

## TEMPERATURE DEPENDENCY OF DIELECTRIC LOSS MEASUREMENTS AT 0.1 HZ IN MEDIUM VOLTAGE POWER CABLES

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### ABSTRACT

*Laboratory-based experiments were performed to investigate how dielectric loss measurements of defect free XLPE power cable samples responded to changes in the insulation temperature. The results showed that  $\tan \delta$  values changed significantly and non-linearly as the temperature varied from 4°C to 65°C. The trend was consistent and independent of the test voltage and confirms similar findings by other researchers. The phenomenon is interpreted in terms of the hopping conduction model in polymers. Possible implications of these findings on in-situ  $\tan \delta$  diagnostic tests are discussed.*

### KEYWORDS

Tan  $\delta$ ; temperature dependency; non-linear relationship; diagnosis standards; 0.1 Hz test voltage, hopping conductivity.

### INTRODUCTION

Dielectric loss factor (also known as  $\tan \delta$ ) is now a popular diagnostic parameter in shielded power cables [1]. It is a measure of cable insulation power losses. Degradation of the cable insulation such as that caused by ageing, water trees, electrical trees or partial discharges manifest as increased  $\tan \delta$ . In diagnostic tests absolute values of the  $\tan \delta$  are compared with the anticipated values for new and aged cables (per cable type) as prescribed in standards such as the IEEE std 400<sup>TM</sup>-2001 [2] and IEEE Std 400.2<sup>TM</sup>-2004 [3]. Furthermore the degree of change in the  $\tan \delta$  as the test voltage is increased (tip up) is also used as an indication of the healthiness of the cable insulation.

Tan  $\delta$  measurement is a global condition assessment of insulation. This is often a limitation in this method of cable diagnosis since in most cases specific location of defects may be desired. In that regard  $\tan \delta$  diagnostic tests are performed in conjunction with other condition assessment techniques such as partial discharge tests [4].

In line with the benefits of low frequency test voltages in power cable diagnosis,  $\tan \delta$  measurements are now widely performed using low frequency test voltages such as 0.1 Hz [4].

A literature survey shows that there has been sustained research work in how dielectric losses in polymer insulation depend on three key variables, namely: (a) test voltage frequency, (b) test voltage magnitude and (c) temperature of the insulation. The knowledge on the relationship between  $\tan \delta$  and test voltage characteristics (frequency and magnitude) has advanced to the extent of being recognised as diagnostic criteria in popular standards such as the Std 400.2<sup>TM</sup>-2004 [3]. The same

cannot be said about the influence of temperature on  $\tan \delta$  measurements. The IEC 60840:2004 standard [5] specifies that  $\tan \delta$  tests should be taken while the cable core conductor is at  $\pm 5^{\circ}\text{C}$  to  $10^{\circ}\text{C}$  above maximum allowable temperature; this is presumably for factory tests. The IEEE Std 400<sup>TM</sup>-2001 which is for field testing of shielded power cable systems, does not explicitly prescribe temperature conditions. Recent studies on  $\tan \delta$  by the likes of Hernández-Mejía et al [6,7] also unfortunately did not include  $\tan \delta$  – temperature dependency. It can therefore be generalised that standards and field experience reports on  $\tan \delta$  diagnosis are silent on how temperature influences the  $\tan \delta$  factor. On the other hand, literature on mainly laboratory based research, consistently reveals that dielectric losses significantly change with changes in the insulation temperature in most dielectrics.

Given that there are other factors that significantly influence cable temperature such as climatic conditions, type of backfill and ground temperatures, it is most likely that in practice, in situ  $\tan \delta$  tests can be performed at a wide range of cable insulation temperatures. A question therefore arises: to what extent are  $\tan \delta$  results compromised by taking measurements at different insulation temperatures?

This paper presents work on an investigation into the influence of temperature on  $\tan \delta$  measurements performed with a test voltage frequency of 0.1 Hz. The rest of the paper is structured as follows: firstly a summary review of sampled literature on the influence of temperature on  $\tan \delta$  measurement and then a description of the experimental procedure followed by results presentation and discussion.

### A REVIEW OF RESEARCH KNOWLEDGE ON TEMPERATURE DEPENDENCE OF DIELECTRIC LOSSES

A summary of key findings in literature pertaining to research on how  $\tan \delta$  measurements depend on temperature is given in Table 1 below. A common ‘golden thread’ that runs throughout the findings of various researchers is that  $\tan \delta$  varies significantly and non-linearly with variations in temperature of the dielectric. The degree of variations and whether with peaks or not, and the location of the peaks depends on the dielectric types and the test voltage frequency.

The work reported in this paper seeks to contribute to this knowledge by performing  $\tan \delta$  - temperature dependence tests on cross-linked-polyethylene (XLPE) cable samples as presented in the experimentation section.