Analysis of longitudinal interfaces by using Frequency Domain Spectroscopy

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ABSTRACT

Interfaces are a common challenge in the insulating system of medium and high voltage electrical accessory. For example, sealing interfaces have to avoid penetrating water, which can seriously influence its insulating behavior and contribute to aging. This paper presents the application of the dielectric testing method - Frequency Domain Spectroscopy (FDS) on longitudinal interfaces between two or more materials and the evaluation of its dielectric properties under the influence of moisture. The FDS-measurements show an increase of the real and imaginary relative permittivity with influence of moisture. Furthermore, the measurements over a large frequency range allow the detection of polarization mechanisms.

KEYWORDS

Dielectric Response Measurements; Frequency Domain Spectroscopy; Longitudinal Interfaces; Polarization; Moisture

INTRODUCTION

Due to the lack of acceptance of overhead cables, underground cables serve as a solution in facing the increasing demand to expand distribution networks. As a result, the insulation system of cable solutions is especially vital in ensuring the reliability of the distribution network. Generally, an inevitable problem of such insulation systems is the presence of interfaces [1]. For example, design related interfaces such as the sealing interfaces in a cable joint can prevent moisture from entering cable accessories. However, insufficient sealing interfaces could result in the corrosion of metallic parts, causing the dielectric strength of the cable accessory to deteriorate [2]. Thus, to avoid moisture penetrating into interfaces, not only is the individual evaluation of the respective materials in the interface necessary, understanding the way they behave as interfaces is also vital in designing a reliable insulation system. Several factors such as such as moisture, frequency and temperature can influence the insulation behaviour of a cable joint [2].

Previous studies on interfaces focus largely on their electric field strength under the influence of moisture. However, these tests usually mean the destruction of test samples and are thus unsuitable for testing on large numbers of specimens. Re-drying of the test samples can also occur due to the high voltages, thereby influencing test results. Regarding this, dielectric response methods such as Frequency Domain Spectroscopy (FDS) and Polarization and Depolarization Current (PDC) propose to be an appropriate alternative to the otherwise destructive electric field strength test. These dielectric response methods allow the dielectric properties of a material to be determined as a function of frequency or time, thus being able to detect changes of dielectric properties in the insulation system. Both are common diagnostic tools in analysing the oil-paper insulation of power transformers [3]. Moreover, re-drying processes could be avoided through these dielectric response methods.

This paper explores the application of a dielectric response analysis - Frequency Domain Spectroscopy (FDS) - in assessing the condition of longitudinal interfaces under the influence of moisture.

DIELECTRIC MATERIALS

Frequency Response of Dielectric Properties

Each dielectric material consists of positive and negative charges at an atomic level. Applying an electric field on the material can cause different effects, namely polarization and conduction processes. Polarization can be classified into four types, each with different polarization speed [4]:

Electronic Polarization: The electric field causes the displacement of the centre of gravity of the electrons. This process is very fast and is effective up to optical frequencies [4].

Atomic or Ionic Polarization: describes the displacement of atoms or ions, causing the distortion of the original lattice formation. This can occur up to infra-red frequencies [4].

Orientation Polarization: occurs only in materials with polar molecules, also known as dipoles. Under the influence of an electric field, the dipoles rotate to align with the field. This can occur up to the frequency range of MHz or GHz.

Interfacial Polarization: occurs between two insulating materials with different permittivity and conductivity, due to congestion of charges at the macroscopic und microscopic interface [4]. This mechanism is slow and is typically found in frequencies below mHz.

When a sinusoidal voltage is applied to the material, the measured current leads the voltage ideally by a phase angle of ϕ = 90°. In practice, due to polarization and conduction, this phase angle is always less than 90°. This angle $\delta = 90° - \phi$ is known as the loss angle, tan δ is defined as the loss factor – also the ratio between the active (P) and reactive power (Q) [5].

Tan δ is defined as the sum of polarization loss $\tan \delta_P$ and conduction loss $\tan \delta_L$ in equation (1) [5]:

$$\tan \delta = \tan \delta_L + \tan \delta_P \quad (1)$$

The frequency response of tan δ can be used to describe polarization and conduction processes in a solid dielectric [5]. In [5, 6], the conduction loss is defined as:

$$\tan \delta_L(\omega) = \frac{1}{\omega \cdot \rho_D \cdot \varepsilon_0 \cdot \varepsilon_r'} = \frac{\varkappa}{\omega \cdot \varepsilon_0 \cdot \varepsilon_r'} \quad (2)$$

Where: ρ_D = specific volume resistivity (Ωm)
$\varkappa$ = specific conductance (S/m)