Suppressing Space Charge Accumulation in XLPE with Voltage Stabilizer

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ABSTRACT

In this research, three different voltage stabilizers were added into XLPE material, aiming at improving the DC conductivity characteristics and space charge behaviours of XLPE insulation. The DC conductivity under different temperature and electric field was measured by a three-electrode system. Meanwhile, space charge behaviours at 90 °C were investigated by PEA method and the trap level distribution was evaluated by the surface potential decay (SPD) process. The experimental results indicate that the voltage stabilizers have improved the DC conductivity characteristics of XLPE. Besides, the XLPEs modified by the voltage-stabilizer B and C show a good ability to suppress space charge accumulation.

KEYWORDS

HVDC insulation; XLPE; DC conductivity; Space charge; breakdown strength.

I. INTRODUCTION

Due to the excellent thermo-mechanical and electrical properties, XLPE is widely used in HVDC cable insulation. Researches show that the electric field distortion induced by the temperature gradient and the space charge accumulation inside the XLPE insulation are the most serious problems in the operation of HVDC cables [1].

For a long time, nanocomposites have been considered as an effective way to improve the performance of XLPE insulating material and a lot of work has been done [2]. However, nanoparticles are easily aggregated and are difficult to be dispersed uniformly in XLPE. It is difficult for nanocomposite to achieve mass industrial production, which greatly increases the difficulty in research and development of XLPE cable insulation. Therefore, voltage stabilizers are put forward to solve the problem of XLPE insulation once again in recent years, which can attenuate the energy of high energy electrons and leave the polymer matrix unharmed under the condition of high electric field [3]. The related researches on voltage stabilizers have lasted for a long time, and it is a few decades earlier than the research on nanocomposites. While due to its poor compatibility with polymeric matrix, it didn't cause much attention and application until the voltage stabilizer with higher solubility was obtained by attaching alkyl side chains to an aromatic core recently. Several new types of voltage stabilizers have been proposed and its stabilizing effect on inhibiting the growth of electrical tree, improving the breakdown strength were reported [4]. Nevertheless, there are few reports on influence of voltage stabilizers on DC conductivity and space charge inhibition for XLPE insulation materials.

In this research, the DC conductivity characteristics with the temperature change and the space charge behaviors at 90 °C of the voltage stabilizers modified XLPE insulation are the focus. Three different kinds of voltage stabilizer with additive content of 0.5 wt% were mechanically mixed with XLPE. The DC conductivity under the temperature from 30 to 90 °C, DC breakdown strength and space charge behaviors at 90 °C were tested. Additionally, the trap level distribution was evaluated by SPD method.

II. EXPERIMENTAL ARRANGEMENT

A. SAMPLE PREPARATION

The voltage stabilizers, 4,4'-Difluorobenzophenone, 4,4'-Dihydroxybenzophenone, 4,4'-Bis (dimethyl amino) benyil, were purchased from J&K Scientific Ltd, denoted by A, B, C, respectively.

The neat XLPE serving as control was made by low-density polyethylene (LDPE) containing antioxidant and dicumyl peroxide that was supplied by Borealis Company. The different voltage stabilizer with additive content of 0.5 wt% was dispersed into XLPE matrix by Bunbury mixer at the processing temperature of 110 °C. Then, samples were made by a stainless-steel mold at 180 °C for 30 min under a pressure of 30 MPa to produce films with a diameter of 10 cm and thicknesses of 250 μm. Before the tests, the samples were put in a vacuum oven at 80 °C for 48 h to ensure uniform initial thermal and mechanical conditions and eliminate cross linking by-products.

B. DC ELECTRICAL EXPERIMENTS

DC conductivity of samples with different voltage stabilizers were measured by a three-electrode system, which was shown in our previous study [5]. The three-electrode system is placed in a temperature control oven, of which the temperature can be controlled from 20 to 180 °C. The electrodes used in this experiment are made of stainless steel. The charging current I is measured by an electrometer (Keithley 6517B) for 12 hours until it reached a steady state. New samples were used in each repeated experiment to avoid the influence of the residual charges in the previous experiments.

DC breakdown strength tests were performed by two copper ball electrodes immersed in pure insulating oil at the temperature of 90 °C [6]. A ramping DC voltage source with speed of 500 V/s is employed in the experiment. Each material was tested for 20 times to plot the Weibull distribution.

The space charge characteristics of samples were measured using PEA method at 90 °C. The experiment arrangement is detailed in our previous report [7], while an oil circulation system with a constant temperature oil-bathing unit was employed to control the experimental temperature. The polarization measurements were performed under a negative DC voltage with the average electric field of 30 kV/mm for 30 min.

The trap level of the samples was measured by SPD method at room temperature using a surface charge measurement system, of which the schematic has been shown in the reference [8]. The experiment was conducted