A Method for Experimental Assessment of Interactions between Cable and Accessory Insulation Materials in HVDC Cable Joints

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ABSTRACT

Development testing of insulation materials for HVDC cable and joint should consider not only the solid dielectrics but also the lubricant used for installation, and focus on the compatibility between these components which form a macroscopic dielectric interface. This paper develops and discusses a test sequence aimed at testing the compatibility based on standardized electrical measurements.

KEYWORDS

HVDC, cable joint, interface, multilayer, XLPE, SIR, space charge, conductivity, compatibility, experiment

INTRODUCTION

Space and surface charge accumulation in HVDC cable joints results from dielectric mismatch between cable and joint insulation not only because of the structural differences between their bulk materials but also from their respective surfaces [1, 2]. The presence of these trapped charge carriers leads to a distortion of the electric field distribution at the macroscopic material interface, which can make the cable joint prone to premature failure if the charge accumulation is not carefully controlled [3].

Apart from the solid cable and joint insulation – typically cross-linked polyethylene (XLPE) is used for the former and an elastomer such as ethylene propylene diene monomer (EPDM) or silicone rubber (SIR) is used for the latter – lubricants required to install the accessories remain at the solid surfaces. Commercially available lubricants for cable accessories usually consist of silicone oil and approximately 40-60 wt. % inorganic fillers added to control the rheological properties such that a pasty grease with thixotropic behavior results [4, 5, 6].

Immediately after installation of the joint, the lubricant fills up any possibly remaining air gaps between the two adjacent solid insulation materials, resulting in a higher partial inception voltage and dielectric strength of the interface, and the charge dynamics are not significantly affected compared to non-greased interfaces without any air gaps [7, 8, 14]. However, over the lifetime of the cable system, the liquid and solid phases of the lubricant may separate, a process known as ‘bleeding’.

The low molecular weight components of the silicone oil will migrate into the cable and joint insulation and cause swelling, resulting in a decrease in electrical resistivity due to an increase in free volume [4, 5, 9, 10, 11].

On the other hand, the solid phase of the lubricant, i.e. the fillers and additives, are immobile and remain at the interface, where they can act as additional trapping centers for space charge [7, 9].

These effects of the interactions between lubricant and the cable and joint insulation on charge dynamics at the interface need to be well understood when designing the insulation system to ensure compatibility of the used materials over the lifetime of the cable system. Prequalification testing of cable systems as described by the International Electrotechnical Commission (IEC) is a suitable approach for testing technical compatibility, as it is carried out on full-scale components in a realistic load scenario over a long period of time, but it is an expensive and time-consuming test. It is therefore advisable to perform a series of development tests first as a way to identify suitable – or unsuitable – material combinations.

A method for carrying out such development tests on material samples based on standardized testing procedures is proposed and discussed in this paper. The aim of this method is to stay close to the operating conditions of the cable system in order to get a realistic impression of how material changes and interactions can affect the electric field distribution. This means that both the thermal and electrical stress imposed on the samples during the experiments is limited in order to avoid excessive ageing of the materials or injection of disproportionate amounts of charge carriers.

INVESTIGATED MATERIALS

Plate-shaped samples made of a two-component room temperature vulcanizing silicone rubber (RTV-2) and DC-grade XLPE are investigated. The shape and dimensions are selected according to IEC 62631-2-1 and 62631-3-1 [12, 13].

SIR plates are produced by mixing the two components as specified by the manufacturer and casting them in an aluminium mould with dimensions of 100 mm x 100 mm x 1 mm. The mould is placed in a degassing oven to remove any air inclusions, and the samples are cured at 100 °C to accelerate the curing process compared to leaving them at room temperature. The surface roughness of the plates was measured on 4 different specimens at 3 different points on the surface using a laser microscope (*Keyence VK-X105*) and corresponds to the surface roughness of the mould of 0.2 ± 0.06 µm.

XLPE plates were prepared from a 320 kV cable insulation. In order to obtain samples with similar dimensions to the SIR samples, the cable outer sheath, screen and conductor were removed and the bare cable insulation was cut into a 100 mm long half-ring which was then flattened by heating it up to 130 °C for 2 hours and cooling it down in a hydraulic press for 6 hours. The resulting XLPE block can then be cut into thin plates of 0.5 mm – 1.0 mm thickness using a band saw. The plate samples are taken from the center of the XLPE blocks to avoid oxidative ageing of the material