Homogenization Approaches for Laminated Magnetic Cores Using the Example of Transient 3D Transformer Modeling

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Abstract

Introduction
Proper modeling and simulation of transformers with finite element methods is a challenge due to the involved nonlinearities and coupling effects between different physical domains. Primarily, there are the highly non-linear magnetic characteristics of the core materials including ferromagnetic hysteresis, eddy currents in the windings and the core, and temperature-dependent material properties like the electrical conductivity. With non-linear magnetic material or a non-harmonic excitation, simulations need to be performed in transient rather than in time-harmonic mode [1, 2].

A specific issue in transformer modeling is the consideration of electric sheets or other laminated core materials which are used to reduce eddy currents and thus to minimize dynamic hysteresis losses. Normally, the thickness of the individual sheets is small as compared to the core thickness. Therefore, it would be impractical to explicitly model a large number of sheets with a high dimensional aspect ratio, as this would lead to a large number of elements and hence to unacceptable computational costs. To overcome this problem, several homogenization approaches for laminated cores have been proposed in the past. They replace the laminated structure with a single domain of an electrically and magnetically orthotropic material which exhibits the same macroscopic behavior in a certain range of conditions. Thus, the computational effort is significantly reduced.

Use of COMSOL Multiphysics®
In our study, we implemented several homogenization approaches for laminated core materials in a transient 3D current transformer model. The influence of core eddy currents on the transfer behavior of the transformer and on the dynamic hysteresis losses are simulated as a function of the frequency and the transformer load. Simulation results obtained on the different homogenization approaches are compared to those on explicitly modeled core sheets and further to experimental results. This comparison is made both for toroidal core arrangements which are used for magnetic material characterization according to DIN EN 60404-6 and for the operation as current transformers. It reveals the accuracy and the application limits of the investigated

homogenization approaches.

For current transformers at small excitation frequencies, amplitude ratio and phase shift obtained on the homogenized material models are in good agreement with the results from tests and the simulations on explicitly modeled cores. In this case skin depth is much larger than the sheet thickness. Dynamic losses differ from those obtained in tests and for explicitly modeled cores. Also, the homogenization approaches become inaccurate at higher frequencies.

Further model improvements include an enhanced approximation of the nonlinear magnetization curve H(|B|), a faster implementation of the excitation current at the presence of eddy currents in the primary winding and an automated script based iteration between the bi-directionally coupled electromagnetic and thermal models.

Reference

[1] T. Bödrich, H. Neubert, R. Disselnkötter: Transient Finite Element Analysis of a SPICE-coupled Transformer with COMSOL Multiphysics. 4th European COMSOL Conference, Par-is (FR), 17.-19.11.2010

[2] H. Neubert, T. Bödrich, R. Disselnkötter: Transient Electromagnetic-Thermal FE-Model of a SPICE-Coupled Transformer Including Eddy Currents with COMSOL Multiphysics 4.2. 5th European COMSOL Conference, Stuttgart (D), 26.-28.10.2011

[3] V. Silva, G. Meunier, A. Foggia: A 3-D finite-element computation of eddy currents and losses in laminated iron cores allowing for electric and magnetic anisotropy, IEEE Trans. on Magn. 31 (1995) 2139-2141
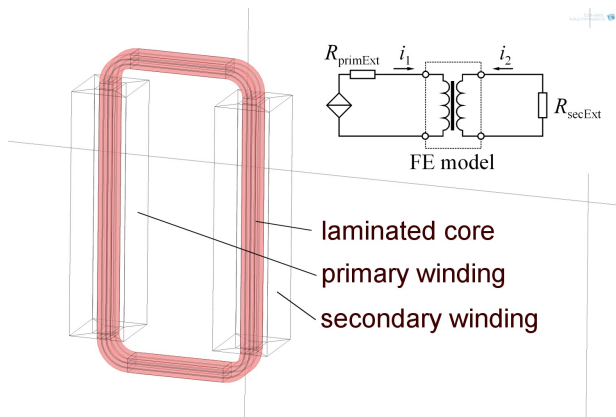
Figures used in the abstract

Figure 1: Geometry and coupled SPICE circuit of the electromagnetic transformer model (surrounding air is neglected)
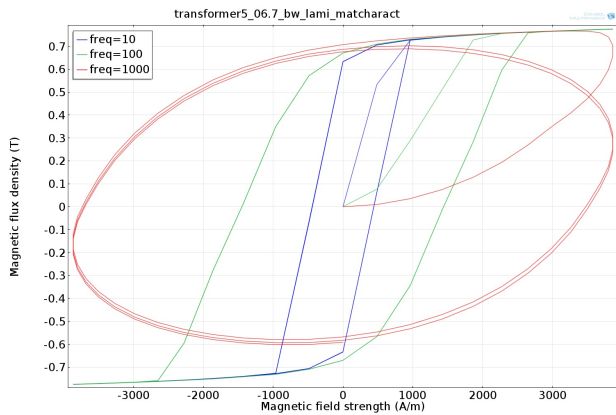

Figure 2: Simulated dynamic hysteresis of a transformer with an explicitly modeled lami-nated Permalloy core, no-load condition
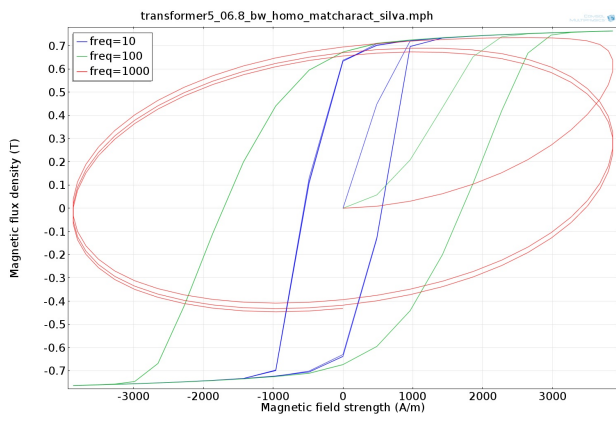
Figure 3: Simulated dynamic hysteresis of a transformer with orthotropic homogenized Permalloy core, no-load condition, homogenization approach according to [3]