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TRANSFORMER TECHNOLOGY MAG

# TRANSFORMER TECHNOLOGY MAG

# POWER SYSTEMS MONITORING & DIAGNOSTICS

SPECIAL SUPPLEMENT INSIDE

POWER SYSTEMS TECHNOLOGY

Managing Plug-In Electric Vehicle (PEV) Charging Profile **Utilizing Online Distribution Transformer Monitoring**
Interview with **Senja Leivo** DGA Monitoring on End-of-life Transformers
**Smart Grid Sensors:** Improving Reliability for Distribution Grids During Energy Transition and Grid Modernization

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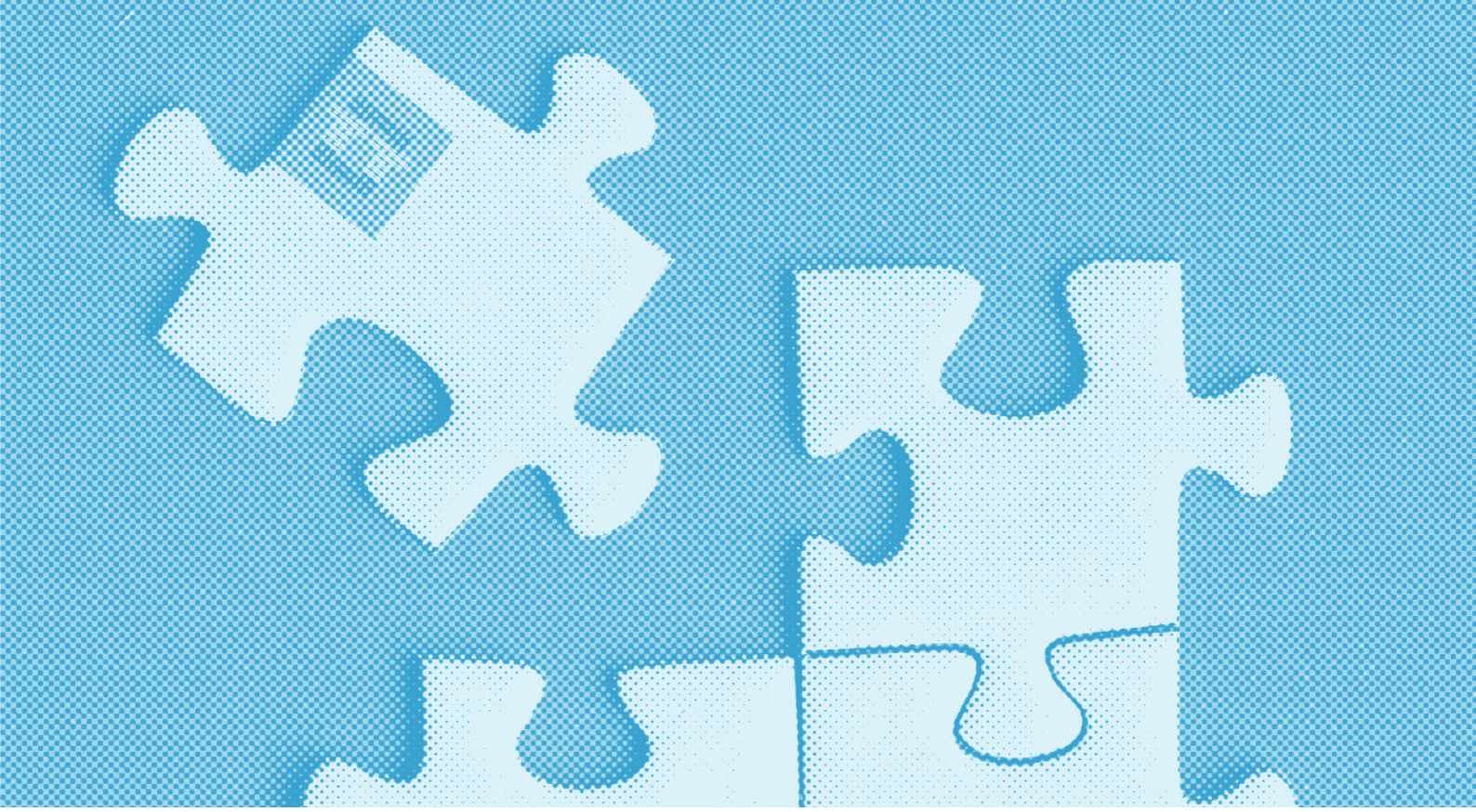

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*Photo: Mike van Schoonderwalt from Pexels*

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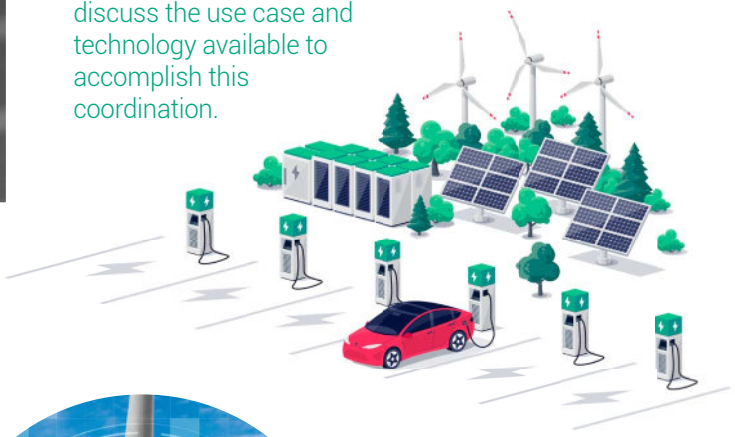
## Managing Plug-In Electric Vehicle (PEV) Charging Profile Utilizing Online Distribution Transformer Monitoring

The use of smart infrastructure solutions based on industrial IoT technology can manage electric vehicle charging based on real time capacity of distribution transformers and circuits. This paper aims to discuss the use case and technology available to accomplish this coordination.



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## Smart Grid Sensors: Improving Reliability for Distribution Grids During Energy Transition and Grid Modernization

In recent years, distribution networks have seen many new challenges in operation and demand which leads to increasing criticality of medium and low voltage grid assets. This drives the need for visibility, efficiency, and automation, while Smart Grid sensor technologies are rapidly improving solutions for distribution system operators (DSOs) to meet this need.

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POWER SYSTEMS TECHNOLOGY

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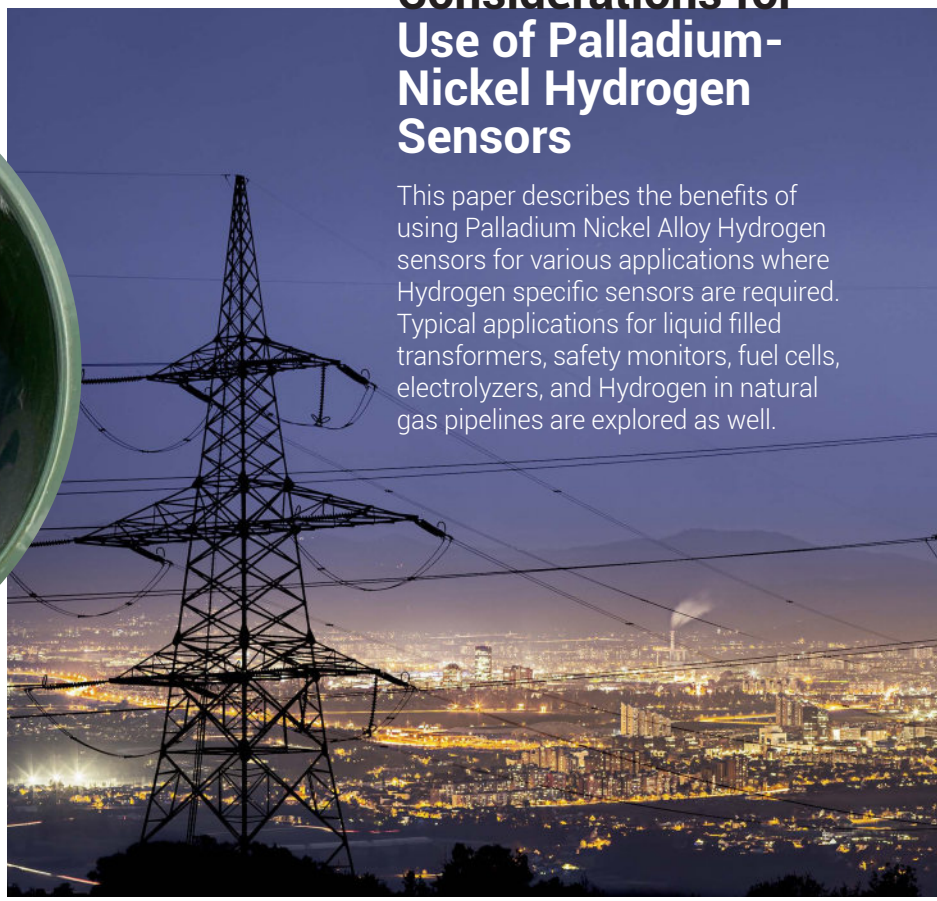

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## InsuLogix® SSK + RFM – Deployment on Renewable Pad Mounted Transformers

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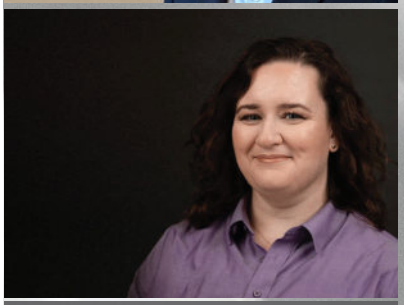
TAB Member
**Curtus Duff**
Power transformer design



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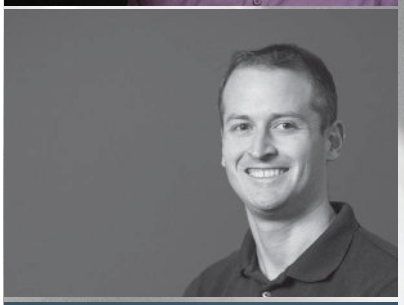

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Power Systems,
Relay protection, Training

**Dear Readers,**

We kick off the June issue of our digital magazine with two key thoughts in mind, and if we were to use keywords to describe them, they would be Retirement and Data.

Let's look at data and the implications it has for Transformer. Technology and for Power Systems Technology, our new platform that will support our widened focus on the entire power systems industry (visit PST webpage and PST LinkedIn page). The key to understanding the reliability and operational functionality of an asset or assets in a system is to have as much real time and actionable information as possible - and information requires data. While this issue is about monitoring and diagnostics, in truth it is about the acquisition of data. Last year, a major northeast utility hired more data scientists from college than they hired electrical engineers. That speaks volumes about how important data is and will be for the power industry.

DGA monitors for transformers are not that new, but the widespread application of them from simple hydrogen monitors to more complex nine-gas monitors has become the industry norm, with most OEMs offering them as standard equipment. What is new is the use of all that data in the decision-making process as to whether a piece of equipment is in imminent failure, and how to prepare for two things: growth in the demand for more electricity and the aging of transformers.

At the recent IEEE PES T&D conference in New Orleans, I had the pleasure of interviewing 38 thought leaders, focusing on what they saw as the future for the power industry in North America and Europe. (visit IEEE PES Interviews page). Nearly every one of those I interviewed mentioned that the demand for more power, led by a revolution in EV transportation along with other mitigating factors, was going to increase over the next decade. Growth in demand, whether you believe it to be a 30% increase, or a 100% increase, will lead to new infrastructure and new infrastructure leads to the need for information. Where and when to replace old, aging assets also adds a new challenge, one which excites those of us who have been part of the power industry for decades.

Many of these incredibly robust assets, especially transformers, are well beyond their expected life, and with lead times increased to six months for smaller units and up to 60 months for major generation units - driven mostly by increased demand, but also by supply chain and labor shortages - these are the two specific challenges that all transformer OEMs I interviewed mentioned. The industry relied on these aging assets for longer than expected, but now is the time to use information from good data for life-cycle management. While not all actions being taken by these OEMs will fix the issues in the short term, they will bring more potential and stability in the future. And it is very likely that most major transformers will have monitors installed at the factory.

**In August we add Power Systems Technology to our offerings, alongside Transformer Technology, as well as new stand-alone digital services like our Webinar, Spotlight and Showcase offerings.**

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That leads me to the second keyword: Retirement. While continuing to serve as co-leader and Technical Director for APC Media, I have retired as the President of the Electric Power Reliability Alliance (EPRA), an organization I helped found in 2018. While I will continue with the drive to create more safety and reliability in industrial and commercial applications as a Fellow of EPRA, I will no longer serve as the formal leader. It has been a tremendous blessing to have founded EPRA and I will support the work of so many committed practitioners who are developing our certification program, the Certified Electrical Reliability Professional (CERP). Retirement also means spending more time with my new granddaughter, Maya, our first, and serving APC Media and IEEE as we deal with all the challenges facing the power industry.

In August we add Power Systems Technology to our offerings, alongside Transformer Technology, as well as new stand-alone digital services like our Webinar, Spotlight and Showcase offerings.

Our August digital magazine will focus on **Substation Solutions** the following sub-themes:

- Role of thermography and ultrasound for testing
- The Art of Partial Discharge testing
- New & Advanced Technology

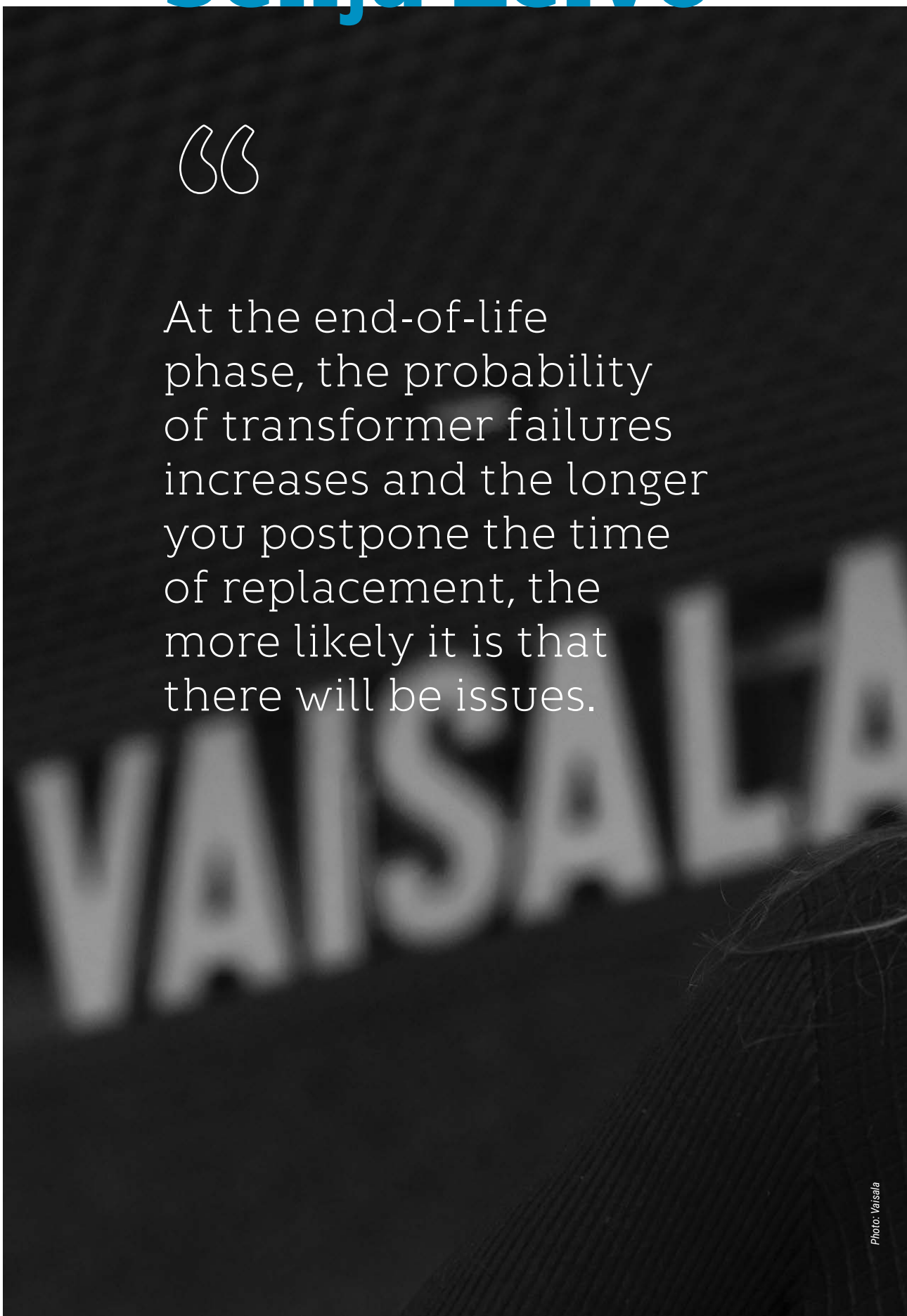
While we already have some key Technical Advisory Board (TAB) members lined up for articles or interviews, I would love to hear from you if you are interested in adding to the Body of Knowledge that you believe will advance the cause of power system asset reliability or life cycle management. We always welcome new content and new contributors to our growing TAB.

Alan M Ross
CRL, CMRP
Editor in Chief
APC Media
Technical Director

# Senja Leivo

**Senior Industry Expert**
at Vaisala Oyj

Interview with **Senja Leivo**

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At the end-of-life phase, the probability of transformer failures increases and the longer you postpone the time of replacement, the more likely it is that there will be issues.

Photo: Vaisala

VAISALA

# DGA Monitoring on End-of-life Transformers

**In this interview with Senja Leivo of Vaisala, we discuss several topics that are both timely and relevant to the safety and reliability of all electrical system assets, particularly transformers. We have focused primarily on DGA monitoring because we believe it is arguably one of the most important tools that you can use if you're looking at the condition of a transformer.**

Senja Leivo and Riku Rantala installing the monitor at a utility in Latin America

**Senja is a thought leader who brings not only her technical insights, but also a grasp of the marketplace and the changes going on in it.**

*Photo: Vaisala*

**Alan Ross:** We are delighted to welcome in this interview Senja Leivo from Vaisala, a Senior Industry Expert and a brilliant leader of the technical and development part of Vaisala.

**Senja Leivo:** Thank you for having me here.

AR I would like us to talk about something that has been quite intriguing, and a very much talked about topic in the industry - DGA. DGA technology is probably one of the most important tools that you can use if you are looking at the condition of a transformer, and probably the most important non-invasive condition monitoring technique. But what we see as almost a phenomenon happening is, what we would call, end-of-life monitoring. A lot of people think, "Well, it's the end of life, I'm just going to replace the unit". And they begin doing their end-of-life capital planning to replace it. But one of our partners who does market research in this area recently told us that the global lead time for power transformers - including anything from a distribution transformer all the way up to a GSU - has gone from about two years and two months to three and a half years, which is almost 50% longer.

So, the end of life has become critically important. With that in mind, why would it be important to continue to monitor end-of-life power transformers in the utility industry?

SL Obviously, it depends a lot on the policies of utilities, and on what grounds they get a replacement, whether the decision is based on age only or on condition as well. I guess it's more and more coming that the decisions are based on the condition of the transformers rather than transformer age just because it is such a huge capital cost for replacing big power transformers. At the end-of-life phase, the probability of getting failures increases and the longer you go, the longer you postpone the time of replacement, the more likely it is that there will be issues. And like you said, DGA is the way to see those evolving or developing issues inside the transformer.

AR As a reliability expert, I love the bathtub curves and they have recently been showing us that that end-of-life stage has been extended. People are taking better care of their transformers. But as you said, if it's just age you are looking at, you're going to probably make bad decisions. If you are also looking at the condition, you will make much better decisions about capital planning. There is a group out of Southern California Edison that did some research and they applied machine learning on the difference between replacing distribution transformers based on age and based on condition and they focused on the seven conditions around a substation. Once they started taking condition into account, they saved $21 million when they first back-tested it in 2017. They then back-tested it again in 2018, and it went up to $40 something million. And given the lead times we've mentioned, that could even now be in the hundreds of millions of dollars for utilities. But there are some specific other things that matter here. Let's say that you have an older transformer, and you already know there is a fault. Why would you put a monitor on that transformer?

**Placing a DGA monitor on a transformer that already developed a fault is one of the biggest benefits of online monitoring at the end-of-life phase. It gives you time to react and prevent the fault developing into something severe or catastrophic.**

SL Because that fault you have there may develop further and become more serious. And I think that's really one of the biggest benefits of online monitoring at the end-of-life phase. You have the fault there already, and it's possible and many times even likely that it will develop for the worse. By having online real-time DGA monitoring there, you can see if the gas build-up is accelerating. And if it is, it means that the fault is developing into something further and more serious. This gives us time to react, even though the lead times are so long. Of course, you don't have the replacement for the next morning, but at least you are able to take that transformer offline before something really severe or catastrophic happens.

AR And the costs of a catastrophic failure are significantly higher. Number one is getting a crew in to replace it. And here we have to talk about safety. In the U.S., OSHA - Occupational Safety and Health Administration, the government agency that tracks injuries and workplace injuries, now has the power to fine and prosecute through civil and even criminal penalties. If a company is not doing a good job at preventing injury, you are ten times more likely to die from a catastrophic failure of a piece of equipment in the electrical world than you are in the mechanical world. That ought to scare us into realizing that we cannot let it come to a catastrophic failure.

Could you talk a little bit about your perception of why the monitors give us an extra measure of safety in the whole process, given what I just said about injuries and fatalities?

SL Yes, I've discussed this topic with a couple of utilities here in Europe. They have internal policies in place for such cases. If they have what they call "suspicious transformers" that are in the end-of-life phase and are showing a tendency towards gas, instead of performing more frequent oil samplings, they fence that transformer off so that people don't get too close to it. And they have online monitoring instead to show if the faults are developing. So that is the safety measure for personnel. No need to go close to a suspicious transformer.

AR You once mentioned in a presentation that I listened to that when you use monitoring, it allows you to do end-of-life or do whatever you're doing in a controlled manner. What does "in a controlled manner" mean?

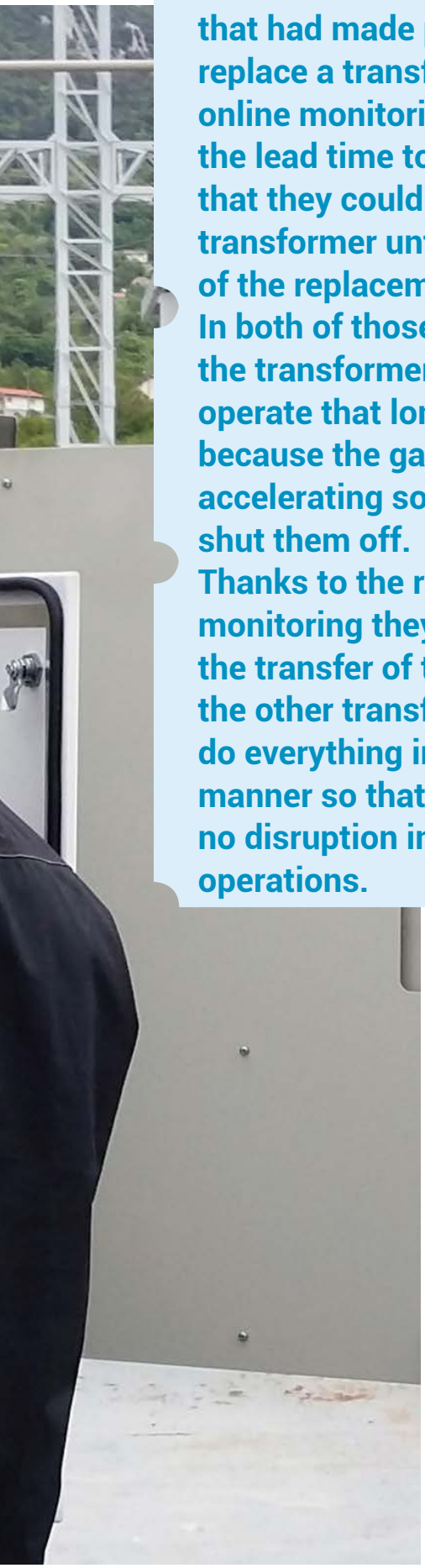
SL For example, we have had a couple of cases recently where the utility company had already made plans to replace a transformer and had foreseen a certain number of months until the ordered transformer would arrive, and the replacement would take place. Meanwhile, they had online monitoring to be sure that they could use the old transformer to the end just before the replacement. In both of those cases I'm talking about, they couldn't wait that long because the gassing was increasing and towards the end even accelerated until they just had to shut it off. Thanks to the remote monitoring they could plan the transfer of that load to the other transformers and do everything in a controlled manner so that there was no disruption in the actual operations.

**The end-of-life phase monitoring is most crucial for transformers with pre-existing gassing issues.**

Senja Leivo, Riku Rantala and Toni Mellin installing the monitor at a utility in Asia

*Photo: Vaisala*

Photo: Vaisala



**We have had a couple of cases where the utility that had made plans to replace a transformer, used online monitoring during the lead time to be sure that they could use the old transformer until the time of the replacement.**
**In both of those cases, the transformers couldn't operate that long because the gassing was accelerating so they had to shut them off.**
**Thanks to the remote monitoring they could plan the transfer of that load to the other transformers and do everything in a controlled manner so that there was no disruption in the actual operations.**

AR It's interesting. Years ago, there was a trip-down, if I'm not mistaken, in Argentina. And that one trip caused an overload because it was unplanned, and it almost shut the entire grid of Argentina down. In fact, there were areas that were shut down and it was because of that uncontrolled manner of a fault causing a problem that exacerbated it. In Europe and in the United States, so many utilities now have created relay systems that enable that load transfer. And it's so much easier to route it around when you know it's going to happen.

With everything we have just said, there is no reason for a utility not to put a DGA monitor on an older transformer. Are there any other reasons why they ought to do it? Because that's the case we're making today.

SL Concerning the end-of-life, I think those are the ones that have occurred to me, and where I have the most experience. There was also one case where a transformer had a thermal issue for years. It was producing some gases and they followed it and added cooling systems to it and so on. But again, towards the end, it was clearly developing and by having the online monitor, they could react to that early enough because they had installed alarms in their systems. There was, of course, some extra work because they had to replace that transformer earlier than they initially anticipated. But everything happened in a controlled manner so that the electricity production was not interrupted at all. The way I see it, online DGA monitoring at the end-of-life phase is most crucial for transformers with pre-existing gassing issues, and they obviously know that based on their manual DGA samples.

AR So last time we spoke, we made a case for putting DGA monitors at the beginning of life on newer transformers in service and now we've made a case for putting monitors on transformers that are at the end of life. You've made a great case for that. Thank you so much for joining us today.

SL Thank you,
it was my pleasure.

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# DRY-TYPE DISTRIBUTION TRANSFORMERS FROM SIEMENS ENERGY

**Keywords:**
dry-type transformers
cast-resin
data center
GEAFOL
Siemens Energy
CARECO

**Since the product launch in 1966, GEAFOL cast-resin transformers from Siemens Energy have been providing a wide range of customer benefits. Some benefits are exactly the same as 56 years ago: the reliability and quality of the transformers haven't changed. But the energy market is growing, changing, and evolving, just like Siemens Energy and other customer benefits of dry-type transformers. The newest GEAFOL dry-type transformer from Siemens Energy with a rating of 45 MVA offers the perfect answer for the challenges of our dynamic times.**

*Photo: Siemens Energy*

## Changing industrial landscape

In the last couple of years, an interesting change has happened in both the industrial and urban landscape. Many metropolitan areas of the world developed rapidly, which naturally has also led to an increasing demand for energy. This steadily growing energy demand is a worldwide phenomenon. For many people all around the world, having energy is something completely natural; for many others, it still seems to be an unattainable luxury. But there is no doubt that everybody needs energy. As metropolitan areas grow, the inclusion of industrial areas into very densely populated and frequented parts of the cities becomes more common. The explanation is simple: free space is becoming a scarce resource. High-rise buildings, hospitals, data centers, metro stations, oil rigs, paper mills, airports, and other infrastructure have high power requirements. Transformers often operate near residents, separated from their immediate surroundings only by a single wall. Accordingly, the safe and secure operation of transformers is simply a must.

Distribution transformers are particularly in focus as they bring the power to the final energy consumers – to factories, to large commercial buildings, to hospitals, or even to data centers. The reliable and safe operation of distribution transformers has become more important than ever.

Is it possible to react flexibly to the customer needs? To maintain safe and reliable grids? To produce transformers which are able to operate safely even in urban areas? To install large transformers near residential areas without any risk for the residents? Is it possible to achieve zero harm and, at the same time, offer a cost-efficient solution? And most important: is it possible to do it in an environmentally friendly way?

Complex questions, one simple answer: **GEAFOL from Siemens Energy**.

**Fire- and explosion-proof, robust, reliable and green, GEAFOL and CARECO dry-type cast-resin transformers from Siemens Energy meet the highest safety requirements of the energy distribution infrastructure, especially in urban areas.**

## The safe, reliable, and green choice

The energy distribution infrastructure, especially in urban areas, must meet the highest possible safety criteria. It must be fire- and explosion-proof, robust, reliable, and green, as transformers and switchgears are often separated from their immediate surroundings only by the wall of the substation.

All these requirements can be met with GEAFOL[1)] and CARECO[2)] dry-type cast-resin transformers from Siemens Energy. Dry-type transformers do not contain any insulation oil and are therefore better suited for use in an urban environment than liquid-filled transformers. Dry-type cast-resin transformers operate with high-voltage windings, fully encapsulated in cast-resin insulation. This avoids the need for a tank with insulation and cooling liquid. Dry-type cast-resin transformers provide a particular degree of safety during operation, especially due to their electrical strength and excellent fire-related behavior. They are flame-resistant, self-extinguishing, and, at the same time, eco-friendly as well as nearly completely recyclable. GEAFOL and CARECO from Siemens Energy are insulated with an epoxy resin / quartz powder mixture instead of oil, which is a very environmentally friendly alternative. They can be used practically everywhere: there are no restrictions on the place of installation.

Cast-resin transformers are the safest choice for high-rise buildings, data centers, oil rigs, hospitals, airports, ships, metro stations, and other infrastructures with high power requirements. At the same time, GEAFOL and CARECO are eco-friendly and up to 99% recyclable.

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1) GEAFOL: Cast-resin transformer with aluminum windings
2) CARECO: Cast-resin transformer with copper windings

There is no risk of oil contamination, as these transformers do not contain any oil. For areas where the protection of flora and fauna is of extreme importance, cast-resin transformers are the perfect, green choice. Additionally, cast-resin transformers are practically maintenance-free and maintenance costs are therefore negligible. The lifetime of cast-resin transformers is 25+ years. These two facts, among others, make cast-resin transformers a cost-efficient solution.

As a result, it is no surprise that more than 150,000 GEAFOLs have been installed by Siemens Energy worldwide so far, and the percentage of cast-resin transformers, compared with oil-immersed distribution transformers, continues to grow.

### High electrical strength and small size

Another advantage of cast-resin transformers, which often receives little attention, is the selection of materials and their precise processing in order to achieve high dielectric and mechanical strength.

GEAFOL cast-resin transformers are available in the rating range up to approximately 50 MVA and for operating voltages up to 72 kV. They operate reliably even at altitudes of -1,500 to +6,000 meters and ambient temperatures from -60 °C to +60 °C.

Distribution transformers are mainly used where electricity needs to be transformed from the medium voltage level down to low voltage, or to another incoming grid voltage level. Coming back to the issue of transmission systems in frequented and metropolitan areas, there is one more aspect to mention. Over the past five decades, the weight of GEAFOL has been reduced by more than one third, without any reduction in output range or adverse effects on operational safety and reliability. The available floor space for the necessary electrical equipment, like a transformer, is often limited. Therefore, the total power throughput has to be maximized and at the same time the necessary floor space for the transformer installation needs to be minimized. As a consequence, large distribution transformers are often more suitable than small power transformers.

**More than 150,000 GEAFOLs have been installed by Siemens Energy worldwide.**

### The largest dry-type transformer of Siemens Energy with a special cooling technique

The world's largest and most complex cast-resin transformers come from the transformer plant in Kirchheim, which is product lead center for development and production of cast-resin transformers at Siemens Energy. The largest GEAFOL produced in Kirchheim so far was quite unique.

With a rating of 45 MVA, Siemens Energy offered a safe, powerful, and environmentally friendly alternative to liquid-filled transformers. The transformer, which weighs 58 tons, has some special features. Thanks to the modern test laboratory in Kirchheim, it was possible to test the transformer – even at such a high rating – directly in the factory. This helped to avoid the time-consuming and work-intensive transport to another location and the related costs. The freedom from partial discharges of this special GEAFOL was tested up to twice the rated voltage, in other words, far beyond the specified standard. This ensures high reliability of the transformer during operation.

The thermal load of the transformer represents a particular challenge in the power range from 20 MVA and above. For GEAFOLs in this rating class, Siemens Energy has developed a highly efficient cooling method which operates by using cooling ducts. Why are cooling ducts special? Because they are used in the higher voltage winding and in the core to dissipate heat losses. In addition, the GEAFOLs from Siemens Energy absorb the high axial forces that occur in the event of a short circuit thanks to a special coil support system. To achieve such a high output, the high-voltage coils consist of six partial coils that are interconnected to create one winding. Excess heat is dissipated via special patented cooling channels in the windings. In this special system developed by Siemens Energy, the smaller coils are spring-loaded to compensate for the thermal expansion of the larger coils. Potential harmful overheating of the core and clamping parts is detected by monitoring the temperature of the tie bolt (connecting the top and bottom clamps) at the core circuit. Converters have higher electrical loads due to steep voltage peaks. These loads and corresponding heat increases are dealt with by providing appropriate insulation for the windings.

Photo: Siemens Energy

### GEAFOL 45 MVA

The increased dimensions of dry-type transformers resulting from the increase in voltage are becoming more and more important for many customers. Siemens Energy has developed a particularly compact GEAFOL, primarily for size-critical applications. Due to the special insulation, higher operating voltages can be safely controlled without the disproportionately large increase in insulation distances that has previously been necessary. This development also leads to reduced dimensions and weight.

Another innovation of Siemens Energy is the new, award-winning housing for GEAFOL which has many customer benefits. To mention just one, the transformer and its housing can be supplied as a fully mounted unit on a common base frame. Besides the freedom from partial discharges (which far exceeds existing standards), the particularly high reliability of the transformer is ensured by the proven GEAFOL technology.

It is important to note that that all these innovations were incorporated in the 45 MVA GEAFOL, the largest cast-resin transformer ever produced in Kirchheim. Of course, this was not a prototype, but it was a customer order for a data center.

In general, GEAFOL is available for power ratings up to 50 MVA. Different electrical and mechanical setups, like double-tier transformers, help to increase the power rating per square meter. Adapted to the circuit of the static converter, these special transformers are manufactured primarily with a Dy5 circuit, or Dy5Dd0 for two-tier design. Any required phase shifts are also possible with GEAFOL technology by installing shift-tip windings. Three-tier GEAFOLs are mainly used in modern direct converter installations. Even four-tier designs are possible with GEAFOL.

**The world's largest and most complex cast-resin transformers come from the transformer plant in Kirchheim, a product lead center for development and production of cast-resin transformers at Siemens Energy.**

### Shaping the future's energy landscape

Siemens Energy, as the inventor of dry-type transformers, has a worldwide network of factories, providing customized GEAFOLs and CARECOs. The factory in Kirchheim, Germany plays a lead role in building big dry-type distribution transformers. Besides Kirchheim, the new and modern Siemens Energy factory in Guangzhou (China) is also capable of designing, building, and testing dry-type distribution transformers of this size. Having this capability on different continents enables Siemens Energy to supply GEAFOLs as well as the copper-based CARECOs to every corner of the world within the shortest possible time. Besides Kirchheim and Guangzhou there are Siemens Energy dry-type transformer factories in Budapest (Hungary), Jundiai (Brazil), and Guanajuato (Mexico).

Cast-resin transformers of Siemens Energy are practically maintenance-free and their high overload capacity ensures maximum reliability. Due to high quality standards in development, design, engineering, and production, GEAFOL and CARECO are reliable in operation, environmentally compatible, flame-retardant, self-extinguishing, and non-toxic.

GEAFOL and CARECO make energy transmission more environmentally friendly, safe, and efficient. Covering an output range from 100 kVA to 50 MVA, with operating voltages up to 72 kV, dry-type transformers from Siemens Energy offer numerous benefits, such as high efficiency, safety, quality, and reliability to customers worldwide. Independent of the customer's core focus, e.g. decarbonization, efficiency, or digitalization, the goal of Siemens Energy is to satisfy customers and make a positive contribution to the future.

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# An accuracy and cost comparison between online DGA monitors and lab analysis

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**Studies have shown that most online gas monitoring models on the market meet the accuracy requirement of IEC (<15%). However, some deliver accuracies as bad as just 50%.**

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

**Transformers are some of the most critical and cost-intensive components in the electrical power system. Their operation condition needs to be closely monitored to ensure safe operation, extend their lifetime and reduce maintenance costs.**

**DGA (Dissolved Gas Analysis) is a well-known and widely used technique to monitor the operating condition of transformers, which also serves as a tool to identify many electrical and thermal fault conditions in transformers and might indicate the severity of the fault.**

Recently, natural ester fluids (vegetable oils) have been used increasingly in distribution transformers to substitute mineral oil. Consequently, the established DGA interpretation methods for mineral oil filled transformers have been revised to apply to these alternative fluids. Research has identified that the fault gases generated by natural esters are similar to those generated in mineral oil under various fault conditions. However, the generation rate of dissolved gases in natural ester is slightly lower than in mineral oil, and natural ester remains remarkably stable under medium-temperature thermal faults. Ethane is generated in natural ester if it is exposed to oxygen under normal operating temperatures (<140°C); and under thermal faults, up to 600°C, ethane and carbon oxides account for more than 70% of fault gas generation [1]. **The key gases generated** under Partial Discharge (PD) and sparking faults are hydrogen and acetylene in both mineral oils and natural ester. Under PD faults, the total volume of fault gases was more than 50 times higher in natural ester than in the mineral oil. This is due to the higher rate of PD occurrence. The total volume of fault gases per unit of fault energy is similar for the two liquids [2].

**Close to end of life, the laboratory analysis does not meet all the requirements, as the transformer needs to be monitored constantly to ensure safe operation. Thus, more frequent inspections, including DGA monitoring, should be carried out to diagnose faults and implement maintenance plans promptly.**

Previously, DGA was performed mainly by periodically sampling liquids from power transformers and analyzing the dissolved gas components in laboratories, using standardized methods for the extraction and analysis. Close to end of life, the laboratory analysis does not meet all the requirements, as the unit needs to be monitored constantly to ensure safe operation. Today, many transformers are approaching the end of life, and thus more frequent inspections, including DGA monitoring, should be carried out to diagnose faults and implement maintenance plans promptly. Another fact to consider is the sampling procedure, handling, and storage; many variables can influence the representativeness of the oil sample compared to the bulk of oil in the transformer. Extreme care should be taken during oil sampling to ensure that the sample retrieved and tested accurately represents the bulk of oil in the transformer.

Photo: Shutterstock

*Online DGA monitor installed on a transformer (Photo courtesy of VAISALA)*

Over the last decade, numerous online multi-gas monitors have become available and are used to continuously monitor the condition of transformers [3]. Online monitors allow the ongoing monitoring of gases in transformers in service, but this needs to be done in combination and comparison to laboratory results. The monitors are pretty robust with an expected cost-effective lifetime. However, it is unknown if the monitor reading is accurate compared to laboratory readings. Even though a unit is fitted with an online monitor, it is still recommended to send a routine sample to the analytical laboratory. The accuracy and reliability of the online monitors need to be determined to ensure accurate fault identification. As natural esters are being used more every year as dielectric fluid in transformers, the application and interpretation of online monitors need to be adjusted for normal and fault identification parameters in all dielectric fluids currently available in the industry. When using headspace gas extraction methods, the gas solubility coefficients should be carefully determined for application to natural esters. A credible comparison between online monitor results and laboratory analysis is required.

## Types of online gas monitors available

Table 1 presents an overview of general online gas monitors that are currently available on the market. In all monitors, the partition coefficient is used. Partition coefficient is temperature-dependent, and this is something that the manufacturer sets so it should be of no concern to the customer. The partition coefficient is also dependent on other factors like the type and age of the oil. Manufacturers do not always compensate for this, leading to incorrect data and inaccurate interpretation of faults.

Monitors using infrared type technology are still to be examined by the Maintenance Team MT25 and IEC Technical Committee TC10 and proposed as an Appendix to IEC 60567, currently only containing guidelines for GC detectors [5].

**Only multimeters of type M7 and M9 were found to provide the complete DGA diagnosis online and indicate the requirement for immediate action.**

| Extraction Method | Gas Measurement Technology | Advantages | Limitations |
|---|---|---|---|
| Membrane, Vacuum | Gas chromatography | Very similar to standardized techniques (IEC, ASTM); Separation of signals to avoid interferences; Automated recalibration with on-board calibration gas | Carrier gas (helium) and calibration gas need to be replaced every 2-4 years<br><br>Depending on the models, GC columns must be replaced every 3 to 5 years, and there is a potential for carrier gas to leak into the transformer<br><br>Requires management of compressed gas cylinders |
| Membrane, Vacuum, Direct headspace | Infra-red (direct absorption or photo-acoustic) | No consumable gases<br><br>No compressed gas cylinders | Other sensors required to measure $H_2$, $O_2$, $N_2$<br><br>Some models are sensitive to contamination by oil vapors, leading to inaccuracy over time and the need for recalibration<br><br>In some models, accuracy is degraded by interfering compounds present in the oil and/or the ambient air |
| Membrane, Direct contact with oil | Thermal conductivity cell | No consumable gases | $H_2$ and CO only |
| | Electrochemical cell | | Composite gas signal |
| | Metal-oxide sensors | | $H_2$ and CO only, limited accuracy |
| | Metal film sensors | | $H_2$ only |

*Table 1. General types of online gas monitors available on the market [5]*

## Possible faults that different types of online gas monitors can identify

Tables 2 and 3 illustrate the faults that can be detected by various online gas monitors.

As a point of interest, it should be noted that several of these monitors can measure moisture in oil, but this will not be discussed in this article.

The next question is which monitor to use for your transformer; the guidelines compiled by CIGRE TB 409 are set out in table 4.

## The cost and benefits of various types of DGA monitoring

The cost and benefit analysis is based on a population of 2,000 large power transformers, having a failure rate of 0.3% per year. This is a commonly observed phenomenon across many networks worldwide [8], which means that **six failures per year on the main tank** (not on any accessories like the on-load tap-changers or bushings) require repairs or replacement. This includes catastrophic failure with fire or explosion in 0.04% of the cases [8] (0.8 such failures per year).

The calculations were based on the following considerations:

- The average cost of these six transformers is $6 million each. Their total cost is $36 million/year.
- The average cost is $6 million for replacing each of them; $2 million for repairs ($4 million/year on average); the cost in the case of a catastrophic failure, including collateral damage, lost revenues and penalties, would be around $30 million (30x0.8 = $24 million/year).
- Laboratory DGA can help avoid approximately two failures due to slow developing faults (2x4 = $8 million/year), while the cost of

| | Fault or stress | Definition |
|---|---|---|
| Basic fault types | T3 | Thermal T>700°C |
| | T2 | Thermal 300<T<700°C |
| | T1 | Thermal <300°C |
| | PD | Partial Discharges of the corona type |
| | D1 | Discharges of low energy |
| | D2 | Discharges of high energy |
| Sub-type faults (PD is also part of this group) | S | Stray Gassing of Oil <200°C |
| | O | Overheating <250°C |
| | C | Possible carbonization of paper >300°C |
| | T3-H | T3 in oil only |

*Table 2. Definition of the types and sub-types of faults or stresses identifiable by DGA [6]*

DGA analysis on all transformers, including oil sampling, is around $1million/year. Avoided costs (8-1) = $7 million/year.

- Monitors M1, M1* or M2 were installed on 2,000 transformers. The cost of each is $10,000$ amortized over ten years (cost = $2 million/year). Two additional failures can be avoided due to medium developing faults ((2x4)-2 = $6 million/year), in conjunction with laboratory DGA ($7 million/year). Avoided cost: (7+6) = $13 million/year.
- Monitors M3 to M9 are installed on critical units and severely gassing units (between 30 and 50 transformers) at the cost of $50,000 each on average, amortized over 10 years (cost <$1 million/year).

| Application | Type of monitor | Gases measured | Faults possible to identify | Faults not possible to identify |
|---|---|---|---|---|
| Fault diagnostic | M8/ (M9) | $H_2$, $CH_4$, $C_2H_6$, $C_2H_4$, $C_2H_2$, CO, $CO_2$, ($N_2$) | All ten faults in Table 2, at an early stage | None |
| | M6/(M7) | $H_2$, $CH_4$, $C_2H_6$, $C_2H_4$, $C_2H_2$, CO, ($CO_2$) | | Faults in the paper very often are not detected correctly with CO only with M6, M5, and M2 |
| | M5 | $H_2$, $CH_4$, $C_2H_4$, $C_2H_2$, CO | The six basic faults only | The five sub-types of faults |
| | M3 | $CH_4$, $C_2H_4$, $C_2H_2$ | | |
| Fault detection | M2 | $H_2$, CO | None of the ten faults can be identified | May not detect faults D1 and D2 in their early stages, only in their late, sometimes catastrophic stages. |
| | M1 | $H_2$ | | |
| | M1* | Composite reading of $H_2$ and other gases | | |

*Table 3. Faults possible to identify in transformers with online gas monitors [7]*

| Type of Monitor | Gases | Transformers |
|---|---|---|
| M7/M8/M9 | $H_2$, $CH_4$, $C_2H_6$, $C_2H_4$, $C_2H_2$, CO, $CO_2$, ($O_2$), ($N_2$) | All Transformers, including critical ones (GSU, nuclear) and those already gassing abnormally, require immediate action |
| M6 | $H_2$, $CH_4$, $C_2H_6$, $C_2H_4$, $C_2H_2$, CO | Critical and gassing transformers that do not require immediate action (oil sample required to confirm paper involvement) |
| M5 | $H_2$, $CH_4$, $C_2H_4$, $C_2H_2$, CO | |
| M3 | $CH_4$, $C_2H_4$, $C_2H_2$ | |
| M2 | $H_2$, CO | Not critical transformers and not already gassing transformers (oil sample required) |
| M1 | $H_2$ | |
| M1* | Composite reading of $H_2$ and other gases | |

*Table 4. Monitors suitable for different types of transformers [5]*

Over time, they can help avoid three additional failures due to medium to fast developing faults (3x4)-1=$11 million/year in conjunction with laboratory DGA ($7 million/year) and 0.8 catastrophic failure ($24 million/year). Avoided costs (7+11) = 18(+24) million/year

Avoided costs include the cost for the monitors, but not for their installation, maintenance and communications, which depend very much on the type and brand of the monitor and should be evaluated with monitor manufacturers and then deduced from the avoided costs. The data presented here is from 2019, when CIGRE compiled the report [5].

**It is recommended that all laboratories follow the new ISO 17025 and 17024 requirements.**

## Evaluation of the accuracy of online monitors

The accuracy of monitors evaluated by WG D1/A2.47 is presented in Table 6. The lower the absolute accuracy values, as stated in Table 5, the more accurate the monitor for this specific gas type. Minus values (-) mean the value is below the detection limits of the laboratory, or no values have been reported. Negative values in columns 3 to 9 mean lower values than expected. Positive values mean the values are higher than expected. Values in column 10 are the average values in columns three to nine, expressed in absolute values.

The values for the Test No.1 (monitor A) are the average values obtained from two reference laboratories (Elektropomyar-Elektryka and Laborelec).

During the Tests No.2 to 5, four different monitors were installed on a test loop of oil attached to a transformer during the year. The tests shown in Table 5 were taken at the end of the test period. Hydrogen readings from these four monitors, marked with an asterisk (*) were significantly lower than expected, by 19-35% compared to corrected laboratory results. The WG investigated the possible reasons for these unexpected low readings and identified the commercial gas-in-oil standard sample used as a possible problem. This could lead to the laboratory not properly correcting their equipment to ensure accurate readings. This was ruled out, as the oil standards were received within a week from the actual testing and were accurate. It was established that helium from the online monitor leaked into the oil sample sent to the analytical laboratory for testing. The standard analytical laboratory equipment uses argon gas as a carrier gas and not helium. The equipment then reads helium as hydrogen gas. Once the proper set-up was made and helium and hydrogen gases could be separated in the GC column, it was possible to identify the problem. The monitors displayed the correct readings. The laboratory readings were contaminated by the helium carrier gas, leading to a false reading of hydrogen.

**Gas leakage and air ingression that may occur during sample transportation and measurement delay might be the main reason for deviations between online and lab analysis. The sealing efficiency of individual sample syringes is crucial to preserving the sample.**

## Conclusion

A study done in 2008 by CIGRE TF15 and WG47 showed that most models on the market meet the accuracy requirement of IEC (<15%). However, some do not. They deliver accuracies as bad as just 50%.
It should be stated that the customer should be familiar with the maintenance requirements for each type of monitor and the added cost for the carrier gas and columns where applicable. If the maintenance requirements are not met, accuracy won't be acceptable. Users should also be aware of the measurement performance under actual operating conditions. How will the surrounding environment and operating conditions impact the monitor's reliability, lifetime and accuracy? Would a monitor require site-specific offsets, or is it designed to provide readings of absolute accuracy? These distinctions are critical in choosing a unit that will work for you.

During investigations done by WG D1/A2.47, only multimeters of type M7 and M9 were found to provide the complete DGA diagnosis online and indicate the requirement for immediate action. The single gas type monitors, M1 and M2, will only indicate an abnormal formation of the gases monitored.

Photo: Shutterstock

| | | Accuracy in % | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Test No. | Monitor | $H_2$ | $CH_4$ | $C_2H_4$ | $C_2H_6$ | $C_2H_2$ | CO | $CO_2$ | Average |
| 1 | A | 13 | 11 | - | 3 | - | 2 | 3 | 6 |
| 2 | A | -19* | 0 | - | -4 | - | 21 | 0 | 5 |
| 3 | B | -25* | -5 | 19 | 4 | - | -16 | 0 | 9 |
| 4 | C | -35* | -8 | -15 | -7 | - | 18 | 0 | 10 |
| 5 | D | -20* | -23 | 0 | 23 | - | 8 | -20 | 15 |
| 6 | D | 0 | 4 | 16 | 31 | - | 16 | 0 | 11 |
| 7 | E | 11 | 17 | 42 | 48 | 51 | 45 | 28 | 35 |
| 8 | F | 11 | - | - | - | - | - | - | 11 |
| 9 | G | 12 | - | - | - | - | - | - | 12 |
| 10 | H | 0 | 7 | 25 | 78 | 8 | 14 | 16 | 21 |
| 11 | I | -26 | 0 | 3 | 0 | - | 10 | 10 | 8 |

*Table 5. Accuracy of online gas monitors tested by members of CIGRE WG D1/A2.47*

An oil sample should be taken and sent to the laboratory for diagnostics if this scenario arises.

Another issue in the industry is the inaccurate DGA results provided by some laboratories and the lack of high-quality oil sampling practices by some companies. It is recommended that all laboratories follow the new ISO 17025 and 17024 requirements. Gas leakage and air ingression might occur during sample transportation and measurement delay. This might be the main reason for deviations between online and lab analysis. The sealing efficiency of individual sample syringes is crucial to preserving the sample. Liquid samples collected from in-service transformers should be sent to the laboratory for analysis as soon as possible. A shorter delay period can provide more accurate results.

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# pst

# POWER SYSTEMS TECHNOLOGY

## SPECIAL SUPPLEMENT

# Smart Grid Sensors: Improving Reliability for Distribution Grids During Energy Transition and Grid Modernization

by **David Eckert**

***Power utilities face increasing challenges associated with rapid transformation of power generation and consumption. Distributed Energy Resources (DER), including renewables, cause stresses on grid assets. Climate change and associated extreme weather events, as well as an aging grid infrastructure, add to growing concerns, while digitalization with Smart Grids contributes to solutions for improved reliability.***

Over the past decades, electrical infrastructure investment has been prioritized for transmission grids due to criticality of high voltage assets. However, in recent years, distribution networks have seen many new challenges in operation and demand which leads to increasing criticality of medium and low voltage grid assets. This drives the need for visibility, efficiency, and automation, while Smart Grid sensor technologies are rapidly improving solutions for distribution system operators (DSOs) to meet this need.

Utility asset managers face pressure from governments and consumers to preserve and enhance grid performance while maintaining assets that are often operating beyond designed life. This is no easy task during grid modernization efforts along with ever-increasing electrical loads combined with complex power flows. Solutions are sought to improve key performance factors such as SAIDI (System Average Interruption Duration Index), and SAIFI (System Average Interruption Frequency Index). This is accomplished by achieving quicker reaction time to locate and repair faults (SAIDI) and reducing frequency of faults with the use of data for predictive maintenance techniques (SAIFI). These indices are measured and reported with rising scrutiny in recent years, as the pressure for improved reliability is ever-increasing. Not only do enhancements of these metrics result in dependable power delivery to consumers, but they also result in reduced operating costs. Sensors can be deployed to help minimize fault durations and now even prevent faults, thus improving SAIDI, SAIFI, and maintenance expenses.

Photo: Megger

**David Eckert** is Sales Manager for Africa and Europe for Megger's Grid Performance Solutions division. David has served in several technical and sales roles including Application Engineer for power system protection testing, Regional Sales Manager for substation testing instructments (transformer, circuit breaker, relay, battery), and Sales Manager of solutions for insulation condition monitoring and diagnostics. Prior to Megger, David served in roles as Plant Electrical Reliability Engineer and Business Analyst in the industrial production sector.

Sensors can be deployed to help minimize fault durations and even prevent faults.

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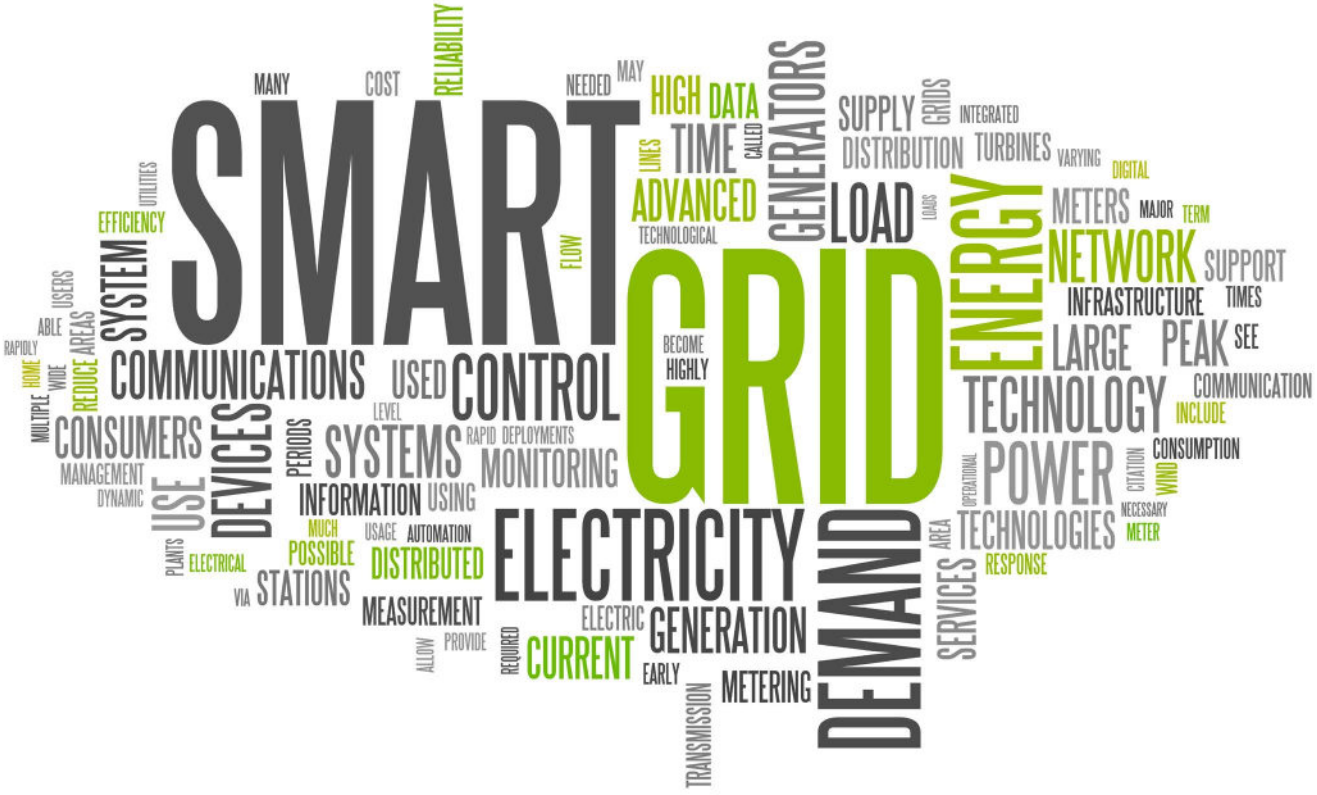
To improve the reliability found in overhead line networks, sensors such as Fault Passage Indicators (FPIs) or Fault Current Indicators (FCIs) are deployed to identify general fault locations as quickly as possible, which reduces time necessary for Fault Location, Isolation, and Service Restoration (FLISR).

**Lowest Hanging Fruit**

Utility distribution staff must consider efficient maintenance and the most cost-effective strategies to improve SAIDI and SAIFI and are focussing efforts on reliability on overhead distribution lines. Outages caused by faults in overhead lines are often an inevitable part of operations as these critical assets are exposed to weather, mechanical stresses, contamination, aging equipment, vegetation, and wildlife.

Many utilities invest extensive efforts in replacing overhead lines with underground cables to significantly improve reliability.

There is a correlation in relation of overhead lines in the network to SAIDI, and as such, regions with more underground cables typically enjoy better performance of their grid. However, it is not always practical to replace overhead lines with underground cables due to high costs, particularly for rural and remote areas with distribution lines covering large geographical distances. Undergrounding projects are expensive and time consuming, requiring a large labour force commitment that is not always readily available. Therefore, overhead lines remain as a necessary means of delivering power to customers by many utilities globally.



To improve the reliability found in overhead line networks, sensors such as Fault Passage Indicators (FPIs) or Fault Current Indicators (FCIs) are deployed to identify general fault locations as quickly as possible, which reduces time necessary for Fault Location, Isolation, and Service Restoration (FLISR). Traditionally, an FPI or FCI is a simple instrument that measures current amplitude. Once current reaches a particular threshold (or exceeds a step-change), a fault is identified and an indication (LED) on the device alerts field technicians to the general location of a fault. These are often installed in strategic locations, for example at junctions of line branches. This helps service restoration crews to know where to start looking for a fault. Then the search begins. In an ideal situation, the faulted powerline runs parallel to a road so that vehicles can be deployed to conduct the search. If this is not the case, all-terrain vehicles, drones, or even helicopters are dispatched, and sometimes even on-foot fault searching is necessary.

Several enhancements in FPI and FCI technology have helped to reduce search time. For example, some devices can now communicate and send an SMS message or alert control room operators via SCADA/DMS with fault localization data, leading to a better reaction time over searching for a flashing light in the field.

**Challenges for FPIs and FCIs**

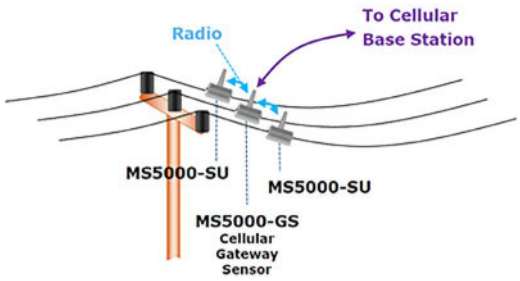
Even after advancements in notification of fault location, additional challenges remain for distribution operators. For example, DER has transformed the grid from a radial, one-directional network to a complex grid with multi-directional power-flow dependant on factors such as power consumption or presence of sunlight or wind at a given time of day. For this reason, fault direction is not a simple parameter to detect. Additionally, comparing current amplitude versus a simple threshold is not sufficient for detecting or locating high impedance earth faults, especially on compensated (Peterson coil) networks. Another challenge for distribution operators is the need to provide high service quality and reduce the number of faults (SAIFI) by identifying weak elements in the grid in advance with the use of predictive maintenance. Simple FPIs cannot provide a solution for this need.

DER has transformed the grid from a radial, one-directional network to a complex grid with multi-directional power-flow dependant on factors such as power consumption or presence of sunlight or wind at a given time of day. For this reason, fault direction is not a simple parameter to detect.

**Modern Innovations of Grid Sensors**

The solution for finding fault direction and identifying high impedance earth faults, transient earth faults, or intermittent earth faults can be found in the algorithms found in power system protection relays or intelligent electronic devices (IEDs). Zero sequence current, phase relationship, harmonics and other

*Photo: Megger*




electrical quantities are essential for fault algorithms. Computing these values requires three-phase, time-synchronized measurement of amplitude, frequency, phase angle, and duration with sufficient sampling rate, resolution, and accuracy. For protection relays, this is no problem, hence the existence of three-phase protection devices.

Modern technology integrates GPS location information, meaning sensor locations and faults can be plotted directly onto a digital map, allowing technicians to navigate more easily and quickly to fault locations.

Grid sensors can be deployed as sets of three sensors at multiple locations across power lines, providing wireless communication of precise location and fault data, even for high impedance earth faults on compensated networks.

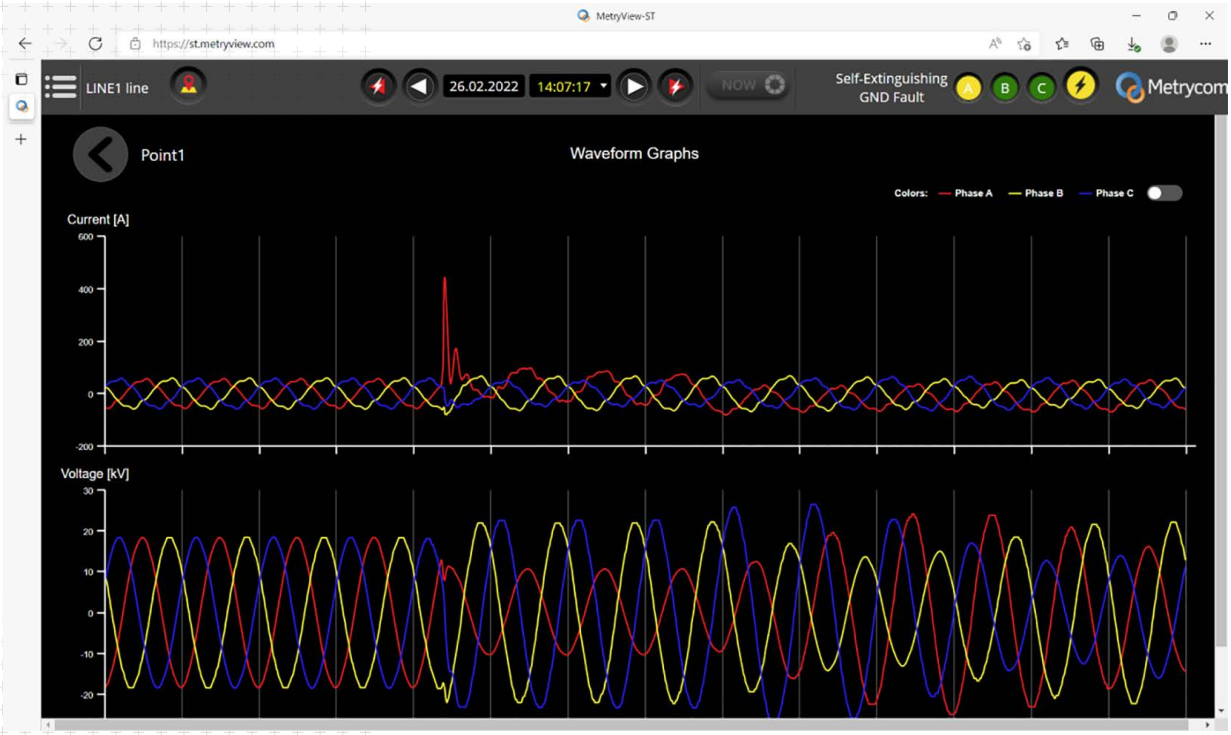
However, this exposes a challenge for simple FPIs and FCIs which measure only single-phase current amplitude.

Conventional FPIs and FCIs simply measure single-phase current amplitude, whereas modern grid sensors now include precise synchronization, communication, and advanced algorithms carried out via edge computing with hardened cybersecurity protocols. With these functionalities, grid sensors can be deployed as sets of three sensors at multiple locations across power lines, providing wireless communication of precise location and fault data, even for high impedance earth faults on compensated networks.

Modern technology integrates GPS location information, meaning sensor locations and faults can be plotted directly onto a digital map, allowing technicians to navigate more easily and quickly to fault locations.

Conventional FPIs and FCIs simply measure single-phase current amplitude, whereas modern grid sensors now include precise synchronization, communication, and advanced algorithms carried out via edge computing with hardened cyber-security protocols.

Since grid sensors now operate with better fault detection and localization capabilities due to enhanced measurement techniques and computing algorhims, why stop at fault location? With precise measurements and collection of data for trending, even transient earth faults and self-extinguished arcing events are identified. These types of faults are often not even detected by utilities or their customers but are often indicators for future outages or asset failure. This means weak spots in the grid can be identified and analyzed over time, and this data can serve as an input into condition-based maintaintance strategies in order to prevent permanent faults and outages, thus reducing SAIFI. Additionally, vegetation growth and encroachment can be identified by modern line sensor data so that growth management can be conducted before catastrophic events such as wildfires occur. Power quality parameters, such as harmonics, can be measured in order to identify extra stresses on the grid, for example from renewable resources. This means that grid sensors are transitioning away from simple FPIs and are now able to additionally serve as local power quality monitors with data that can be used for predicitive grid analytics.




*Example of self-extinguishing earth fault now detectible for analysis thanks to modern grid sensing algorithms.*

Thanks to digitalization, edge-computing, Artificial Intelligence (AI), cloud computing, and internet of things (IoT), grid sensors and their associated data can be expected to integrate more with advanced DMS systems.

## The Future

Thanks to digitalization, edge-computing, Artificial Intelligence (AI), cloud computing, and internet of things (IoT), grid sensors and their associated data can be expected to integrate more with advanced DMS systems. Ongoing efforts for interoperability allow data between sensors and other assets to be shared, for example with power system protection schemes, self-healing grids, energy management, metering, and more. Artificial intelligence and pattern recognition contribute to automated analytics for increased asset reliability and efficiencies.

Photo: Megger

# Enhance your insights to optimize your grid performance

Megger offers unprecedented insights into the health of your distribution grid with smart grid sensors and analytics.

Our solutions enable intelligent predictive maintenance decisions and improved delivery of dependable power. Our solution consists of the following items:

- **Smart grid sensor MS5000 to monitor your grid**
- **Mesh radio or cellular option to provide continuous communication**
- **Gateway/Router 3010 (Needed when no cellular coverage exists)**
- **MetryView software to collect and report data**
- **Service to support you with our expertise**

The **MS5000** is an online wireless monitoring system that provides reliable fault detection and data of a grid - it is the core of our offering.

The sensors measure current and electric field waveforms to calculate the voltage and various power quality values.

It is designed to be integrated into a distribution management system (DMS) to deliver online information about your grid. Once deployed, the sensors automatically create a secured mesh network among themselves and connect to the communication infrastructure.

## Your Advantages:

- **Predictive maintenance reduces interruptions by identifying weak spots (SAIFI)**
- **Improve efficiency of grid by reducing duration of power interruptions events (SAIDI) and damages**
- **Efficient in saving costs of energy not supplied**
- **Enhance power quality**
- **Increase understanding of your grid due to visibility of valuable data**
- **Improved safety**
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# Q&A

# PREPARING FOR THE GRID OF THE FUTURE

## Q&A WITH MICHAEL CUNNINGHAM

### CHIEF OPERATING OFFICER, CAMLIN GROUP / MANAGING DIRECTOR, CAMLIN ENERGY

**Michael Cunningham, Chief Operating Officer of the Camlin Group is a keen observer of the industry and sees Camlin playing a key role helping utilities.**

"Decarbonization and the road to Net Zero underpin everything," he says. "The topology of the network is going to be very different ten years from now, with onboarding of renewable energies and low carbon technologies at every level in the grid, from the consumer with electric vehicles and solar panels right up to high voltage renewable generation and everything in between. That means an electricity grid with multi-directional power flows and a changing demand landscape, making it very difficult to plan and predict the behavior of the grid into the future. Utilities can only see with any reliability a short time into the future, and the grid must withstand that. As it stands right now, this is exceptionally difficult. To meet these challenges successfully, the industry needs to evolve rapidly, which needs new technologies, new methodologies, new partnerships and new ways of thinking."

Michael sees conventional understanding of the industry being severely disrupted: the view that on one side there are network operations focused on timely and efficient energy flow, and on the other side, asset management focused on the management of both risk and capital assets. This is not how the industry is likely to operate in the rapidly approaching future as the rise of renewable power generation turns this industry orthodoxy on its head. Alongside large, centralized power generation plants, sources of renewable generation will proliferate rapidly and lead to much more complex,

**THE ELECTRIC UTILITY INDUSTRY IS FACING MAJOR CHALLENGES IN THE NEXT DECADE: THE NEED TO INVEST IN RENEWABLE GENERATION AND LOW CARBON TECHNOLOGIES; MAINTAINING AGING NETWORK ASSETS WITHIN SIGNIFICANT BUDGET CONSTRAINTS; AND AT THE SAME TIME PROVIDING RELIABLE AND AFFORDABLE ENERGY IN THE FACE OF A RAPIDLY CHANGING CONSUMER LANDSCAPE. THESE DEMANDS MEAN THE TRANSITION TO A MORE ROBUST, RESILIENT, FLEXIBLE, DECARBONIZED GRID.**

Photo: Camlin Group

decentralized networks where traditional lines between networks and power generation become blurred. The tried and tested approaches established over decades, such as the asset management function of analysis of risk and risk mitigation, which have served utilities for the last thirty to forty years, will need to be updated significantly to manage the new complexities. Central to managing the new paradigm will be data and digital tools.

**For forty years, Camlin has been supplying asset monitoring equipment for transformers, generators, and circuit breakers. More recently though, the company's focus has been on bringing together both monitoring and diagnostics, using artificial intelligence and machine learning to provide informed actionable insights for utilities.**

Michael says: "The network is experiencing increasing rates of disturbances, such as through fault currents and transient over voltages, and multidirectional power flows. These will likely impact power transformers and as a result they are going to live a very different life in the future. It means that the approach to running a network must change. Many asset management programs are based on models built over the last forty years around empirical evidence of risk. These will almost certainly need to be upgraded significantly to be fit for purpose in the flexible and decarbonized grid of the future because the network is going to be very different.

Many of the large generator units on the grid will also live a different life. Generators that have been designed and installed for baseload generation will be utilized more commonly for backup generation capacity because the baseload will be met, wherever possible, by renewables. So instead of the generator operating constantly, which it was designed and installed for, and on which its maintenance program and entire asset risk profile is based, it's now switching in and out in a way that was completely unplanned. Traditional offline monitoring and diagnostics models are no longer adequate for this situation and a new methodology is needed. This is exactly the type of area where we can help on the journey."

**For Camlin, that means working on a "vertical data pipeline", bringing together monitoring, diagnostic software capabilities, artificial intelligence and machine learning, as well as deep domain expertise in assets and networks to provide the actionable insights required for the grid of the future.**

Michael says: "As the utility industry evolves over the next decade, although many other companies will start to offer data mining services for utility assets and networks, only a few will be able to match Camlin in terms of translating that diagnostic data into prescriptive actions. Our experience with utilities over the last forty years means that we have an immense bank of knowledge. Many utilities are now facing not only a skills deficit as experienced technical employees retire, but also a whole new set of operating challenges. Our approach means that utilities can fill this breach, make decisions and operate with the benefit of actionable insights developed with the support of Camlin."

At a time when many utilities are seeking to cut costs, there are big financial benefits too. These prescriptive and actionable insights mean fewer visits to sites, fewer repeat visits and much more productive and efficient use of resources. Maintenance is carried out just when it is needed, not at fixed time intervals and asset managers have a much clearer view of the potential lifetime of an asset which helps with budgeting and replacement strategy. Ultimately the utility will be able to drive performance as well as manage risk with increasing reliability.

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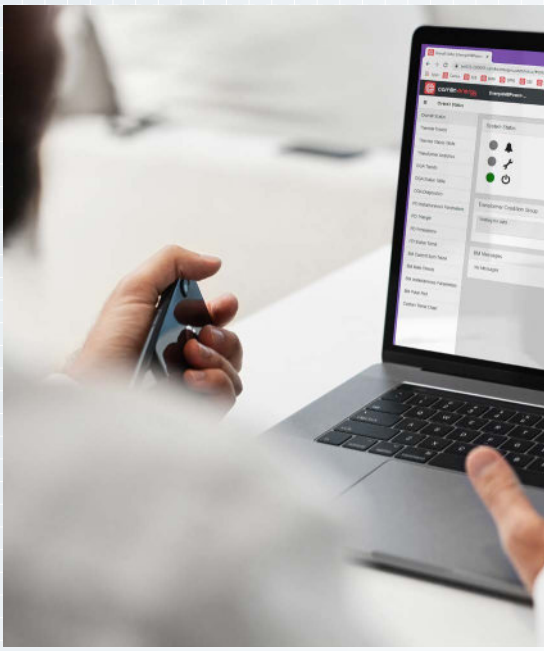


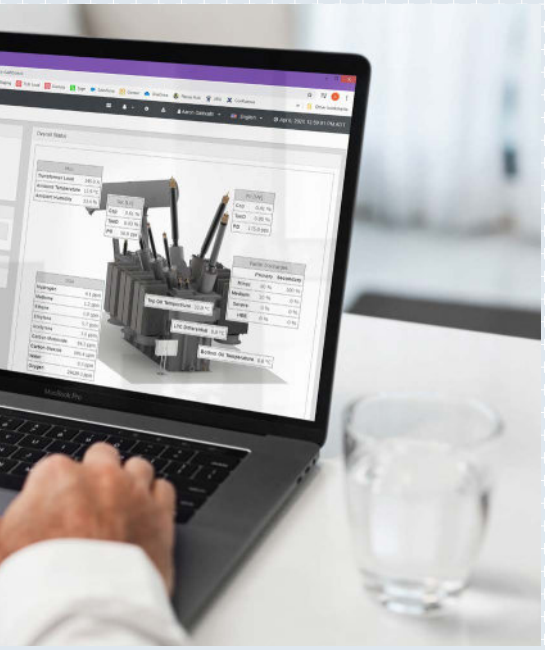
Photo: Camlin Group

**Utilities are at different stages in the transition to digital, for a variety of reasons. The task is often huge and daunting and many are grappling with large, customized and complex proprietary systems.**

Michael sees utilities which have an interest in renewable generation as often the most forward-thinking when it comes to data and digital tools: "Often these are start-ups and they build data and analytics into their business processes from day one, but we are also seeing more of the larger established utilities taking this path now. Those who get best results break up the task into specific and measurable projects and partner with external providers like Camlin. It becomes a team effort and we work very closely together. These partnerships are a crucial part of the journey ahead."

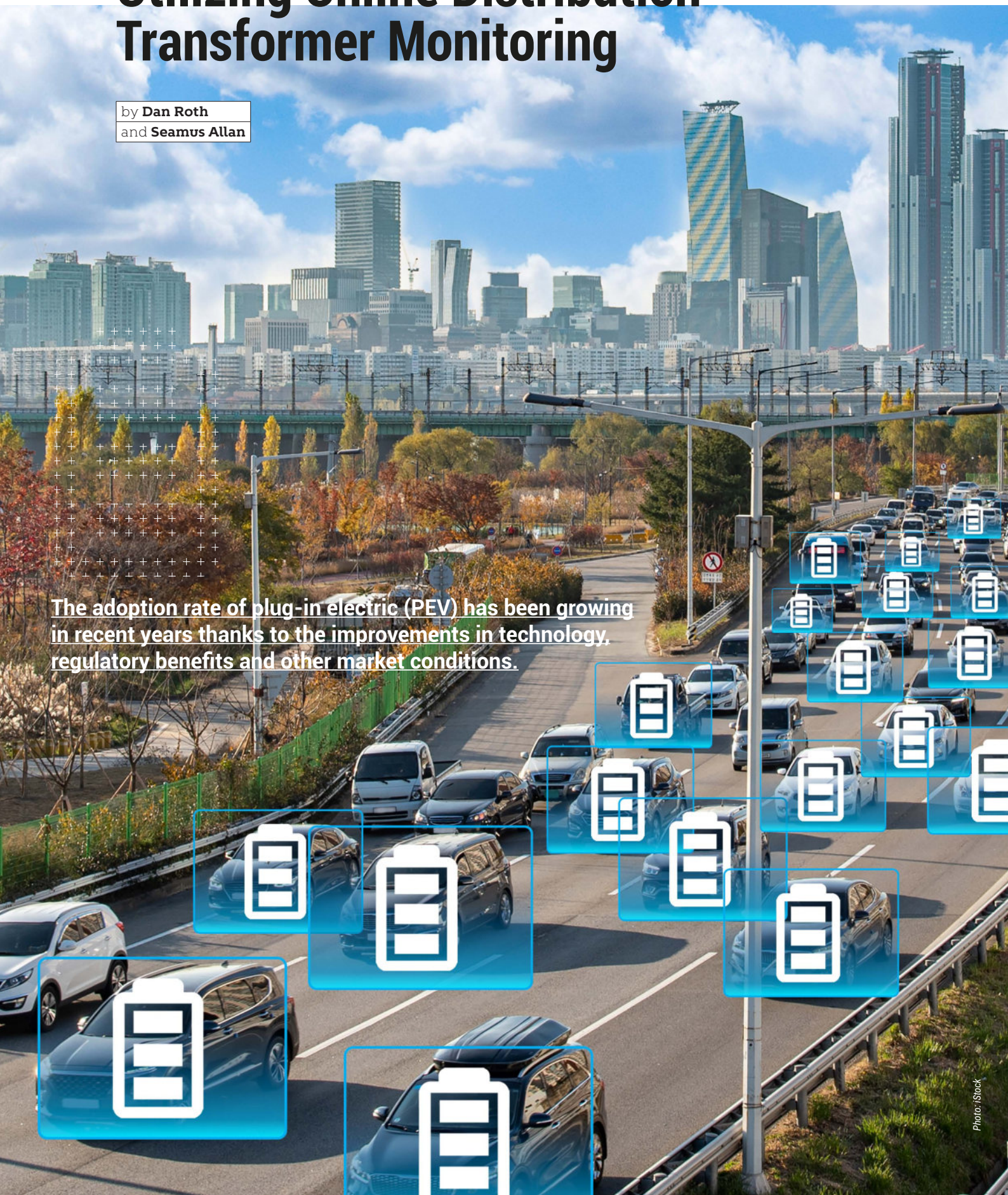
**The challenges facing utilities are huge but the rewards for those which embrace change are significant.**

Michael says: "We at Camlin have a part to play. We can help because we can supply the asset monitoring hardware both in the networks and in the assets. We can create and collate the data, we can supply the AI machine learning and our unique breadth of deep domain expertise. We can bring this to bear in partnerships to work with others, delivering the change and progress needed. We can refine and improve existing models and we can create the new insights, models and methodologies that are necessary. At Camlin we see ourselves very much as a trusted partner on the journey to the grid of the future."



# Managing Plug-In Electric Vehicle (PEV) Charging Profile Utilizing Online Distribution Transformer Monitoring

by **Dan Roth**
and **Seamus Allan**



**The adoption rate of plug-in electric (PEV) has been growing in recent years thanks to the improvements in technology, regulatory benefits and other market conditions.**

Photo: iStock

**Dan Roth** is the Sales and Marketing Director for Dynamic Ratings based in Sussex, Wi. He received his Bachelor of Science degree in electrical engineering from the University of Illinois at Urbana-Champaign. He possesses more than 20 years of industry experience having previously been employed at Eaton (Cooper Power Systems) and Schweitzer Engineering Labs. His career has allowed for a wide range of experiences from relay system protection, feeder automation, communicating smart sensors to distribution line installation and protective equipment. Mr. Roth has contributed several papers and patents to the industry in that time.

**Seamus Allan** is the Product Manager for LV & Distributed Monitoring at Dynamic Ratings' Australian headquarters office based in Melbourne. Seamus has a background in embedded system and software development, and within the last decade has applied this knowledge to the field of transformer and electrical machine monitoring. Having good field experience in transformer monitoring and control, with both a customer and product development focused perspective; Seamus provides invaluable direction leading to innovations in Dynamic Ratings' continually evolving sensors, monitors and software product solutions. Seamus graduated with an honours degree in electrical and electronic engineering from the University of Canterbury, New Zealand in 2007.

**Electric Vehicles are recognized as a key role in the United States transportation future as it already is in other parts of the world. Since 2008 the Department of Energy has invested in technology to reduce the costs of producing electric vehicle batteries by more than 85%. This coupled with the increasing cost and dependency on global petroleum imports is accelerating the adoption of plug-in electric vehicles (PEVs). Additionally, while it is accepted the bulk power grid must be modernized to support clean energy initiatives, most of the investment is going into transmission infrastructure improvements. This leaves a technical problem at the distribution system level on how to maintain system reliability and manage the increased electrical demand from PEV adoption. The use of smart infrastructure solutions based on industrial IoT technology can manage electric vehicle charging based on real time capacity of distribution transformers and circuits. This paper aims to discuss the use case and technology available to accomplish this coordination.**

Electric Vehicles are recognized as a key role in the United States transportation future as it already is in other parts of the world. This is driven by a need for the more efficient use of energy that reduces impacts to environment. The adoption rate of plug-in electric (PEV) has been growing in recent years from the improvements in technology, regulatory benefits and other market conditions. Specifically, the Department of Energy (DOE) Vehicle and Technology Office has been investing in the improvement of specific areas [1]:

- Reducing the cost, volume, and weight of batteries by developing cells and modules, improving lithium-ion electro-chemistries, and investigating new materials;
- Improving electric traction drive systems by reducing the cost, decreasing the weight and size, improving the performance, and increasing the efficiency of power electronics and electric motors.

These investments have driven down the estimated vehicle lithium-ion battery cost by nearly 87% since 2008 [2]. The reduced cost along with Federal, State and Utility tax credits with other incentives makes PEVs financially accessible for majority of light vehicles users. The rising cost of oil per barrel because of domestic regulatory policies aimed to reduce fossil fuels, coupled with trade sanctions that are increasing the cost of foreign oil imports creates the ideal market conditions to increase PEV consumer sales.

The electric grid and distribution system is recognized as a key conduit for enabling PEVs and the benefits to energy efficiency goals. The challenge is to determine how the system is going to be impacted by the wider adoption and increased population of PEVs. Modeling suggests that the grid already has generation capacity to meet this demand [3]. While generation capacity improvements have been largely flat for the past decade, the modest gains still are able to keep pace with PEV forecasted adoption rates by 2030 [3]. The true challenge is going to be how the distribution system and fixed assets can handle additional load.

Uncontrolled charging occurs when the PEV charges as soon as its plugged in. It is simple to implement and maintain. The problem with this methodology as it relates to distribution system is this demand becomes additive to the peak load profile that already exists. The average residential feeder in the US will have a peak between hours 16 and 20 of each day [3]. Uncontrolled charging only adds to this load and starts to encroach on the equipment ratings of distribution transformers and other circuit components.

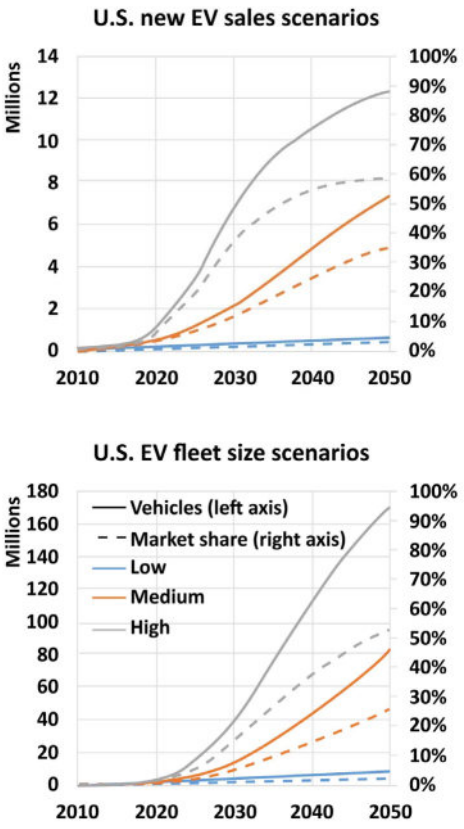
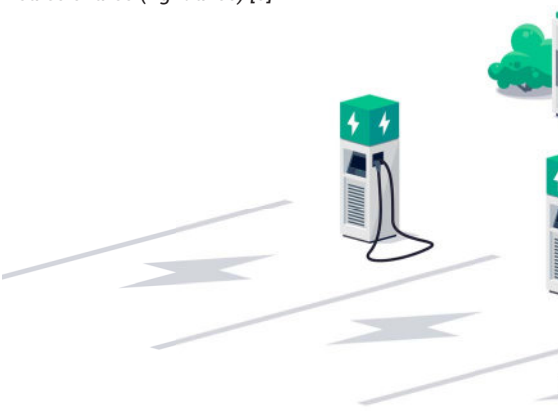
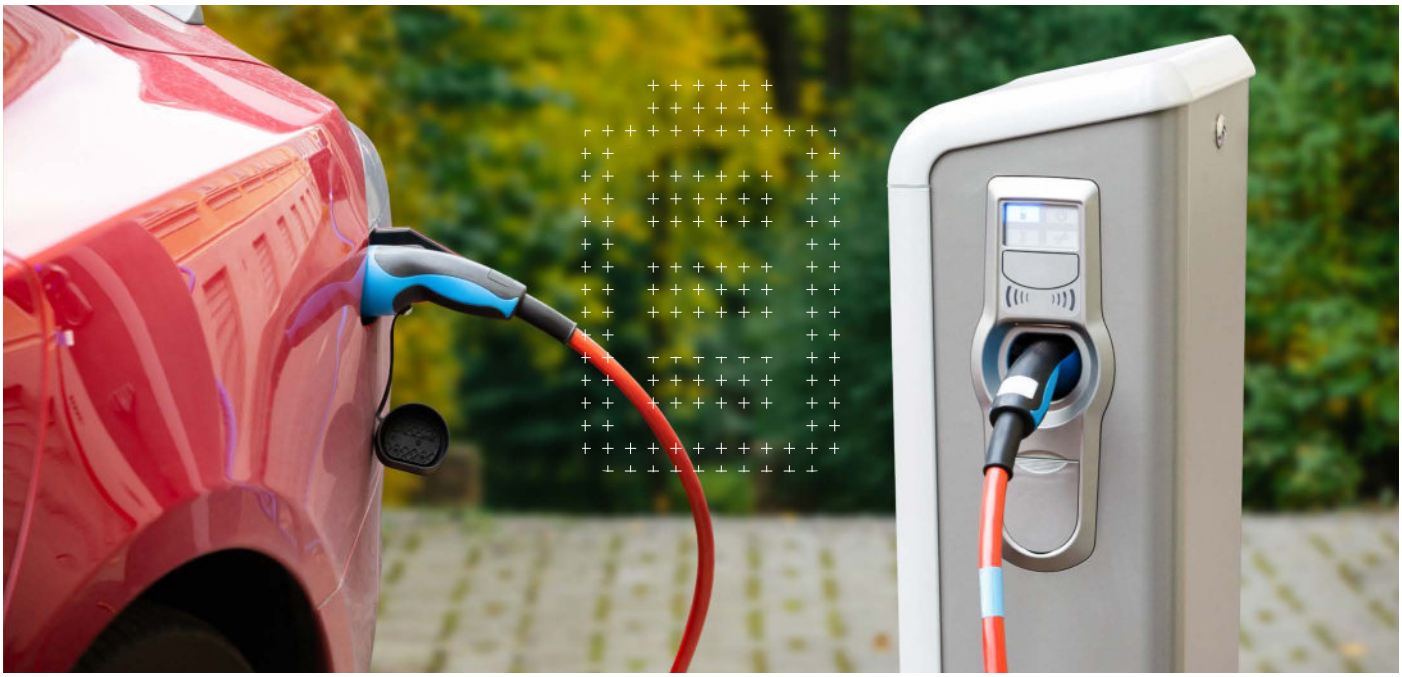



*Figure 1. Low, medium, and high PEV market penetration scenarios, shown both as annual sales (at left) and total PEV fleet size (i.e., cumulative vehicles in service, at right). Solid lines correspond to number of vehicles (left axes) and dotted lines correspond to sales shares (right axes) [3].*



In other parts of the world this can cause voltage quality issues, but this is less of a concern in the US because utilities actively regulate distribution voltages by means of tap changing transformers, line regulators and

**Since 2008 the Department of Energy has invested in technology to reduce the costs of producing electric vehicle batteries by more than 85%. This coupled with the increasing cost and dependency on global petroleum imports is accelerating the adoption of plug-in electric vehicles.**



**The use of smart infrastructure solutions based on industrial IoT technology can manage electric vehicle charging based on real time capacity of distribution transformers and circuits.**

switched capacitor banks to follow load changes [4]. The increased load however can impact coordination studies of protective equipment causing unplanned outages and further accelerate the aging and failure of grid assets.

One approach to offset the increased PEV charging demand is to upgrade transformers and other assets to accommodate the higher load. This is sometimes mandated with extremely fast charging systems. The deferral of distribution system upgrades can have strong financial benefits to utilities. The key is shifting the charging profile based on time of need, not when the PEV is plugged in. Time of use (TOU) rates is a financial mechanism used by many utilities to change customer energy consumption behavior. Delayed charging during off peak TOU rate times does not ensure charging is properly staggered to prevent creating a second peak and can only deliver 80% of operating cost savings as a managed charging system [5]. The better approach is to manage the charging of PEVs based on system constraints with a smart infrastructure solution that gives utility direct control of charging. This benefits utilities by allowing deferral of distribution system upgrades, reduction in unplanned outages, and better information on distribution system operating conditions to assess future planning.

Photo: iStock

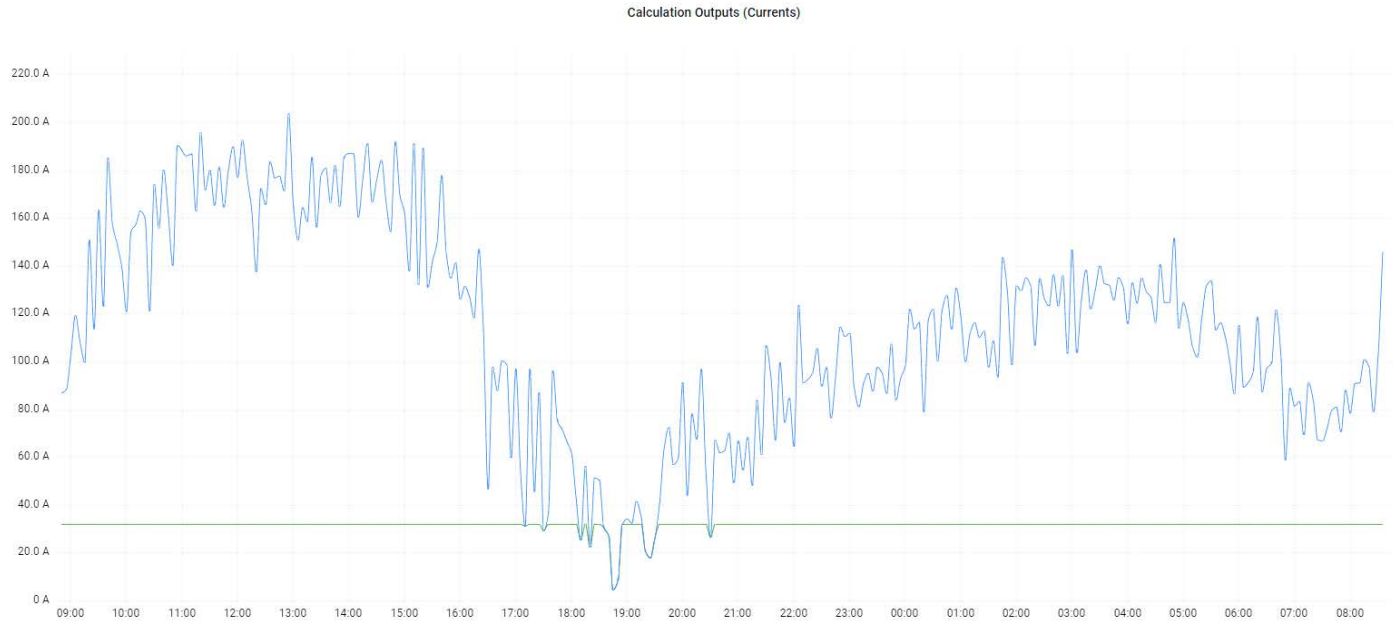



*Figure 2. Circuit and transformer capacity analytic*

A smart infrastructure solution combines software, sensors and communications to deliver a scalable and agile platform for improving connectivity to grid edge assets. To manage PEV charging, a utility-grade IoT architecture can be utilized to bring distribution transformer capacity information to an application running on a cloud service. This solution will integrate data from distribution transformer monitors, energy metering (AMI) data and the PEV chargers to run advanced analytics to determine circuit and transformer capacity. The analytic can replace live transformer monitoring data with historical load profiles to supplement areas without fully deployed monitoring. Meteorologic data is also integrated to support a forecast model on load fluctuations due to ambient temperature changes.

At the end of the analytic, if the available capacity is less than the PEV chargers connected to the distribution transformer, the remaining capacity (if any) is shared among the connected chargers that are currently in session. The charging limits are sent to the PEV chargers to manage the additional load put on distribution system. This can be seen in above diagram where the

Photo: Dynamic Ratings

**The digital transformation of the bulk power industry is going to change the way the electric grid is operated and managed. The data and tools available with Smart Infrastructure Solutions will improve grid efficiency, defer equipment upgrades, and provide better information for system planning.**

blue line represents circuit capacity for PEV charging and green line is the limit imposed on charger(s). When the capacity drops below limit, a new limit is issued to charger to prevent adding additional load onto system. The digital transformation of the bulk power industry is going to change the way the electric grid is operated and managed. The data and tools available with Smart Infrastructure Solutions will improve grid efficiency, defer equipment upgrades, and provide better information for system planning. These new solutions will all have a positive impact on the options available for utility asset managers to make better informed decisions.

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**An Infrared Inspection Window is a window that is used to separate environments of differing pressures or temperatures while allowing light energy at a specified electromagnetic wavelength to pass between the two environments. They must meet the strength and environmental requirements for the type of equipment in which they are fitted, as well as be compatible with the infrared inspection equipment being used.**

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# Foresight Can Be 20/20 with IRISS IR Inspection Windows

IR Inspection Windows enable the following:

1. Collection of real-time, condition status data on critical electrical systems and components
2. Mitigates the risk of injury or fatality during inspections because the window maintains an enclosed and guarded condition
3. A comprehensive, safe, and intelligent protocol be designed and used for performing essential energized inspections on electrical equipment

***Infrared Inspection Windows are used to separate environments of differing pressures or temperatures while allowing light energy at a specified electromagnetic wavelength to pass between the two environments.***

Photo: IRISS

***The CAP-ENV series features a reinforced environmentally sealed door design while also providing the largest visually clear infrared (IR) transmissive viewing area available on the market today.***

CAP-ENV-PDS

## IR Inspection Windows from IRISS

### CAP-ENV series

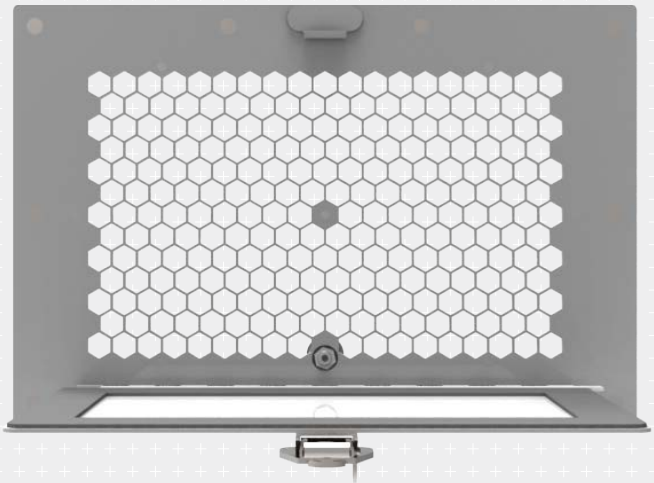
The CAP-ENV series features a reinforced environmentally sealed door design while also providing the largest visually clear infrared (IR) transmissive viewing area available on the market today. The exclusive reinforced polymer system allows any thermography camera to monitor completely undisturbed assets inside energized electrical equipment in the visual, UV and shortwave, mid-wave and longwave IR spectra. The larger rectangular viewing area provides an unparalleled field of view when compared to traditional round IR windows. Constructed completely from stainless steel, the CAP-ENV series is recommended for outdoor applications.

Offering an unparalleled Field of View and the IRISS Unconditional Lifetime Warranty, these windows are also available with ports for Ultrasound and Partial Discharge inspections to increase their value and efficiency.

### CAP-CT Series

The CAP-CT Series has the largest visually clear infrared (IR) transmissive viewing area available. The exclusive pharmaceutical-grade reinforced Poly-View System™ polymer allows any thermography camera to monitor completely undisturbed assets inside energized electrical equipment in the visual, UV and shortwave, mid-wave and longwave IR spectrums. These are useful in areas of high traffic and protect the IR viewing panes from impacts, flying debris and dust. Constructed from aluminum, the CAP-CT series is recommended for all indoor applications.

Offering an unparalleled Field of View and the IRISS Unconditional Lifetime Warranty, these windows are also available with ports for Ultrasound and Partial Discharge inspections to increase their value and efficiency.



CAP-CT-PDS

***The CAP-CT Series has the largest visually clear infrared (IR) transmissive viewing area available.***

***Perfect for smaller areas/applications, and an evolutionary step in Infrared (IR) windows, the Platinum Series VPT utilizes our exclusive Poly-View System™ technology to allow the use of any thermography camera to monitor energized electrical equipment.***

## VPT Series

Perfect for smaller areas/applications, and an evolutionary step in Infrared (IR) windows, the Platinum Series VPT utilizes our exclusive Poly-View System™ technology to allow the use of any thermography camera to monitor energized electrical equipment. The world's only clear polymer round IR window optic enables visual inspections, traditional IR inspections utilizing cameras across the entire IR spectrum and allows for UV inspections to be performed with a corona camera. The Platinum Series VPT IR windows are industrial grade with a patented reinforced grill that exceeds high voltage switchgear viewing pane standards.

## FlexIR Custom Designs

There is no such thing as a standard IR inspection so why should there only be a standard IR Window? IRISS is the only IR window manufacturer with solutions for unique applications. The patented IRISS reinforced optic is flexible and can be manufactured in an infinite number of shapes and sizes ensuring that the FlexIR Custom IR window meets your needs and applications.

IR Inspection Windows from IRISS are UL Listed, Arc-Safety tested, and feature the patented Poly-View technology that is unaffected by environmental stresses and allows visual and IR inspections. They allow for fast and easy installation, fixed and stable transmission, and feature an environmentally sealed design.

Custom IR Windows

***IRISS is the only IR window manufacturer with solutions for unique applications.***

*Photo: IRISS*

## What Specifications Must Be Considered When Choosing Infrared Inspection Windows?

IR windows allow infrared cameras to see and measure temperature of objects and connections inside energized electrical equipment with the covers and doors in place (maintaining a safe and guarded condition). **IR Windows allow visual, Infrared, and Ultrasound inspections and they provide a safe and cost-effective way to conduct inspections on energized electrical equipment.**

- Multi-technology Maintenance Inspection Windows: These windows go beyond just infrared inspection by adding ultrasound capability. In addition to allowing for thermal imaging, visual and UV inspections, ultrasound and partial discharge inspections can be performed – all from a single window. This approach is cost-effective for the company overall as one type of window can accommodate multiple inspection modalities.

Additional criteria for specifying windows includes:

- **Field of View (FOV)** – Field of View takes into consideration the viewing angles and distance from the object of the camera and window working simultaneously. Are all the internal objects visible to the camera or is something blocking the camera's view? The FOV calculation determines the size of inspection window needed for each piece of equipment. When specifying windows on new equipment, make sure to specify the targets you want to be able to see and put the responsibility for selecting appropriately sized windows onto the OEM's design team.
- **Window Design** – compliance with flammability, impact and load requirements and OEM specifications for materials and color. The Window cover protects the window itself and the maintenance team.
- **Viewing Lens Materials** – the lens material must withstand mechanical impact and load requirements with the cover open. The lens must also have a fixed and stable **transmission rate** for the life of the unit and not change over time. Likewise, the lens material should not change with exposure to humidity or other environmental factors such as vibration. Outdoor lens material should withstand exposure to the sun and not change when exposed to water.
- **Certifications Required** – Windows, depending on application, may need to comply with multiple certifications such as UL, IP Ratings, CSA for Canada, IEEE Standards for specific equipment types and specialized certification for marine applications such as Lloyd's of London Approval, ABS or DNV.
- **Performance specifications** – specify the environment temperature where the Window will reside. Arc Containment testing may be required depending on the application of the Window or switchgear that contains the Window – on new equipment this becomes the responsibility of the OEM as part of their "type testing" protocols. Specify the lens material transmission rate be stable over the window's operating life. Ensure that the Windows are compatible with all makes and models of IR and ultraviolet cameras. If you choose a Window with IR, Ultrasound and Partial Discharge applications, the Window must be IP2X compliant.

## The Business Benefits of IR Inspection Windows

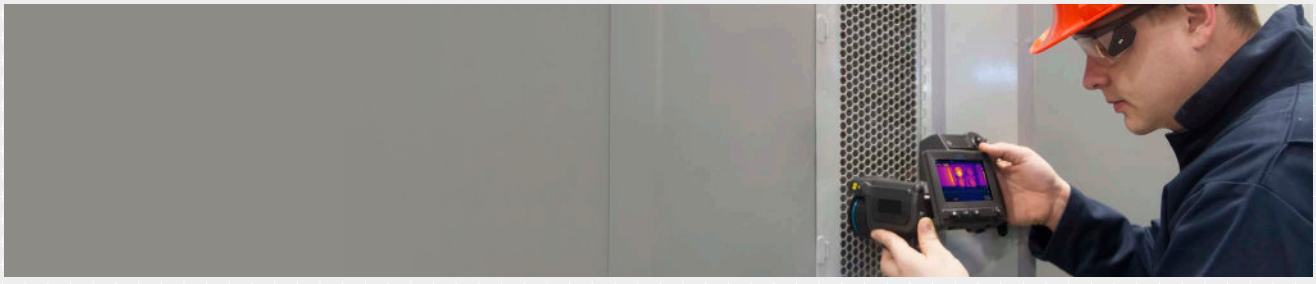
### Safety & Standards Compliance

Workplace electrical accidents claim hundreds of lives and cause thousands of serious injuries each year in the US. OSHA requested that NFPA 70E be created because as new technologies become available it is recognized that most of these fatalities and injuries could be prevented. Hence the publication of NFPA 70E, Standards for Electrical Safety in the Workplace. Maintenance inspection windows with infra-red, visual, and ultrasound capabilities are products that fall under the substitution stage in the Hierarchy of Risk Control Methods, enabling routine and safe inspections of energized electrical assets in a very safe and guarded condition.

### Reliability Improvement, Increased Efficiency & Cost Savings

Historically electrical asset inspections were time consuming, expensive, and potentially dangerous to personnel. Assets had to be powered down, panels had to be removed, personnel had to dress in personal protective equipment, assets had to be powered up and allowed to reach thermal stability. Then thermal imaging and ultrasound data was collected followed by powering down, reinstalling the panels and finally powering back up. Most of the time spent during these inspections was considered nonproductive work adding little or no value.

Maintenance inspection windows dramatically decrease the unproductive time seen with inspections. They provide nonintrusive access to the electrical asset so personnel can perform the inspection in a closed and guarded state eliminating the need for removal and reinstallation of panel covers and the need to wear special PPE.



## Case Study

A regional Power Generation Facility had been tasked by their insurance carrier to perform regular preventive maintenance on the switchgear within their facility. Unfortunately, regular downtime was not a practical option for them as the processes required to do the live inspections were hazardous and required more manpower and resources than they had to provide. In addition, they too were feeling the pressure of the requirements of NFPA 70E and were starting to re-think their strategy since inspections of energized equipment was becoming more restrictive, more time consuming and more costly.

The insurance carrier had done the necessary research and determined that the facility should consider Infrared windows as an alternative method of conducting safer, standards-compliant inspections. Previously, none of the primary switchgear or transformers had been included in the site's inspections due to the inherent safety hazards associated with their being safely inspected while energized. A review showed that some of the plant's critical assets were never inspected during the annual survey.

**It was determined that a reduction in hazard liability and maintenance costs could be attained through:**

- Use of Infrared Windows for routine inspections of healthy equipment did not require the elevated levels of PPE required in 70E, since as stated in 70E 100: "Under normal operating conditions, enclosed energized equipment that has been properly installed and maintained is not likely to pose an arc flash hazard."
- Maintaining an "enclosed" state for the switchgear, MCC, Transformer, etc., and maintaining energized components and circuit parts in a "guarded" condition, in NFPA terms. Therefore, the hazard/risk category would be equal to that of reading a panel meter, using a visual inspection pane for lockout/tagout confirmations, or walking past enclosed, energized equipment and could even be conducted during peak hours for best diagnostic data.
- Use of IR windows would eliminate the need for a supporting cast of electricians to remove and reinstall panel covers.
- Allowing critical personnel to then be available to perform other tasks which were often being outsourced.
- Providing the ability to perform more frequent inspections feasible for critical or suspect applications to ensure plant uptime and appease the insurance carrier of the reduced insurance liabilities.

In search for an alternative approach that was both safer and standards-compliant, the corporate reliability engineer investigated how IR windows be utilized. **It was determined that:**

- Use of IR windows would provide non-intrusive access to electrical applications. Surveys could be conducted during periods of peak-load without elevating risk to either plant assets or processes. They would also eliminate the need for a supporting cast of electricians to remove and reinstall panel covers. These critical personnel would then be available to perform other tasks which were often being outsourced.

*Photo: IRISS*

- Use of IR windows and closed-panel inspection would eliminate high-risk tasks during inspections – increasing safety for thermographers. They did not require the elevated levels of PPE required in 70E, since as stated in 70E 100: "Under normal operating conditions, enclosed energized equipment that has been properly installed and maintained is not likely to pose an arc flash hazard."
- In NFPA terms, an IR window maintains electrical equipment in an "enclosed" state and it maintains energized components and circuit parts in a "guarded" condition. Therefore, the hazard/risk category would be equivalent to reading a panel meter, using a visual inspection pane for lockout/tag-out confirmation, or walking past enclosed, energized equipment. They would improve inspection efficiency and allow increased inspection frequency for those mission critical or suspect applications.

The new inspection process with IRISS IR Windows brought significant ROI to the plant in just two inspection cycles, while reducing the risk of catastrophic failure among the plant's critical power distribution systems. Management succeeded in increasing safety, facilitating inspections of previously "un-inspectable" equipment, and increasing the frequency of inspection – while saving money. Safeguarding profitability by eliminating high-risk behavior that posed a risk to plant assets and production.

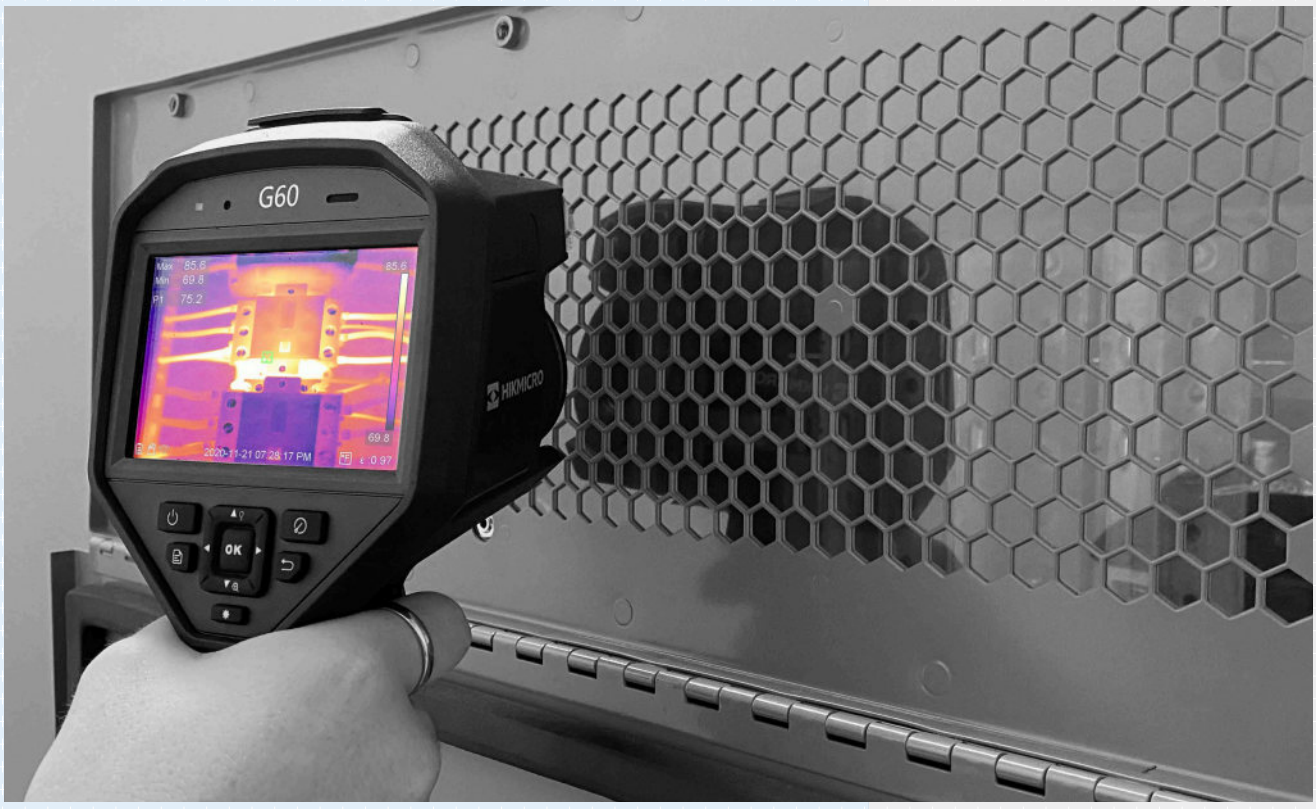
***IR Inspection Windows from IRISS are UL Listed, Arc-Safety tested, and feature the patented Poly-View technology that is unaffected by environmental stresses and allows visual and IR inspections.***

## Conclusion

IR Inspection Windows from IRISS are a Reliability Technology that allows a safer method of monitoring and inspecting critical electrical assets. These should be adopted as part of a comprehensive Condition-Based Maintenance System, where closed-panel inspections can take place with the equipment under full operational load. With the proper procedures in place that take advantage of this technology, technicians can monitor the health of assets and schedule necessary maintenance before an unplanned event occurs, causing costly downtime and possible injury or fatality.

Performing frequent inspections of critical electrical/electro-mechanical assets and performing trend analysis of inspection data over time may pin-point an asset that is beginning to show signs of deterioration. Once an asset has been identified and a potential failure risk, preventative maintenance can be scheduled and performed. Making use of IR inspection windows from IRISS increases the company's asset reliability and minimizes their downtime by scheduling repairs when needed as opposed to when the asset fails.

IRISS ENGINEERED RELIABILITY



A BETTER ENERGY FUTURE IS A FUTURE OF COLLABORATION

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# JENNIFER GREEN

**Jennifer Green** has been labelled as a fearless trailblazer and glass ceiling breaker for women in non-traditional careers and continues to advocate and be a leader in the skilled trades community.

**Through passion, dedication and mentorship, Jennifer has a rich history of breaking new ground and destroying stigmas. She is an influential leader with extensive experience building and supporting world-class programming and change culture.** Jennifer is the Director of Competitions at Skills Ontario, an organization focusing on encouraging youth to explore and pursue careers in skilled trades and technologies. Recently, she also completed an Appointment with the Government of Ontario's Ministry of Labour, Training and Skills Development, as an Apprenticeship Youth Advisor. **In November 2021, the Ontario Government invested an additional $90 million over three years to further promote the skilled trades to young people, which was in response to the Advisors final report to the Minister.** She has promoted the advancement of the skilled trades across Canada and beyond for almost 20 years in various roles through volunteerism, speaking engagements, and consulting. **As a mom of two, Jennifer parents the same way she advocates, ensuring that her children aren't discouraged from exploring careers that may be considered "non-traditional".** Jennifer enjoys using her transferable trades skills for at-home projects with her family, including her husband, a skilled tradesperson. **Among her accolades, she has been presented with the Universal Women's Network Women of Inspiration Award, WXN Top 100 Canada's Most Powerful Women Award, and the Conestoga College Alumni of Distinction Award.** Jennifer has also founded several initiatives, including the Skills Ontario Alumni Association as President, and the National Alumni Committee as Chair and the Ontario Lead, prior to employment at the organization. **Jennifer holds a Certificate of Qualification, a Certificate of Apprenticeship, and an Ontario College Certificate for Industrial Mechanic Millwright.**

Source:
**Jennifer Green**

Photo: Jennifer Green, rawpixel.com

# ONLINE TRANSFORMER BUSHING MONITORING

**Traditional offline testing techniques have proven to be very effective in detecting and identifying defects that involve *slow* diffusion of moisture and air, *slow* accumulation of particles and oil aging products, and the occurrence of faults that can develop *over many years*. This is not the case when defects rapidly progress over months or weeks.**

**Beside the obvious economic benefits of online diagnostics, online monitoring of HV bushings and current transformers permits the user to significantly improve the capability to detect more problems with apparatus at an earlier stage of development. ZTZ Services pioneered the online bushing monitor nearly 40 years ago. This makes ZTZ the most experienced provider with the most highly refined system for detecting failure modes in Bushings, CCVTs, CT, and GIS-AIS transitions.**

## WHY?

TRANSFORMER MONITORING SYSTEMS FOCUSED ON THE BUSHINGS IS THE PRIMARY BUSINESS OF ZTZ SERVICES - A SPECIALIST ENTERPRISE NEARING FOUR DECADES OF EXPERIENCE.

One detection method will not catch all failures. However, irrespective of different diagnostic responses of defective units, relative PF ratio at operating voltage has been successful in practically all typical cases of developing failure.

An online method is required because of the erratic and sometimes rapid nature of HVCT and bushing failures.

For instance, at 10% of rated voltage, the PF of two bushings is practically the same. That means that an offline Power Factor test will not show any defect in the bushings. With the increase of applied voltage, the PF of the defective bushing rapidly grows. The higher applied voltage reflects in higher PF magnitude.

Online measuring exploits the advantages of PF testing under *real operating conditions* (at rated voltage, at variable operating temperature). These advantages include the ability to record the changes of PF with temperature, with voltage, with time, as well as correlation between PF, capacitance, sum current, and leakage current – in the case of an internal fault involving short-circuits between layers.

ZTZ engineers took this capability to the next level in 1990 with two new test methods, then a third in 2012 and fourth in 2018:

1. The External Reference Method
2. Direct Method using PT as external reference voltage source
3. CCVT Poly-Phasor Method
4. GIC Disturbance Method

**Online Transformer Bushing Monitoring, But from Who?**
A good and reliable system has some stringent requirements.

1. The bushing sensor (sometimes called a tap-adapter) must be designed as a perfect replacement for the OEM grounding cover. From the mechanical perspective, the threads, thread depth, material, sealing surfaces, sealing gasket and interface to the flexible conduit must all be considered and be built without blemish.

2. From the electrical perspective, the connection and interface to the C1 connection prong must be flawless, as close to the OEM grounding cover design as possible. The material for the tang must be considered for the lowest contact resistance, compatibility with the prong metal, corrosion resistance and temper stability, for a firm reliable grip on the prong for the life of the system.

3. From the safety perspective, the bushing sensor must limit the voltage potential output to a safe level in case of contact with personnel from accidental damage of cabling. This limiting circuitry must be located within the bushing sensor, built with the finest electronic parts, and be twice redundant.

4. From the overall reliability perspective, all unnecessary removeable electrical connectors must be deleted. The bushing sensor cable must be continuous from the sensor internal circuitry all the way to the shorting switches in the monitor cabinet.

5. The installation of the sensors to the bushings – there can be 3, 6, 9, or even 12 sensors per transformer, must be done by experienced field personnel. Extreme care must be exercised when working with older bushings to avoid any damage to them and to ensure a perfect weather-tight seal is attained for each sensor. Turnkey installation by trained and experienced field engineers is the best way to ensure long-term reliability with all the other requirements being met.

These guidelines for quality are only just the beginning. There are many other nuances which come from our experience that is nearing four decades. Only ZTZ Services can offer this.

*Photo: ZTZ Services*

**Experience With Online Tests of HV CTs and Bushings**

In 1989, the experience of more than 1,000 units of 330 kV and 750 kV CTs in Europe proved the method to be very successful.

In one utility, 43 defective units were identified. In another, 14 violent failures were prevented during the period 1990-1999.

The availability of monitored data recorded during the maximum temperature of the HVCT in summer enabled the detection of many defective units having symptoms of dielectric overheating, presumably due to excessive aging of oil-paper bulk.

**Alabama Power Philosophy for Condition Based Maintenance**

Alabama Power made a decision to go with online monitoring of transformer bushings based on the then 25-year experience of ZTZ Services. The proven ZTZ monitoring system requires the installation of sensors to the bushing capacitor taps.

One of the most important features of the ZTZ system is the design integrity of the bushing sensors and how the sensor maintains personnel safety while maintaining the ground connection of the capacitor tap.

Budget cuts and manpower reductions during the 1980s did not change the need for providing reliable service. There was a need to reduce the number of outages due to failure or planned outages for offline testing.

Alabama Power moved from all time-based maintenance to condition assessment using the ZTZ Services bushing monitor but also applied to CCVTs and PTs. Alabama Power has installed ZTZ monitors on transformers ranging in size from 115/12 kV, 230/115 kV 250 MVA to 500/230 kV 400 MVA auto banks. More than 600 ZTZ monitoring systems are in service at the three operating companies of Southern Company.

The online bushing test data combined with DGA of both the main tank and LTC compartment has allowed Alabama Power to move from a six-year maintenance interval to strictly condition based interval, possibly as long as ten to twelve years.

As mentioned above, the ZTZ system allows for online monitoring of CCVTs and Potential Transformers. Offline testing of this equipment often requires a bus outage with manpower involved in switching and disconnecting.

In the first three years, Alabama Power found two CCVTs that were in the failure mode. The benefit of finding these two before failure greatly outweighed the initial cost of the equipment. The last CCVT failure on APCo property cost $250,000 ($750,000 in 2022 dollars) just for PCB cleanup, in addition to loss of revenue caused by additional equipment damage.

*Photo: ZTZ Services*

ZTZ Bushing Monitor
in service since 2013

## 30+ Years Onward

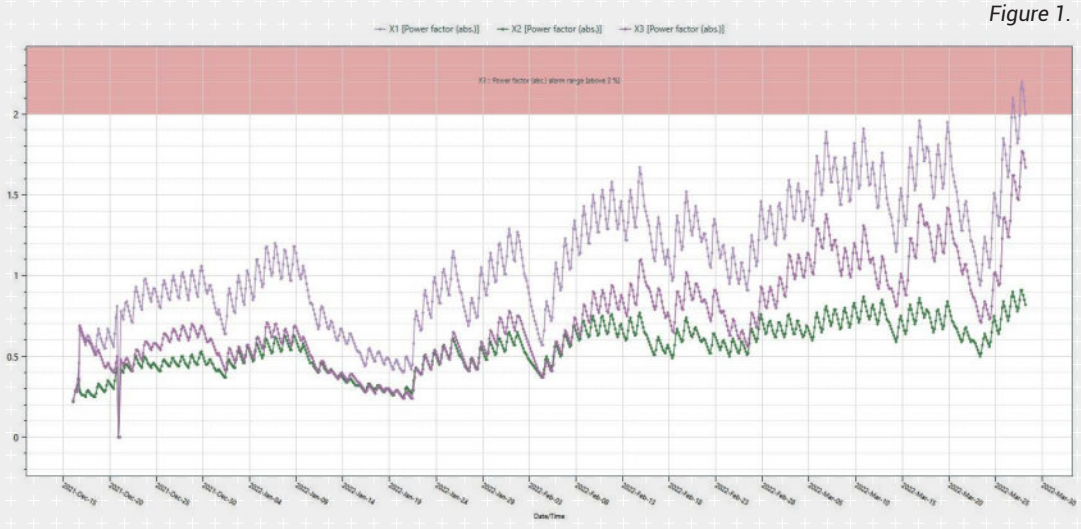
With more than 5,000 transformer bushing monitors in service, ZTZ Services is the most experienced supplier, having achieved an unmatched level of refinement, including a lifetime warranty. There has never been a reported false alarm by a ZTZ Bushing Monitor. Used ZTZ systems are never found on eBay™ as are the competitors', which is a testament to the long useful life of ZTZ monitoring systems and high customer satisfaction.

ZTZ Services has become very popular with renewables operators. The problems they face with transformers are similar to those faced by investor-owned utilities (IOU). However, whereas IOUs can tolerate an occasional transformer failure by switching the network around, a renewable operator is in trouble. There is usually no replacement nearby and every sunny day means hundreds of thousands of dollars in lost revenue while waiting for the new transformer to arrive.

At $100 MW/hr, a renewable operator cannot afford to risk a catastrophic failure. The **ZTZ TRANSMAX2000** system offers the utmost in bushing condition awareness and is fully installed on a turnkey basis by trained ZTZ factory field engineers. The TRANSMAX2000 represents very low-cost insurance against transformer failure – usually the installed cost is far less than one day of lost revenue.

Transformer bushings can fail on either the low voltage side or the high voltage side. Solar sites have the characteristic of going from cold to full-on at dawn and full-off at dusk, day after day. This is shown in the plot below by the power factor shape of a saw-tooth pattern. The power factor is shown to be affected by ambient temperature. This transformer use is called "Rough Service", and it is one of the most severe applications for the bushings. In April of 2022, a 200 MW solar site main transformer monitor produced the four-month power factor plot shown in Figure 1.

*Figure 1.*



RENEWABLE OPERATORS ENJOY OVER 200 YEARS OF UTILITY EXPERIENCE OFFERED BY ZTZ SPECIALIST ENTERPRISE ON THE TOPICS OF TRANSFORMER OIL, TESTING, BUSHINGS AND FORENSICS. THIS EXPERTISE IS MADE FREELY AVAILABLE TO ALL ZTZ SYSTEM USERS.

The purple traces represent the measured power factor of the X1 and X3 bushings (the low voltage side) facing the voltage converters. The plot shows data from December 2021 to March 2022. The power factor increases from nominal to alarm stage during this time. Obviously, if the transformer was on a five-year test cycle with traditional measuring tools, it is likely the problem would have gone to full failure – which would mean a $240,000 revenue loss per day for this site.

The online measured power factor is not the only way that ZTZ monitoring systems verify a problem. There are other exclusive algorithms that are applied to the measured data which are used to corroborate and add confidence to the alarm status. No system operator wants to receive false alarms and ZTZ monitoring systems do not give them.

Renewable operators enjoy over 200 years of utility experience offered by ZTZ on the topics of transformer oil, testing, bushings and forensics. This expertise is made freely available to all ZTZ system users.

*Photo: ZTZ Services*

ZTZ HAS ONLY ONE FOCUS – TO FULLY SUPPORT THE USER OF THE ZTZ TRANSFORMER MONITORING SYSTEMS.

Renewable operators are choosing ZTZ because it is a specialist enterprise. Transformer monitoring systems focused on the bushings is the primary business of ZTZ Services. ZTZ is also a highly stable, privately held U.S. company. There are no "cut corners" to increase "shareholder value". Customer service resources are not shared between multiple corporate pursuits/acquisitions and originate from the ZTZ factory in the Eastern U.S. Time Zone – not Europe or Canada.

ZTZ has only one focus – to fully support the user of the ZTZ transformer monitoring systems. ZTZ supports the customer with as-needed consultative services, field training, formal training at ZTZ headquarters, and full turnkey system installations – all for maximizing up-time of the transformer. ZTZ presently has four installation teams located at the Miami, Florida headquarters.

**Into the Future**

Offshore wind is growing in significance and remote offshore substations and interconnecting cables require monitoring. ZTZ Services supplies the **Hydrocal H1008 Offshore DGA System**. Extreme ruggedization sets the H1008 apart from any other online DGA system. In the picture above, the device is shown at the Hornsea-Two offshore substation, world's largest offshore wind farm.

As older renewables sites are repowered, up-rated, and improved; ZTZ monitoring systems will provide the systems which keep a careful watch on the most important part of the system – the main step-up transformer. With the transformer supply chain presently suffering long delivery delays, the preservation of this critical asset becomes even more important.

# Transformer Dissolved Gas Analysis:

# Diagnostics from Factory to Operation

by **Paul Pillitteri**

**Paul Pillitteri** has been in the medium and large power transformer industry for 50 plus years. He has worked for three leading transformer manufactures prior to becoming a transformer consultant for the last 20 years. His experience covers most areas of power transformers including design, manufacturing, testing, repair/refurbishment, field service, and facility operations manager.

Photo: Shutterstock

Experience has shown that a problem or failure can go undetected at the very end of a HV dielectric test or temperature test. Large power transformer manufacturers should therefore test the quality of the oil before oil testing the transformer and perform a DGA test after HV dielectric testing or temperature run test.

## Factory Diagnostics

The basic concept for dissolved gas analysis (DGA) of transformer oil has existed for at least the last 70 years. DGA was first used in the 1950s to diagnose the status of the oil/insulation system specifically after high-voltage dielectric and/or temperature run testing in the transformer factories. Experience has shown that a problem or failure can go undetected at the very end of a HV dielectric test or temperature test. Large power transformer manufacturers should test the quality of the oil before oil filling/testing the transformer and perform a DGA test after HV dielectric testing or temperature run test.

In the 1950s, and that is true even today, most end users were not aware that some large power transformer manufacturers use a DGA test to determine the final integrity of the transformer after testing. Manufacturers can or may have a table qualifying the levels of gas generation before shipment. In the early 2000s, IEEE published "PC57.130 Draft Trial-Use Guide for the Use of Dissolved Gas Analysis During Factory Temperature Rise Test for the Evaluation of Oil-Immersed Transformers and Reactors".

An example of a **table for factory guidelines after testing** might be similar to Table 1. Example of a factory table for gas generation guidelines after HV & temperature testing is given in Table 2.

A DGA sample on all new large power transformers after final factory testing is recommended to be included in customer specifications.

| | |
|---|---|
| **LEVEL 1** | **Acceptable** |
| **LEVEL 2** | **Investigate** (requires engineering investigation) |
| **Above LEVEL 2** | **Not Acceptable** without additional diagnostics and engineering approval |

*Table 1. Example of a table for factory guidelines after testing*

| **GAS COMPONENT** | **GAS CONTENT IN PPM** | |
|---|---|---|
| | **LEVEL 1 Acceptable** | **LEVEL 2 (engineering OK required)** |
| $H_2$ (Hydrogen) | <11 | >30 |
| $CH_4$ (Methane) | <6 | >25 |
| $C_2H_6$ (Ethane) | <6 | >25 |
| $C_2H_4$ (Ethylene) | <6 | >25 |
| $C_2H_2$ (Acetylene) | 0 | 0 |
| CO (Carbon-Monoxide) | <76 | >200 |
| $CO_2$ (Carbon-Dioxide) | <401 | >1000 |

*Table 2. Example of a factory table for gas generation guidelines after HV & temperature testing*

The DGA inquiries of almost all clients result in wanting answers to these two questions:
Why is my transformer gassing?
And what should we do about it?

**Operational Diagnostics**

As a technical support manager for a large power transformer manufacturer and a consultant for approximately 20 years, I have reviewed and given numerous DGA analysis reports for clients. The intent of a consultation is to **help the end users understand DGA** and determine a course of action for their transformer. In many cases I found it helpful to explain why DGA is necessary and the value of monitoring DGA. An example is as follows:

"**All liquid filled power transformers generate gases during operation.** This can occur with or without load on the transformer. It is well recognized that the gases generated are directly related to the transformer oil and the solid internal insulation materials. These materials undergo gradual or abrupt degradation (gassing) depending on whether the electrical stresses and thermal temperatures are mild or severe. With this understanding, diagnosis of transformer gassing must take into account many variables, but at a minimum, the following factors:

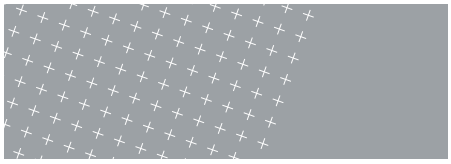
a) transformer type and age
b) loading (temperatures) on the transformer
c) transformer events
d) DGA, preferably a DGA history, as supplied by the end user

Ideally, this history shows not only all relevant gases being generated but also indicates their rate of acceleration."

Photo: Shutterstock

All liquid filled power transformers generate gases during operation, which are directly related to the transformer oil and the solid internal insulation materials. These materials undergo gradual or abrupt degradation (gassing) depending on whether the electrical stresses and thermal temperatures are mild or severe.

Many manufacturers, field service groups and commercial suppliers of online monitoring equipment provide their own recommendations for interpretation of DGA results. This includes digital software programs for interpretation of DGA results.
A good source of detailed information for the *transformer engineer* is IEEE STD C57.104 Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers [1].



As a technical support manager or transformer consultant, you are often required to provide DGA guidance to the following types of clients:

a) utility maintenance supervisors,
b) operations managers,
c) power plant managers, or even the CEO of a major utility.

The DGA inquiries of almost all clients result in wanting answers to these two questions:

1. Why is my transformer gassing?
2. What should **we** do about it?

For all end users of large power transformers that do not have an in-house transformer engineer/expert on DGA, I would recommend the following options:

1. If possible, contact the original equipment manufacturer (OEM) for DGA guidance. This is normally done if the transformer is still in warranty. If out of warranty, most OEMs will still provide DGA guidance. OEMs will have historic design details, design changes and a history of operational knowledge that can be extremely valuable in DGA evaluation.
2. If OEM guidance is not possible, research the IEEE/PES Transformer Consultant Listing to obtain a transformer expert.
3. If online monitoring equipment provides the DGA results, contact the commercial provider of the online monitoring equipment.

**Common end users' inquiries** pertaining to troubling DGA readings often occur with the transformer installation, required field maintenance, or an operational event. These inquires by end users are usually considered urgent and require an immediate response.

To conclude this article, I will outline a number of repetitive and documented cases that have occurred and continue to occur, and they are as follows:

a) **Acetylene** – An arcing or intermittent sparking condition in transformer oil can produce acetylene and hydrogen. High proportions of acetylene and hydrogen are characteristic of arcing conditions in the oil. This condition in large power transformers is extremely critical and requires immediate attention. Common repetitive occurrences:

- Transformers with centrifugal or axial flow oil pumps, rated FOA or OFAF, operate with a portion of the transformer oil circulating through the pump motor to provide cooling and lubrication for the bearings. A fault occurring in the motor winding of the pump can and will produce acetylene gas in the oil for a prolonged period of time before the pump fails to operate. This condition can be detected and corrected with a routine maintenance operation without taking the transformer offline.
- Field modifications or maintenance operations that require welding on the transformer tank walls can produce acetylene gas in the oil adjacent to the welding area.
- Field equipment used to oil fill, degas the oil, hot oil processing or add oil to a transformer may be contaminated from use on other equipment.
- Transformers with separate compartments for arc in oil load tap changers or other switching mechanisms are usually separated by a gasketed terminal board. Oil from these separate compartments may seep into the transformer tank from a defective gasket or a damaged terminal board.

*Photo: Shutterstock*

- A thru-fault condition on a transformer can cause an arc (acetylene) in the transformer oil without causing the transformer to fail. It is imperative that follow-up DGAs be taken to determine if acetylene is increasing, stable or decreasing. A DGA sample is recommended on all large power transformers after a thru-fault condition.

b) **$CO_2$/CO Ratio** (carbon dioxide/carbon monoxide ratio) – The ratio of these gases provides a good indicator of normal or abnormal cellulose degradation. A frequent field incident that occurs all too often is the loss of power supply to the control cabinets on large power transformers. Transformers that have auxiliary cooling equipment that lose their power supply may be mildly or severely overloaded depending on the length of time before power is restored to the control cabinet. Severe/prolonged overload cases can result in a very low $CO_2$/CO ratio, abnormal cellulose degradation, and a very high ppm moisture content in the oil. A transformer expert should be consulted before taking any remedial actions on the transformer oil.

c) **Sulfur Hexafluoride** (SF6 gas) – SF6 gas is used primarily in gas insulated circuit breakers and switchgear. SF6 is an excellent insulator that is inert, colorless, odorless and the most potent greenhouse gas used in industry. Because of its excellent insulating properties, it is sometimes **misused** in place of nitrogen on medium and large power transformers. SF6 gas should **never** be used in oil insulated transformers for the following reasons:

1) SF6 gas is 3 to 4 times more soluble in transformer oil then either nitrogen or air. This creates a greater possibility of flashovers and arcing due to gas bubble evolution (bubbling).
2) Even with very low corona levels in transformers or load tap changer compartments small corona arcs may be present. Any sources of arcing will chemically breakdown the SF6 gas dissolved in the oil. This breakdown of the gas produces corrosive by-products, contaminating the oil and reducing its dielectric strength.

d) **Argon** (Ar) **vs Nitrogen** ($N_2$) – Argon is a chemically inert gas which may be used in oil filled transformers when Nitrogen gas is not readily available from a supplier. Diagnostic complications can occur if an oil sample for DGA is sent to a laboratory using gas chromatography and the laboratory is not made aware to test for Argon. Unless the laboratory is told to test for Argon, the Argon gas will show up in the total oxygen content. There are a fair number of commercial online DGA monitoring devices. I am not aware if any of them test for Argon. Argon gas is not recommended as a standard or option in oil filled transformers.

**References**

[1] C57.104-2019 – IEEE Guide for the Interpretation of Gases Generated in Mineral Oil-Immersed Transformers

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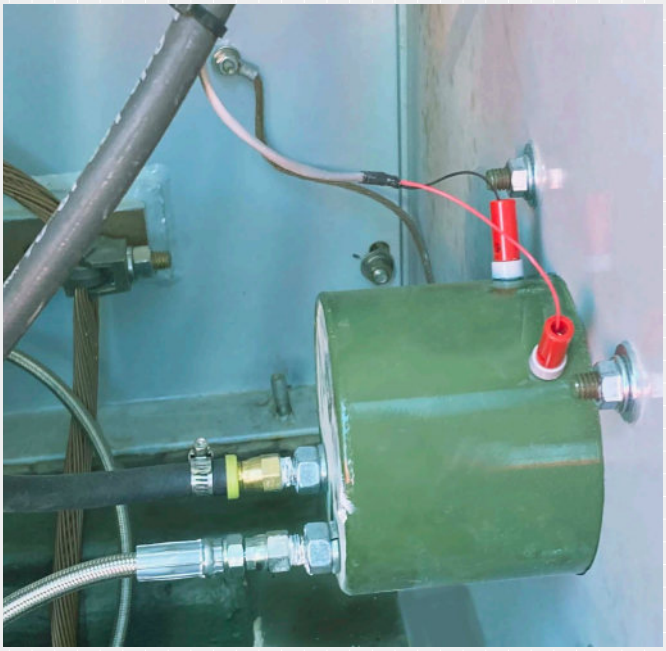
# InsuLogix® SSK + RFM | Deployment on Renewable Pad Mounted Transformers

## Mitigate Risk: Safeguard Assets, Property, Line Crew, and the Public

*Replacing the existing pressure relief valve (PRV) with an InsuLogix® RFM adds the ability to monitor for overpressure events while maintaining the pressure relief functionality with the RFM's built in PRV.*



*Two insulated banana jack sockets are then installed into the top of the InsuLogix® SSK's housing, as shown above. The two wires of the RFM's switch contact are outfitted with banana jacks and then plugged into the sockets. With the installation completed, the cabinet door can now be closed and locked and the transformer is ready to go back in service.*

A customer in central Texas was looking for a safe and efficient method for determining whether or not their pad mounted transformers had seen an overpressure event at any point in time.

The **CHALLENGE** of using an overpressure fault indicator on this type of transformer is that the indicator is not visible without opening the cabinet door. This means one must take an outage to confirm if an unsafe pressure condition has occurred or is actively occurring. Unless, of course, the fault indicator contacts were made accessible from the outside.

### Insulogix® SSK + RFM Application Details

In this installation, both InsuLogix® RFMs and InsuLogix® SSKs are installed in six three-phase 1750 kVA 34.5 kV x 690Y/398 V step-up transformers. These transformers are each located at the base of a wind turbine in Central Texas and are part of a larger renewable network that provides green energy to Austin, San Antonio, and many of the surrounding communities.

As these transformers are used whenever conditions allow for wind power generation, they are a vital part of the customer's network. A transformer being out of service during favorable generation conditions means a reduction in revenue for the customer as the associated wind turbine would also be out of service.

WEIDMANN

Photo: Weidmann

*Looking at the open InsuLogix® SSK on the outside of the transformer, notice the two posts protruding from the top of the housing. These provide a safe location for personnel who are either oil sampling or preparing to service the transformer to confirm whether a pressure fault has occurred.*

*Using a digital multimeter and measuring continuity, an open circuit indicates that the transformer has not seen an unsafe pressure event, while a closed circuit indicates that a fault has occurred.*

## Installation Details

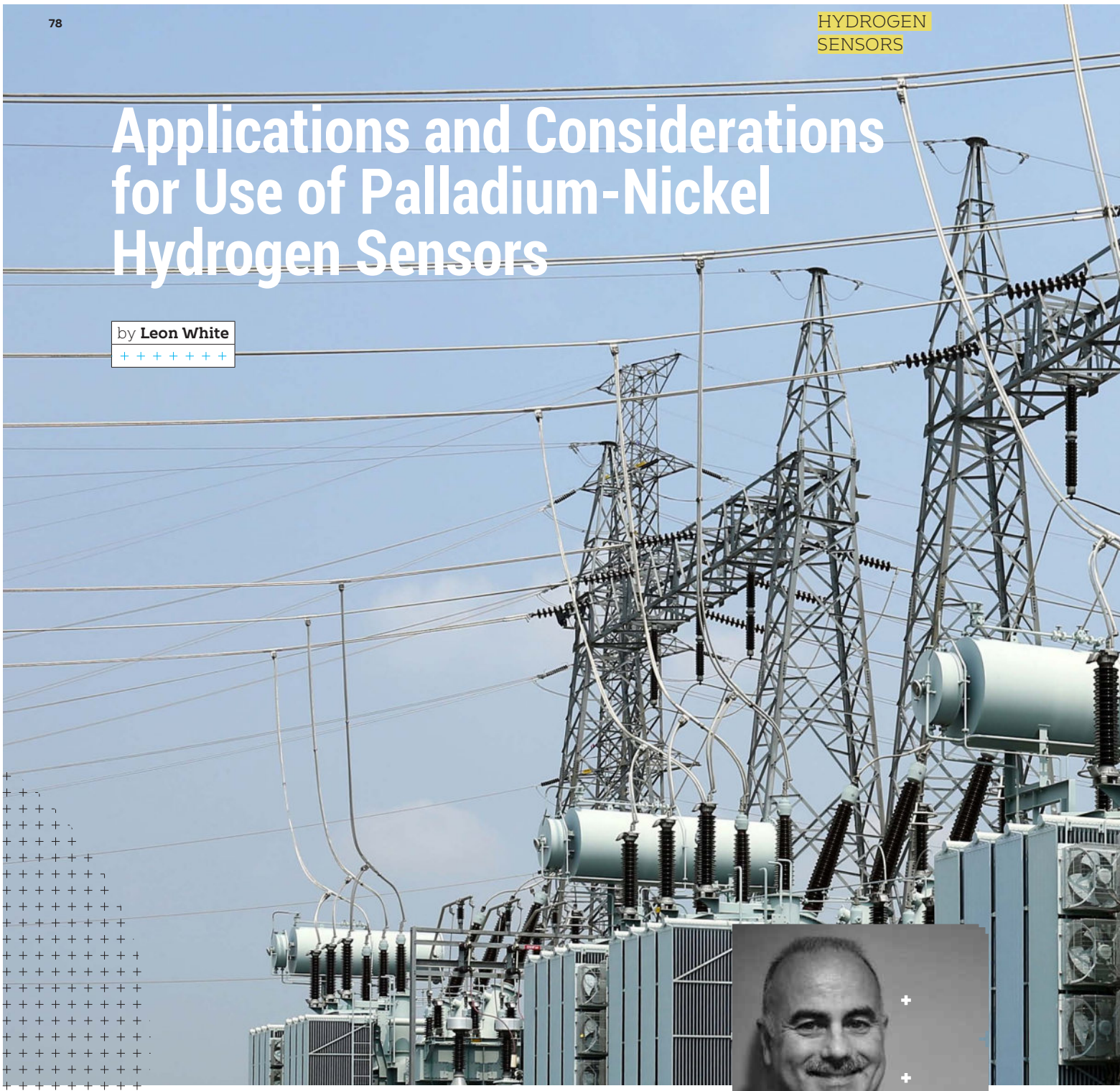
Since the installation of the InsuLogix® SSK and RFM requires accessing the inside of the transformer cabinet, the following installation took place during a planned customer outage. These particular units were already outfitted with InsuLogix® SSKs so installation time to add the RFMs was reduced to less than an hour; however, an install of both components could be completed in under two hours as the sockets for the RFM connections would be preinstalled at the factory prior to going on-site.

The InsuLogix® RFM is a dual function device in that it includes both a pressure relief valve (PRV) and a fault indicating flag, each of which function and are calibrated independently. In this application, the existing PRV of the transformer is replaced by the RFM which conveniently uses the same port for mounting.

**SOLUTION:** Combining the Weidmann InsuLogix® RFM (Retrofittable Fault Monitor) with the InsuLogix® SSK (Safe Sample Kit) provides service personnel a safe and convenient way to determine if a pad mounted transformer has experienced an overpressure event.

# Applications and Considerations for Use of Palladium-Nickel Hydrogen Sensors

by **Leon White**



**This paper describes the benefits of using Palladium Nickel Alloy Hydrogen sensors for various applications where Hydrogen specific sensors are required. Typical applications for liquid filled transformers, safety monitors, fuel cells, electrolyzers, and Hydrogen in natural gas pipelines are explored as well.**

*Keywords: Hydrogen sensor, Palladium, Nickel, Palladium Alloys, Solid-state Sensors, Thin Films*

With over 30 years of electric utility and on-line monitoring experience, **Leon White**, P.E. has a strong background in the application of online sensors for a variety of applications. While at Ameren, the electric utility in St. Louis, Missouri, he held various positions including substation design, transmission regulatory and real time power trading. He has worked for GE and Qualitrol where he developed strong working knowledge of online sensors, substation communications and project management. He is a Professional Engineer and a member of the IEEE Power and Energy Society. He received his Electrical Engineering and MBA degrees from Southern Illinois University at Edwardsville.

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*Most sensors used for dissolved gas analysis in transformers require gas to be extracted from the liquid to enable measurement of the Hydrogen content. Palladium Nickel sensors can accurately measure the Hydrogen content directly in the insulating liquid, which ensures the best accuracy since there is no error introduced in the gas extraction process.*

## Introduction

Although many technologies exist to measure Hydrogen, users need the best technology to fit their application. Sensors must be designed and manufactured to work in a variety of environments where other gases or compounds may affect the Hydrogen measurement. Additional considerations besides the measurement environment are: the required accuracy, the measurement range, the possibility of sensor drift over time, and how the data will be obtained. In addition, users must also evaluate the lifetime cost of using one technology versus another.

The typical Palladium Nickel sensor die is attached to a flexible circuit as shown below. A thin film of Palladium Nickel is deposited onto a substrate to form a resistor. Included on the sensor die is the Palladium Nickel alloy Hydrogen sensing element, a heating element and a temperature sensing element. The material properties of palladium alloys, as well as proprietary coatings, allow the sensor to provide Hydrogen specific measurement without sensitivity to other gases.

## I. ENVIRONMENT

When users determine the need to measure Hydrogen, they must evaluate the environment where the sensor will be installed. Can Hydrogen be measured in the native environment, or will a sample be required? What temperatures will the sensor be subjected to? What other gases or substances could affect the Hydrogen measurement? Will the pressure of the environment affect the measurement? Will the life of the sensor be negatively affected by the environment where the sensor is installed? Let us investigate each of these questions in more detail and look at typical applications for Hydrogen measurement.

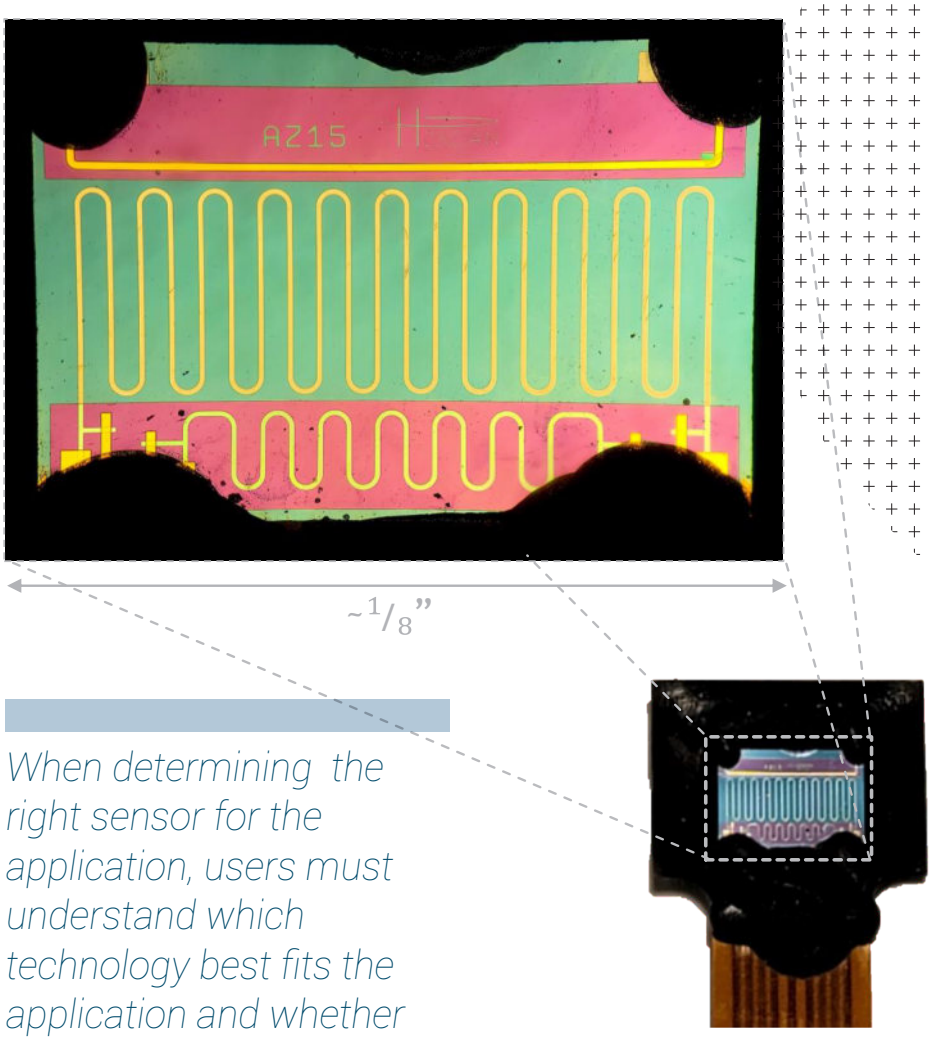
### A. Native Environment or Sample?

If Hydrogen cannot be measured in the native environment, a representative sample must be obtained from the native environment in a suitable manner and injected into a monitor or analyzer for measurement. Sample extraction can be manual or automatic. Since the procurement of manual samples can introduce errors due to imperfect sampling techniques, automated sampling or measurement in the native environment are preferred. Measurement devices that analyze samples typically control the temperature and pressure of the measurement environment which increases accuracy. Whether samples are taken manually or automatically, some amount of time delay will exist between the time the sample is procured and when the results of the measurement are provided. Many applications require continuous real-time measurement. In those cases, the sensors must be able to survive in the primary environment where the Hydrogen measurement is required. Some advanced systems use a sample conditioning system that removes a sample from a process stream and automatically measures Hydrogen real-time.

### B. Temperature

If the sensor is to be mounted in the primary environment, the sensor must be able to withstand the temperatures of that environment. In many cases, sensors must be rated for -40 to 105°C. Palladium

*Figure 1. Example of a Palladium Nickel sensor die*




*When determining the right sensor for the application, users must understand which technology best fits the application and whether a low cost/short life sensor is appropriate or if the application requires a more expensive, long-life solution.*

Nickel sensors can withstand most environments that require very high or low temperature ranges. These sensors monitor the temperature of the environment and can use that information to provide more accurate measurement.

### C. Cross Sensitivity

Cross sensitivity is a key issue that users must consider. General purpose sensors like thermal conductivity detectors (TCDs) are sensitive to many gases and are typically only applied in gaseous environments. Devices that use a TCD to measure Hydrogen must separate the Hydrogen from other gases in the sample using an extraction technique. While this typically provides accurate Hydrogen measurement, the equipment necessary to extract and/or separate the Hydrogen is costly. There is also a typical time delay of 15 to 60 minutes between the time the sample is obtained and when the result is available. Palladium Nickel sensors can normally be mounted in the primary environment and are designed to be Hydrogen specific, negating the need to separate the Hydrogen from the primary environment. These sensors can also be conditioned to survive in harsh background environments like carbon monoxide and hydrogen sulfide. The use of proprietary coatings and conditioning techniques allow Palladium Nickel sensors to survive in harsh environments for the life of the sensor.

### D. Pressure

Since most measurement devices require samples to be obtained from the primary environment for testing,

the measurement device can provide a controlled environment for testing, typically at normal atmospheric pressure. When the sensor is installed in the primary environment, the gas pressure is likely to affect the Hydrogen measurement. Palladium Nickel sensors are partial pressure devices. These sensors are typically calibrated at 1 atmosphere, so they are very accurate at that pressure. If the pressure changes, the hydrogen measurement directly correlates with the increase or decrease in pressure. For instance, if the pressure is increased from one atmosphere to two atmospheres, the sensor will read twice the measurement it would read at one atmosphere. For that reason, operating a Palladium Nickel sensor in a high-pressure environment requires the pressure to be measured to compensate the Hydrogen measurement to a normalized value.

## II. OTHER SENSOR CONSIDERATIONS

### A. Sensor Life

For most applications, users desire a Hydrogen sensor or monitor that lasts as long as possible without the need for calibration or replacement. Typical sensor life of most Hydrogen sensors is one to five years because the sensor element is either consumed or otherwise reaches end of life. The sensor can become 'worn out' due to chemical changes in the sensor when exposed to Hydrogen or due to other environmental factors like exposure to destructive gases, heat, or moisture. Palladium Nickel sensors are not consumed in the presence of Hydrogen. Proprietary protective coatings enable Hydrogen to enter the Palladium Nickel lattice where the presence of Hydrogen changes the resistance of the sensor. The change in resistance is measured in nano-ohms (10-9 ohms). Hydrogen moves freely in and out of the Palladium Nickel lattice without being consumed or changing the chemical makeup of the sensor. For this reason, the Palladium Nickel element is not the limiting factor to the life of the sensor. The limiting factor is determined by the electronics design that measures the resistance of the sensor, controls the temperature at the sensor (if required), and otherwise manages administration of the sensor, data processing, communications, and power supply. Robust designs allow for Palladium Nickel sensors to last 10 to 15 years or longer.

*The largest application for Hydrogen sensors to date has been to measure Hydrogen generated in the insulating liquids of electrical transformers. Hydrogen is also monitored in battery rooms, and more recent applications include Hydrogen electric generation facilities, electric fuel cells, electrolyzers and natural gas pipelines that are now utilizing a mixture of Hydrogen with natural gas.*

### B. Lifetime Cost

Hydrogen sensors are available for a variety of applications which provide varying accuracies, measurement ranges and which survive in a variety of environments. When determining the right sensor for the application, users must understand which technology best fits the application and whether a low cost/short life sensor is appropriate or if the application requires a more expensive, long-life solution. For instance, manned facilities where qualified 'analyzer staff' is readily available may choose a low-cost sensor that requires periodic calibration and/or can be replaced regularly. If a user is designing a system to monitor for Hydrogen leaks at a remote, unmanned Hydrogen filling station, the designer would most likely choose a more expensive sensor that has a long life and does not require periodic calibration. Recent advancements in Palladium Nickel sensor technology allow for continuous measurement with no calibration required for the life of the sensor.

### C. Data Access

Once the Hydrogen is measured, the data needs to be provided to another system or the end user. While some applications simply require alarm relay contacts, others might require analog outputs (typically 4-20mA) or a communication protocol like Modbus RTU. It is important to recognize the data requirements to ensure the sensor communications are correct for the application.

## III. POPULAR HYDROGEN SENSOR APPLICATIONS

Historic applications for Hydrogen sensors include processes and equipment that generate Hydrogen, Hydrogen storage facilities, and facilities where Hydrogen is used. Interestingly, perhaps the largest application for Hydrogen sensors to date has been to measure Hydrogen generated in the insulating liquids of electrical transformers. Hydrogen is also monitored in battery rooms where lead-acid batteries generate Hydrogen during charging cycles. More recent applications include Hydrogen electric generation facilities, electric fuel cells, electrolyzers and natural gas pipelines that are now utilizing a mixture of Hydrogen with natural gas.

### A. Liquid Filled Transformers

Hydrogen monitors have been used for more than 40 years to detect Hydrogen that is generated due to the breakdown of transformer insulating liquid (typically mineral oil). Tens of thousands of Hydrogen and multi-gas monitors are installed globally because Hydrogen generation indicates problems inside the transformer. Most sensors used for dissolved gas analysis (DGA) in transformers require gas to be extracted from the liquid to enable measurement of the Hydrogen content. Palladium Nickel sensors can accurately measure the Hydrogen content directly in the insulating liquid. This ensures the best accuracy since there is no error introduced in

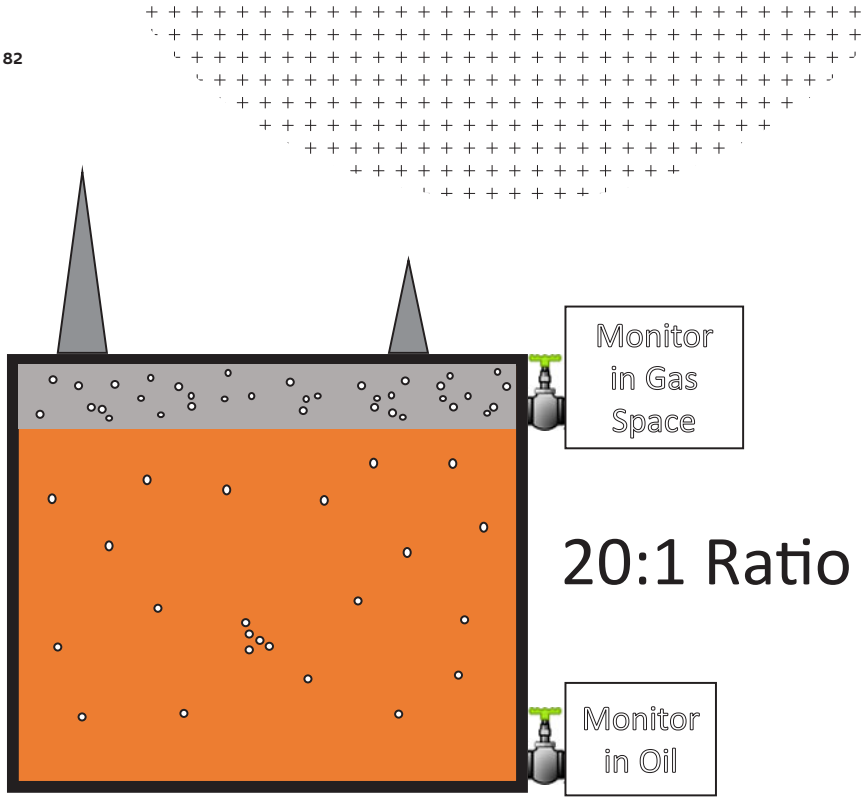



*Figure 2. Sensors may be mounted in the insulating liquid or in the gas space to measure Hydrogen inside liquid filled transformers.*

the gas extraction process. Common insulating liquids today include mineral oil, natural esters (vegetable oil), synthetic esters, and silicone oil. Not all sensors are rated for use with these liquids, so users need to ensure the sensor used is rated for the liquid in their transformers. Since Hydrogen dissolves at different rates in each liquid, a factor called the Ostwald Coefficient defines the dissolution rate in each liquid. By understanding the properties of each liquid and factoring in the use of the Ostwald Coefficient, Palladium Nickel sensors can accurately measure Hydrogen in each of these liquids. Measurement accuracy is maintained by adjusting the calculation algorithm with the appropriate Ostwald coefficient for the desired liquid.

Many liquid filled transformers have an inert gas space above the liquid. In these transformers, Hydrogen can be measured in either the liquid or in the gas space. Hydrogen that is generated in the liquid also fills the gas space. At equilibrium, the Hydrogen concentration in the gas space is approximately 20 times the amount dissolved in the liquid. Therefore, it is important that users choose sensors with the appropriate measurement range for each environment. Typical Palladium Nickel sensors measure up to 5000 PPM in the insulating liquid and up to 100,000 PPM (10% Hydrogen) in the gas space. In rare cases, transformers in operation can reach up to 30,000 to 40,000 PPM of Hydrogen in liquid or 60-80% Hydrogen in the gas space. Recent advances in Palladium Nickel sensors now allow measurement of very high levels (up to 100%) in these transformers with sensors that require no periodic calibration. See "Fig. 2" for typical sensor mounting locations for liquid filled transformers.

**B. Safety Monitors/Battery Rooms**

When users are interested in monitoring for Hydrogen leaks, they install sensors in areas where the leaks can be detected. In this case, the sensor must be able to measure low levels of Hydrogen and remain stable when Hydrogen is not present for long periods of time. It is important to note that Hydrogen becomes combustible at a level of 4%. Therefore, typical safety application solutions designed for battery rooms activate a vent fan at 1%, then have an alarm setpoint of 2% to ensure employees are notified if dangerous levels of Hydrogen are present. Many safety solutions refer to the Hydrogen level in terms of the Lower Explosive Limit (LEL). For instance, in this case the fan is turned on at 25% LEL (1% in air) and the alarm is triggered at 50% LEL (2% in air).

Many systems include audible alarms and flashing lights to ensure employees working in the area are made aware of the possible danger. Most sensors used for this application require periodic calibration and replacement every one to five years. Palladium Nickel sensors are available for this application with a 10-to-15-year life requiring no field calibration for the life of the sensor. See "Fig. 3" for a typical battery room safety solution.

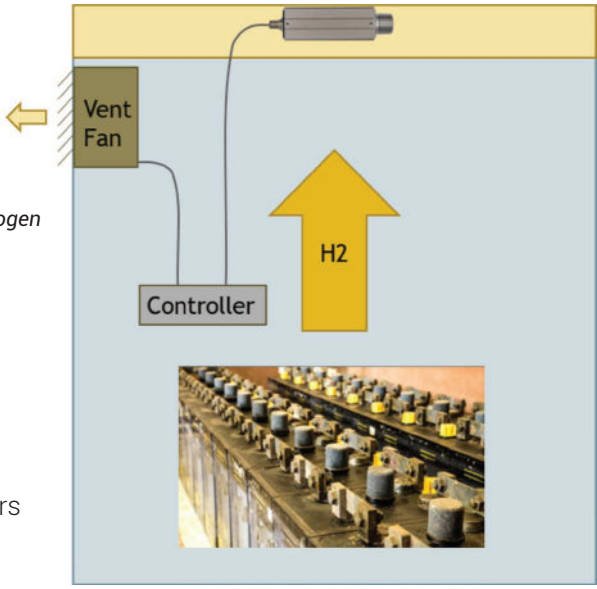



*Figure 3. Example of a Hydrogen monitoring safety solution for a battery room that uses vented lead acid batteries*

**C. Fuel Cells**

In addition to monitoring for leaks in the primary Hydrogen system, fuel cell manufacturers also need to know if Hydrogen migrated through the fuel cell and reached the exhaust without being consumed. In addition, manufacturers need to measure excess Hydrogen that was fed to the fuel cell but exceeded the amount required for fuel cell operation. See "Fig. 4" for sensor locations in a fuel cell.

**D. Electrolyzers**

Electrolyzers separate Hydrogen and Oxygen from water. Due to recent interest in green fuels, electrolyzer system installations are increasing rapidly. Since the electrolyzer is designed to produce pure Hydrogen, the Hydrogen output of the electrolyzer is monitored to ensure other gases or compounds

are not contaminating the desired pure Hydrogen output. A Hydrogen sensor is also installed on the Oxygen side to ensure Hydrogen is not mixed with the Oxygen. See "Fig. 5" for sensor locations in an electrolyzer.

### E. Hydrogen in Natural Gas

Natural gas companies are investigating how they can inject Hydrogen into natural gas pipelines. This concept presents many challenges since Hydrogen molecules are significantly smaller than Methane molecules. Methane is the primary component of natural gas. Gas companies are working on ways to ensure Hydrogen does not leak out of the pipeline prior to reaching the desired destination. There are many locations where gas companies will need to install Hydrogen sensors. Those include the Hydrogen production facility, the blending/ injection stations, the compressor stations, the storage locations, along the pipeline, and at local commercial, residential and fueling locations.

*The global growth of Hydrogen use in everything from fuels cells to natural gas pipelines has given rise to the demand for high quality Hydrogen sensors. Palladium Nickel sensors are available for most environments, have a long life, and remain Hydrogen specific in the presence of other gases, providing designers with an excellent option that ensures end users see the value of using these maintenance free sensors.*

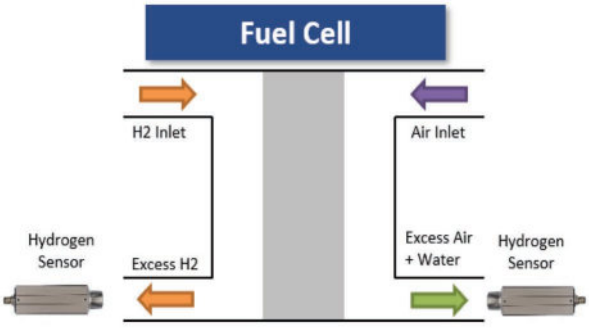



*Figure 4. Example of sensor locations in a Hydrogen fuel cell*

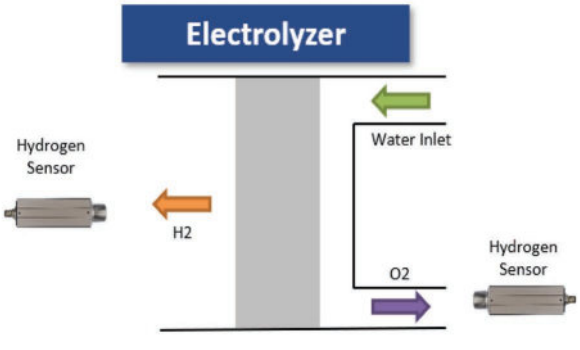



*Figure 5. Example of sensor locations in an electrolyzer*

**Acknowledgments:**

I would like to acknowledge Gid Herman (H2scan – Sales) for assisting with the fuel cell, electrolyzer and natural gas pipeline applications and Dylan Thomas (H2scan – Engineering) for his help with some of the technology points. I would also like to acknowledge Tim Howard (H2scan – Engineering) for the countless hours he has spent helping me to understand the benefits of Palladium Nickel sensors.

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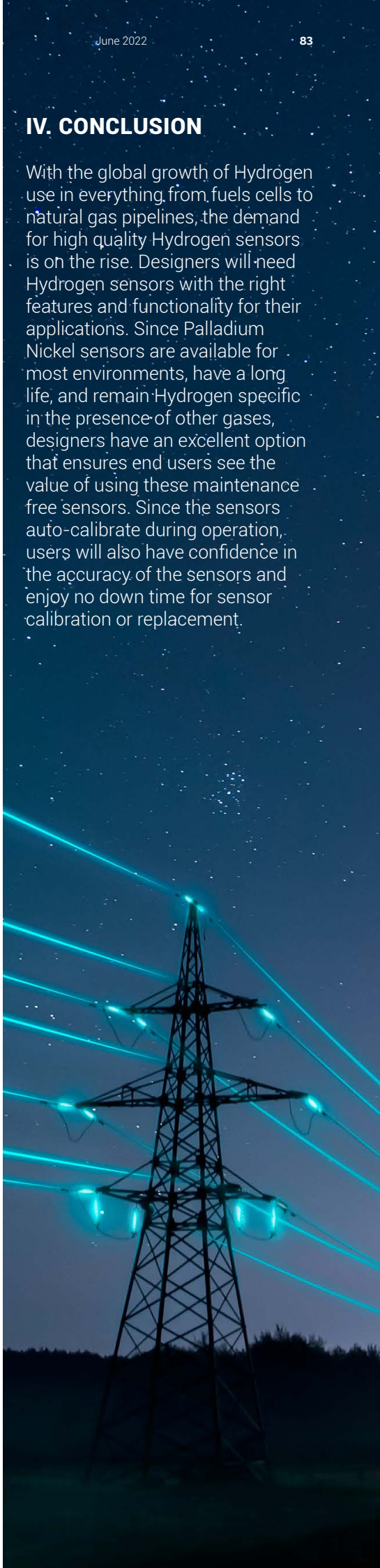
## IV. CONCLUSION

With the global growth of Hydrogen use in everything from fuels cells to natural gas pipelines, the demand for high quality Hydrogen sensors is on the rise. Designers will need Hydrogen sensors with the right features and functionality for their applications. Since Palladium Nickel sensors are available for most environments, have a long life, and remain Hydrogen specific in the presence of other gases, designers have an excellent option that ensures end users see the value of using these maintenance free sensors. Since the sensors auto-calibrate during operation, users will also have confidence in the accuracy of the sensors and enjoy no down time for sensor calibration or replacement.



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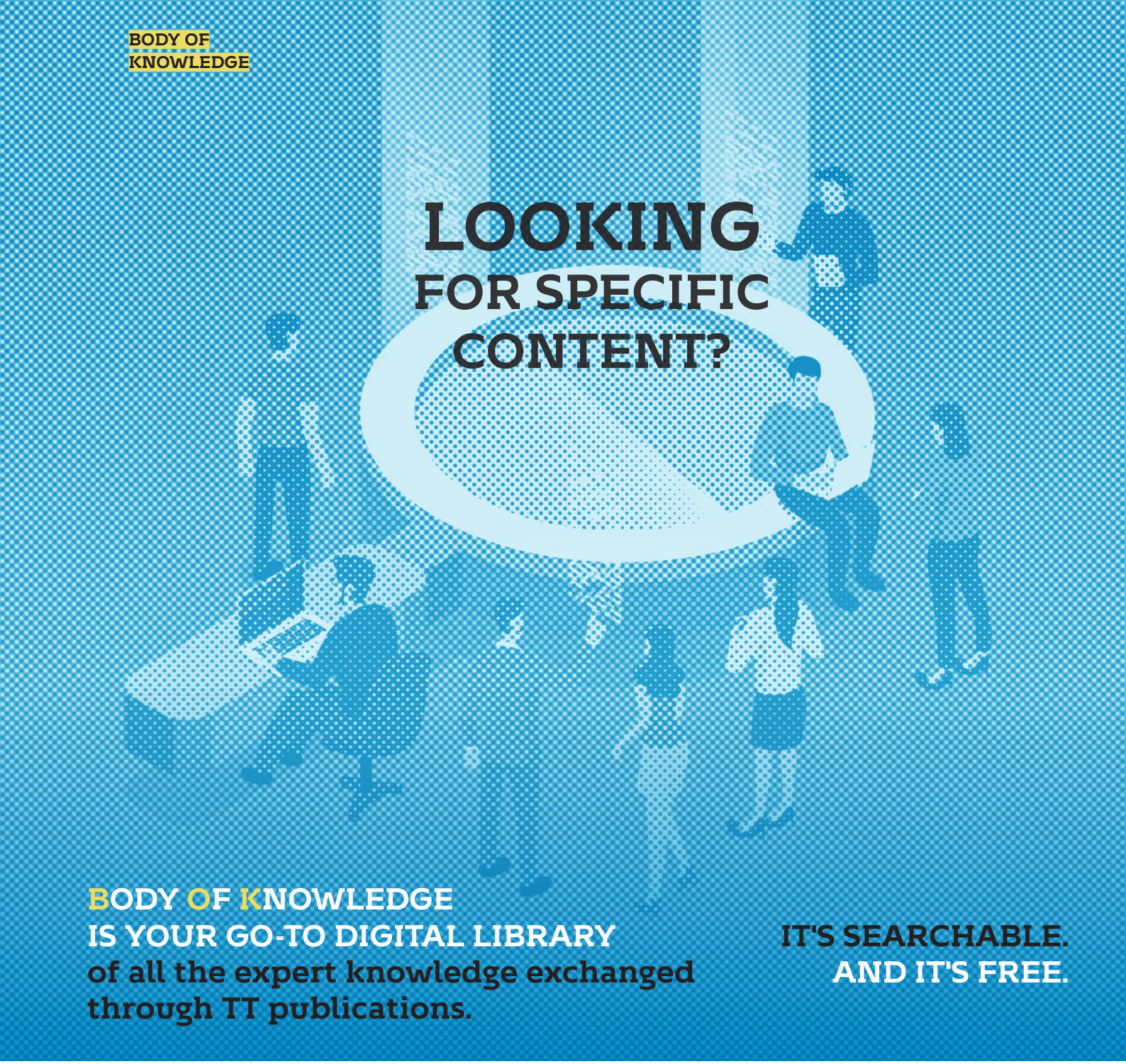

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