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Experience with dielectric response measurements on oil-paper insulated cables

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Abstract: Deterioration of the underground power cables insulation has been established to be caused by electrical, thermal and environmental stresses. With the degradation of dielectric strength of the insulation, the underground cables will not be able to function optimally or as planned. As a supplement to the existing dissipation factor and other conventional cable diagnostic measurements, the Decay Voltage (DV) and the Return Voltage (RV) measurement technologies are currently being proposed for non-destructive diagnosis of cable insulation. The main purpose of this paper is to present results from laboratory measurements of DV, RV and Polarisation and Depolarisation Current (PDC) on a number of samples of oil-impregnated paper insulated cables. Comparison of these results has also been made with the conventional dissipation factor measurement data for the same cables.

1. Introduction

The widespread use of underground cables in the high-voltage (HV) power industry today stems from the many advantages of using underground cables in preference to using overhead lines. Nevertheless a common existing problem encountered by the industry is determining the condition of the insulation of the underground cable. Over the period of time, it is inevitable for insulation materials to undergo chemical and physical deterioration, causing the performance of the cables to suffer. Such deterioration will weaken the dielectric strength of the insulation, resulting in a decline in the condition of the cables and subsequently, decreasing the life span and efficiency of the underground power cable.

Several traditional and the newer diagnostic testing methods, such as dielectric loss, absorption and dispersion coefficient measurements and Partial Discharge (PD) Localization by Time-Domain Reflectometry [1] have been used over the years for cable testing purposes. However, the relation between these measured quantities and the fundamental insulation degradation processes have not been explored adequately. This has many times lead to incorrect or contradictory interpretation of the results [2].

To identify the two fundamental characteristics of the cable insulation material, namely the conduction and the polarisation, and hence to assess its condition, non-destructive dielectric diagnostic techniques are currently being investigated [3-7]. These include the Decay Voltage (DV) measurements and the Return Voltage Measurements (RVM).

The present paper reports the investigation results of insulation diagnostics on several oil-paper insulated cables by traditional techniques like the dissipation factor (tanδ) measurement, newer techniques like the DV and RV measurements and also a relatively new dielectric diagnostic technique, namely the Polarisation and Depolarisation Current (PDC) measurement [8-10].

2. Dielectric Diagnosis Techniques [2, 4-10]

The different dielectric diagnostic measurements including DV, RV and PDC can be performed on the three-core cable using the basic circuitry as shown in Figure 1.

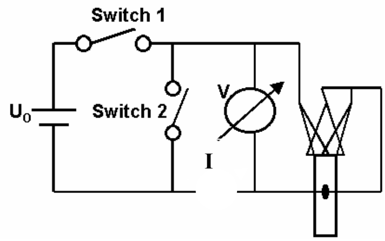
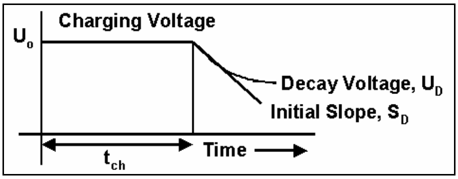
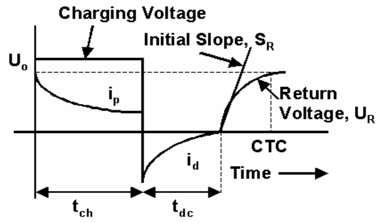


Figure 1: Circuit for dielectric diagnosis

The Decay Voltage (DV) is measured between the two electrodes after charging the insulation for sufficiently long time (~1000sec) and the removing the voltage source as described in Figure 2(a). The return voltage (RV) is measured between the two electrodes after a period of short circuit following a longer period of charging. In the PDC technique, the charging current due to a DC step voltage and the subsequent discharging current after replacing of the voltage source by a short-circuit are measured for long periods of time. The process of RV and PDC measurements are combined in Figure 2(b).



(a)



(b)

Figure 2: DV, RV and PDC measurements, (a) DV curve (U_D) and its initial slope (S_D), (b) RV curve (U_R) and its initial slope (S_R) and PDC curves (i_p and i_d)

It has been shown [4, 6] that the steepness of the decay voltage curve (S_D) is proportional to the intensity of conduction, while the steepness of the return voltage curve (S_R) is proportional to the intensity of polarization process. The specific conductivity, γ [A/V] and the polarization conductivity, β [A/V] can thus be computed from S_D and S_R respectively using (1) and (2):

$$S_D = \gamma E / \varepsilon_O \tag{1}$$

$$S_R = \beta E / \varepsilon_O \tag{2}$$

where
S_D is the initial slope for decay voltage curve
S_R is the initial slope for return voltage curve
E is the applied DC electric field [V/m], and
ε_O is the permittivity of vacuum

The RV Spectrum is obtained from multiple cycles of the RVM with increasing charging times. The peak of the maximum RV among all the cycles and the corresponding time, called the central time constant (CTC) are parameters used for assessment of the insulation condition [6].

A newer technique used to monitor the condition of the insulation is the Polarisation-Depolarisation Current (PDC) measurement. From the values of the measured polarisation and depolarisation currents (i_p and i_d), the oil conductivity and the paper conductivity can be measured and studied to evaluate the oil condition and the paper condition in the insulation [8-10]. Equation (3) is used to calculate the conductivity:

$$\sigma = \frac{\varepsilon_O}{U_O \frac{C}{\varepsilon_r}} \left(i_p - i_d \right) \tag{3}$$

where
U_o is the charging voltage, C is the measured capacitance of the cable and ε_r is the combined relative permittivity of oil and paper insulation.

The oil conductivity is calculated from the initial values of the polarisation and depolarisation currents, whereas the paper conductivity is calculated from the final values of the polarisation and depolarisation currents.

3. Experimental Techniques

Figure 3 shows five different oil-paper insulated cable samples collected from a university distribution system with no prior history known to the authors. The lengths of the cables are given in Table 1.

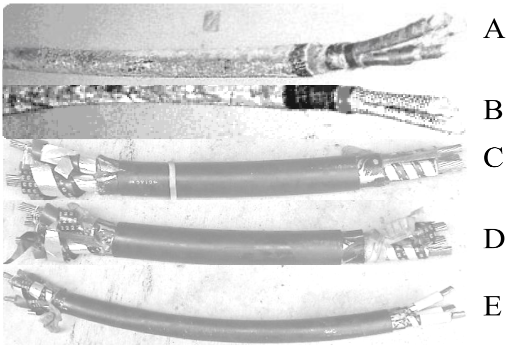


Figure 3: Oil-paper Insulated Cable Samples

Dielectric response measurement equipment, which was developed at the School of Information Technology and Electrical Engineering, at the University of Queensland [9-10], was used for all the dielectric response measurements. For Dissipation Factor measurement, it was done with Capacitance and Dissipation/Power Factor Test Set Type 2816, Tettex Instruments.

4. Results and analysis

Dissipation Factor (tan δ) measurement

The dissipation factor at 50 Hz was measured at 500V and the results are shown in Table 1.

Table 1: Dissipation Factor

Cable	Length [m]	tan δ
A	1.6	0.0116
B	1.5	0.0569
C	0.8	0.0047
D	0.9	0.0035
E	1.0	0.0033

Cable B having the highest dissipation factor indicates that the condition of the insulation in cable B is in a degraded state. Cables C, D and E have smaller dissipation factors which imply that the average insulation conditions in these three cables are relatively good. The dissipation factor for cable A is between cable B and Cables C, D and E. Thus, the insulation condition of cable A is moderate.

Decay Voltage measurement

Figure 4 shows the decay voltage curves obtained from the experiment for the five cable samples.

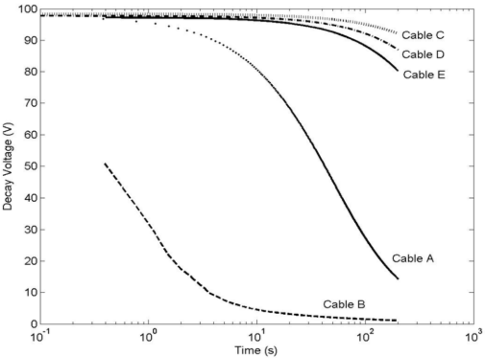


Figure 4: Decay Voltage measurement results

Based on the decay voltage curves, cable B produced the steepest gradient while cables C, D and E produced the lowest initial gradient. Since there is a strong correlation between the initial tangent and the amount of moisture in each individual cable, the insulation condition of cable B is in a much advanced stage of insulation degradation as compared to the relatively good cables C, D and E. Along with that, the condition of the insulation for cable A is intermediary of cable B and cables C, D and E.

Table 2 contains the initial slopes and the corresponding specific conductivities for all the five cable samples.

Table 2: Specific Conductivities from Decay Voltage slope

Cable	S_D [V/s]	γ [A/V]
A	1.97	1.75E-13
B	27.2	2.41E-12
C	0.07	5.71E-15
D	0.09	7.99E-15
E	0.11	9.51E-15

As seen in Table 2, the cable B is having the highest value of specific conductivity – indicating its degraded condition of insulation. Whereas cables C, D and E are in good condition with low values of specific conductivities. Cable A lies in-between.

Single Cycle Return Voltage measurement

The return voltage curves obtained from the measurement with 1000 sec charging and 1 sec discharging are illustrated in Figure 5 while Table 3 shows the initial slopes and the polarisation conductivities for the five cable samples.

Table 3: Data obtained from return voltage measurement

Cable	S_R [V/s]	β [A/V]
A	4.07	36.2E-14
B	2.14	18.9E-14
C	0.32	2.87E-14
D	0.22	1.91E-14
E	0.25	2.21E-14

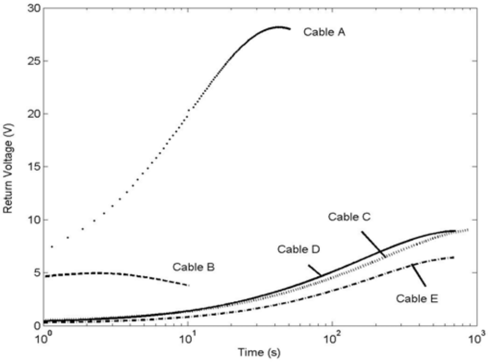


Figure 5: Return Voltage measurement results

Cable A and B have quite high values of the polarization conductivity – which is indicative of their degraded condition of insulation. Some anomaly of the values of S_R and β were found between cables A and B. As can be seen from Figure 5, though the initial slope of cable B is lower than cable A, cable B has a very low value of CTC – which denotes worst condition of its insulation than all the others. On the contrary, cables C, D and E have low polarization conductivity values. Hence, it can be deduced that all these three cables C, D and E are in better conditions as compared to cables A and B.

Return Voltage spectrum

Figure 6 shows the RV spectrum for the cable samples and Table 4 shows the measured parameters obtained from the measurement. Cable B is not available for this measurement as it was suspected to have developed some permanent damage during the previous test.

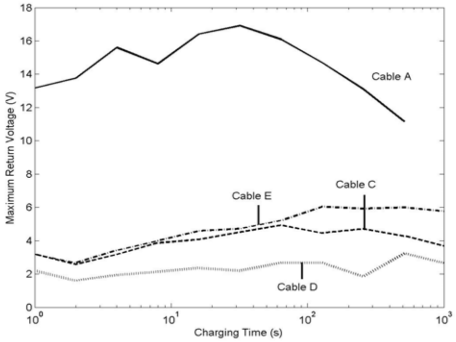


Figure 6: Polarisation Spectrum

Table 4: Data obtained from PDC measurement

Cable	Max RV (V)	CTC (s)
A	16.91	39.6
B	N.A.	N.A.
C	4.93	537.83
D	3.23	426.66
E	6.04	690.8

From the data, Cable A can be seen to have the smallest CTC while all three cables C, D and E have large CTC. This again confirms that the condition of insulation for cable A is worse than cables C, D and E.

Polarisation-Depolarisation current measurements

Figures 7 and 8 show the polarisation and depolarisation current plots respectively for all the cable samples. Using (3), the calculated values of oil and paper conductivities (σ_O and σ_P) for the cable samples are shown in Table 5. Again, Cable B is not available for this measurement.

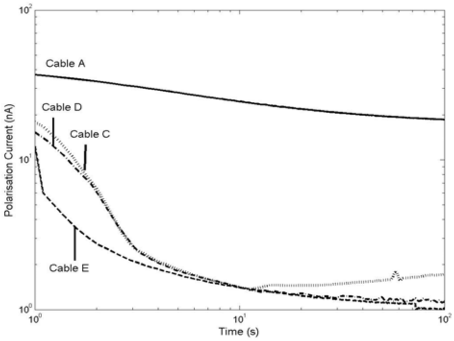


Figure 7: Polarisation Currents

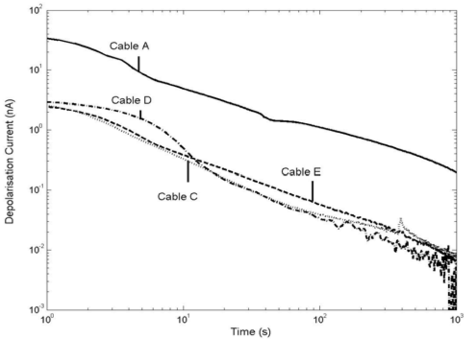


Figure 8: Depolarisation Currents

Table 4: Data obtained from PDC measurement

Cable	σ_O (S/m)	σ_P (S/m)
A	1.11E-14	9.84E-15
B	N.A.	N.A.
C	3.00E-15	1.05E-15
D	3.21E-15	1.13E-15
E	3.02E-15	6.69E-16

The higher values of the polarisation and depolarisation currents for cable A as compared to the other three cables C, D and E indicate that cable A insulation is in a more degraded condition than the other three. This is supported by the fact that cable A has higher oil and paper conductivities as compared to the other cables, as shown in Table 4. A higher conductivity obviously implies a degraded condition of the insulation. From this measurement, it is thus once again confirmed that the insulation of cables C, D and E are in better condition among all the cable samples.

From the above measurements, we can thus observe a good agreement between the results of all the different dielectric diagnostic techniques as well as the traditional dissipation factor measurement results.

5. Conclusions

Five different oil-paper insulated cable samples have been tested with different dielectric techniques like the Decay Voltage, Return Voltage and PDC measurements. The results obtained show that the non-destructive diagnostic techniques proved to be reliable, effective and efficient in determining the insulation condition of the oil-paper cable samples. Different parameters like specific conductivity, polarisation conductivity, CTC, oil and paper conductivities have been calculated from the different measurements and have been used for assessing the condition of the cable insulation. The results obtained from these dielectric tests are in good agreement with the values of the dissipation factors for all the cables.

6. References

[1] Z. Du, P. K. Willett and M. S. Mashikian, “Performance Limits of PD Location Based on Time-Domain Reflectometry”, *IEEE Trans. Dielectrics and Electrical Insulation*, vol. 4, no. 2, pp. 182-188, 1997.

[2] E. Nemeth, “Measuring the Voltage Response, A Diagnostic Test Method of Insulations”, *7th International Symposium on High Voltage Engineering, Dresden*, Paper No. 72.06, pp.63-66, 1991.

[3] E. Nemeth, “Practical Experiences of Diagnostic Testing of Power Cable Lines by the Voltage Response Method”, *40. IWK, TU Ilmenau, Band 4*, pp. 699-708, 1995.

[4] E. Nemeth, “Some Newest Methods of Diagnostic Testing of Impregnated Paper Insulated Cables”, *10th International Symposium on High Voltage Engineering, Canada,* 1997.

[5] M. G. M. Megens, A. Rama and R. Ross, “Return Voltage Measurements on Paper insulation of Windings and Cables”, *IEEE International Conference on Conduction and Breakdown in Solid Dielectrics, Sweden*, pp. 98-101, 1998

[6] E. Németh, “Measuring Voltage Response: A Non-destructive Diagnostic Test Method of HV Insulation”, *IEE Proc.–Sci. Meas. Technology.*, vol. 146, no. 5, pp. 249-252, September 1999.

[7] R. Neimanis, T. K. Saha and R. Eriksson, “Determination of Moisture Content in Mass Impregnated Cable Insulation Using Low Frequency Dielectric Spectroscopy”, *IEEE Power Engineering Society Summer Meeting*, vol. 1, pp. 463 -468, 2000.

[8] J. J. Alff, V. Der Houhanessian, W. S. Zaengl, and A. J. Kachler, “A Novel, Compact Instrument for the Measurement and Evaluation of Relaxation Currents Conceived for On-site Diagnosis of Electric Power Apparatus” *IEEE International Symposium on Electrical Insulation*, pp. 161 -167, 2000.

[9] T.K. Saha, P. Purkait and Z.T. Yao, “Condition Monitoring of Transformer Insulation by Polarization and Depolarisation Current Measurements”, *Australasian Universities Power Engineering Conference, Melbourne, Australia*, 2002.

[10] Z. T. Yao and T. K. Saha, “Separation of Ageing and Moisture Impacts on Transformer Insulation degradation by Polarisation Measurements”, *CIGRE Paris session*, paper no. 15-304, 2002.