MODEL OF THE CAPACITIVE EFFECTS IN MAGNETIC COMPONENTS

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Abstract: A model for the capacitive effects in magnetic components for Switch Mode Power Supplies (SMPS) has been developed. It can be applied to multiwinding transformers. A Finite Element Analysis (FEA) tool is used to compute the frequency behavior of the magnetic component, taking into account geometry and materials. The parameters of the model can be calculated before the magnetic component is built. An accurate capacitances modeling is expected to be crucial for common-mode EMI transmission modeling. The model takes into account winding floating voltages and the capacitance among each winding. Several model levels with different degrees of freedom are proposed. Some experimental results comparing the actual magnetic component results with the behavioral simulator results, are presented.

1.INTRODUCTION

Magnetic components are widely used in power supplies. They are indeed one of the most important components in power electronic devices. Accurate models are necessary to obtain accurate computer simulations. It is necessary to obtain the actual waveforms of the circuit to control component stresses and ElectroMagnetic Interferences (EMI).

The classic model of the transformer capacitive effects is not enough to obtain accurate waveforms. Furthermore, the calculation of their parameters is only possible once the magnetic component has been built.

This work presents a procedure to calculate a model of the capacitive effects in a magnetic component, inlcuding multiwinding transformers. The model is based on the physical description (geometry and materials) of the magnetic component.

The parameters of the model are calculated by means of a Finite Element Analysis (FEA) Tool, so it is not necessary to build the mangetic component, which means time and money in the design process.

There are only few references of the capacitive effects description in high frequency transformer [1]-[4]. The use of FEA tools in the capacitive effects modeling has been studied in [5] for high power transformers, but it is necessary to build the transformer to obtain an experimental constant that is necessary for the capacitances calculation. Some authors present capacitive effect models based on reference [6], but these models are only accurate for high voltage transformers and cylindric windings.

The present work proposes a theoretical model that complements the High Frequency Transformer Windings Model presented in [1], so a full model of the magnetic component based on the component geometry (it is not necessary to build it) is obtained.

An accurate model helps to obtain accurate simulations of the electrical waveforms and the electromagnetic interferences (EMI), so the design procedure of the whole power electronic circuit (SMPS) is improved.

2.THEORETICAL DESCRIPTION OF THE MODELS

Depending on the degree of accuracy desired, it is possbile to use different models with several degrees of freedom to model the capacitive effects in the magnetic component. Four different levels are presented in this paper. The accuracy level depends on the degrees of freedom taken into account in each level.

2.1. Level 1 Model

The first level model assumes only two degrees of freedom, which are the voltage applied to the first winding and the offset voltage among the different windings.

All voltages are referred to one of the first winding terminals, and the rest of the winding voltages are obtained by means of the turns ratio.

2.1.1. Two winding transformers

The electric energy stored in a volume can be obtained by means of (1):

$$I = \frac{1}{2}\iiint_v \overline{D}\cdot\overline{E}\,dv \tag{1}$$

The first level has only two degrees of freedom (variables). Therefore, using only two variables, voltage applied to the first winding (V_I) and offset voltage between first and second winding (V_{off}), the formula (1) becomes in (2):

$$\begin{aligned} I &= \frac{1}{2}\iiint_v (\overline{D_1}+\overline{D_{off}})\cdot(\overline{E_1}+\overline{E_{off}})\,dv = \\ &\frac{1}{2}\iiint_v (\overline{D_1}\cdot\overline{E_1}+\overline{D_{off}}\cdot\overline{E_{off}}+\overline{D_1}\cdot\overline{E_{off}}+ \\ &+\overline{D_{off}}\cdot\overline{E_1})\,dv = \frac{1}{2}\iiint_v \overline{D_1}\cdot\overline{E_1}\,dv + \\ &+\frac{1}{2}\iiint_v \overline{D_{off}}\cdot\overline{E_{off}}\,dv + \frac{1}{2}\iiint_v (\overline{D_1}\cdot\overline{E_{off}}+ \\ &+\overline{D_{off}}\cdot\overline{E_1})\,dv = I_I + I_{II} + I_{III} \end{aligned} \tag{2}$$

The three terms that compose the energy can be associated to three capacitors:

- One capacitor to store part of the global energy of the transformer referred to the primary winding (C_I).
- One capacitor to store part of the offset voltage energy (C_{off}).

- One capacitor to store part of the offset energy and part of the global energy (C_{1off}).

One of the possibilities to place these capacitors in the model is shown in figure 1:

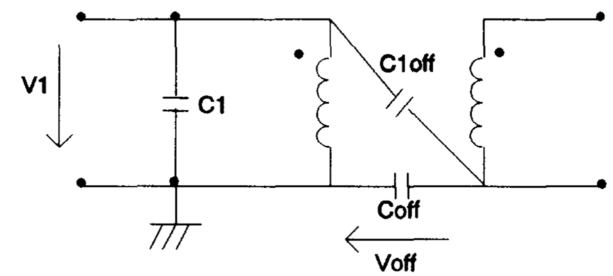

Fig. 1. Level 1 Model for two winding transformer

The energy associated to this model is represented in (3):

$$\begin{aligned} I &= \frac{1}{2}C_1 V_1^2 + \frac{1}{2}C_{off}V_{off}^2 + \frac{1}{2}C_{1off}(V_1 - V_{off})^2 = \\ &= \frac{1}{2}(C_1 + C_{1off})V_1^2 + \frac{1}{2}(C_{off} + C_{1off})V_{off}^2 - \\ &- C_{1off}V_1 V_{off} = I_I + I_{II} + I_{III} \end{aligned} \tag{3}$$

Comparing (2) and (3) the parameters of the model can be obtained. The resulting parameters are given by equations (4), (5) and (6):

$$C_{1off} = -\frac{I_{III}}{V_{off}V_1} \tag{4}$$

$$C_1 = \frac{2I_I}{V_1^2} - C_{1off} \tag{5}$$

$$C_{off} = \frac{2I_{II}}{V_{off}^2} - C_{1off} \tag{6}$$

Parameters extraction

The three capacitors can be calculated by means of two different simulations in the FEA tool, and applying the superposition theorem. One of the degrees of freedom (voltages) has to be zero in each simulation.

Simulation 1

A voltage is applied to the primary winding. The voltage in the secondary winding is given by the turns ratio. The offset voltage has to be zero (see figure 2). ($V_I \neq 0$; $V_{off} = 0$)

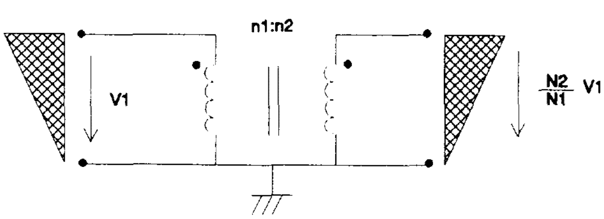

Fig. 2. First simulation for the extraction of the parameters of the model

The energy in this simulation is given by equation (7):

$$I_1 = \frac{1}{2}\iiint_v \overline{E_1}\cdot\overline{D_1}\,dv \tag{7}$$

Simulation 2

The same voltage is applied to all the turns of the secondary winding. All primary winding turns are grounded (see figure 3).

($V_I = 0$; $V_{off} \neq 0$)

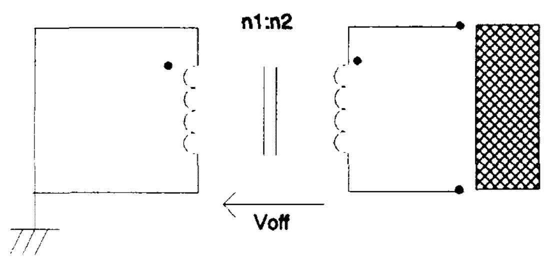

Fig. 3. Second simulation for the extraction of the parameters of the model

The energy of this system is given by equation (8):

$$I_2 = \frac{1}{2}\iiint_v \overline{E_{off}}\cdot\overline{D_{off}}\,dv \tag{8}$$

It can be seen that:

$$I_1 = I_i \qquad I_2 = I_{ii}$$

The FEA tool post processor can save the value of the field E_I, D_I, E_{off} and D_{off}, so I_{iii} (see equation (2)) can be obtained applying hte superposition theorem. C_I, C_{off} and C_{Ioff} can be obtained using equation (4), (5) and (6).

2.1.2. Three winding transformer

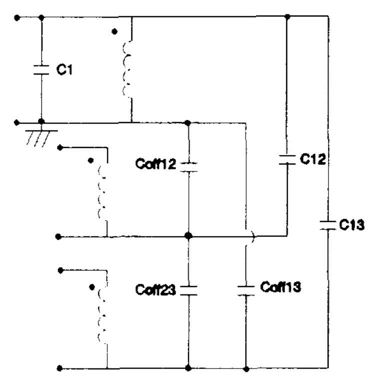

Fig. 4. Level 1 model for three winding transformer

In a three winding transformer there are three degrees of freedom for the level 1 model:

- Voltage applied to the primary winding (V_I)
- Offset voltage between primary and secondary winding (V_{off12})
- Offset voltage between primary and third winding (V_{off13})

The energy in this transformer is given by (9):

$$
\begin{aligned}
I &= \frac{1}{2}\iiint_v (\overline{D_1} + \overline{D_{off12}} + \overline{D_{off13}}) \cdot \\
&\cdot (\overline{E_1} + \overline{E_{off12}} + \overline{E_{off13}})\, dv = \frac{1}{2}\iiint_v (\overline{D_1} \cdot \overline{E_1} + \\
&+ \overline{D_{off12}} \cdot \overline{E_{off12}} + \overline{D_{off13}} \cdot \overline{E_{off13}} + \overline{D_1} \cdot \overline{E_{off12}} + \\
&+ \overline{D_{off12}} \cdot \overline{E_1} + \overline{D_1} \cdot \overline{E_{off13}} + \overline{D_{off13}} \cdot \overline{E_1} + \overline{D_{off12}} \cdot \overline{E_{off13}} + \\
&+ \overline{D_{off13}} \cdot \overline{E_{off12}})\, dv = \frac{1}{2}\iiint_v \overline{D_1} \cdot \overline{E_1}\, dv + \\
&+ \frac{1}{2}\iiint_v \overline{D_{off12}} \cdot \overline{E_{off12}}\, dv + \frac{1}{2}\iiint_v \overline{D_{off13}} \cdot \overline{E_{off13}}\, dv + \\
&+ \frac{1}{2}\iiint_v (\overline{D_1} \cdot \overline{E_{off12}} + \overline{D_{off12}} \cdot \overline{E_1})\, dv + \\
&+ \frac{1}{2}\iiint_v (\overline{D_1} \cdot \overline{E_{off13}} + \overline{D_{off13}} \cdot \overline{E_1})\, dv + \\
&+ \frac{1}{2}\iiint_v (\overline{D_{off12}} \cdot \overline{E_{off13}} + \overline{D_{off13}} \cdot \overline{E_{off13}})\, dv = \\
&= I_I + I_{II} + I_{III} + I_{IV} + I_V + I_{VI}
\end{aligned} \tag{9}
$$

There are six terms of the energy to consider, so six capacitors should be placed in the model to store the energies. Figure 4 represents the level 1 model for a three winding transformer. The energy stored in those capacitors is given by (10):

$$
\begin{aligned}
I &= \frac{1}{2} Ceq V_1^2 + \frac{1}{2} C_{off12} + \frac{1}{2} C_{off13} V_{off13}^2 + \\
&+ \frac{1}{2} C_{12}(V_1 - V_{off12})^2 + \frac{1}{2} C_{13}(V_1 - V_{off13})^2 + \\
&+ \frac{1}{2} C_{off23}(V_{off12} - V_{off13})^2 = \frac{1}{2}(C_{eq} + C_{12} + C_{13}) V_1^2 + \\
&+ \frac{1}{2}(C_{off12} + C_{12} + C_{off23} V_{off12}^2 + \\
&+ \frac{1}{2}(C_{off13} + C_{13} + C_{off23}) \cdot V_{off13}^2 - \\
&- \frac{1}{2} C_{12} V_1 V_{off12} - C_{13} V_1 V_{off13} - C_{off23} V_{off12} V_{off13} = \\
&= I_I + I_{II} + I_{III} + I_{IV} + I_V + I_{VI}
\end{aligned} \tag{10}
$$

The model presents the same structure as the two windings one:

- One capacitor referred to the primary winding, that stores part of the global energy C_I.
- One capacitor that stores part of the offset energies in each pair of windings (C_{offij}).
- One capacitor that stores part of the offset energy and part of the global energy (C_{ij}).

So it is necessary to add additional offset capacitors to obtain the desired number of parameters.

The parameters extraction has the same process than in the two winding transformer:

- Energies are calculated by means of the FEA tool
- The energies are asociated to the capacitors
- The superposition theorem is applied

Parameters extraction

Three simulations are enough to obtain all the parameters of the model:

1. Applying voltage to the primary winding. The rest of the winding voltages are given by the turns ratio:
   $V_1 \neq 0$; $V_{off12} = 0$; $V_{off13} = 0$
   All the windings are referred to ground. D_1 and E_1 are calculated.
2. Applying the same voltage to all the turns of the secondary winding. The rest of the windings are grounded.
   $V_1 = 0$; $V_{off12} \neq 0$; $V_{off13} = 0$
   D_{off12} and E_{off12} are calculated.
3. Applying the same voltage to all the turns of the third winding. The rest of the windings are grounded.
   $V_1 = 0$; $V_{off12} = 0$; $V_{off13} \neq 0$
   D_{off13} and E_{off13} are calculated.

Each of these simulations makes zero all the degrees of freedom except one of them.

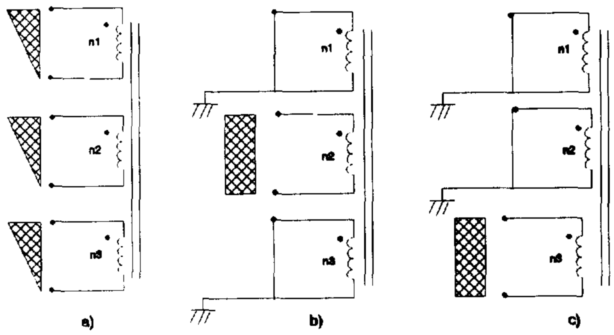

Fig. 5. *Simulations needed for the extraction of the parameters for a three winding transformer for level 1 model*

2.2. Level 2 model

A model with higher accuracy is obtained by adding a new degree of freedom to the Level 1 model. In the level 2 model, the voltage in all the windings is a new degree of freedom, so it is not given by the turns ratio. This way, the effect of the leakage inductances is modelled with more accuracy in the whole model of the magnetic component. All the voltages are referred to one of the primary winding terminals.

For simplicity, only two winding transformer is described in level 2 model.

The electric energy, using three degrees of freedom, is given by (11):

$$
\begin{aligned}
I &= \frac{1}{2}\iiint_v (\overline{D_1} + \overline{D_2} + \overline{D_{off}})(\overline{E_1} + \overline{E_2} + \overline{E_{off}})\, dv = \\
&= \frac{1}{2}\iiint_v (\overline{D_1} \cdot \overline{E_1} + \overline{D_2} \cdot \overline{E_2} + \overline{D_{off}} \cdot \overline{E_{off}} + \overline{D_{off}} \cdot \overline{E_1} + \\
&+ \overline{D_1} \cdot \overline{E_{off}} + \overline{D_{off}} \cdot \overline{E_2} + \overline{D_2} \cdot \overline{E_{off}} + \overline{D_1} \cdot \overline{E_2} + \overline{D_2} \cdot \overline{E_1})\, dv = \\
&= \frac{1}{2}\iiint_v \overline{E_1} \cdot \overline{D_1}\, dv + \frac{1}{2}\iiint_v \overline{E_2} \cdot \overline{D_2}\, dv + \\
&+ \frac{1}{2}\iiint_v \overline{E_{off}} \cdot \overline{D_{off}}\, dv + \frac{1}{2}\iiint_v (\overline{E_1} \cdot \overline{D_2} + \overline{E_2} \cdot \overline{D_1})\, dv + \\
&+ \frac{1}{2}\iiint_v (\overline{E_1} \cdot \overline{D_{off}} + \overline{E_{off}} \cdot \overline{D_1})\, dv + \\
&+ \frac{1}{2}\iiint_v (\overline{E_2} \cdot \overline{D_{off}} + \overline{E_{off}} \cdot \overline{D_2})\, dv = \\
&= I_I + I_{II} + I_{III} + I_{IV} + I_V + I_{VI}
\end{aligned} \tag{11}
$$

There are six terms of the energy, so six capacitor are needed to store these energies. A six parameters model is obtained for a two winding transformer (see figure 6):

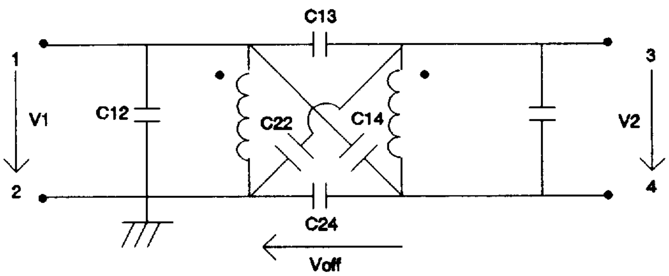

Fig. 6. Level 2 model for two winding transformer

The energy associated to the system of figure 6 is given by (12):

$$
\begin{aligned}
I &= \frac{1}{2}C_{24}V_{off}^2 + \frac{1}{2}C_{12}V_1^2 + \frac{1}{2}C_{34}V_2^2 + \frac{1}{2}C_{13}(V_1 - V_{off} - V_2)^2 + \\
&\quad + \frac{1}{2}C_{14}(V_1 - V_{off})^2 + \frac{1}{2}C_{23}(-V_{off} - V_2)^2 = \\
&= \frac{1}{2}(C_{12} + C_{13}C_{14})V_1^2 + \frac{1}{2}(C_{34} + C_{23} + C_{13})V_2^2 + \\
&\quad + \frac{1}{2}(C_{24} + C_{13} + C_{14} + C_{23})V_{off}^2 + (-C_{13})V_1V_2 + \\
&\quad + (-C_{13} - C_{14})V_{off}V_1 + (C_{13} + C_{23})V_{off}V_2 = \\
&= I_I + I_{II} + I_{III} + I_{IV} + I_V + I_{VI}
\end{aligned} \tag{12}
$$

Parameters extraction

For a two winding transformer, three simulations are enough to obtain all the parameters of the level 2 model (applying the superposition theorem):

1. Applying voltage to the primary winding (referred to ground) and grounding the second winding.
   $V_1 \neq 0;\ V_{off} = 0;\ V_2 = 0$
   D_1 and E_1 are calculated.
2. Applying voltage to the secondary winding (referred to ground) and grounding the primary winding.
   $V_1 = 0;\ V_{off} = 0;\ V_2 \neq 0$
   D_2 and E_2 are calculated.
3. Applying the same voltage to all the turns of the secondary winding and grounding the primary winding.
   $V_1 = 0;\ V_2 = 0;\ V_{off} \neq 0$
   D_{off} and E_{off} are calculated.

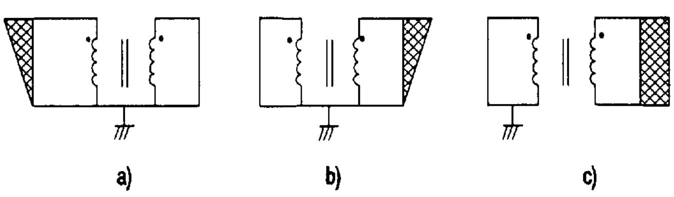

Fig. 7. *Simulations needed for level 2 model*

2.3. Level 3 model

Level 3 model is similar to level 1 model. For simplicity, for two winding transformer is described for level 3 model. The difference is that the voltage of the windings are not referred to ground but they are floating voltages. Figure 8 shows the implementation of this model for a two winding transformer:

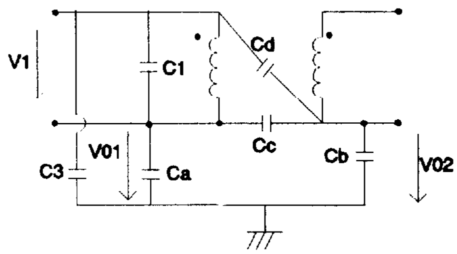

Fig. 8. *Level 3 model for two winding transformer*

The voltage in the secondary winding is given by the turns ratio. There are three degrees of freedom in this model: V_I, V_{0I} and V_{02}.

- Voltage applied to the primary winding (V_I)
- Floating voltage of the primary winding (V_{0I})
- Floating voltage of the secondary winding (V_{02})

The electric energy associated to this system is given by (13):

$$
\begin{aligned}
I &= \frac{1}{2}\iiint_v (\overline{D_{01}} + \overline{D_{02}} + \overline{D_1})(\overline{E_{01}} + \overline{E_{02}} + \overline{E_1})dv = \\
&= \frac{1}{2}\iiint_v \overline{D_{01}}\cdot\overline{E_{01}}dv + \frac{1}{2}\iiint_v \overline{D_{02}}\cdot\overline{E_{02}}dv + \\
&\quad + \frac{1}{2}\iiint_v \overline{D_1}\cdot\overline{E_1}dv + \frac{1}{2}\iiint_v (\overline{D_{01}}\cdot\overline{E_{02}} + \overline{D_{02}}\cdot\overline{E_{01}})dv + \\
&\quad + \frac{1}{2}\iiint_v (\overline{D_{01}}\cdot\overline{E_1} + \overline{D_1}\cdot\overline{E_{01}})dv + \\
&\quad + \frac{1}{2}\iiint_v (\overline{D_{02}}\cdot\overline{E_1} + \overline{D_1}\cdot\overline{E_{02}}) + dv = \\
&= I_I + I_{II} + I_{III} + I_{IV} + I_V + I_{VI}
\end{aligned} \tag{13}
$$

There are six terms of the energy to be stored in six capacitors (figure 8). The electric energy stored in these capacitors is given by (14):

$$
\begin{aligned}
I &= \frac{1}{2}C_aV_{01}^2 + \frac{1}{2}C_bV_{02}^2 + \frac{1}{2}C_1V_1^2 + \frac{1}{2}C_c(V_{01} - V_{02})^2 + \\
&\quad + \frac{1}{2}C_d(V_1 + V_{01} - V_{02})^2 + \frac{1}{2}C_e(V_1 - V_{01})^2 = \\
&= \frac{1}{2}(C_a + C_c + C_d + C_e)V_{01}^2 + \frac{1}{2}(C_b + C_c + C_d)V_{02}^2 + \\
&\quad + \frac{1}{2}(C_1 + C_d + C_e)V_1^2 + (-C_c - C_d)V_{01}V_{02} + \\
&\quad + (C_e + C_d)V_1V_{01} + (-C_d)V_1V_{02} = \\
&= I_I + I_{II} + I_{III} + I_{IV} + I_V + I_{VI}
\end{aligned} \tag{14}
$$

Parameters extraction

The way to extract the parameters of the model is the same as in level 1 and level 2 models.

For a two winding transformer three simulations are needed (one of the degrees of freedom should be zero in each simulation).

The ground reference should be chosen in the core.

2.4. Level 4 model

This is the more complex model. This model assumes all the voltages floating; and the voltages in all the windings are not given by the turns ratio but they are also a degree of freedom.

The resulting model for a two winding transformer is shown in figure 9.

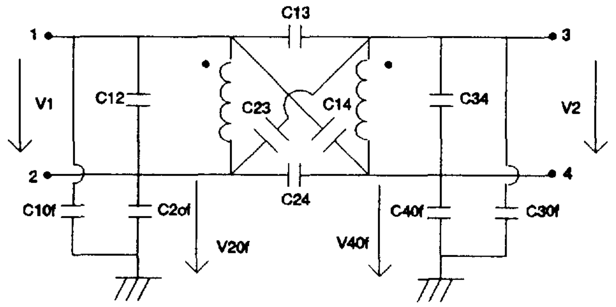

Fig. 9. *Level 4 model for two winding transformer*

This model considers four degrees of freedom for a two winding transformer:

- Voltage applied to the primary winding (V_1)
- Voltage applied to the secondary winding (V_2)
- Floating voltage of the primary winding (V_{01})
- Floating voltage of the secondary winding (V_{02})

The electric energy is given by (15):

$$\begin{aligned} I &= \frac{1}{2}\iiint_v (\overline{D_{01}} + \overline{D_1} + \overline{D_{02}} + \overline{D_2})\cdot(\overline{E_{01}} + \overline{E_1} + \overline{E_{02}} + \overline{E_2})\,dv = \\ &= \frac{1}{2}\iiint_v (\overline{D_{01}}\cdot\overline{E_{01}})\,dv + \frac{1}{2}\iiint_v (\overline{D_{02}}\cdot\overline{E_{02}})\,dv + \\ &+ \frac{1}{2}\iiint_v (\overline{D_2}\cdot\overline{E_2})\,dv + \frac{1}{2}\iiint_v (\overline{D_{01}}\cdot\overline{E_1} + \\ &+ \overline{D_1}\cdot\overline{E_{01}})\,dv + \frac{1}{2}\iiint_v (\overline{D_{01}}\cdot\overline{E_{02}} + \overline{D_{02}}\cdot\overline{E_{01}})\,dv + \\ &+ \frac{1}{2}\iiint_v (\overline{D_{01}}\cdot\overline{E_2} + \overline{D_2}\cdot\overline{E_{01}})\,dv + \frac{1}{2}\iiint_v (\overline{D_1}\cdot\overline{E_{02}} + \overline{D_{02}}\cdot\overline{E_1})\,dv + \\ &+ \frac{1}{2}\iiint_v (\overline{D_1}\cdot\overline{E_2} + \overline{D_2}\cdot\overline{E_1})\,dv + \frac{1}{2}\iiint_v (\overline{D_{02}}\cdot\overline{E_2} + \overline{D_2}\cdot\overline{E_{02}})\,dv = \\ &= I_I + I_{II} + I_{III} + I_{IV} + I_V + I_{VI} + I_{VII} + I_{VIII} + I_{IX} + I_X \end{aligned} \tag{15}$$

There are ten terms of the energy to compute. Therefore, ten capacitors should be included in to the model to store the energies (figure 9). The energy stored in these capacitors is given by (16):

$$\begin{aligned} I &= \frac{1}{2}(C_f + C_e + C_a + C_b + C_c + C_d)V_{01}^2 + \\ &+ \frac{1}{2}(C_1 + C_e + C_a + C_c)V_1^2 + \\ &+ \frac{1}{2}(C_h + C_g + C_a + C_b + C_c + C_d)V_{02}^2 + \\ &+ \frac{1}{2}(C_2 + C_g + C_a + C_d)V_2^2 + \\ &+ \frac{1}{2}(C_e + C_a + C_c)V_{01}V_1 + \\ &+ (-C_a - C_b - C_c - C_d)V_{01}V_{02} + \\ &+ (-C_a - C_d)V_{01}V_2 + (-C_a - C_c)V_1V_{02} + \\ &+ (-C_a)V_1V_2 + (C_g + C_a + C_d)V_{02}V_2 = \\ &= I_I + I_{II} + I_{III} + I_{IV} + I_V + I_{VI} + I_{VII} + I_{VIII} + I_{IX} + I_X \end{aligned} \tag{16}$$

3. EXPERIMENTAL RESULTS

Several magnetic components have been tested to validate the accuracy of the presented model.

The model has been tested with:

- Different core sizes: RM12 and RM14
- Different core materials: Philips 3F3 and Philips 3C85
- Air gap inclusion
- Different magnetic components: transformer and inductors

The different tests developed are small signal ones. The use of higher accuracy levels (level 2, 3 and 4) should have great advantage in large signal tests, because of the EMI conduction modeling. Therefore, all the tests have been developed using level 1 model. Future developments will include EMI tests with level 2, 3 and 4 models to compare the difference among all the presented models.

Level 1 model has been tested with different magnetic components.

TEST1: Two winding **transformer. RM12** core **Philips 3F3** material. Primary with 37 turns in two layers and secondary with 18 turns in one layer. Solid wire of 0,7mm∅.

TEST2: **Inductor. RM12** core. **Philips 3F3** material. 18 turns in one layer. Solid wire of 0.75mm∅.

TEST3: **Inductor** with **air gap** of 1.5mm. **RM14** core. **Philips 3C85** material. 24 turns in one layer. Solid wire of 0.7mm∅.

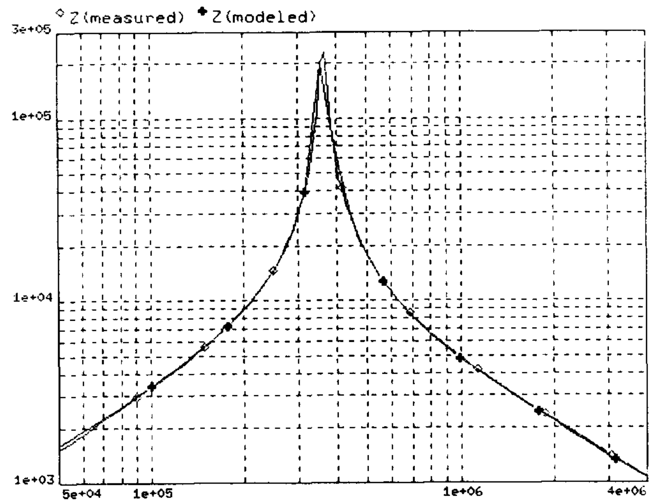

Fig. 10. *Transformer TEST 1. Open circuit*

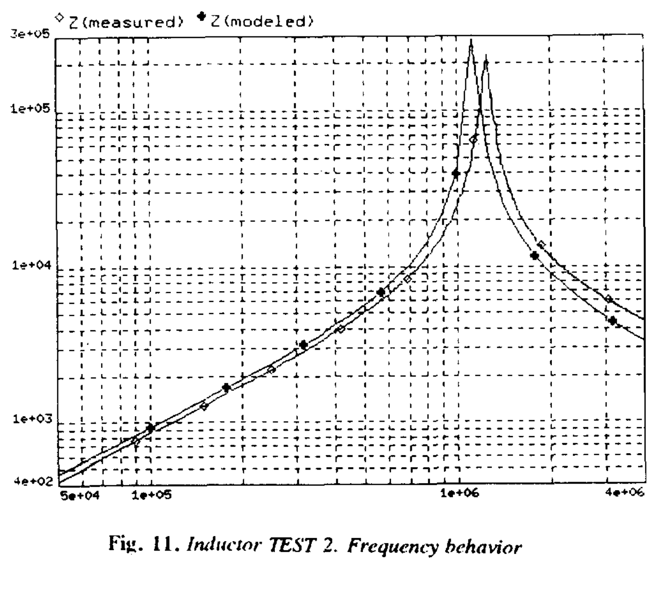

Fig. 11. *Inductor TEST 2. Frequency behavior*

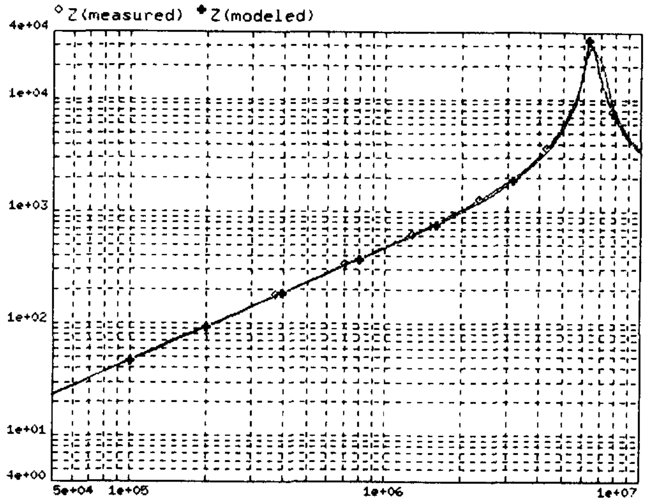

Fig. 12. *Inductor TEST 3. Frequency behavior*

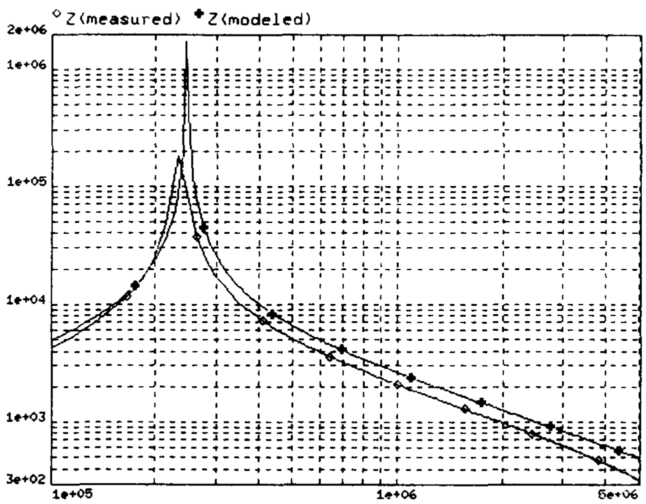

Fig. 13. *Transformer TEST4. Open circuit*

TEST4: Two winding **transformer**. **RM12** core. **Philips 3F3** material. Primary 36 turns in two layers and secondary with 35 turns in two layers. Solid wire of 0.7mm∅.

Figure 10 shows the open circuit test in TEST1 transformer. Figure 11 shows the frequency behavior of TEST2 inductor. Figure 12 shows the frequency behavior of TEST3 inductor. Figure 13 show the open circuit test in TEST4 transformer. All figures show the comparison between measured (using an HP4195 impedance analyzer) and simulated (using ELDO behavioral simulator) results.

4.CONCLUSIONS

A new theoretical model to take into account the capacitive effects in high frequency magnetic components has been presented. The procedure allows to calculate the parameters of the model using only the geometrical description and materials of the magnetic components. The model considers a distributed representation of the capacitive effects by means of a set of lumped capacitances. The advantage of this models in EMI conduction analysis will be studied in future developments. Experimental results show the accuracy of the level 1 model.

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