Frequency Dielectric Spectroscopy and Dissipation Factor Measurements during Thermal Cycles on Different Types of MV Cable Joints

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***Abstract*- Results of periodic measurements of Dissipation Factor (DF) and Frequency Dielectric Spectroscopy (FDS) on Medium Voltage (MV) cables during thermal cycles, are reported and discussed in this paper. Twelve cables equipped with different types of joints were connected together to form a ring in short-circuit. The ring was energized at rated voltage and current. Temperature cycles with a period of one day (11 hours of heating) were applied by controlling the current. Periodically, each cable was tested separately using both DF and FDS techniques to monitor the ageing progression. This paper focuses on the experimental results obtained testing six new cables provided by different types of new joints while the other six coming from the field, are not considered here. Results obtained testing the six new cables indicate that FDS evaluation is a reliable tool to distinguish the aging progression of the insulation from the seasonal and reversible changes while DF values recorded at different voltage levels show a non-regular behavior particularly in XLPE cables. These results clearly suggest that the systematic use of FDS in condition assessment of underground cables can provide more information on the ageing progression than the traditional DF measurements.**

I. INTRODUCTION

Insulation diagnosis is of great importance for evaluation of the global conditions of the insulation of Medium Voltage (MV) underground cables and accessories. Among the different non-destructive diagnostic techniques, the Frequency Dielectric Spectroscopy (FDS) is gaining popularity on the traditional Dissipation Factor (tanδ) measurements for the possibility to monitor the global conditions and the ageing progression from the analysis in frequency domain of the polarization processes occurring within the insulation, [1-4]. In this experiment, both FDS and tanδ techniques have been applied to monitor the ageing evolution of twelve underground cables rated 23kV provided of different types of joints in the middle, coming from two different suppliers. These cables were aged by means daily thermal cycles while subjected to the rated voltage and current. Periodically, the ageing progression of each cable has been investigated by means of FDS and tanδ measurements.

This paper focuses on the experimental results obtained testing six new cables equipped with homogeneous (oil/paper and XLPE) and mixed (XLPE-oil/paper) joints. Results obtained testing the other six cables coming from the field after different periods of ageing and provided by mixed XLPE-oil/paper insulation, are not discussed here. It is shown that FDS evaluation applied to the six new cables, is a reliable tool to distinguish the ageing progression of the insulation from the seasonal reversible changes, while dissipation factor values, recorded at different voltage levels, show a non-regular behavior, particularly in XLPE cables. These results clearly suggest that the systematic use of FDS in condition assessment of underground cables can provide more information than the traditional tanδ measurements.

II. THE EXPERIMENTAL SET-UP

The six cables here considered are about ten meters long and they are equipped with different types of joints in the middle: 2 XLPE-XLPE (Cables N.3 and N.4), 2 oil/paper (Cables N.5 and N.6) and 2 mixed XLPE and oil/paper joints (Cables N.1 and N.2). They are connected together to form a cable ring (main ring). The six new joints come from two different providers for a comparison (Cables 1, 3, 5 and Cables 2, 4, 6, are from providers A and B, respectively). XLPE and oil/paper insulated cables connected by the joints, are new and come from the same provider. Using this configuration, it is possible to argue that differences in test results during ageing, are mainly due to the different cable-joints. All the cables have the same ratings of 23kV and 275A. Stranded conductors of XLPE and oil/paper cables are in aluminum with a cross section of 185 mm^2 and 240 mm^2, respectively. The groundwall insulation thickness of both cables is about 3 mm.

Cycles of temperature having a period of one day, from the ambient to a maximum value that depends on the ambient conditions, have been applied by controlling the current in the main ring by means of external coils for a period of 11 hours, then cables were left cooling by natural convection . During the heating/cooling periods, 13kV phase-to-ground voltage was constantly applied to the cable ring. Cables were covered by felts to simulate dry underground conditions in laboratory.

The temperature was measured using thermocouples installed on the joint surface (two on the mixed joints). A mirror-ring composed by new XLPE and oil/paper cables also equipped with new joints and with the same ratings, has been prepared. In this ring, the same current of the main ring was induced in the absence of the voltage supply. In the mirror-ring, temperature sensors were installed both on the joint surfaces and close the conductor to measure the temperature differences thus allowing a more accurate estimation of the real temperature of the conductors of the main ring.

Periodically, the main ring was disconnected and the global conditions of each single cable were tested by means of FDS and tanδ measurements using commercial instruments. Table I reports the reference name of a sub-set of thermal cycles after which the cables were individually tested, as well as the progressive number of the thermal cycles and the number of thermal cycles between two consecutive measurement sessions.

TABLE I
REFERENCE OF THERMAL CYCLES

Period Name	Number of Thermal Cycles	Number of Thermal Cycles per Period
T0	**0**	**0**
T1	**42**	**42**
T2	**88**	**46**
T3	**144**	**56**
T4	**208**	**64**
T5	**301**	**93**
T6	**349**	**48**
T7	**435**	**86**
T8	**548**	**113**
T9	**644**	**96**

II. DIAGNOSTIC MEASUREMENTS

The DIRANA_OMICRON was used for FDS tests. A frequency range of 10^{-3} – 10^{+3} Hz and 200 V of supply voltage were selected for these tests. All FDS measurements were performed at room temperature and reported at the reference temperature of 20°C according to the correction implemented in the instrument in [5]. This method is based on a Volt-Ampere measurement method that determines the input impedance as a function of frequency, Z(ω), from which complex permittivity and dissipation factor data are obtained as a function of frequency for each cable, [1]. The supply voltage was applied to the cable conductors while the cable shield was connected to return connection of the instrument.

During the same measurement session, tanδ has been measured at different voltage levels that is 6.5kV ($0.5U_0$), 13kV (U_0), 19.5kV ($1.5U_0$), 26kV ($2U_0$), using an OMICRON MI600. Again, the supply voltage has been applied to the cable conductors while the cable shields were connected to return connection of the instrument.

Experimental results dealing with new cable joints are reported and discussed in the following. Table II summarizes the references of these cables.

TABLE II
CHARACTERISTICS OF THE NEW CABLE-JOINTS

Cable Number	Provider	Joint Type
C1	**A**	**XLPE-Oil/Paper**
C2	**B**	**XLPE-Oil/Paper**
C3	**A**	**XLPE-XLPE**
C4	**B**	**XLPE-XLPE**
C5	**A**	**Oil/Paper-Oil/Paper**
C6	**B**	**Oil/Paper-Oil/Paper**

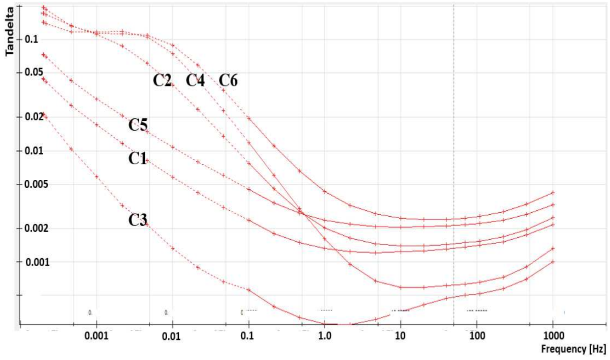
III. EXPERIMENTAL RESULTS

A. Initial Characterization (T0)

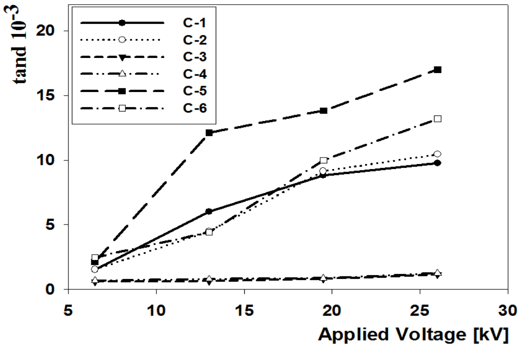
The experimental FDS and tanδ curves obtained testing the six new cable-joints before the application of the thermal cycles, are reported in Figure 1. As can be seen, FDS curves (Fig.1A) relevant to the two joint-providers, are quite different: half U-shaped for provider A; S-shaper for provider B. Since the geometrical structures of the joints are similar, it can be argued that this difference is due to the different materials adopted by the two providers.

XLPE cable-joints show lower power losses with respect the other type of joints (Fig.1B). The latter are quite similar.

These curves constitute the initial point from which ageing progression was evaluated.



A



B

Fig. 1. Experimental results obtained testing the six new cables, before the application of the thermal cycles: A) FDS and B) tanδ curves.

B. AgeingProgression (T0-T9)

Figures 2, 3 4, 5, 6 and 7 report significant FDS and tanδ curves recorded on Cables N.1, 2, 3, 4, 5, and 6, after different thermal cycles.

As can be seen from most of the figures, the initial FDS curves maintain their specific shape during ageing progression, up to the application of the last period of thermal ageing that is, half-U and S shaped curves from providers A and B, respectively, (see Figure 8). By comparing Figures 1A and 8A, FDS curves shift in the right direction thus indicating a progressive ageing as reported in literature for cables and transformers, [6, 7]. Always from Figure 8A, joints coming from Provider B show more losses than those from Provider A.

The analysis of FDS curves recorded during the ageing progression leads to interesting considerations.

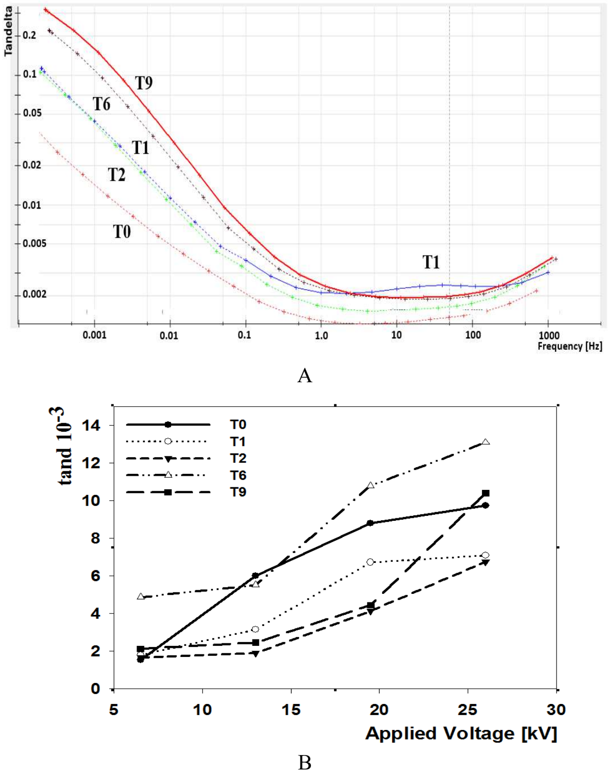
Looking at Figure 4B relevant to FDS tests on Cable N.3, equipped with homogeneous XLPE insulation (Provider A), new polarization processes are evident in the range of 1-100 Hz after periods T1, T5 and T6. Less evident polarization processes appear on FDS curves on Cable N.4 (XLPE joint, Provider B) and Cable N.1 (XLPE/Oil-Paper joint from Provider A), after Period T1 (see Figures 2A and 5A, respectively). FDS curves relevant to the other cables (Cables N.2, N5 and N.6, Figures 3A, 6A and 7A) do not present any deformation after the different thermal ageing periods.

While FDS curves relevant to Cables N.5 and N.6 equipped with homogeneous Oil/Paper joints show a quite regular ageing, represented by a right-shift of the curves in correspondence of the progressive application of the ageing cycles, those recorded on Cables N.3 and N.4 with XLPE joints present an irregular behavior. In fact FDS curves can be left-side shifted after the application of a specific ageing period, that means less polarization losses (Figures 4A and 5A). An intermediate picture is relevant to FDS curves recorded on Cables N.1 and N.2, provided with mixed XLPE/Oil-Paper cable-joints.

Since interfacial polarization processes are more evident in homogeneous XLPE joints, less evident in mixed joints and completely absent in homogeneous Oil-Paper joints, it has been argued that the additional polarization processes are due to the presence of humidity on surface of XLPE insulation. Moreover, looking at Figures 2A, 4A, 3A and 5A, the interfacial polarization is more evident in cable-joints coming from Provider A.

It is well known that below the Partial Discharge (PD) inception voltage, tanδ measurements provide information mainly on the power losses due to polarization processes at fixed frequency. Once incepted, Partial Discharges (PD) inject additional free-charges into the bulk thus increasing power losses and tanδ values, [8].

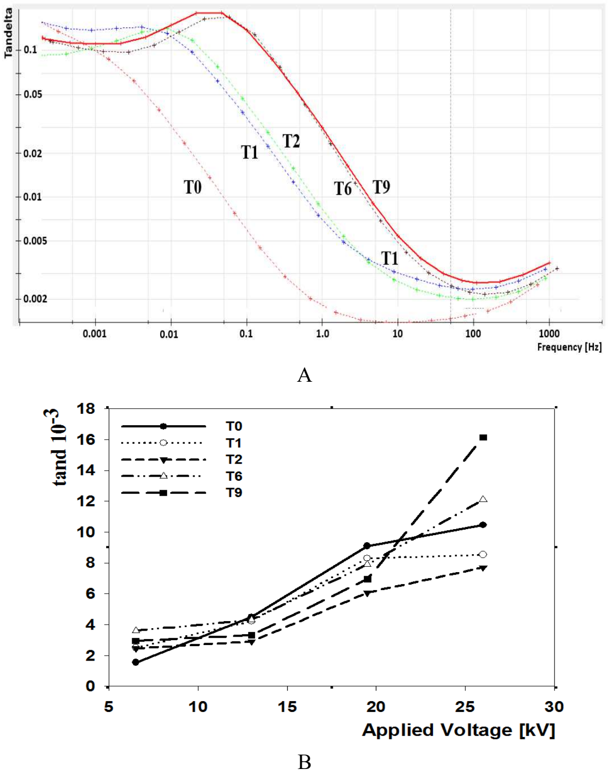
Initially, cables equipped with XLPE cable-joints (N.3 and N.4) show lower tanδ values with respect to those having homogeneous and mixed oil-paper joints (see Figure 1B). At the end of the thermal cycles (Period T9, Figure 8B), tanδ curves are well separated: lower tanδ values in homogeneous XLPE cable-joints, higher in oil-paper joints and intermediate



A

B

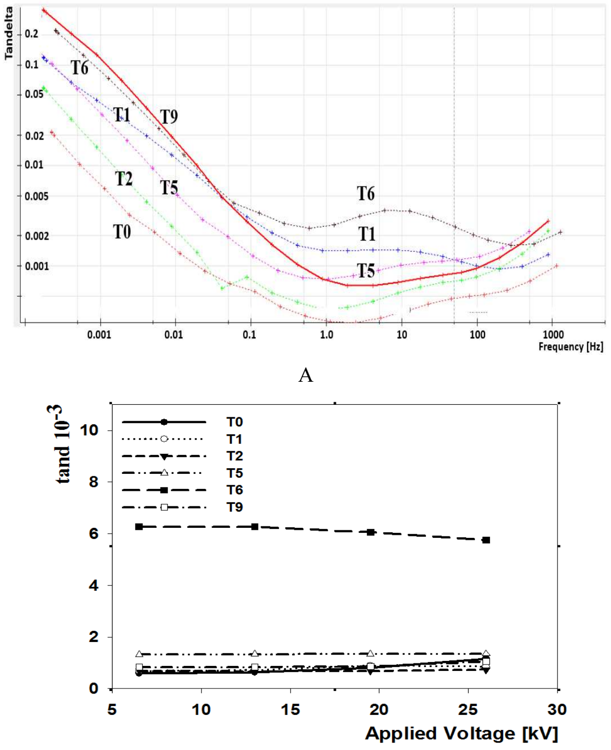
Fig. 2. Experimental results obtained testing Cable N.1 Provider A (mixed XLPE-oil/paper joint) after different thermal cycles: A) FDS and B) tanδ curves.



A

B

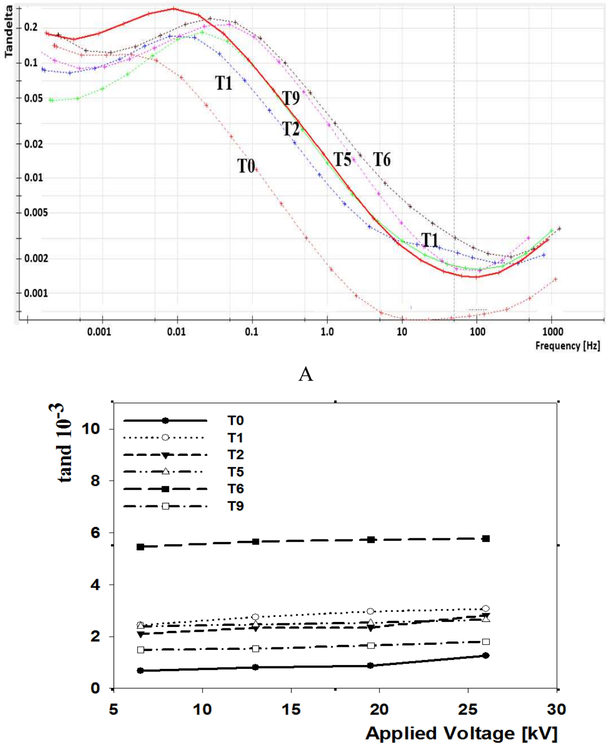
Fig. 3. Experimental results obtained testing Cable N.2 Provider B (mixed XLPE-oil/paper joint) after different thermal cycles: A) FDS and B) tanδ curves.



A

B

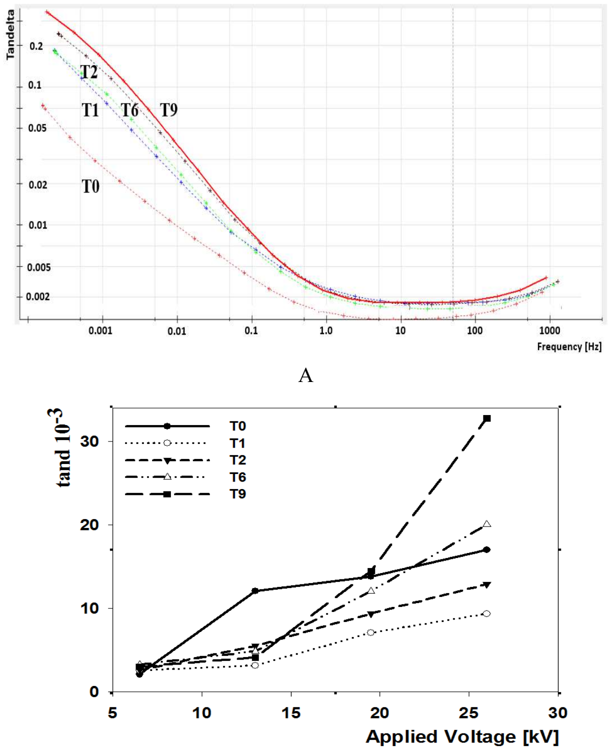
Fig. 4. Experimental results obtained testing Cable N.3 Provider A (XLPE joint) after different thermal cycles: A) FDS and B) tanδ curves.



A

B

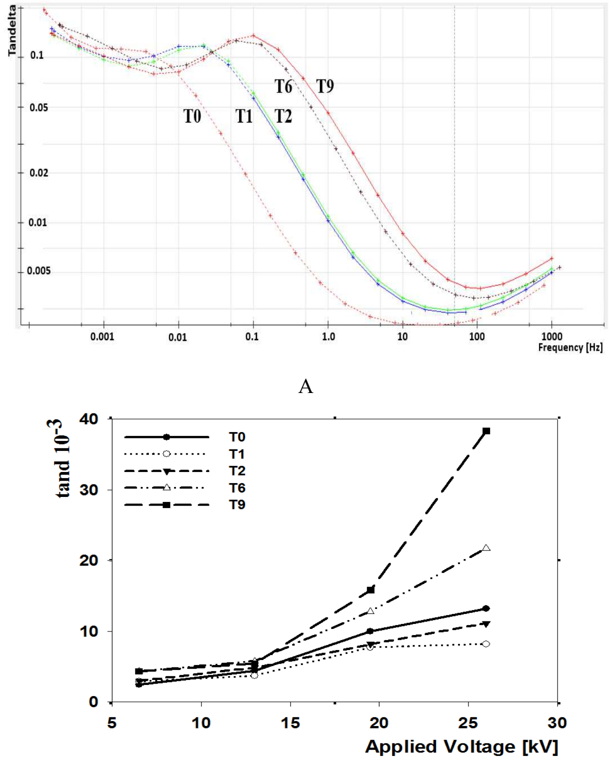
Fig. 5. Experimental results obtained testing Cable N.4 Provider B (XLPE joint) after different thermal cycles: A) FDS and B) tanδ curves.



A

B

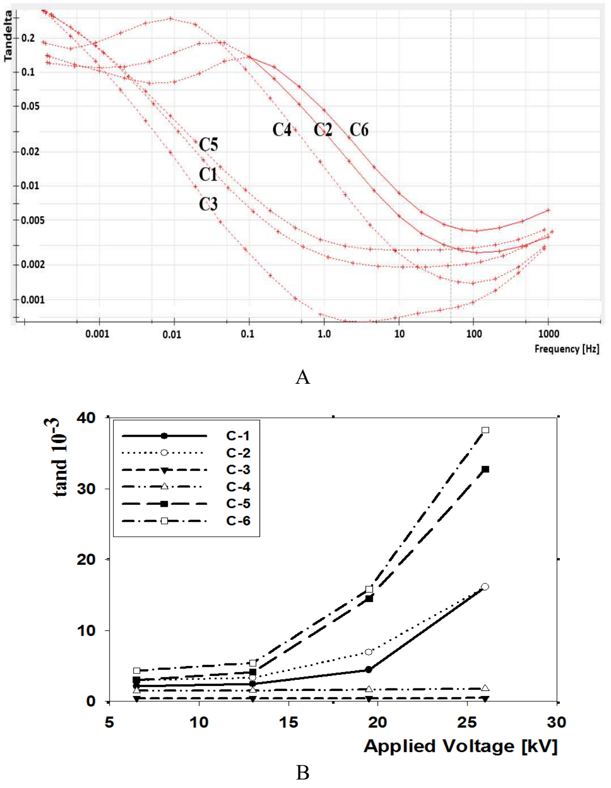
Fig. 6. Experimental results obtained testing Cable N.5 Provider A (oil/paper joint) after different thermal cycles: A) FDS and B) tanδ curves.



A

B

Fig. 7. Experimental results obtained testing Cable N.6 Provider B (oil/paper joint) after different thermal cycles: A) FDS and B) tanδ curves.



A

B

Fig. 8. Experimental results obtained testing the six new cables, after the application of the 9th thermal cycle: A) FDS and B) tanδ curves.

values between the two previous types in mixed XLPE/oil-paper joints. The different PD activity in XLPE and oil-paper insulation explains well these differences. In fact, during the ageing progression, cables with XLPE joints show tanδ curves with a very low slope thus indicating the presence of a PD activity with very low amplitude (see Figures 4B and 5B).

Moreover, only the tanδ curves recorded after period T6 differ remarkably from the others on both cables. Looking at FDS curves recorded on the same cables, it is possible to argue that this behavior is due to interfacial polarization due to humidity penetration (see e.g. FDS curves at 50 Hz in Figures 4A and 5A).

Changes in the slope of tanδ curves recorded testing cables containing oil/paper joints are evident above 13 kV (U_0) (See Figures 2B, 3B, 6B and 7B) thus indicating the presence of PD. In particular, the increment of tanδ values appears more evident in cables containing homogeneous oil/paper joints after the ageing period T6.

Below U_0, tanδ values are quite low but do not increase with the periods of application of thermal cycles. Figures 9, 10 and 11 show the behavior of FDS values recorded at 200 V and 50 Hz and tanδ values obtained testing the different cables below PD inception voltage (6.5kV, $05U_0$, 50Hz) as a function of the number of thermal cycles. In particular, Figure 9, 10 and 11 summarize data of cables C1-C2, C3-C4 and, C5-C6 (Providers A and B), respectively. As can be seen, behavior of FDS and tanδ values recorded at 50 Hz are in agreement but the real reason of their not regular behavior cannot be explained only looking at these graphs. This result demonstrates once again the importance of the information provided by FDS curves that is, the influence of humidity absorption due to seasonal weather changes (see Figures from 2 to 7).

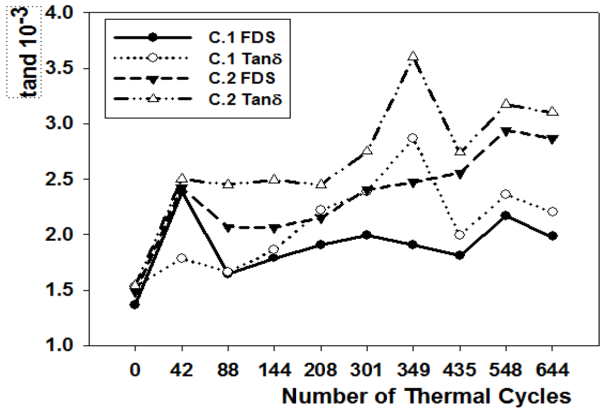


Fig. 9. Behavior of FDS values recorded at 200V, 50Hz and tanδ values recorded at 6.5 kV (0.5U0), 50Hz, as a function of the number of thermal cycles. Cables C1 and C2, Providers A and B, respectively.

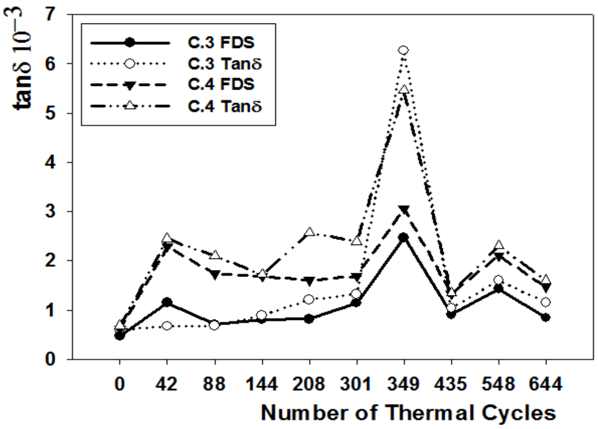


Fig. 10. Behavior of FDS values recorded at 200V, 50Hz and tanδ values recorded at 6.5 kV (0.5U0), 50Hz, as a function of the number of thermal cycles. Cables C3 and C4, Providers A and B, respectively.

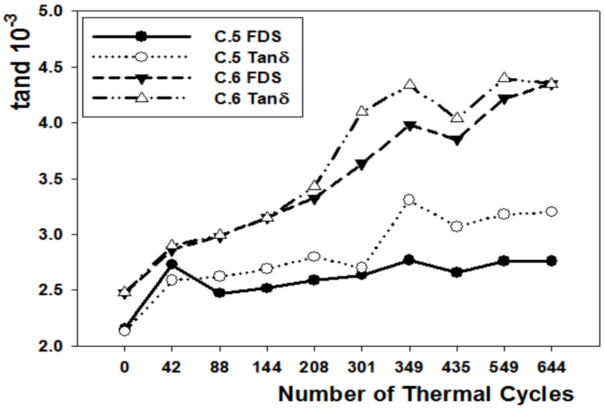


Fig. 11. Behavior of FDS values recorded at 200V, 50Hz and tanδ values recorded at 6.5 kV (0.5U0), 50Hz, as a function of the number of thermal cycles. Cables C5 and C6, Providers A and B, respectively.

IV. CONCLUSIONS

FDS and tanδ curves have been used to monitor the electric-thermal ageing progression in different types of cable joints coming from two different providers. Ageing was mainly due to daily thermal cycles applied using a particular test set-up. The experimental results shown that cable-joints of Provider B present higher power losses varying both with frequency and test voltage. Cables equipped with homogeneous XLPE joints present transitory interfacial polarization processes due to humidity absorption, in particular on Cable N.3 of Provider A. This phenomenon is less evident in cables having mixed XLPE-oil/paper cable joints and it is completely absent in homogeneous oil/paper joints. This because the humidity diffusion in the paper/oil insulation.

It was also found that tanδ curves provide less diagnostic information than FDS curves. In fact, at higher test voltages, PD activity influence tanδ values while below PD inception, these values are sensible to seasonal weather changes. These conclusions are confirmed looking at FDS curves at 50Hz.

In conclusion, cable performances can be better evaluated using FDS curves instead of the traditional tanδ test. The influence of humidity penetration can be better evidenced at lower frequencies looking at the variation of the FDS curves and the presence of additional polarization losses. Information provided by tanδ curves above PD inception voltage, can be better obtained with PD measurements.

These results clearly suggest the systematic use of FDS tests to evaluate the conditions of MV cables equipped with different types of insulation.

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