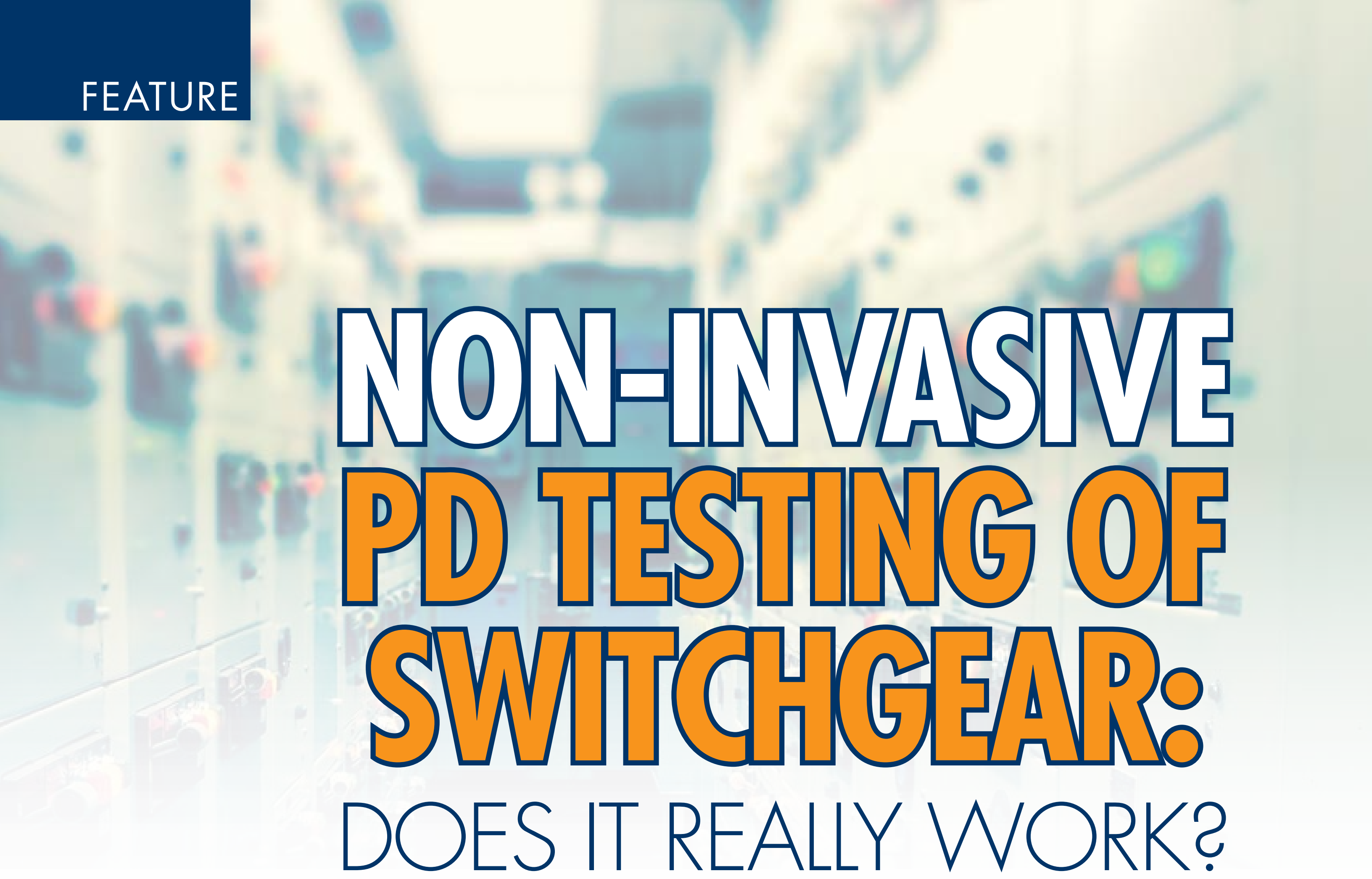

NON-INVASIVE PD TESTING OF SWITCHGEAR:

DOES IT REALLY WORK?

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Condition assessment of electrical assets is often compared to going to the doctor: It's best to find out about minor issues before they become major problems. Another analogy: You ask your doctor, "What's the best exercise I can do to get in shape?" His response: "The one you can actually do!" The most effective exercise might be spending three hours in the gym every day and training for a marathon on the side. However, the one you might actually do is walk a mile each day and add some light calisthenics. The point is, while different levels of exercise might have different benefits, don't attempt something so difficult that you just won't do it.

The same thought process applies to medium-voltage maintenance. If you had no other considerations, you might disassemble everything every year and do offline VLF PD tests, visual inspections, etc. However, just because that's not practical doesn't mean you should do nothing. Online, non-invasive tests are practical and cost effective, and doing them is a much better alternative to doing nothing.

This article will explain the technology behind the main non-invasive techniques used for switchgear, ultrasonic, and transient earth voltage (TEV) detection, and show how they can provide much of the value commonly associated with off-line testing. Field results from around the world are included.

ULTRASONIC TESTING FOR PARTIAL DISCHARGE

Two forms of partial discharge — surface discharge and corona — emit high levels of sound waves. Most of that energy is above the frequency range of human hearing, so it is called ultrasonic. By measuring and analyzing the ultrasonic spectrum, we can detect this energy and, more important, discriminate it from other sources of ultrasonic noise.

Sound can be measured on the Sound Pressure Level (SPL) scale, which is a logarithmic scale where 0 SPL is approximately the threshold of human hearing and 100 SPL is the sound of a pneumatic jackhammer. Ultrasonic energy can be measured on the same scale using equivalent electrical output levels from a sensor even though you cannot hear this energy.

If you measure the sound energy in a narrow frequency band around 40 KHz, you get some surprising results. The air coming out of an HVAC vent may contain 40 SPL of ultrasonic energy and virtually nothing in the audio band. Conversely, the ultrasonic energy given off by a freight train 50 feet away may be 0 SPL. Ultrasonic energy given off by surface discharge at close range is typically -10 to 60 SPL. PD instruments tend to display levels in dBuV where 18 dB SPL = 0 dBuV. This will vary with sensor sensitivity and manufacturer.

More important than the sound level are its characteristics. Ultrasonic energy from PD will have four characteristics that make it straightforward to detect.

1. When super-heterodyned down into the range of human hearing (2 KHz center frequency), it has a distinctive sound much like bacon frying or fizzing.
2. The sound will be concentrated in 120Hz bursts related to the positive and negative rising edges in the power system sine wave.
3. The sound will have a repetition rate in the range of 6 to 50 pulses per cycle.
4. The sound will not be perfectly repetitive in phase angle, amplitude, or energy level from pulse to pulse.

These characteristics make it possible to design an instrument that can pick out PD from the cacophony of ultrasonic energy present in some locations. When trying to detect sound pressure waves, an air path is needed from the source to the sensor. Fortunately, an air path is almost always present in metal-clad switchgear. Switchgear has louvers, vents, loosely fitting panels, and doors. Moving a sensor along these openings allows the user to pick up PD from outside a closed cabinet. In the event no air path (well-sealed compartments) exists, contact sensors can pick up the very slight vibrations on the panel due to ultrasonic energy inside. Such sensors must be incredibly sensitive.

Once you've heard the sound and recognized it, make sure the other characteristics are present. Modern instruments provide phase-resolved and pulses-per-cycle (PPC) displays that confirm presence of the second and third characteristics. The latest instruments also include advanced algorithms that look for all four potential characteristics and automatically classify detected energy as PD or noise.

TRANSIENT EARTH VOLTAGE PHENOMENON AND TESTING

In 1979, Dr. John Reeves of EA Technology discovered the Transient Earth Voltage (TEV) phenomenon and developed it to measure internal partial discharge inside metal-clad switchgear. Figure 1 shows how the partial-discharge-induced current pulse travels along the internal and then external surface of the switchgear. The pulse travels through the impedance of the ground connection. Because the typical grounding of metal-clad switchgear

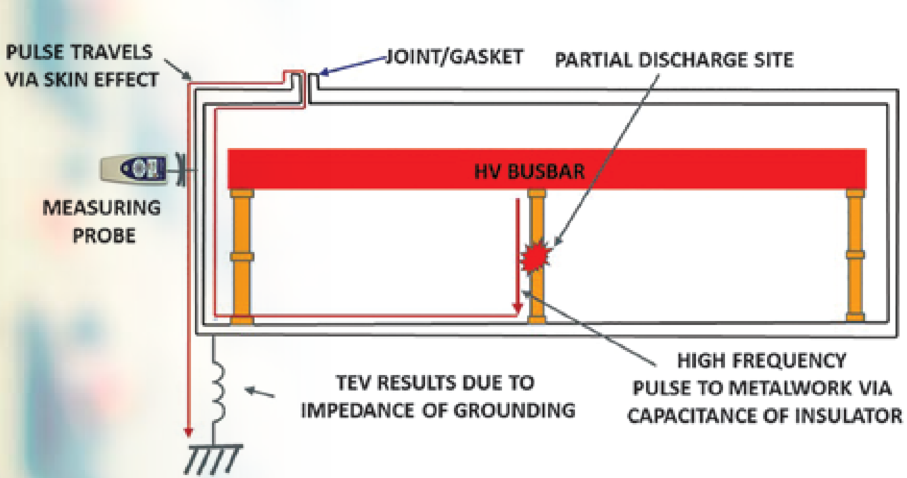

Figure 1: *Current Flow Resulting in Transient Earth Voltage*

presents high impedance to high-frequency currents, a voltage is developed on the gear's surface.

With a highly selective, very sensitive meter capacitively coupled to the outside of the switchgear, this voltage can be discriminated and measured. Levels as low as 10 mV can indicate significant PD, and measuring this in the presence of tens of kV requires a very selective meter. The absolute level of the TEV reading will vary significantly due to the variability of the high-frequency impedance of the grounding system, but comparing measurements over time or over similar devices provides a good indication of PD severity.

Doing an on-line, non-invasive TEV test involves pressing the capacitive sensor plate to the metal cladding of each compartment for a few seconds and taking a reading.

TEST RESULT VALUE

Offline VLF testing has recognized thresholds, and visual inspection produces obvious results. So, can on-line, non-invasive PD testing provide quantitative results? While this type of testing won't reveal as much as other methods, it will provide a wealth of information you might not otherwise have if practical realities prevent testing every piece of gear. It is "the one you can actually do."

One challenge is ensuring that the values obtained are repeatable and useful. Obviously, if you get a different answer every time you do the test, the test is useless. This has been a concern connected with PD testing for a long time, and past methods suffer from poor repeatability. Most likely, Dr. Reeves' first TEV test instrument took a fair amount of expertise to generate repeatable results. One advantage of modern instruments is that their use is more straightforward. A good PD test instrument will have minimal manual settings available so that results are consistent, regardless of who conducts the test.

Another advantage of modern equipment is multiple testing modalities. For example, an ultrasonic test by listening for the sound is good, but seeing phase-resolved plots, PPC counts, and algorithmic results gives users more confidence in what they are hearing. Of course, the ability to record the results for discussion with support staff and comparison to past results improves results even further. Instruments with built-in humidity recording make tests more repeatable, as ultrasonic readings are highly variable with changes in humidity.

If the repeatability is good, then the next question is how to relate the levels to asset condition. Measured levels will vary with grounding, air path attenuation, humidity, etc. Even if all variables are controlled, it is difficult to relate the measurement results to the time to failure. There is no magic solution for that problem, but some methods can help.

- **Trend the levels over time to give an indication of the rate of change.** Because the effects of the process influence the process, the levels are exponential. As the rate of change begins increasing, the asset approaches failure.
- **Compare similar pieces of gear.** Among 10 identical cabinets, if one is putting out significantly more TEV, it's time for further investigation.

- **Compare large bodies of data to obtain guidelines.** If the test equipment manufacturer has a large user's group and a database of thousands of results from similar assets, they can establish guidelines for when action is required.
- **Narrow down TEV to a specific cabinet.** It's an unfortunate fact that PD in one cabinet can produce TEV of equal or higher levels in adjacent cabinets. Using a time-precedence-based location system can pinpoint the TEV source to a single cabinet for further investigation. Such devices use the time of flight of PD currents to determine where it occurred first.

Finally, it's important to understand the limitations of non-invasive testing and its place in the world. Non-invasive testing allows a user to quickly scan all gear and trend it over time until a more invasive test is warranted. Because an enormous population of gear is significantly aged and has never been scanned, the first pass often dictates immediate action. Upon initial scan, it is typical to find 5 to 10 percent of gear with a major issue. Performing more invasive testing on assets flagged in the initial scan is often a viable and cost-effective method for improving reliability and reducing unplanned outages.

REAL-WORLD RESULTS

Example 1 — Industrial Site in Florida

The user acquired a combined ultrasonic and TEV test instrument and, without any training, donned the headphones and started taking ultrasonic measurements. At first, much of it sounded unremarkable; then they came upon one cabinet where the classic ultrasonic sound of bacon frying was present. When the cabinet was opened, six partial discharge sites (one on each edge of each busbar) were found (Figure 2) where contamination along a horizontal brace was causing severe discharge (Figure 3). This equipment was on the verge of failure

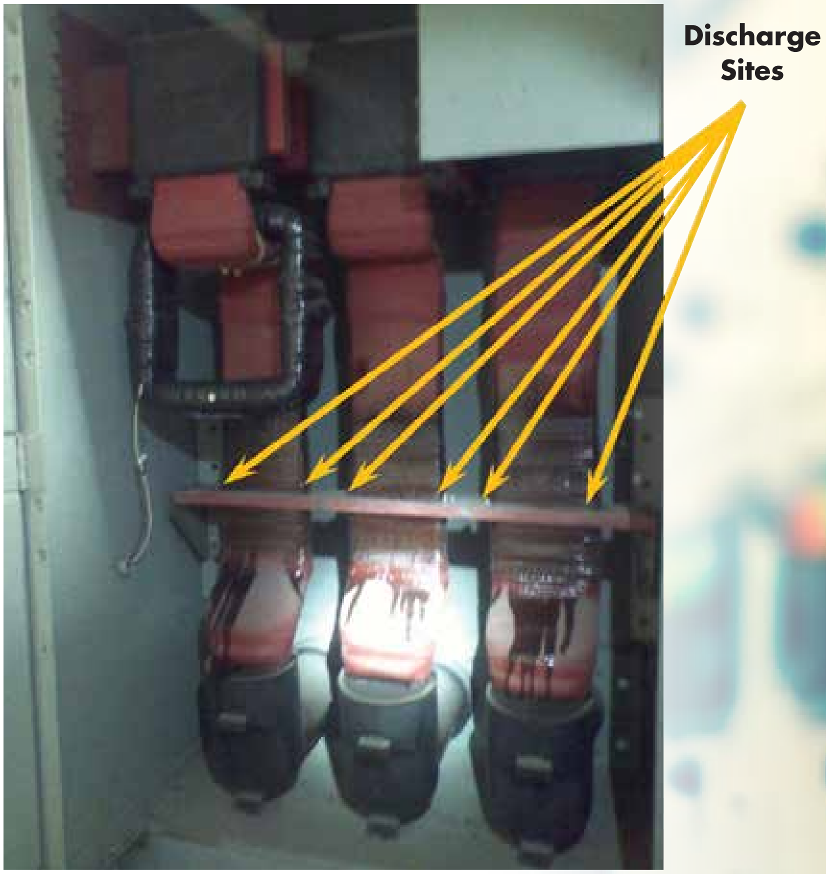

Figure 2: *Surface Discharge Across Horizontal Brace*

Figure 3: *Close-Up of Damage on Edge of Busbar*

Figure 4: *Damaged Cable Termination*

Figure 5: *Improper Cable Installation*

Figure 6: *Damaged PT Cables*

and, without remedial action, would have soon caused significant damage and potential risk to personnel.

Example 2 – Office Building in Virginia

A large office building had full-time partial discharge monitoring installed due to the critical nature of its operations. The monitor found a workmanship issue in a termination (Figure 4) that was approaching catastrophic failure. In addition, an installation mistake common to all the installed potential transformer cables (Figure 5) was discovered. The improper installation was causing degradation to dozens of cables throughout the installation (Figure 6). These were all corrected with a planned, orderly shutdown and returned to service.

Matthew Vaughan, AECOM, who maintains the site, said, "The advance notice that the PD monitoring system gave us enabled us to plan an outage to resolve the problem and significantly increased the client's confidence in our high-voltage maintenance program."

Example 3 – Petrochemical Plant in Southern U.S.

An ultrasonic and TEV survey was performed on the assets of a petrochemical plant. During the initial survey, ultrasonic energy in one cabinet was significantly higher than all others. The distinctive sound of PD was heard. The phase-resolved plots were distinctive (Figure 7) and the algorithm indicated PD with 100 percent certainty (Figure 8). Because all three modalities agreed, PD was conclusively identified. The cabinet was de-energized, and a visual inspection showed a significant PD site due to improper clearances with obvious tracking and nitric oxide buildup. The damage would have led to a failure had it not been caught.

CONCLUSION

In summary, on-line, non-invasive partial discharge testing of metal-clad switchgear provides repeatable, actionable information

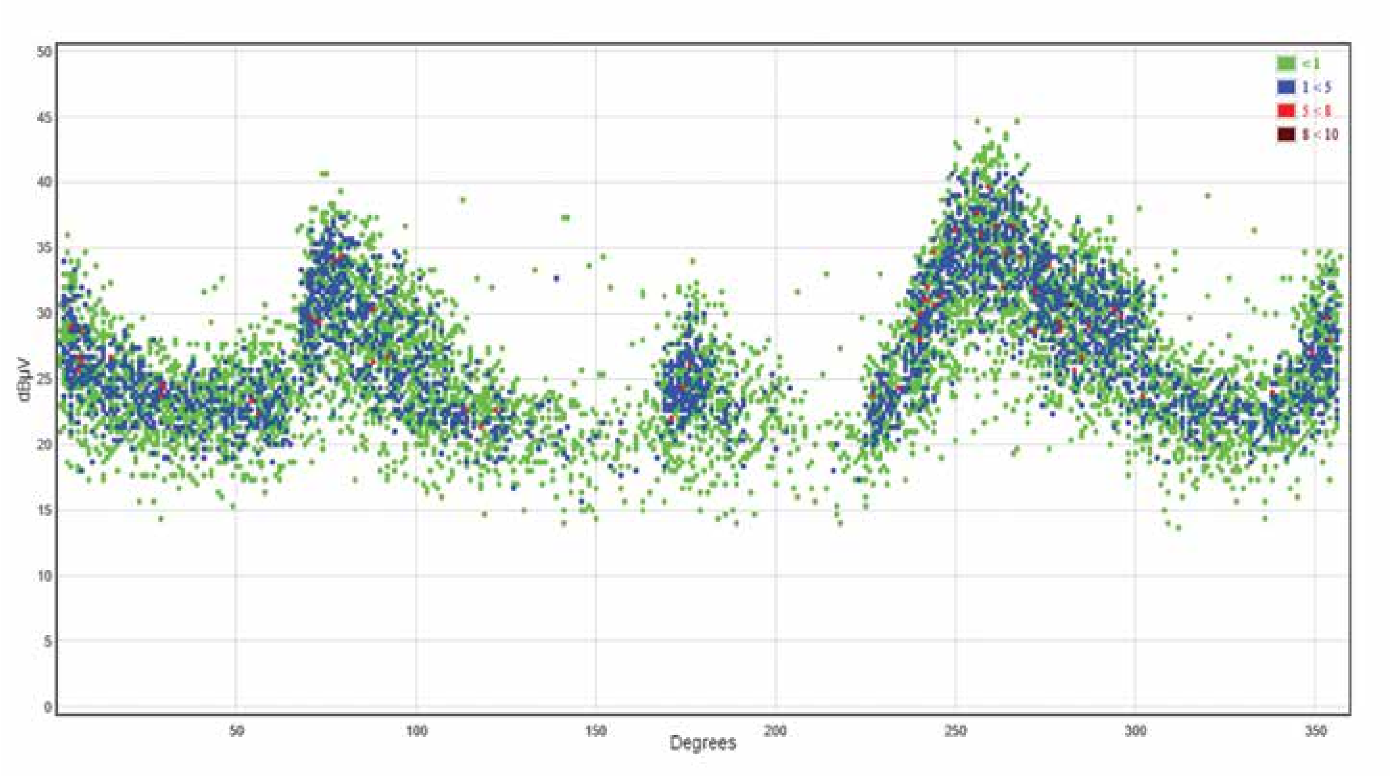

Figure 7: *Phase-Resolved Plots Showing Ultrasonic Energy Caused by PD*

that is impractical to take any other way. Test hundreds of assets per day without taking an outage or subjecting employees to risk. Do "the one you can actually do."

After all this talk about exercise, I think I'll go take a nap.

***William G. Higinbotham** has been president of EA Technology LLC since 2013. His responsibilities involve general management of the company, which include EA Technology activities in North and South America. William is also responsible for sales, service, support, and training on partial discharge instruments and condition-based asset management. He is the author or co-author of several industry papers. Previously, William was vice president of RFL Electronics Inc.'s Research and Development Engineering Group, where his responsibilities included new product development, manufacturing engineering, and technical support. He is a senior member of IEEE and is active in the IEEE Power Systems Relaying Committee. He has co-authored a number of IEEE standards in the field of power system protection and communications, and holds one patent in this area. William received his B.S. degree from Rutgers, the State University of New Jersey's School of Engineering in 1984, and worked in the biomedical engineering field for five years prior to joining RFL.*

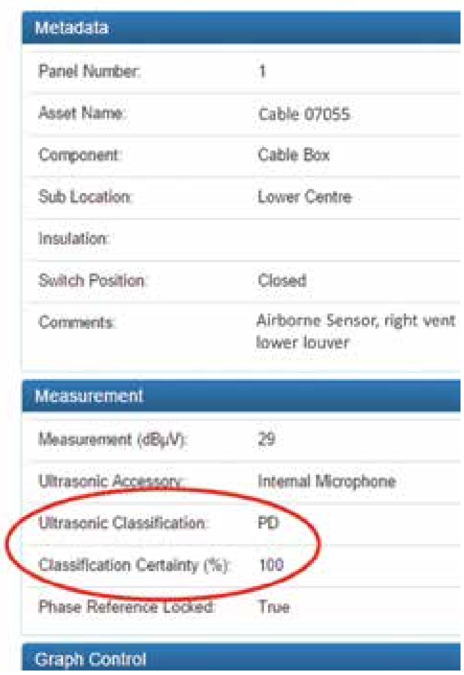

Figure 8: *PD Classification Algorithm Showing Certainty*