Partial discharge propagation in high voltage XLPE insulated cables – measurement vs. modelling

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ABSTRACT

The goal of this study is to develop a numerical tool that would allow for prediction of certain characteristics of high voltage (HV) cables necessary for commissioning testing. These characteristics describe both: power frequency and high frequency PD performance. This document summarizes the results of the measurement of PD pulse propagation in a high voltage 230 kV cable and an attempt to model the propagation of such pulse using FEM. The results of the simulations show attenuation of the HV cable which is in agreement with the results of the measurement and the results previously published.

KEYWORDS

High voltage, extra high voltage, HV cable, EHV cable, partial discharge, PD, propagation, attenuation, modelling, commissioning.

INTRODUCTION

Underground and subsea high voltage (HV) and extra HV (EHV) cables are optimized to carry load at high voltage and, as opposed to the concentric telecommunication cables, they are not optimized for high frequency (HF) or radio frequency (RF) signals ([1], [2], [3], [4], [5]). However, during commissioning (after installation) testing, the cables should be subjected to a high voltage test for 60 minutes ([6], [7], [8], [9]) which is often combined with partial discharge (PD) measurement. PD are low magnitude sparks ([1], [2], [3], [10], [11], [12], [13], [14]) that occur either in the impurities of the insulation or at the interfaces where the geometry of the insulation changes. These "sparks" or PD result in small magnitude current pulses that have very high frequency content ([1], [2], [3], [4], [5], [10], [12], [15] [16] [17], [18],), and since the HV/EHV cables are not designed to carry these signals, there are natural constraints that have to be taken into consideration when PD measurement is to be performed.

There are various methods of detecting PD in high voltage cables ([10], [12], [19]), but if the distance from the PD source to the sensor is long, the PD measurement may be lacking the sensitivity (regardless of the sensor and method applied). The phenomenon of pulse propagation in HV cables is well researched, but the question: "how far from the source can a PD signal be detected?" still remains unanswered. Unfortunately, this cannot be answered easily answered, as it depends on several factors.

HF SIGNALS IN POWER CABLES

PD are electrical pulses [1], [2], [3], [4], [10], [12] and as a results, they have high frequency content and are subject to the same rules as HF signals used in telecommunication cables. Considering the fact that the wavelength of these high frequency pulses is much lower than the length of most of the HV cables, the PD propagation can be described by application of the telegrapher's equations. Although this principle applies to both telecommunication and power cables, the difference between one and the other is in the dimensions and the design of the carrier – the power cables are not optimized for high frequency signal propagation because they have semi-conductive layers (semicon) which are absent in telecommunication cables. These semicon layers have very high permittivity and relatively low resistivity [3] and these characteristics contribute to the attenuation of HF signals at much higher degree than the XLPE insulation [2], [3], [16], [19], [18].

Another difference between telecommunication cables and HV/EHV cables is that HV/EHV land cables can only be shipped and installed in limited and shorter lengths which then have to be jointed together after installation/pulling. In extreme cases the number of joints on each phase on HV/EHV cables may exceed 30. These joints usually have bigger diameters and different materials than the cables and because dimensions and permittivity of material affect the surge impedance, the impedance of the joints is often different than that of the cables. For HF signals this means reflections and further attenuation.

The weakest links in the entire HV/EHV cable installations are the joints [10]. Therefore, the commissioning testing efforts are focused on exposing defects in cable accessories (joints and terminations) and when the PD measurement is included, all accessories should be monitored during the test. When PD sensors are installed near or on the accessories, they are close to the potential PD source which increases the probability of detecting a defect if such occurs [10].

MEASUREMENT OF PD PULSE PROPAGATION IN 230 KV XLPE CABLE

A large amount of research on PD pulse propagation has been done on medium voltage (MV) cables [2], [3], [14], [19]. When comparing HV/EHV with MV cables, the latter are less expensive, easily available, easy to handle and share concentric geometry with the HV cables. There is also a difference in length, presence and number of joints, as MV cables are usually much shorter and have fewer joints. Nevertheless, there has also been research on high voltage cables that show the attenuation in the cable and the joints [1], [4], [16]. Using the information presented in [1] and [4], a test system was assembled to measure the attenuation in the 230 kV XLPE cable. The cable under test (CUT) consists of approximately 280 m of 230 kV rated (U_m=245 kV) XLPE cable with 500 mm2 aluminium conductor and aluminium concentric neutrals as presented in Figure 1. The insulation thickness is 20 mm, the semi-conductive conductor screen is 0.5 mm while the insulation shield is 1 mm thick. The cable was on a steel