Space Charge Measurement of 9 mm-thick XLPE Cables with Different Amounts of Cross-linking Byproducts under the Mean DC Electric Field of 20 kV/mm

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ABSTRACT

This study investigates the impacts of cross-linking byproducts on space charge behavior and electric field distribution in 66 kV AC-XLPE cables under constant temperature conditions, using a mean DC electric field of 20 kV/mm. Experimental results show that charge and electric field distributions are affected by temperature and the amounts of cross-linking byproducts. A model for space charge accumulation is discussed based on the calculation of the electric field distribution using volume resistivity. This research finds that interfacial polarization dominates space charge accumulation, as supported by the excellent agreement between calculated and experimental results.

KEYWORDS

XLPE cable, space charge measurement, pulsed electro-acoustic method, cross-linking byproduct

INTRODUCTION

Cross-linked polyethylene (XLPE) cables are widely used for high-voltage direct current (HVDC) cable systems up to 400 kV and are being considered for even higher voltage classes[1]. However, one of the main challenges in DC electrical insulation is space charge accumulation, which can cause electric field enhancement and impact the overall insulation performance[2]. To address this issue, it has been proposed to monitor the electric field distribution by measuring space charge accumulation during prequalification and type tests for DC XLPE cables [3].

However, the space charge measurements of cables are often hindered by low signal intensities due to the insulation thicknesses of cable samples. They result in a complex correction process to convert measured signals to a space charge distribution[4]. Recent advancements have introduced a new type of device that uses a polymer coupler to solve these issues of signal strength[5], thereby enabling accurate space charge measurements of cables under various temperature conditions[6-7]. In addition, a method using Laplace transform instead of the Fourier transform has been developed to improve the stability of the deconvolution process in the correction process[8]. The above advances have expanded measurable cable sizes and temperature conditions and enabled accurate space charge measurements of cables.

Despite numerous previous studies on the impacts of cross-linking byproducts on space charge behavior in insulation[9-11], none have examined the effects of these byproducts on space charge behavior through the space charge measurements of cable samples. This study aims to fill this gap by investigating the effects of cross-linking byproducts on space charge behavior occurring in cable insulation. The findings deepen our understanding of the impact of space charge behavior on dielectric breakdown phenomena in cable insulation.

Our study employs two cable samples with different amounts of cross-linking byproducts to investigate the effects of these byproducts on space charge behavior. The applied DC voltage is ±180 kV, meeting the 20 kV/mm typical operating electric field of DC-XLPE cables. The measurement temperature conditions are a 24-hour load cycle condition and constant conductor temperatures of ambient, 60°C and 90°C. A model for space charge accumulation is discussed by calculating the electric field distribution based on volume resistivity in insulation.

EXPERIMENTAL SETUP

Cable sample

Two 66 kV XLPE cable samples were prepared with different amounts of cross-linking byproducts. Fig. 1 shows the results of the gas chromatographic analysis of the amounts of byproducts. The sample with a relatively large amount of byproducts is referred to as Sample A, and the one with a small amount is referred to as Sample B. The amount of byproducts in Sample A was analyzed before and after the experiment. By contrast, the amount of byproducts in Sample B was measured only before the experiment because it was almost at the low sensitivity limit already before the experiment. Thus, the amount after the experiment was not measured. The amount of byproducts in the inner layer of Sample B before the experiment was about 1/50 of sample A's.

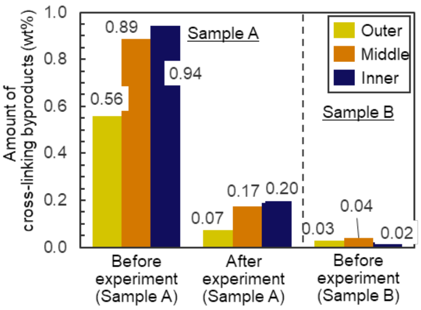

Fig. 1: Amount of cross-linking byproducts

Table 1 shows the geometrical characteristics of Samples A and B. Note that cross-linking byproducts have more