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Dielectric Diagnosis of Extruded Cable Insulation by Very Low Frequency and Spectroscopic Techniques - A Few Case Studies

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Abstract

This paper presents few case studies of condition assessment of extruded cables using very low frequency and spectroscopic techniques. Medium voltage distribution cables were assessed using VLF Techniques in addition to techniques like insulation resistance and spectroscopy. Few case studies of using low frequency partial discharge measurements for localisation of incipient faults are also presented and discussed. Studies indicate very low frequency tan δ and partial discharge techniques are promising tools for condition assessment of long length cables.

Keywords: Dielectric Diagnosis, Very Low Frequency Tan δ, Water Logged Cables, VLF PD

1. Introduction

Electric transmission and distribution network comprises of large number of power cables which are quite expensive and form significant portion of the network. More importantly they are vital components for reliable delivery of electric power. However, the reliability of power distribution depends to a large extent on the healthy condition of the extruded cable insulation. Power cables with extruded insulation like EPR, PVC, XLPE are largely used in distribution and transmission network and these cables undergo different stresses during their service life period leading to insulation degradation and deterioration and hence forced outages. Forced outages are of serious concern and are not economical. In order to check healthiness of a cable system, it is important to perform diagnostic tests on in service cables. Though several diagnostic test methods like measurement of Insulation resistance, Polarization index, Dissipation factor, Loss angle and capacitance, VLF testing exist, there are certain merits and demerits in each technique and no technique can give the complete information about the healthiness of the cable. Applying effective technologies and remedial measures can reduce costs and improve the performance of cable systems. Lot of research efforts and activities are directed towards better understanding of degradation phenomena[1,2] and finding suitable techniques for insulation diagnosis and remaining life estimation techniques. This paper presents and discusses few case studies of condition assessment of extruded cables using very low frequency and spectroscopic techniques.

2. Evaluation techniques[5-8]

Techniques used in the present study include Insulation resistance, very low frequency tan δ, capacitance, PD measurements and dielectric spectroscopy[3,4].

3. VLF testing

Measurement of tan δ and capacitance or partial discharge of long length cables at power frequency by conventional bridge methods require large and expensive test sources for energizing the cable. Therefore, measurements using either VLF test sources or resonant transformers are preferred. The main advantage of VLF testing[5] is that lower rating test source is required for onsite testing. The

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power requirement at 0.1Hz is 500 times less compared to 50Hz.

The VLF tests at frequency 0.1, 0.05, 0.02, or 0.01Hz produce the same dielectric stress as at power frequency without deteriorating the cable due to harmful effects of DC polarization. Long length of cables can be charged using test sources operating at lower frequencies thus enhancing the range of the equipment. The VLF tests are conducted at voltages 1.5 to 3 times Uo. Special VLF source can charge cables up to 50 mF. VLF AC test[7] equipment can be extremely useful for locating cable faults, thereby reducing fault location.

4. Dielectric spectroscopy (Dielectric response in frequency domain)

Dielectric spectroscopy measurement technique is essentially a dissipation factor measurement performed at multiple frequencies ranging from a few milli Hz to kHz. In principle, dielectric spectroscopy may be used to detect dipole orientation effects, and thereby detect increase in the polar molecules due to ageing, moisture absorption, contamination and incomplete curing. Changes in permittivity in the frequency domain may also reflect space charge polarization or partial discharges that can occur in composite insulation having internal voids. The plot of ε" versus frequency may be used to evaluate increased losses due to change in carrier movement, polarization effects and partial discharges.

5. Case Studies

A few case studies of condition assessment of extruded cables using very low frequency and dielectric spectroscopy techniques are discussed in the succeeding sections.

Case study 1

Insulation diagnosis was carried out on 11kV, 3 x 400 mm² XLPE cable which was in service in one of the steel industry that had failed abruptly. From the failed cable a section of healthy part approximately 18 metres long was cut and diagnostic tests were conducted on individual phases separately. The measured insulation resistance (IR) values were 462 GΩ, 540 GΩ and 444 GΩ for R, Y and B phases respectively. Though these values were in the acceptable range, the tan δ @ 0.1 Hz (VLF) values on R-Phase showed higher values. The variation of VLF tan δ with voltage (from 2.2 kV to 6.4 kV in steps of 2.2 kV) is shown in Figure 1.

The tan δ values at U_0 were 7.4 $x10^{-3}$, 1.8 $x10^{-3}$ and 2.3 $x10^{-3}$ for R, Y and B phases respectively. It is evident from the results that R phase had undergone a higher level of deterioration as compared to Y and B phases. In order to confirm the deterioration of R phase of the cable, dielectric spectroscopy measurement was carried out. Figure 2 shows the dielectric spectra obtained on the cable for frequencies ranging from 10 Hz to 0.01 Hz, at test voltages upto 6.4 kV.

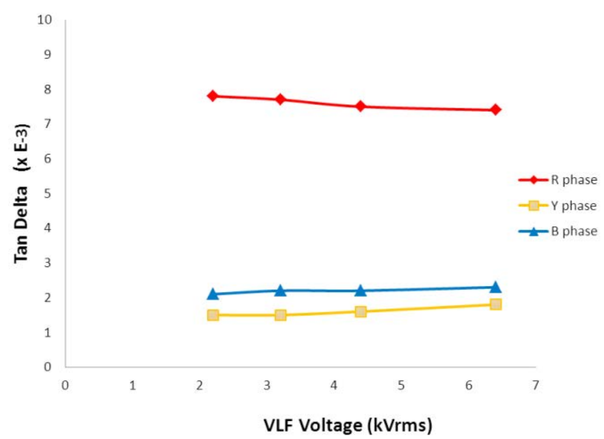

Figure 1. VLF Tan delta characteristics.

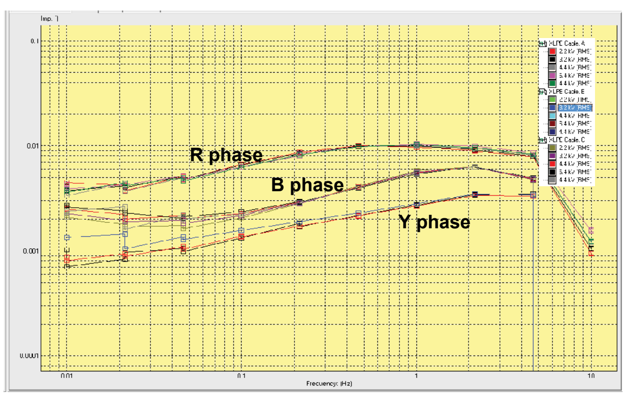

Figure 2. Dielectric spectra.

These results further confirm that the dielectric losses in the R phase were higher, in agreement with the VLF tan δ results. Also, the dielectric spectroscopy results did not show much variation in tan δ values with voltage, indicating that there are no polar contaminants in the cable.

Case study 2

Three lengths of 33 kV, 3x300 sq.mm, 3 core, underground XLPE cable, laid in a region where the water table level is high was tested to assess cable insulation condition before putting into service. As the water table was high there was likely hood of ingress of moisture. The test results are presented and discussed in the following sections:

3(a) (Cable length 5201.5 m)

The measured IR values were 4.33 GΩ, 4.52 GΩ and 5.20 GΩ and the VLF tan δ values at U_o were 3.5 x10^{-3}, 6.3 x10^{-3} and 1.9x10^{-3} for R, Y and B phases respectively. Figure 3 shows the plot of variation of VLF tan δ with voltage.

The VLF tan δ values obtained for a new cable were higher than the permissible value < 1.2 x10^{-3}. The VLF tan δ - voltage characteristics also exhibited voltage dependency. Such high VLF tan δ values may be attributed to either of the following:

a) Ingress of moisture into the cable insulation
b) Stress grading materials with non-linear voltage characteristics i.e. high dielectric constant might have been used in accessories.

Figure 3. VLF tan δ characteristics.

Based on the above results it is concluded that the cable is not suitable for immediate charging.

3(b) (Cable length 448 m)

The IR values were 255 GΩ, 260 GΩ and 236 GΩ and the VLF tan δ results at U_o were 1.0x10^{-3}, 0.9x10^{-3} and 0.6x10^{-3} for R, Y and B phases respectively. The VLF tan δ – voltage characteristics is shown in Figure 4.

The cable 3(b) exhibited relatively lower tan δ values as compared to the cable 3(a). High IR values and low tan δ values indicated that the cable was healthy and the dielectric losses in the cable insulation were low.

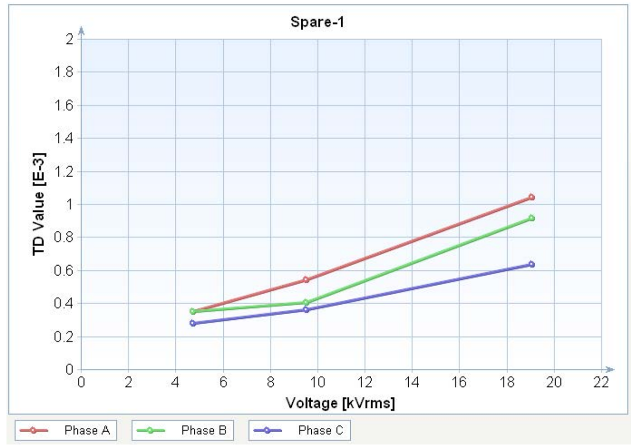

Figure 4. VLF tan δ characteristics.

3(c) (Cable length 208 m)

The IR values were 187 GΩ, 198 GΩ and 159 GΩ and the VLF tan delta results at U_o were 0.8x10^{-3}, 0.5x10^{-3} and 0.7x10^{-3} for R, Y and B phase respectively. Figure 5 shows the variation of VLF tan δ with voltage.

Figure 5. VLF tan δ characteristics- cable 10.

The IR values are high and lie in the normal permissible range for such a new cable. The VLF tan δ values are low and lie in the normal permissible range for XLPE cables. The test results inferred that the dielectric losses in the cable insulation system were low and the cable showed no sign of abnormality. The test results were comparable to cable 9.

Case study 3

VLF Partial Discharge (PD) Measurements and localization of incipient faults.

VLF (0.1Hz) Partial Discharge (PD) Measurements were conducted on 33 kV, 3 x 240 sq.mm, XLPE cables laid in a process industry, to locate the incipient faults along the length of the cable. Measurements were carried out on either side of the cables to reduce the probability of PD signals getting attenuated due to longer length.

The VLF partial discharge test data obtained on the R-phase of the cable (length 780m) connected between substation 1 and substation 2 are presented in Figures 6 and 7.

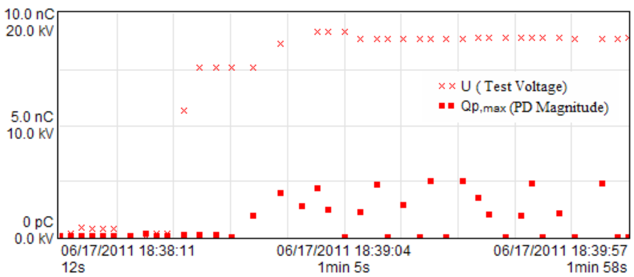

Figure 6. PD Events of R phase measured at Substation – 1 end.

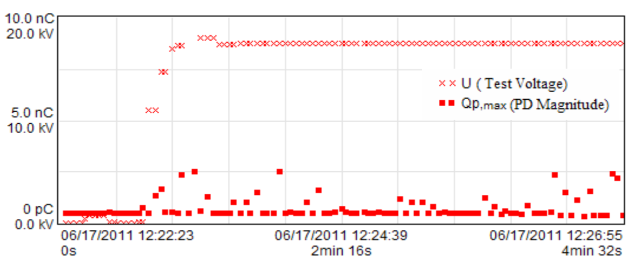

Figure 7. PD Events of R phase measured at Substation – 2 end.

As it can be seen in the Figures 6 and 7, the R phase of the cable exhibit partial discharge activity measured at both ends of the cable. The average magnitude of the PD signals were 1600 pC and 2500 pC at substation-1 end and substation-2 end respectively. The Time Domain Reflectometry (TDR) technique was then employed to detect the location of the partial discharge.

Figures 8 and 9 present locations of the PD signals along the cable length. The pulse1 in Figure 15 is the direct pulse (reference pulse) that has propagated directly from the PD site to the measuring end of the cable. The pulse 2 is the reflected pulse that has travelled in opposite direction from the PD site and reflected back at the far end of the cable. The time difference between the direct pulse and the reflected pulse is related to the distance of the PD site along the cable from the far end. Referring to the Figures 8 and 9, the location of the PD site corresponding to the time difference is 488 m from the Substation-2 end with an accuracy of 0.1% of the total cable length.

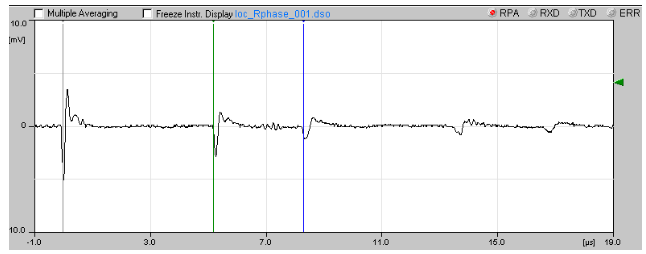

Figure 8. Reflectogram of R phase detected at Substation-1 end.

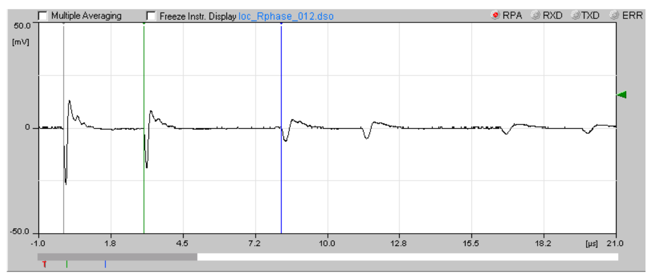

Figure 9. Reflectogram of R phase detected at Substation-2 end.

The VLF partial discharge test data obtained on the Y-phase of the cable (length 780 m) connected between substation 1 and substation 2 are presented in Figures 10 and 11.

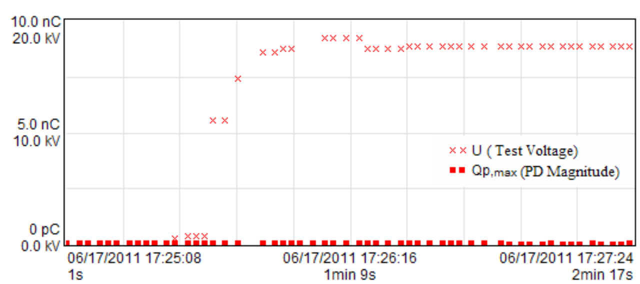

Figure 10. PD Events of Y phase measured at Substation – 1 end.

Figure 10 shows that the Y-phase of the cable does not exhibit partial discharge activity up to the rated phase voltage of 19 kV at substation -1 end. The low magnitude pulses (max. 250 pC) shown in the Figure10 are due to the background spurious noise signals. However, PD magnitudes of the order of 5000 pC were recorded for Y phase during the measurements at the Substation – 2 end, as shown in Figure 11.

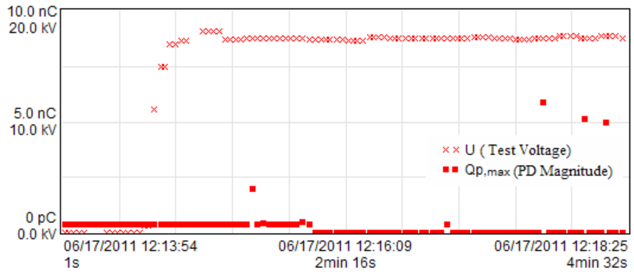

Figure 11. PD Events of Y phase measured at Substation – 2 end.

Figure 12 shows the reflectogram obtained at the substation-2 end for the Y phase of the cable. It can be inferred from Figures 12 that the source of the PD is at the termination itself or near the termination with accuracy of 0.1% of the total cable length.

The VLF partial discharge test data obtained on the B-phase of the cable (length 780 m) connected between substation 1 and substation 2 are presented in Figures 13 and 14.

As seen from Figures 13 and 14 that the B phase of the cable did not exhibit any PD activity at both ends of the cable except for the background spurious noise of about 250 pC.

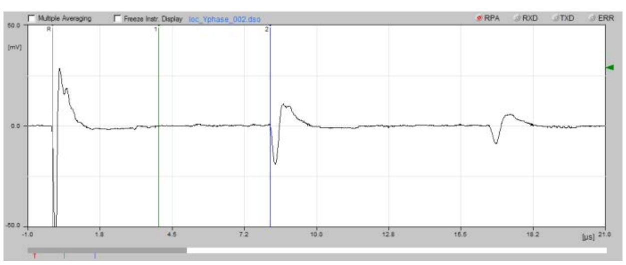

Figure 12. Reflectogram of Y phase detected at Substation-2 end.

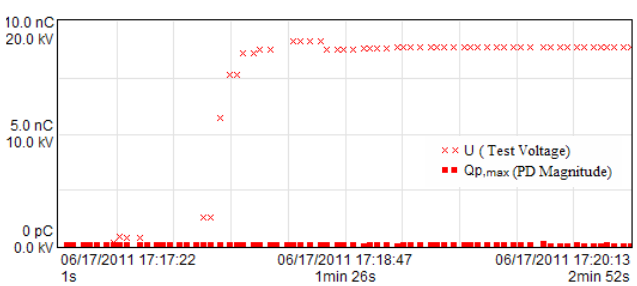

Figure 13. PD Events of B phase measured at Substation – 1 end.

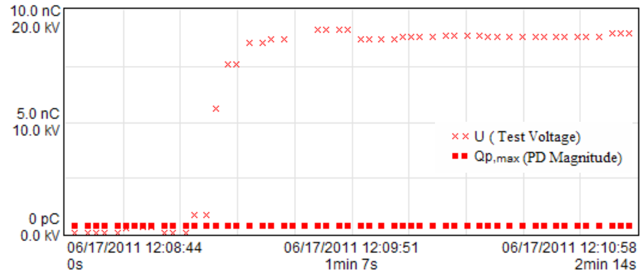

Figure 14. PD Events of B phase measured at Substation – 2 end.

Case study 4

Insulation resistance, VLF (0.1Hz) tan delta and partial discharge measurements were conducted on Single core, 66 kV, XLPE cables in a Hydro station connecting from Generator transformer to switchyard.

5(a) Unit #01 Cables, Length R phase-345 m, Y Phase-337 m, B Phase 332 m. The diagnostic test data obtained on this cable are summarized in the Table 1.

Table 1. Measured diagnostic parameters of 66 kV XLPE Cable, Unit No. 1

Phase	IR @ 2.5 kV DC (GΩ)	VLF-TD Time Stability (VLF - TDTS) (x 10^{-3})	VLF-Differential TD (VLF - DTD) (x 10^{-3})	VLF Tan Delta @ 38 kV (x 10^{-3})	Capacitance (nF)
R	156	0.1	1.78	1.88	66
Y	178	0.1	1.56	1.66	63
B	120	0.1	3.02	3.12	64

It can be inferred from the test data that the cables exhibit high insulation resistance value and low tan delta values indicating low dielectric losses in the cable insulation system. No partial discharge activities observed along the length of the cables in all phases. The diagnostic test results indicate that insulation condition of R, Y and B phase cables are healthy.

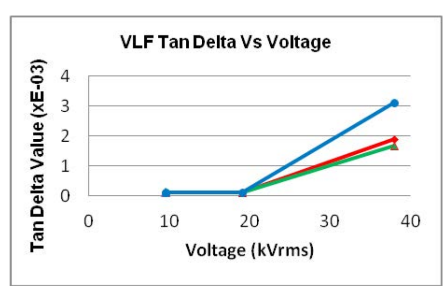

Figure 15. VLF tan delta vs test voltage on Unit #01 Cables.

5(b) Unit #02 Cables, Length R phase-326 m, Y Phase-317 m, B Phase 318 m. The diagnostic test data obtained on this cable are summarized in the Table 2.

Table 2. Diagnostic parameters of 66 kV Cable, Unit No. 2

Phase	IR @ 2.5 kV DC (GΩ)	VLF-TD Time Stability (VLF - TDTS) (x 10^{-3})	VLF-Differential TD (VLF - DTD) (x 10^{-3})	VLF Tan Delta @ 38 kV (x 10^{-3})	Capacitance (nF)
R	111	**0.5**	**16.95**	**13.81**	63
Y	131	**0.5**	**14.41**	**14.51**	61
B	161	0.1	3.63	3.73	60

It can be inferred from the test data that the cables exhibit high tan delta values, high differential tan delta and high time stability indicating low dielectric losses in the cable insulation system. No partial discharge activities observed along the length of the cable in B phase. R and Y phase cable exhibit partial discharge (R-12000 pC, Y-5000 pC) activities in the termination at switchyard end terminations. The diagnostic test results indicate that insulation condition of R, and Y phase cables are not healthy. In view of surface discharge in the R and Y phase terminations at switchyard, it is recommended to repeat the tests after one year to monitor the trend.

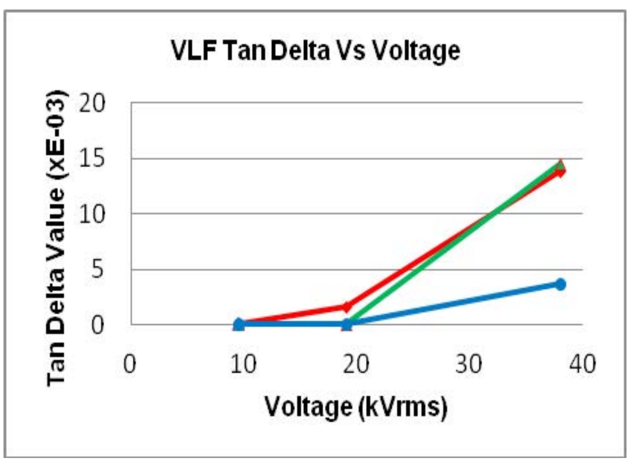

Figure 16. VLF tan delta vs test voltage on Unit #02 cables.

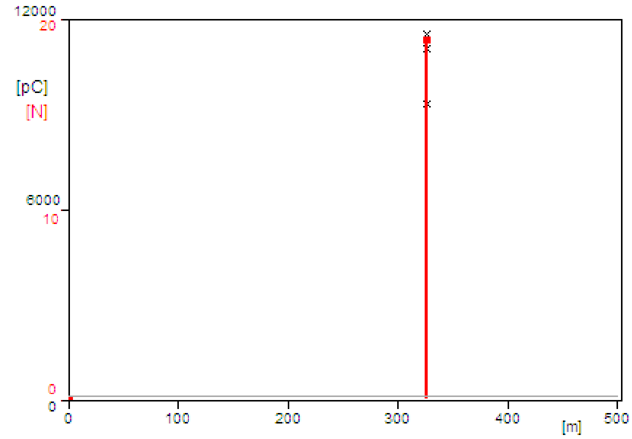

Figure 17. PD Mapping for Unit # 02 R-phase.

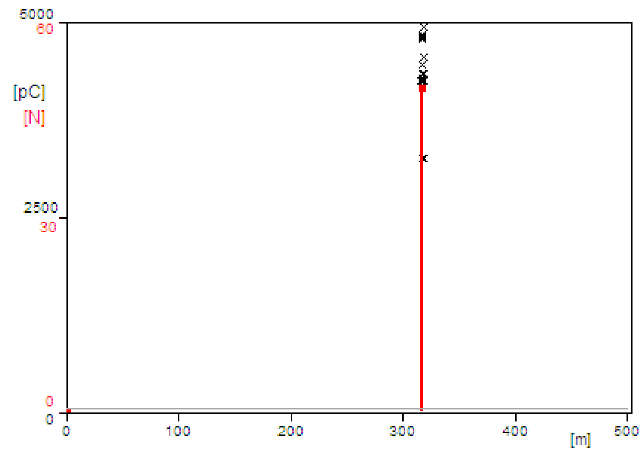

Figure 18. PD Mapping for Unit # 02 Y-phase.

6. Conclusions

Dielectric diagnosis studies conducted on extruded cables have indicated that very low frequency tan δ and partial discharge techniques are promising tools for condition assessment of long length cables. Though there are several condition monitoring techniques available, combination of several methods may be necessary to adequately and accurately diagnose. An early detection of incipient faults in the cable and taking appropriate remedial measures in time could enhance the availability and reliability of the cable.

7. Acknowledgement

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