LOW FREQUENCY DIELECTRIC SPECTROSCOPY APPLICATIONS TO AGED MEDIUM VOLTAGE POWER CABLE DIAGNOSTICS

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ABSTRACT

Low frequency dielectric spectroscopy (LFDS) based dielectric loss diagnostics on aged MV cable systems can provide unique advantages over 'conventional' fixed frequency 0.1Hz (VLF) tan δ measurements. Such advantages include enhanced interpretative potential and ability to discriminate between various aging mechanisms. Despite the above advantages, there is very limited published information on field experiences with LFDS based techniques for MV cables. This paper will present currently utilized field application protocols for MV cable LFDS, frequency domain dielectric spectroscopy (FDDS) based experience case studies, and FDDS interpretation guidance to extend the value of dielectric loss based condition assessment beyond that gained from fixed 0.1Hz VLF tan δ measurements alone.

KEYWORDS

Dielectric spectroscopy, condition assessment, FDDS, LFDS, TDDS, VLF, medium voltage cable

INTRODUCTION

The need for new diagnostic methods to assess the condition of cables led to extensive research in the 1990s and early 2000s to characterize changes in dielectric properties of insulation systems [1][2]. The successful application of Frequency Domain Dielectric Spectroscopy (FDDS) and Time Domain Dielectric Spectroscopy (TDDS) to monitor the insulation of power transformers paved the way for the development of commercial equipment to perform these tests in the field and provided insights into the potential for these technologies to test cables.

Oil-paper and mass-impregnated cables were found to be well suited for the use of dielectric spectroscopy techniques, due to their similarities with power transformer insulation systems [2]. Neimanis et al. showed that the average moisture content in mass-impregnated cable insulation could be estimated by measuring the minimum value of tan δ in the 10^{-3} to 10^{3} Hz range and using a master calibration curve developed in the laboratory [3]. Lennon further demonstrated the sensitivity of FDDS to changes in moisture content in paper insulation of mass-impregnated cables caused by thermal aging [4].

For extruded cables, and specifically XLPE insulated cables, the initial focus of dielectric spectroscopy was characterization of water related degradation through FDDS [2]. Werelius et al. demonstrated the sensitivity of the technique to water treeing damage in the 10^{-1} Hz to 1 Hz range [5]. The frequency and voltage-dependent dielectric loss (tan δ) and capacitance were noted to be useful parameters to monitor. Subsequent work found similar results for tests conducted in the field and the laboratory [6][7][8][21]. The voltage dependency of tan δ at low frequency for water related damage was also highlighted in these publications. These studies, and others not included in this short review, led to the development of the Very Low Frequency (VLF) – 0.1 Hz - tan δ methodology and associated acceptance criteria that is widely used today to characterize water related degradation of cables in the field [9]. Features from FDDS results have been used to characterize the severity of water treeing in XLPE insulated MV cables, and in particular discriminate the effect of bridging versus non-bridging water treeing effects [5][6][10][21]. FDDS has also been shown as sensitive to thermal related degradation of the cable insulation in the 10^{-4} to 10^{2} Hz range, especially in terms of tan δ and capacitance frequency response [11][12][13].

FDDS measurements conducted in the lower frequency range (i.e. below 0.1 Hz) require longer times which are not always practical in the field. The application of TDDS can provide a faster means to obtain very low frequency characterization of the dielectric material while providing additional defect discrimination benefits. An up to date review of TDDS application and interpretation for MV cable systems is provided in [14] by Institut de recherche d'Hydro-Québec (IREQ), who have conducted extensive investigations in the application of this technique.

This limited literature review shows that FDDS can provide enhanced diagnostic capability for insulation degradation when compared to fixed low frequency testing at 0.1 Hz, with the potential to discriminate between different types of aging. However, little practical information is available in the literature about field deployment of this technique. This paper thus introduces field validated methodologies for FDDS testing, recommendations for interpreting FDDS test results, and a few FDDS based case studies highlighting their unique diagnostic features. The content of this paper is based on more than a decade of practical field experience from FDDS testing of primarily 5 – 15kV extruded and oil-paper cable systems in utility and plant environments.

THEORY

As noted in the introduction, Zaengl [1] provided a detailed description of the theory behind FDDS testing. Only a brief overview of this theory is thus included here.

FDDS testing is used to illustrate the frequency dependence of the dielectric loss (tan δ) and capacitance of a test object, although voltage, time and temperature dependence characteristics of tan δ and capacitance can also be illustrated through multi-variable measurements. FDDS results are obtained from direct, highly accurate measurements of the complex impedance over variable voltage and frequency, calculated using Ohm's Law $Z^* = U/I$ (where Z and U/I are complex entities). Although various impedance models can be used, the complex