Electrical Diagnostic Techniques to Asses Water Trees in Extruded Underground Power Cables

Z. Al-Hamouz [a,*] , K. Soufi[b] , M. Ahmed[c] , M.A. Al-Ohali[d] , and M. Garwan[c]

[a] Electrical Engineering Department

[b] Center for Engineering Research, HV Laboratory, Research Institute

[c] Center for Applied Physical Sciences, Research Institute

[d] Physics Department

King Fahd University of Petroleum & Minerals

[*] email: zhamouz@kfupm.edu.sa

Abstract: In this paper, different electrical diagnostic techniques reported in the literature to predict the life of extruded underground power cables are reviewed. Destructive and non-destructive AC and DC measurements for detecting water trees are discussed. One of these techniques, namely the DC current method is applied to some underground cables rated between 15 kV and 69 kV collected from the Eastern Province of the Kingdom of Saudi Arabia. For this purpose, a setup has been constructed at the High Voltage Laboratory of King Fahd University of Petroleum & Minerals. The results obtained show a correlation between the DC current and the presence of water trees in the insulation material of cables. The results obtained are verified using the microscopic testing of the insulating material.

1. Introduction

Diagnostic testing for the condition assessment of power cables is increasingly becoming important. A fundamental interest of power utilities is to increase the total reliability at a minimum cost by improved maintenance routines [1]. Diagnostic testing of installed crosslinked polyethylene (XLPE) power cables is of high interest because of the large number of old cables in service with high probability of failure caused by water tree degradation [2]. Water trees have been known to be a factor that deteriorates an insulation of XLPE cables. Many studies have been made on water tree deterioration in XLPE distribution cables rated from 6.6 to 33 kV [3]. Compared to distribution cables, there have been a smaller number of research on water tree deterioration in HV transmission cables rated > 66 kV [4-10].

Different electrical testing have been conducted for the detection of water trees in XLPE cables [11-26]. In reference [11], a correlation between the space charge distribution in water treed samples under AC voltage is made. It has been found that homo charge was formed around the tip of water trees. Electrical characteristics of 93 aged 33 kV, XLPE cables removed from the field after 2 to 19 years of service has been studied and the same findings were reported [12]. It has been reported that the AC breakdown strength decreased as the water tree grew, and the space charge with same polarity of electrode was distributed across the water treed region, especially concentrating near the tree tip. The AC, DC, and impulse breakdown strengths, tan d , residual voltage and DC leakage current were measured [13]. A correlation coefficient between the measured values is calculated. It has been found that AC, DC and impulse breakdown strengths decreases with service years. Tan d increases with service years. The residual voltage do not show clear correlation with service years. It has also been found that tan d increases with maximum length of bow tie tree. A correlation between electrical signals, tree sizes and breakdown voltages is reported in [14]. The DC conductivity (related to the polarization and depolarization currents) and loss tangent tests were performed. It has been reported that water trees increase the DC current and lead to specific polarization and depolarization currents [15,16]. Again, it has been observed that tan d increases with the concentration with water trees. In [17], it has been reported that the presence of humidity in the exterior of the cables constitutes the necessary input for the development of water trees and that it leads, in a parallel way, to a reduction of the deformations in the insulation that appear by its thermal expansion. The average partial discharge values of a 15 kV cable tested under impulse voltages were 0.5 pC initially and <15 pC, and < 50 pC after one and two 35 kV impulse voltage applications. The effect of water trees on the distortion of the loss-current is investigated in [18]. It has been found that the distortion of the loss current increases with the presence and concentration of water trees. The permittivity and conductivity of water tree has also been studied [19,20]. In [19], it has been found that the average permittivity of water trees in XLPE changes from 2.3 (for non treed cable) to 3.7 (for a water tree of 325 mm after 170 hours of aging). The increase in permittivity induces an enhancement of the electric field outside the water tre e zone which could be a cause of breakdown. It has also been found that even as the water tree length saturates, the permittivity continuos to increase, thus increasing the risk of breakdown. In [20], it has been found that the conductivity of the treed re gion is very high and becomes 10^6 times higher than the original untreed region if the water content in the treed region is high. Correlation between AC breakdown strength and low frequency dielectric loss of water tree aged XLPE cables is reported in [21]. It has been found that water treeing causes reduced residual AC breakdown strength, and high and non-linearly increasing low-frequency dielectric loss. AC breakdown tests were conducted in [22] to get correlation between the ac breakdown strength and the existence of water trees. No such correlation was proved. In [23], the return voltage method proves to be an efficient method for water tree detection. The differential variation of loss tangent and capacitance independence on the temperature [24] can be used as a measure of water tree degradation of polymer insulated medium voltage cables. A residual charge method, in which a DC voltage is applied, followed by short-circuiting and the application of AC ramp voltage has been proposed [25]. It has been found that the DC component current has a fairly good correlation with the degree of degradation such as breakdown strength and dielectric loss tangent, as well as water tree length. A group of testing (such as AC electric breakdown, depolarization current, visual inspection, and return voltage) were applied for 12 kV and 24 kV XLPE cable samples [26]. The results reported correlates between the presence of water tree and the breakdown voltage and return voltage. The correlation was not evident for the measurements of depolarization current.

In this paper, different electrical diagnostic techniques reported in the literature to predict the life of extruded underground power cables are reviewed. One of these diagnostic techniques, namely the DC current method is applied to some underground cables rated between 15 kV and 69 kV collected from the Eastern Province of the Kingdom of Saudi Arabia. For this purpose, a setup has been constructed at the High Voltage Laboratory of King Fahd University of Petroleum & Minerals.

2. Cable Samples Collected

One fresh 13.8 kV, two 34.5 kV (one used and one fresh) and one 69 kV used cable insulated by XLPE were collected from two different areas of the Eastern Province of Saudi Arabia. Collected cables were in operation for a period that ranges from 17 to 25 years. Table 1 shows a summary of the samples collected for measurement.

Table 1: Cable Samples Collected

Cable No.	Voltage (kV)	Operation (Yrs)	Length (m)	Cond. Material
1	34.5	17	1.41	Cu
2**	34.5	Fresh	2.0	Cu
3	69	18	1.2	Al
4**	13.8	Fresh	1.75	Cu

** Fresh samples

3. Experimental Setup and Sample Preparation

3.1 Experimental Setup

The experimental setup for the measurement of the DC current is shown in Fig. 1. The setup consists of the cable sample, HV DC source, insulating holder, and a measuring circuit. The HV source is manufactured by MWB with a rating of 140 kV DC and 5 KVA. The insulating holder is used to mount the cable above the ground level. The measuring circuit is constructed from a 5.08 kΩ resistor, a 60 V varistor for protection and a digital voltmeter across the resistor. It is very important to notice that the whole setup has one ground; i.e., the HV source ground and the measuring circuit ground are the same.

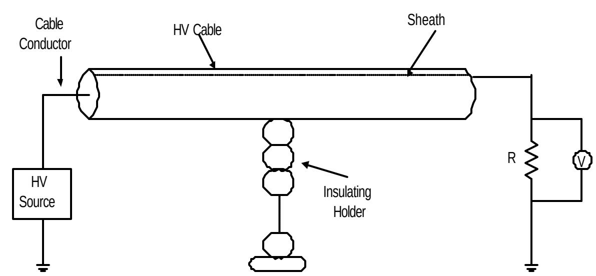

Fig. 1: Experimental Setup

As can be seen, the sheath is grounded through the measuring resistor. The DC current will be the measured voltage divided by the resistor R.

3.2 Sample Preparation

Step 1:

The first step in the sample preparation was to pre-condition the test samples by putting the cables in containers of tap water at room temperature for at least one weak (some work reported in the literature proposed 5 months [22]) prior to testing. Pre-conditioning is very important since water trees, which may be formed during cable service, may disappear if the cable becomes dry. If this is the case then the cable insulation will recover its insulation characteristics and hence the results obtained under testing may be misleading.

Step 2:
Few hours before testing, the cable is removed from water and left to dry.

Step 3:
This step was the most challenging one that faced the investigators. The HV re-usable terminations available in the market are extremely costly. The other solution was to use plastic pre-molded terminations. Although these terminations are available at lower cost, still they were unaffordable from the point of view cost and the variety of sample sizes. After thorough searching, the investigators decided to use high voltage insulating tape, which is capable of withstanding up to 69 kV if installed professionally and correctly. The investigators tested the insulating tape withstand capabilities against HV AC and DC voltages. These tapes proved to provide the required insulation for the cable terminals. On the other hand, one should practice well the way of preparing the sample ends and the way the termination is applied. The insulating tape used is 130C EPR material rated up to 69 kV manufactured by 3M. For such a termination technique, the next step is very essential.

Step 4:
The two ends of the cable sample are prepared properly to minimize the possibility of discharging or flashover. For the end to be connected to the high voltage source, the cable outer jacket, lapping, copper screen (sheath), conductive crepe paper, and outer semi-conducting shields are removed for a length of 20-25 cm. One to two cm of the insulating material is also removed from the cable end to connect the cable conductor with the HV source, Fig. 2. The cable end that will be connected to the measuring circuit is prepared in the same way. The only difference is that the grounded sheath is folded opposite to the cable end and is connected to the measuring circuit, Fig. 2. The cable two ends were cleaned appropriately to minimize leakage current and reduce the possibility of flashover on the surface. The conductor surfaces were also covered well with the insulating tape so that corona is prevented.

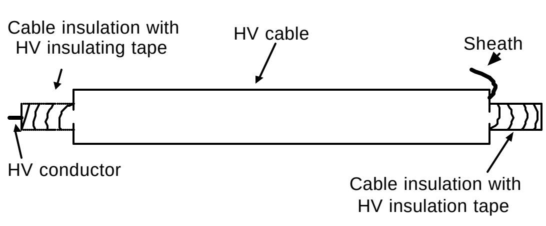

Fig. 2: Cable preparation for termination

4. Experimental Procedure

After connecting the cable ends to the HV source and measuring circuit, a DC voltage is applied in steps of 10-20 % of the rated voltage. The reading of the voltmeter is recorded after 15 seconds from the time of applying the DC voltage. This time is found to be sufficient for the capacitive current to decay where the voltmeter reading becomes constant. Then the voltage is raised again and the voltmeter reading is recorded after the elapse of the discharging time of the capacitive current. The process of applying a voltage and recording the voltmeter reading continues until the testing voltage is reached. The cable DC current is calculated as the voltmeter reading divided by the measuring resistance. This procedure is repeated for all cables, new and old. In the literature [27], it has been reported that if the slope of the voltage –current characteristic changes from linear to a nonlinear relation, then this is a sign that the insulating material is deteriorating.

5. Results and Discussion

For cable number 1 that has a rated voltage of 34.5 kV, the voltage is increased in steps of 5 kV until the testing voltage of 75 kV [27] is reached. The voltage-current characteristic is then plotted as in Fig. 3. From the figure, it can be seen that there is a linear relation between the applied voltage and the DC current. This is a sign that the cable sample insulating material is in good condition and, therefore, it has been concluded that no water tree exists. This conclusion is confirmed by taking a sample of the cable for visual microscopic checking. Again, no evidence of water tree was found.

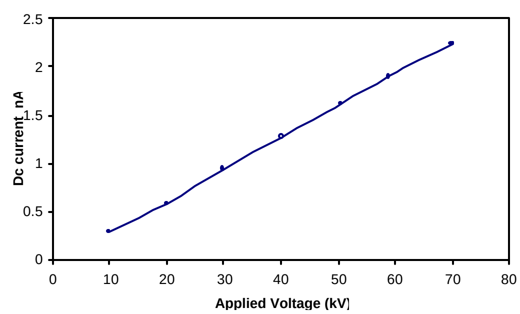

Fig. 3: Voltage –current characteristic of cable #1.

On the other hand, the voltage-current characteristic for cable 3 which is rated at 69 kV is shown in Fig. 4. It is quite interesting to see the nonlinear nature of the characteristic when the applied DC voltage becomes more than 40 kV and becomes very clear when the voltage is around 50 kV. According to the method presented, a conclusion has been made that there are water trees. Again, doing visual microscopic checking, it has been confirmed that water trees do exist as shown in Fig. 5. Although samples 2 and 4 are fresh, the same testing has been applied to both of them. Their voltage-current characteristics are linear. This result confirms again that the linear voltage-current characteristic is a measure of a healthy cable and therefore supports the conclusion that no water tree exists.

6. Conclusions

In this paper, different electrical diagnostic techniques reported in the literature to asses water trees in underground power cables are reviwed. A setup for one of these diagnostic techniques, namely the DC current method is constructed at the HV Laboratory of KFUPM. The method has been applied to some underground cables rated between 15 kV and 69 kV. For the four samples tested, the investigated diagnostic method predicts the presence of water tree only in the 69 kV cable. The findings of this method are in agreement with the visual microscopic findings.

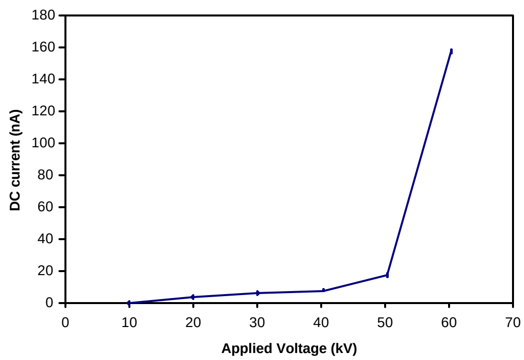

Fig. 4: Voltage –current characteristic of cable #3.

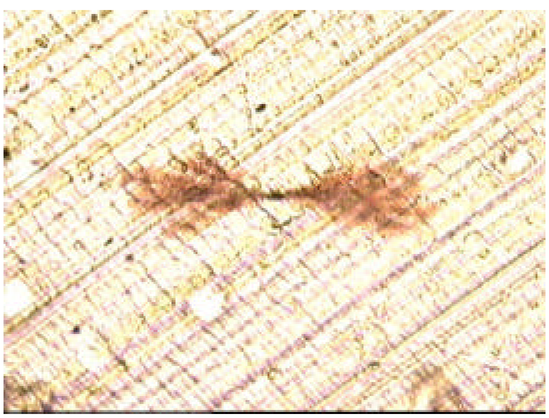

Fig. 5: Shape of a water tree in cable #3.

Acknowledgment

This work forms a part of a project being carried out at the Center for Applied Physical Sciences, Research Institute, with a grant from King Abdulaziz City for Science & Technology (KACST). The authors would like to thank KACST for the support, Saudi Electricity Corporation (SEC)-Eastern Province for supplying the tested samples and the Center for Engineering Research, Research Institute, for the use of the HV laboratory.

References

[1] U. Gafvert et al. "XLPE cable diagnosis by measurement of dielectric losses as a function of frequency and voltage", 13th Int. Conf. And Exh. On Electricity Distribution (CIRED), Brussels, Paper no. 3.06, 1995.

[2] H. Faremo at al, "12 and 24 XLPE cables in Norway, faults related to water treeing", 12th Int. Conf. And Exh. On Electricity Distribution (CIRED), Birmingham, Paper no. 3.10, 1993.

[3] M. T. Shaw and S. H. Shaw, "Water treeing in solid dielectrics", IEEE Trans. EI, Vol. 19, pp. 419-452, 1984.

[4] A. Ishibashi et al., "A study of treeing phenomena in the development of insulation for 500 kV XLPE cables", IEEE Trans. Dielectric and Electrical Insulation, Vol. 5, pp. 695-706, 1998.

[5] S. Hvidsten et al., " Understanding water treeing mechanisms in the development of diagnostic test methods", IEEE Trans. Dielectric and Electrical Insulation, Vol. 5, pp. 754-760, 1998.

[6] R. Ross, "Inception and propagation mechanisms of water treeing", IEEE Trans. Dielectric and Electrical Insulation, Vol. 5, pp. 660-680, 1998.

[7] H. Suzuki et al., "Water-tree characteristics in low-density PE under simulated inverter voltages", IEEE Trans. Dielectric and Electrical Insulation, Vol. 5, pp256-260, 1998.

[8] G. Katsuta at al., "Experimental investigation on the cause of harmfulness of the blue water tree to XLPE cable insulation", IEEE Trans. Dielectric and Electrical Insulation, Vol. 6, pp. 887-706-891, 1999.

[9] D. L. Dorris et al., "Current pulses during water treeing: Detection system", IEEE Trans. Dielectric and Electrical Insulation, Vol. 3, pp. 515-522, 1996.

[10] D. L. Dorris et al., "Current pulses during water treeing: Procedures and results", IEEE Trans. Dielectric and Electrical Insulation, Vol. 3, pp. 523-528, 1996.

[11] G. Tanimoto et al., "A study on electrical breakdown by water treeing in XLPE", Int. Symp. On Electrical Insulating Materials, pp. 431-434, 1995.

[12] J-H Lee et al., "Correlation between AC breakdown strength and spacecharge distribution of water tree aged XLPE",

[13] T. Nagata and N. Shimizu, "Deterioration in aged XLPE cables", Electrical Insulation and Dielectric Phenomena Conference, pp.579-585, 1992.

[14] R. Patsch and A. Paximadakis, "Correlation between electrical signals, tree sizes and breakdown voltages of water treed model cables", Proc. 4th Int. Conf. on Conduction and Breakdown in Solids, pp. 363-367, 1992.

[15] H. Oonishi et al., "Development of new diagnostic method for hot-line XLPE cables with water trees", IEEE Trans. Power Delivery, Vol. 2, pp. 1-7, 1987.

[16] P. Romero and J. Puerta, "Diagnostic of water trees using DC and AC voltages", 1996 IEEE International Symp. on Electrical Insulation, Montreal, Quebec, Canada, pp. 159-162, June 16-19, 1996.

[17] D. S. Elizabeth et al., "Diagnosis of XLPE insulated cables aged under conditions of multiple stresses: Thermoelectric and humidity", 1998 IEEE International Symp. on Electrical Insulation, Arlington, Virginia, USA, pp. 117-121, June 7-10, 1998.

[18] J. Kawai et al., "A consideration of distorted ac loss-current from water treeing degraded polyethylene",

[19] I. Radu et al., "A study on the dependence of water tree permittivity with time", 1996 Conference on

Electrical Insulation and Dielectric Phenomena, San Francisco, pp. 762-765, October 20-23, 1996.

[20] T. Toyoda et al., "Conductivity and permittivity of water tree in polyethylene", 1999 Conference on Electrical Insulation and dielectric Phenomena", pp. 577-580,1999.

[21] S. Hvidsten et al., "Correlation between AC breakdown strength and low frequency dielectric loss of water tree aged XLPE cables", IEEE Trans. Power Delivery, Vol. 13, pp. 40-45, 1998.

[22] R. Bartnikas et al., "A-C breakdown characteristics of in-service aged XLPE distribution cables", IEEE Trans. Power Delivery, Vol.3, pp. 545-562, 1988.

[23] R. Patsch and J. Jung, "Improvement of the return voltage method for water tree detection in XLPE cables", 2000 IEEE International Symposium on Electrical Insulation, Anaheim, CA, USA, pp. 133-136, 2000.

[24] R. Patsch and J. Jung, "Non-destructive diagnostics of insulated systems- Water trees in cables: generation and detection", Proc. IEE, Pt. A, pp. 253259, 1999.

[25] T. Takada, and N. Hozumi, "Space charge measurements as a diagnostic tool for power cables", PES winter meeting, pp. 1609-1614, 2000.

[26] S. Hvidsten at al., "Non-destructive diagnostic testing of service aged MV XLPE cables", 2000 IEEE International Symposium on Electrical Insulation, Anaheim, CA, USA, pp. 137-140, 2000.

[27] P. Nobile and C. Laplatney, "Field testing of cables: Theory and practice", IEEE Trans. IA, Vol. 23, pp. 786-795, 1987.