Investigation of a Novel Integrated Magnetic System using Finite Element Method in Comparison to Conventional Integrated Magnetic Devices

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Abstract — Integration of passive magnetic devices is essential to design highly efficient DC/DC converters. Due to the need for green electronics, but also to save as much space as possible for modern designed devices such as LED TVs and space saving bright LED illumination, the development of such devices is highly necessary nowadays. This paper deals with this multi-physics issue and presents a novel Integrated Magnetic System (IMS), investigated by the Finite Element Method (FEM). Two different FEM approaches are applied to give proof of evidence for the correctness of the analyzed data. Two different kinds of IMS are assayed in this research, one vertical design and one new horizontal configuration. Both magnetic systems are developed with a novel capacitor arrangement to save as much space as possible.

I. INTRODUCTION

Many structures of integrated magnetic systems (IMS) are showing that the development of these constructions is affected by different kinds of side effects. One of these effects is the rising temperature of a compact integrated system [1], due to the fact that all components are packed in one device, which reduces the surface to the environment. Therefore 3-D FEM simulations which take heat transfer coefficients and the electric conductivity into account [2] must be adopted for the IMS. Another unwanted effect can appear through the usage of parasitic elements such as the inter-winding capacitance and the inductance of the transformer primary and secondary windings to build a resonant tank in the desired operational frequency range [3]. The involvement of these generally avoided elements is a good solution to save room, however the values of the system might change with the temperature and material inaccurateness causes changes of all integrated parts. One of the common passive magnetic configurations involves a vertical arrangement [3]. Hence, this model is compared to the novel planar IMS.

Since computing power has sufficiently increased to apply 3-D based FEM electromagnetic fields, including circuit network analysis, it can be used to examine complex interconnections of multiple magnetic devices nowadays [4]. Due to the complex asymmetric structure and several connections between the layers of the flat IMS, the meshing process is complicated. A structured mesh would be easier to generate and the elements would be more even than in conventional finite element mesh [5].

This paper is focused on the structure configuration of the IMS as a multi-physics problem, and the investigation of the electromagnetic field using the Finite Element Method (FEM). The material issues and effectiveness of such IMS will be also discussed in the full paper.

II. NUMERICAL MODELING OF THE IMS

The modeling process involves the whole magnetic system as shown in the equivalent circuit (Fig.1). However, in order to save simulation time and to achieve proper results, investigations of just one or two components are more efficient for the FEM simulations.

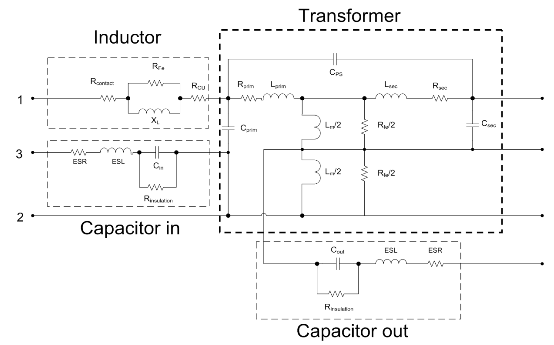

Fig.1: Equivalent circuit of the integrated magnetic system

A. IMS Structure Configuration

For the integrated magnetic systems, novel kinds of bifilar capacitor layers (Fig.2) are applied in the vertical as well as in the horizontal IMS. It is important to reduce the impact of the outer electro-magnetic-field on the capacitor layers to avoid a reduction of the capacitance.

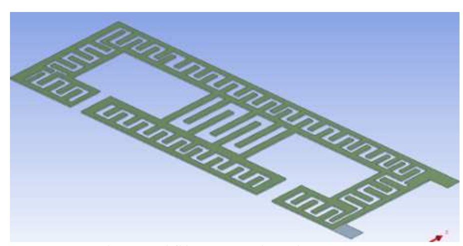

Fig.2: Bifilar capacitor layer

Figure 3 shows the vertical IMS FEM model with the transformer windings on the top and inside the double E-Core, including the capacitor and induction layers on the bottom, attached via a single E-Core. The horizontal IMS model is visualized in Figure 4 and contains all components in one special designed magnetic core.

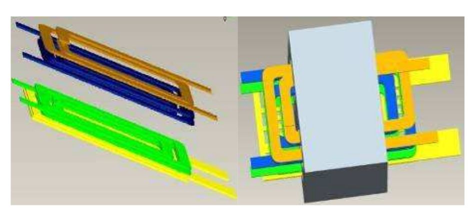

Fig.3: Top-Up IMC configuration
3-D FEM model, with core (left) and conductor layers without core (right)

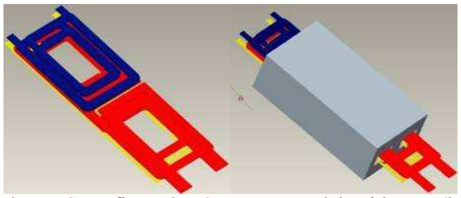

Fig.4: Flat IMC configuration 3-D FEM model, with core (left) and conductor layers without core (right)

B. *Magnetic Field Computation*

To compare the vertical with the horizontal IMS, finite element simulations are focused on the core saturation and disturbances of the components to each other. Thus, the equation for the non-linear magnetic field is applied to determine the magnetic flux inside the different core parts. The non-linear magnetic field can be expressed as

$$\nabla \times \nabla v \times A - J = 0 \ , \tag{1}$$

where J is the current density, including the eddy current density and exciting current density, A defines the magnetic vector potential and v is the reluctivity. For the three dimensional field the equation can be written as

$$\frac{\partial}{\partial x}\left(v\frac{\partial A}{\partial x}\right)+\frac{\partial}{\partial y}\left(v\frac{\partial A}{\partial y}\right)+\frac{\partial}{\partial z}\left(v\frac{\partial A}{\partial z}\right)+\sigma\frac{\partial A}{\partial t}-J=0 \ . \tag{2}$$

Based on the Galerkin`s method, the FEM matrix can be obtained as follows:

$$[S]\{A\}+[M]\{A\}-K=G \ , \tag{3}$$

where the matrix [S] is the global coefficient matrix and [M] is the time harmonic matrix.

C. *Capacitance Calculations*

Based on the Maxwell theory, the relation between potential and charge in the multi-conductor system can be described by the electric scalar potential V, which satisfies Poisson's equation,

$$-\nabla\cdot(\varepsilon\nabla V)=\rho \ , \tag{4}$$

where ε is the permittivity, and ρ is the space charge density. By using a FEM approach, the relationship between charge and potential can be obtained as

$$[S]\{V\}=\{Q\} \ , \tag{5}$$

where [S] is the global coefficient matrix and {Q} is the charge matrix. By setting up the boundary condition, $V_1=1$, $V_2=V_3=\ldots=V_N=0$, we can obtain $Q_1=C_{11}$, $Q_2=C_{21}$, …, $Q_N=C_{N1}$, and in the same manner, the coefficients C_{ii}'s and C_{ij}'s can be calculated.

III. RESULTS AND ANALYSIS

The simulation of the vertical IMS shows, that the shared core in the upper part of the transformer core is highly stressed (Fig.5a). The relationship in equation (6) shows that if the effective magnetic area A_e decreases, the magnetic flux density B in the shared core area rises.

$$B=\frac{V_{rms}}{\sqrt{2}\cdot\pi\cdot l\cdot A_e\cdot f} \tag{6}$$

Furthermore, the system must be connected in the right way; otherwise the magnetic flux is cancelling each other (Fig.5b). This might not cause a problem at lower power level, but decreases the efficiency at higher power levels.

Fig.5: (a) FEM simulation: Constructive interference of magnetic flux, vertical IMS (core saturation). (b) FEM simulation: Destructive interference of magnetic flux, vertical IMS

As the core area of the horizontal IMS is not shared, this configuration is more effective and easier to calculate. Simulations of the novel capacitor layers visualize that the magnetic field of the cores has no significant impact on the capacitor layers (Fig.6). It can be seen that the induced voltage is negligible.

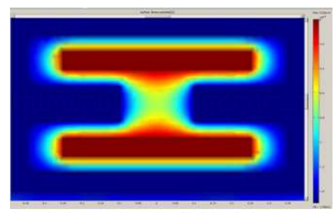

Fig.6: FEM simulation: Electric field of the capacitor conductor induced by the magnetic field of the core

IV. CONCLUSION

A novel type of horizontal IMS has been introduced and simulation results demonstrated that, in comparison, the vertical configuration has major problems in handling high power. The new construction of the capacitor layers is successful with respect to the low impact of the magnetic core onto the capacitor. Further investigations and optimizations will show how much effectiveness can be achieved with this novel device.

V. REFERENCES

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