Long-Term behavior and analysis of selected polymeric LVAC cables under thermal, electric and moisture multi-stress with DC Voltage.

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ABSTRACT

This paper gives an overview of and highlights the importance of LVDC applications with emphasis on polymeric cable insulation. Results of short-term breakdown voltage and long-term behavior of various polymer insulated low voltage cables are presented and discussed.

KEYWORDS

PVC, LVDC, dehydrochlorination, thermal degradation, long term behavior

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INTRODUCTION

The use of direct current (DC) is common for the transmission of electrical energy over long distances (HVDC) due to the reduction of typical AC losses and for interconnection of AC grids when their frequency shall be decoupled. For low voltage (LV) applications, there is also a trend towards DC, albeit for different reasons. LV is defined as 1 kV for AC and 1.5 kV for DC [1].

Most LV loads in households and industries operate at DC, either required to or able to do so. For households the benefit might come from simpler construction of devices needing only an DC-DC converter and no rectifier. Battery storage in combination with photovoltaic is easier and more efficient to install, however, a hybrid approach may be the most efficient. [2], [3] In the industries benefits arise from recuperation of variable drives if the DC-Grid is acting as the intermediate section of a converter [4]. With power cables, there is also a benefit regarding Ohmic losses in the cable due to higher voltage compared to common 400 V AC grid. The higher voltage of nominal 650 V is a direct consequence of the intermediate section of the converters [5], [6].

With the electrification of traffic, the board grid of cars rises from 12 V to low voltage range (up to 800 V) [7]. Also, on ships, there is an application for DC grids [8].

There is a broad range of applications for polymeric cable insulation. Typically, one polymer material will not cover the entire range.

Few studies show and investigate failures of LV cables [6], [9]–[13] (not a full list). Failure may occur for different reasons than failures in HVDC cables. Therefore, Investigation and Research is necessary.

STATE OF THE ART

In this section a brief overview of theory for electric currents in polymers is given. Also, analysis methods used in this paper are introduced shortly.

Theory

Ampere's Law with Maxwell's addition:

$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \dot{\boldsymbol{D}} \tag{1}$$

Can be separated in conduction, displacement and polarization current and written as:

$$\nabla \times \boldsymbol{H} = \sigma(\vartheta)\, \boldsymbol{E} + \varepsilon_0\, \dot{\boldsymbol{E}} + \dot{\boldsymbol{P}} \tag{2}$$

Current trough the dielectric at AC is dominated by the capacitive displacement current $\varepsilon_0\, \dot{\boldsymbol{E}}$. At DC the displacement current decays when the time derivative becomes zero. When the material is polarized, the polarization term $\dot{\boldsymbol{P}}$ becomes zero as well and the current is therefore dominated by the remaining conductivity $\sigma(\vartheta)$.

Thus, a different behavior of the insulation and a different engineering is to be expected and observed at HVDC cables [14], [15]. However, due to lower field strength, water and electrical trees are not expected to be an issue [16].

There are several polarization processes taking place, the ones with a longer time constant are orientation of dipoles with ranging from pico seconds to hours and polarization at interfaces with significantly longer time constants due to limited mobility of charge carriers. [17], [18]

Mechanical and chemical defects leading to deep traps are generally an issue in HVDC applications due to the high electric field strength. One may assume these are of no concern for LV applications due to the much lower field strength. However, with high amount of additives and filling material, the number of defects is strongly increased leading to significantly reduced space charge inception voltage [19].

Shallow traps may contribute significantly to charge transport via hopping conduction, therefore a higher conductivity of highly filled materials is to be expected. [20]