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ADVANCES IN BUSHINGS TECHNOLOGY

SPECIAL SUPPLEMENT

PST POWER SYSTEMS TECHNOLOGY

When Bushings Go Bad: **Check Your Data**

Building Transformers. Building Quality. Interview with **Prabhat Jain**, CEO-CTO of Virginia Transformer Corp

Integrating Condition Monitoring into the Product: **Economical, Accurate and Hassle-free**

How can modern monitoring methods upgrade laboratory testing practice ?

Passerro

Transformer monitoring is the measurement, collection and careful analysis of all relevant data. If we measure the right data in real time and learn to interpret that data, we can get a good insight into the operating condition of a transformer. Constant monitoring then provides information about possible and necessary immediate maintenance or can result in a guarantee for maintenance-free and carefree availability.

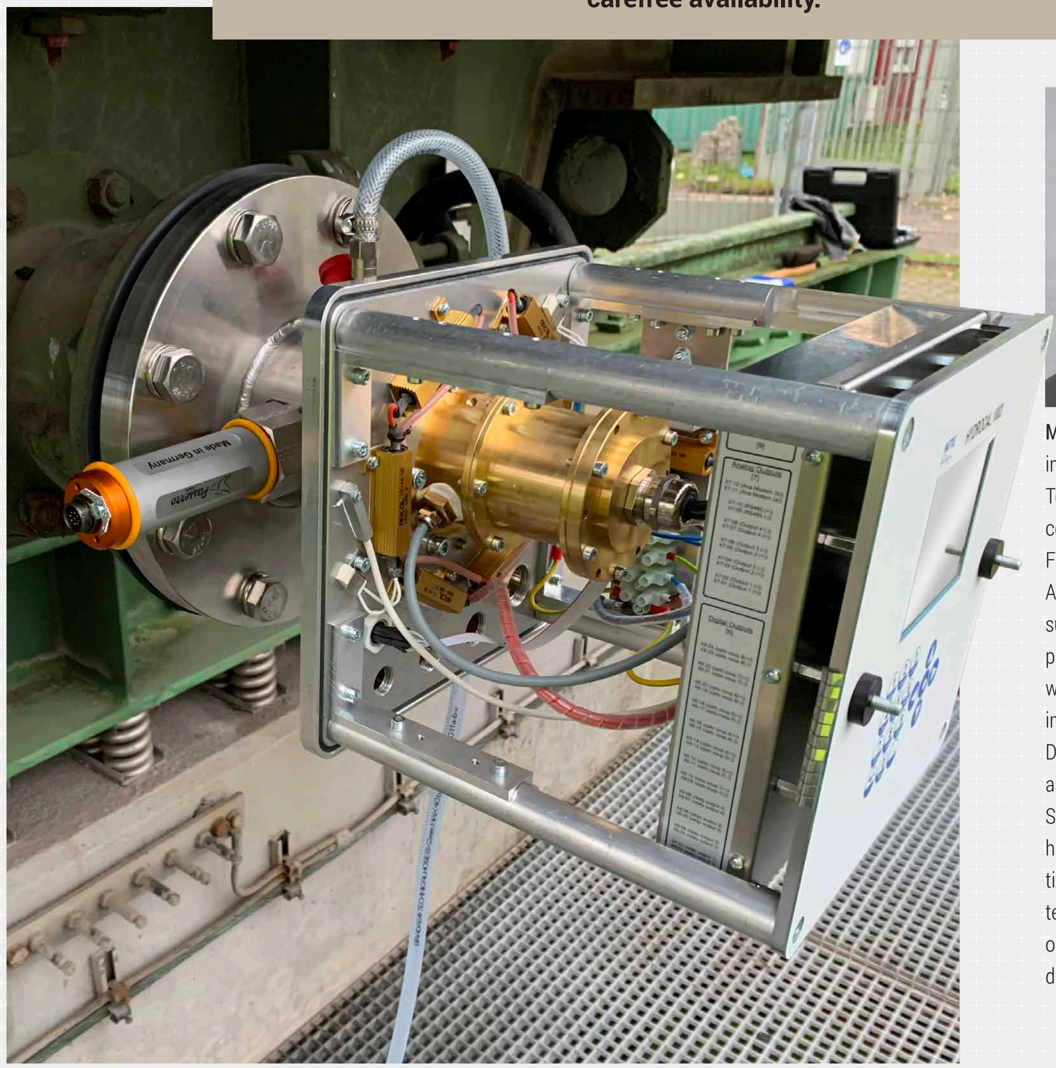

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Photo: Passerro

The digital revolution has changed everything in our lives these days. Every day we face new opportunities and challenges. Internet search engines allow us to answer almost any question that comes to our mind. So-called social media give us the opportunity to connect with like-minded people all over the world, just like e-commerce gives us the opportunity to buy or sell products in a global marketplace. Information is freely accessible; people are instantly connected, and markets are available worldwide. The mankind has integrated digital technology into the "soul of its being". It is hard to imagine a day without a smartphone, WiFi or social networks, but then the question arises, why are our all-important but vulnerable high-voltage systems still being monitored with the "steam gauges" systems known from the last few centuries?

Electrical systems make a significant contribution to the stability of the global energy supply, but their aging and stress lead to irrevocable changes in the insulation material. These changes can inform the operator about the electrical insulation and cooling ability of the oil during the operation of the transformer and about its safety status. Therefore, monitoring these parameters is crucial.

Extensive repertoire of laboratory test procedures

Theoretically, this task is solved by regular sampling and testing according to the IEC regulations. Basic monitoring consists of recording the easily ascertainable main parameters of the system, e.g. of the transformer. These consist of mainly two methods – a dielectric-chemical analysis, which gives an insight into the oil quality; and the chromatographic methods, which allow a statement to be made about the "inner life" of the oil-insulated high-voltage system. The dielectric-chemical parameters are the breakdown voltage (IEC 60156 [1]) and the dielectric loss factor tgδ (IEC60247 [2]). Determining the breakdown voltage (BDV) and the dielectric loss factor tgδ (tan DELTA) offers the possibility of assessing the current insulation condition of the oil. An increased (Wc) water content (IEC 60814 [3]) drastically worsens the insulating properties of the oil.

Other oil properties such as the neutralization number (IEC 62021-1 [4]) are used to make a prognosis about the further operation of the transformer. The neutralization number or Total Acid Number (TAN) indicates the oxidation state of the insulating oil. If the neutralization number is too high the formation of organic acids is very advanced and there is a risk of sludge precipitation, which can result in serious consequential damage. An increased neutralization number is often reflected in a reduced surface tension of the oil (ISO 6295 [5]). The oxidized oil components act as surfactants and therefore influence the surface tension. This is measured as the interfacial tension (IFT) in the oil/water system and is a very sensitive measure for the expected further aging behavior of the insulating oil.

As a preventive measure against accelerated oxidation, the oil is usually treated with approx. 0.3% of the oxidation inhibitor DBPC (IEC 60666 [6]). Determining the decomposition gases dissolved (DGA) in the oil (IEC 60567 [7] and 60599 [8]) allow conclusions about impending faults in the transformer. Local thermal overloads of the insulation system or partial discharges within the solid insulation can be detected. The determination of the furans in the insulating oil (IEC 61198 [9]) has been used for some time as an additional information-source about the condition of the solid insulation. With abnormal thermal aging of solid insulation (cellulose), various furan derivatives are formed, which greatly accelerate the aging of the solid insulation.

Passerro has found the solution to integrate all the necessary sensors and mathematical processes into an online oil sensor.

Unfortunately, these types of measurements and analysis for the purpose of monitoring the correct operation of any given transformer are only being carried out by selective and sporadic laboratory analyzes of the oil far away from actual operation and with sometimes great delay. This means that no real-time and immediate action can be taken and a response to measured parameters is taking place, long after the circumstances have changed. Only a proactive approach based on real-time and online oil condition monitoring can extend the transformers life. The "gold standard" is the best study and laboratory test we could do right now – but the downsides are cost and delay. However, this is still necessary, e.g. because of insurance cover. The many standards and guidelines cover almost all aspects of good laboratory practice but cannot keep up with the changing times. Laboratory tests are extremely accurate when done well but are only performed sporadically.

How can we change it and what procedure can give a more power grid security and cheaper overall cost?

Figure 1. Typical connection and sampling field of a 40 MVA, 110 kV/15 kV transformer

Standard procedures are not enough to keep the grid safe and future-proof

Authorities agree that despite the current IEC 60567 regulation [7], incorrect and careless sampling and testing techniques are at the root of 99 percent of "poor" dielectric and DGA readings; showing once again that the human factor is the weakest "link in the chain".

According to IEC 60567 "Oil-filled electrical equipment – Sampling of gases and oil for analysis of free and dissolved gases" [7] and IEC 60475 "Method for sampling liquid dielectrics" [10], the sample should be taken from that part of the container where the insulating liquid is likely to be most contaminated. Two samples can usually be taken to assess the quality of a delivery (point 4.1.1). Furthermore, in the same standard, in point 4.1.2, the quantity of the sample to be taken is explained. It depends on the tests to be carried out and the methods used.

Typically, a 2-liter sample is taken. In addition, there is the clarification in point 4.1.4.1 Sampling from transformer tank: "the valve is opened and at least 10 liters of insulating liquid are allowed to flow slowly into a waste oil container; the sample bottles are rinsed with the insulating liquid; The sample bottles are filled". What does 10 liters mean for a medium-sized 110 kV/15 kV, 75 MVA transformer with approx. 30 m³ oil volume (Figure 1)?

When developing and testing the sensors, we paid special attention to the use of modern materials and energy-efficient components and assemblies.

When using the drain valve AA023 "Bottom" for oil sampling, we have approx. 0.5 liters of oil in the line (this is negligible). If we use the drain valve AA022 "Middle" for oil sampling, we will already have approx. 1.5 liters in the line (no longer negligible).

What is then the volume we can take for our sampling by running, say, 12 liters of oil through – then grabbing 2-liter sample of new oil for the lab test? Assuming that the new oil is tapped in a sphere around the connection, this results in a sphere with an effective radius of 13 to 15 cm around the tapping point. Let us compare this with the transformer LxWxH dimensions, which are 7,350 x 2,970 x 4,755 cm. We know that every oil-insulated high-voltage system is unique due to its aging, its design and its load history. The oil reflects this history. So, the question arises: Is it a representative sample of our oil? Does the single sample give an insight view into the "inner life" of this oil-insulated high-voltage system? The measurement practice that has been common up to now "only" provides us with a snapshot under laboratory conditions, the measurement done of the oil parameters under IEC guidelines – usually at 20°C – cannot provide any information on the behavior of the oil at operating temperatures which are greatly deviating from 20°C; also keeping in mind that an error due to falsifying oil samples by incorrect human handling is omnipresent.

Figure 2. A bypass cabinet with oil pump and sensors

Just image a cabinet created by Passerro containing a sensor connected to the transformer oil filler necks or to the top/bottom oil check valves as a bypass to a transformer to feed the oil, in a closed circuit with an average capacity of about approx. 1.4 m³/h, see (Figure 2) or other online systems such as online DGA (Figure 3).

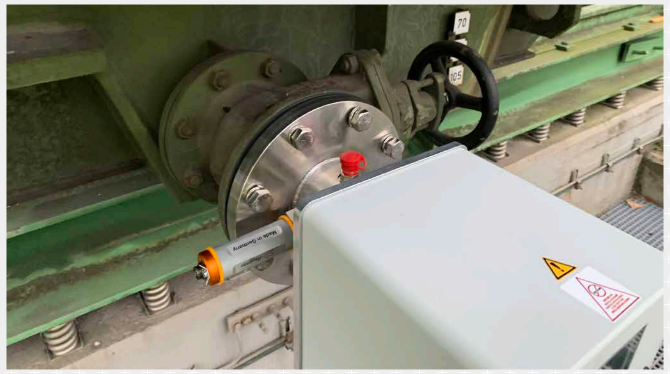

Figure 3. Direct installation on the transformer oil connections – with DGA, moisture and break-down-voltage sensors

Such sensor, with full digital and true Internet of Things capability is able to make several measurements a second and depicture the fast changes in an inhomogeneous liquid insulation system. Some very "gas flares" coming from PD or spontaneous environmental gas intrusions as it is O_2 can be detected and traced. This can be made only with direct-in-oil immersed gas sensors without using membranes to separate the liquid and gas sections.

The innovation includes the research, development and integration of a measurement method that also enables inspection and targeted monitoring of ester-based transformer fluids.

Photo: Passerro

Passerro was able to build an online sensor that can measure the following oil properties:

- ✖ Temperature [°C]
- ✖ Relative humidity (RS) [%]
- ✖ Water content [ppm]
- ✖ Dielectric strength (BDV) [kV]
- ✖ Color [N]
- ✖ Dissolved gas:
  - × Hydrogen – H_2 [ppm]
  - × Carbon Monoxide – CO [ppm]

Other parameters will follow shortly:

- ✖ Neutralization number (TAN) [mg/kg]
- ✖ Interfacial tension (IFT) [mN/m]
- ✖ Dissipation factor (tan_Delta) [deg]
  - × Ethylene – $C2H_2$ [ppm]
  - × Methane – CH_4 [ppm]
  - × Carbon Dioxide – CO_2 [ppm]

and as the parameters acquired with Passerro's system are completely in line with already established, well-known and implemented IEC procedures, this then becomes a real online "laboratory" allowing a constant and real time monitoring (Figure 4). Some very important readings nowadays are coming from laboratory methods knowns as titration (KF for water and KOH for TAN). Applying a stringent chemical titration in an online procedure is currently not possible without contaminating the oil with the titrant. In this case, some substitutes must be used for this procedure. The engineers at Passerro GmbH have solved already the KF-Water measurement Wc using the acoustical resonator and working very intensively on some online solutions to the TAN challenge.

The constant monitoring of oil parameters provides accurate and up-to-date values as well as trends over time and with this knowledge the electrical systems can be operated and loaded in a more targeted manner, so that the economic efficiency of the systems is optimized.

Passerro has found the solution to integrate all the necessary sensors and mathematical processes into an online oil sensor. One of the main challenges, besides estimating the Wc and BDV, is estimating the neutralization number (TAN). Other challenge is to find a high-performance gas sensor that could withstand the everyday environments of multi-megavolt-ampere power transformer for long periods of time. We build new platinum-palladium-doped MOX selective gas sensors specially designed for such missions.

When developing and testing the sensors, special attention was paid to the use of modern materials and energy-

Figure 4. Installation in OLTP top hatch

efficient components and assemblies. At the same time, the innovation includes the research, development and integration of a measurement method that should also enable the inspection and targeted monitoring of ester-based transformer fluids. Ester-based transformer fluids will, not only in our opinion, replace the current and long-used standard mineral oil in the future. From an ecological point of view, transformer oil based on mineral oil is not the optimal dielectric. Mineral oil spills can have devastating effects on the natural environment – including animals, plants, water, and humans – due to the polychlorinated biphenyls (PCB) and polychlorinated terphenyls (PCT) found in mineral oil. Unlike mineral oils, natural ester dielectrics (ester oil) are non-toxic in water and soil, non-hazardous, and quickly and thoroughly biodegradable. Recent installations of ester oil filled power and distribution transformers around the world, due to their natural dielectric properties, have shown the industry that this can be a path towards a cheaper, more resilient, better performing, and safer industry. However, the corresponding measuring and monitoring sensors must also work for this type of oil.

So, the constant monitoring of oil parameters provides accurate and up-to-date values as well as trends over time and with this knowledge the electrical systems can be operated and loaded in a more targeted manner, so that the economic efficiency of the systems is optimized.

Look out for more of our articles in the following editions of the magazine, where we will talk more about alternatives that use modern digital monitoring systems.

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