View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by UTHM Institutional Repository

EEE_16

STUDY ON THE PERFORMANCE OF UNDERGROUND XLPE CABLES IN SERVICE BASED ON TAN DELTA AND CAPACITANCE PARAMETERS

Asmarashid Ponniran, Tarmidi Tamsir
Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Johor, Malaysia.
Email: asmar@kuittho.edu.my

ABSTRACT

The performance of underground XLPE cables in service is critical because of ageing mechanisms influences. Many appropriate techniques can be used to evaluate the performance of aged and unaged underground XLPE cables. One of the techniques is based on tan delta and capacitance parameters of the cable insulations. This study focuses on underground XLPE cables which rated at 11 kV and 22 kV for both 1-core and 3-core types. Tan delta and capacitance data of underground XLPE cables are obtained using a Schering bridge instrument. Tan delta and capacitance measurements are performed at ambient temperature (about 26.6^{o}C) and at 50 Hz power frequency. The analysis of data shows that tan delta values increased in proportion to the aging time of the cables. Meanwhile the data analysis of the capacitance values of the cable insulator shows that the values of capacitance inconsistent. From this study, tan delta parameter is more accurate and appropriate parameter for evaluating performance of underground XLPE cables as compared to capacitance parameter. Therefore, the finding of this study shows that aging mechanisms contributes the deteriorations of underground XLPE cable insulations in service and consequently the value of tan delta increases with aging time of the cables.

Keywords: *tan delta, capacitance, underground XLPE cables, Schering Bridge.*

INTRODUCTION

Underground XLPE insulator cables are widely used for underground cables system especially in urban or compact area that provides many facilities to its community. Although underground XLPE cables possess excellent dielectric strength, low dielectric permittivity, low loss factor, good dimensional stability, solvent resistance and good thermo-mechanical behaviour [1], unfortunately, there are some weaknesses faced by XLPE cables, which bring down their performance during service. Moisture and water absorptions from environment into cable insulation are some important factors that deteriorates the cable performance in service and for worse cases, it would cause the cable system to breakdown [2,7]. From these absorptions activity, water treeing phenomena is introduced inside the cable insulation and causing the value of tan delta of the cable insulator to increase [3,6].

Tan delta and capacitance parameters of cable insulators can be used to describe the losses in the dielectric between insulator and core (conductor of cable) of the cables [4]. Ionic mobility in solid insulation such as PE and XLPE is greatly reduced and consequently, the tan delta values of insulation are very small [4]. Indeed, values of tan delta < 10^{-4} suggest that the minuscule detectable losses may be caused by an electronic mechanism, since the conductivity is considerably less influenced by temperature than in the case of oil-impregnated insulation.

Therefore, tan delta and capacitance are the parameters that capable to determine the performance of underground XLPE cable insulator in service. In this study, tan delta and capacitance parameters of XLPE cables are being considered on several samples of cables, which are taken from services. Then, certain conclusions and findings regarding the performance of underground XLPE cables, which is after sometimes in service, based on tan delta and capacitance parameters are obtained and evaluated.

ISBN 978-983-41705-6-1 ©2007 FEIIC

MEASUREMENT METHOD

The measurements are carried out to determine the tan delta and capacitance values of both, aged and unaged XLPE cable insulators. The entire measurements are performed at 50 Hz power frequency using Tettex Instruments – Schering Bridge Model 2816 with automatic guard potential regulator.

The tan delta and capacitance data, as a function of U test voltage, are measured by keeping some of the cable samples for a week in the test room with ambient temperature about 27^{o}C before the measurements are carried out and some other sample of cables are located at the open place. This is because to expose some sample of cables in moisture condition and some other samples of cables in dry condition. To avoid termination and flashover problems, the maximum measuring voltage in this case is limited to 10 kV for the whole samples of cable insulators. All samples of cables are taken from service.

Before the measurements are performed, the room temperature was recorded at 26.6°C (ambient temperature) while pressure was at 1000.0 mbar. The tan delta and capacitance as a function of U test voltage data are measured and categorized by the operating voltage of the cable and their number of core.

The measurements are performed by injecting U test voltage to the underground XLPE cable samples starting with 2 kV and then doubled to 4 kV till it reached 10 kV. Therefore, five readings are obtained in one set of a measurement. To assure the accuracy of tan delta and capacitance readings, every sample of cables are injected 20 times with U test voltage between core conductor and screen conductor (Figures 2.1 and 2.2.). Every set of measurement is injected by 20 times of U test voltage and final reading from every measurement is taken from the average calculation of 20 times readings. Table 1 shows the related values for the several samples of cable.

Twelve samples of cable with various lengths are obtained from TNBD Johor Bahru and TNBD Kulai. Among these samples of cables, three cables are single core and nine cables are three cores. One sample of cable is unaged cable (cable 12) and the rest are aged cables. About the operating voltage of the cables, only one sample of cable is 22 kV and the remaining eleven cables are having 11 kV operating voltage, Table 1. The corresponding measurements setup is shown in Figures 1 and 2.

Table 1. Related data of underground XLPE cable samples

Cable Sample	Operating Voltage (kV)	No. of Core	Size (mm)^2	Length (m)	Service (years)
Cable 1	11	1	150	1.3	6 – 8
Cable 2	22	1	500	2.0	6 – 8
Cable 3	11	3	150	2.0	6 – 8
Cable 4	11	3	240	2.5	6 – 8
Cable 5	11	1	500	2.4	3 – 5
Cable 6	11	3	240	1.6	3 – 5
Cable 7	11	3	150	4.2	3 – 5
Cable 8	11	3	240	2.2	3 – 5
Cable 9	11	3	240	1.5	3 – 5
Cable 10	11	3	150	1.4	3 – 5
Cable 11	11	3	240	1.4	3 – 5
Cable 12	11	3	150	2.4	unaged

ISBN 978-983-41705-6-1 ©2007 FEIIC

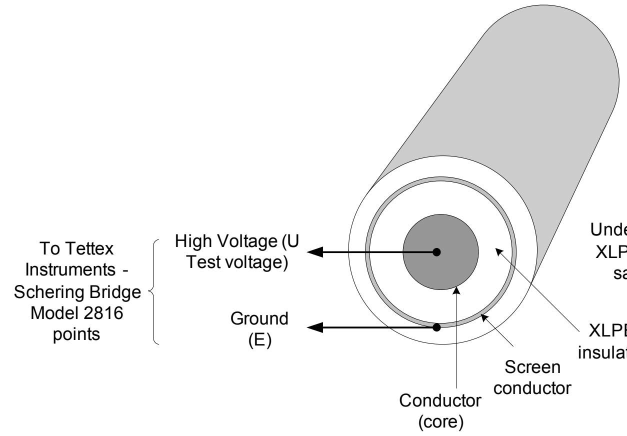

Figure1: Measurement setup for single-core of XLPE underground cables

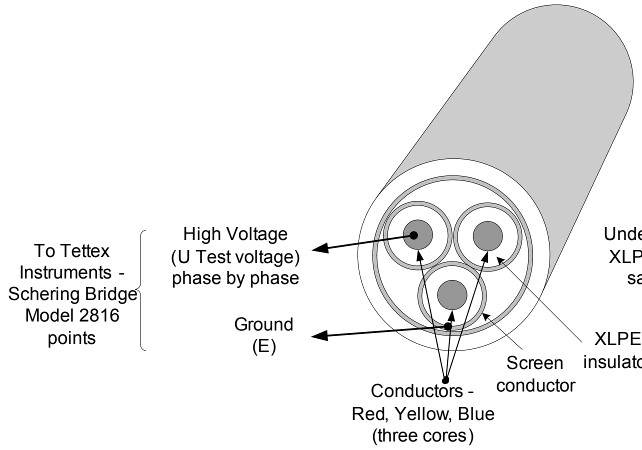

Figure 2: Measurement setup for three-core of XLPE underground cables

RESULTS AND DISCUSSIONS FOR TAN DELTA PARAMETER

CONSTRAINTS CONSIDERATION

According to IEC Standard Publication 502, 1978, the maximum value of tan delta (dissipation factor) at ambient temperature is 0.004 at U_o, where U_o is the rated power-frequency voltage between conductor and earth or metallic screen for which the cable is designed [5]. In this measurement, maximum value of U test voltage is only considered at 10 kV although the operating voltages for XLPE cable samples are 11 kV and 22 kV.

For analysis purpose, only 3.5 kV is being taken into account for the maximum of U test voltage versus tan delta and capacitance parameters. This step is incorporated as to avoid corona effects phenomena at the end of the cable samples during measurement process. Tan delta value of standard capacitance at Schering Bridge is assumed as zero.

SINGLE-CORE CABLES

From the observation, tan delta values of a cable insulator will increase with its aging time during its service. Figure 3 shows a comparison of tan delta versus U test voltage for three single-core cables after sometime in service and compared to unaged cable. Unaged cable indicates very low tan delta value as compared to other cables after sometimes in service. Cables 1 and 5 gives high values of tan delta and this condition occurs due to moisture absorption; the cables sample are located on the open place before measurement process performed. This data shows that the increasing of tan delta value is not only depending on water or moisture absorption from surrounding environment into cable insulations. Besides, there are other factors like temperature of the cable, electrical stress and mechanical stress that contribute for this situation but in small weighted [8].

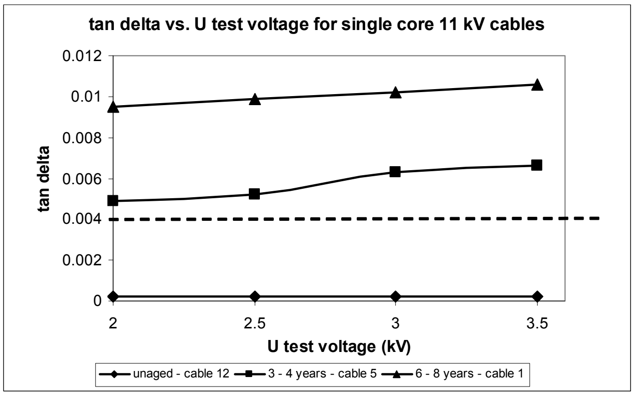

Figure 3: Comparison of tan delta versus U test voltage after sometime in service and unaged of cables

THREE-CORE CABLES

For three core sample of cables, after being in service for sometimes, each core (red, yellow and blue) given different value of tan delta. According to Figure 4, the red and blue cores correspondingly, shows high tan delta value as compared to the yellow core. Although this cable is located at the open place before the measurement performed, the increment of tan delta values is not consistently similar for every single core. The measurement results then, shows that it is impossible for the value of tan delta to increase simultaneously and same value for every single core after being in service for sometimes. Thus, from this condition, it can be concluded that the strength of cable insulator for every single core that deteriorated is different.

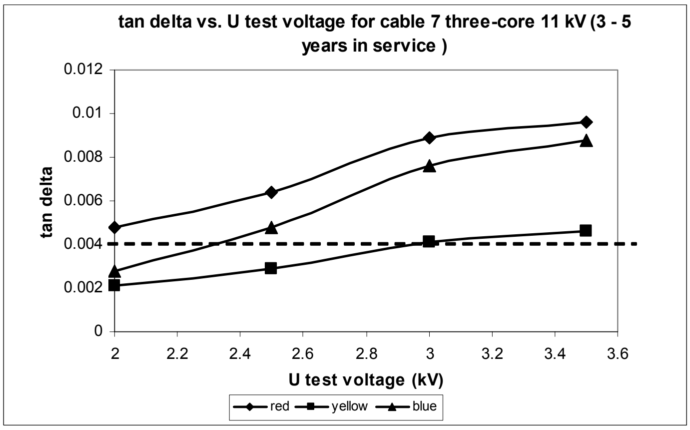

Figure 4: Inconsistent the increasing of tan delta value for every single (red, yellow and blue) three-core cable after 3 - 5 years in service

When the tan delta value of a cable insulator is high, the potential for this cable to breakdown during service is also high. This situation occurs when the insulator of the cables loss their strengths then causing the ionic mobility to increase and influence the conductivity level within cable insulator. As a result, the value of tan delta would rise and promote the breakdown to occur. Hence, the conductor of the cable will be shorted to the earth or metallic screen of the cable and in worse condition, the cable will be breakdown. These phenomena initiate paths for current, where current from the conductor of cable will be shorted to the earth or metallic screen of the cable. Figure 5 represent a condition with very high values of tan delta as compared to 0.004, IEC Standard [5] due to excessive content of moistures inside the insulator of the cable.

Figure 6 illustrates very low values of tan delta, for every single core, as compared to 0.004, IEC Standard [5]. Although the cable is taken after 3 – 5 years in service, the value of tan delta is still very small. This data

ISBN 978-983-41705-6-1 ©2007 FEIIC

indicates that if the content of moisture inside the insulator is very low, the value of tan delta will be remained under 0.004, IEC Standard [5].

Figure 7 depicted the comparison of the tan delta values between two three-core cables with the same duration in service, 3 – 5 years. The graph (Figure 7) indicates that moisture absorption inside the insulator of cable influences the performance of underground XLPE cable in service. In worse condition, the cable will breakdown and underground cable system will be affected.

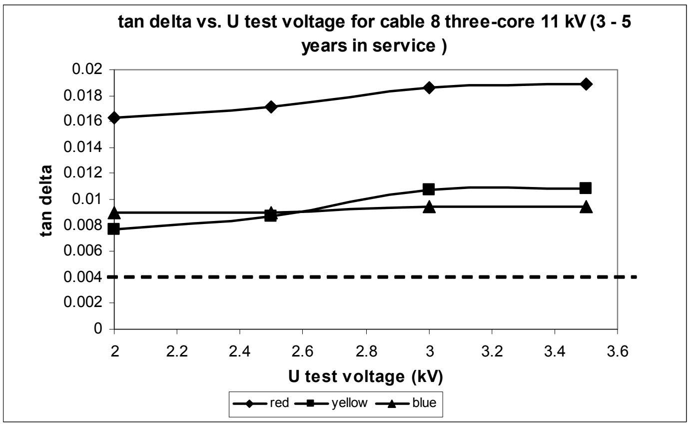

Figure 5: The high value of tan delta for three-core cable after 3 – 5 years in service

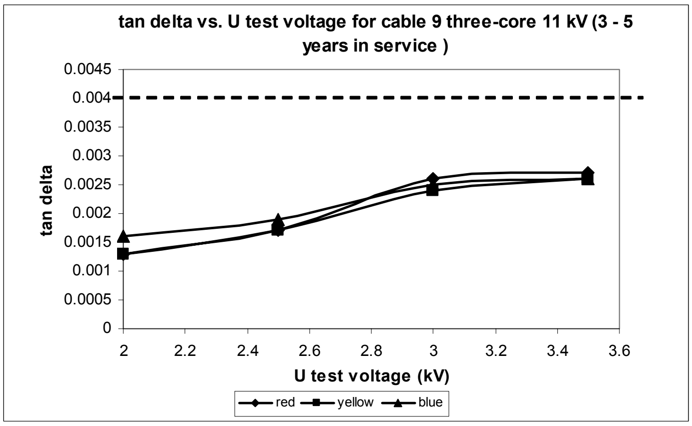

Figure 6: The low value of tan delta for three-core cable after 3 – 5 years in service

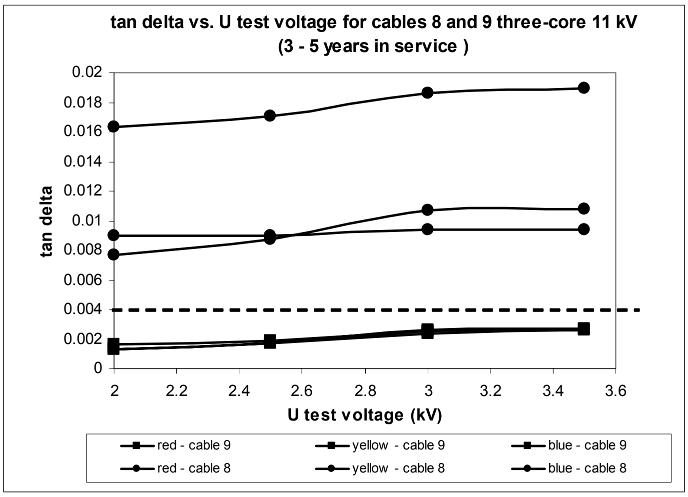

Figure 7: The comparison of low and high values of tan delta for two three-core cables after 3 – 5 years in service

ISBN 978-983-41705-6-1 ©2007 FEIIC

RESULTS AND DISCUSSION FOR CAPACITANCE PARAMETER

If the pure capacitance without losses is considered, the phasor diagram of an ideal capacitor and a capacitor with a lossy dielectric are shown in Figure 8. Figure 8 shows there are no losses appear if a pure capacitor characteristic is obtained. Because of lossy dielectric characteristic, the power losses will be introduced and heat from conductor is one of the aging mechanisms [4,6]. An introduced of heat (thermal) in conductor, aging of insulator will be accelerated and can cause strength of capacitance deteriorated. Nevertheless, in real situation, the lossy component in capacitor (insulation) will be appeared and should be considered because that component causing capacitor lack of their strength.

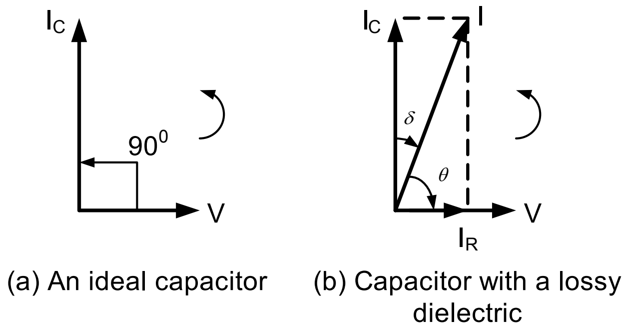

Figure 8: Capacitor phasor diagrams

THREE-CORE CABLES

Data from measurement shows that the capacitance values increased when U test voltage is step up meanwhile some other sample cables shows that capacitance values decreased when U test voltage is step up. Although, the differences are not obvious, this situation shows that the dielectric is contaminated by foreign materials. In the same reasons, voids, contaminants and protrusions in XLPE insulator cables are defects that greatly affect the insulating properties of those cables [8]. Figure 9 shows the capacitance values in some of XLPE cable samples versus U test voltage. From Figure 9, cables 8 and 9 are taken after three to five years in service; meanwhile cable 12 is unaged cable. The value of capacitance for cables 8, 9 and 12 versus U test voltage showing that the behaviour of capacitance values of aged and unaged cables in uneven condition.

Form these capacitance analyses and discussions, an ideal case; the value of capacitance of cable should be constant. However, in these measurements the values of capacitance are not constant when U test voltages are varying from low to high. This situation can be justified, because of voids, contaminants and protrusions in XLPE cables are defects that affect the insulating properties of those cables [8].

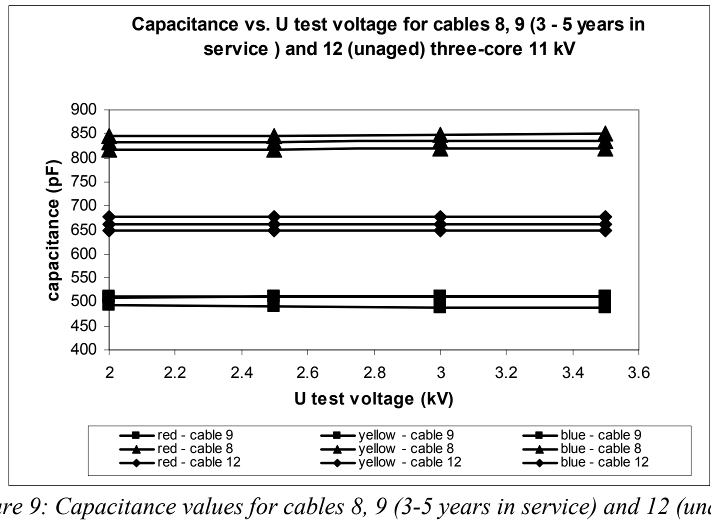

Figure 9: Capacitance values for cables 8, 9 (3-5 years in service) and 12 (unaged)

ISBN 978-983-41705-6-1 ©2007 FEIIC

CONCLUSION

After a cable operates for sometimes in service, the value of tan delta will increased. This is showed, although at initial value of stress voltage (U test voltage, 2 kV) is injected to the cable samples, the value of tan delta is high as compared to IEC standard value. This condition occurs because of the presence of moisture inside the cable insulator. Also, the value of tan delta is increased when the U test voltage is increased. It is because, in most insulating systems, the value of tan delta will intensify with the increment in applied voltage or stress voltage. However, for unaged cable (cable 12), the increment of tan delta value against U test voltage is extremely small (0.0002) at 3.5 kV of U test voltage with referring to IEC standards Publication 502 (maximum value of tan delta = 0.004 at U_o at ambient temperature) [5]. The results from these measurements shows, only three samples of cables indicate the values of tan delta below 0.004 at 3.5 kV of U test voltage. Meanwhile, for the remaining sample of cables, the values of tan delta are greater than standard value of tan delta, 0.004 at ambient temperature.

In addition, the cable systems performance is also highly affected by aging mechanisms [8] during its service. In this case, according to TNBD, most of underground cables system breakdown located at a surrounding with very high moisture. Therefore, the main factor that contributes to the breakdown of cables system in service is by entering moisture inside the cables insulator. In worse cases, water-treeing phenomena will be initiated in cable system and lead to breakdown phenomena during in service.

From above findings, tan delta parameter of XLPE cables insulation is most effective than capacitance parameter in order to evaluate and investigate performance of underground XLPE cables in service. It is because, if the value of tan delta is greater than 0.004 from IEC Standard Publication 502, that means the quality of dielectric strength is become deteriorated. However, with capacitance parameter, it is difficult to evaluate and investigate the performance of XLPE cables in service because the values of capacitance versus U test voltage are inconsistent.

ACKNOWLEDGMENTS

The author would like to thank Tenaga Nasional Berhad Distribution, Johor Bahru, Malaysia and IVAT, Universiti Teknologi Malaysia, Malaysia for their technical assistances and for performing experiments.

REFERENCES

[1] R. Sarathi, Supriyo Das, C. Venkataseshaiah and N. Yoshimura (2003). "Investigation of growth of electrical trees in XLPE cable insulation under different voltage profile." *Annual Report Conference on electrical Insulation and Dielectric Phenomena*. IEEE. 666-669.

[2] S. V. Nikolajevic. "Investigation of water effects on degradation of crosslinked polyethylene (XLPE) insulation." *IEEE Transactions on Power Delivery*. Volume 8, Issue 4. IEEE. 1993. (1682 – 1688).

[3] Nikolajevic, S.V.; Kostoski, D.D. "Accelerated aging of cross-linked polyethylene (XLPE and TR XLPE) cable insulations in wet conditions." *Electrical Insulation and Dielectric Phenomena Annual Report*. Conference on 25-28 Oct. 1998. (694 - 697 vol. 2).

[4] R. Bartnikas and K.D. Srivastava. Power and Communication Cables: Theory and Apllications. New York: Institute of Electrical and Electronics Engineers, Inc. B., 2000.

[5] IEC Standard, Publication 502 – 2nd ed. Extruded Solid Dielectric Power cables for Rated Voltage from 1 kV to 30 kV, 2nd ed., 1978.

[6] Nikolajevic, S.V. "The influence of the water on water absorption and density of XLPE cable insulation." *Power Delivery, IEEE Transactions* on
Volume 13, Issue 2, April 1998. (297 – 303).

[7] Nikolajevic, S.V. "Investigation of water effects on degradation of crosslinked polyethylene (XLPE) insulation." *Power Delivery, IEEE Transactions* on Volume 8, Issue 4, Oct. 1993. (1682 – 1688).

[8] John Densley. "Aging and Diagnostics in Extruded Insulations for Power Cables." *IEEE 5th International Conference on Conduction and Breakdown in Solid Dielectrics*. 1995. (1-15).

ISBN 978-983-41705-6-1 ©2007 FEIIC