The Tony Davies High Voltage Laboratory

2D finite element modelling of the AC transport power loss in multi-layer Bi-2223 cables

1-LP-PC-S12

Alexander N. Petrov, James A. Pilgrim, Igor O. Golosnoy

Electronics and Computer Science, University of Southampton, Southampton, UK

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Introduction

Modelling the AC loss of first generation (Bi-2223) power cables where each layer has a different twist pitch is widely known to be challenging in the 2D domain. In fact, in [1] it is explicitly stated that AC loss simulation of twisted-layer Bi-2223 cables require a 3D model to be solved!

The proposed model in this paper seeks to provide an easy-to-build and fast-to-simulate tool to estimate the AC loss in such cables, in 2D, by utilizing the homogenization technique described in [2]. The computational and time cost of finite element modelling can then be greatly reduced, enabling FEM to be easily used for AC loss calculations, and establishing a base for further multiphysics studies.

3D-2D Approximation Technique & Considerations

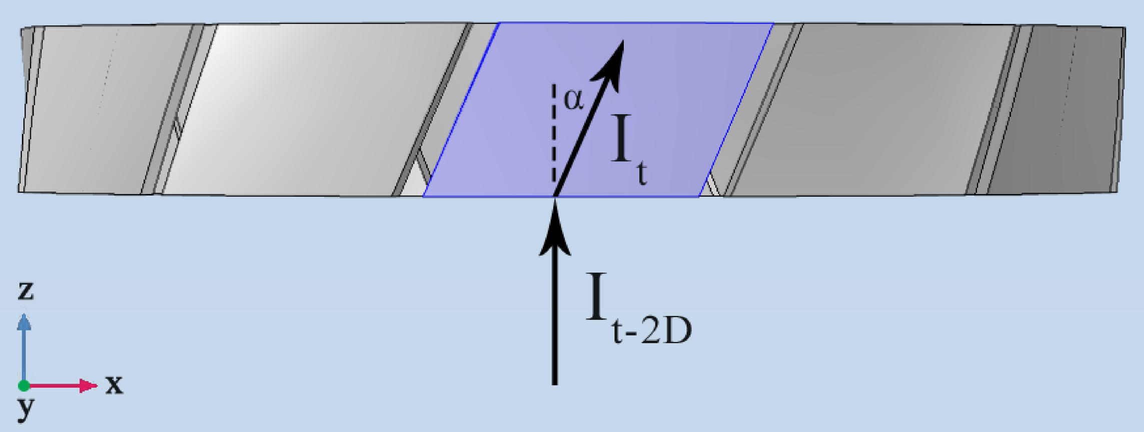

Figure 1: A top-down view of a small section of the 3D geometry of a power cable, the piece shaded in blue is a twisted tape.

$$I_{t-2D} = \frac{I_t}{\cos\alpha} \qquad w_{t-2D} = \frac{w_t}{\cos\alpha}$$

$$Q_{ac} = \frac{Q_{tog} + Q_{tot}}{2}$$

The total AC loss under transport conditions Q_{ac} is equal to sum of the AC losses of the "tape-on-gap" Q_{tog} and "tape-on-tape" Q_{tot}, divided by two.

Modifying $J_c(H_x, H_y)$ into $J_c(H_{m-x}, H_{m-y})$ is required:

$$H_{m-x} = \sqrt{\left(H_x \cos\phi_r - H_y \sin\phi_r\right)^2 + H_z^2}$$

$$H_{m-x} = H_x \cos\phi_r - H_y \sin\phi_r$$

$$\phi_r = \tan^{-1}\left(\frac{x}{y}\right)$$

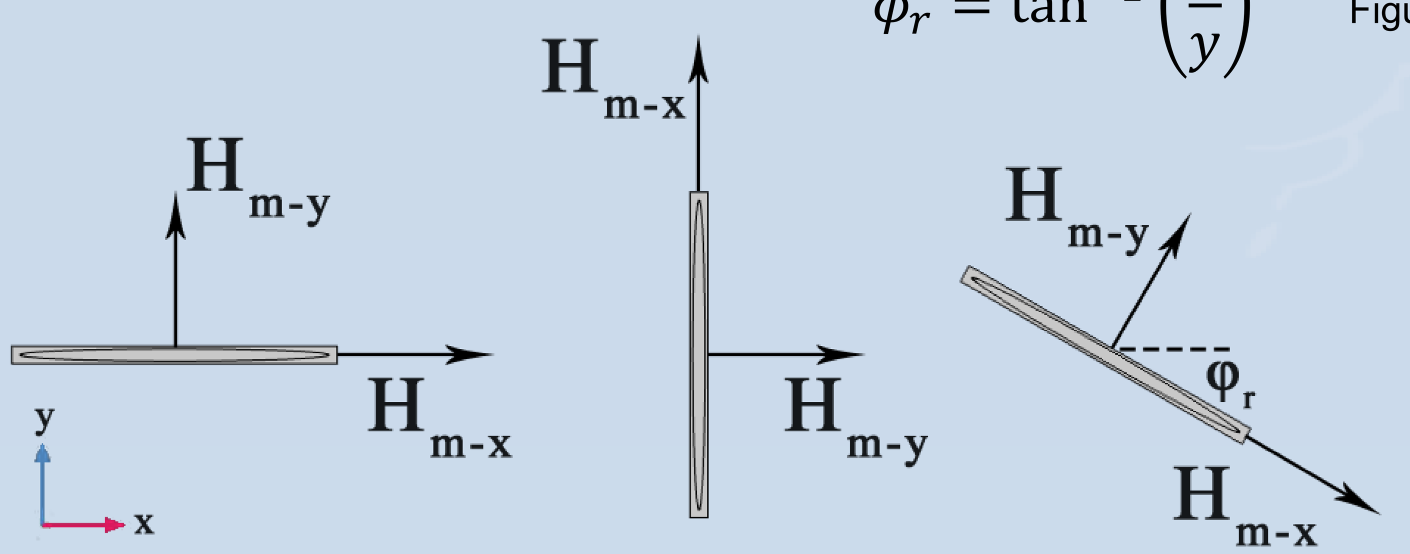

Figure 4: Illustration of the relationship between H_{m-x}, H_{m-y} and the axes of the coordinate system in 2D.

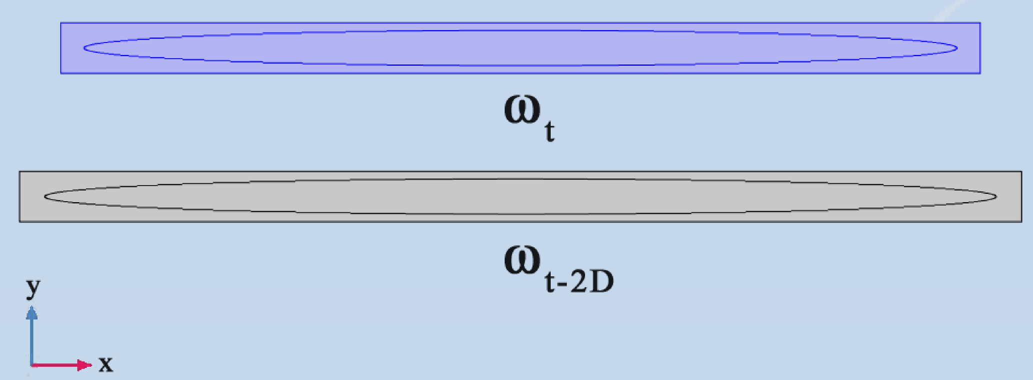

Figure 2: Visual description of the modification a tape's width must undergo under this method.

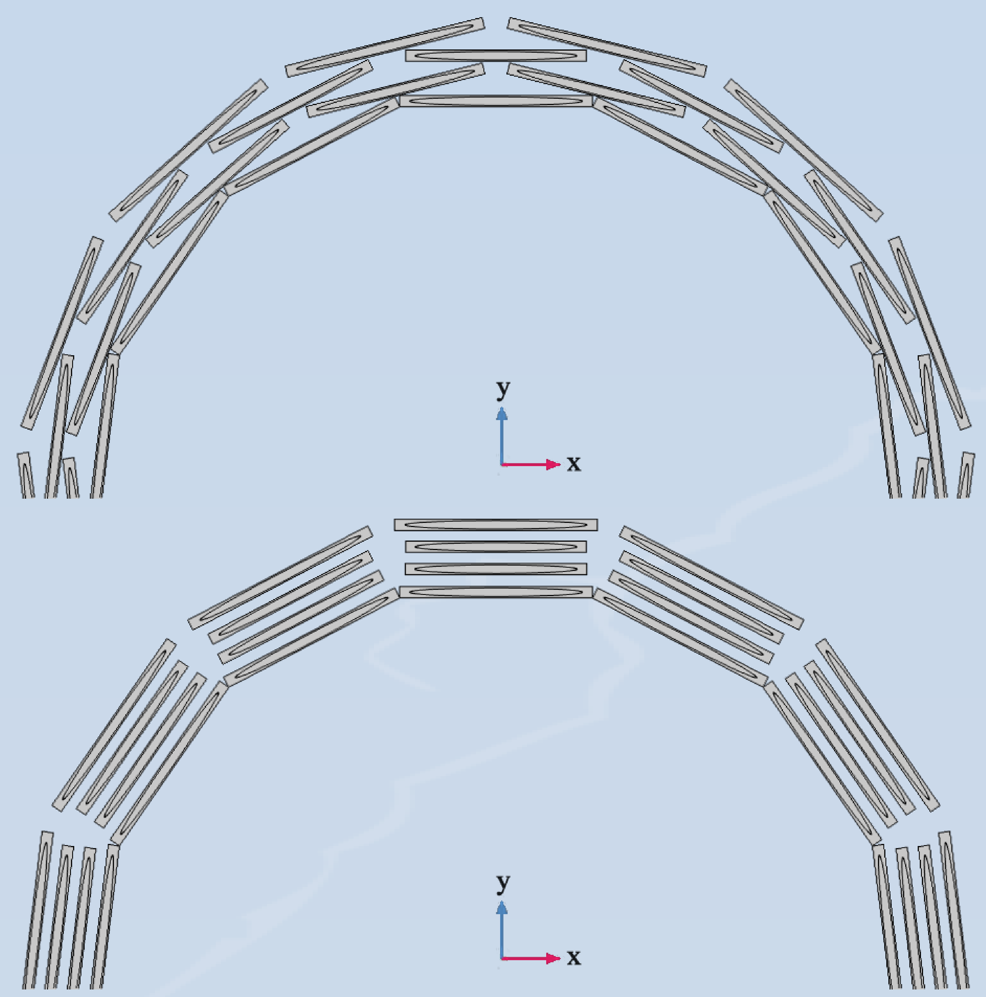

Figure 3: The "tape-on-gap" (top) and "tape-on-tape" (bottom) cross sections, as applied to [3].

Three two-layer cables with varying pitch lengths are built and simulated in 3D, and in 2D via the proposed technique.

A real cable from [3] is simulated only in 2D.

The numerical model for COMSOL is presented in [2] and [4].

Results

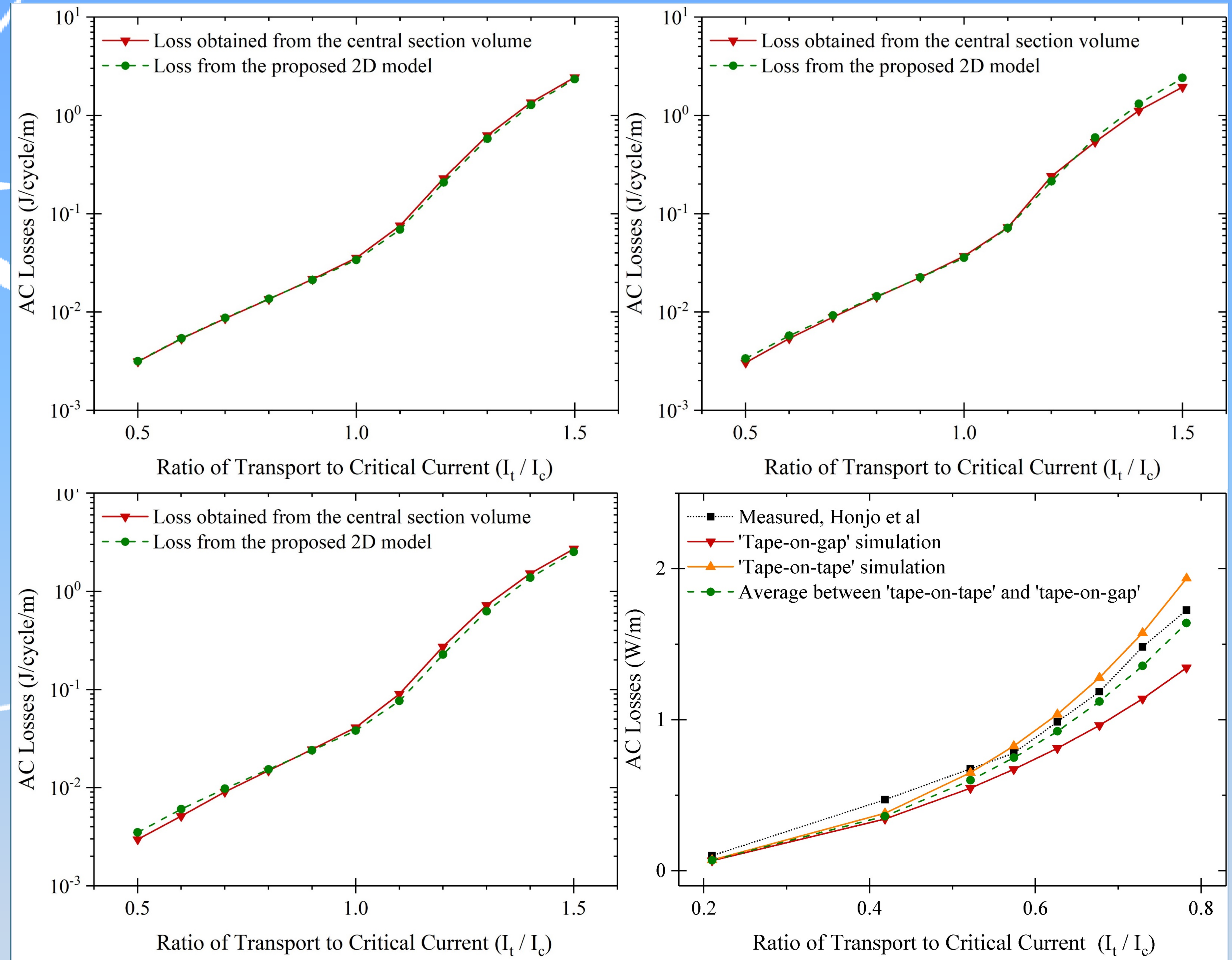

Figure 5: AC loss results. Cable 1 (top left), Cable 2 (top right), Cable 3 (bottom left), the real cable from [3] (bottom right).

Conclusions

Simulations achieved a match with differences within the range of 5-10%, and no more than 20% in individual cases. It would also be beneficial to observe how useful the averaged cross-sections model is when observing other effects within the cable, or attempting to simulate longitudinal and radial temperature rise.

References

[1] – F. Grilli, E. Pardo, A. Stenvall, D. N. Nguyen, Y. Weijia, and F. Gomory, "Computation of Losses in HTS Under the Action of Varying Magnetic Fields and Currents," IEEE Transactions on Applied Superconductivity, vol. 24, pp. 78-110, 2014.
[2] – A. N. Petrov, J. A. Pilgrim, and I. O. Golosnoy, "Revisiting the homogenized domain model for fast simulation of AC transport power losses in first generation high temperature superconducting tapes and cables," Physica C: Superconductivity and its Applications, vol. 557, pp. 33-40, 2019/02/15/ 2019.
[3] – S. Honjo, M. Shimodate, Y. Takahashi, T. Masuda, H. Yumura, C. Suzawa, et al., "Electric properties of a 66 kV 3-core superconducting power cable system," IEEE Transactions on Appiled Superconductivity, vol. 13, pp. 1952-1955, 2003.
[4] – M. Zhang and T. A. Coombs, "3D modeling of high-Tcsuperconductors by finite element software," Superconductor Science and Technology, vol. 25, p. 015009, 2012.

Contact details : A.Petrov@ecs.soton.ac.uk