TAN δ (DELTA) CABLE TESTING

OVERVIEW AND ANSWERS TO FREQUENTLY ASKED QUESTIONS

What Is Tan δ, Or Tan Delta?

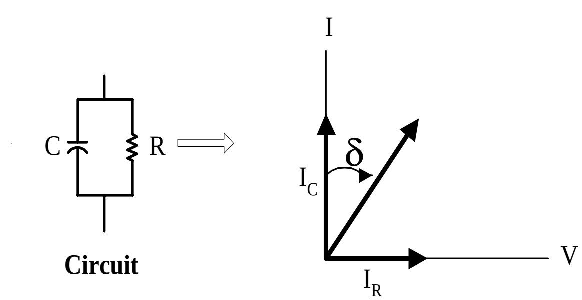
Tan Delta, also called Loss Angle or Dissipation Factor testing, is a diagnostic method of testing cables to determine the quality of the cable insulation. This is done to try to predict the remaining life expectancy and in order to prioritize cable replacement and/or injection. It is also useful for determining what other tests may be worthwhile.

How Does It Work?

If the insulation of a cable is free from defects, like water trees, electrical trees, moisture and air pockets, etc., the cable approaches the properties of a perfect capacitor. It is very similar to a parallel plate capacitor with the conductor and the neutral being the two plates separated by the insulation material.

In a perfect capacitor, the voltage and current are phase shifted 90 degrees and the current through the insulation is capacitive. If there are impurities in the insulation, like those mentioned above, the resistance of the insulation decreases, resulting in an increase in resistive current through the insulation. It is no longer a perfect capacitor. The current and voltage will no longer be shifted 90 degrees. It will be something less than 90 degrees. The extent to which the phase shift is less than 90 degrees is indicative of the level of insulation contamination, hence quality/reliability. This "Loss Angle" is measured and analyzed.

Below is a representation of a cable. The tangent of the angle δ is measured. This will indicate the level of resistance in the insulation. By measuring I_R/I_C (opposite over adjacent – the tangent), we can determine the quality of the cable insulation. In a perfect cable, the angle would be nearly zero. An increasing angle indicates an increase in the resistive current through the insulation, meaning contamination. The greater the angle, the worse the cable.



What Are Water Trees?

Water trees are small tree shaped channels found within the insulation of a cable, caused by the presence of moisture. They are very prevalent in service aged XLPE and other solid dielectric cables, like PE and EPR cables. These tree shaped moisture channels, in the presence of an electrical field, eventually lead to the inception of partial discharge (pd), which eventually leads to the formation of electrical trees, which grow to a point where insulation failure occurs. The tan delta test shows the extent of water tree damage in a cable.

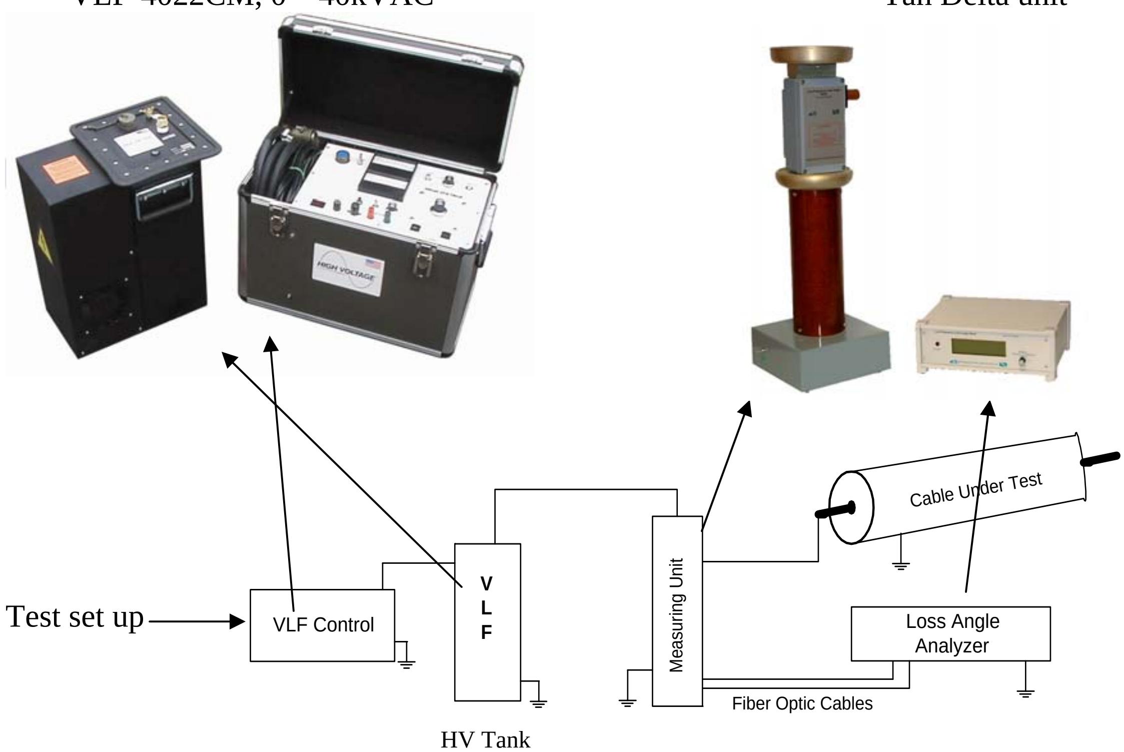
What Hardware Is Necessary?

The tan delta unit consists of a high voltage divider and a fiber optically linked measurement box. The high voltage divider measures the voltage and current input to the cable, sends this information to the controller, which analyzes the voltage and current waveforms and calculates the tan delta number. A connected laptop computer displays and stores the results.

A voltage source is needed to energize the cable. What is typically used is a **Very Low Frequency (VLF) AC Hipot.** The VLF pictured here is a 40 kV (peak) unit that is capable of testing from 1.1 uF of cable load at 0.1 Hz, up to 5.5uF at 0.02 Hz. Other models offer an output frequency of 0.01 Hz, used to test very long cables. VLF hipots are also widely used for testing newly installed and/or repaired cable before reenergizing to insure the cable is sound and for testing critical cable runs.

VLF-4022CM, 0 – 40kVAC

Tan Delta unit



How Is The Test Performed?

The cable to be tested must be de-energized and each end isolated. Using a VLF AC Hipot, the test voltage is applied to the cable while the tan delta controller takes measurements. Typically, the applied test voltage is raised in steps, with measurements first taken up to 1Uo, or normal line to ground operating voltage. If the tan delta numbers indicate good cable insulation, the test voltage is raised up to 1.5 – 2 Uo. The tan delta numbers at the higher voltages are compared to those at lower voltages and an analysis is made.

Why Is A VLF Hipot Used Instead Of A Regular 60 Hz Model.

Two reasons. First, to test a cable with 60 Hz power requires a very high power supply. It is not practical, nearly impossible, to test a cable of several thousand feet with a 60 Hz supply. At a typical VLF frequency of 0.1Hz, it takes 600 times less power to test the same cable compared to 60 Hz.

Secondly, the magnitude of the tan delta numbers increase as the frequency decreases, making measurement easier. As the below equation shows, the lower the frequency (f), the higher the tan delta number.

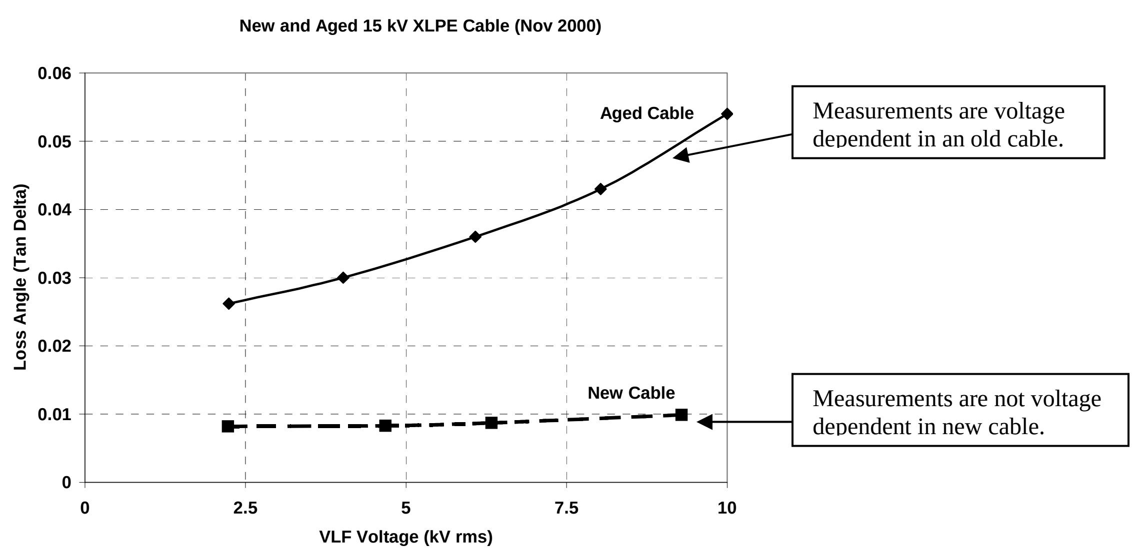
Tan Delta (δ) = I_R / I_C = 1/(2p**f**CR)

(tan delta is measured in radians)

How Are The Test Results Interpreted And Is It Necessary To Have A Benchmark, Or Standard, Result For Comparison?

While it is beneficial to have a standard or previous test to compare to for trending purposes, like with many diagnostic methods of testing, it is not necessary. The very first test on a cable yields valuable information about the insulation. Also, most tan delta testing is performed on a comparative basis. More on that in the next section.

If a cable's insulation is perfect, the loss factor (tan delta) will change little as the applied voltage is increased. The capacitance and loss will be similar with 1 kV or 10kV applied to the cable. If the cable has water tree contamination, thus changing the capacitive/resistive nature of the insulation, then the tan delta numbers will be higher at higher voltages. Rather than a flat curve for the loss number versus voltage, the curve will be non linear. See the below graph.



From this graph, we can see that the aged cable has extensive water tree damage. The Loss Angle increases with increasing voltage, indicating a high resistive current element to the insulation. These results can be compared to other cables tested to determine which cables are in need of immediate replacement and which can wait a bit longer. Also, many tests are measured on a comparative basis. Many of the same type of cables may be tested, with the results compared against each other. An average value for the tan delta can be calculated and possibly used as a future benchmark.

If There Are No Recognized Standards For Tan Delta Test Values, What Good Is The Test? How Do We Know If A Cable Is Good, Marginal, Or Bad?

Fair question. It is correct to say that there is not an extensive library of test values for all types of cables and accessories. As mentioned earlier, much of the testing is done on a comparative basis, as with partial discharge testing, where established pd levels do not exist for all cable types, accessories, and varying installation methods. There is no reliable consensus on what are good versus bad pd levels. Splices can exhibit very high levels of partial discharge yet last for years, while those showing lower pd levels might fail sooner.

One must keep in mind what the purpose of the test is. Whether using partial discharge or tan delta techniques, the point of the test is to grade all cables tested on a scale from high quality to low. The point in the testing is to help a utility prioritize cable replacement or injection. Again, comparative testing will show which cables are worse than others and will, over time, permit the user to develop their own in-house guidelines, unique to their situation.

In the real world, once a utility tests hundreds of cables and grades them from good to bad, giving them a starting point for cable replacement, they generally run out of time and money long before they get to the cables that were marginal. This fact also demonstrates that tan delta testing is not an exact, precise test. Again, we're just trying to figure out which cables are most worrisome. The tan delta results, along with other knowledge of the cables history, and possibly other test data like partial discharge, all help to give us some guidance.

Important note regarding partial discharge versus tan delta: Accepting that there are not established, well proven standards for pd or tan delta testing, and both are best used on a comparative basis to help prioritize cable replacement, then why not use the method that is easier and cheaper? Pd testing services charge thousands of dollars per day while a tan delta and the required VLF AC Hipot may cost $ 35,000 to own. The VLF hipot is useful in its own right as the best method of AC hipoting cables to expose defects in insulation and splices. With the VLF and tan delta bridge, you actually have two tools to use for cable testing, both of which can be operated with minimal training. That's not the case with a pd system, which requires a highly trained operator, and is very expensive.

Might The Cable Fail During The Testing?

Since test voltages of up to 2Uo are used, there is a possibility of a cable failing during the few minutes needed to perform the test. This can usually be avoided if tan delta numbers are measured at several voltages up to 1Uo and an inspection of the tan delta versus voltage curve is made. If the curve is flat, continue the test. If the curve shows that as the test voltage is raised, the loss angle increases sharply, then it is known that the cable has extensive water tree contamination. By comparing numerous test results, one can determine which cables are good, marginal, or bad. Remember, the point of the test is to help prioritize cable replacement, so absolute numbers are less important than test results comparing many cables.

Also, since the test takes only 5 – 10 minutes, the cable is not voltage stressed for a long enough period of time for breakdown to occur, unlike a VLF AC hipot test where up to 3 times normal voltage is applied for at least 30 minutes.

How Long A Cable Can I Test?

That depends on the AC voltage source used. The standard VLF unit from High Voltage, Inc. can test 3-4 miles of cable: one model can test 30 miles. It is generally advantageous to test shorter lengths rather than a long cable, because the shorter the section of cable that is tested, the more precise we can be in determining where the cable is good or bad.

Can The Test Find The Locations Of Cable Defects?

No. Tan delta tests the cable from point A to point B and gives an assessment of the insulation quality between those points. A determination can then be made if, and when, to replace or enhance the cable. For any value of tan delta, there could be many minor defects or a few major defects: it cannot discriminate. When you are tan delta testing, you are only determining how good a cable is between two points. Again, it’s not a faultfinding tool. It is a tool to permit a utility to make educated decisions regarding cable replacement.

This assumes the cable being tested is in conduit and entire lengths will be replaced. In direct buried situations, a better test is to use the VLF unit as an AC hipot and apply the IEEE recommended 3 times normal voltage for at least 30 minutes. Any serious defect within the insulation or accessories may fail: the reason for the stress test. Find the fault, repair it, and move on.

Isn’t This The Same As A Power Factor Test?

Not quite, although it essentially provides the same qualitative assessment as a power factor test. With power factor, the cosine of the angle between the voltage and current is measured, yielding the power factor. With tan delta, we are measuring the tangent of the complimentary angle, and it is measured in radians, not degrees as power factor is done. For slight angles, the tan delta readings will be the same as power factor. As the angle, hence loss, increases, the tan delta numbers and the power factor numbers will not be the same.

Are There Any Limitations To Using Tan Delta Testing?

Since we are measuring the loss angle of an insulating material, and making an analysis about the test results possibly based on historical data, it is not advisable to test a cable length that contains more than one type of cable. Different cables have different loss characteristics. It is not a good practice to test a cable length of XLPE insulation spliced to an EPR or PILC cable. The only way in which this is meaningful is when many tests are done on the same cable length over time and the results are carefully trended.

Concentric Neutral

Since we are measuring the loss angle between the conductor and the outer shield, the outer shield must be intact. It is advisable to test the integrity of the concentric neutral before performing the test. (This is a worthwhile test anyway for several reasons, whether or not a tan delta test is being performed.) If there are large gaps in the neutral, the tan delta (or partial discharge) numbers will not be meaningful. There are easy ways to test the neutral integrity and we can help with that.

How Long Does The Whole Test Take?

The test itself can take less than twenty minutes, depending upon the settings of the instrument and the number of different test voltage levels used. It is only necessary to capture a few cycles of the voltage and current waveform to make the analysis. At 0.1 Hz, the period of the sine wave is 10 seconds, so it takes 20 – 30 seconds for a reading to be made. At .02 Hz, the period is 50 seconds, requiring perhaps 3 minutes of test time at each voltage setting.

Other Uses Of VLF AC Hipots

VLF hipots should be used by every utility. An AC hipot test is the best way to expose defects in insulation and accessories. It's fast, easy, and economical.

- Test cable/accessories after installation or repair to insure integrity
- Test critical cable runs
- Test substation cables and getaways
- Test rotating machinery
- Use the VLF as a voltage source for off-line partial discharge testing