Modeling of Losses and Current Density Distribution in Conductors of a Large Air Gap Transformer Using Homogenization and 3D FEM

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Abstract— A large air gap transformer has a strongly inductive behavior and leakage flux is very important. In some cases, in order to improve the coupling coefficient of a large air gap transformer, it is interesting to have a low turn number and a large winding window. As a result, coils are composed of a large number of conductors in parallel and variation of flux in winding window is important. Therefore, losses and current density distribution are not uniform. This paper presents a study of current density distribution and losses in conductors of a large air gap transformer composed of two E cores using homogenization and 3D FEM. Moreover, solutions to improve current density distribution are proposed.

I. Introduction

This paper presents a study of current density distribution and losses in conductors of a large air gap transformer composed of two E cores and two windings (Fig. 1). For this study, the converter chosen to supply the magnetic component is a series parallel resonant converter with LC filter [1].

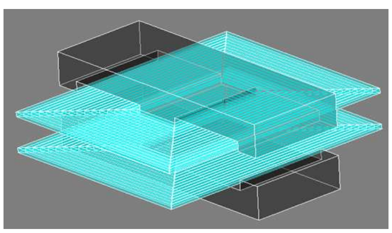

Fig. 1. 3D view of a large air gap transformer with two windings.

Capacitors are used to compensate inductive behavior of large air gap transformer. In order to realize magneto dynamic simulations, the full bridge is considered like an alternative voltage source and the rectifier plus the load are represented by an equivalent resistance (Fig. 2). On Figure 2, primary and secondary windings are composed of n conductors in parallel. In this study, n is equal to 16.

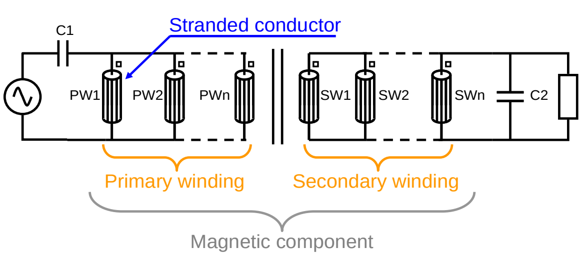

Fig. 2. Electrical circuit with n conductors in parallel at primary and secondary

II. Homogenization of Conductors

In this study, the working frequency is equal to 25 kHz. In order to compensate skin effect, Litz wires have been used. Representation of these conductors is very difficult on account of the complex geometry. Moreover, with FEM in order to have a good accuracy, it is necessary to have two elements in skin thickness. Therefore, it is very difficult to represent and mesh these conductors and it is very expensive in time computation. But an alternative method proposes to homogenize Litz wire. Indeed a bundle of conductors of resistivity and reluctivity properties could be represented by equivalent complex properties. Some works deal with this problem of homogenization [2], [3], [4], [5], and [6]. Equivalent complex permeability are calculated from analytic expression of [3], [4] but numerical method could be used [2]. Equivalent complex permeability is an anisotropic property. But, in this study, geometric properties of conductors and working frequency allow to suppose equivalent complex permeability is isotropic.

III. Study and Results

In order to have a good current density distribution, it is possible to use passive or active solutions. Passive solution consists in use of dedicated conductors, that is to say winding window are filled up with only one conductor. The equivalent electrical scheme is the one of Figure 3. Active solution consists in supplying each elementary conductor by a current source (Fig. 4).

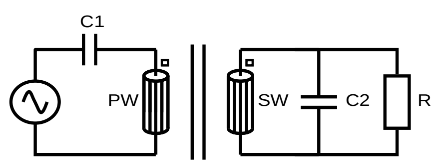

Fig. 3. Electrical circuit with 1 conductor at primary and secondary

In this study, we compare five simulations results. In first, we have supposed there are no losses in conductors and the current density is uniform (case 1). Then we simulate the working of the magnetic component with 16 conductors in parallel at primary and secondary (Fig. 1) (case 2). Case 3 corresponds to passive solution (Fig. 3) with one conductor at primary and secondary. Current density is supposed uniform. In case 4, the 16 conductors in parallel at primary are supplied by a current source. And secondary winding is composed of 16 conductors in parallel (Fig. 4). The last case is the same that case 4 except for secondary winding which is composed of only one conductor (passive solution).

In Table 1, normalized electrical magnitudes are presented functions of the five case of study. P_O, P_I, Q_I, and S_I represent respectively the active output power, the active input power, reactive input power and apparent input power. These results have been obtained from simulations with FLUX® [7] in 3D.

TABLE 1
NORMALIZED ELECTRICAL MAGNITUDE FUNCTIONS OF CASE OF STUDY

	P_O (p.u.)	P_I (p.u.)	Q_I (p.u.)	S_I (p.u.)
1 : Non meshed coils	0.935	-0.935	-0.108	0.941
2 : 16 conductors in parallel at primary and secondary with µ complex	0.378	-1.55	-0.050	1.56
3 : 1 conductor at primary and secondary with µ complex	1.03	-1.07	-0.169	1.09
4 : Current sources at primary and 16 conductors at primary and secondary with µ complex	0.265	-0.276	-0.359	0.453
5 : Current sources at primary and 1 conductor at secondary	0.786	-0.806	-0.133	0.819

Case 1 can be considered as the reference. In case 2, desired output power is not reached and losses are very important. In case 4, losses are reasonable but reactive power is important. Case 3 and 5 allow reaching desired output power without too important losses and reactive power.

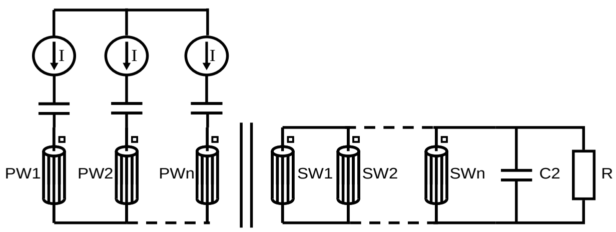

Fig. 4. Electrical circuit with current sources at primary and n conductors in parallel at secondary

IV. Placement of Conductors

By adjusting the placement of conductors, it is possible to improve current density distribution. In this study, three kinds of windings are compared. The first is the classical, that is to stay windings are concentric. The second is a winding use in

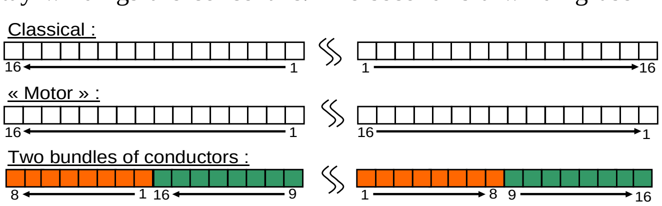

Fig. 5. Electrical circuit with current sources at primary and n conductors in parallel at secondary

electrical motors where coils is bored so as to inverse the place of conductors. The last is deduced from the current density distribution of Figure 6.a where current density is maximum at edges that is to say near the air gap and minimum at center. The goal is to place conductors at center of winding window of right whereas they are at the edges in the winding window of left. Figure 5 shows the order of conductors in the left and right winding window for a coil composed of 16 conductors in parallel for each solution.

Different kinds of winding are simulated with 2D FEM software. Figure 6 shows the current density distribution functions of kind of windings. The most important difference

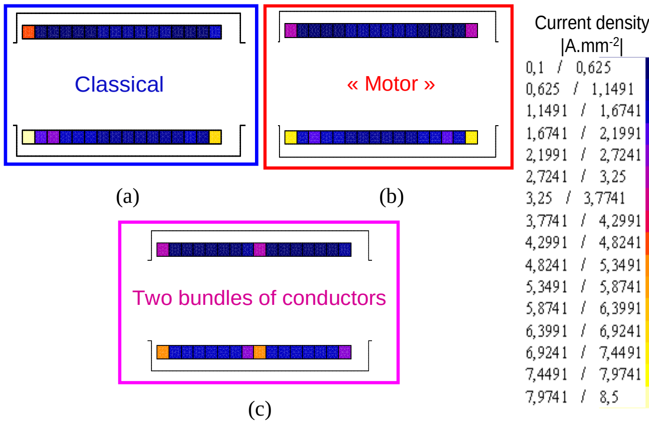

Fig. 6. Electrical circuit with current sources at primary and n conductors in parallel at secondary. (a) Classical. (b) “Motor”. (c) Two bundles of conductors.

of current density is obtained for classical winding. “Motor winding” allows obtaining a symmetrical current density distribution. And “Two bundles of conductors” winding allows minimizing the maximal current density.

V. Conclusion and Perspectives

This study shows the influence of a non-uniform distribution of current density between conductors in parallel. It modifies inductive behavior of magnetic component and increases losses. Moreover, desired output power is not reached. Some methods are presented in order to solve this problem with passive or active solutions.

In order to be more accurate, it would be interesting to calculate equivalent complex permeability numerically and to be able to implement an anisotropic complex permeability in the FEM software. Future works will implement these possibilities in the software.

VI. References

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