Hybrid 2D/3D fully coupled electrothermal model for three-core submarine armored cables

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INTRODUCTION: The computation of the power losses in submarine three-core lead sheathed armored cables is overestimated by the IEC 60287 standard, and hence its size and cost. 3D finite element simulations in COMSOL Multiphysics have proved to provide accurate results in losses computation thanks to recent advances that help in reducing the model length by applying rotated periodicity boundary conditions [1,2]. However, for obtaining the ampacity of a particular cable a fully coupled 3D electrothermal model would require a highly detailed 3D geometry, something that can be difficult due to the especial operations required to create and mesh the geometry for applying such boundary conditions [3].

PROPOSED MODEL: To overcome this problem, a hybrid 2D-thermal/3D-electromagnetic fully coupled model is proposed, where the *AC/DC* module is employed to obtain the electromagnetic losses in a simplified and periodic 3D geometry (Fig. 1). Then, they are taken as the heat sources for a detailed 2D thermal model where temperature distribution (Fig. 2) is obtained using the *Heat Transfer* module. Additionally, *Surface-to-surface Radiation* and *Laminar Flow* modules are also included to make the thermal model more accurate. The full model is solved iteratively to update the electrical resistivity of the materials.

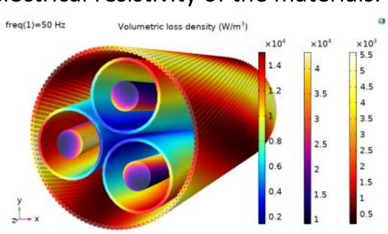

Figure 1. Electromagnetic losses in a simplified 3D model

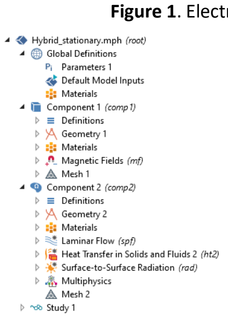

Figure 2. Full hybrid model setup

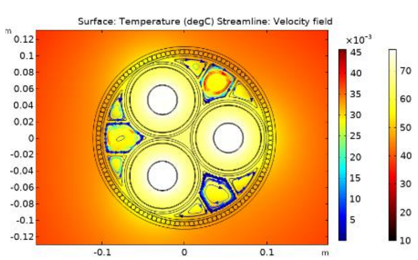

Figure 3. Temperature distribution in a detailed 2D model

General Extrusion operators are required to map the electromagnetic losses from the 3D model into the 2D one, and to map the temperature distribution from the 2D geometry to the 3D model. These operators should be adequately configured to consider the helical path of phases and armor wires (Fig. 4).

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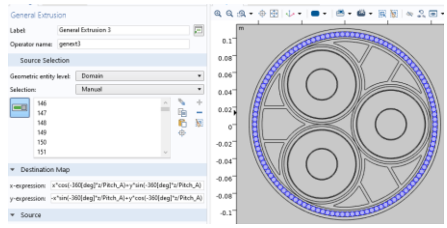

Figure 4. General Extrusion setup for the armor wires.

Thanks to rotated periodicity, the length of the 3D model can be as short as *CP*/*n*, where *CP* is the so-called crossing pitch and *n* is any divisor of the number of armor wires [2], making possible to solve the fully coupled electro-thermal model in less than 5 minutes in a 64 Gb of RAM laptop.

RESULTS: Different cables ranging from 115 kV to 275 kV have been simulated (Table 1). The 2D/3D hybrid model takes into account effects that are not properly evaluated in 2D models, such as the armor twisting, as shown in Fig. 5, where it is observed how this parameter increases the cable maximum temperature. Similarly, Fig. 6 shows how the maximum temperature in the armored cable increases with the magnetic permeability of the armor wires when using the hybrid model, while it remains almost constant (or even decreases) when 2D models are employed.

U_n (kV)	115	150	220	275
S_n (mm^2)	800	1200	1800	2000
I (A)	850	1000	1050	1100

Table 1. Cable data

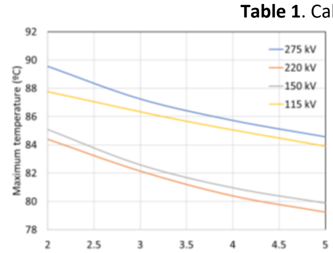

Figure 5. Evolution of the maximum temperature with the armor twisting

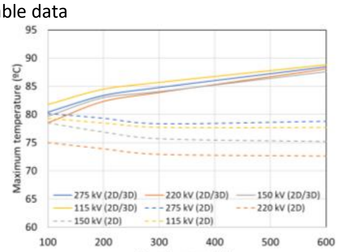

Figure 6. Evolution of the maximum temperature with the magnetic permeability of armor wires

CONCLUSIONS: The proposed model provides a new tool to evaluate accurately the maximum temperature in submarine power cables, and hence its ampacity. It also helps in the design stage of these type of power cables, leading to cable solutions optimized for a particular location.

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