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Lumped parameter modeling to improve planar transformers design

A. Besri (*), B. Delinchant (*), J-P Keradec (*), C.R Sullivan (**)

(*) G2ELab
CNRS UMR 5269 INPG/UJF
ENSIEG BP 46, 38402 St Martin d'Hères Cedex,
Grenoble, France
Phone: +33 / (0) – 476826299
Fax : +33 / (0) – 476826300
E-mail:
Abdelhadi.Besri@g2elab.inpg.fr
benoit.delinchant@g2elab.inpg.fr
Jean-Pierre.Keradec@g2elab.inpg.fr

(**) Thayer School of Engineering
8000 Cummings Hall, Hanover, NH 03755-8000
USA
Phone: 603-646-2230
Fax: 603-646-3856
E-mail:
Charles.Sullivan@Dartmouth.edu

Abstract: This paper presents a modeling and simulation tool based on a 1D modeling of planar transformers. The main goal is to help designers to easily describe, simulate and improve a planar transformer.

Keywords: Analytical modeling, Topology, Optimization, Planar Transformers.

I INTRODUCTION

Transformers and inductors are very important parts in power electronics, the main stream now is to reduce volumes and costs, this choice leads to use HF excitations but drawbacks are the increasing AC losses. The model presented in this paper takes into account these frequency behaviors. The tool offers to simulate in frequency domain and get the currents and voltages in each layer of the planar transformer. Due to power electronics coupling, a time domain circuit is required and is automatically built with identification procedure

II MODELING TO OPTIMIZATION

II.1 1-D Analytical model of a planar transformer

Several analytical models are developed for transformers [1] [2], for the planar transformers, Maxwell equations in 1D for each layer are solved. This model expresses the magnetic and the electrical field in each side of a layer (ferrite, copper and insulator), the approach developed in our study is to represent these relations between fields and sources with a lumped elements circuit. This circuit is then used for the frequency domain simulations [3] (Fig.1). These circuits are a result of a development in Taylor series of the analytical solutions (1) and (2) of 1D propagation in a layer (x, y) infinite with a as the thickness located between two other mediums (1 and 3, Fig1). (E_g, H_g) and (E_d, H_d) are the electrical and the magnetic fields in both sides of the layer. E_s is the static electrical field generated by a source. J is the current by unit of length.

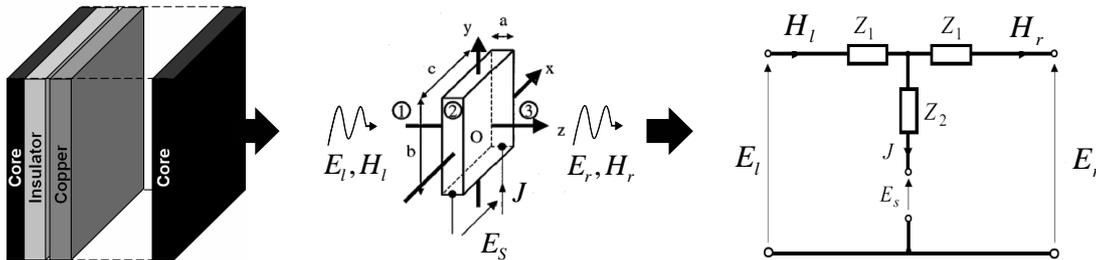


Figure 1: Equivalent circuit for layer of a planar transformer

$$Z_1 = Z_c \frac{1-A}{1+A} = Z_c \cdot j \cdot \tan\left(\frac{\phi}{2}\right) \quad (1)$$

$$Z_2 = Z_c \frac{2A}{1-A^2} = Z_c \frac{1}{j \cdot \sin(\phi)} \quad (2)$$

A is the attenuation introduced by the layer, Z_c is the characteristic impedance and ϕ is the complex phase.

This analytical model gives access to the geometrical parameters and the possibility to do an optimization. The power electronics (switches) and the load bring non-periodic wave forms so the frequency model is not suited, a time domain model is then required.

II.1 Improvement of a 2 winding planar transformer

In order to give a clear idea of the modeling, a 2 winding transformer with 4 copper layers is used as an example. There are many possible topologies and a variety of copper thicknesses available. 3 topologies, as described by Prieto [4]: SSPP, SPPS, SPSP, (S for secondary and P for primary) with the primary layers in series and the secondary layers in parallel. They can be compared regarding copper losses.

	P 100 μm	P 10 μm	P 10 μm	P 100 μm
	S 100 μm	S 10 μm	S 100 μm	S 10 μm
SPSP:	135.7 W	24.4 W	16.5 W	381.3 W
SPPS:	135.7 W	24.4 W	30.8 W	91.3 W
SSPP:	135.7 W	24.4 W	18.4 W	803.5 W

Figure.2: Copper loss values (at $f = 105$ Hz)

This figure shows an important fact which is that the copper losses are lower for the first topology (the most interlaced). Core losses can also be included by adding the complex values of μ for example.

II.2 Time domain model identification

The time domain (Fig.3) model is identified using open and short circuit impedances curves provided by the previous frequency model. Given this, we can simulate (e.g. Pspice [5]) the transformer inside a converter circuit.

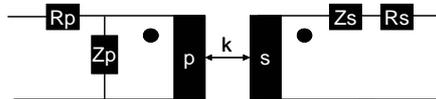


Figure.3: Time domain equivalent circuit for a two winding transformer

A new identification can be provided to the user, or scripted to be included in an optimization loop.

III SIMULATION AND OPTIMIZATION PROCEDURE FOR A PLANAR TRANSFORMER

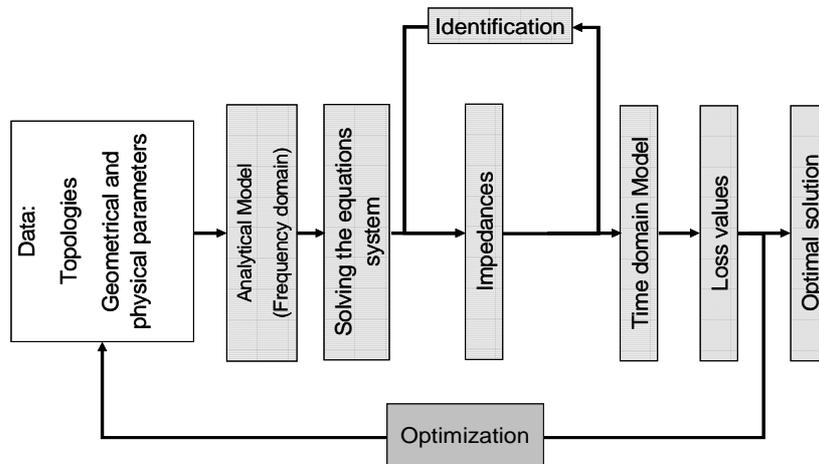


Figure.4: Procedure to solve the sizing problem

IV CONCLUSIONS

The proposed modeling gives many opportunities of optimization and simulation for planar transformers and inductors. The complexity of such systems comes from the large variety of topologies. Several optimization procedures can be tried, mixing topology choosing (discrete optimization) with sizing of continuous parameters with gradient based algorithms, in order to get the best feasible topology.

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