High Frequency Alternating Current (AC) Tangent Delta Measurement Technique for Underground Power Cable System

[1]Ahmad Basri A. Ghani, [2]Chandan Kumar Chakrabarty, [3]Agileswari K. Ramasamy [4]A.R. Avinash, [5]Huzainie Shafie,[6] Navitharshaani Permal and [7]M.G. Danikas
[2,3,6] Universiti Tenaga Nasional, Selangor, Malaysia
[1,4,5] TNB Research Sdn. Bhd, Selangor, Malaysia
[7]Democritus University of Thrace, Xanthi, Greece

Abstract: **The aim of this paper is to show that Tan delta HFAC technique is applicable for longer cables. As underground cables are in service for years, it is necessary to carry out diagnostic test to rectify the possible problem that may occur in a cable so that precautionary action can be taken to avoid unnecessary in-service failure of the cable. One of the diagnostic testing techniques, known as Tangent Delta, is a method of testing cables to define the insulation condition of the underground cable. The phase shifts caused by the lossy current due to the existence of impurities in cable insulation is measured in this method. As most of distribution cables are long lengths, it becomes necessary to measure the tangent delta for these longer cables. In this paper, HFAC technique on longer length of good condition 11 KV power cables were used as samples to determine the tangent delta. Higher frequencies (>100Hz) were used to determine the tangent delta of cables at voltage of 1kV. The current (I) and phase (θ) were obtained in this experiment using HFAC measurement technique. CST Cable Suite software was used for simulating the experiment to verify the HFAC experimental setup by attaining sufficient dielectric current obtained through simulation and compare the leakage current values with the experimental values. The tangent delta results were attained for good cable with the length of 40 m, 70 m and 140 m and compared with 20 m length of good condition cable. The tangent delta results show that the HFAC technique is also applicable for the longer cable as well.**

I. Introduction

All MV and HV power cables are constantly subjected to thermal, electrical and mechanical stresses during their service life which lead to ageing of the insulation material. Ageing of the insulation means that the insulation degrades or gets older. When the insulation is degraded, it does not have the same physical properties anymore as compared with new cable. The risk of failure for degraded cables has been increased [2]. So, it is necessary carry out diagnostic test to resolve the possible problem that may occur in cable insulation so that precautionary action can be taken to avoid unnecessary in-service failure of the underground cable [3].

One of the solution to determine the condition of the cable insulation is the dielectric loss measurement. With the dielectric loss measurement which is also known as tangent delta measurement, the phase shift between the voltage and the current is measured. By using the measured phase shift, the tangent delta value is calculated. A flawless cable can be electrically shown by a single capacitor. Longer cable produces larger capacitance in the cable.

As the impurities start to associate in the flawless cable insulation, the capacitor will start to have some resistors in parallel within the insulation. As a result, the current is no longer 90° phase-shifted from the applied voltage. High tangent delta value indicates that the cable insulation is poor and good cables produce low tangent delta value. It is concluded that the bigger the Tan delta is, the worse the condition of the insulation is as referred to Ref. [4]. Hence, this paper presents a method using High Frequency Alternating Current (HFAC) tangent delta for good condition cable with longer length.

HFAC tangent delta measurement technique was developed to extract the tangent delta results of tested samples. The equivalent circuit of tangent delta measurement method is shown as Fig. 1 below. The equivalent circuit consists of the resistance of the cable insulation, R_C and capacitance of the cable, C_C, as the series resistance and the bold assumption made was ignoring R_S as it is very small in value. If impurities exist in the cable insulation, the resistance of the cable insulation decreases thus increasing the resistive current through the insulation.

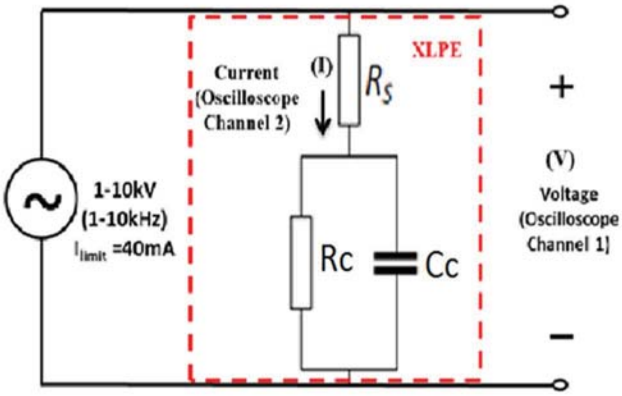
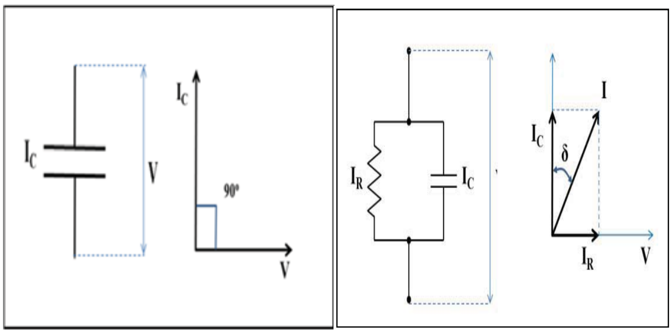


Figure 1. Equivalent circuit of tan delta measurement method of a cable

978-1-5386-5086-8/18/$31.00 ©2018 IEEE

Apart from that, tangent delta method is used, and the values are calculated based on ratio of resistive current flow to the capacitive current flow in cable insulation. Higher ratio shows high dielectric loss in the insulation. Ref. [1] states that a pure insulator works as a perfect capacitor in an ideal condition where there will be no resistive current flow through ideal insulating material which results in zero percent impurity. The capacitive current (I_C) leads the applied voltage (V) by 90° as illustrated in Fig. 2(a). However, there will be no pure insulator exist in real due to ageing of insulator and impurities like dirt and moisture enter the cable. The added impurities will result in decrease of resistance of insulation by increasing the resistive current (I_R) through the insulation making it no longer a perfect capacitor as illustrated in Fig. 2(b) as in Ref. [5,6,7]. A phase shift between the leading capacitive current (I_C) and the voltage is utilized to determine the tangent delta (tan δ).



(a) (b)

Figure 2. a) Characteristics of a Ideal Insulation (Perfect Capacitor) b) Characteristics of an Insulation with Impurities

When the loss angle increases, it is also indicating an increase in resistive current through the cable insulation that in the long run lead to high dielectric loss. The degree of change in loss angle (δ) represents the tan delta values of ageing level in cable insulation which is obtained from (1) below.

$$tan\theta = -\frac{1}{tan\delta} \quad (1)$$

θ = Phase between current and voltage
δ = Dissipation angle

II. Cable Preparation for HFAC Technique

Table 1 shows the requirement of sample cables that needed for HFAC testing. There were 3 different length of cables prepared.

TABLE 1 REQUIREMENT OF TEST SAMPLES FOR HFAC TESTING

Type of sample	No. of sample	No. of Joint	Length of cable per sample(meter)
Good condition cable	1	0	40
Good condition cable	1	0	70
Good condition cable	1	0	140

Table 1 above shows the details of cable preparation with three different lengths of test samples. In this experiment, three sets of cables without joint of 40m, 70m and 140m were prepared and tested using HFAC measurement technique.

III. Methodology

The methodology in this paper is discussed as follows. The first part was software simulation using CST Cable Suite, followed by HFAC tangent delta experimental measurement and lastly data analysis and comparison.

The 11 kV cable were modeled and dielectric current was obtained through CST Cable Suite simulation for good cable with length of 40 m, 70 m and 140 m using high frequency range. The cables were prepared with the length of 40 m, 70 m and 140 m long length for testing with appropriate equipment setup. The HFAC testing was performed for the good condition test samples of 40 m, 70 m and 140 m using high frequency range.

The leakage current obtained in CST simulation was compared with HFAC experimental values. Tangent delta values for 40 m, 70 m and 140 m cables obtained through HFAC technique were analyzed and compared with 20 m good condition.

IV. Dissipation Current Simulation

For the simulation part, the Computer Simulation Technology Studio Cable Suite (CST Cable Suite) was used to model the required 11 kV cables of different length. The 11 kV cable was modeled in 3D structure using CST Cable Suite software. The cable was designed using real cable specifications of length and diameters. The schematic diagram is constructed along with the modeled cable.

The inputs are inserted as in the real testing conditions. The results taken is the results of the leakage current against frequency which is from 100Hz to 1kHz. The simulation results are then compared with the data results from the High Frequency AC tangent delta measurements.

V. Simulation Results

The Table 2 shows the leakage current simulation data for good condition cable of 40m, 70m and 140m length. Table 2 also shows the leakage current obtained for higher frequency (100Hz-200Hz) for 40m, 70m and 140m good condition cables. The leakage current increase when the frequency increases and it is proportional with the increasing length of cable. The longer length cable produces more capacitance where leads to increase of current through the cable insulation. These results were then validated using experimental measurement results using HFAC technique.

TABLE 2 SIMULATED LEAKAGE CURRENT FOR GOOD CABLE OF 40 m, 70 m AND 140 m LENGTH

Freq (Hz)	Voltage(V)	Good Cable (40 m)	Good Cable (70 m)	Good Cable (140 m)
		Current(A)	Current(A)	Current(A)
100	997.8	1.019E-02	1.783E-02	3.567E-02
130	1000.0	1.325E-02	2.318E-02	4.637E-02
150	1002.0	1.529E-02	2.675E-02	5.350E-02
170	1004.0	1.732E-02	3.032E-02	6.063E-02
200	1000.0	2.038E-02	3.597E-02	7.133E-02

VI. HFAC MEASUREMENT SETUP

The experiment is conducted in laboratory which is secured with grounded screen cage as shown in Fig. 3 below. Few steps are taken to measure the tangent delta value. Firstly, sinusoidal AC waveform from the waveform generator was fed into the HV amplifier with 1kV output voltage. The total current flow through the test sample insulation is measured using a current monitor that was attached to the HV amplifier output cable. HV probe is used to measure the voltage across the cable insulation to get the required tangent delta value.

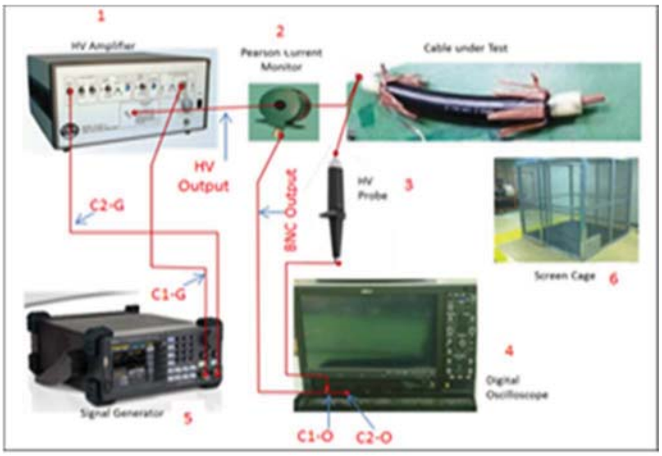


Figure 3. Experiment setup in cable laboratory

VII. RESULTS AND DISCUSSION

Leakage current for CST simulation results was compared with HFAC measurement technique results. Fig. 4 below shows the comparison of leakage current obtained from 3 different lengths of 40m, 70m and 140m.

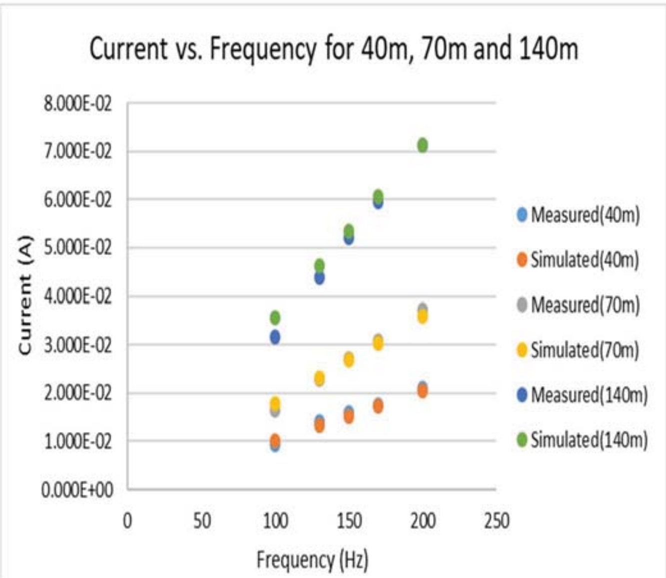


Figure 4. Graph of Current vs. Frequency for 40m, 70m and 140m good cable

Based on Fig. 4, the leakage current of simulation results and experimental results were compared. The data were obtained for cable length of 40 m, 70 m and 140 m with the frequency of 100Hz to 200Hz. The results above show the simulated leakage current which was almost same with the measured leakage current using HFAC technique. The leakage current attained from simulation results has shown the validation of HFAC experimental setup to obtain the tangent delta values.

In Fig. 5 below, the measured leakage current from HFAC technique for 3 different lengths of test samples were compared with 20 m good condition cable.

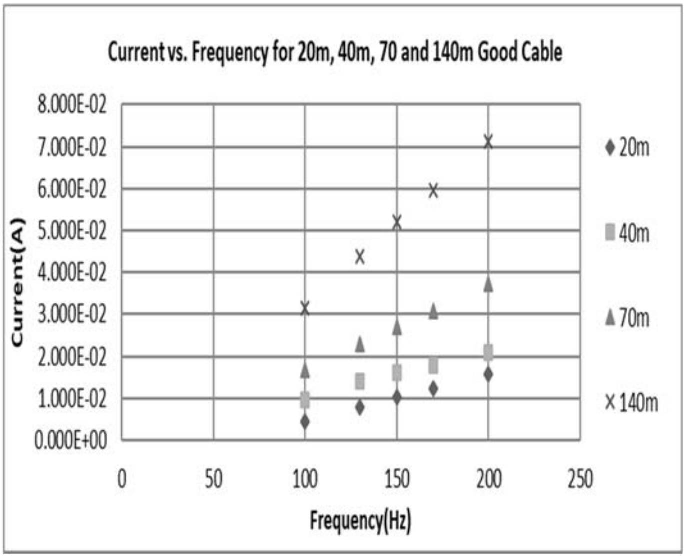


Figure 5. Current vs. Frequency for 40m, 70m and 140m of good cables

By using Equation (1), the tangent delta values of good condition cables are computed. Fig. 6 shows for 40m, 70m and 140m good condition test samples. These results were compared with 20 m good condition cable as a reference cable.

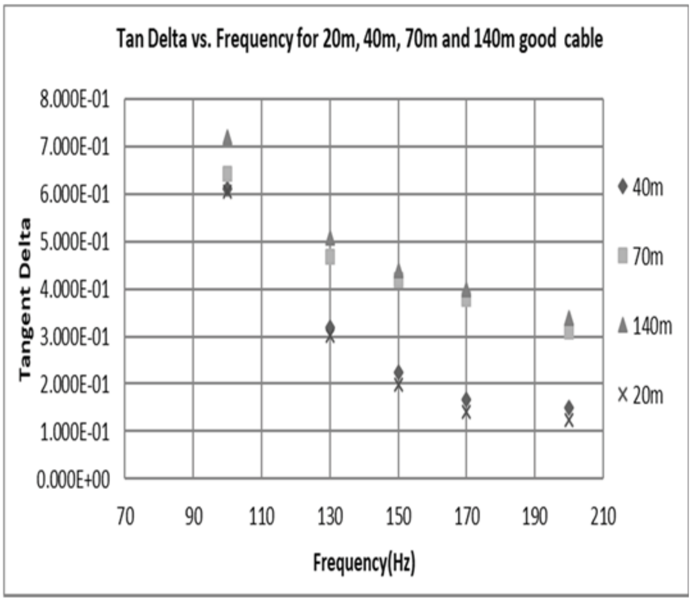


Figure 6. Tangent Delta vs. Frequency for 40m, 70m and

140m of good condition cables with 20m good cable as reference

The HFAC tangent delta experiment was performed at 100Hz to 200Hz. In Fig. 6, the graph shows the results of tangent delta of good condition cable with 3 different lengths of 40 m, 70 m and 140 m that are compared with 20 m length of good condition cable. The tangent delta results of 20 m and 40 m cables are lower and different from 70 m and 140 m cables. This may be due to the longer cables were prepared from a different cable drum.

VIII. CONCLUSIONS

The 11 kV good condition cable with 3 different lengths were prepared and tested using HFAC measurement technique. Simulation using CST Cable Suite was used to validate the HFAC measurement setup by comparing leakage current with experimental values that obtained through the experiment. It showed the simulated leakage current using CST Cable Suite was almost same with the measured leakage current using HFAC technique. Good condition cables with 40 m, 70 m and 140 m were prepared and tested using HFAC technique. These values were compared with the 20 m good cable as reference and the experiment was performed at 100 Hz to 200 Hz. The capacitance value in each cable was proportional to the length of cable tested. The preparation of the cable from different cable drum whose origin were not known at time of experiment may have resulted in differing tangent delta values.

REFERENCES

[1] Avinash A.R, Chandan Kumar Chakrabarty and Navinesshani Permal, 2015, High frequency tan delta measurement method for 132kv transmission underground cables, Research Journal of Applied Sciences, Engineering and Technology 10(8): 903-913, 2015

[2] A. Tzimas, S.M. Rowland, L. A. Dissado, M Fu and U. H. Nilsson, 2009, Effect of Long-Time Electrical and Thermal Stresses upon the Endurance Capability of Cable Insulation Material, IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 16, No. 5, pp. 1436-1443

[3] Craig Goodwin, 2004, Diagnostic Field Testing of MV cables, HV Diagnostics Inc

[4] R. Sarathi, Arya Nandini, Michael G. Danikas, 2011, Understanding electrical treeing phenomena in XLPE cable insulation adopting UHF technique, Journal of Electrical Engineering, Vol 62, 2 (2011) 73-79

[5] Fothergill, J.C., S.J. Dodd, L.A. Dissado, T. Liu and U.H. Nilsson, 2011, The measurement of very low conductivity and dielectric loss in XLPE cables: A possible method to detect degradation due to thermal aging. IEEE T. Dielect. El. In., 18(5): 1544-1553.

[6] Hernandez-Mejia, J., J. Perkel, R. Harley, N. Hampton and R. Hartlein, 2009, Correlation between tan δ diagnostic measurements and breakdown performance at VLF for MV XLPE cables. IEEE T. Dielect. El. In., 16(1): 162-170

[7] Ponniran, A. and M.S. Kamarudin, 2008, Study on the performance of underground XLPE cables in service based on tan delta and capacitance measurements. Proceeding of IEEE 2nd International Power and Energy Conference (PECon, 2008), pp: 39-43.