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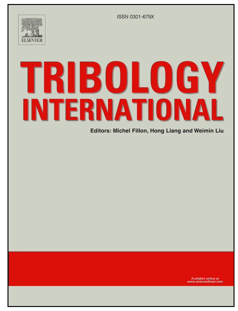

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Emre Kantar, Sverre Hvidsten, Frank Mauseth, Erling Ildstad

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A Stochastic Model for Surface Asperities at Polymer Interfaces Considering Contact Pressure, Elasticity and Surface Roughness

Emre Kantar[a,*], Sverre Hvidsten[b], Frank Mauseth[a], Erling Ildstad[a]

[a]Department of Electric Power Engineering, NTNU, O.S. Bragstads Plass 2E, 7491 Trondheim, Norway
[b]SINTEF Energy Research, Stiftelsen SINTEF, P.O. Box 4760 Torgarden, 7465 Trondheim, Norway

Abstract

Morphology of the contact area between solid insulation materials ultimately determines the long-term electrical properties of the complete insulation system. The primary purpose of this paper is not only to propose a statistical model to scrutinize the real area of contact between solid dielectric surfaces but also to verify and correlate the model outputs with experiments. The model computes real area of contact, number of contact spots and average cavity size at the interface as a function of elasticity, contact force and surface roughness. Then, using the average cavity size and the Paschen's law, cavity AC partial discharge inception field strength (PDIE) is calculated. As experiments, AC breakdown strength (BDS) testing of solid-solid interfaces was carried out, where cross-linked polyethylene (XLPE) samples with four different surface roughnesses were subjected to various contact pressures.

Following the increased contact force, the calculated average cavity size decreased by a factor of $4.08 - 4.82$ from the roughest to the smoothest surface, that in turn yielded increased PDIEs by a factor of $2.01 - 2.56$. Likewise, the experimentally obtained BDS values augmented by a factor of $1.4 - 1.7$ when the contact pressure was elevated from 0.5 MPa to 1.16 MPa.

A linear correlation between the PDIE and BDS was assumed, yielding a correlation coefficient varying within $0.8-1.3$. When the 90% confidence intervals were considered, the range reduced to $0.86 - 1.05$. This close affinity suggests that interfacial breakdown phenomenon is strongly governed by the cavity discharge. Hence, the proposed model is verified with experiments.

Keywords: Cables, contact surface, contact mechanics, elastic, optical microscopy, polishing, polymer, texture, XLPE.

1. Introduction

The series connection of two or more dielectric materials constitute the electrical insulation system in most high voltage apparatus. The alternating current (AC) breakdown strength (BDS) of insulation systems is limited by the lowest BDS of either the bulk insulating materials or the interface between the adjacent insulating materials. The interfacial breakdown between two solid insulating materials is complex and accounts for one of the principal modes of failure for power cable joints [1]. The interface increases the risk of tracking failure due to the local electric field enhancements caused by the imperfections at the interface such as microscopic cavities, protrusions and impurities [2–6].

Cable accessories as power cable joints, outdoor composite terminations, and subsea connectors have solid-solid interfaces, which undergo electrical stress in the course of entire service life by the tangential component of the electric field [3]. Hence, it is of paramount importance to study and identify the parameters affecting the breakdown strength of such interfaces to develop cost-effective, long-lasting, and most importantly, reliable high voltage apparatus and equipment. With this motivation, many researchers and engineers have studied polymers, as insulating materials in cable accessories to a large extent [2–7]. The impacts of contact pressure and surface roughness on the interfacial BDS were studied in [1–5], where a higher interfacial pressure and a smoother surface reportedly led to an increased tangential BDS. However, mostly only empirical studies have been performed using the complete designs of connectors, accessories, and apparatus. The polymer interfaces should be scrutinized separately and diligently by considering the contact surface texture, type of the contact (i.e., elastic or plastic), surface roughness, elasticity modulus and applied contact force. Thus, comprehensive theoretical models incorporating these parameters should be developed in addition to the experimental studies in the literature because the understanding of tribological principles dominating in solid interfaces paves the path for the successful design of advanced apparatus.

The primary motivation of this paper is to model the contact surfaces between solid materials as a function of the applied mechanical contact pressure, surface texture/roughness, and elastic modulus using the tribological principles presented in [8–15]. For this purpose, a stochastic model of multiple-asperity dry contacts

*Corresponding author. Department of Electric Power Engineering, NTNU, O.S. Bragstads Plass 2E, 7491 Trondheim, Norway.
Email address: emre.kantar@ntnu.no (Emre Kantar)

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