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TANGENT DELTA LOW VOLTAGE HIGH FREQUENCY AC METHOD TO MEASURE HV UNDERGROUND XLPE CABLES

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ABSTRACT

The Tangent Delta utilizing Low Voltage High Frequency Alternating Current is a method to test cables insulation durability. Phase shifts between the current and voltage across the cable are utilized to obtain the Tangent delta measurement. Advantages of this method compared to the market equipments are that the experimental setup is shrunk and special resolutions are improved. This method can measure as short as 1 meter HV cable's. This method was calibrated using cables manufactured with imperfections to distinguish various severities and also with a good cable as benchmark. A calibration curve was established by correlating the HFAC tangent delta measurement system's results with a 50 Hz marketed measurement system. The HFAC method is then used to measure actual field samples taken 20 meters away from a breakdown. Failure Analysis and HFAC result corresponds with the insulation measured being aged.

Keywords: 132 kV cables, dissipation factor, HFAC, high frequency, tangent delta, XLPE.

INTRODUCTION

Tangent Delta testing is a diagnostic method of testing cables to determine the quality of the cable insulation. This helps create a systemized method to analyze aging of cables in the long run. It utilizes the phase shifts caused by the displacement current induced due to the existence of impurities in the insulation or stress on the cable.

At present, the gross measurements of tan delta values in medium voltage (MV) and high voltage (HV) cables are performed to assess their state of deterioration due to aging. As these measurements are performed at VLF (0.02 and 0.1 Hz) or power frequencies of 50 and 60 Hz, the required cable capacitance are significantly larger as it requires the cables to be charged to the maximum operating test voltage and this results in cables with very large lengths, several tens of meters to hundreds of meters or even larger. The tan delta results are purely for the total length of the cable used in the measurement. Hence these measured results are significantly lacking in the spatial resolution [1]. The problem using the conventional tangent delta method is the need of space for experiment and also the high cost. Power frequency and very low frequency technique utilizes a high voltage source and is considerably large in size to meet the required output power and the test setup generally requires dedicated space to be occupied hence the whole test system and setup is expensive, perhaps not economical to procure for non-routine test application in the laboratory.

The new method involves the use of high frequency (radio frequency) technique at 10 kHz and maximum voltage of 10kV to generate equivalent stress in HV cables that will induce the process of deterioration in continuous operation. This method is unique and will be applied for the first time for HV cables.

The advantage of this method is that this setup utilizes a small testing environment which can sample small lengths with minimum 1 meter length of cable. Also, this study is Undertaken using low voltage application and more economical to assess dielectric insulation condition for transmission class cables in the laboratory. The tangent delta testing method utilizing High frequency Low voltage application was designed to access the condition of high voltage underground cables.

For a perfect capacitor, the voltage, V and current, I is phase shifted 90 degrees as in Figure-1(a). Current through the insulation are purely capacitive current, IC, which means no resistive current, IR. Impurities in dielectric reduce the insulation resistance resulting in resistive current through insulation. Therefore insulation is no more a perfect capacitor. Current and voltage will no longer be shifted 90 degree as depicted in Figure-1(b).

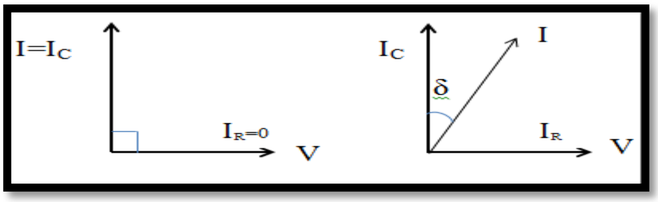

Figure-1. Equivalent circuits of (a) an ideal capacitor and (b) capacitor with dielectric loss.

$$Tan\delta = \left|\frac{1}{Tan\theta}\right|$$

Figure-2. Tan delta formula. [2]

Measurement of tan delta is calculated using formula in Figure-2 as follows:

a) The angle δ (in deg) is measured from the phase shift from the voltage and current waveform.
b) From the oscilloscope as shown in Figure-3, the angle δ can be measured
c) The tangent of the angle δ is calculated; hence tan δ.

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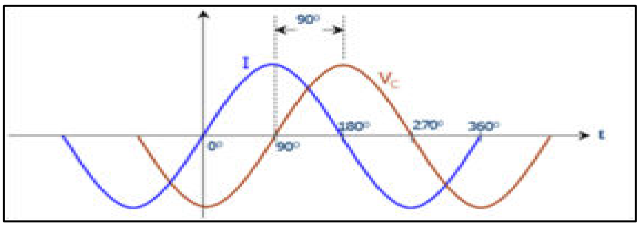

Figure-3. Current leading voltage resembling ideal capacitive insulation with $\theta = 90°$.

To test the sensitivity of the current system, a selected range of cables were manufactured to represent the severity of aging in the 132kV cable. The manufactured cable samples consisted of good cable, induced defect cables having void (low severity), contaminated with foreign material (medium severity) and purposely overheated and scorched (high severity). These cable samples were tested with the newly developed low voltage high frequency tangent delta measurement method.

METHODOLOGY

In this project, the research methodologies are as in Figure-4:

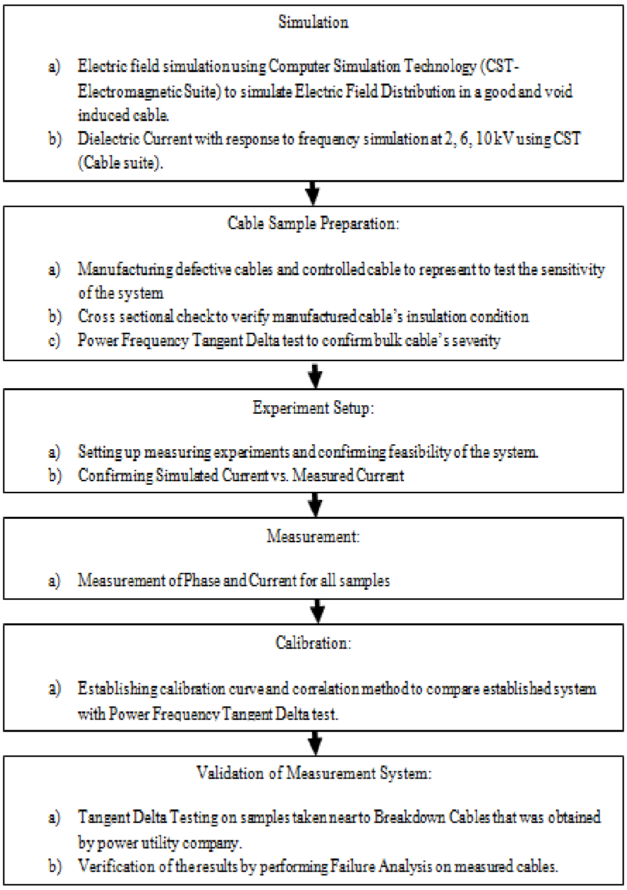

Figure-4. Research methodology.

SAMPLE PREPARATION

To test the sensitivity of the current system, a selected range of cables were manufactured to represent the severity of aging in the 132kV cable. There are four types of 132kV 400mm^2 Cu XLPE cable samples were prepared by cable manufacturer which consisted of good cable, induced defect cables having void (low severity), contaminated with foreign material (medium severity) and purposely overheated and scorched (high severity).

There are some examples of cross cut shown in below figures for XLPE cable. The cross cut confirmed the existence of defect in the insulation meanwhile the Power Frequency Tangent Delta conducted by the manufacturing company indicated that induced defect cables having void as low severity, contaminated cable as medium severity and scorched cable as high severity.

a) Good cable

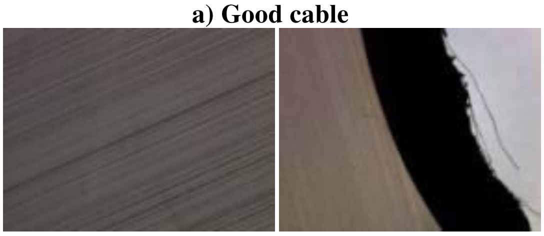

Figure-5. Cross section of good cable.

b) Scotched Cable

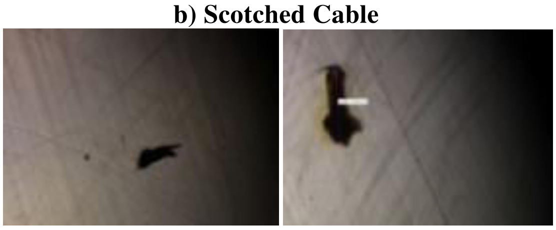

Figure-6. Cross section of scotched cable.

c) Void cable

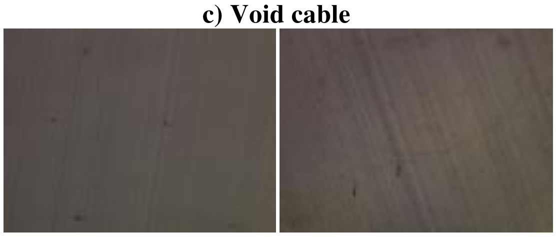

Figure-7. Cross section of void cable.

d) Contaminated cable

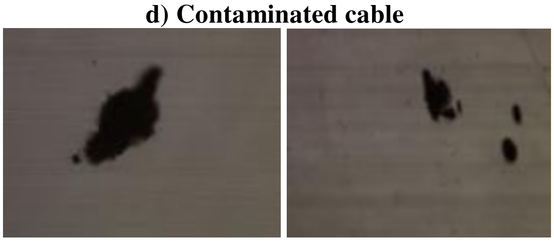

Figure-8. Cross section of contaminated cable.

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HF EXPERIMENT SETUP

The laboratory test was carried out using the newly developed tan delta measurement method. The setup is shown in Figure-9 below.

Figure-9. Laboratory setup for HF tan delta measurement system.

RESULT AND DISCUSSIONS

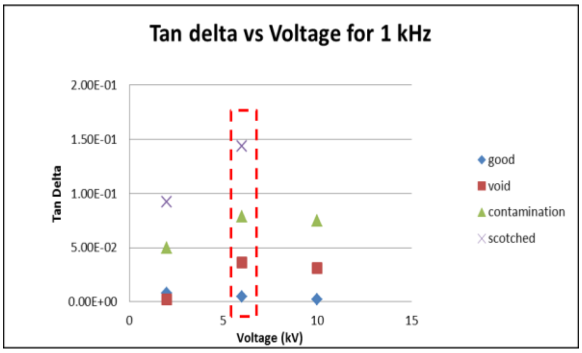

Figure-10. Tan delta vs. voltage at 1 kHz.

The tan delta measurement method is able to discriminate better at 6kV and 10 kV. The best resolution of tan delta between all the cables is clearly seen at 6kV at 1 kHz as shown in Figure-10 above.

A linear trend line equation is observed from the plot as follows [2]:

$$y = 0.3668x + 0.6190 \quad (1)$$

Calibration curve obtained is with 90.17% confidence level. All HF tan delta value obtained in the future will divide with base value and substituted as x value into equation. After obtaining the y value using linear equation above, it has to be multiplied with base of 50 Hz. The result will be HF tan delta value that is converted to 50 Hz.

A. Actual failure

The method was then put to the test by measuring samples taken 20 meters away from a breakdown cable provided by an electricity utility company. Pre-commission Test conducted before installation showed no abnormality. The pre-commission test is:

a) Core Insulation Resistance
b) Sheath Test
c) Link box earth resistance

Laboratory examination was then conducted on the break down sample. First analysis was a gross analysis on the construction and dimensional check.

No abnormalities were detected based on the requirements of the insulation and cable sheath dimensional check.

Figure-11. The overall view of the affected cable viewed from the top. The jacket and amour were damaged and punctured due to flashover.

Requirement for the insulation (IEC 60840)

The lowest measured thickness shall not fall below 90% of nominal thickness. Based on this standard the XLPE insulation shall not fall below 18mm; and based on the measurement taken both the samples passed the requirement.

Requirement for the cable oversheath (IEC 60840)

The lowest measured thickness shall not fall below 85% of the nominal thickness by more than 0.1mm. Based on this standard the cable oversheath shall not fall below 3.3mm. From the physical examination of the cable construction and dimension, all the samples meet the required standards and design specification of the cable.

The Silicone oil bath examination was then conducted on the insulation sample. Test pieces were taken with the outer screen removed. There were no signs of irregularities, voids, ambers or black contaminants found in the XLPE insulation for affected sample (A).

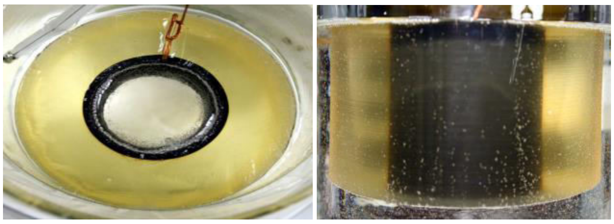

Figure-12. Upper and side view of silicone in oil bath.

The water tree examination managed to detect some abnormality. The objective is to identify any water tree formation and impurities in the XLPE insulation. Thin wafer slices of the XLPE insulation are dyed (blue dye) and subjected to microscopic examination as shown in Figure below.

Table-1. Preparation to identify water tree formation.

Prepared Volume	
Diameter over conductor screen	**4.785cm**
Diameter over insulation	9.015cm
No. of slices cut	30
Thickness of slices	0.04cm
Total volume investigated	$54.20cm^3$

1. Bow Tie Examples

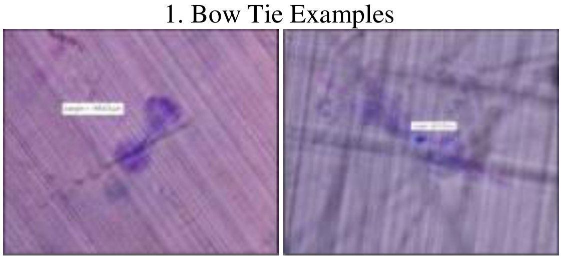

Figure-13. Examples of water tree with different length.

2. Vented Tree from Screen

Figure-14. Examples of vented tree.

1. Measurement of voids, contaminants (power utility company specification)
– Max void size: 0.05mm
– Max contaminant size: 0.125mm
2. Measured water tree size
– Max: 0.646mm

Remarks - Water tree's were observed from the affected cable sample (A).

Water trees are well known to cause reduction in the breakdown strength of the cable by increasing the electrical stress in the cable. Both bow tie and vented trees are common water trees detected when a breakdown occurs. Bow-tie trees are related to impurities and they grow in the opposite direction along the electric field lines [5].Vented tree are mostly related to the mechanical damage of the cable insulation and irregularity in the semiconducting screen that cause contact issues with the insulation. [6].

HFAC Tangent Delta

Samples taken 20 meters away from the breakdown cable were also monitored. This was to determine if it was due to continuous water tree causing electrical stress on the cable or an intermittent issue of water tree at the breakdown point. Therefore the HF Tangent Delta method was put to the test. In order to correlate tan delta between LF (50 Hz) and HF (1 kHz), the established normalization method is used.

The 1 kHz tan delta was normalized using the equation.[2]:

$$Norm = \frac{TanDelta}{7.88e^{-2}} \tag{2}$$

The 50 Hz tan delta was normalized using the equation.[2]:

$$Norm = \frac{TanDelta}{3.6e^{-3}} \tag{3}$$

Table-2 below displays the Leakage current,Tangent Delta and normalized values for both the cables at 6 and 10 kV each. Current observed is below 20mA which is safe operating region based on amplifier limit. Current is almost the same for both sets of cables.

Table-2. Tangent delta results and normalized value.

Frequency(kHz)	Voltage(kV)	Cable 1			
		Current(mA)	Phase (θ)	Tan delta	Normalized
1.000	6.000	8.867	93.04	0.053	0.673
1.000	10.000	14.830	93.12	0.054	0.685

Frequency(kHz)	Voltage(kV)	Cable 2			
		Current(mA)	Phase (θ)	Tan delta	Normalized
1.000	6.000	8.707	93.09	0.053	0.673
1.000	10.000	14.517	93.02	0.052	0.660

Figure-15 to Figure-18 displays the traces for both the cables at 6 and 10 kV each. Signals were averaged to 1000 samples to display a clearer and more reliable result. No distortion were observed from the traces thus proving a reliable tangent delta result.

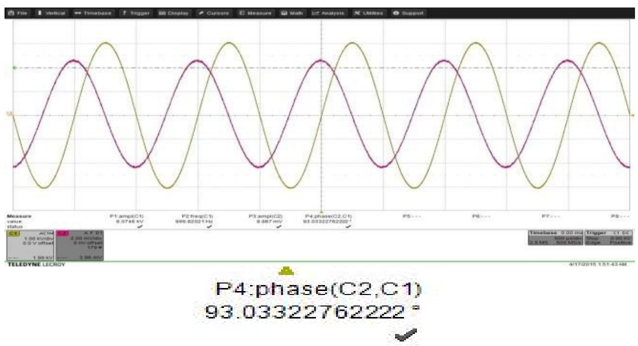

Figure-15. Signal traces for cable 1 at 6kV.

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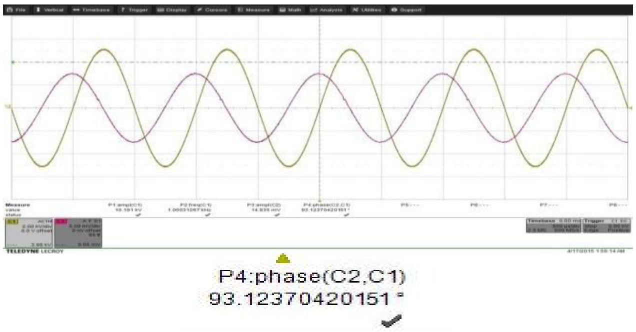

Figure-16. Signal traces for cable 1 at 10kV.

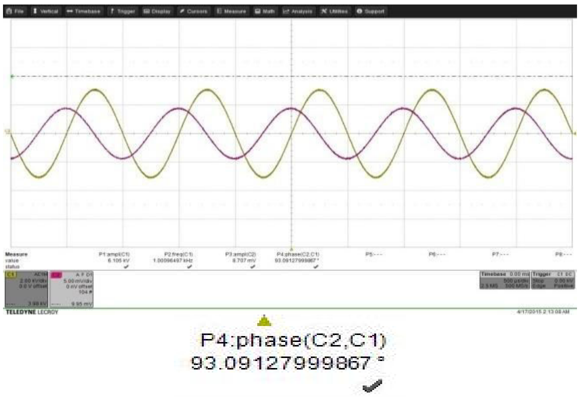

Figure-17. Signal traces for cable 2 at 6kV.

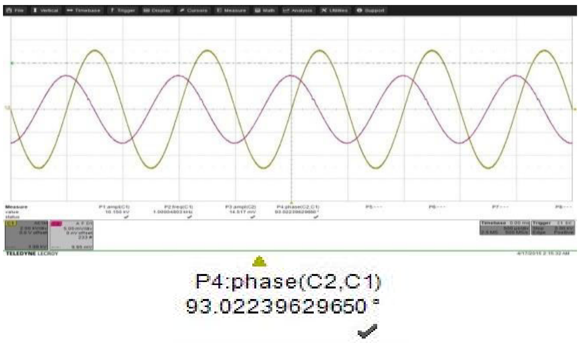

Figure-18. Signal traces for cable 2 at 10kV.

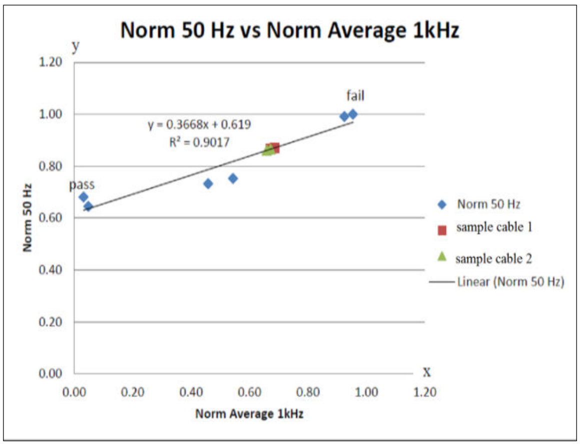

Figure-19. Calibration curve of normalized 1 kHz.

A linear trend line equation is used to plot the normalized values of cable 1 and 2 [2]:

$$y=0.3668x+0.6190 \quad (4)$$

Calibration curve obtained is with 90.17% confidence level. The HF tan delta value obtained is divided with base value and substituted as x value into equation to get y value using linear equation above. Tangent delta for both cables is very close based on the calibration curve in Figure-19above.

Table-3. Normalized values obtained using equation 10.

Cable#	normalized 1kHz	normalized 50 Hz
Cable #1	0.67	0.87
	0.69	0.87
Cable #2	0.67	0.87
	0.66	0.86

The sample 1 and 2 correlates to the calibration curve and is very close to the high severity range of the cables. This shows that cables 20 meters away are also affected and may breakdown if used continuously. This results had been fedback to the power utility company and the cables has been escavated and removed.

CONCLUSIONS

The sensitivity of the HF Tangent Delta Measurement system to discriminate defective cables and controlled cable that were manufactured is effective. This newly developed HF tan delta measurement system can be used as an indicative test to pre-determine the condition of one meter cable in the laboratory.

The test taken 20m away from defective cables were tested and also verified to be defective thus indicating the whole 20m as a defect. This shows that cables 20 meters away are also affected and may breakdown if used continuously.

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