Large HVAC export cables under tensile loading

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ABSTRACT

This paper covers a study that has been performed to improve the understanding of the mechanical properties of large HVAC submarine cables when exposed to tensile loads where tension-twist coupling of the cable and the stress response in the internal cable components has been of special interest. Both 3D finite element analysis and an analytical model has been applied where the model predictions have been compared to the results from a full-scale tensile characterisation test. Good agreement was found between the prediction of the 3D FE analysis and the experimental results and between the stress predictions of the analytical model and the FE analysis.

KEYWORDS

HVAC cables, finite element (FE) analysis, axial tension–twist coupling

INTRODUCTION

HVAC export cables are used to transport power from off-shore wind parks to shore. As the size and power output from constructed wind farms has been increasing, so has also the voltage level and cross section of the export cables. For export cables rated at 245 kV it is common with outer diameters larger than 250 mm and weights above 100 kg/m. Due to the relatively shallow water depth, and therefore limited tensile loads during cable laying, the export cables are most commonly designed with a single armour layer and are not torsional balanced. At the landfall, it is often desirable to allow large tensile forces to be applied to simplify the installation by for instance allowing long pull-ins. The mechanical behaviour of these large, non-torque balanced submarine cables, when exposed to large tensile forces, can be quite different compared to more compact, conventional HVAC and single core cables. Effects such as twisting and radial contraction of the different layers will affect the stiffness properties of the cable and the resulting force distribution between the layers. To improve the understanding of the mechanical properties of this type of singled armoured, large cross section cables, an investigation has been performed involving 3D finite element analysis (FEA). 3D FEA has previously been applied to study component stresses during combined tensile and bending loads in dynamic power cables in [1] and [3] with the application primarily related to fatigue loading. The purpose of this study has been to achieve a better understanding of the tensile properties, the tension-torque coupling and the load distribution between the different components in large HVAC cables when being exposed to tensile loads.

The result of the 3D FE analysis has been compared with experimental results from full scale tensile-characterization tests performed on an export cable design where the cable elongation and induced twist has been measured as a function of the applied tensile load.

For a non-torque balanced design, the boundary conditions at the cable ends will affect the overall mechanical behaviour of the cable. According to CIGRE TB623 [1], the tensile test shall be performed with one end free to rotate and one end fixed. This results in a torque free condition where the cable is free to rotate and there will be no build-up of torque in the cable as the tensile load is increased. If both ends instead are fixed, the cable is in twist constrained condition, and application of the tensile force will result in a torque being created along the cable and at the end fittings.

STUDIED CABLE DESIGN

The basis for this paper is analysis and testing performed on a 245 kV AC export cable with a design that is typical for offshore wind applications. The cable is a 3x1800mm^2 Al submarine cable where the three power cores are helically wound together with three polymeric fillers over which a single armour layer has been applied. The armour layer consists of 50% steel wires and 50% wires made of a polymeric material. The power cores and the armour wires are laid in opposite direction to achieve a more torque balanced design. An illustration of the cable design is shown in Fig. 1.

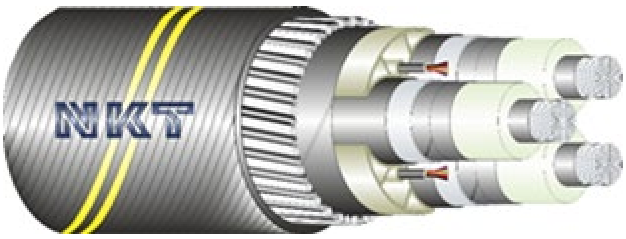

Fig. 1: Design of large HVAC cable (3x1800mm^2 Al)

3D FINITE ELEMENT MODEL

3D FE model for HVAC cable has been developed, with all parts/components of the cable taken into account, including extrinsic contacts and sliding between the components. Due to the nature of the 3-core cable, a segment of one-third of the cable lay-length is considered in the present 3D simulations, where proper periodic/anti-periodic boundary conditions have been applied on both ends of the segment. Axial tensile straining has been applied in combination with different types of rotational constraints, e.g. twist-constrained or torque-free

The analysis is performed using Abaqus/standard FE solver. The FEA model for the studied HVAC cable under axial tension is shown in Fig. 2. The model comprises a 1 m-long cable segment that corresponds to 1/3 of the lay-length of the helically-interwound cores.

In the present model, main components of the cable, i.e. cable cores, profile fillers, armour wires and cable exterior