2.5-D Modelling of Cable Armour Using Flux2D.

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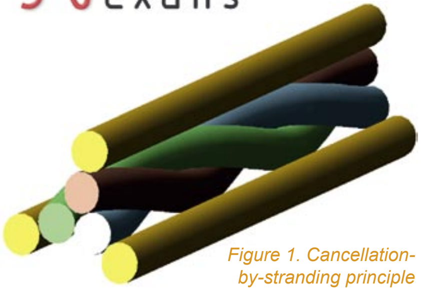

Figure 1. Cancellation-by-stranding principle is a 3D effect.

Suspicions that the present IEC formulae for both cable impedance and current rating were not correct for three-core cables are not new. Recent years show that the demand for the use of large three-core cables continues to rise, caused primarily by offshore wind farm developments.
At Nexans Norway we have been working to verify a six-year-old alternative approach to calculate cable impedance and power loss utilising the existing features within Flux2D. Solid evidence to back up any proposed method to replace the well-established IEC (empirical) method will be required, meaning it will be necessary to compare with full-scale, three-phase measurements at near-nominal current

This new idea was originally born after some contemplation on the fundamental effects/properties of stranding/twisting. Twisted pairs are known to have high immunity against differential induction from external magnetic fields. This immunity originates from the simple, geometrical twisting of the two conductors, meaning that the external field cannot influence one more than the other.

Limits of the traditional 2D approach

The armour wires of a three-core cable are helically stranded onto a bundle of three differently stranded insulated conductors. The principle can be illustrated by Figure 1, where three straight and heavily oversized armour wires are used for clarity. Conventional 2D-models, on the other hand, consider the armour wires as being individually parallel to three straight conductors, resulting in a relatively large induced current in the wires being closer to a conductor as shown in Figure 2. Comparison with real life, where each armour wire moves around the circumference as a function of axial position, clearly implies that a 2D-approach will be incorrect.

Real-life conditions, where each armour wire is equally influenced by the three phases, should in fact result in a net induced voltage/current near zero, given the analogy with the twisted pair.

This could be confirmed by measurements, as shown in Figure 3. One consequence of this finding was that any substantial armour power dissipation would have to arise from hysteresis in the carbon steel wires.

Taking into account the phenomena with 2.5D modelling

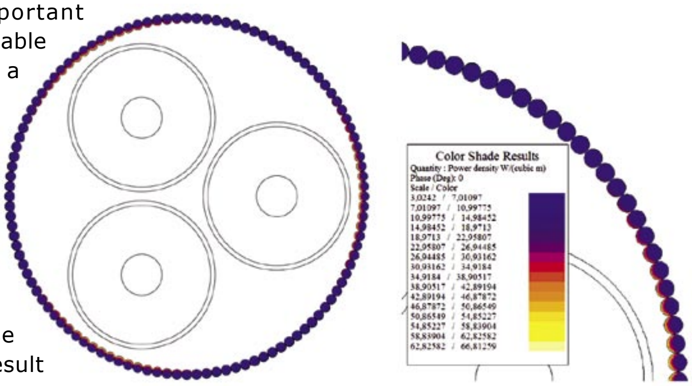

Figure 2. Computed armour power density obtained with 2D model, i.e. with net induced current in each armour wire: maximum value = 67 W/m3 at 51 A (= test current).

Figure 3. Measured current in armour wires at 90° displaced locations: not possible to distinguish any armour wire current (left: 0,06 A reading) from background interference (right: 0,05 A).

The presence of armour wires is undoubtedly important with respect to cable impedance, so a method to include it, but without introducing false effects such as large induced armour current, was needed. Considering that unbalanced phase currents could result in a net armour current in real-life, the model should allow for the same. This meant that a 2D-model where armour wires were modelled as disconnected regions would not be correct for a case of unbalanced currents.
One of the major advantages of Flux, as we see it, is the simplicity of the built-in coupling between finite element regions and elements in the electric circuit.
A simple solution was found: cascading all armour wires in the electric circuit would yield perfect cancellation of net armour current for a set of perfectly balanced currents, while unbalanced currents could set up a circulating armour current. This way of combining a 3D-effect/restriction with a 2D-geometry/model, as shown in Figure 4, is what we refer to as "2.5D".
For the cable design shown in the figures above, maximum computed flux density in the steel armour is less than 100 mT at rated cable current.

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Consequently, hysteresis loss cannot play any significant part, again implying that actual power loss in the armour must be very small indeed.

A comparison of results for the above plus the results for quite a differing three-core design are shown in Table 1 and Table 2 below.

An unsurpassed accuracy

Based on these and other full-scale results we have concluded that Flux2D can be used to compute cable (series) parameters with unsurpassed accuracy. The infamous "armour loss" has been found to be virtually zero for three-core cables carrying a balanced set of currents. Inductance computed by the described 2.5D-approach is always higher than predicted by conventional methods. 2.5D results comply very well with measured parameters for a wide range of designs.

This comparison between values obtained from IEC, 2D and 2.5D Flux models, and full-scale measurements where also presented at the latest CIGRE session in August 2010 (paper B1-116). As a consequence, it is considered likely that work on revising relevant parts of IEC 60287 will commence within the near future.

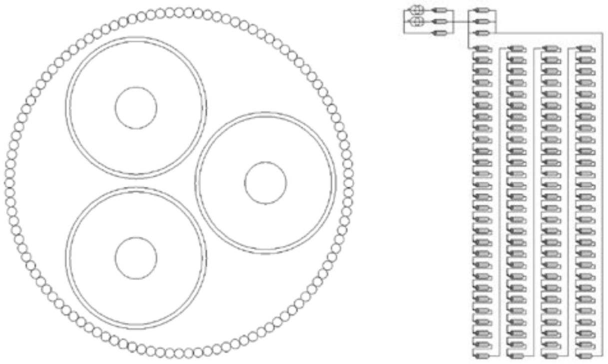

Figure 4. 2.5D: Metallic regions of FEM model (left) and corresponding circuit model (right).

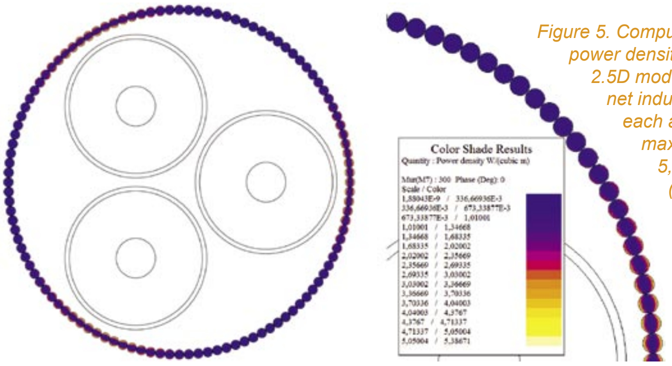

Figure 5. Computed armour power density obtained with 2.5D model, i.e. with zero net induced current in each armour wire: maximum value = 5,4 W/m3 at 51 A (= test current).

Parameter	IEC 60287	IEC, λ2=0	2D FEA	2.5D FEA	Measured
R [Ω/km]	0,0679	0,0525	0,0557	0,0540	0,054
L [mH/km]	0,449		0,441	0,465	0,47

Table 1. Computed and measured (positive sequence) parameters for a 245 kV, 500 mm² cable.

Parameter	IEC 60287	IEC, λ2=0	2D FEA	2.5D FEA	Measured
R [Ω/km]	0,0838	0,0708	0,0702	0,0682	0,067
L [mH/km]	0,320		0,323	0,328	0,34

Table 2. Computed and measured (positive sequence) parameters for 12 kV, 300 mm² cable at 50 Hz.

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