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Buried Cables - Water Trees

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Considerable attention has been directed at buried cables not only for Nuclear Facilities but also for distribution and transmission cables. It is estimated that there are at least 200,000 miles of buried transmission cable currently in the United States. As these cables age their likelihood of failure increases, thus impacting the distribution of electric power. A contributing mechanism towards failure of buried cables continues to be water trees. Water trees first came to the attention of the cable industry in 1969. Extensive research has been performed on water trees to better understand their formation and growth mechanisms. Although research has proven beneficial, the current buried cables remain prone to the formation of water trees.

Water trees are structures formed in an insulating material and are referred to as either vented or bow tie. Bow tie trees are formed internal to the insulating material while vented trees form at the boundary of the insulation. Figure 1 depicts the two types of trees. As stated, vented trees start at the boundary of the insulation and grow through the insulation to the other boundary, following the lines of the electrical stress. Because vented trees grow from one boundary to the other they are more of a concern since they form a breakdown path. As the water tree grows the insulating material breakdown strength is reduced. This is shown in figure 2 [1] where there is a significant drop in withstand capability as the water tress growth approaches the full thickness of the insulation. This growth mechanism leads to the eventual failure of the cable.

Figure 1

Buried cables are exposed to water and moisture under normal service conditions. Underground cables have been found submerged in water. Also, for those cables not directly submerged in water, they are exposed to 100% humidity at 1 to 2 meter depths [2]. The saturated water vapor provides a source for water ingress into the cable. The water fills micro-cavities within the insulation.

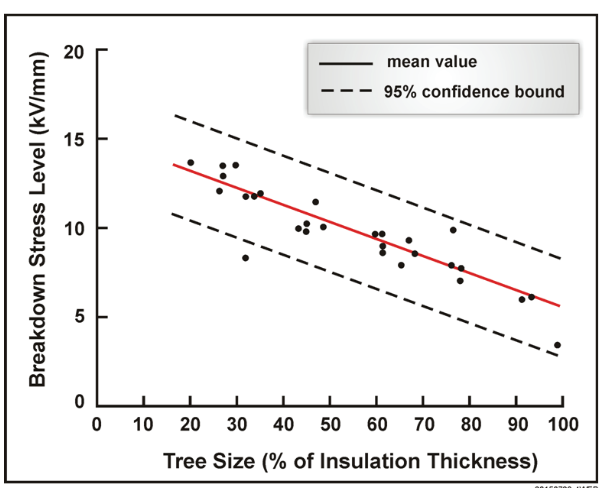

Figure 2: Breakdown stress vs. water tree thickness

Once water enters the insulation, water tree growth begins through a number of mechanisms. Figure 3 graphically depicts the two main sources of this growth. For vented trees, mechanical damage or an imperfection at the boundary of the insulation and semiconducting surface are examples of sources for vented tree formation. The electric field in the area of these imperfections become amplified and the combination of water and an amplified or inhomogeneous field create forces through dielectrophoresis leading to tree growth. These forces are supported by the permittivity difference between water and the bulk of the insulation.

Insulating materials are hydrophobic, however, water trees become hydrophilic as a result of a change in the chemical composition of the insulating material. It is believed that impurities such as salts and ions contained in the water lead to the material change. The hydrophilic nature of the water trees results in the propagation of the water trees.

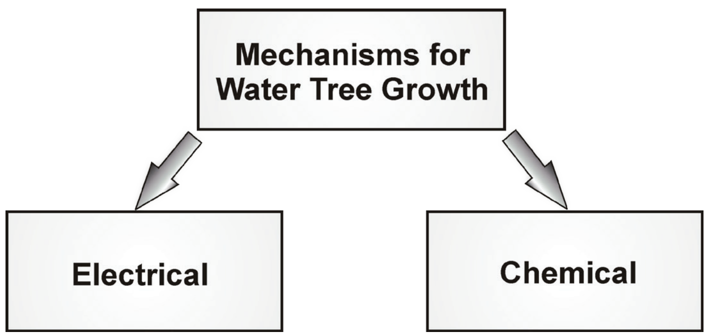

Figure 3

Many mechanisms can be involved in water tree development and growth. This bulletin was intended to provide a snapshot of water trees and their potential for cable failure. Key to further development is identifying a field test which can determine water tree status. Some testing is capable of defining water tree density but cannot correlate the data to indicate the length of the longest tree which is the primary source of failure due to water trees.

Further bulletins will look closer at water trees.

References:
[1] E. Steennis, F. Kruger, "Water Treeing in Polyethylene Cables", IEEE EI Vol 23, October 1990
[2] G.J. Bertini, "Molecular Thermodynamics of Water in Direct-Buried Power Cables," IEEE EI Magazine Vol 22, 2006

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