Parametric analysis of three-core submarine power cables by means of simplified 3D FEM simulations

Juan Carlos **DEL-PINO-LÓPEZ**, Pedro **CRUZ-ROMERO;** Department of Electrical Engineering – Universidad de Sevilla (Spain), vaisat@us.es, plcruz@us.es

ABSTRACT

This work presents an in-depth parametric analysis for different very high voltage three-core armored cables developed by means of simplified 3D finite element simulations. Using shortened 3D geometries both the hardware requirements and running time of simulations are reduced without losing accuracy, helping in analyzing the influence of the armor twisting on the positive sequence impedance and the induced losses in complex high voltage armored cables. Results show that the relative twisting between phases and armor has an important influence on these topics, leading in some circumstances to numerical values far from being similar to those obtained through 2D FEM approaches.

KEYWORDS

Three-core cable, 3D finite element, armor; parametric analysis; losses; sequence impedance.

INTRODUCTION

There has been an important development in offshore wind farms in the last decades, helping in improving the efficiency of all the components involved in these power plants [1]. One of the main components are the submarine power cables employed for collecting energy from each wind turbine and exporting the power energy to the onshore grid. Its size should be optimized for having high efficiency and reliability in the power transmission [2]. To this aim, the electrical and thermal performance of these power cables must be adequately characterized. In this sense, three-core armored cables are usually assumed as pipe-type cables, where the armor is considered as a steel pipe [3]. Therefore, it is assumed that currents may flow along the "tube" armor. This is the case in the IEC 60287 standard commonly employed for the computation of the current rating of power cables [4]. This standard assumes that armor losses are mainly due to end-to-end circulating currents through the armor, neglecting the eddy-current losses. However, this approach doesn't take into account the fact that armor wires and phase conductors are helically twisted (usually in opposite direction for achieving torsion stability). In this sense, many studies have proved experimentally that the armor twisting leads to zero net current flowing through the armor wires in balanced systems [5-8]. Consequently, power losses due to end-to-end circulating currents are below those of eddy currents, in contrast to the hypothesis assumed by the IEC standard. Alternatively, other studies suggest that also sheath losses may be influenced by the presence of the armor [9], being higher than expected. In any case, there is a broad consensus that cable losses are overestimated by the IEC standard, and hence providing oversized cables. Additionally, the presence of the armor also influences the series impedance of the power cable [10,11].

At this point, it is clear the need of new analytical expressions for the computation of the power losses and the electrical parameters of three-core armored cables. However, this requires multiple experimental tests that are only possible by manufacturers. Nonetheless, numerical methods, such as the finite element method (FEM), have been extensively employed as an alternative to costly experimental setups [5,7,9-12]. This tool is suitable and accurate for analyzing complex geometries as that of three-core armored cables. However, most of these studies assume 2D geometries for the cable, so the armor and phase twisting are not taken into account. Therefore, in [5] it is proposed a new 2D approach where the net current through the armor is forced to be zero to emulate the armor and phase twisting. This method is known as 2.5D and it is the most extended one at this moment. However, this is still based on 2D geometries, where only the transverse magnetic field is modeled, but not its component parallel to the armor wires, which is the main cause of the eddy currents induced in the steel wires. For this task, 3D geometries are required, but only few studies have tackled the 3D-FEM simulation of three-core cables [13-16]. These simulations are very time consuming and require the use of powerful computers with plenty of RAM memory. For these reasons, only a short portion of the cable is usually modelled [13,14]. However, the length of this portion may affect the results obtained from the FEM simulations if no periodic boundary conditions are properly applied at both ends of the geometry. Unfortunately, this can be done only when the length of the model is equal to the least common multiple of the lay length of phases and armor, which usually leads to very long models also. Consequently, this is only easy to achieve in small cables, as it is developed in [15], where a 35 mm^2 and 10 kV armored cable with 6-mm thick armor wires is analyzed. In this study, an in-depth parametric analysis was carried out, showing that there may be an important influence of the relative twisting between phases and armor wires in the power cable positive sequence impedance and its induced losses. However, in that moment it was not possible to verify this results in larger and more complex cables due to the computational requirements for simulating cables with hundreds of armor wires. This is the main aim of this work, where a new parametric analysis is carried out in three high voltage cables (145 kV, 170 kV and 245 kV). This is now possible thanks to a new approach, presented in [16], that helps in reducing the size of the 3D geometry to be simulated in FEM, hence reducing simulation time and computational requirements.

SIMULATION APPROACH

The use of periodic boundary conditions helps in reducing the size of the geometry to be simulated in many FEM applications. Regarding three-core armored power cables, periodicity occurs when the length of the model is equal to the least common multiple of phases and armor lay lengths. In this situation, the geometries seen at both ends of the 3D model are equal. An example is shown in Fig. 1, where the lay length of the phases (P_f) and the armor (P_a) are 3.6