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FEATURE

# ONLINE VERSUS OFFLINE

## PARTIAL DISCHARGE TESTING FOR CABLE ASSESSMENT

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Medium voltage cables have three distinct phases to their lifecycle: (1) new — just manufactured, still in the factory; (2) installed — ready for commissioning but not yet energized; and (3) aged — in service for some period of time. These different periods of their life provide opportunities for condition assessment.

Tan delta and partial discharge testing are excellent indicators of insulation health and can be applied in all phases of a cable's life. Tan delta provides an overall average condition assessment, whereas partial discharge testing can indicate weak spots that might not appear in tan delta results.

This article will explore the differences between tan delta and partial discharge testing as well as the differences between on-line and off-line testing. Advantages and disadvantages will be explored.

### TAN DELTA BASICS

An ideal cable insulation system will be entirely capacitive in nature. The only current flowing through the insulation is a result of the reactive impedance at the power line frequency. This current will be 90 degrees out of phase with the voltage and is given by the following formula:

$$I_C = V/(2 * \pi * f * C)$$

In the real world, a resistive current results from impurities in the insulation and is increased by aging effects such as water trees. This current is in phase with the voltage and is given by the following formula:

$$I_R = V/R$$

Combining these two phasor currents, you can see the relationship and the resultant leakage current (Figure 1).

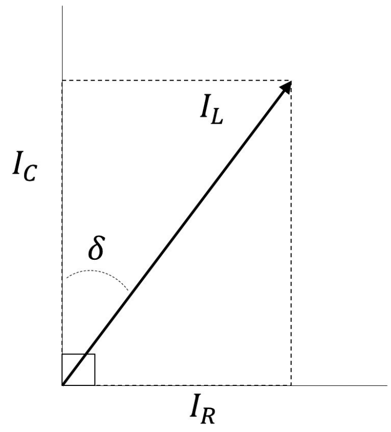



**Figure 1:** *Relationship Between Capacitive and Resistive Currents*

The ratio of the two currents ($I_R/I_C$) is the tangent of the angle δ (delta) or tan delta, for short. It is also known as dissipation factor or loss angle. As can be seen from the previous formulas, the capacitive current is a function of frequency, so the result is also a function of frequency. Therefore, not only do you need to know tan delta, you also need to know the frequency used for testing. Very low frequencies are typically used to limit the amount of power required to run the test.

For a given frequency and voltage, tan delta increases as the resistive current increases (as the resistance in the insulation decreases). This provides a measurable way to see how aging and impurities have affected a given cable. As this measure applies to the entire cable, it is a measure of the average condition over the length of the cable.

As a cable ages, its tan delta figure becomes more voltage dependent. Water trees exhibit a conductivity that increases with voltage, so the tan delta measurements taken at higher voltage increase. This plays an important part in analyzing cable condition.

## PARTIAL DISCHARGE BASICS

Partial discharge is best described as a failure of part of an insulation system to withstand the electrical field applied to it. This can be a result of poor design, poor workmanship, defective materials, contamination, or aging. The result of this failure is a high-frequency, unipolar discharge and accompanying current that flows through and on the insulation from the conductor to ground. This current pulse is low energy due to its short (microsecond) duration, but it can negatively affect the insulation and eventually cause catastrophic failure.

The discharge spark erodes the insulation from within through its heat and ionization. If occurring on the surface, the discharge also causes the breakdown of air molecules into oxygen (ozone) and nitrogen (nitric oxide). The nitric oxide forms nitric acid, which erodes the insulation from the outside.

As any erosion of the insulation causes an increase in discharge — and therefore, more erosion — the effects are exponential until catastrophic failure occurs.

Partial discharge cable testing involves applying a voltage conducive to partial discharge and then directly or indirectly measuring the discharge current pulses.

## OFFLINE TAN DELTA TESTING

Tan delta testing requires isolation from equipment not under test, and therefore, must be done offline. A high-quality, low-frequency voltage supply is typically used. The supply is attached to the cable under test and a tan delta analyzer is connected to measure the current and its phase angle relative to the voltage (Figure 2).

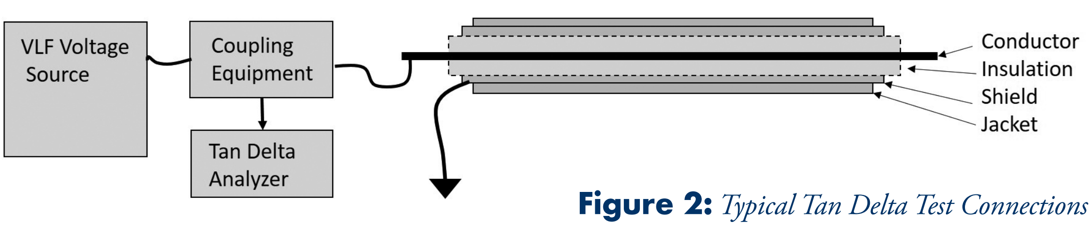



**Figure 2:** *Typical Tan Delta Test Connections*

The measurement is relatively quick and is taken at several voltages. Getting the outage, switching the load, disconnecting attached equipment, setting up the test equipment, and taking high-voltage safety precautions take much longer than actually running the test.

When looking at the results of a tan delta test, two characteristics are significant. Whenever possible, comparing to a baseline measurement done at commissioning can show deterioration by a shift in the leakage current amplitude. If a baseline is not available, the value versus voltage is an excellent indicator of water intrusion. The more water tree damage present, the greater the influence of voltage on tan delta amplitude. A rising trend as test voltage rises indicates damage or aging.

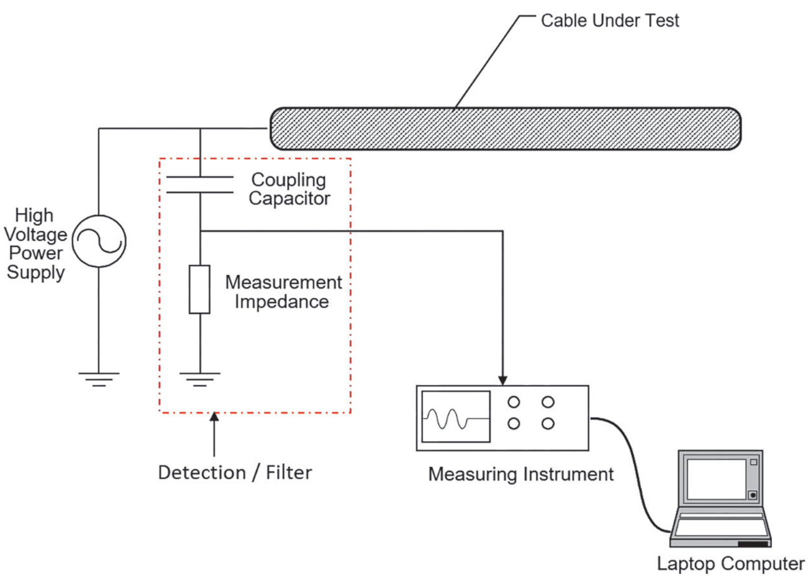



**Figure 3:** *Typical Offline PD Test Connections*

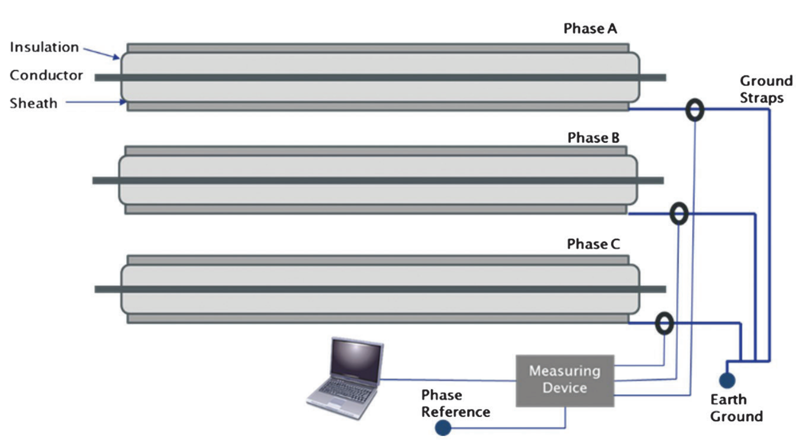



**Figure 4:** *Typical Online PD Test Connections*

## OFFLINE PARTIAL DISCHARGE TESTING

Offline partial discharge testing uses a similar setup to tan delta testing in that the cable should be disconnected from external equipment and connected to a high-quality, low-discharge voltage source. Additional precautions must be made because any discharge in the test equipment or setup will render the results meaningless.

Figure 3 (left) shows a typical offline PD test setup. While the goal is to measure the PD current pulse, it is not measured directly; rather, it is inferred from the voltage drop when the discharge occurs. For this reason, a known pulse generator is typically required to calibrate the system by relating a measured voltage drop to a Pico-Coulomb amount. Test procedures and general evaluation guidelines are given in the relevant IEEE 400 series standards.

## ONLINE PARTIAL DISCHARGE TESTING

Online partial discharge testing makes use of the power system voltage and only requires a monitoring circuit. While it is possible to attach a monitoring circuit to the conductor, it is also possible to connect to the ground strap of the conductor since the discharge must travel down it to ground. This ground connection is preferable due to its increased safety and the fact that the connection will not adversely affect the electric field at the conductor. By connecting via a radio-frequency current transformer (RFCT), a direct measurement can be made, eliminating the need for a calibrator (Figure 4). Tests can be done in a few minutes, as a periodic survey or as continuous monitoring.

## COMPARISON OF TECHNIQUES

**Tan delta vs. online partial discharge.** These two tests are similar in setup, invasiveness, test equipment, and time to test. They do,

**Table 1:** *Comparison of Offline and Online PD Testing*

| Criteria | Offline Partial Discharge | Online Partial Discharge |
|---|---|---|
| **Outage Required?** | Yes | No |
| **Cost of Test Equipment** | High | Medium |
| **Skill required to run test** | High | Low |
| **Time per test** | Long (>2 hours) | Short (<10 minutes) |
| **Test qualities** | | |
| Partial discharge presence | Yes | Yes |
| Partial discharge severity | Yes | Yes |
| Partial discharge location | Yes | Sometimes |
| Inception / extinction voltage | Yes | No |

however, test two different aspects of the insulation system. Tan delta tests the health of the insulation as an average value of the length of the cable, and therefore, small sections with significant defects cannot be detected. Partial discharge detects these small defects but cannot detect aging effects (like water trees) until they result in discharge. Thus, these two tests are complementary, and it is advisable to do both at the commissioning of any cable.

Baseline tan delta and offline PD test results are useful in the future when a serious concern exists about the cable's condition.

**Online PD vs. offline PD.** Both of these tests have advantages and disadvantages, and both should be applied in the right circumstance. Table 1 provides insight into these techniques.

Table 1 shows that offline testing provides more detailed results but is much more of a commitment to perform. Some of that commitment is lessened if done at commissioning. Online testing provides less detail but is economically feasible to perform on larger cable populations.

## FIELD RESULTS DISTRIBUTION

**Online example #1.** A major U.K. utility recently completed an evaluation of online partial discharge testing with positive results. As this was a technology assessment, no attempt to address suspect cables was made during the trial. Over an 18-month period, 188 33KV cables were tested with an online cable test device as described previously. The cable results were classified into green, amber, and red as shown in Table 2.

Within the 18-month test period and six months afterward, 13 cables failed. The results below showed that the red and amber categories had significantly higher failure rates. This proved to the utility that this type of online testing was effective for identifying at-risk cables.

**Online example #2.** An oil refinery operator hired a contractor to splice 80 – 100 feet of XLPE cable and new terminations onto existing PILC cable. Three splicing technicians performed the work. One of the technicians was not qualified to do the splice, and as a result, several of his

**Table 2:** *Online PD Test Results*

| Cable category | Quantity Identified | Failed Within 2 Years |
|---|---|---|
| Green | 157 | < 2% |
| Amber | 14 | 21% |
| Red | 17 | 41% |

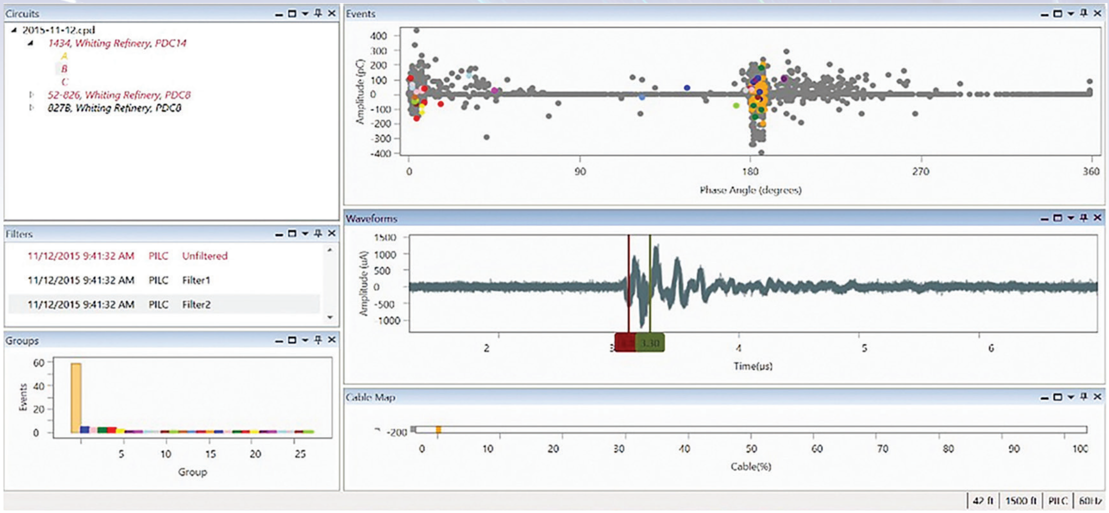



**Figure 5:** *Oil Refinery PD Test Results*

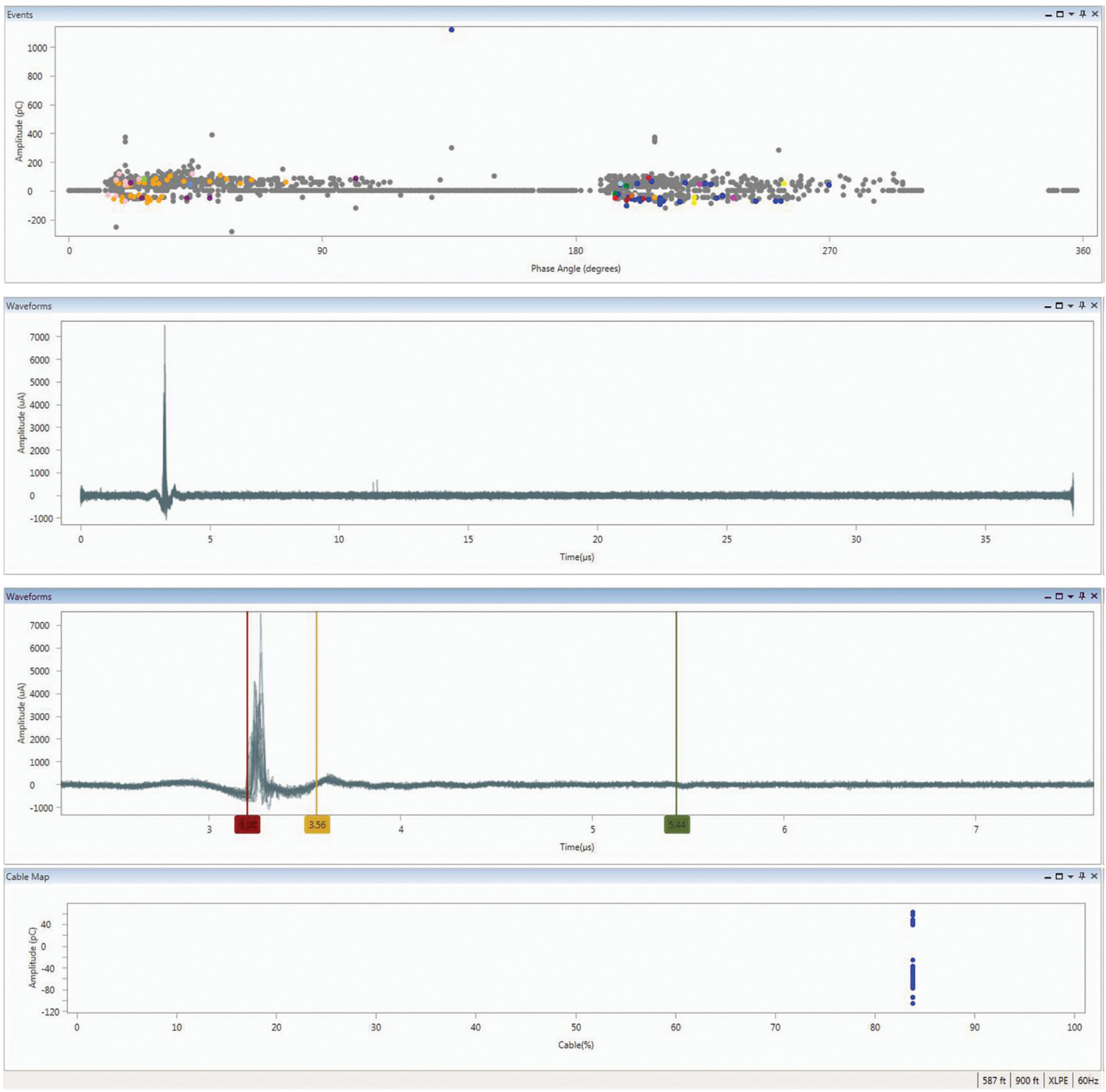



**Figure 6:** *Phase Resolved, Waveform, and Location Mapping Plots for 34.5 KV Cable*

*Partial Discharge Damage at Field Terminations as a Result of Poor Workmanship*

splices were suspected as faulty. The customer wanted to know if an online cable tester could confirm the bad splices.

Online testing was performed on three cables where the known bad splicer did the joints and found that all three had excessive amounts of PD (Figure 5). A cable with known good splices was tested as a comparison and that cable was PD free. For the cables where PD was detected, the online test also discerned the location of the bad splices.

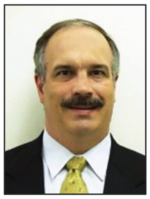
**Online example #3.** A municipal underground 34.5 kV XLPE cable was tested using online test technology (Figure 6). In this case, not only was the presence of PD detected, but also its location at 490 feet from the RFCT was mapped by looking at the primary and reflected pulse timing.

## CAUSE OF PARTIAL DISCHARGE ON CABLES

The leading cause of partial discharge in cable systems is field workmanship. As opposed to sterile factories with tight quality control measures, field installation of cables is difficult. Cables are spliced and terminated under adverse conditions, including weather, access, visibility, and cleanliness. Repairs are often made in the rain, in middle of the night, and in a hole with bad lighting and severe time pressures.

## SUMMARY

In summary, all three test methodologies are effective ways to determine cable insulation health. Tan delta and offline partial discharge are excellent commissioning tests, whereas online partial discharge testing is ideal for in-service screening of large populations of cables. Cables identified as suspect in the online tests can be addressed or selected for offline PD and tan delta testing before deciding on a remediation.



***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. 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.*