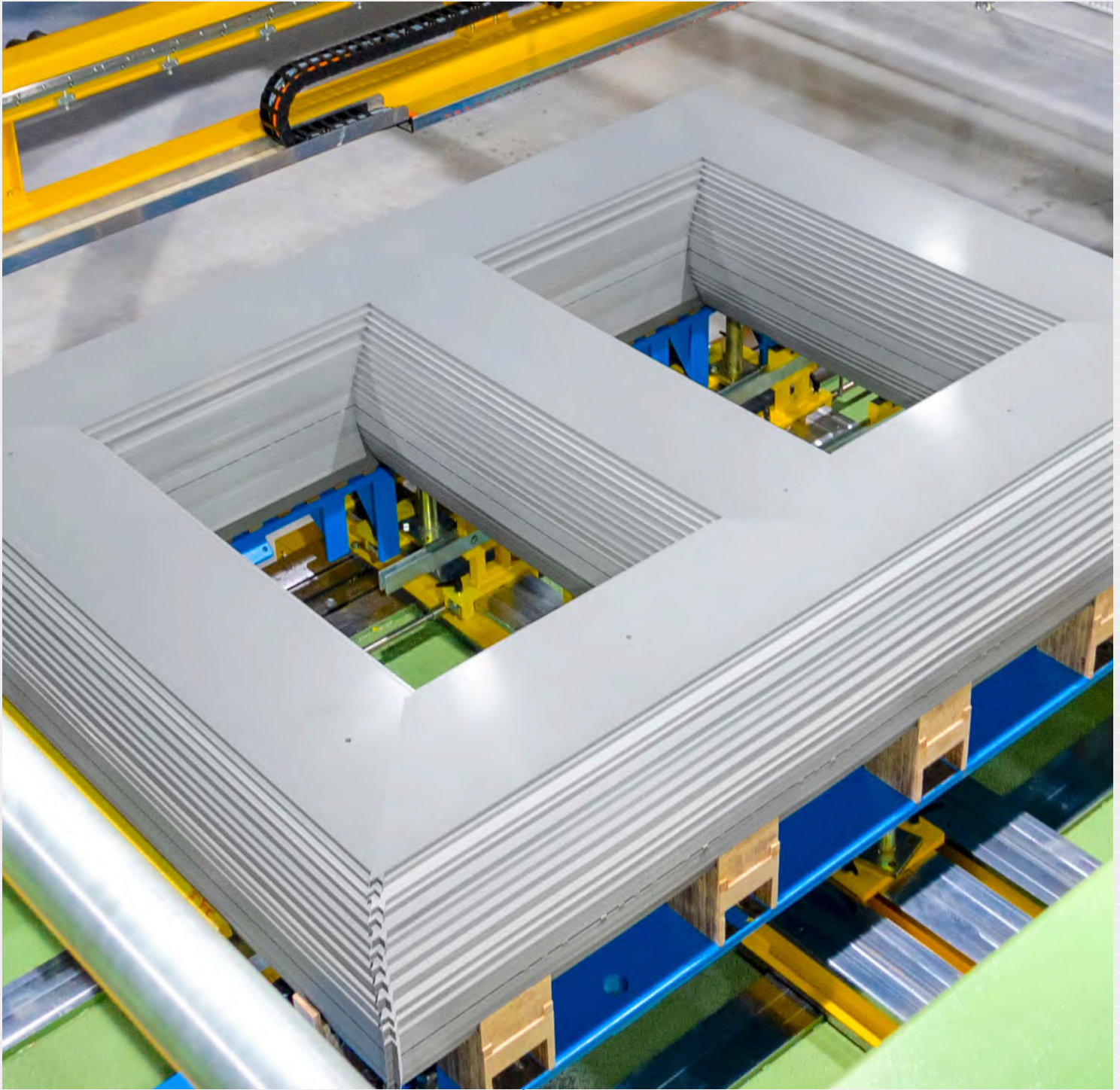


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PTTX LATE-MODEL ECO-FRIENDLY TRANSFORMER CORE



BOOSTING LOW-CARBON DEVELOPMENT

PTTX promotes the manufacture of late-model eco-friendly transformer cores with professional technical support, novel production technology, and supporting full-process services, so as to reduce transformer no-load losses, save energy and reduce emissions. PTTX uses practical actions to boost 'carbon peaks and carbon neutrality', aimed to promote the green development in the power industry.

China strives to achieve carbon peaks by 2030 (once *carbon peaks* are reached, carbon dioxide emissions no longer increase, but start to decline) and achieve carbon neutrality by 2060 (*carbon neutrality* is reached when enterprises, groups and individuals offset the carbon dioxide emissions they generate and achieve zero carbon dioxide emission by afforestation, energy saving, emission reduction, etc.). As a leading enterprise in the transformer core industry, PTTX takes the lead in low-carbon emission reduction green manufacturing, taking social responsibility, and making contributions to the power industry.

On June 1, 2021 China officially implemented the new version of the "Minimum allowable values of energy efficiency and the energy efficiency grades for power transformers" (GB 20052-2020) standard. In the new standard, the standard loss index for all types of transformers will be reduced by about 10-45% compared to the old standard. This is better than the requirements set by the European Union (which implemented the new standard on July 1, 2021) and the United States.





The implementation of the new energy efficiency standard further promotes the transformation of the entire power transformer network. If the new Grade-1 energy efficiency transformers, which are made from high grade oriented electrical steel, can cover China's current distribution network, it is estimated that this can save 87 billion kWh of electricity per year, equivalent to 86.7 million tons of carbon dioxide emissions.

Facing such astonishing data, PTTX firmly believes that we should make our due contribution at the times when the power industry needs it.

High performance grain-oriented electrical steel is the most suitable material for the manufacture of the Late-model Eco-friendly Transformer under the new energy efficiency standard. The production technology of high grade grain-oriented electrical steel is complex, and PTTX actively carries out research and development of this steel, material innovation and technology upgrade. Through the efforts of our R&D team, the quality of PTTX grain-oriented electrical steel is steadily improved.

PTTX's research is not only based on the upgrade of grain oriented electrical steel materials. Approaches to applying high-performance grain oriented electrical steel in the design of the Late-model Eco-friendly Transformer Core is an added value that PTTX R&D team has brought to clients.

The higher the performance of grain-oriented electrical steel, the higher the calculation requirements for transformer core design. The higher the grade of grain-oriented electrical steel, the thinner its thickness, the higher the level of processing technology requirements.

In the case of 0.20 mm and 0.23 mm thick grain-oriented electrical steel, which is in highest demand, many transformer companies have come under the pressure of design and processing difficulties.

PTTX provides clients with Late-model Eco-friendly Transformer Core design solutions to solve design problems.

Through the use of high quality PTTX grain oriented electrical steel, with design and processing technology innovation and the use of intelligent manufacturing technology, we offer clients an ability to customize Late-model Eco-friendly Transformer Core.

Transformer cores are different from general mechanical manufacturing products which can be shipped to clients in simple packaging. If the transformer core is not properly protected, this will have a great impact on its performance. For example, in severe weather, we should pay more attention to strengthening external anti-corrosion. During the shipment, appearance damage under the influence of stress should be avoided. Attention should also be paid to avoiding attachment of metal dust and other foreign bodies, etc.

At PTTX we investigate best logistics solutions for the transformer core and we develop exclusive transformer core packaging protection and logistics operations and services to ensure that the product arrives intact to the client.

PTTX is not only a transformer core manufacturer, but also a developer of green manufacturing system solutions. For the transformer core manufacturing requirements, we have asked ourselves many questions and devised many solutions accordingly, which seem to have exceeded the necessary core requirements. This speaks of our dedication to every detail of transformer core manufacturing, and the focus on each of our client's expectations of our quality.

PTTX uses practical actions to boost 'carbon peaks and carbon neutrality', aimed to promote the green development in the power industry.



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Reliability: A Compound Effect

by Traci N. Hopkins

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What is your definition of reliability?

If you ask this question 100 different people, you will receive nearly 100 different answers.

However, the underlying theme will remain the same: **Reliability is the expectation that the asset in question will perform as designed and as expected without fail.**

However, at some point in the life of that asset, there will be a “blip” in its operation that will lead to two very definite outcomes.

The first is that this item will now be viewed as “unreliable”.

The second is permanent failure.



Traci Hopkins started her journey in electric power reliability in June 2012 with SDMyers, LLC in the Training & Education department. Shortly after, she transitioned into the role of Diagnostic Analytic Coordinator for the international market while continuing to support training & education through international events. In 2017 she made her way back to T&E as the Sr. Training & Education advisor and Adjunct Instructor. Recently, she has joined the Electric Power Reliability Alliance (EPRA) team as Membership Recruitment Coordinator. Traci has received the CRL, MTMP, MTRP and DPS Training certifications. Traci is also a member of IEEE PES, the Association of Asset Management Professionals, and WIRAM (Women in Reliability and Asset Management) organizations.

What is the definition of reliability and how do you maintain an asset's reliability? Your answer should funnel down to three distinct areas: small changes, consistency, and time.

Now that we've defined Reliability, let me ask the question: How do you maintain your asset's reliability? Similar to the first question, if you ask 100 people, you will receive a multitude of strategies and actions to ensure an asset's reliable status. However, the key to maintaining reliability can be written as a simple equation:

Small Changes + Consistency + Time = Reliability

This "Reliability Equation" is nothing more than the "Compound Effect". Let us break down this equation, evaluate each variable and observe how they apply to electric power reliability, specifically transformer reliability.

Small Changes

In our current culture we want results, and we want them now! We need to be able to produce evidence that our efforts to maintain an asset will produce a significant Return on our Investment. For many, this means big changes = big impact. However, if we look at the effects of small changes to not only maintenance activities, but budgets, time and ability, and the willingness of staff to implement said changes, we can observe that small modifications are a more effective and efficient means to achieve higher reliability and maximize the life of our assets. Small changes also provide the flexibility to course-correct without any significant negative impact to the factors mentioned above.

Table 1 - Aging acceleration factor

Temperature °C	Age Factor	Temperature °C	Age Factor	Temperature °C	Age Factor
<37	0.0000	65	0.0054	94	0.1813
38	0.0001	66	0.0062	95	0.2026
38	0.0001	67	0.0071	96	0.2263
39	0.0001	68	0.0080	97	0.2526
40	0.0002	69	0.0091	98	0.2817
41	0.0002	70	0.0104	99	0.3141
42	0.0002	71	0.0118	100	0.3499
43	0.0002	72	0.0134	101	0.3897
44	0.0003	73	0.0152	102	0.4337
45	0.0003	74	0.0172	103	0.4823
46	0.0004	75	0.0195	104	0.5362
47	0.0004	76	0.0220	105	0.5957
48	0.0005	77	0.0249	106	0.6614
49	0.0006	78	0.0281	107	0.7340
50	0.0007	79	0.0318	108	0.8142
51	0.0008	80	0.0358	109	0.9026
52	0.0009	81	0.0404	110	1.0000
53	0.0011	82	0.0455	111	1.1074
54	0.0012	83	0.0513	112	1.2256
55	0.0014	84	0.0577	113	1.3558
56	0.0016	85	0.0649	114	1.4990
57	0.0019	86	0.0729	115	1.6565
58	0.0021	87	0.0819	116	1.8296
59	0.0024	88	0.0919	117	2.0197
60	0.0028	89	0.1031	118	2.2285
61	0.0032	90	0.1156	119	2.4576
62	0.0037	91	0.1295	120	2.7089
63	0.0042	92	0.1449	121	2.9845
64	0.0048	93	0.1622	122	3.2865

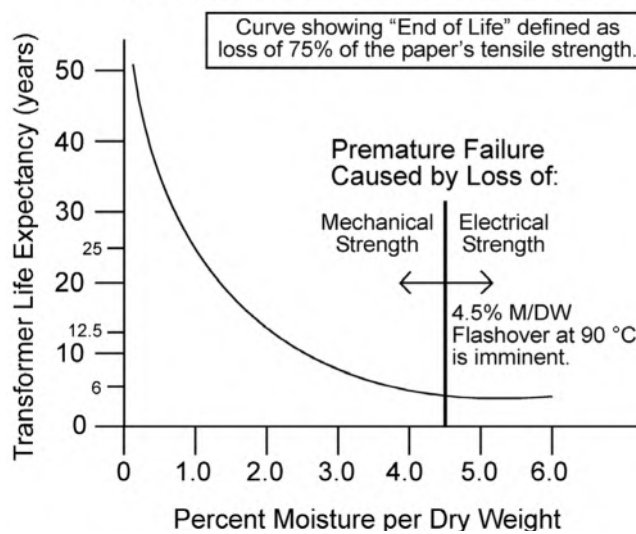
IEEE C.57.106.1995, Table 1 – Aging acceleration factor (Source: [1])

In the case of transformers, it's important to consider the asset's criticality, health status, and the impact and consequences of failure to the organization. In today's power systems, the average age for an in-service power transformer is 38 years. Many electric power reliability professionals find themselves in situations where they must manage multiple units that include not only "average-aged transformers", but new units and ones that far exceed the average transformer age. This assortment of transformers possesses great challenges, especially when the age gap of these assets can span ten, fifteen, even twenty years or more. In situations like these, it's imperative to realize that the robust overbuilt transformer of yesteryear and the new, sleek, more streamlined transformer of today each require a different maintenance philosophy.

Knowledge and understanding of the test data joined with experience affords the reliability professional an opportunity to implement big changes in the transformer management program through smaller, more manageable steps.

The mediocre maintenance strategy on the over-built unit has sufficed up until this point; mostly, due to an overabundance of caution on the manufacturer's part with an added cushion of solid and liquid insulation beyond the design requirements. This minimalist strategy that has worked for decades is now antiquated, inefficient and harmful to a reliability-focused strategy, as new units require a more conscientious and active approach in their maintenance and management strategies. Small changes in the chemical, mechanical, and electrical evaluations of these assets, on all sides of the age spectrum, can be extremely impactful.

How does the Percent Moisture per Dry Weight affect the Life of a Transformer?



The use of online gas monitors for new and in-service units, customized testing programs for the liquid insulation, the use of appropriate electrical test methods and testing intervals during the transformer's lifecycle, and the adaptation and inclusion of newer evaluation technologies such as Ultrasound and Vibration Analysis are all part of the necessary tasks required to assess a transformer's health and reliability. Yet one must not discount the importance of active participation in organizations dedicated to the advancement of electric power reliability, and, most importantly the establishment of a consistent training and education program for everyone involved in the care of these assets.

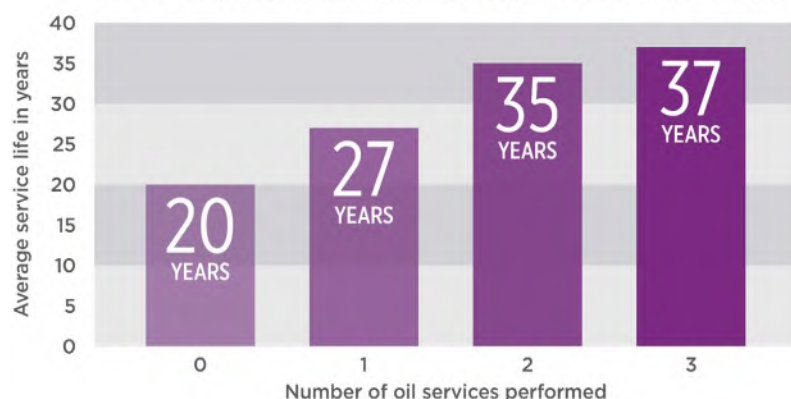
Knowledge and understanding of the test data joined with experience affords the reliability professional an opportunity to implement big changes

in the transformer management program through smaller, more manageable steps, providing an opportunity to course-correct as needed without significant impact to the asset, the maintenance program, or operations.

Think about this interesting fact: by performing one service, for example: re-inhibiting, moisture reduction, oil reclaiming, etc. on a transformer, you can gain an average of seven years of in-service life on that unit.

Average Service Life Related to Number of Oil Services Performed

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



Consistency

Once we've developed a plan and begun to implement those changes, it's imperative to remember the next part of our equation: Consistency – Trust the Process. Change occurs when you are motivated and disciplined. Discipline is what is left after motivation leaves the room. In the case of power transformers, we need to have the discipline and wherewithal to resist the temptation of falling back into old maintenance habits. Understanding the “Why” helps us to remain uniform with all our tasks and activities.

Transformer maintenance and management is all about the data. The consistency of transformer testing: chemical and electrical, visual inspections, infrared thermography, and other test data provides us with a baseline of information about the health of the transformer. Over time, the data we accumulate from these tasks becomes information. We couple this with knowledge acquired through training and education efforts and we begin to develop a complete assessment of the health of the transformer. This assessment is then used for trending analysis, industry comparison, predictive maintenance, and planning for end of life.

The ability to avoid turning new habits into complacent tasks, and the act of continuously seeking knowledge is what sets reliability professionals, thought leaders and subject-matter experts apart from the crowd. It's this ability to keep moving forward, routinely evaluate the effects of these small, incremental changes and a consistent and faithful dedication to the process that begins the transition from simply maintaining the asset to a true reliability mindset.

It's the ability to keep moving forward, routinely evaluate the effects of the small, incremental changes and a consistent and faithful dedication to the process that begins the transition from simply maintaining the asset to a true reliability mindset.

Time

The third and equally as important addend in this equation is time. You have to be willing to “be in it for the long haul”. Theoretically, power transformers have a life expectancy of more than 400 years. I have had the pleasure of being witness to the celebration of several units that have exceeded 100 years of service and are still going strong. Time is our most precious resource and one that we cannot regain. However, in the world of power transformers I like to challenge that last statement. Think about this interesting fact: by performing one service, for example: re-inhibiting, moisture reduction, oil reclaiming, etc. on a transformer, you can gain an average of seven years of in-service life on that unit.

Consider these interesting facts about the transformer's solid insulation system and temperature: we can observe and calculate the temperature interval (increase) that will cut the life of the paper in half; conversely, we can also calculate the temperature interval (decrease) that will double the life of the solid insulation and increase the life of the transformer. Finally, did you know every time you double the moisture content in a transformer you are

CRITICAL TRANSFORMERS:

HOW DOES YOUR
reliability plan
MEASURE UP?



effectively halving the reliable life of that unit? Imagine how much time could be gained on the life of an in-service unit if we started off with a reliability mindset from the very beginning, the design phase.

When it comes to time, it's important to remember to be confident in your decisions, knowledge, and abilities. There are many documents to help you achieve success in your journey, covering everything from the what to the how and even the why. Think about it this way, you wouldn't throw in the towel after one workout at the gym, NO! So why do we regularly implement new programs and processes only to abandon them

three months later? It is said "the best things take time". Well, so does Reliability. I'm sure we all remember the lesson from story of the Tortoise and the Hare, slow and steady wins the race.

Imagine how much time could be gained on the life of an in-service unit if we started off with a reliability mindset from the very beginning, the design phase.



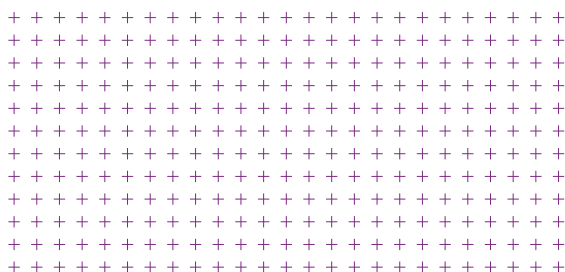
The compounding effects of these three factors when done carefully and with intention are what set the reliability professional apart from the average maintenance worker. A dedication to the art of interpreting data, converting it to information, translating that information into knowledge and eventually into wisdom is a path which all "reliability focused" organizations must take. Fortunately, in today's world of power transformers, we have access to the resources, training, subject matter experts, colleagues, associations, and organizations at our fingertips. With a click of a mouse, the stroke of a keyboard, or a phone call we can easily access communities of electric power professionals and find many potential solutions to our inquiries.

The ability to implement small changes on a consistent basis over a period of time will unify the organization, achieve the intended goals and extend the reliable life of one of the most valuable assets in any electric power system, the transformer. Now, I urge you to go back to the beginning and ask yourself the same two questions again, what is the definition of reliability and how do you maintain an asset's reliability? Your answer should funnel down to three distinct areas: small changes, consistency, and time. These three addends, when given the opportunity, will equal an increase in the reliability of our assets and personnel, and effect positive change in our organization's reliability culture.



References

- [1] IEEE C57.91-1995 – IEEE Guide for Loading Mineral-Oil-Immersed Transformers



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Aleezeh Shahid



Aleezeh is a senior analyst at Power Technology Research. She leads the power grid research team in developing PTR's syndicated power grid services and manages custom research projects for various clients across the world. Aleezeh comes from a technical background and has a M.Sc. in Electrical Power & Energy Systems and a B.Sc. in Electrical Engineering. Growing up, mathematics was her favorite subject, so she always wanted to pursue engineering as a career. During her undergrad, she developed an enthusiasm for research and maintained that during her master's program as well, where she completed her degree with a thesis on the topic, 'Impact and Mitigation of Harmonics on Distribution Grid with Enhanced Nonlinear Loads'. Aleezeh wanted to choose a career path that was related to her degree but was also not "dry" or monotonous. Consequently, this led her to the field of market research, where she continuously keeps up to date with the industry trends. She currently leads the power grid research team at Power Technology Research. Topics under her mandate include HV switchgear, MV switchgear, power transformers, distribution transformers, substation automation and power factor correction etc. Aleezeh has several publications to her name including whitepapers and thought pieces in trade press. As a pastime, she loves watching horror shows and movies, Mike Flanagan being her current favorite horror director.

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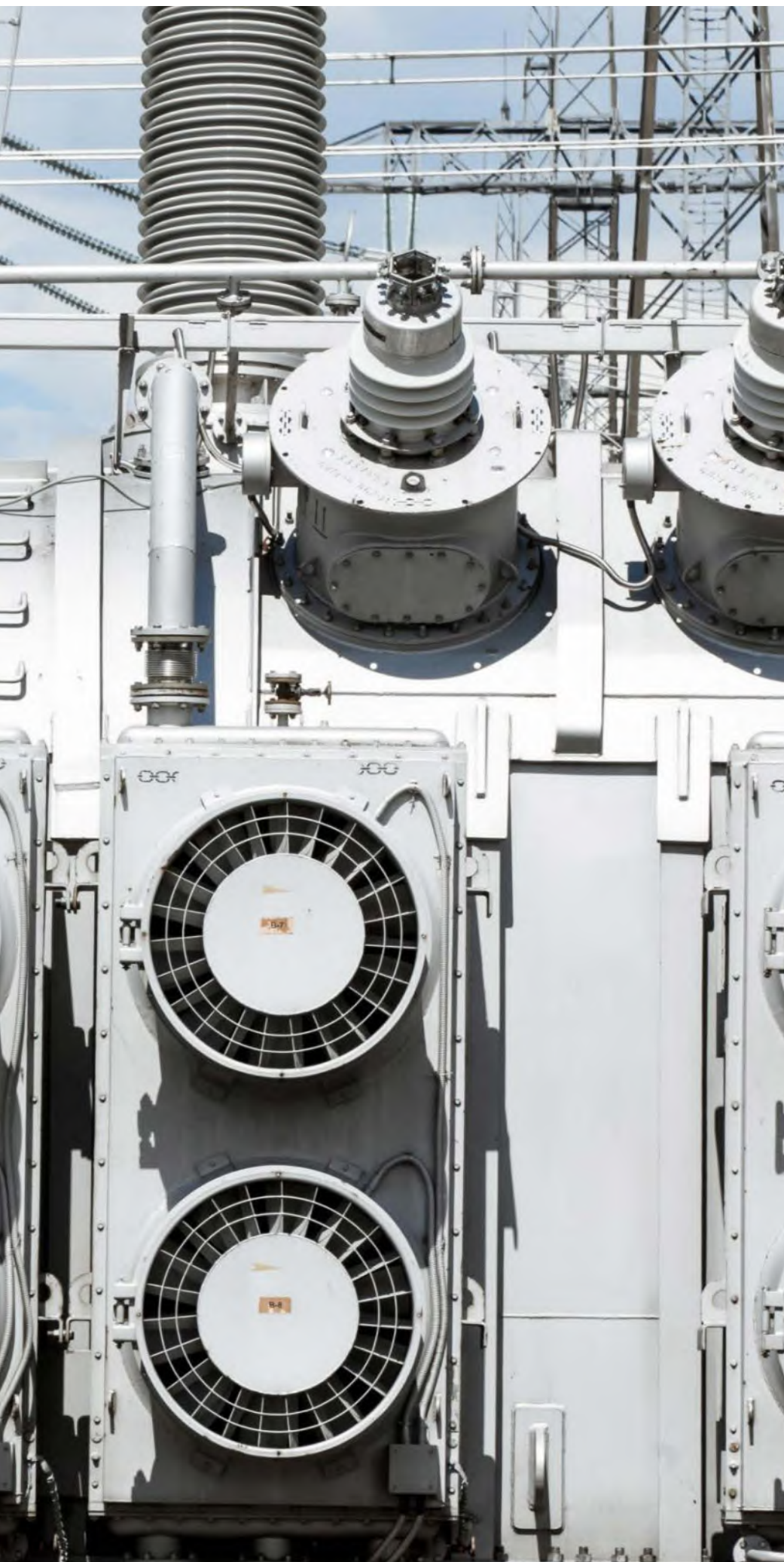
Aleezeh Shahid

Transformer Condition Assessment: Moving from Data to Actions

by **Emilio Morales**
and **Thomas Linn**

Correlative analyses and data analytics enable users to evaluate the probability of failure by using different parameters, which can be supportive or contradictory to each other when used individually in failure mode assessment.





Emilio Morales attended Nuevo Leon State University in Mexico, receiving his bachelor's degree in Electromechanical Engineering in 1980. He has over 30 years of experience in power transformer design which includes transformers up to 500 MVA and 500 kV, furnace and rectifier transformers and reactors. He is member of the IEEE/PES Transformer Committee, IEC and CIGRE. He previously worked with GE-Prolec, Ohio Transformer, Sunbelt Transformer and Efacec. He joined Qualitrol in June 2012 as a Technical Application Specialist in transformer applications. His focus is to support solutions in comprehensive monitoring for transformer applications.



Thomas Linn graduated from the Technical University of Dresden with a degree in Electrical Engineering, specialized in High Voltage Techniques. In 1998 he joined ABB in Switzerland where he was responsible for high voltage onsite testing for GIS and cables, on-site PD measurements and PD monitoring of Gas Insulated Switchgear. Afterwards he worked for 10 years with high voltage transformer bushings at Micafil. During that time, he was responsible for high voltage test laboratories for routine and type testing and later for the whole manufacturing process. Latterly, he was senior project manager for strategic projects, project portfolio manager and senior technical expert for high voltage techniques and equipment. Today he is working as a Technical Application Specialist for Qualitrol.

Introduction

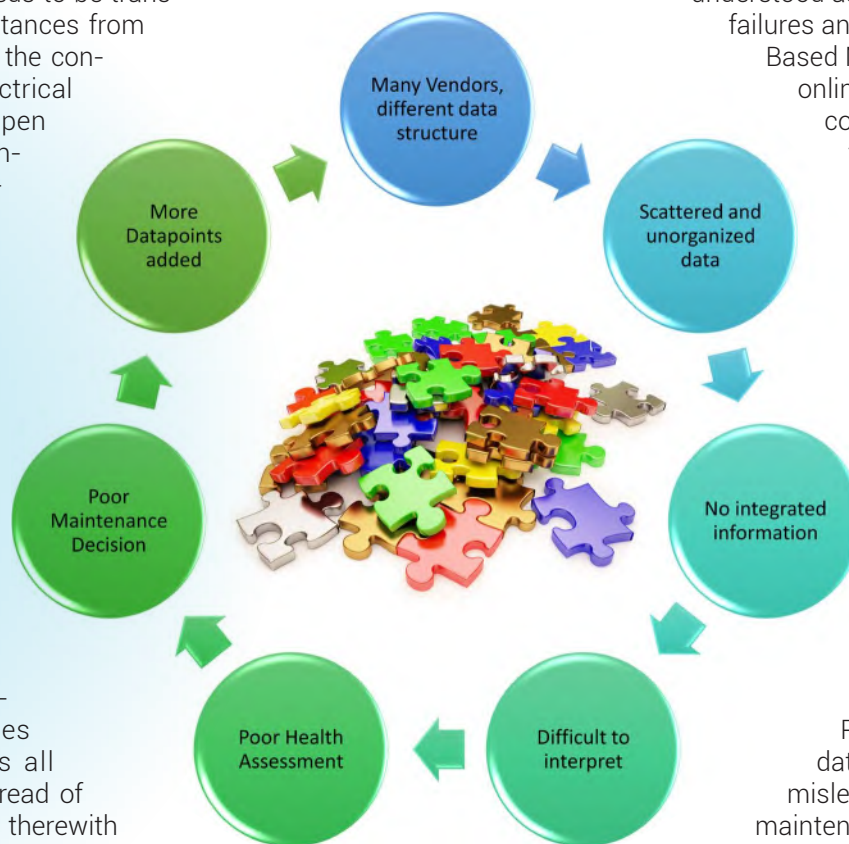
The changes in global energy politics, motivated by multiple reasons, have driven the electrical power industry not only to devising more efficient solutions, but also to an increased use of renewable energy resources. Energy production today has become more decentralized with renewable energy being generated regionally, away from the main consumers. The decentralized power generation meant that electrical networks needed to be reconfigured. The electrical energy today needs to be transmitted over longer distances from generating stations to the consumers. Reverse electrical energy flow can happen and it needs to be controlled, placing an additional burden on electrical network components.

With these higher complexities and the requirement to increase the speed and reliability of asset health assessments and maintenance decisions, the collection of condition data and the translation into actionable data becomes more essential. This all happens under the thread of climate change and is therewith connected to more severe climate conditions which have been proven to test the resilience of the electrical energy network even further.

Transformers as a key asset of electrical networks receive special attention regarding condition and risk assessment based on availability requirements. Offline condition assessment methods are established and used for decades with success but require an outage to be able to perform them. Nevertheless, they give a momentary screenshot of the asset at the time of the measurements, so the development of incipient faults can be missed between outages. Introducing online monitoring in the past was most often limited to some

independent parameters or basic trending. Users struggled accessing the true overall condition of an asset. Typical statements were and still are "I got an alarm, but what does it mean to my asset? What are the actions to mitigate an immediate threat?". In a lot of cases confusion prevailed over clear decisions. "False alarms" lead to a lack of trust in the installed monitoring solutions.

Figure 1. Scattered data approach



To efficiently assess the condition of a transformer and to convert the data into actionable information, the failure mechanism, its associated monitoring parameter(s) and the dedicated analytic model must be known and must be considered in their entirety. Correlative analyses and data analytics are gaining more importance as they enable users to evaluate the probability of failure by using different parameters, which can be supportive or contradictory to each other in their individual failure mode assessment. Once a potential incipient fault has been identified, a

set of actions for rectification needs to be determined.

Analytic Models – Creating Information Instead of Data

The knowledge of failure statistics, problems and failures of a particular transformer fleet, and an understanding of failure mechanisms combined with criticality analysis are essential to choosing the right parameter for an assessment and building up analytic models. Today asset assessment will be mostly understood as a tool to prevent failures and enable Condition Based Maintenance (CBM). But online condition assessment could also be a powerful tool for asset operation. The prediction of a certain load condition and the risk status of electrical assets can be used for dynamic loading. As the pressure on the owners regarding financial efficiency increases, dynamic loading becomes more and more important.

Presenting "only" the data and trending can be misleading, leading to poor maintenance and/or operational decisions and unnecessary interventions, which usually have the potential to introduce new risks. Figure 1 illustrates this scattered data approach and how it often fails. In many cases users find it difficult to analyze scattered data. Data are analyzed separately ignoring the possible relationship to other parameters or even legacy data.

A practical example is partial discharge (PD) measured on a transformer bushing tap. Considering only the detected PD could lead to the decision to further investigate and perhaps open the transformer trying to find the failure. Since the source of PD can be the overhead lines or the bushing surface, it would be

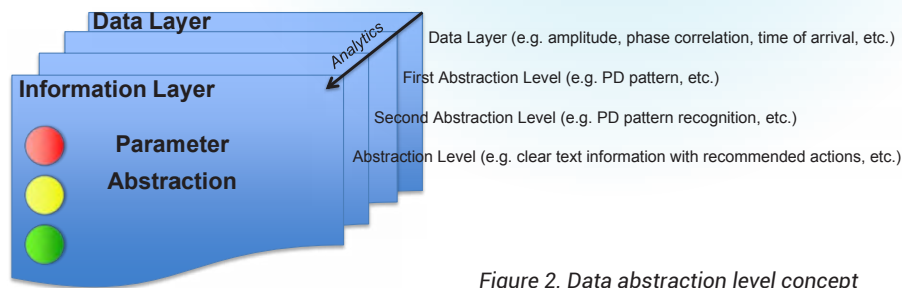


Figure 2. Data abstraction level concept

necessary to consider the possibility that the discharge originates from outside of the transformer. Appearance and disappearance of PD for longer periods, mostly related to climatic conditions, is a clear sign of external discharges (e.g. surface discharges on the surface of the bushings or corona discharges on the overhead lines). At first sight this example might seem very basic, but it is one of most common problems in terms of PD monitoring on the bushing tap. It would need a lot more parameters than just the PD from the measuring tap to be able to distinguish between internal and external origins of PD.

Besides reliable capturing of the data for the chosen parameters, it is also

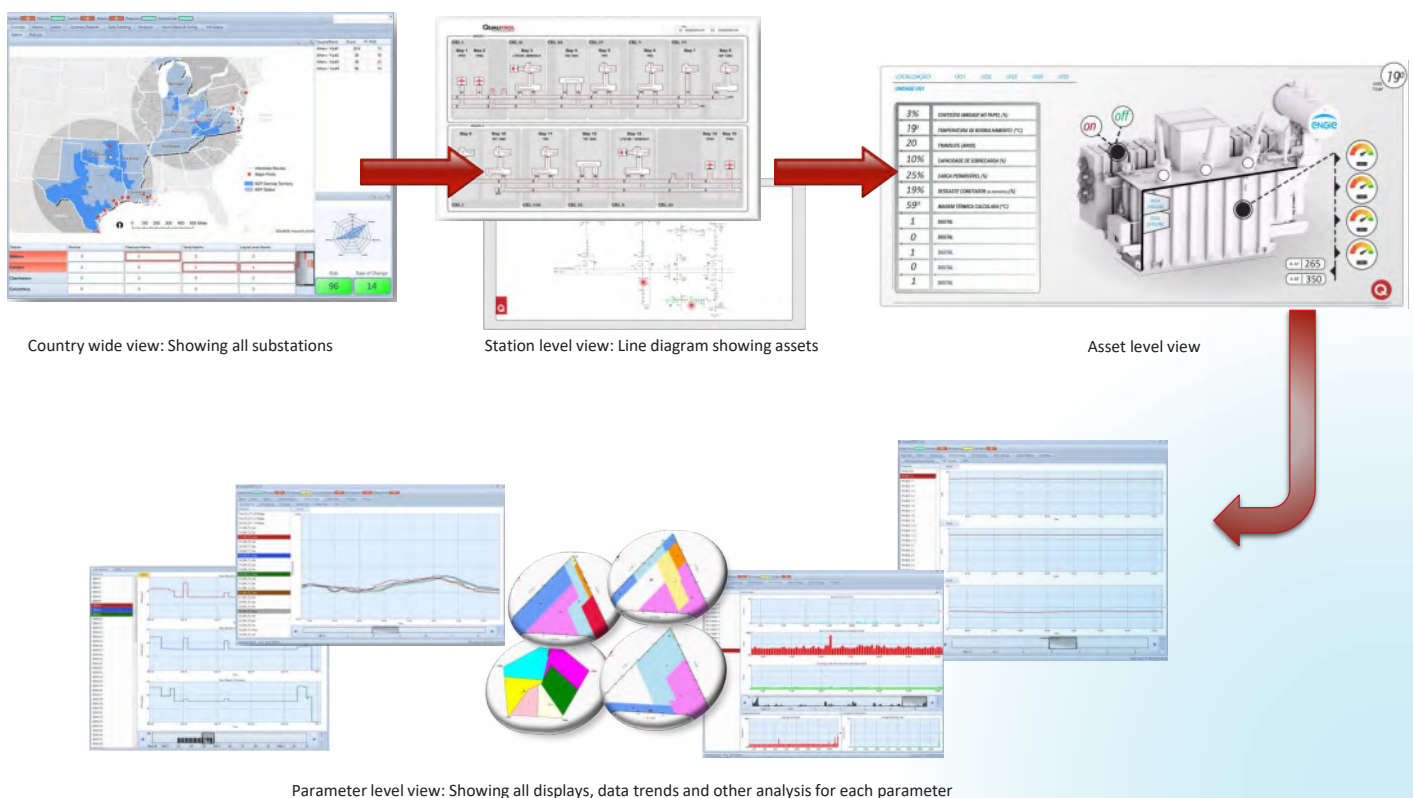
important to extract the relevant information. Using the PD example again, this means that PD impulses must be related to their position in the phase of the line voltage, which then allows to combine the single impulses to different pattern types (PRPD pattern – phase resolved partial discharge pattern, 3D pattern, point of wave, etc.). Adding the time of occurrence will also provide additional information for PD analysis. For example, comparing additionally the time of arrival and/or amplitudes of the same PD impulses at different sensors will give further useful information about PD origin. Figure 2 shows how the collected data can be analyzed through different abstraction levels (analyzed by simple logic or

sophisticated artificial neuronal network approaches, fuzzy logic, etc.) and further verified with the help of other related data (e.g. PD and Dissolved Gas Analyses (DGA) for transformers).

The abstraction level can be arbitrarily continued. Figure 3 shows the abstraction level at the network layer (top left picture) and the substation layer (top middle) for the substation under concern.

To assess a certain alarm or warning condition, different parameters should be correlated to each other, including online and offline data, as well as data from different sources, e.g. SCADA systems, periodical visual checks, load data, etc. This would allow correlation of complementary parameters. Automated correlation of data can be done for online data. Available offline data has often been reviewed manually but seldom automatically via an interface uploaded to an analytical tool or platform which has the analytic ability to marry online and offline data and convert these into actionable information for operators and maintenance crews.

Figure 3. Information abstraction from network to substation and down to parameter level view



Failure Statistics, Asset Components and Failure Mechanisms

Failure Statistics

The latest transformer reliability study, published in CIGRE Brochure 642 [2], shows that windings are the major cause of transformer failures with 45%, followed by tap changers with 26%, bushings with 17% and lead exits with 7%. All other major transformer components play a minor role (see Figure 4). The overall transformer failure rate according to [2] is 0.44%, while transformers for extra high voltage (EHV) and the lower end of high voltage are showing a failure rate of around 1%.

Asset Components

All transformer incipient faults will somehow result in the creation of detectable signs of their presence. These signs could be chemical, electrical, optical, or acoustic in nature, but often they will be a combination of these. Further, a selection of possible fault mechanisms related to certain components will be described as simple examples to illustrate the potential of certain parameters to be used as indicators of incipient faults.

Transformer Main Tank

The main concern regarding the transformer main tank is the dielectric integrity of the liquid, bulk and paper insulation, as well as their accelerated aging by local and general overheating and moisture. This is tightly connected with the risk of bubble creation at high moisture and dissolved gas content combined with high temperatures. Moisture and overheating will accelerate the aging of the cellulose. This will create decomposition products of the cellulose, among them water (moisture), which in turn will accelerate its aging even more. Over time, the insulating paper will lose its insulating and mechanical properties until it cannot withstand any electrical or mechanical stress, increasing the probability of transformer failure in the event of voltage transient or through fault.

Loose parts, sharp edges, delamination of bulk insulation, conductive particles in oil, bad contacts and gas bubbles in oil all have the potential to weaken the liquid and solid insulation system and to create partial discharges (PD) and arcing. Strong discharges as a result of these defects can decompose the oil/paper insulation and/or erode the conductive material.

Further failure can be caused by local overheating and burnings due to bad contacts, by circulating core ground current or bad or missing connections from core to ground and from magnetic or electric screens.

Transformer LTC

Load tap changers (LTCs) are the only part in a transformer that actively mechanically operate. Wear and tear of the mechanical parts and contacts can influence the ease of movements. Parameters like liquid temperature difference between the main tank and LTC compartment, DGA, motor drive torque, motor drive current index, operating time, contact wear or vibro-acoustic signature can be a good indicator to detect any abnormalities.

Transformer Cooling System

The main concern regarding the cooling system of a transformer is to ensure the oil and air flow through the coolers/radiators is always guaranteed. This can be done by natural convection for smaller transformers or, in case of larger power transformers, by a forced cooling system. In oil forced cooling system pumps are used to circulate the oil through the radiators/coolers and fans are meant to circulate the air through the radiator fins and cooler ribs to take the heat away. More complex systems are using water to cool the oil. In that case pumps are also circulating the water. If the cooling system is disturbed by malfunctions of fans or pumps, the oil and thus the transformer cannot be cooled down in an appropriate way, which can lead to overheating and transformer failure. Changes in the relationship of inlet and outlet temperatures of the cooling banks or changes of motor load currents,

fans and pumps can support an early detection of malfunctions. In a simplified approach, the top and bottom oil temperature correlation with the actual load condition can give a rough indication of a severe condition as well.

Transformer bushings

Bushings are components that guarantee the transport of the electrical energy (voltage and current) into and out of the transformer from and to the electrical network. For higher voltages mainly above 36 kV (for generator step up units and also high current bushings of 24 kV and 36 kV) capacitor type bushings are being used. The major causes of failure in bushings are moisture and partial breakdowns (breakdown between two or more conductive layers of the bushing insulation). Partial breakdowns are mainly caused by transient overvoltages or pre-deterioration due to partial discharges. Leakages on porcelain sealings especially in case of oil impregnated paper bushings (OIP) are responsible for moisture ingress. Meaningful indicators to look for here are the Power Factor and the Capacitance Considering catastrophic failures, according to [3], bushings are in 70% of the cases the cause, there are other components leading the transformer to fail but with less risk of a catastrophic failure.

Analytics and Correlative Analyses

Analytics is concerned with finding meaningful patterns based on input data, existing static models (like formular/calculations) to dynamic models (like machine learning data analytics) and converting it to a useful output. Correlative analyses can be part of the analytics or in a simpler way a standalone technique, combining information based on different parameters and from different sources. Both are using abstraction algorithms. The bubbling temperature model, which calculates the temperature for bubble evolution based on existing static model (formular) is an example of a simple static analytic model. It is used to determine the temperature

Table 1. Transformer failure statistic [2]

FAILURES & POPULATION	HIGHEST SYSTEM VOLTAGE [kV]						All
	69 ≤ kV < 100	100 ≤ kV < 200	200 kV< 300	300 kV< 500	500 ≤ kV < 700	>= 700 kV	
FAILURES	144	300	229	241	36	14	964
TRANSFORMER - YEARS	15,420	67,996	41,656	32,045	6,611	3,731	167,459
FAILURE RATE/YEAR	0.93%	0.44%	0.34%	0.75%	0.54%	0.37%	0.57%

Figure 4. Transformer major failure statistic [2]

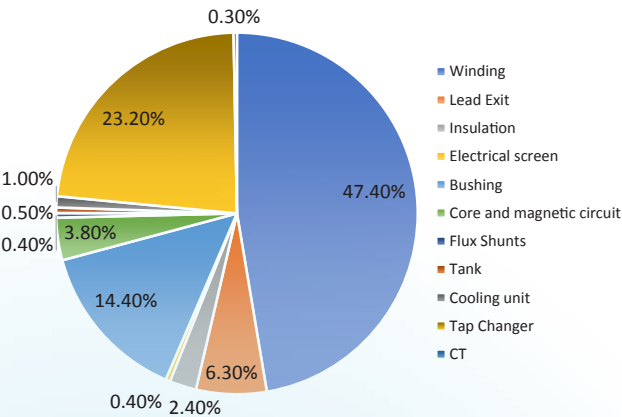


Figure 5. PD pattern recognition on PD data abstraction process

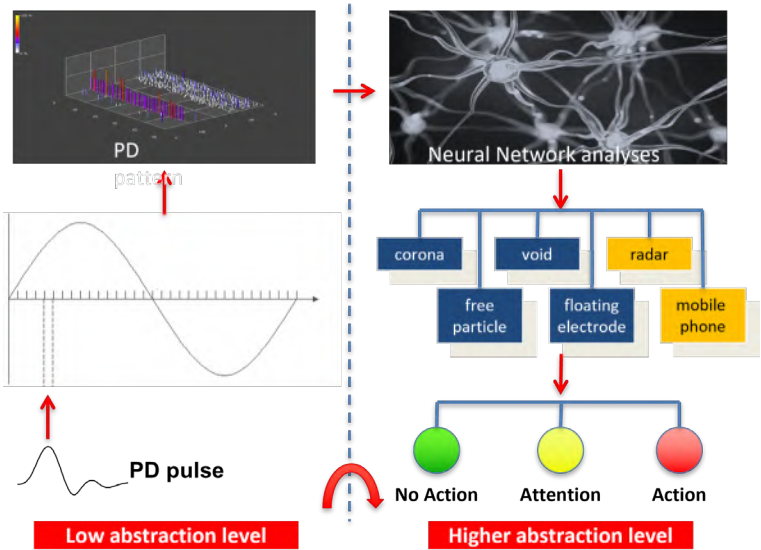
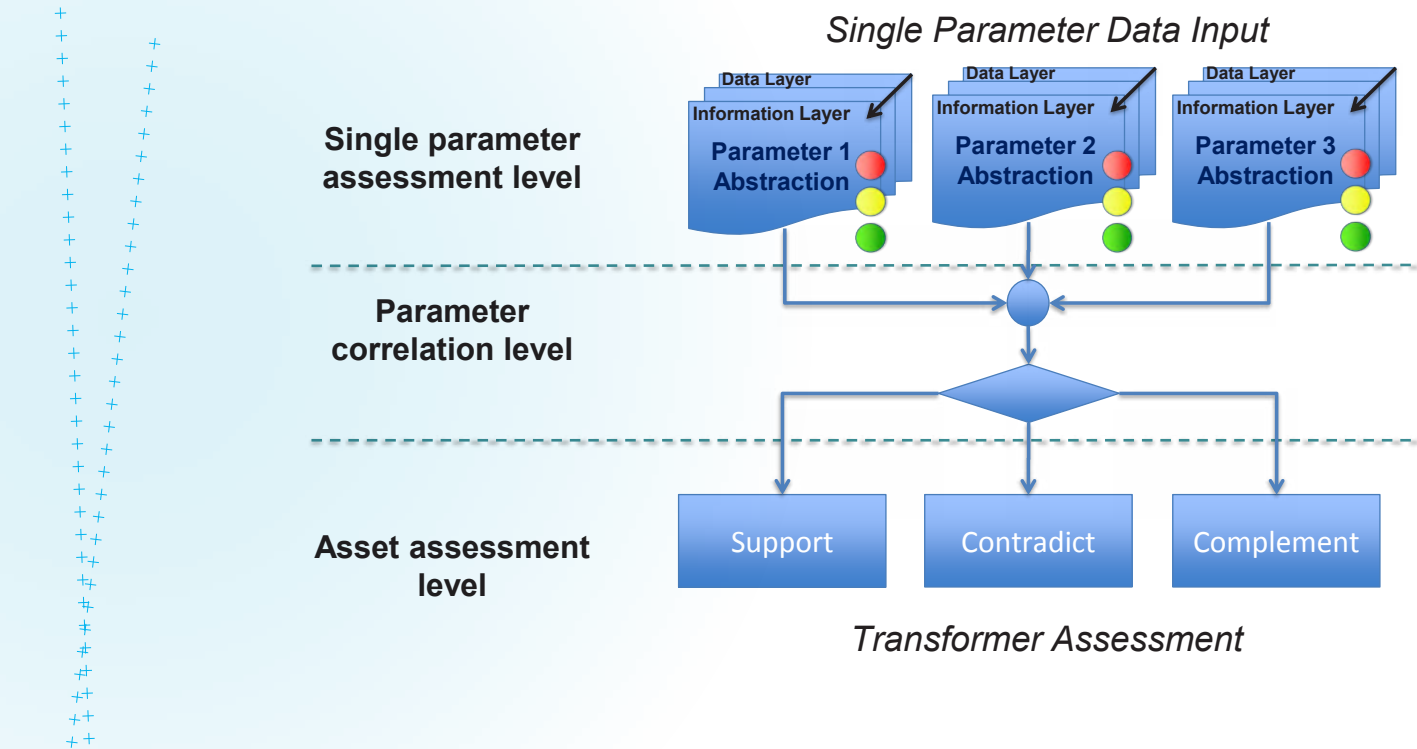


Figure 6. Overview correlative analyses



at which the gas bubble generation starts. To enable this calculation, a set of different input parameters needs to be known, like the hot spot temperature, moisture in oil, gas content in oil, pressure at the hot spot, temperature of the oil at the moisture sensor and the ambient temperature. A more sophisticated approach is the artificial neural network-based PD pattern recognition as shown in Figure 5.

Correlative analyses, instead, aim more at the "if...then...." approach (Figure 6). For example, if the detected moisture value in the transformer is higher than usual, this can be caused by different reasons. Reviewing the site visit reports shows that some oil drops have been discovered on the sealing of the transformer. That can be translated to *"If moisture has been detected and oil drops (signs of leakage) can be discovered, then there is a severe oil leak which influences the condition of the transformer"*. Similar approaches can also be taken between PD activity and DGA, PD activity and core ground current, etc.

Table 2 shows an example of correlative analytic models for failures in the magnetic circuit considering different parameters and its detection time.

Five different analytic models shown in Table 2 are readily available. For each of the models different input parameters need to be gathered and each of the models/parameters has its own detection time. It is useful to use more than one analytic model for a certain failure mechanism. In the above example most probably the DGA model, the core ground current model and the PD model would be the best fit. In that case the parameters to measure are dissolved gases, PD and the core ground current.

Similar models are made for different kind of failure mechanisms in the transformer main tank, LTCs, bushings, cooling systems, GIS, etc. Regarding the importance of that particular asset and its history a decision about the types of failure mechanisms needs to be considered for monitoring.

Practical Example

In this case a single phase, extra high voltage (EHV) autotransformer was equipped with a comprehensive monitoring package including DGA, UHF PD, bushing, and temperature monitoring. The transformer had been three months in service and experienced a catastrophic failure. DGA and bushing monitor did not alarm, but the PD monitor showed strong PD activity eight hours before the fault occurred. This shows that correlative analyses not only support or contradict each other, but also can complement each other as seen in this case. One method, the UHF PD, was able to detect the change of condition in real time, while one of the other two methods, the DGA, was too slow due to the time needed by the generated gasses to dissolve in the oil [5]. The utility did not have experience with the UHF PD monitoring and was not expecting this new transformer to fail. It decided to observe the PD behavior before setting thresholds to activate alarms, therefore, the UHF PD monitoring system was not connected yet to their Scada System and the failure was not detected. After this experience, the utility applied the history data to establish PD thresholds and was able to detect this type of behavior in similar transformers and avoid catastrophic failures.

Conclusion

The power industry today demands, besides the conventional transformer gauges and well established online DGA applications, a more comprehensive condition assessment approach to implement condition based monitoring principles, to make transformer operation more efficient and optimized, as well as to be able to detect incipient faults in an early stage.

The demand for analytic models, which allow users to make reliable decisions about their assets, is exponentially increasing. Using correlative analyses increases the confidence in transformer health assessments and will allow the use of complementary models.

Using analytic models and correlative analyses allows users to make reliable decisions about their assets, increasing the confidence in transformer health assessments and allowing the use of complementary models.

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Table 2. Magnetic circuit correlative analyses

	Component	Failure mechanisms	Analytical model	Measured signals/ parameters	Detection time
Magnetic Circuit	Core ground lead	Loss of core ground	DGA Model	Hydrogen or multi-gas	Hours
	Magnetic shield	Unintentional core and shield grounds create problems and discharges	Core Ground Current Model	Core ground current	Days
			Gas Accumulation Rate Model	Gas accumulation	Real time
			Thermal Model	Core hotspot (Fiber) Temperature	Hours
			PD Model	PD	Real Time

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2022 IEEE PES T&D Conference and Exposition: Reconnecting in the **Big Easy**

**Pre-show Interview with Wayne Bishop Jr.
Vice President of Meetings & Conferences
for IEEE PES**



Alan Ross

It's my pleasure to talk to a dear friend, Wayne Bishop, the Vice President of Meetings & Conferences for IEEE PES, about the IEEE PES T&D Conference and Expo coming up in April 25th through the 28th in New Orleans. But before we go there, I want to talk about how after you took over the role as Vice President of Meetings and Conferences, this thing called COVID hit. How has that impacted what you all have been able to do?

Wayne Bishop

I became the VP of Meetings & Conferences, a volunteer position for IEEE PES, back in 2019, and I was in it for about a year and a few months when COVID hit. And boy, did it hit. We had to quickly pivot all our meetings. Keep in mind, I oversee all our meetings worldwide for IEEE PES. We had to pivot from in person to virtual meetings and it was a tremendous undertaking. But we ended up reaching more members that way, digitally. For example, for our annual Power Africa conference we doubled the number of countries that attended the event, so we actually reached more members. But we can't wait to be back face to face. We just miss the camaraderie, not even necessarily the meetings themselves, but the coffee breaks, the meetings that occur outside of the main meetings and main conferences. So, I just can't wait to get back face to face.

Alan Ross

Having been to the last five IEEE PES T&D Conferences and Expos, the one thing I've missed is what happens on the Expo floor.

That's not a buying floor; people don't go there to buy. They go to learn. And it is a great opportunity for the people that show up and support the Expo to be able to explain new things. Technology is changing so much and rapidly, and you can deliver technical knowledge. But when you discuss technical knowledge, it kind of creates a camaraderie that you just have to experience. We get to meet with old friends, talk about new things, and connect with new people. I know that the host of this conference is Entergy, and they have put on a really good technical program to present. Talk a little bit about that.

**Alan Ross**

When we were set to do this in 2020, you had an innovation platform, and we were going to have a media platform. You had a lot of things that you were doing, including the "pay for one and get ten" to come from the utility industry, to try to get more practitioners. Are those initiatives still in place?

Wayne Bishop

As mentioned, this year's T&D Conference and Expo will be in New Orleans, and the host is Entergy, a great utility that got behind this with their team. The chair of the Conference and Expo is Michelle Bourg. Michelle is Vice President of Asset Management at Entergy, and she has assembled a great team. Heading up the technical program is Chang Wang, another very active IEEE PES member from Entergy. He has put together a great program that will consist of a great opening session with four super sessions throughout the week, panels, papers - literally hundreds of presentations. And as we mentioned earlier, there are so many changes happening right now in the utility industry and the power industry: everything from integrating DER onto the grid, through dealing with electrification of the transportation system, to our assets getting older and what we need to do with these assets and how we should be maintaining them with all of the trends that are happening. Our industry has had more changes in the last 10 years than the last 100 years. Many of these changes and how the utilities are dealing with the changes will be addressed at T&D.

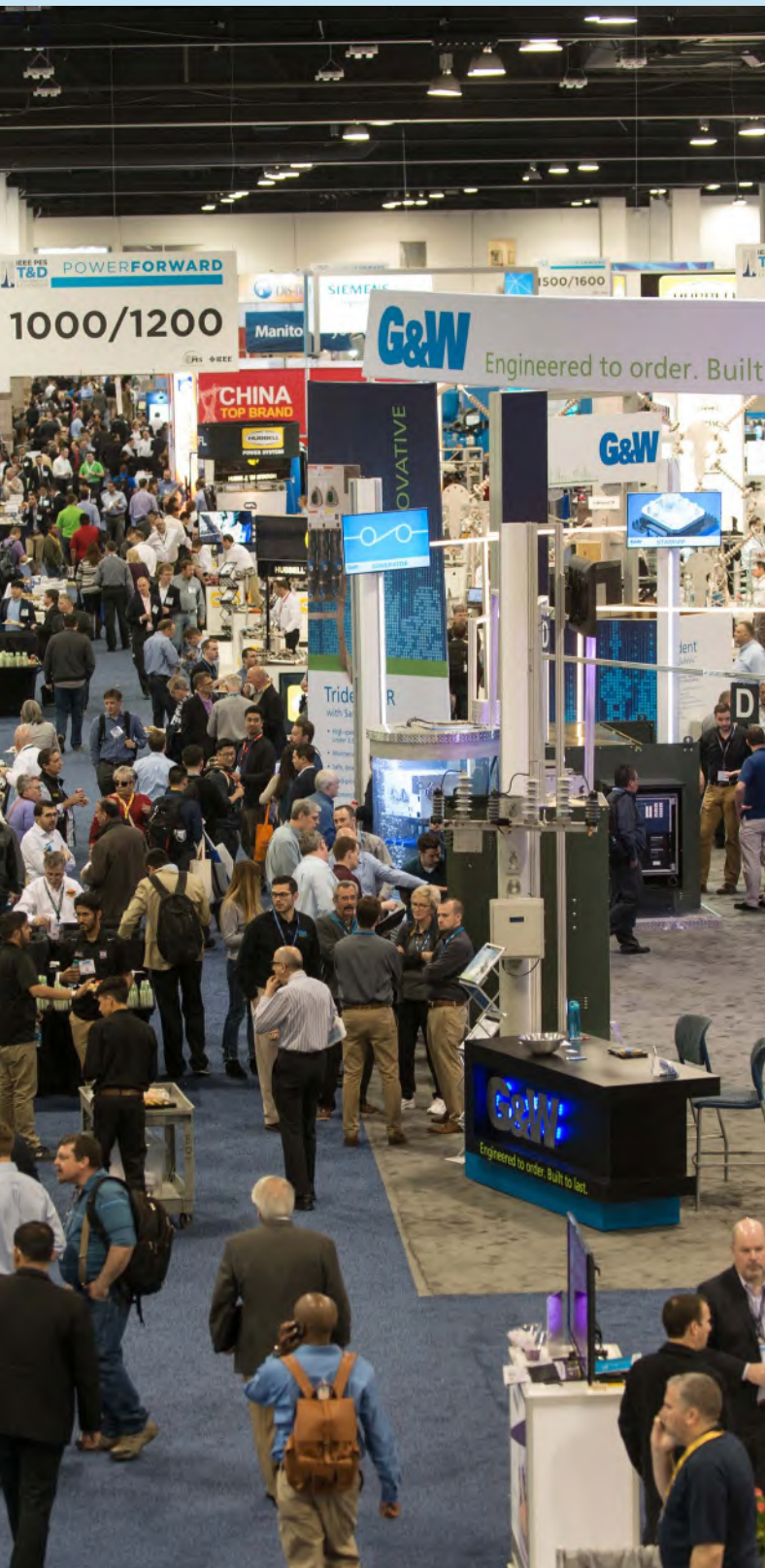
Regarding the Expo floor, I can't help but mention that we have over 550+ exhibitors covering every aspect of transmission and distribution, along with more big trends. We have made a lot of changes to T&D as well, new changes, new initiatives.

**Wayne Bishop**

We are proud of what we are launching for this T&D. We tried to launch it in 2020, but of course, T&D was cancelled. So this year we will launch officially our utility bundled pricing package and how that works.

Alan Ross

It sounds like you're a marketer.

**Alan Ross**

As a member of the IEEE Smart Grid program, we are envious of smart cities getting their own Pavilion. It has re-energized as well to focus on the 2023 Grid Edge Conference in San Diego. I'm sure you'll talk a little about that, and the Innovative Smart Grid Technologies (ISGT) for this year.

Wayne Bishop

I'm part marketing so that's the marketing coming out. As you said, we really want the practitioners there. We want the utility engineers to come, and we want the price to be attractive. **We are offering utilities to send ten people from the utility for only \$1,000. In other words, \$100 a person, grand total of \$1,000.** When we launched this back at the last T&D in 2020, we had over 100 different utilities take advantage of that, and you can send more than ten if you want to. If you send 20 engineers, it's \$2,000 still \$100 per person. That's the first big initiative to bring more people on the show floor.

The second initiative is the **Innovation Stage**. As you mentioned, we will have two of these innovation stages set up on the Expo floor. Our Technical Committee has chosen, I believe, 15 different companies who will make presentations on these innovation stages. The presentations will be on the new technologies and what's new, with big data, incorporating DERs onto the grid, and more.

The third initiative is the **IEEE Smart Cities Pavilion**. There is a lot of talk these days about smart cities, smart buildings and electrification of the transportation system, which are some exciting things happening in our industry. The IEEE Smart Cities Pavilion will address these changes.

**Wayne Bishop**

You'll be happy to hear, we were supposed to have our annual ISGT (Innovative Smart Grid Technologies) conference in February in Washington D.C., and of course, we had to cancel that because of COVID. What we decided is to co-locate ISGT in New Orleans in the Convention Centre at the same time as T&D. We are going to do our best not to have conflicting programs, but T&D attendees will be able to sit in on ISGT presentations, and vice versa. ISGT attendees will also be able to attend T&D, and they have some wonderful speakers lined up, including people from FERC, NERC, and utility executives as well, talking about a lot of the trends that relate to smart grid and some of the big trends that are happening in our industry.

Alan Ross

How are you handling Covid rules? Since you are letting the city, is the city requiring you to live by their compliance issues?

**Alan Ross**

For people in the utility industry, there's an excitement afoot with the change that is taking place. AV charging is going to change the grid. DER is changing the grid. An inverter-based system is completely different. Solid state technology is changing the grid. This is probably the most exciting time since we created the grid. There's a lot happening around the world.

At APC Media, we are going to visit the showroom floor and we are going to learn about new technologies and share the value that IEEE brings. The 2023 Grid Edge Conference and Expo is also going to build the new foundation for IEEE PES, and people should be excited to come and learn, come and share, or come and just network with each other.

Wayne, any last thing that you want to share?

Alan Ross

Wayne, thank you for the work that you do for IEEE. All of the volunteers give so much, but soon you are hooked because the giving that takes place allows others to take knowledge and understanding. IEEE is much more than a standards organization. Absolutely.

Alan Ross

Wayne, it has been good to talk to you. See you in April in New Orleans.

Wayne Bishop

Exactly, Alan, we want to reconnect safely, and we want everyone to know that IEEE PES T&D will take your safety as the first priority, and our number one priority. We will not only comply with all the mandates of the city of New Orleans, but we'll do whatever else we need to do.

We are going to have the hand sanitizer stations set up everywhere around the Convention Center. If they mandate masks, which they probably will, we'll have those on in the Convention Center. There will be several events that will be partially outdoors, like the opening session, or the opening reception that will be on Monday evening, the 25th, at the Mardi Gras Pavilion.

But they are ready for us and they are excited about T&D. [Registration is now open. The housing block is open](#) and there are good discounts available. I'm extremely excited to be back in person and I can't wait to see all my colleagues ready to reconnect with everybody.

**Wayne Bishop**

The only other thing to mention is that T&D event is not a U.S. centric or North American centric show and event. It's very much international. In normal times, we would get over 90 different countries to attend and be represented. I think we'll easily have 60 or 70 different countries represented this time. You can go to the show floor, talk with the subject matter experts at the exhibitor's booth and discuss new concepts or products with them. You can now go to the innovation stages as a new initiative, or you can visit our IEEE Smart Cities Pavilion. This is definitely not your same old T&D. It is something for everyone. And now with ISGT being co-located, it's even better. I am looking forward to seeing all our colleagues there in April.

Wayne Bishop

It really is. It's a big family of over 40,000 members strong.

Wayne Bishop

Thank you, Alan.

Leading the Charge: Coatings Stand on Front Lines in Protecting Electrical Components

by **Maria Lamorey**

+++++

Coatings are the first line of defense to safeguard the critical infrastructure from a variety of conditions. Selecting the proper coating materials to help preserve power generators, transformers, switchgear and more is crucial.



Maria Lamorey is a commercial strategy manager at PPG. With over 20 years of industry experience, Maria plays a leading role in PPG's commitment to delivering high-performance coatings products across a variety of general industrial applications including electrical equipment of all types.

Millions of cars and trucks over the next decade will be running solely on electricity, while wind- and hydrogen-based power sources continue to gain momentum. In fact, 20% of all electricity generation in the United States came from renewables in 2020, a number that is only expected to increase.

This growing demand, coupled with an aging power grid in the U.S., creates a need for an infrastructure built for longevity. Promising new developments will help. The recent infrastructure bill has become law, an act that allocates \$65 billion in support for our electric and grid infrastructure.

While most electrical equipment holds a minimum life expectancy of 20 years, many components are expected to survive 50 years or more. Harsh elements can accelerate corrosion and leave sensitive instrumentation vulnerable during storms and compromise its reliability. Unfortunately, many manufacturers still combine old “cut-and-paste” specifications that date back 20 to 30 years with current industry-standard regulatory requirements written by IEEE, UL, CSA and ASTM when painting and protecting new equipment.

Coatings are the first line of defense to safeguard this critical infrastructure from a variety of conditions. Selecting the proper coating materials to help preserve power generators, transformers, switchgear and more is crucial. According to the Electric Power Research Institute (EPRI), the cost of corrosion-related problems in the electrical industry exceeded \$17 billion as recently as just a few years ago. Yet, roughly 20% or more of these corrosion costs are avoidable.

There is a wide range of coatings available that are engineered to preserve the future of our power generation infrastructure.

Gaining an Edge

Metal substrates that typically comprise electrical components can corrode for a number of reasons, including repeated exposure to high temperatures and humidity,

damaging pH (acid) levels, electrolytes, chemicals and ultraviolet (UV) light.

This type of corrosion typically starts on sharp edges or an oddly shaped part that may be difficult to coat. In harsh environments, weaknesses on areas like louvers and sharp corners can lead to subsequent damage. That's why high-edge coatings, equipped with superior sharp edge coverage, along with edge and face corrosion protection properties, can help to provide the exterior durability that electrical components require for reliability and longevity.

For components such as transformers that contain elements like oil, it's important to utilize coatings not only for their corrosion resistance, but for their chemical-resistant properties. It's also important to consider heat dissipation and size when it comes to coating transformers. Some transformers, especially those that are larger, are required to be fully assembled prior to their last coat of paint, then properly air-dried. High-edge coatings help to ensure that even the hardest-to-reach parts are covered.

Smart Specification

On average, finished electrical components are composed of about 70% metal and 30% non-metal substrates, yet nearly 100% of electrical equipment manufacturers view painting metal as beyond their core competency. An average-sized switchgear manufacturer running 10 to 15 million square feet of coated metal through its facility is staking a lot of its reputation on work considered outside of their scope.

Additionally, some equipment manufacturers still base their paint specifications solely on achieving a minimum industry standard or according to a specification written by a paint supplier. Paint manufacturers often contribute to the problem by designing coatings systems that merely meet old specifications or achieve industry standards dictated by customers, instead of featuring the newer technologies that provide better field appearance and anti-corrosive properties.

According to the Electric Power Research Institute (EPRI), the cost of corrosion-related problems in the electrical industry exceeded \$17 billion just a few years ago; yet, roughly 20% or more of these corrosion costs are avoidable.

If the goal of an electrical equipment manufacturer is to build next-generation components that exceed performance mandates while protecting its brand reputation, paint specifications should be reviewed and updated regularly. In addition to product scope and substrate type, manufacturers should address the following criteria:

- Paint type
- Substrate preparation and protection
- Color
- Gloss
- Texture
- Cure
- Product handling and storage
- Performance

High-edge coatings, equipped with superior sharp edge coverage, an edge and face corrosion protection properties, can help to provide the exterior durability that electrical components require for reliability and longevity.





Three's Company

When reviewing these specification criteria for electrical components, there are three major coatings technologies that can be considered—powder, liquid and electrocoating formulations.

Powder coatings are formulated for applications that require the ultimate combination of corrosion resistance,

weathering performance and operational attributes. These coatings are typically formulated with specific resins combined to provide excellent corrosion and chemical resistance, as well as all-around application versatility.

Since powder coatings are made without solvents, they generate virtually no volatile organic compound

(VOC) emissions, which can help to achieve environmental compliance and reduce material usage, energy consumption and maintenance costs, thanks to a first-pass transfer rate of up to 85%.

Liquid coatings use solvents or water and are applied to pretreated metal with electrostatic spray, dipping and other conventional methods before



If the goal of an electrical equipment manufacturer is to build next-generation components that exceed performance mandates while protecting its brand reputation, paint specifications should be reviewed and updated regularly.

being air-dried or force-cured. When used as part of an integrated primer, pretreatment and topcoat system, liquid coatings offer exceptional resistance to corrosion and chemicals, excellent sag resistance and strong adhesion.

During the electrocoating process, pretreated metal substrates are immersed in an electrically charged paint bath. Charged coating particles form a tightly packed, insulating layer that reaches every recessed area of the coated part. At the end of the coating line, the metal part is baked, creating a tough finish that offers more thorough coverage.

Aesthetic Considerations

While anti-corrosive properties

are the driving force behind most specifications, color is also an important consideration. In fact, corrosion and color are essentially linked. The best-looking generators are the ones you can't see, as weathered components that appear orange and rusty are not aesthetically pleasing.

Transformers and generators that are rusty often raise questions about performance and effectiveness. Coatings that help these components essentially blend into their environments tend to be preferred, helping these components look the part and withstand corrosive environments.

Finding the Best Solutions

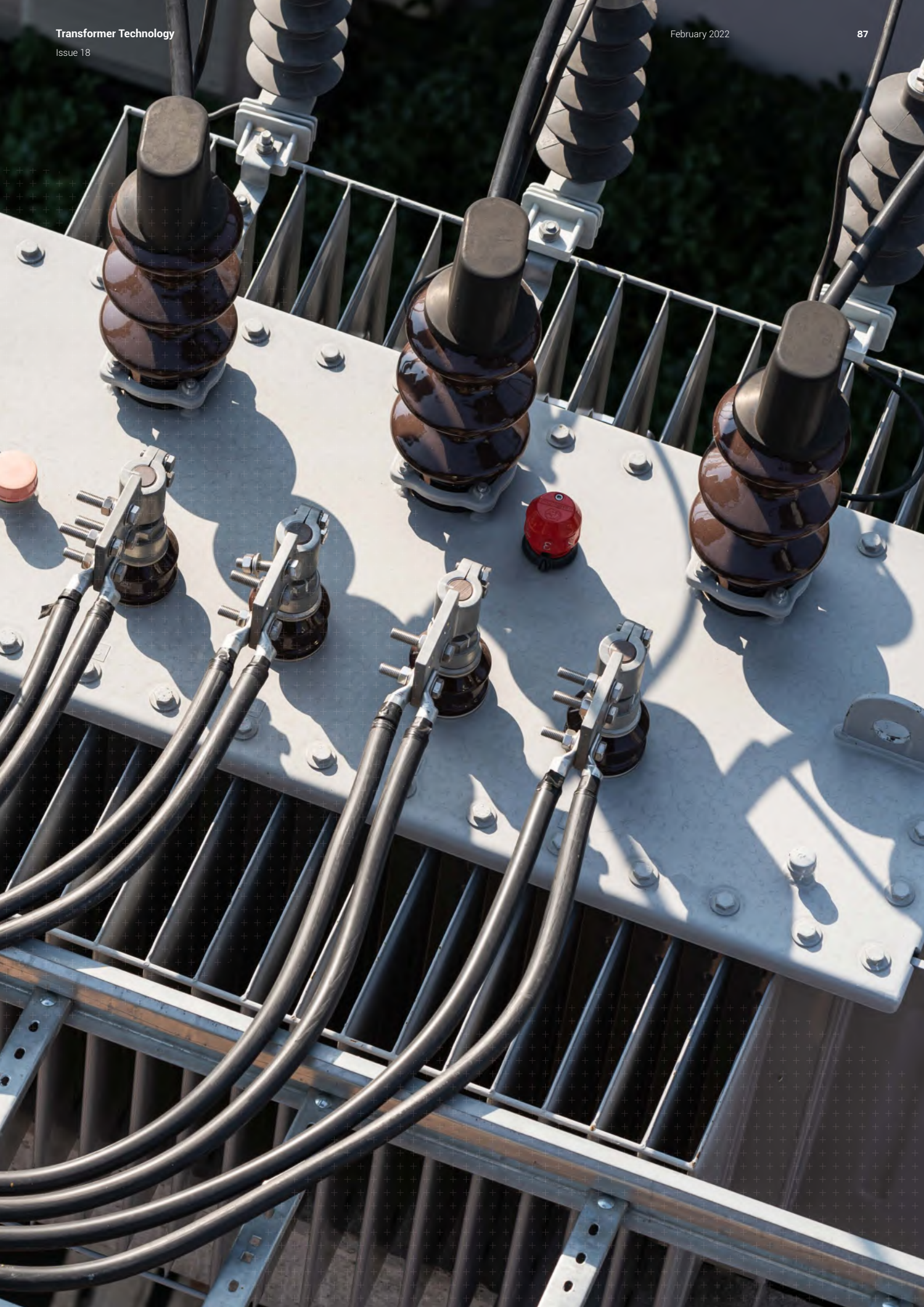
Electrocoat, pretreatment, powder and liquid technologies are all great coating

solutions for electrical equipment. It is important to consider several different factors to select a customized coating system that is ideally suited for the project and based on specific objectives, including:

- The specific region to determine how the weather will influence corrosion, color fade, performance, etc.
- The specific substrate and shape to be coated; specific coatings are better for coverage on complex parts and sharp edges
- Aesthetics and color
- Product longevity and life cycle requirements

Utilizing this information and working with an industry expert can help determine the best coating system for the project.





New Design and Advances in Technology

When we were planning the themes for 2022, we believed it was time to expand them beyond the “power transformer” and the technical aspects relating to those transformers, without moving too far afield.

The upcoming April digital magazine focuses on **New Design and Advances in Technology**, with the following suggested topics:

ADVANCES IN DRY TYPE TRANSFORMERS
FANS AND RADIATORS
GAUGES
PROTECTION SYSTEMS
CONTROL TRANSFORMERS
CABLES AND BUS WORK

Of course, at the heart of the power system is the transformer, so expect some great content from our community members who consistently provide valuable technical insight. And if you have an idea for an article, please contact me at

Alan Ross, *Editor in Chief*

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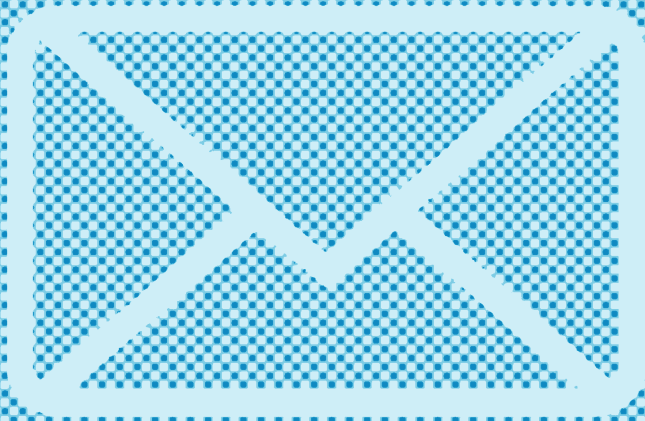


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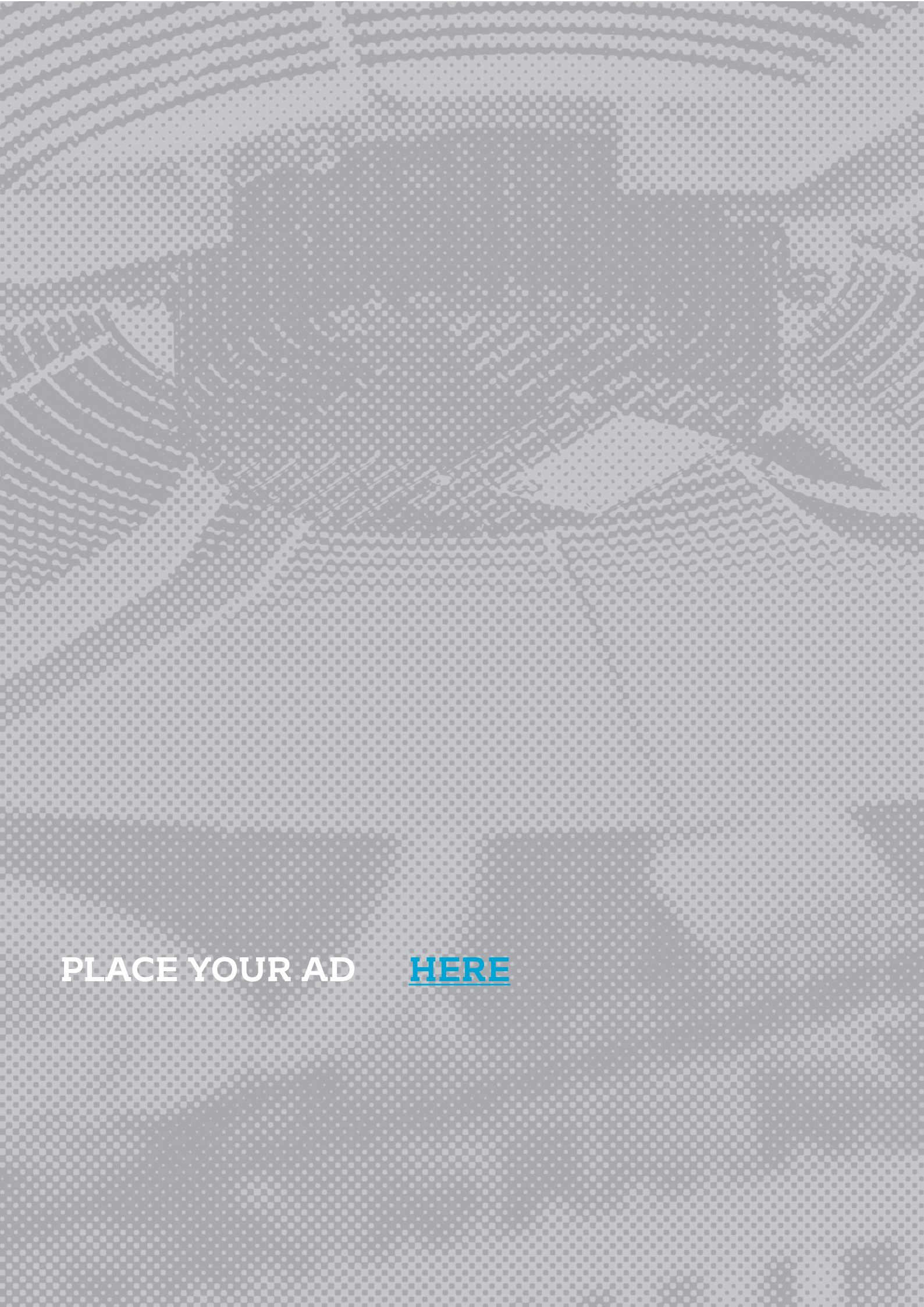
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