HTS Coated Conductor Losses Model Using the Coupling Method and the T-A Formulation

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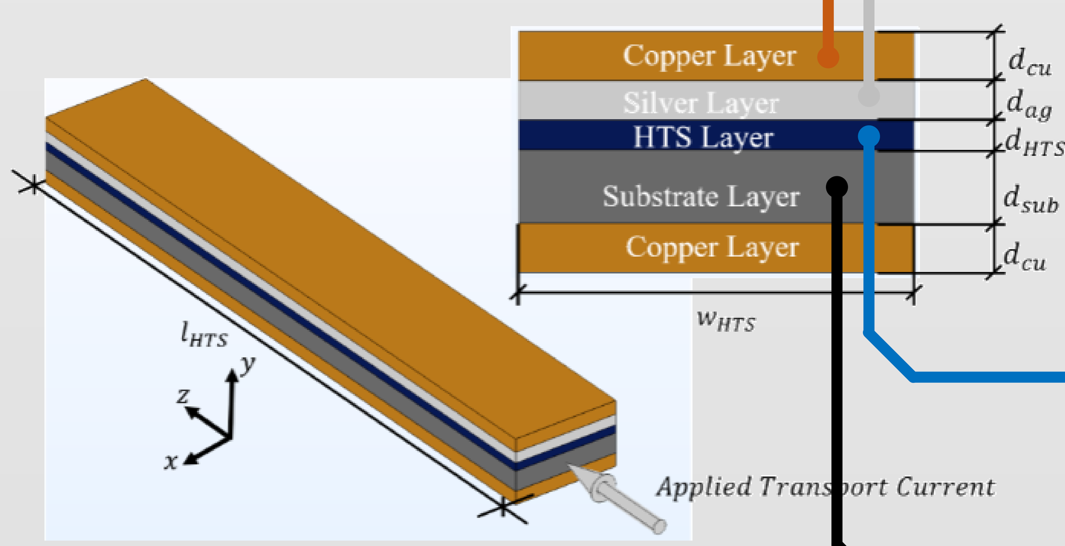
ABSTRACT

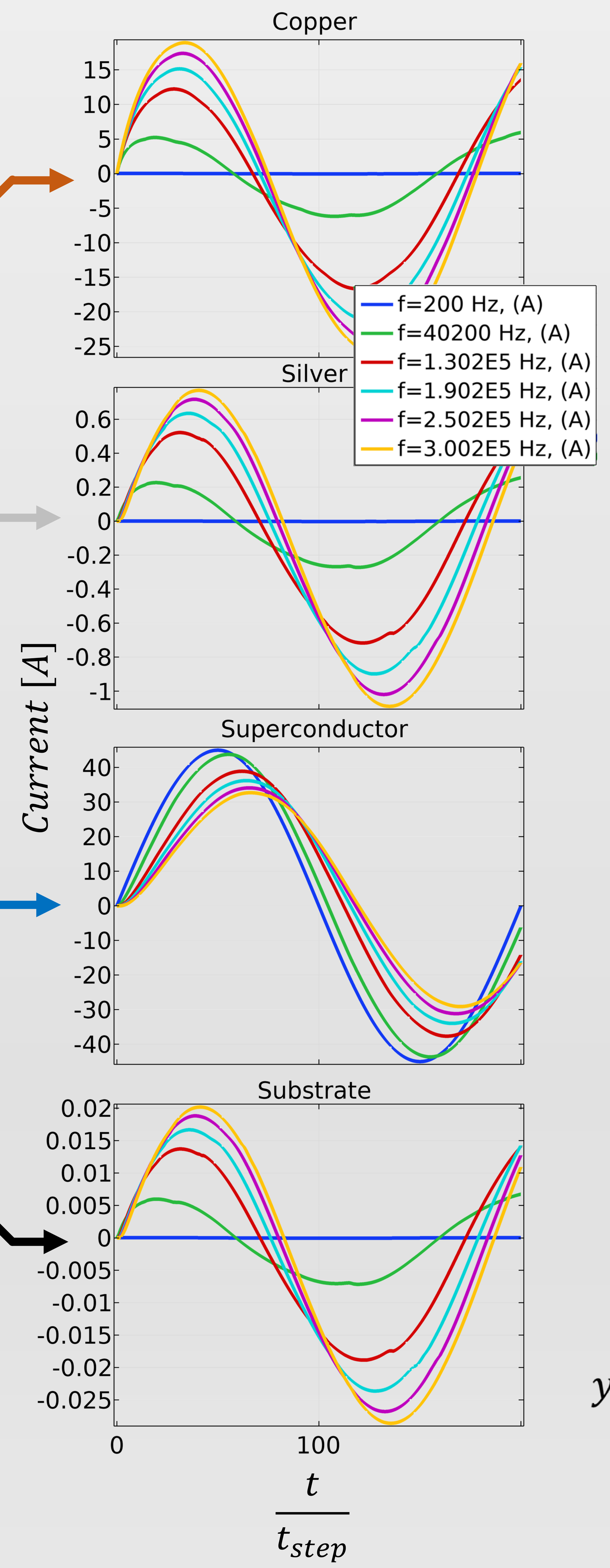
The power loss in electric power equipment is a fundamental topic to the superconductivity largescale applications. The literature presents several methods developed to predict these losses in superconducting tapes. The finite element method (FEM) has been widely studied among the existing methods, using formulations as the H and the T-A. However, to compute the HTS coated conductor losses in a large frequency range, just the H-formulation has presented a good accuracy and precision. Using the T-A formulation and the coupling method, the authors propose a new and innovative method to calculates the losses in a large frequency range. The results of this method are compared with the consolidated H-formulation to validate them.

HOW CURRENT AND LOSSES DISTRIBUTE AS FREQUENCY INCREASES?

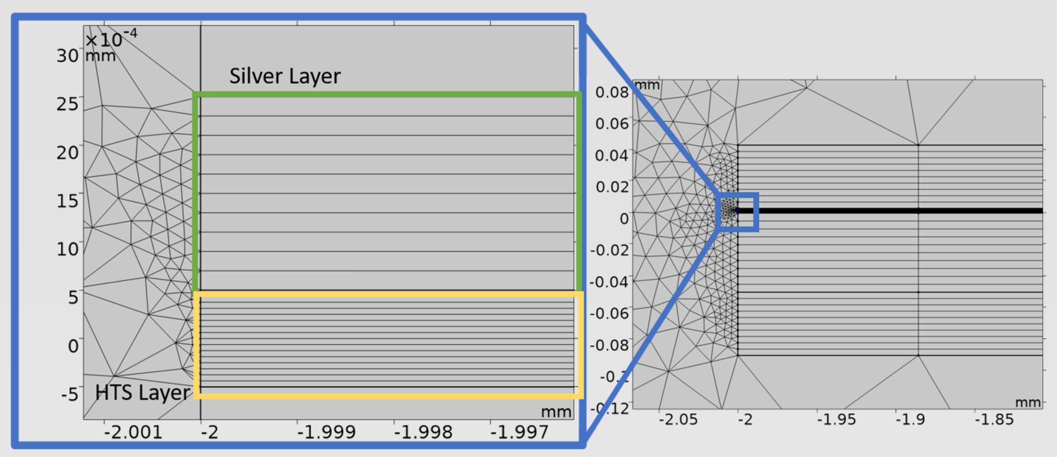
Could be obtained by H or 2D T-A Formulations, but at a higher computational cost.

How to do it using 1D T-A Formulation (thin film approximation)?





Simulation in 2D T-A or H Formulations:



PEEC SOLVERS

PARTIAL ELEMENTS EQUIVALENT CIRCUITS

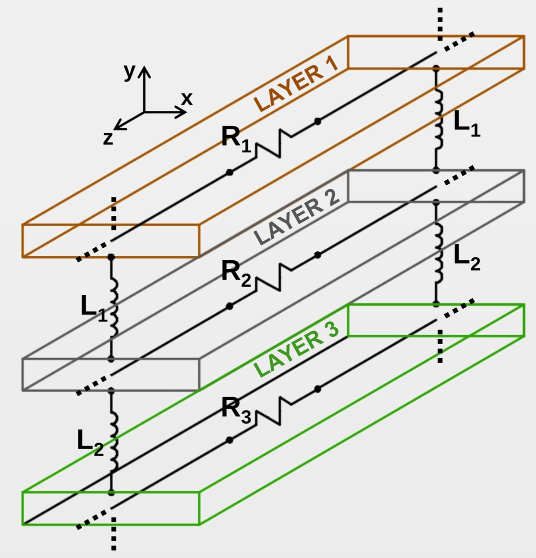
Represents the skin depth as a partial inductance in thin film conductors.

In a general assumption, a finite number of cells divides the thickness of each layer. A uniform thickness is not required. In this studied case, each layer uses just **one** cell.

Considerations:

- HTS tape layers are thin films;
- Current flows only in z axis;
- One cell per tape layer;.
- Layers self and mutual inductances are neglected (low frequency).

$$L_k = \frac{\mu}{2}\frac{l_k d_k}{w_k}$$



AC LOSSES ASSESSMENT

HTS Resistivity:

$$\rho(J,B) = \frac{E_C}{J_C(J,B)}\left(\frac{J}{J_C(J,B)}\right)^{n-1}$$

Critical Current Density:

$$J_C(B_\parallel, B_\perp) = \frac{J_{C0}}{\left[1+\left(\frac{k^2 B_\parallel^{\,2} + B_\perp^{\,2}}{B_0^{\,2}}\right)^{\frac{1}{2}}\right]^{\alpha}}$$

HTS Layer Losses:

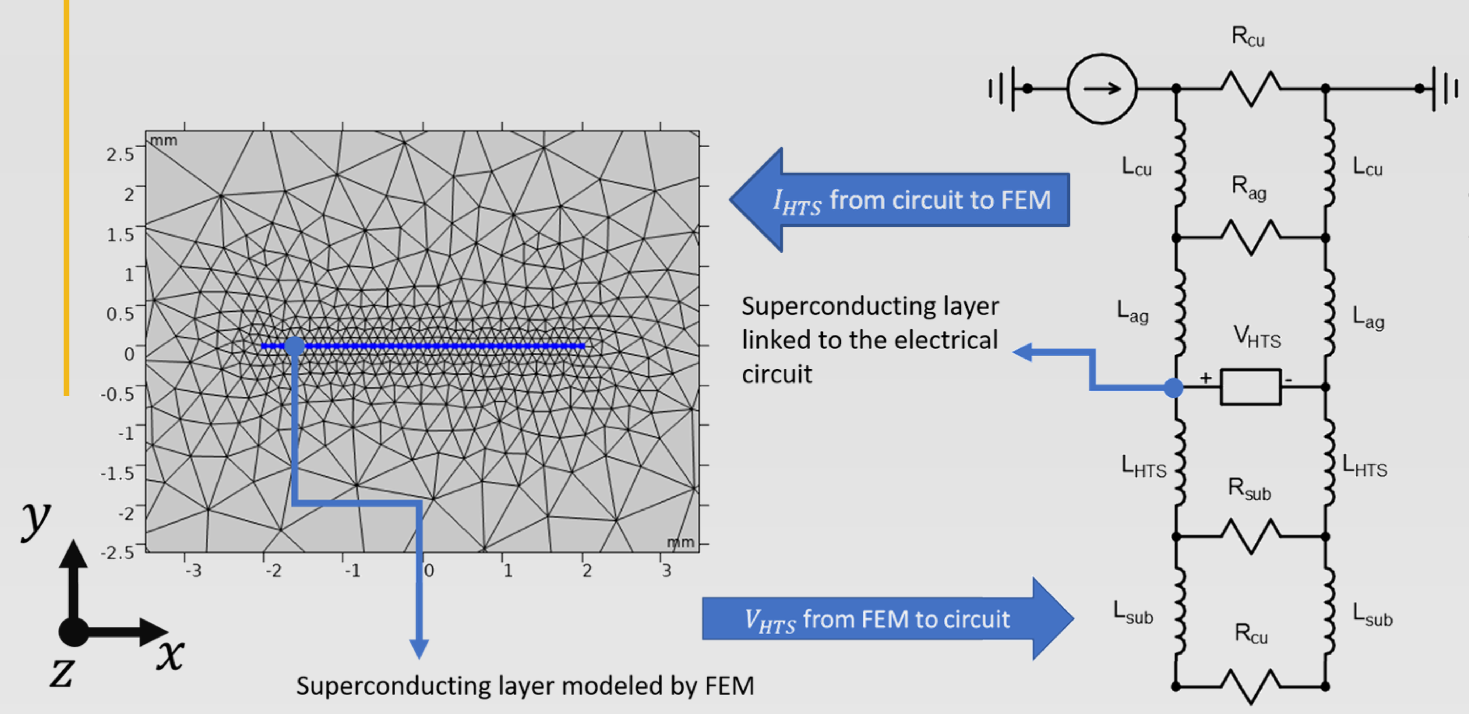
$$P_{HTS} = \left(\int_{length} \boldsymbol{E}\cdot\boldsymbol{J_{HTS}}\, dl\right) d_{HTS}$$

Metal Layers Losses:

$$P_k = \frac{R_k I_k^{\,2}}{length}$$

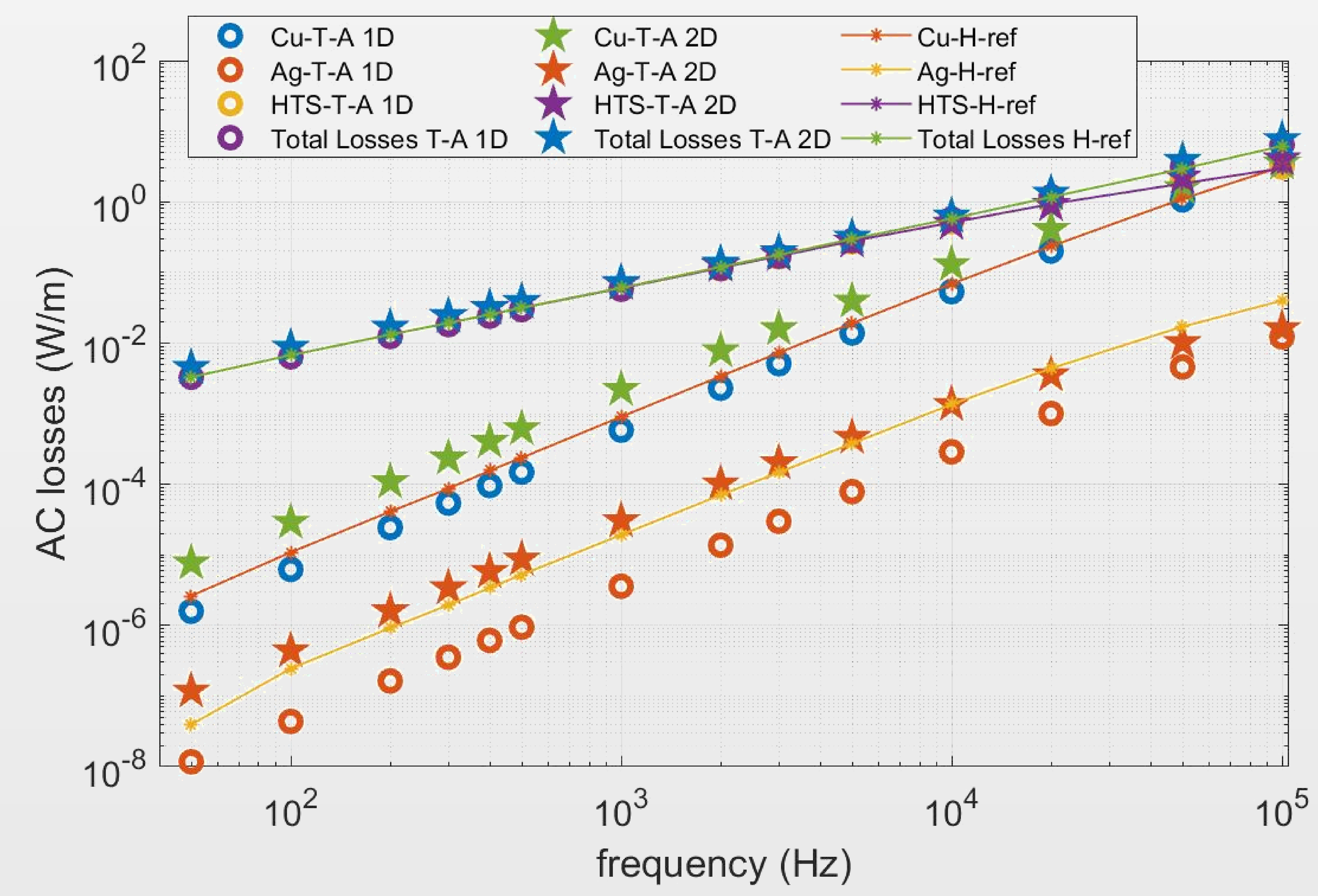
1D T-A FORMULATION + PEEC LUMPED PARAMETERS

Only the HTS layer is modelled through FEM

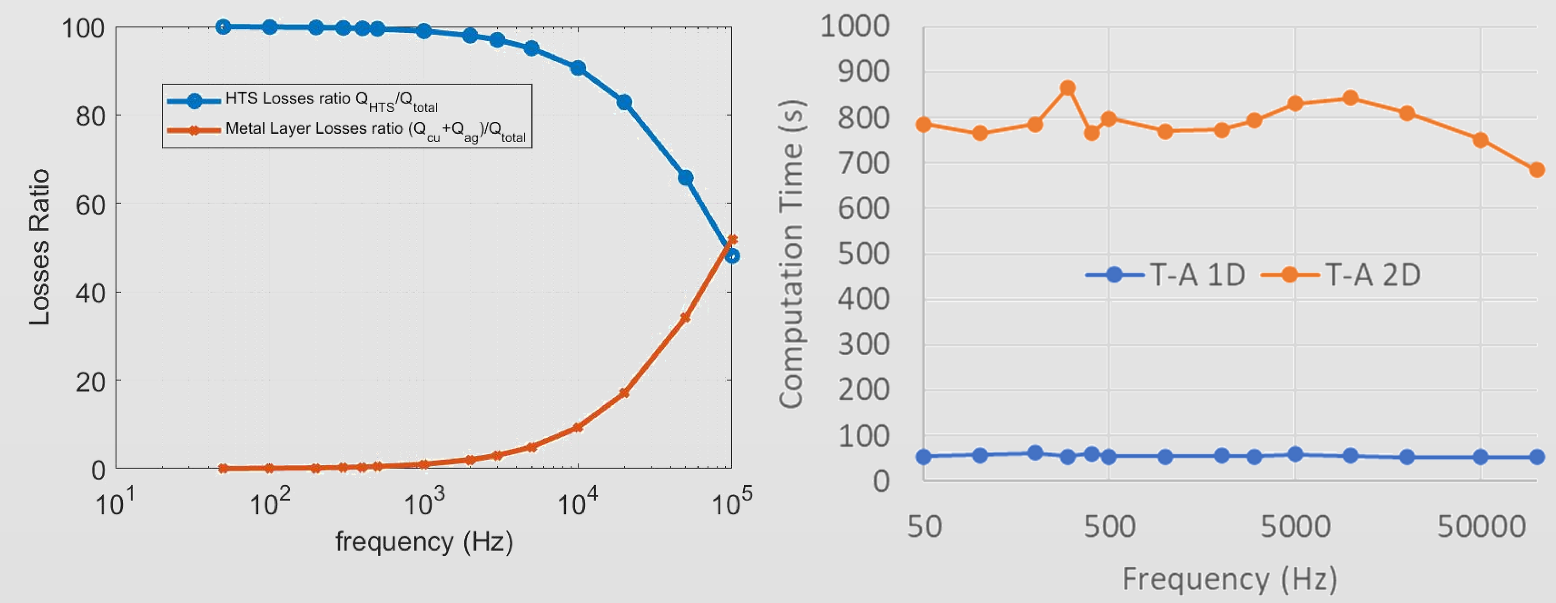


Parameters	values
Critical current	99.23 A
E_c	1 μV/cm
Power law index	38
Superconductor width	4 mm
Superconductor height	1 μm
B0	42.65 mT
k1	0.29515
a	0.7
Copper conductivity @77K	5.076×10^8 S/m
Copper height	20 μm
Silver conductivity @77K	3.704×10^8 S/m
Silver height	2 μm
Substrate conductivity @77K	8×10^5 S/m
Substrate height	50 μm
Total tape length	25 cm
Side of the air square	50 mm
μ_0	$4\pi \times 10^{-7}$ H/m
I_{ext}	50 A

RESULTS AND CONCLUSIONS



Using H formulation as a reference, results in T-A 1D are better than the ones from T-A 2D, except for the silver layer. Regarding this difference, it is observed that the deviation keeps constant. The authors attribute this fact to the self and mutual inductance neglecting among the layers.



As frequency increases, relative losses in the HTS layer decrease, and the metal layers losses increase. Close to 100 kHz, metal layer losses are over 50% of the total, being greater than those from the HTS layer.

It is observed that the total simulation time in 1D T-A is approximately 18 times less than 2D T-A and comparing the results it is possible to see the efficiency and precision of the proposed approach.