Aging of oil impregnated insulation paper of subsea HV cables in decades of service

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ABSTRACT

This work presents the results of seldom opportunity; to analyse the status of aging of oil impregnated paper insulation of two subsea HV cables applied for AC and DC, which have been in service for about 60 and 45 years. The degree of polymerization (DP) of different paper layers of the insulations were studied. The results showed good conditions on both, also compared to recently produced oil impregnated paper insulation without any service time. The aging from outer to inner layers have shown to have a profile that may be considered as unexpected.

KEYWORDS

High voltage, Insulation, aging, paper, oil impregnation, degree of polymerization

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INTRODUCTION

Prepared and carefully dried paper was already demonstrated to be used as cable insulation at higher voltages as far back as in 1880's by the British electrical engineer Sebastian Z. de Feranti [1].

Oil (so called mass, an expression that in this connection means oils with high viscosity at temperature conditions under service) impregnated paper insulated cable were commercial available some years later, in 1895. Cables with HV oil impregnated electrical insulation are still in service, and new cables are under production or planned. Almost all new cables with paper insulation produced today are used for HVDC transmissions. These are almost without exception mass impregnated something that make them environmental friendly in terms of insulation oils with without mobility in regard of spilling. The HVAC marked is nowadays dominated by polymer insulation, but oil impregnated paper insulation (normally pressurized thin oil insulation) was earlier used for HVAC as well. The construction had a hollow conductor with oil under pressure; maintaining the impregnation by pressing oil out between the strands of conductor into the paper insulation.

In present work, the aging of oil impregnated paper insulation has been studied. The paper samples investigated were taken from mass impregnated HVDC, which had been in service for about 40 years, and thin oil impregnated HVAC, which had been in service for about 60 years.

Testing by accelerated aging processes, i.e. at elevated temperatures, are often performed to make basis assessments of life time of materials or whole constructions. Such testing regimes are often, with background in good reasons, questioned in regard of reliability and relevance. Therefore, testing the degree of aging of HV cable insulations been in service for several years is an attractive opportunity.

ANALYTICAL METHOD

The degree of aging of paper insulations has been determined by applying the analytical method described in the standard IEC60450, "Measurement of the average viscometric degree of polymerization of new and aged cellulosic electrically insulating materials" [2]. The degree of aging / status of length of polymer chains is given by the degree of polymerization, so called DP value. Degree of Polymerization is defined as the average number of glucose ring units in the cellulose chains [3], hence the size of DP value is reduced by aging.

AGING OF PAPER

The relevant aging process of paper is cleavage of the β(1→4) glycosidic bond to produce shorter cellulose chains. Hydrolysis and thermolysis are the main relevant mechanisms for such breakage [4], in which water and heat play important roles

Cellulose fiber materials, paper included, are very hydrophilic and water is attracted easily. Water is bonded into the fiber structure in different extent; from strong bonding deep into the fiber and fiber network structure to relative weak bonding at the surfaces. The mobility of the different "types of water" will be very different from very low; i.e. stuck into to the structure, to very high; making an equilibrium to the ambient air [5]. The energy needed to release the water from the paper fiber structure will increase in relation to reduced mobility.

The release of water with strong bonding is connected to aging of paper with cleavage of glycosidic bonding. That is, extensively drying of paper introduce an aging onset. Consequently, extensively drying of paper where the water contents are reduced significantly means structure change of cellulose fibers. The fibers go through irreversible processes in which the fibers get stiffer and less flexible, so called hornification process, and, on even lower water contents, cleavage of the cellulose chains is initiated.