New insulation aging detection algorithm for HV and MV cable based on the study of the harmonic content in leakage current

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ABSTRACT

Early detection of degradation is crucial to prevent severe cable damage. This paper explores the possibility of using the cable screen currents as an indicator of cable aging status. A T-circuit model is developed for three single-core coaxial cables excited by three-phase voltages, where the XLPE insulation is modelled using a parallel conductance (G) and capacitance (C) branch representing a non-linear, voltage-dependent admittance. A set of differential equations are defined for the above configuration to describe the harmonic content of the leakage current under partial discharges as a result of insulation deterioration and water treeing.

KEYWORDS

Optical current transformer, harmonics, leakage current, partial discharge, water tree, XLPE cables, thermal aging, health index.

INTRODUCTION

With an increase in the need for a secure grid, the impact of unscheduled decommissioning of medium and high-voltage transmission cables is a subject of particular concern. This attracts high interest in researching aging studies of cables, in particular, that of its insulation. For this purpose, continuous monitoring of the cable condition is necessary. At present, two types of tests are available for detecting aging: tan delta measurements and partial discharge measurements [1] These tests have excellent detection accuracy but come with some challenges. The former requires taking the cable out of service and the latter involves the deployment of complex systems that require a power supply along the entire length of the cable. This indicates a need for developing a measurement technique that can detect aging while overcoming these drawbacks.

It is becoming increasingly common to have current measurement systems at cable screen earthing. The current content can be examined to explore the relationship between the cable age and the harmonic characteristics and content of the leakage current migrating through the cable insulation, which eventually is reflected in the frequency-resolved current content distribution in the cable screen. The deterioration of the XLPE insulation because of aging results in the generation of harmonics of specific (odd) orders in the leakage current, as a result of the non-linear behaviour of the XLPE insulation conductance. Water trees formed inside the XLPE insulation is one type of severe deterioration, and former studies have correlated non-linear dielectric responses as a result of water trees, with some focus being on the generation of third harmonics in the leakage (loss) current, where the harmonic current magnitude and phase angle has been shown to, respectively, increase and decrease with water tree degradation [2]–[4]. Furthermore, thermal aging has been shown to generate harmonics of especially third, sixth, and thirteenth order in the leakage current [5]. It is thus evident, that the non-linear V-I relationship of the XLPE insulation and associated harmonic current generation caused by water trees, is a promising diagnostic benchmark for the health of the cable insulation, where early detection is of great interest.

Due to the nature of the coaxial cable geometry, the generated harmonic content in the leakage current is reflected in both the phase conductor and screen conductor current flows, and thus any system-level harmonics that may be present in the cable conductor and screen voltages themselves or from inductive coupling from the other phases, must carefully be separated from the analysed harmonic current content generated by the insulation. The effects of said system-level harmonics are examined on the proposed circuit model of this paper.

The loss tangent, tan(δ), is commonly used to describe cable insulation health, and is basically the relationship between the resistive leakage current to the capacitive (charging) current, where for an ideal insulator, the former is zero, resulting in a phase difference of the two components equal to 90 degrees. As XLPE insulation ages, the loss tangent is seen to increase in value [6].

For water trees and insulation breakdown in general associated with partial discharge generation, the proposed circuit model in this paper adapts a parallel conductance/capacitance (GC) branch, where the conductance of idea cable insulation is zero, however, the generation of partial discharges can basically be seen as a degradation of this conductance (and to some degree capacitance), and the accumulation of these discharges can constitute a measurable (leakage) current. This current is, in principle, dependent on the operating voltage, since partial discharges only occur in certain areas of the voltage waveform. This current will therefore lead to an increase in the harmonic content of the screen current.

MODEL DESCRIPTION

The basis for the theoretical modelling is a simple circuit of 100 m of three single-core, high-voltage coaxial cables of 420 kV, 2500 mm^2 Al, excited by three-phase voltage sources at both ends. Any variation of phase at one end, results in a corresponding current flow, which can be as high as 100A as seen in a case study in this paper. The cable circuit screens are shorted, representing a double-point grounded screen configuration.

The development of circuit equations assumes that capacitances are restricted to a per-phase basis. Mutual inductive coupling is included for each phase to each