



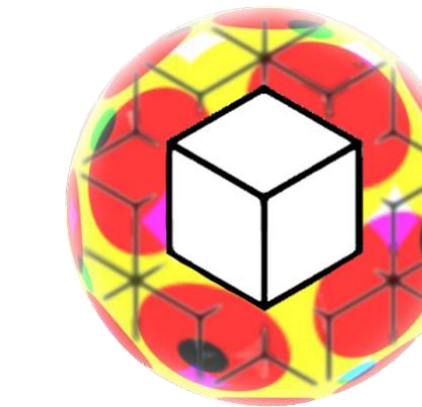
# Modeling of high-temperature superconducting pancake coils using the axisymmetric partial element equivalent circuit method

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## → INTRODUCTION

The partial element equivalent circuit (PEEC) method has great potential to solve electromagnetic problems coupled with electric circuits. Such capability is useful for modeling the integration of superconducting devices with power electronics converters for exemple. In this article we implement an axisymmetric PEEC model of pancake coils made of high-temperature superconducting (HTS) tapes fed by arbitrary voltage and current sources. The results obtained with the PEEC model are compared to an H-formulation finite element (FE) model.

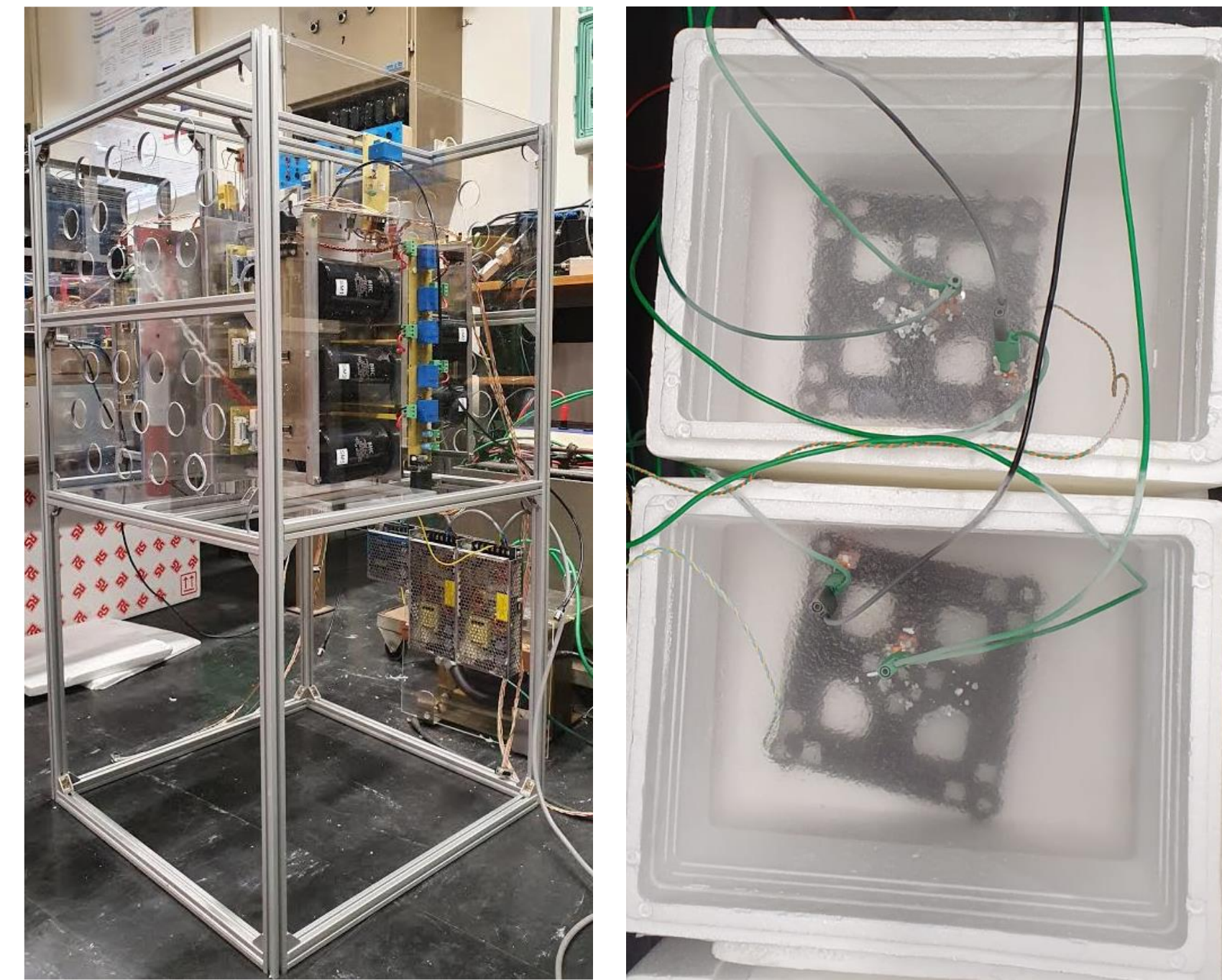


Fig. 1. The Cryo-MMC, an integration between superconducting coils and a power electronic converter.

## → AXISYMETRIC PEEC

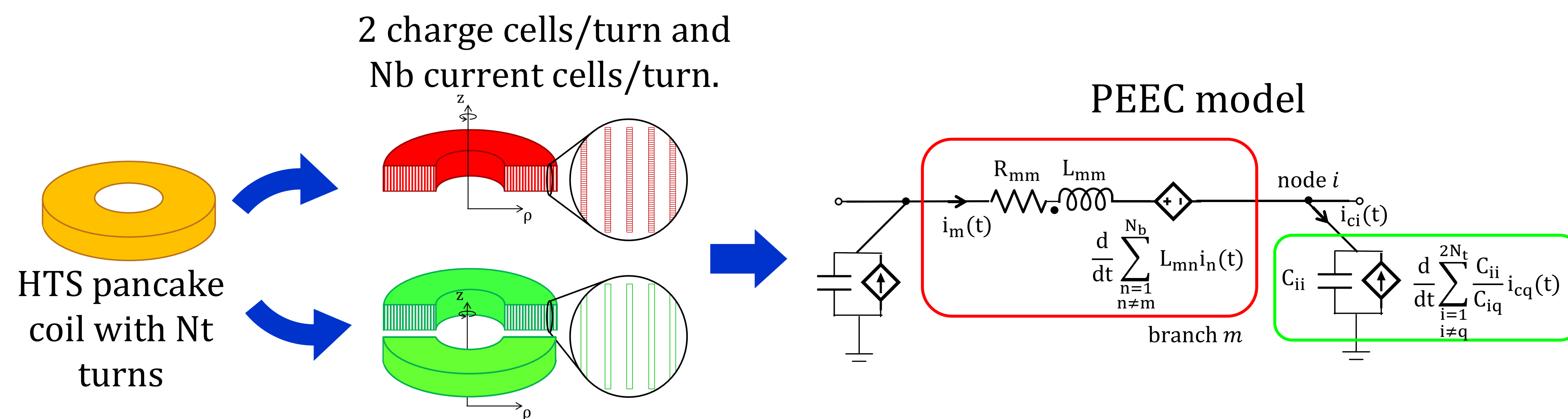


Fig. 2. PEEC modelling of HTS pancake coil.

We use an EJ power law for the superconducting regions. Thus the PEEC model leads to a non-linear system of equations of the form,

$$\mathbf{M} \frac{d}{dt} \mathbf{x}(t) = \begin{bmatrix} \mathbf{R}(\mathbf{I}(t))_{N_b \times N_b} & \mathbf{k}_{1, N_b \times 2N_t} \\ \mathbf{k}_1^T & \mathbf{k}_{2, 2N_t \times 2N_t} \end{bmatrix} \mathbf{x}(t) + \begin{bmatrix} \mathbf{k}_{v, N_b \times 1} & \mathbf{k}_{i, 2N_t \times 1} \end{bmatrix} \mathbf{u}(t)$$

$\begin{bmatrix} \mathbf{L}_{N_b \times N_b} & \mathbf{0}_{N_b \times 2N_t} \\ \mathbf{0}_{2N_t \times N_b} & \mathbf{C}_{2N_t \times 2N_t} \end{bmatrix}$

$\begin{bmatrix} \mathbf{I}(t)_{N_b \times 1} \\ \mathbf{V}(t)_{2N_t \times 1} \end{bmatrix}$

$\begin{bmatrix} \mathbf{V}_s(t) \\ \mathbf{I}_s(t) \end{bmatrix}$

## → SIMULATION RESULTS FOR A 10-TURN PANCAKE COIL

### Results with current excitation

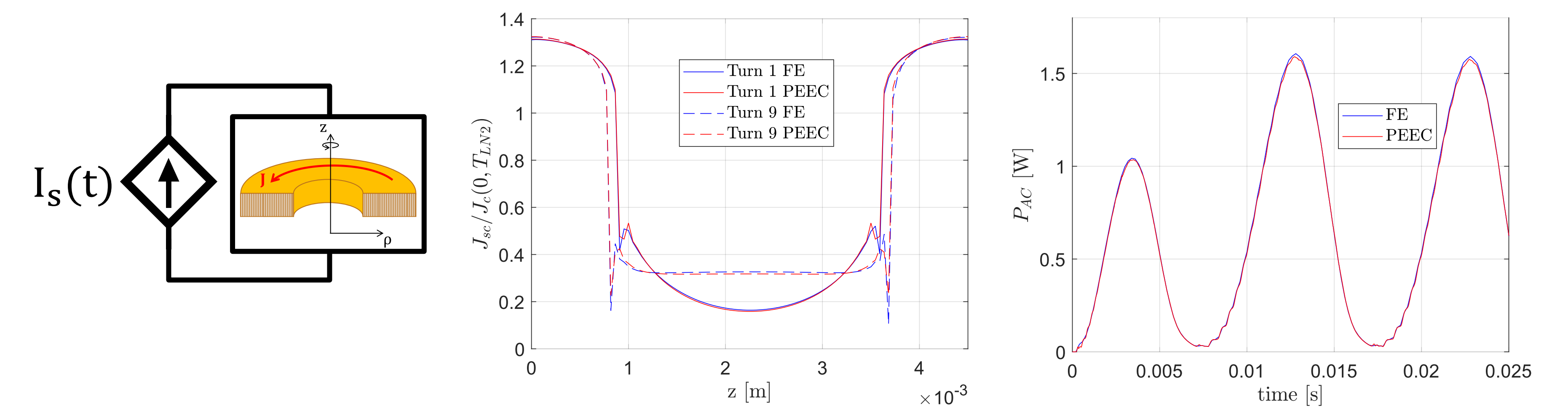


Fig. 3. The PEEC and the FE models results for  $I_s(t) = 120\sin(2\pi 50t)$ . The current density is plotted at  $t = 0.025$  s (2nd AC peak).

### Results with voltage excitation

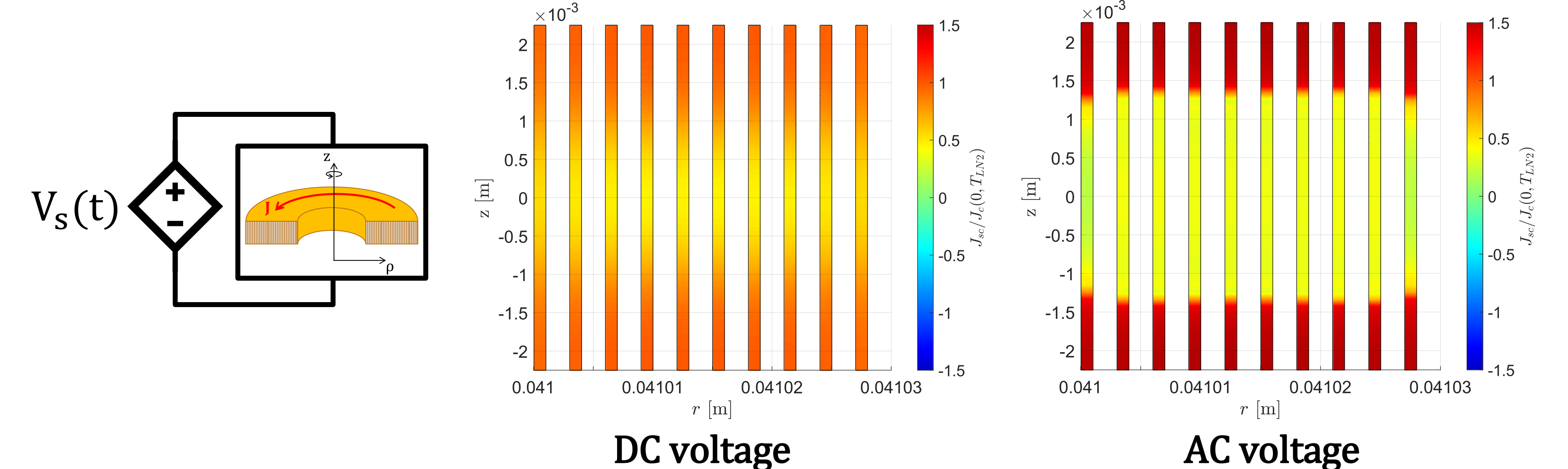


Fig. 4. The PEEC results for  $V_s(t) = 0.142$  and  $V_s(t) = 0.71\sin(2\pi 50t)$ . The current density is plotted at  $t = 0.1843$  s (9th AC peak).

## → CONCLUSION

- ▶ The PEEC model is an alternative to FE model to simulate HTS coils' behavior in circuit-based simulations.
- ▶ The PEEC can treat both voltage and current source excitation problems.
- ▶ The highest average relative error in the current density distribution is 7.3 % while the relative error in AC losses is 4.7 % which validates the proposed model.
- ▶ Coming soon: PEEC model of HTS coil integrated into a modular multilevel converter.

