STUDY OF INCEPTION MECHANISM OF ELECTRICAL TREES FROM BOW-TIE TREES

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ABSTRACT

The relationship between bow-tie tree length and breakdown strength of XLPE cables was obtained both experimentally and by calculation. Assuming the models where both permittivity and resistivity of BTTs vary near the BTT tip, it was verified that electrical trees may be initiated from inside the BTT, quantitatively. In cases where the length of the BTT is short, the equivalent phenomenon as if ε_r= 80 occurs because the resistivity of the BTT may decrease non-linearly under high electric fields. Using these results, the influences of BTTs on EHV cables in service were estimated.

KEYWORDS

XLPE cable, bow-tie tree (BTT), electrical tree, breakdown, permittivity, resistivity, EHV cable

INTRODUCTION

Water trees are generated and grow from the defects of crosslinked polyethylene (XLPE) cables when the cables are energized in the presence of water [1]. Therefore, metallic sheaths or metal laminated sheaths are widely used for HVAC cables in Japan to prevent water penetration to the insulation. However, a considerable number of cables without such water proof layers still exist, and the cables with the water proof layers have already been in use for a long time. In addition, so called wet-design cables without any water proof layers have been introduced recently for array submarine cables used for offshore wind farms[2]. It is important to study the mechanism of water tree growth and the influence of water trees on the insulating properties of XLPE cables. Here, the inception mechanism of electrical trees from bow-tie trees (BTTs), a kind of water tree, and the relationship between BTT length and breakdown strength of XLPE cables are presented. Furthermore, the influence of BTTs on EHV cable performance using the above results is evaluated.

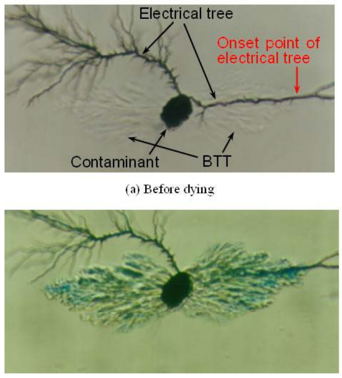
RELATIONSHIP BETWEEN BTT LENGTH AND BREAKDOWN STRENGTH OF XLPE CABLES

The authors have investigated the life performance properties of XLPE cables [1] [3]. Using the pre-breakdown partial discharge detection (PDD) method [4] on residual breakdown tests of XLPE cables in wet conditions, it is often observed that electrical trees initiate from BTTs. Figure 1 shows an example of electrical tree inception from the BTT. The electrical tree usually initiates from the tip of the BTT when the length of the BTT is short. Conversely, the electrical tree initiates from inside the BTT near the tip when the BTT becomes longer after extended usage as shown in Fig. 2.
Figure 3 shows the experimental results of the relation between BTT length and the residual breakdown strength of XLPE cables. These results were formerly obtained by the authors [3]. The residual breakdown strength decreases as the BTT lengthens.

SIMPLE MODEL EVALUATION

High permmitivity model in XLPE

BTTs are composed of a number of micro cavities filled with liquid [5]. Then, the permittivity of the BTT area is considered to be greater than that of XLPE, $\varepsilon_{r\,(XLPE)}$ = 2.3. As seen in Fig. 1, the onset point where the electrical tree initiates is the tip of the BTT, which can be explained qualitatively by considering that the BTT is a different substance which has high permittivity in XLPE. Table 1 shows the cut-off voltages, the positions in the cable insulation, and the BTT lengths obtained by the residual

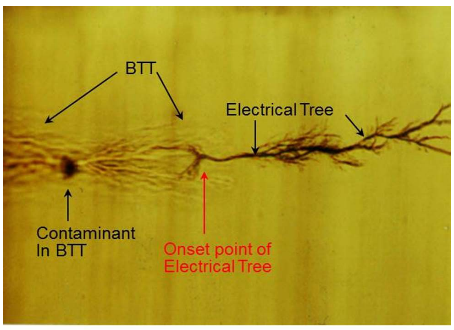


(a) Before dying

(b) After dying 50μm

・XLPE Cable with 6-mm wall-thickness after long-term testing under V = 75 kV for 20,100 h (Sample No.① in Table 1.)
・Residual breakdown voltage V_{PDD}=210 kV (E_{mean}: 35 kV/mm)
・BTT length: 300 μm

Fig. 1: A BTT obtained as a cause of breakdown on residual breakdown test by PDD method.



50 μm

・Actual 66 kV XLPE cable (11 mm-t, 150 mm^2) used in the field for 16 years
・Residual breakdown voltage V_{PDD} = 180 kV
・BTT length attached to the conductor shield: 360 μm

Fig. 2: Example of electrical tree starting from a BTT attached to the conductor shield of an actual 66 kV XLPE cable