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Study Committee B1

Insulated Cables

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Validation of an efficient 3D finite element model for the calculation of losses in three-core armoured power cables

Andreas I. CHRYSOCHOS* Dimitrios CHATZIPETROS* Ioannis ZTOUPIS* James A. PILGRIM**
Vasileios L. KANAS* Konstantinos PAVLOU* Konstantinos TASTAVRIDIS* George GEORGALLIS*
*Hellenic Cables, Greece
**University of Southampton, United Kingdom

Motivation

- Calculation of losses in 3C armoured cables used in offshore wind farms
- IEC 60287-1-1 overestimates the losses
- Previous FE models: Suffer from end effects and require high computational resources
- State-of-the art FE models: free of end effects & significantly faster
- Present study: Validation of state-of-the art FE models against literature and in-house measurements

Method/Approach

- Full periodic models: Model length equal to the Least Common Multiple (LCM) of lay lengths of cores (L_C) and armour (L_A)
- Model length in full periodic models is likely to be up to 10s or 100s of meters for real cable geometries: e.g. LCM of $L_C = 3.7$ m and $L_A = 4$ m equals to 148 m
- Because of the extremely long models, non-periodic (*NP*) models could be a solution
  - Plus: Lower computational burden
  - Minus: Models suffer from end effects
- Crossing-pitch (*CP*) periodic models with length and rotation (Euler) angle:

  $CP = \left|\frac{1}{\frac{1}{L_C} \pm \frac{1}{L_A}}\right|$ and $\theta = \pm 2\pi \frac{CP}{L_C}$, respectively
  - Plus: Efficient models for contra lay cases (*CP* = 1.9 m), no end effects
  - Minus: *CP* may still be very high, e.g. for uni-lay geometries (*CP* = 49 m)
- Short-twisted (*ST*) periodic models with length and rotation (Euler) angle:

  $ST = \frac{CP}{N_A}$ and $\delta = \frac{\theta}{N_A}$, respectively, where N_A is the number of armour wires
  - Plus: Efficient models for any lay cases (*ST* = 0.5 m if N_A = 100 and uni-lay), no end effects

Objects of investigation

- Cable 1a: 3x1200 Al conductor, contra lay, single round wire armoured cable
- Cable 3: 3x1600 Cu conductor, uni lay, single round wire armoured cable
- Cable 4: 3x2000 Al conductor, double flat wire armoured cable
- Cable (in-house): 3x1000 Cu conductor, contra lay, single round wire armoured cable

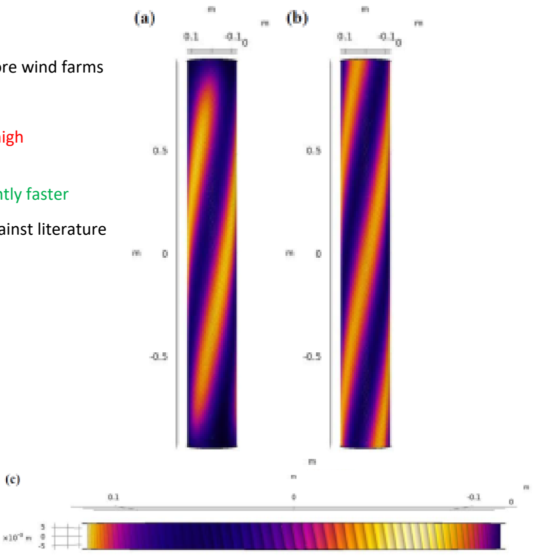

Figure 1: Armour loss density in **(a)** NP, **(b)** CP and **(c)** ST 3D FE models. End effects observed only in case **(a)**. Remarkably short model length in case **(c)**.

Numerical results - Existing literature

- Compare *ST* models with *NP* models and measured data existing in literature

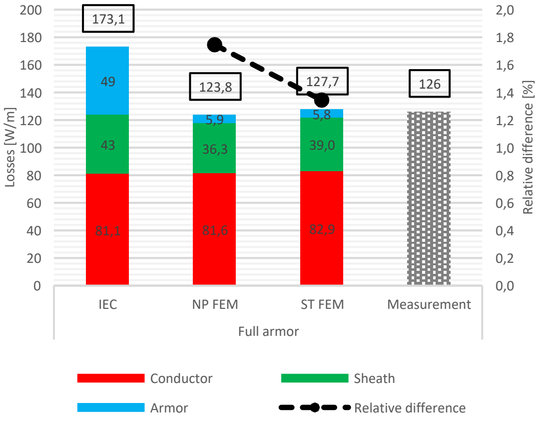

Figure 2: Cable 1a (contra) in solid bonding – comparison of IEC, *ST* and *NP* models against measurements.

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Numerical results - Existing literature

- Compare *ST* models with *NP* models and measured data existing in literature

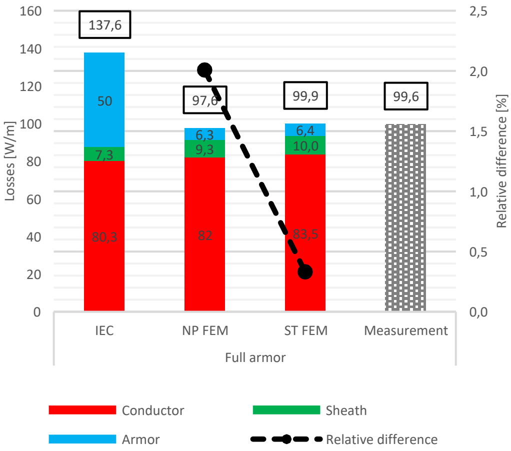

Figure 3: Cable 1a (contra) in single-point bonding – comparison of IEC, *ST* and *NP* models against measurements.

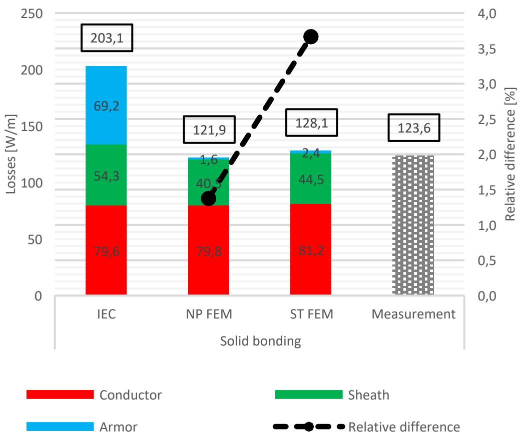

Figure 4: Cable 1a (uni) in solid bonding – comparison of IEC, *ST* and *NP* models against measurements.

Numerical results - Existing literature

- Compare *ST* models with *NP* models and measured data existing in literature

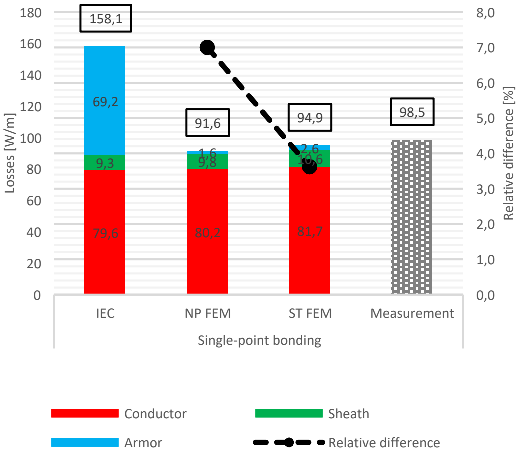

Figure 5: Cable 3 (uni) in single-point bonding – comparison of IEC, *ST* and *NP* models against measurements.

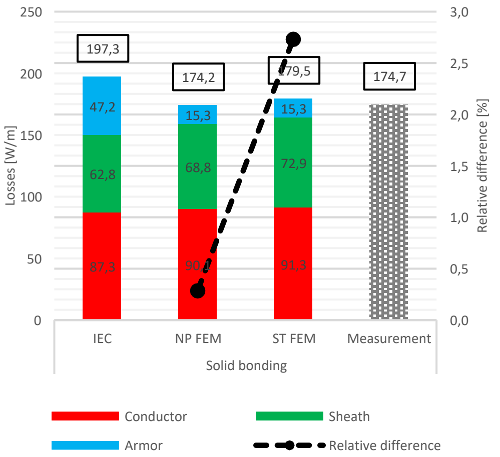

Figure 6: Cable 4 (double-flat) in solid bonding – comparison of IEC, *ST* and *NP* models against measurements.

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(continued)

Numerical results - Existing literature

- Compare *ST* models with *NP* models and measured data existing in literature

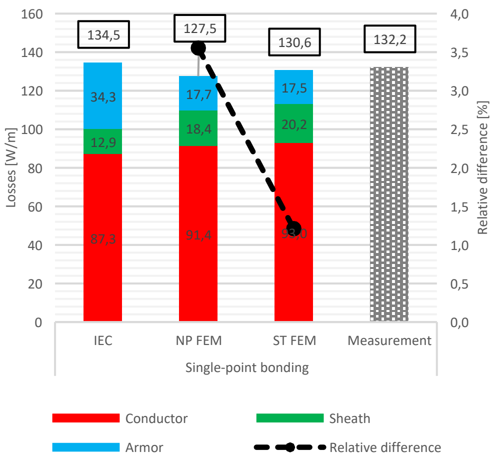

Figure 7: Cable 4 (double-flat) in single-point bonding – comparison of IEC, *ST* and *NP* models against measurements.

Numerical results – In-house tests

- Compare *ST* models with measured data and IEC
- Quantification of measured losses

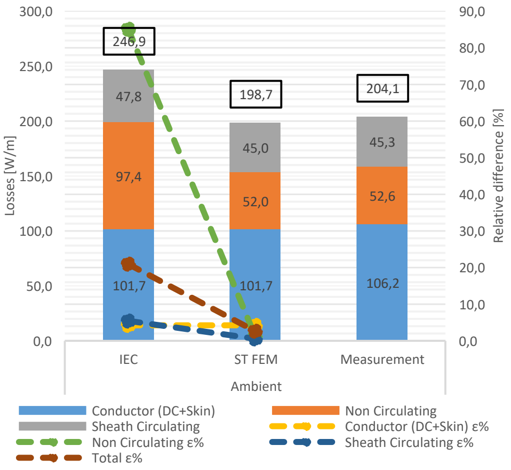

Figure 8: Cable in solid bonding – comparison of IEC and *ST* models against measurements.

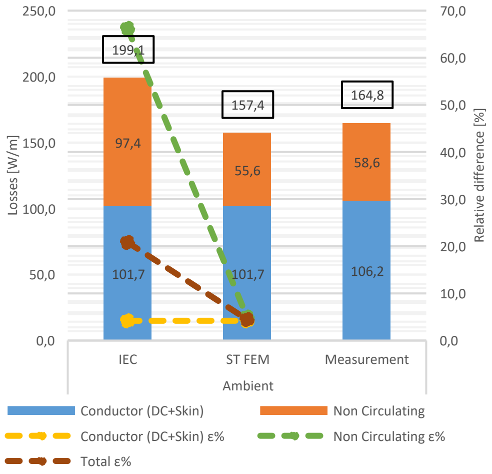

Figure 9: Cable in single-point bonding – comparison of IEC and *ST* models against measurements.

Table 1: *ST* model efficiency in numbers

	Cable 1a Solid-bonding	Cable 3 Solid-bonding	Cable 4 Solid-bonding
Model length	1.3631 cm	6.392 cm	39.012 cm
Average element quality	0.6242	0.5901	0.5858
DoF	688,429	1,842,027	3,153,552
Execution time	2 min 14 sec	4 min 51 sec	14 min 5 sec

Discussion

- *ST* model close to measurements in terms of total loss:
  - Relative difference ≤ 4%
  - Better agreement than *NP* models in many cases
- *ST* model exploits at maximum the cable periodicity and is capable of treating end effects
- Extension of the basic *ST* model logic to simulate cables with multiple-helices, e.g. double flat (cable 4)

Conclusion – Future Works

- IEC 60287 appears overly conservative, as expected
- *ST* model proves to be fast, efficient and accurate for simulating export cables
- Further investigation and development to simulate inter-array cables (uni-lay with multiple helices)

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