Diagnostic of Underground Cable Systems Based on the Combination of Time Domain Dielectric Spectroscopy (TDDS) and VLF Tan Delta

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ABSTRACT

Dielectric loss measurement, as a testing approach for performing condition assessment of underground cable systems, poses a number of challenges in terms of interpretation, related to the fact that it constitutes a "global" measurement. As for example, with the current tools and diagnostic features available, the use of dielectric loss measurements does not allow yet to discriminate between the various types of degradation that may be present. This paper will discuss the benefit of performing both VLF Tan δ and Time Domain Dielectric Spectroscopy (TDDS) as a combination in order to significantly improve the diagnostic interpretative information, including possibilities to discriminate problems with cable vs problems with joints. A new interpretative grid will be proposed, that includes classical and new "advanced" diagnostic features for VLF Tan δ along with a number of new proposed TDDS diagnostic features. Furthermore, a number of new preliminary interpretative criteria will also be formulated.

KEYWORDS

Diagnostics, Dielectric loss, Dielectric spectroscopy, Tan delta, Aging, Cables, Accessories

INTRODUCTION

Dielectric loss (DL) measurement, as a testing approach for performing condition assessment of underground cable systems, poses a number of challenges in terms of interpretation of the results data, related to the fact that it constitutes a "global" measurement. Indeed, the dielectric loss measured on a whole cable system is the result of the summation of all the specific loss contributions of each individual component (various pieces of cables, plus a number of accessories constituted of joints and terminations) averaged over the total direct capacitance of the cable system.

With the current tools and diagnostic features available, the use of dielectric loss measurements does not allow to discriminate between the various types of degradation that may be present. Compared to the classical diagnostic based on measurement of VLF Tan Delta (typically at 0.1 Hz), experience with dielectric spectroscopy has shown the potential to bring more interpretive information's [1][2].

Accordingly, in a first part, this paper will address and discuss the specific application of Time Domain Dielectric Spectroscopy (TDDS), which is based on polarization and depolarization currents (PDC) measurements performed with DC voltage application. This will be preceded by a theoretical review of the constitutive elements of dielectric loss (DL) and a discussion about the influence that each of these elements have on the DL spectrum characteristics.

In a second part, this paper will discuss the benefit of performing both VLF Tan δ and TDDS as a combination in order to significantly improve the diagnostic interpretative information. As an early tool, this paper will propose a new preliminary interpretive grid that takes benefit of the classical VLF Tan δ diagnostic features & criteria, along with the introduction of new "advanced" VLF Tan δ diagnostic features (proposed in a parallel JICABLE 2019 paper [11]) and new TDDS diagnostic features that are proposed in the present paper.

PHYSICS BEHIND DIELECTRIC LOSS: THE CONSTITUTIVE ELEMENTS OF DIELECTRIC LOSS

When subjected to the application of an electrical field, every kind of insulating material will undergo a polarization process. Some of the polarization mechanisms are extremely fast. Following such mechanisms, the "charging effect" within the material will be practically synched with the application of the electrical field (hence the voltage). This phenomena corresponds to what is generally known as the "capacitive charging" of the material. Other polarization mechanisms, primarily related to aging and/or degradation, are much "slower". These are the "interfacial polarization" and the "trapping & hopping of charge carriers" mechanisms [3].

If we try to express the overall process of polarization vs time as P(*t*), because of the different timing of those mechanisms, P(t) need to be described by two different terms, as shown in Equation (1):

$$P(t) = \varepsilon_0 \chi_\infty E(t) + \varepsilon_0 \int_{-\infty}^{t} f(t-\tau)E(\tau)d\tau \qquad (1)$$

Furthermore, at a certain level, every "real" (i.e. non-ideal) insulating material (in good condition) is also characterized by a conductivity component σ_o, which is obviously extremely small. However, for insulating materials that are severely degraded, another conductivity component (sometime significant) becomes present.

Taking all these processes in consideration, the total charging current vs time that will circulate through an insulating material subjected to an electrical field can be expressed in details following Equation (2):

$$\boldsymbol{i_{TOT}(t) = C_0 U_C\left(\square_\infty \delta(t) + f(t) + \frac{\sigma_o}{\varepsilon_o}(t)\right)} \qquad (2)$$

In this equation, the first term corresponds to the capacitive charging current ($\boldsymbol{i}_{Cap}$), the second term to the "polarization" current ($\boldsymbol{i}_{Pol}$) and the last term to the "quasi-conduction current ($\boldsymbol{i}_{QC}$), as summarized in Equation (3) and illustrated in **Figure 1**.

$$\boldsymbol{i_{TOT}(t) = i_{Cap}(t) + i_{Pol}(t) + i_{QC}(t)} \qquad (3)$$

In terms of impedance, the "capacitive" and "polarization" terms constitute the global capacitance of the insulation, which could be expressed as:

$$C(\omega) = C'(\omega) - j\,C''(\omega) \qquad (4)$$

where *C'(ω)* corresponds to the ideal capacitive component of the global capacitance and *C''(ω)* (*the "slow polarization term", called imaginary capacitance*) corresponds to the loss component, both terms being frequency dependent.

Typically, for an insulation in good condition, or just "mildly" aged, the quasi-conduction component could be considered as null or very negligible. In such case, dielectric dissipation factor, tan δ (ω) corresponds to the