

Conditioning of High Voltage XLPE Cables in Salt Water – A Review of Ion Diffusion and Impact on Water Treeing

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ABSTRACT

Knowledge of ion diffusion in polymeric cable materials is important as wet-designed high voltage submarine cables are becoming an attractive alternative to the traditional dry designs. This paper summarises the literature on the impact of ionic impurities in cable insulation, including the mechanism of NaCl diffusion in cable materials, and the techniques available to assess ionic diffusion in materials for submarine power cables. The main discussion addresses the relevance to service performance of using salt water during conditioning and ageing of power cables according to CIGRE TB 722.

KEYWORDS

High voltage XLPE cables, ionic diffusion, water treeing, water diffusion, service lifetime.

INTRODUCTION

Renewable energy sources, and especially offshore wind, can in the future become one of the major sources for electrical power production. Inter array cables are one of the main components in these wind parks, and lately there has been a demand for high voltage rating of 60 kV for such cables. The background for this need includes the increased power rating of the wind turbine generators, but also the new topologies of the local offshore networks. In order to reduce the overall cost for the wind parks, the HV subsea AC power cables can be designed with either non-traditional water barriers or as wet cables with polymer outer sheaths allowing water molecules to diffuse into the electrical insulation system of the subsea cables.

In a submarine cable the water tightness is normally achieved by introducing a metallic laminate or an extruded lead layer close to the outer sheath, while in a cable with wet design an extruded polymer sheath is used. Water vapour cannot permeate through metals (or glass) but can diffuse through polymer materials at a varying rate dependent on their morphology and physical state, where temperature is the main parameter or equivalently the water vapour pressure. The water vapour pressure does only slightly change by a dilute content of salt, or by an increase in hydrostatic pressure [1].

The recently published CIGRE technical brochure TB 722 includes test recommendations for submarine high voltage cables ($U_m > 42$ kV) without a radial water-tight design. Prior to wet electrical ageing outlined in TB 722, the cable cores are soaked in salt water with an ionic content in the range of 3–6wt%. The specified preconditioning time is minimum 500 hours at 55 °C, but with insulation thickness over 8.8 mm a slightly longer time is specified to reach saturation of water in the insulation system before the subsequent electrical ageing. For a more accurate assessment of the saturation level of water in the insulation system after conditioning, the radial water vapour pressure

can be numerically calculated. This requires that the materials involved are characterised with respect to water permeability, diffusion and saturation content at the required temperatures [2].

The time to saturation of sodium chloride ions in a cable with wet design is yet unknown. Open questions regarding salt water diffusion include the permeation rate and the solubility of ions in the polymeric materials used for the cable core and outer sheaths. Relevant materials must be characterised as a function of temperature to determine the diffusion parameters. Only a few examples of such data are found in literature for power cable materials. Material characterisation to determine the diffusion parameters as function of temperature is necessary as input to calculations of the required preconditioning time in cables with wet design.

The effect of permeated ions at the interface between the XLPE insulation and the insulation screen on the initiation and growth of water trees is also less clear. The main purpose of this paper is therefore to present mechanisms of ion diffusion in polymeric materials, and to review experimental results on ion permeation in submarine XLPE cable insulation systems including available measurement methods to determine the ionic content. The review is mainly limited to sodium and chloride ions, as only NaCl is added during laboratory ageing specified by TB 722.

IONIC IMPURITIES IN POLYMER CABLES

Ions are strongly associated to water tree initiation and growth. The ions can either be present in the insulation system after manufacturing or by diffusion into the cable core during service in seawater. This section discusses both situations with emphasis of the latter.

Effect of ionic impurities on water treeing

The main inception sites for water trees are contaminations at the interface between the semi-conductive layers and the insulation, or within the electrical insulation. Two types of water trees are identified dependent on the location of their initiation sites: Vented trees appearing at the interfaces and bow-tie trees growing from defects and contaminations in the bulk of the insulation. The moisture needed to initiate the trees has to permeate from outside of the cable core in modern cables, as the water content in the insulation system from production is too low to cause any treeing. Measurements of the chemical compositions of inception sites indicate that the water tree region contains a wide range of chemical species, with various forms of metal and carbonyl ions, and water being dominant. For the carbonyl species, the carboxylate ions are dominant, with trace amounts of esters and ketones. The semi-conducting layers play an important part in the treeing process as a reservoir of metal ions. In addition to the semiconducting layers, other sources of metal ions