



# TAN DELTA ( $\delta$ ) MV & HV CABLE TESTING

## TECHNOLOGY OVERVIEW AND FREQUENTLY ASKED QUESTIONS

### What Is Tan Delta (Tan $\delta$ )?

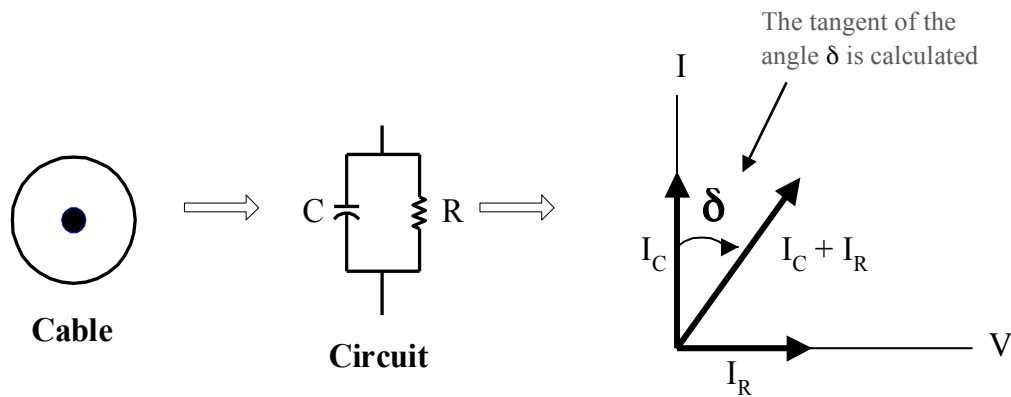
Tan Delta, also called **Loss Angle** or **Dissipation Factor**, is a diagnostic method of testing cables to determine the quality of the cable insulation. This is done to predict the remaining life expectancy of cables, to prioritize cable replacement, rejuvenation, or to determine what additional tests may be of value.

### 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 as the two plates separated by the insulation.

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 90 degrees out of phase, but something less, perhaps 89.5. 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  $\delta$  is measured. This will indicate the level of resistance in the insulation. By measuring  $I_R/I_C$ , we can determine the condition 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 loss angle, the greater the degradation in 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 insulations, like PE and EPR. 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?

A VLF AC hipot is needed to supply the overvoltage to the cable while the Tan Delta transducer measures and captures the voltage and current waveform data used to calculate the phase shift between them. This data is automatically recorded in the VLF memory, to the VLF front panel mounted USB memory stick, and wirelessly to a laptop if used.

Pictured below is the HVI **VLF-65E VLF** hipot connected to the **TD-65E Tan Delta** measurement transducer, connected to the cable under test. A wirelessly connected laptop computer can be used to run the preprogrammed test, record and display the results, and create custom test reports.

A voltage source is needed to energize the cable. In most cases, a **Very Low Frequency (VLF) AC Hipot** is used. The **VLF-65E** pictured here is a 65 kVac (peak) unit that is capable of testing from 1.0  $\mu\text{f}$  of cable load at 0.1 Hz, up to 10.0  $\mu\text{f}$  at 0.01 Hz. VLF hipots are also widely used for testing newly installed and/or repaired cables before reenergizing to ensure the cable is sound, and for testing critical cable runs to expose defects to make repairs when convenient.



VLF-65E with TD-65E

Testing a 35 kV cable

## 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. The applied test voltage is raised in steps, with measurements first taken up to  $0.5U_0$ , or one half of normal line to ground operating voltage. If the tan delta numbers indicate good cable insulation, the test voltage may be raised up to  $1.0$ ,  $1.5 U_0$  and  $2 U_0$ . The tan delta numbers at the higher voltages are compared to those at lower voltages and an analysis is made. A known indicator of severely deteriorated cable insulation is a strong tip-up to the curve plotting the TD numbers measured at  $2 U_0 - 1 U_0$  applied voltage.

## Why Is A VLF Hipot Used Instead of a Regular 60 Hz Model?

To test a cable with 60 Hz power requires a very large high voltage 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 0.1 Hz, it takes approximately 600 times less power to test the same cable compared to 60 Hz.

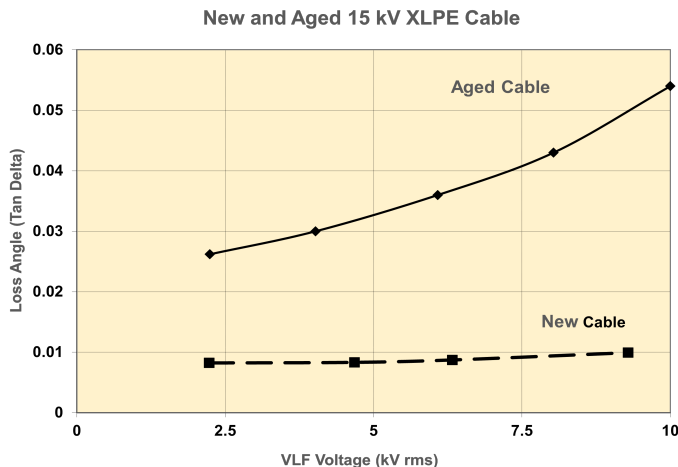
Also, the magnitude of the tan delta numbers increases as the frequency decreases, making measurement easier. The lower the frequency (f), the higher the tan delta number.

$$\text{Tan Delta } (\delta) = I_R / I_C = 1 / (2\pi f C R)$$

## How are the Test Results Interpreted? Is it Necessary to Have a Benchmark, or Standard, Result to Compare to?

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 between many like cables and/or similar installation conditions.

If a cable's insulation is perfect, the loss factor (tan delta) will not change 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 trend upwards at higher voltages. Rather than a flat curve for the loss number versus voltage, the curve will be nonlinear. See the graph.



From the 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 the condition assessment criteria within IEEE400.2 and/or other cables tested to determine which cables need corrective action 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 for the same or similar cable installations.

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 for the same or similar cable installations.

## Are there reference points and applicable standards?

There are many reliable studies and test standards to which we can refer to obtain relevant Tan Delta numbers. These numbers can help the user assess the quality of the cable system under test and allow the user to prioritize any corrective action needed. The **Cable Diagnostic Focus Initiative**, (CDFI) conducted by **National Electric Energy Testing Research and Applications Center (NEETRAC)** has produced volumes of data related to this field. This is an invaluable resource that should be accessed by those conducting Tan Delta tests on shielded cable systems.

NEETRAC operates within the Electrical and Computer Engineering School at Georgia Tech. The IEEE standard 400.2-2013 includes cable assessment criteria based on insulation type and data for **VLF Withstand** testing and testing that users can reference for aid in methods of testing and interpretation of the results.



One must keep in mind what the purposes of the tests are. 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, to help a utility or industrial prioritize cable replacement. 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.

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 E Series and TD-65E from HVI, you actually have two tools to use for cable testing, both of which can be operated by anyone. That is not the case with a PD system, which requires a highly trained operator, and is very expensive, although useful when performed under the right conditions.

### **Might the Cable Fail During the Testing?**

Since test voltages of up to  $2 U_0$  are used, there is a possibility of a cable failing during the time needed to perform the test. This can usually be avoided if the tan delta numbers are measured at several voltages up to  $1 U_0$  and an inspection of the tan delta versus voltage curve is made. If the numbers look acceptable and the curve is relatively flat, continue the test. If the curve shows that the loss angle increases sharply as the test voltage is raised, then it is known that the cable has extensive water tree contamination. You have learned what you came for, stop raising the voltage and end the test. Perhaps compare numerous test results to help 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 10 - 12 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 from 2 to 3 times normal voltage is applied for at least 30 minutes.

### **How Long of 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 able to test up to 30 miles, or 10 km. It is generally advantageous to test shorter lengths rather than a long cable, only because the shorter the sections a cable is broken down to for testing, the more precise we can be in determining where the cable is good or bad.

### **Can the Test Find the Locations of Cable Defects?**

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 about if and when to replace the cable. There is no way to discriminate between many minor defects or a few major defects when measuring tan delta, which in most cases is fine. You are testing to determine how good a cable system is between two points. It is not a faultfinding tool, it is one of several tools to permit a utility to make educated decisions regarding cable replacement, rejuvenation, or what additional testing may be beneficial.

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 AC unit to perform an overvoltage withstand test, applying the IEEE 400.2-2013 recommended test voltage for 30+ minutes. Any defect severe enough that cannot hold the test voltage will initiate partial discharge and should fail during the allotted test time 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. For slight angles, the tan delta readings will be the same as the power factor. As the angle increases, hence loss severity, 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, 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 insulation. Different cable insulations have different loss characteristics. It is not a good practice to test a cable length with 300' 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.

The length of cable tested should be limited to runs as short as practical to test in an efficient and economical manner. Remember, the test result is one number representing the average loss value, or insulation degradation, over the entire length. The shorter the cable the better the test reveals its condition. The longer the cable, the more difficult it becomes to learn how severely and how much of the insulation is defective, as a cable with many minor defects may return the same test result as a cable with only a few major locations of deterioration. Also, the longer the cable the more the signal attenuates, same with PD testing, along the length and the less reliable the numbers become.

## 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. 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. While it is only necessary to capture a few cycles of the voltage and current waveform to make the analysis usually nine or ten are used as the sampling range, to insure stability in readings and accuracy in standard deviation calculations.

## Concentric Neutral Integrity- How Good are your Neutrals?

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 TD or PD 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 numbers will not be as meaningful if there were no gaps. There are easy ways to test the neutral integrity and we can help with that.

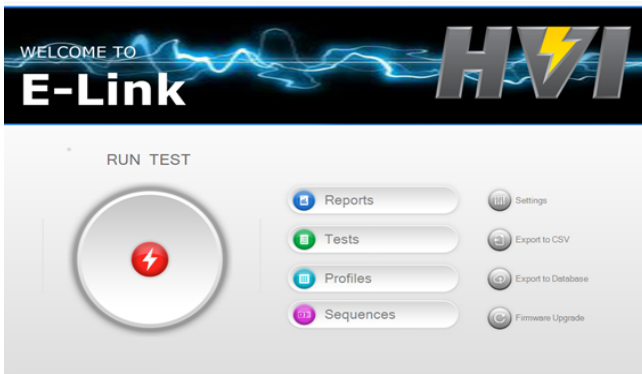


## Other Uses of VLF AC Hipots

VLF hipots should be used by anyone responsible for the installation and/or maintenance of a medium or high voltage cable installation. It is used as an Installation or Acceptance test tool to perform Withstand testing and it is vital when used as a periodic maintenance tool, usually combined with Tan Delta or Partial Discharge diagnostics. After more than twenty years of field and factory VLF testing experience, there is no reason to not use VLF 0.10 Hz output AC hipots.

It is also easy to perform, portable, affordable, and only practical method of performing high voltage AC testing in the field. VLF hipots are also used for testing **motor and generators per IEEE 433**.

- ⚡ Test cable/accessories after installation or repair to ensure integrity
- ⚡ Test critical cable runs to avoid outage surprises
- ⚡ Test substation cables and getaways
- ⚡ Test rotating machinery



HVI E-Link Software for VLF E Series & TD 65E



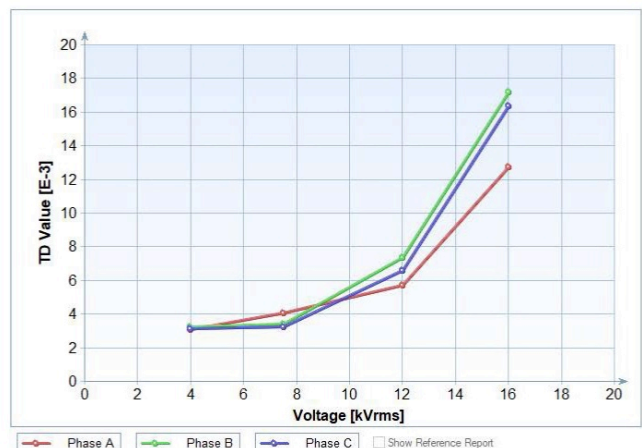
HVI VLF-34E & TD 65E testing 15kV cable



TD-65E

VLF-34E

VLF-65E



TD Test of Three-Phase System

