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SENSITIVITY OF PD INCEPTION TO CHANGE OF ELECTRICAL DESIGN IN POLYMERIC INSULATED POWER CABLE SYSTEMS

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ABSTRACT

A methodology was developed to calculate the partial discharge inception voltage in MV, HV and EHV cable systems for different electrical designs. By doing so, the sensitivity of the PD inception voltage to change in design of the insulation system can be defined and quantified. As the result, the effect on the change of the acceptable maximum size on potential defects may be estimated, indicating the increase of risk on PD inception when changing the design. The methodology and calculations presented quantified the extend to which the quality of the extrusion process as well as the precision of accessories assembly must be maintained or improved to assure discharge free operation of cable systems after design modifications. They also show that margins specified in the range of type approval in the current IEC standards are sufficient and that they should not be broadened.

KEYWORDS

Partial discharge, inception voltage, power cables, XLPE insulation, design modifications, voids, fissures.

INTRODUCTION

The insulation of power cables and their accessories has to be able to withstand electrical fields of high magnitude. Small impurities, voids or fissures distort this electrical field and can cause small, partial, discharges to occur if the local electrical field becomes higher than the local breakdown strength. Partial discharges (PDs) themselves cause further deterioration of the insulation material and therefore shorten the lifetime considerably. Discharge-free operation of power cable systems is therefore paramount to a safe and long operation lifetime of power cable systems.

To verify the insulation integrity, international standards, such as IEC60502, IEC60840 and IEC62067, as well as national standards describe the required set of pre-qualification and type tests. Tests like this are essential for safe and reliable operation of HV equipment. But inevitably, with every kind of test there are time and costs involved. Therefore, the standards also include a range of type approval, where the ranges of the applicable design parameters are defined for which the tests of only one variant are valid. From this, the question has arisen whether the range of allowable dimension variations can be widened further in order to reduce the amount of testing associated with a new design. For this reason, CIGRÉ Working Group B1-06 was formed in 2002 with the task to revise these ranges of approval.

If the dimensions of a power cable change, the electrical field strength will also change, and with this the risk on PDs. An important aspect of the investigation of the CIGRÉ Working Group B1-6 was therefore to investigate the influence of dimensional change on the risk of PD occurrence. Specific recommendations resulting from this analysis were published by CIGRÉ [1]. The aim of this paper is to present a systematic analytical approach developed for this purpose.
The topic of the mechanisms of partial discharges in solid dielectrics is well covered in literature, however, few articles refer directly to partial discharge inception in high voltage cable insulation. Three-phase belted cables pose special challenges in this respect. This is addressed in [2] with the focus on PD excitation, the induced voltages on the surrounding conductors resulting from PDs and their resulting detectability. The PD inception voltage in single-core cables with radial electrical field in the insulation was investigated in [3] and [4], focussing on conditions for discharge-free operation itself. Generally, and these two papers serve as an example, such work is done by either computer simulations or focussing on a narrow range of power cables from one specific class.
To enable such analysis to apply over the entire range of practical cable designs, we have developed a methodology based not only on absolute values of dimensions, electric stresses and breakdown voltages, but added sensitivity relations between these parameters. These sensitivity parameters allow a clear view on how varying a particular design parameter would influence all the others. This paper uses this methodology to relate the dimensional change to the maximum defect size allowed for a discharge-free operation. This relationship is demonstrated for a range of practical cable dimensions with some examples given. The methodology is valid for the complete range of MV, HV as well as EHV single-core power cables.

ELECTRICAL STRESSES IN POWER CABLES

We restrict our analysis to concentric electrical fields found in screened single-core power cables, which form the majority of installed cable population. An interesting study of electrical field distribution and partial discharge propagation in three-phase belted cables can be found in [2].

The electric field intensity E_x at a radial location x in a concentric cable is expressed by a well known formula

$$E_x = \frac{U_0}{x \ln \frac{R}{r}} \tag{1}$$

where r and R are the radii of the conductor and the insulation shield respectively and U_0 is the voltage between