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Partial discharge: *an interview with the experts*

Jill Duplessis, editor of Electrical Tester, talks to Dr. Detlev Gross and Markus Söller about partial discharge and benefits of partial discharge analysis. Dr. Detlev Gross and Markus Söller are uniquely placed to answer her questions as they are the founder and managing director, respectively, of Power Diagnostix (a Megger company), one of the world's most experienced developers and manufacturers of test equipment for partial discharge investigations.

Jill Duplessis: In a recent webinar that introduced Partial Discharge (PD) testing, Megger's Charles Nybeck explained that for partial discharge to occur, the two conditions that must be met are the availability of a free electron to start a discharge avalanche and a local electric field that has surpassed the critical inception field. With this in mind, could you comment about voltage distribution in a dielectric and what causes non-homogeneity, whereby a disproportionate share of voltage is placed on a small, localised portion of the entire insulation?

Detlev Gross and Markus Söller: Those are good questions and are hard to answer in just a few sentences. As you said, the occurrence of PD depends on these two main conditions. Your questions also highlight the need for a physically correct understanding of the local electric field distribution. The electric field at the origin of the PD pulses significantly affects the pulse distribution of the PD pattern, and as a result it helps with determining the location of the problem in an HV asset. This is particularly true in three-phase systems where the local electric field can be influenced by one, two or even all three phases, depending on the area affected. Non-homogeneities can be caused by voltage shape distortion due to core saturation, harmonics, lightning impulses or inverter switching pulses, to name just a few. Furthermore, the electric field is affected by the use of materials with different dielectric properties and by the geometric design.

JD: Moisture contamination can be a trigger for partial discharge, largely because moisture lowers the dielectric strength of insulation. PD inception voltage decreases with higher moisture content, so it is conceivable that PD could occur at normal operating voltages. Thinking of transformers in particular, partial discharge is a risk with high moisture content in the oil because the bubbling inception temperature decreases as moisture content increases. Therefore, in some cases, bubbles (i.e. voids) can form in a wet transformer at operating temperatures and introduce one or more, possibly moving, areas of significantly reduced dielectric strength. Can you give an idea of the typical amount of moisture contamination at which PD becomes a real concern? Is there a general approximation of how wet an asset must be before it is susceptible to PD due to moisture?

DG and MS: To the best of my knowledge, there is no general formula that relates the moisture content in oil with PD activity. However, the more the insulating properties of the transformer oil deteriorate as it gets wetter, the higher the risk that PD will occur, and further gases will be generated.

JD: PD occurs under specific conditions (a high enough field and a free electron) and, in AC systems, it is repetitive rather than a one-time occurrence. There is a recovery period and then another breakdown, recovery, breakdown, and so on. Once PD is initiated under normal operating conditions, what real-world conditions might extinguish it in an energised asset?

DG and MS: Let's look at one example that comes to mind. A metallic particle jumping up and down in a Gas Insulated Switchgear (GIS) enclosure will continue to do so as long as the electric field is strong enough to lift it up. A PD pulse occurs whenever the particle comes close to the inner conductor and the gap between particle

and grounded metal enclosure is sufficient for a small discharge. If the metallic particle remains within the enclosure and within the electric field, this process will continue indefinitely. It can, however, be stopped by particle traps at the bottom of the GIS. When the particle falls into such a trap, it will stop bouncing, as the electric field is zero in this area. In general, it can be said that the PD stops either if there are no further free electrons available, or if the local electric field strength falls below the inception field strength.

JD: I would now like to turn to the subject of visualising PD activity. Each PD event produces a current pulse, associated magnetic field, gas, light and sound. Detecting these symptoms can indicate that PD activity is taking place. Recording PD pulse occurrences (that is, time of occurrence and magnitude) and correlating this data with the applied test (and/or system) voltage in order to plot the phase position of the PD pulses provides additional insights into the nature of the PD activity. I hope that this is an adequate description of Phase Resolved Partial Discharge (PRPD) patterns! But what determines the appearance of the PRPD pattern? For example, why does PD sometimes appear immediately after the zero crossing of the applied voltage, while in other cases it's concentrated around the peak?

DG and MS: That was a good description of PRPD, which we believe to be the best way to characterise PD phenomena in AC systems. We see hundreds of different PD patterns and the visual variations between them are the result of many factors. We already mentioned the importance of the electric field distribution at the origin of the insulation defect as one criterion which makes it necessary to synchronise the measurement system with the applied voltage. If you don't, it's difficult or even impossible to interpret the PD pattern. Furthermore, PD activity is strongly dependent on the materials involved and the potentials they're held at, because conductive, semi-conductive and non-conducting materials provide different quantities of free electrons. In most cases, we are talking about the physics of electrical discharges in gases, because unless gases are pressurised, they have a much lower electrical breakdown strength than solid or liquid insulating materials. The stochastic ionisation of gas molecules as the starting point for producing free electrons fundamentally affects the appearance of a PRPD pattern. So, there's no general answer to your question about why PD pulses sometimes appear in the PRPD pattern close to the zero crossing and other times near to the peak. With a simple laboratory set up, we can create corona discharge that shows all pulses at the peak. In this case, the discharge electrons are provided by conductive materials at HV or ground potential. Conversely, if the PD starts in an area without direct link to HV potential, such as a surface discharge in a gas inclusion within an insulation layer, we see most of the pulses appearing just after the zero crossing because of the capacitive coupling and the resulting phase shift.

JD: Thank you. Let's move on to 3D patterns. What additional information do they provide compared with PRPD patterns?

DG and MS: PRPD patterns are a representation of a three-dimensional (x, y, z) data set, with PD phase position (x), PD amplitude (y), and the pulse quantity (z) at the phase amplitude position over a certain period of time. To make the pattern easier to interpret, we show it as two-dimensional x-y view, and code the number of pulses (z) by using different colours. We've been using this approach since 1993 and, at that time, Power Diagnostix was the first company in the world to offer a commercially available instrument with this visualisation feature for PD measurements. The different colours are very helpful for identifying hot spots in a pattern, and they also help to separate the different types of defects that may be contributing to a pattern. With three-phase systems it's also possible to see the phase-to-phase crosstalk in a pattern.

JD: Would you please explain cross-coupling and tell me about the method, or methods, used to deal with it?

DG and MS: Cross-coupling means that a high frequency PD pulse originating close to one-phase potential becomes detectable on all three phases in a three-phase system, such as a transformer or generator, if a cross-coupling path (RLC network) is available and the signal amplitude is large enough. Cross-coupled signals are usually phase shifted by 120 ° or 240 ° and the amplitude is often different when compared to the other phases. Cross-coupled signals are actually very helpful when it comes to fault analysis and fault location. With offline PD tests or tests under laboratory conditions, the PD amplitude can be compared under different energising regimes (induced, applied, lifted neutral, etc.). With transformers in particular, this method is often used to find defects within the windings.

JD: I am interested in knowing more about false negatives (missed problems) in PD testing. For example, I understand that this is a potential issue with epoxy-moulded insulation if testing duration is not adequate. How long should testing continue to be sure that epoxy-moulded insulation is truly PD-free? Are some defects more likely to be missed than others because of measuring sensitivity?

DG and MS: To answer this question, I have to go back to gas discharge physics. Let us imagine we have a gas bubble in solid material, such as an epoxy-moulded spacer. As long as there is no ionisation of the gas molecules by natural radiation (photons), no free electrons will be available. Ionisation is a statistical process, unless it is triggered artificially by, for example, x-ray exposure. Based on figures from the scientific literature relating to this subject, a 1 mm diameter spherical void with no free electrons of its own will, on average, have to wait for 103 s before being hit by a photon. This implies that it takes on average about 16 min until PD activity starts in such a 1 mm void, which sheds an interesting light on standard testing times of 1 minute!

The sensitivity required strongly depends on the type of asset being tested. Epoxy- moulded components are tested in a range of < 2 to 10 pC. With these components, sensitivity is more critical than is the case with other assets, where acceptance levels are usually in the range of several hundred pC.

JD: I recently learned that Power Diagnostix is one of very few calibration laboratories in the world that can perform calibration procedures according to IEC standards. What is the significance of calibration in a PD measurement?

DG and MS: All partial discharge measurements that reference the IEC60270 testing standard require a calibration procedure that yields an apparent charge value shown in pC. Calibration is done with a test object connected to a decoupling device and measurement system. The reference signal is generated by a calibrated PD impulse generator that has to meet the specification of the standard and which has to be calibrated in an accredited laboratory, such as the one at Power Diagnostix. Our laboratory enables us to calibrate our own impulse generators and also provide a calibration service for third parties.

JD: I am very excited about Power Diagnostix joining the Megger family. Would you explain how Power Diagnostix measuring solutions are unique in the market?

DG and MS: Power Diagnostix has been developing and manufacturing PD measuring instruments since the early 1990s. We are proud to say that we are one of a very few companies worldwide that covers all PD applications with its products. The unique modular concept of our products makes them easy to match to any measuring task. You can select from various PD sensors and decoupling units, HF and UHF amplifiers and signal converters, portable and monitoring instruments, and software to produce a system that's uniquely well matched to your own specific requirements.

JD: Partial discharge testing can be performed off-line at user determined intervals or on-line on a continuous monitoring basis using conventional or non-conventional methods. With so many options, how does a potential user decide on the best combination for their particular application?

DG and MS: Our experienced team of application engineers and sales managers will always help users to find the package best suited to each application and customer. Finding the best combination may look difficult at first but getting it right really does pay off when it comes to real PD measurements, fault investigations and defect location.

JD: For someone who is relatively new to PD testing and diagnostics, what resources would you recommend to them that would help them gain a solid understanding of these subjects?

DG and MS: The study of partial discharge goes back many years and researchers all over the world have published a huge amount of material on the subject. Today, you can find a lot of authoritative information about PD testing in general and also about specific applications in IEC, IEEE and CIGRE publications. In addition, you will find a lot of commercially driven publications on the Internet, but many are of doubtful quality, so read them critically and with a healthy amount of scepticism! Finally, this year, engineers from Power Diagnostix are presenting webinars that address various topics relating to PD testing on transformers, generators, cables and GIS. If you're interested, have a look at the Megger website to find the latest information.

JD: Thank you, Detlev and Markus, for giving us the benefit of your comprehensive knowledge and wide experience in the field of PD testing. To some, it's an unfamiliar and sometimes confusing area, but your interesting and revealing answers have done much to dispel this confusion and to make the concepts, techniques and benefits of PD testing easier to understand and more accessible.