Effect of Polarity Reversal on Water Tree Growth in Insulating Material of Power Cables

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ABSTRACT

This paper deals with effect of polarity reversal on water tree growth in insulation material of power cables. The thorough design and implementation of the experiments reported in this research suggests that how variation in the frequency of polarity reversals affects the growth of water tree. Water trees starts from the protrusion in the semi conducting layer (conductor or insulation), but generally it was observed starting from the outer layer and grow towards the conductor. The growing water tree may eventually lead to premature breakdown of the insulation resulting in cable failure.

KEYWORDS

Cable insulation, water treeing, polarity reversal

INTRODUCTION

The High Voltage Direct Current (HVDC) transmission has gained a lot of importance in the last few yeas. This is mainly due to the advantaces done in this field which yields better power transmission with less losses as compared to traditional alternating voltage, especially for longer distances[1]. Conventional HVDC systems employ Line Commutated Converter (LCC) technology for power conversion from AC to DC and then this DC is transmitted. At the same time, in our increasingly interconnected world, underground and submarine cables form the crux of DC power transmission, be it for intercontinental transmission, tapping power from offshore wind farms, within a region/country, etc. These extruded polymeric insulation based cables with XLPE (whose base material is LDPE) as insulating material are a promising candidate for future HVDC transmission[2].

In HVDC systems with LCC, polarity reversal is typically carried out frequently to control the bi-directional power flow between interconnected transmission systems either for load balancing or grid restoration. High stresses are observed at the interface of different layers immediately after reversing the polarity and these may lead to insulation failure if not designed properly. During the moment of polarity reveral, space charge injected during preceding polarity produces high local electric field in the insulation, which is very critical as space charge movement distorts the electric field dynamics. The cables which are expected to operate at least for 30-40 years fail prematurely due to several factors which includes the ingress of moisture into the insulation leading to water tree formation under stress due to polarity reveral. Be it due to moisture in the soil, or due to hydrostatic pressure on the cable insulation in the case of submarine cables, water tends to protrude through the insulation defects and forms a tree near the insulation shield. Due to the differences in permittivity, the surface charges which are formed at the interface of water and insulation distorts the electric field inside the insulation. This non uniform electric field leads to the further enhancement of propagation of water treeing inside the cable insulation.

A respectable amount of work has been done on the water tree initiation and growth in literature [3, 4, 5]. In laboratories, accelerated water tree growth/propagation is carried out using water-needle method [3, 4] and is characterized by tree width and tree length [4, 5]. These methods employ high frequency ac (kHz range) to grow water trees. Effect of temperature on water tree growth in XLPE cable insulation has also been observed [6] which shows that that as the temperature increses, tree growth also increses. Recent studies on the effect of water tree growth on the crystalline structure of the insulating material[7] suggests that crystallinity decreases with tree growth and the non-crystalline region increases gradually resulting in degradation of polymeric insulation. Also, the role of number of consecutive voltage zero-crossings in propagation of water trees have been observed with ac and dc superimposed with ac [8]. Various fast water tree growing techniques or standards have been developed using high frequency voltages and combination of dc superimposed ac. But very little work on effect of dc polarity reversal on water tree growth has been reported, which actually represents the reversals happening in HVDC cables.

In the current study, the authors have tried to replicate the actual condtion of HVDC cables and see the effect of polarity reversal on tree growth in insulation. Different reversal time and different voltages (resulting in different electric field) have been selected to see their effect on tree growth in LDPE block samples with needle defects.

SAMPLE PREPARATION

LDPE granules supplied by a local cable manufacturer were used to prepare block samples. After placing the granules in the holes of top plate of mould (shown in Fig. 1), they were first preheated at 120° C for 20 minutes and then pressed in hydraulic press for 20 minutes under a pressure of 90 bar and temperature of 120° C. And then after cooling down block samples of LDPE with needle impression were obtained, whose cross sectional view can be seen in Fig. 1(c). The length of needle tip is 3.2 mm and radius of curvature is 3µm. The voltage applied will appear across the needle defect (through water needle electrode) with small radius of curvature will cause huge electric field resulting in growth of water tree after a certain number of reversals as LDPE starts degrading.