DC conductivity measurements of polymeric HVDC insulation materials under consideration of a dynamic temperature profile

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ABSTRACT

Detailed consideration and evaluation of DC-specific influences on insulation systems of cables and accessories must be taken into account during the development process for extruded HVDC cable systems.

In this paper, a novel method for evaluating polymeric insulation materials is described, using DC conductivity measurements under a dynamic temperature profile. A general overview and evaluation of the apparent DC conductivity measurement set-up is given. Preparation of the test samples and the applied test profiles are presented. Inestigations of apparent DC conductivity measurements on LDPE and XLPE samples are described and discussed.

KEYWORDS

HVDC, Cable, LDPE, XLPE, DC Conductivity

INTRODUCTION

With the devlopment use of regenerative energy sources and the increasing distances between energy generation and consumption, HVDC cable systems play a significant role in grid stabilization and the transmission of energy over very long distances. The demand for increasing HVDC power ratings has led to the continuous development of higher system voltage levels. However, the impact of DC-specific influences on cable and cable accessory insulation systems requires a detailed understanding of electrical insulation system behaviour.

According to Maxwell's equations, the electric field distribution in HVDC insulation systems is controlled by the conductivity *σ*, as shown in equation (1):

$$J = E \cdot \sigma \qquad [1]$$

where *E* is the electric field strength and *J* is the current density. The conductivity *σ* of a solid insulation material is expressed in the form of an Arrhenius equation in equation (2) according to [1].

$$\sigma(E,T) = Ae^{\left[\frac{-\varphi \cdot q}{k_B \cdot T}\right]} \cdot \frac{\sinh(B \cdot |E|)}{|E|} \qquad [2]$$

Here, φ is the thermal activation energy, k_B the Boltzmann constant, *T* is the temperature and *q* is the elementary charge. A and B are constants relating to the temperature and electric field dependency.

Investigations into the apparent DC conductivity of HVDC insulation materials have been discussed in detail in numerous studies, [e.g., 2, 3]. Most of the investigations focus on static temperature conditions. However, HVDC cable systems experience a wide variety of thermal conditions during development testing, qualification testing and system operation. The thermal system boundaries are specified by the cable conductor temperature, ambient thermal conditions, cable design, and material thermal properties. Hence, the understanding of electrical conductivity under dynamic temperature profiles is essential for the development of innovative HVDC insulation systems.

In this paper, a novel method for investigating the apparent DC conductivity under dynamic temperature profiles is presented. Besides the discussion of the measurement set-up and sample preparation, results of the apparent DC conductivity measurements on low-density polyethylene (LDPE) and cross-linked polyethylene (XLPE) plaque samples are given and discussed.

MEASUREMENT OF APPARENT DC CONDUCTIVITY

Measurement of apparent DC conductivity is a common material characterization method in the field of solid insulation materials [1, 2, 3]. The apparent DC conductivity σ_a of a test specimen is evaluated according to equation (3) as

$$\sigma_a(t) = \frac{i_a(t) \cdot d}{U \cdot A} \qquad [3]$$

where *d* is the sample thickness, *U* is the applied test voltage and *A* is the effective measurement electrode area given by the electrode design, considering the fringing effect, with $A = \pi(D_1+Bg)^2/4$ [5].

The measured current through a polymeric test specimen $i_a(t)$ can be described as a superposition of various conduction and polarization mechanisms. Typically, the measured current through a test specimen is expressed following [4] in equation (4):

$$i_a(t) = i_l(t) + i_p(t) + i_{sc}(t) + i_c(t) \qquad [4]$$

where $i_l(t)$ stands for the charging current caused by application of a DC step voltage, $i_p(t)$ is the polarization current, $i_{sc}(t)$ is the current caused by the existing space charge and $i_c(t)$ is the conduction current.

The intricate relationship between long-term relaxation processes and complex conduction mechanisms requires consideration of the conductivity-time behaviour $\sigma_a(t)$. Several scientific studies describe the conductivity-time behaviour of polymeric insulation materials, using the Curie-von Schweidler law with $\sigma_a(t) \sim t^{-n}$, among other techniques [2].