Local surface field- and charge distributions and their impact on breakdown voltage for HVDC cable insulation

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ABSTRACT

The surface topography on material interfaces plays a crucial role in performance of HVDC cable systems. In this work, the texture of interfaces was analyzed and its impact on electric field distributions at the surface was simulated. It was found that the effect of roughness and field dependent bulk conductivity of the insulation on the field distribution is associated with significant local quantities of space charges accumulated at the surface. It is shown that charge accumulation and corresponding local electric field enhancements are the parameters defining local conduction, injection and material degradation at insulation interfaces. A correlation between simulated/calculated field distributions and ramped DC breakdown voltages on cable peelings was observed.

KEYWORDS

HVDC, XLPE, cable accessories, surface preparation, cable peelings, roughness, surface topography, electric field distribution, space charge, DC breakdown voltage.

INTRODUCTION

Introducing significant amounts of renewable energy sources in the power grid creates new challenges in power transmission infrastructures. Fluctuations in the power output of such resources and production remoteness (far away from urban centers) may be challenging to match with daily consumer needs. Implementing HVDC transmission systems can overcome some of these challenges by providing fully controllable long-distance power transmissions with low losses. This allows for operators to level out supply-demand imbalances over a larger geographical area.

HVDC cable technology with thermoset cross-linked polyethylene (XLPE) benefits from having improved short-circuit thermal stability over thermoplastic insulation types (homopolymer or polymer blends) [1], and in addition features higher rated operating temperatures compared to conventional mass-impregnated insulation materials [1]. Such a system has been qualified for a rated voltage level of 525 kV [2]. The elastomeric pre-molded joints used in this cable system allow for electrical factory acceptance testing and a reliable installation process.

On-site manufacturing of an HVDC cable accessory commences by removing the outer semiconductive layer from the cable. This removal can be realized using different cable preparation methods. Depending on this method, different degrees of surface roughness and topographical features can be obtained. This difference impacts electrical performance of the thermoset-elastomer interface in the manufactured component. Understanding the relation between topography, local electric field distributions, and space charge related phenomena may allow for better design and control of interface quality. It will thus ensure long-term reliability of the component within the HVDC cable system.

Earlier work [3, 4], showed that very different degrees of roughness, texture, topography, and surface free energy can be obtained depending on preparation method. It was shown that these characteristics affected not only DC breakdown channel shape, but also the voltage level at which it occurred for MV sized DC cables. This work thus aims to expand on our earlier work [3], by using the obtained profilometry data to quantify the local field and charge magnitudes at the surface. By relating these to our previous breakdown tests [3] and additional breakdown tests in this work, we can better understand the local conditions and phenomena that trigger electrical breakdown.

EXPERIMENTAL

The test samples were cable peelings obtained from the surface of a prepared full-size cable end. The insulation material (DC grade XLPE) was priory degassed and subjected to AC screening according to normal industrial procedures. Once the desired surface texture had been prepared, peelings were cut off, using a rotational cutting tool. This created thin parallel-plane samples with suitable geometry, as shown in Fig. 1.

Five different surface types were used in the investigation; “A: rough abraded”, “B: abraded”, “C: smooth abraded”, “D: backside” and “E: remolded”. Their alphabetic notation (A – E) is arranged from roughest to smoothest. All surfaces are obtained with different preparation methods, except for the backside surface obtained after cutting in the peeling process. The samples have their declared surface type on one side and a backside surface type on the other side. This configuration originated from the peeling process indicated with step 2 in Fig. 1. The peeling samples benefit from having identical surface texture and morphology to what can be realized in an on-site accessory installation.

All cable peelings were stored in an incubator at around 10-12 % related humidity (RH) to reduce the effect of moisture and to allow for additional outgassing as confirmed in previous measurements [3]. The content of crosslinking by-products was thus kept at very low levels in this study as well.