VLF TESTING vs. TAN DELTA vs. PARTIAL DISCHARGE

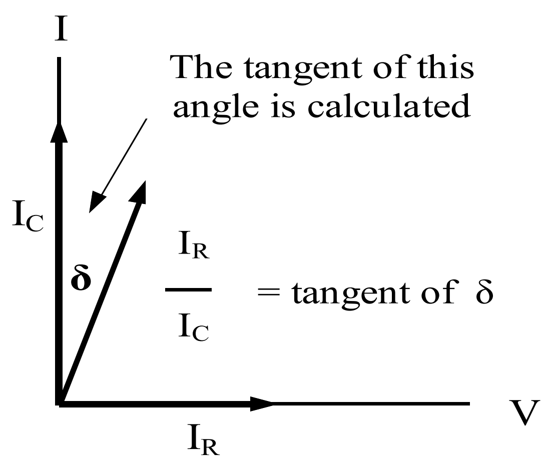
Which is right for you?

The answer is easier than you might think. If you can first answer the question: **what do I intend to do with the test data provided**, then you're halfway there. Match the test method and data collected to the desired, and practical, repair approach. Too many times people perform a test without first thinking it through and having an action plan afterward based on the test results. Testing is time consuming and expensive: make sure the data collected is useful and possible to act on. For example: you do PD testing on direct buried cable and see locations of worrisome PD. What do you do with that data? Are you really prepared to dig a hole where you believe the defect to be, cut out a piece of cable hoping to get it, and then perform two more PD tests to look each direction from the cut to make sure you got it? Wouldn't it have been easier, quicker, and far less expensive to perform a VLF withstand test? If there's a weakness, let the VLF cause failure, find the fault with conventional fault locators, make the repair and move on. If your cable is critical and you cannot risk failure during the test, then a VLF withstand test is not the right approach. If PD testing is to be used to rate many cables by severity of PD, in order to make a hit list of the worst cables to the best in order to prioritize replacement or possible injection, using a TD test to perform that comparison would be far easier and less expensive and as effective. If a cable is newly installed, the insulation is probably good. PD testing can be used to expose problem accessories.

Every method offers useful information. To select the right approach or multiple approaches, it is what you plan to do with the information collected that must be certain.

The three methods of testing. Which to use when and where?

A Very Low Frequency high voltage AC tester is used to perform a withstand test. A VLF instrument is relatively inexpensive, very easy to use, and quite portable, depending on model. VLF models are available from 20 kV to 200 kV and in many power levels. They output 0.1 Hz to 0.01 Hz and are rated by the capacitance of the load they can test. Models available can test from 3000' to 30 miles. IEEE400.2-2004 defines VLF testing methods.



In many situations, a simple proof test is desired. If there are weaknesses in the cable that cannot withstand the voltage, let them fail and then find the fault. It is very useful in performing Acceptance testing. The cable insulation is probably good (brand new cable) but there may be installation problems like improperly installed splices, terminations, cable damage, etc. There is no more effective test to weed out bad cable then the VLF test. Another reason to use VLF is to test the integrity of a cable after repair. Apply the proper voltage for maybe five minutes (for just a quick check, not a proper VLF test of 30+ minutes) to make sure the cable holds to provide some comfort that the fuses won't blow upon re-energization. It is a far better tool that the others now used: resistance testers, DC hipots, hot stick adaptors connected to another phase, soak test, etc. No one wants to return to the same neighborhood a week later due to another fault created when the crew thumped the cable many times with an excessively high voltage, creating another fault.

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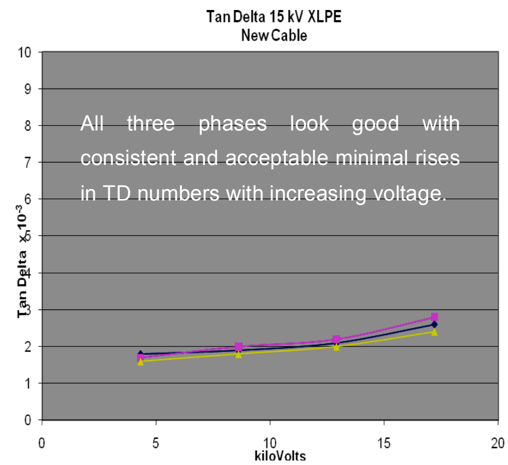
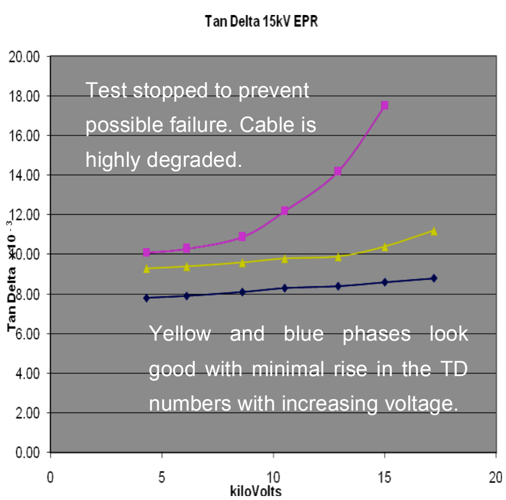
The VLF approach in not good for all circumstances. In many cases, it is not desired to cause failure in a cable during the test. A diagnostic test is better to learn about the quality of the cable insulation and accessories without cable failure. With this information, a plan can be made to either fix or replace the cable when convenient. One can use a Tan Delta or Partial Discharge approach, or both.

Sample TD Results





Tangent Delta testing, sometimes shown as Tan δ, provides the user with an overall condition assessment of the cable. It is also called Dissipation Factor or Loss Angle testing. The test is performed on a cable to learn the condition of the cable from start to finish. It does not show individual defects along the cable, only the condition of the total cable. The test is relatively simple to perform and the results are not difficult to analyze. This is an off-line test with the cable disconnected at both ends. A VLF is used to provide the variable voltage for the test while the TD instrument takes the measurements. The test is most useful as a comparative test, where many cables are tested, evaluated, and ranked from bad to good, or Highly Degraded, Slightly Degraded, Good. Some rate the cables by Action Required, Further Study Required, and No Action Required. This rating helps the user prioritize cable replacement, repair, and/or silicon injection. It also provides information to determine what other tests may be useful.

If a cable is in perfect shape, it simulates a capacitor. With perfect insulation, the capacitive current is 90° out of phase with the applied voltage. The more deteriorated the insulation, the more this angle becomes something less than 90°, as a resistive element is added to the circuit. It is this angle that is measured.

The VLF is used to apply the voltage, usually up to 2Uo, or two times the normal line to ground voltage. As the voltage is raised to capture perhaps 5 or 6 test points, measurements are taken. The TD numbers measured are important but the shape of the curve as the voltage is increased is more important. In a perfect cable the graph is flat, indicating there are no major defects: the cable is good. If a cable is highly deteriorated, the graph will trend upwards as voltage is increased. The cable is not a pure capacitor, as it has a resistive element to it due to defects. The worse it is, the higher the graph trends. The difference in the numbers between 2Uo and 1Uo is a good acid test as to the quality of the cable. Remember, we are performing a diagnostic test where we want to learn the cables quality but do not want to risk failure. As the voltage is raised and the measurements taken, if the cable shows that it is highly deteriorated, the voltage is not raised any further. We have learned what we need to know, the condition of the cable. The maximum test voltage in many cases is no higher than 1.6 – 1.7Uo and performed quickly, perhaps 10 minutes total but only a few at the higher voltages, as to not stress the cable any more than necessary.

A variation of this test is called a VLF Monitored test. The intention is to perform a full VLF test if possible. As the voltage is raised, the TD numbers are measured. If the numbers look good, indicating a relatively good cable, then the voltage is raised and a full VLF test is performed. The theory here is that if a cable has good TD numbers, it is in good shape; however there may still be one or two defects that do not show up in the overall numbers. A mile long cable may have one or two bad spots but are swamped out in the measurement due to the good condition of the overall cable. The VLF test is performed and in some cases, there is no cable failure, since the TD numbers were good. Once in a while there is a failure and the cable is repaired or replaced. Conversely, you would not continue to raise the voltage if the TD numbers show the cable to be very deteriorated and has no chance of passing a VLF test. You've learned the cable should be replaced soon.

Off-Line Partial Discharge testing is used to identify cable defect locations and their severity. What follows is brief look at the method of testing and a simplified description of PD. PD testing and especially analysis of results is far more complicated than what is described here. Having said that, PD cable testing technology has advanced to the point where it is fairly accurate in its determination of location and severity of cable flaws. What is described should be sufficient to know enough about PD and PD testing to make an informed decision of testing options.

Opposite from the TD test that grades the overall cable quality, PD hopes to show discreet locations of electrical discharges. Once identified, the user can make a decision as to whether the level of discharge is acceptable or not. That interpretation and ambiguity is the trick that makes PD testing more difficult and interpretive compared to the other testing methods. That is not say it does not have value, it does, but in choosing any test method, ease of use, useful data gathered, and cost must be balanced again the usefulness of the data gathered.

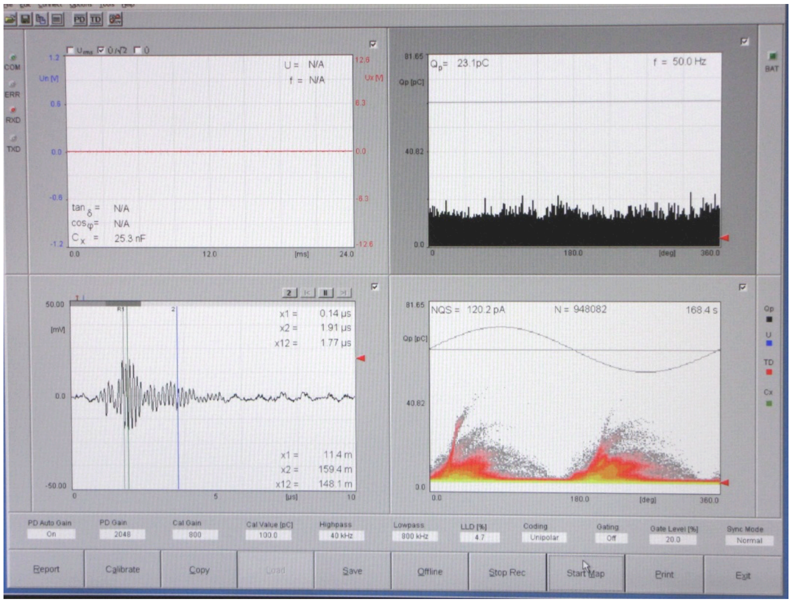
PD is just that, a partial discharge in a localized void, moisture pocket, or some other defect that creates an imperfection in the insulating material. Under voltage stress, the defect discharges energy. It is a partial discharge because it is in a localized area of the insulation and does not bridge the insulation between the live conductor and ground, causing a total failure of the material. Left to continue discharging, it will spread through the material until the insulation is compromised enough that the voltage stress causes a total failure.

During the test, the voltage is raised above normal operating voltage to measure where the PD initiates, called the **Partial Discharge Inception Voltage**. The voltage is then lowered to see where the PD extinguishes, called the PD Extinction Voltage. If the inception voltage is in the insulation and is just 10% or 20% above normal operating voltage that is worrisome, for low level line transients can initiate the PD. If the PD is ~1.8+ times normal, that is acceptable. This is not true with most accessories. That is sometimes difficult. Splices and terminations can exhibit high levels of PD and operate for years, decades. Some judgment must be made as to what is acceptable or not with accessories. A company performing the test could just say everything exhibiting PD is bad and should be replaced. This way they can never be wrong. Of course the cost would be prohibitive and the effort unnecessary. That is not an acceptable way to approach the test. Again, accessories can live for decades with some level of PD. The problem is there is no guideline for acceptability in aged accessories. The manufactures' of accessories measure the PD in the factory and they should exhibit less than 10pc. Once they are installed and aged, it could be anything. Consult your splice and/or termination vendors for some guidance. It is this unknown that makes PD testing very interpretive with a lot of guesswork. Any PD in the insulation that is at or near operating voltage is a problem and action must be taken. Any PD at operating voltage will destroy the cable very quickly. Usually PD at operating is not found, since the cable probably fails before you get there. If the is PD at perhaps 1.1 - 1.5 times operating, it should probably be called defective and replaced.

*PD is measured in the energy emitted. **The unit of measure is the picocoulomb, or pc**. For reference, cable insulation must have less that 5pc when factory tested. Also, high frequency current impulses are created by PD and measured. Over time, due to chemical, thermal, and physical degradation the PD level increase. Also a very prevalent contributor is water ingress.*

There are two methods of measurement for PD. The first is measuring the time it takes for a microburst of PD energy to travel back to the PD sensors and the time it takes to travel to the other end of the cable and reflect back to the sensors. Knowing the speed of this wave and measuring the time it takes for the reflections to return, the distance is calculated. Another method of detection is to use Time Domain Reflectometry, much like when using a thumper and tdr/radar. The tdr signal reflects off the PD and returns to the TDR, where the time is measured and distance calculated.

Usually the PD is found to emanate from splices and terminations or from the insulation but at levels higher than operating. Ultrasonic sound waves are also created. These can be measured, usually on the cable accessories if available, by a handheld listening device.



Here is an example of what the measurement and analysis screen looks like. It may look complicated, and is, compared to the tan delta method, but once learned, it does provide valuable data. The location and amplitude of the PD are shown, and to some degree, the type of defect can be learned.

Many use PD detection as a comparative test. Many cables are tested and their level of PD activity compared. The worst offenders are dealt with first.

If a comparative test is going to be used, it is much easier and less expensive to perform tan delta testing on the cables, or do both.

Limitations of each method

There are limitations to each of the three methods. This will often be the deciding factor in which technology will be used. Sometime it is possible to perform all three tests to gather all the data possible about your cables.

1 **VLF Testing:** A VLF withstand test can be performed in more situations than the others. One limitation to using VLF is the voltage rating of the cable and the capacitance of the cable. VLF generators are rated by their voltage and then by the capacitance of the load they can test. The uF/1000' or uF/kM, etc. are known for every cable. The total cable capacitance can be calculated and compared to the rating of the VLF. Most VLF units have output frequencies of 0.1 Hz – 0.01Hz. Although all are accepted in IEEE400.2-2004, most of the world data is based on 0.1Hz testing. However, much testing is done, and necessary in many instances, at the lower frequencies to accommodate longer cables. At 0.05 Hz output, which is commonly used, the VLF can test twice the cable length that at 0.1 Hz. When using the VLF to provide the voltage for TD or PD testing, usually 0.1 Hz is used. A common VLF rating is 0 - 40kV at 1.1 uF @ 0.1Hz. This uF rating equates to approximately 3 miles of 15 kV cable or 4 – 5 miles of 35 kV cable. The highest voltage rated VLF available now available is 200kV. This is high enough in voltage to perform VLF testing on 138kV cable and enough voltage to be used for TD and PD testing on 250kV, since the voltage levels for these tests are lower than the VLF stress test.

Another limitation is the condition of the neutral. Since the VLF tests between the conductor and shield, it is important that the shield, or neutral, be fairly intact. If the neutral is completely corroded, the test is not that effective.

2 **Tan Delta Testing:** There are four main limitations of using this method. The first is cable length. The shorter the cables tested the better. This is since the TD measures the overall degradation of a cable and provides one number for each test. The shorter the cable length the more accurate the numbers will be. If a very long cable is tested, maybe >3000', then any severe defect locations may not be observed in the context of the average reading over the long run. It is not realistic to test a cable a two miles long with TD.

Although one method, as described earlier, is to perform a VLF Monitored TD test. If the numbers indicate a good cable, continue raising the voltage to the VLF hipot level and VLF test it to expose possibly one or two defects, usually in accessories.

The next limitation is the length of cable that the VLF used can test at 0.1Hz. If it can only power up a 2000' cable, then that's the limitation. 0.05 Hz can be used but not comparable if trending to earlier 0.1 Hz testing. At the lower frequency, the trend of the numbers can be observed and useful, especially if comparison testing. In this case, the absolute readings are not as important as the curve shape with increasing voltage.

The next limitation is the concentric, or taped neutral. It should be fairly intact to provide a good ground shield around the cable to make the readings accurate. Possibly a TDR can be used first to examine the neutral condition prior to testing. The TDR cannot measure if just a few strands of many are broken or if many are corroded but still intact, but it will show any location where the neutral is completely or nearly completely absent.

The last limitation is the type of cables that comprise the circuit. Every type of cable insulation has a different loss characteristic, or TD number. The test should be performed on circuits that are of one cable type. It is not a very useful test to measure the TD on a run with XLPE spliced to EPR, or PILC.

Tan Delta testing is the best way to determine the extent of water tree damage in a cable. It is best as a comparison test of many cables to help the user prioritize cable replacement or injection and determine what other tests may be useful.

3 **Partial Discharge Testing:** Like with TD, there are several limitations to its use. These are the length of the cable, the condition of the shield, what type of shield, jacket or non-jacketed, installation type - direct buried or conduit, and the attenuation level of the signal through the cable. Background noise can also influence the results.

The first is the cable length. There is a practical limit to how far one can PD test and get accurate results. The longer the cable the more attenuated the signal becomes, making it harder or not possible to read the results. This distance depends on several factors but generally the cable should not be more than maybe 2 miles in length. The length possible to test is also determined by the power of the VLF set.

The next limitation is the condition of the neutral. Like with other testing, the usefulness of the test relies on a good neutral, since we are testing between the conductor and grounded neutral. The neutral should first be inspected with a TDR to see if there are discontinuities before considering the PD test.

A good PD test is a calibrated test. That means a method is used to see what PD levels can be sensed by the PD equipment on that cable. A calibrator device, which emits a known PD pulse, perhaps 5, 10, or 20 pc, is injected into the far end of the cable. The PD detection equipment tries to read it. If it does, then the PD equipment will be able to measure that level of PD created in the cable during test. If the cable is in such a condition or length that low levels of PD cannot be seen, then the test is of lesser value, since the measurement of low, possibly dangerous levels of PD in the insulation cannot be seen. One problem with this is that you won't know until your all setup.

If there is a high level of background electrical noise, this can affect the reading. Although the PD equipment can cancel out much of it, it can still pose problems if it is at a level above the desired PD level testing to.

The greatest limitation to the value of the test is that it is very subjective as to what the PD levels measured mean. As said earlier, a splice or termination can live for years with relatively high levels of PD. It is not practical to say replace everything showing PD. It also depends on the nature of the PD, Is it from insulation material containing voids or is it tracking along the outside of the material, or something else? Many PD service companies have gotten in trouble by claiming accessories to be bad, and when inspected by the makers of the accessory, they were found to be within acceptable levels and the device would live forever. (That's one reason why a VLF stress test may be better. If the bushing is truly bad, let it fail during the test. But if it holds 2 – 3 times normal voltage, who cares what the PD is, it will last for years.)

Summary

All three methods of testing provide useful information but different information. None are suited for every situation. None can provide all the information needed about a cable system. An analysis of all three technologies and the data they provide should be performed before making a decision. The cost of the test, the cost to buy the equipment, the ease of the test, the ease of interpretation, the skill of the operator necessary, the availability of the equipment, the cable design, age, ease of repair, the data needed to make cable maintenance decisions, and whether cable failure during the test is permissible are all very important.

Match the test to the situation. For example, in a new installation, the cable insulation can be assumed to be good. What we are really checking for is improperly installed accessories. The best test is to perform a simple VLF hipot test. If there is a problem in a splice, let it fail during the test and replace it. There is no ambiguity to a VLF test. If nothing fails during the test, then all are good, who cares what the PD level or TD numbers may have shown.

If a cable is aged and in an application where a failure during test would be a problem, then a PD test can be made to find where there may be dangerous levels threatening the cable in the near term. Or, a TD test can be performed to measure the extent of deterioration. This method is good if you are to measure many cables and rate them by degree of degradation to establish a hit list of where your repair efforts should go first. PILC feeder cables are a good candidate for PD testing by exposing the locations of trouble and replacing the section affected.

Many engineers, contractors, testing services, etc., specify a test not suited for the situation. For example, a wind farm has many miles of 35kV cable, quite often direct buried. Many of the cables are far too long to perform a TD or PD test. Often a PD test is specified. The insulation is new. The test is to find poorly installed accessories. Also, with the cross bonding of the neutrals, a PD test and TD test is not possible unless those locations are accessible and the neutral configurations can be changed for the test. The only thing possible and best suited for the situation is a simple, inexpensive, conclusive VLF hipot test. There are VLF models that can test over 20 mile of cable at one time. Weed out the bad locations, repair them and move on.

As an aside, too many cable installations, like wind farms, are designed in such a way that makes testing and fault finding nearly impossible. Think about the maintenance that will be required. A cable that is 5 miles long with no exposed splice boxes and cross bonding boxes is a bad design. Proper testing and future cable fault location are severely compromised.

All three methods of testing provide information about the cable system. They all provide different data. Not any one method can supply all the information about your cable system. The best is if both TD and PD can be done followed by a VLF test if appropriate. Since it takes a VLF generator to provide the voltage for the two diagnostic tests, it makes sense to make the best use of it.

Again, when weighing which method(s) to use, the cost of the test and the equipment, the ease of the test, the data obtained, the level of operator knowledge required, the availability of the test equipment or service company, and the ability of the user to act on the information gathered all must all be considered. HVI can provide all three methods.

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