Core laying pitch-long 3D finite element model of an AC three-core armoured submarine cable with a length of 3 metres

Roberto Benato a,∗, Sebastian Dambone Sessa a, Michele Forzan a, Marco Marelli b, Davide Pietribiasi b

a Department of Industrial Engineering, University of Padova, Italy
b Prysmian Power Link, Milano, Italy

A R T I C L E   I N F O

Article history:
Received 6 September 2016
Received in revised form 3 April 2017
Accepted 8 May 2017

Keywords:
Insulated power cables
Power loss computation
Steel wire armour
Submarine armoured three-core cables

A B S T R A C T

This paper presents a complete three metre long 3D finite element method (FEM) model of a three-core submarine armoured cable. In this model, the different laying pitches of cores and armour steel wires are correctly taken into account. For the first time in technical literature, a 3 m long model has been successfully solved. The CPU times are very high i.e. about 70h (mesh plus solver). IEC 60287-1-1 gives a strong overestimation of armour and screen power losses and consequently an important underestimation of cable current rating. It is worth noting that IEC gives an overestimation even if a 2D model is considered, i.e. the stranding is not taken into account; however, 2D model presents the same limitations of IEC if compared to real measurements.

In order to have an overview of the international experience on power loss computation for armoured three-core power cables, an analysis of the most significant contributions in the scientific literature [6–11] is summarised in this section, and the most relevant conclusions are here reported. The main aspects, on which the three-core power cable researches focused, are:

• Representing three core power cables by means of finite element method (FEM), by taking into account armour and conductive layers;
• Highlighting the effects of different laying designs in terms of power loss reduction;
• Comparing the IEC 60287 power loss computation approach with real measures or simulations.

For example, in Ref. [6], 2D and 3D FEM analysis of three core armoured cables are described and the simulation results are discussed in comparison with the losses calculated according to IEC 60287. The FEM model represents a three-core armoured cable, in which armour and cores are stranded in opposite directions. The model length is 1/3 of the core laying pitch.

In Ref. [8] a FEM model is developed with 10 straight armour wires around three twisted phase conductors. The wires are assumed to be nonconductive in order to simplify the model, and to reduce the mesh inside the wires. In these conditions, a sub-
stantial decrease of armour losses can be obtained by increasing the effective pitch length between the armour and the phases. The losses at rated current are much lower than the IEC 60287 predicted ones, and the potential to optimise a design is significant if a more accurate model is used to calculate the cable losses.

In Ref. [9], measurements of a 245 kV 3 × 1 × 630 mm² armoured and unarmoured cable are presented along with a description of the data processing of the measured quantities. The armoured cable has a higher loss than the unarmoured one.

In Ref. [10] armour losses are measured and calculated during the design process of submarine cables using IEC 60287–1–1 formulae. In this paper, armour losses are investigated on two different high voltage (HV) three-core submarine power cables. One cable is with full steel armour wires, the other one with armour composed of steel and polyethylene (PE). It has been observed that the substitution of steel wires with PE wires reduces armour losses and that the IEC approach for power loss computation involves overestimations.

In Ref. [11] the measured armour losses of an armoured three-core cable are compared with 2.5 FEM model results and with IEC 60287 procedures and, once again, it has been demonstrated that IEC 60287 approach could imply considerable overestimations of cable power losses. Moreover, in the paper, the basic principle of cancellation by stranding/twisting is presented. What clearly yields within this context is that there are no technical contributions which analyse the total armour and core laying pitches by means of FEM approach [6–11]. This is due to the fact that the typical laying pitch length for such cables is some meters (from 1 to 3 m), and it involves a considerable computational complexity of FEM models which require very powerful computer and very long CPU times.

It is worth highlighting that the idea of using in FEM analysis core laying pitches which are shorter than the real ones, in order to reduce CPU time and model complexity, does not allow representing the real electromagnetic interaction between the conductive elements of the cable. Therefore, from one hand, it is not possible to calculate the cable power losses correctly and consequently it is difficult to identify an optimal three-core cable layout in terms of laying pitch length and stranding direction. On the other hand, it is evident that the longitudinal cable construction influences the cable total power losses [6,7,10].

All the technical community agrees that the IEC 60287 approach is very conservative [6,8–13].

With regard to the armour magnetic permeability, Ref. [6] compares the results of a three-core cable model considering an armour permeability function inferred by measurements with the model results obtained by a constant permeability value: the results are very similar. Therefore, the hypothesis of considering an armour constant permeability value is acceptable.

Besides FEM analysis [14] of three-core armoured cables, scientific literature offers analytical approaches as well [15–21]. A very interesting approach is proposed in Ref. [19] in order to include the stranding of wires into impedance calculations.

2. Two-dimensional analysis of three-core armoured cables

The considered three-core armoured submarine cable is shown in Fig. 1: its geometric parameters are reported in Table 1 whereas the electrical ones in Table 2.

In order to have a deep understanding of the phenomena occurring without stranding, it seems necessary to analyse the electric behaviour of voltage and current phasors by assuming a two-dimensional symmetry which corresponds to the absence of the strandings.

In order to have a wide overview of the available commercial and free FEM software, the two-dimensional analysis has been performed with FEMM, FLUX 2D, COMSOL MULTIPHYSICS and ANSYS MAXWELL so to achieve a complete comparison of the different software results [22–25]. By comparing the different software results of Table 3, a very good agreement yields.

Obviously, the comparison has been performed with the same injected currents equal to 800 A.

The simulations are not time consuming and CPU times are always within 10 s. This confirms that for two-dimensional assessment all the commercial and free software are suitable.

The last column of Table 3 reports the computation in accordance with IEC 60287–1–1. Even without strandings of cores and armour wires, IEC results give a strong overestimation of power losses (and consequently an underestimation of the current rating). Fig. 2 shows a detail of the mesh employed in FLUX2D. In all these analyses the domain has been limited to 3 times the external

![Fig. 1. Three-core armoured submarine reference cable.](image)

### Table 1

<table>
<thead>
<tr>
<th>Geometric parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>r_core</td>
<td>Core conductor radius</td>
</tr>
<tr>
<td>r_ins</td>
<td>Core insulator external radius</td>
</tr>
<tr>
<td>r_screen</td>
<td>Core plastic sheath external radius</td>
</tr>
<tr>
<td>r_jacket</td>
<td>Cable radius up to lay-up included</td>
</tr>
<tr>
<td>r_armour</td>
<td>Cable radius internal to armour</td>
</tr>
<tr>
<td>r_armour_conductor</td>
<td>Cable radius external to armour</td>
</tr>
<tr>
<td>r_armour_wire</td>
<td>Armour wires number</td>
</tr>
<tr>
<td>r_armour_wire_sheath</td>
<td>Single armour wire radius</td>
</tr>
<tr>
<td>d0</td>
<td>Distance between centre of the three-core cable and one core conductor</td>
</tr>
<tr>
<td>S_armour</td>
<td>Core conductor section</td>
</tr>
<tr>
<td>S_screen</td>
<td>Metallic screen section</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Element</th>
<th>Electrical resistivity [Ω m]</th>
<th>Relative magnetic permeability [-]:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper core conductor</td>
<td>2.0489 × 10⁻⁸</td>
<td>1</td>
</tr>
<tr>
<td>Lead metallic screen</td>
<td>21.3785 × 10⁻⁸</td>
<td>1</td>
</tr>
<tr>
<td>Galvanised steel wires</td>
<td>20.8 × 10⁻⁸</td>
<td>300</td>
</tr>
</tbody>
</table>
دریافت فوری
متن کامل مقاله

امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات