An integral model for the computation of the magnetic field emission of MV/LV oil transformer

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***Abstract*—In this paper an integral model for the simulation of the outer magnetic field generated by MV/LV three-phase oil transformer is presented. The proposed model takes into account the contribution of: primary and secondary winding, the LV terminals (including their internal connection to the coils) and the shielding effect of the external metallic enclosure. Moreover, the model has been tested with experimental measurement in order to evaluate the accuracy of results. The comparison points out a good agreement between model and measurement.**

***Index Terms*—magnetic field, oil transformer, shielding.**

I. Introduction

The presence of standards and guidelines that limit the exposure to magnetic field and impose their evaluation (e.g Directive 2004/40 EU [1], ICNIRP guidelines [2]) makes interesting the use of fast and accurate methods for the calculation of magnetic field generated by electric devices in domain with a lot of air region. For massive components like transformers, a possible simplified model is obtained by accepting a wrong evaluation of the inner field (i.e. inside the magnetic core) by focusing the attention on the outer field that is of main interest in the exposure evaluation [3]. In this paper an integral model for the evaluation of the outer magnetic field emission of MV/LV oil transformer will be presented.

II. Model description

Magnetic field generated by oil transformers is related to the current flow inside its conductors and windings. Moreover, for an exact evaluation the magnetic field, it should be necessary to analyze the effect of the magnetic core and the effect of the metallic enclosure of the oil transformer. In this paper a simplified model that avoid the modelling of the magnetic core is presented.

A. LV terminals/conductors

LV terminals and conductors can ben accurately described by a straight current carrying wire. The wire is placed in the barycenter of the relative conductors so that the Biot-Savart law can be integrated along the straight wire leading to a closed analytical expression for the magnetic field [4]. It is worth noting that MV conductors can be introduced in the model with the same approach because it is independent from the voltage value. However, they are often neglected because close to the transformer their low level of current generates a negligible contribution to the overall magnetic field.

B. Primary and secondary windings

Primary and secondary windings are introduced in the model as massive coil with rectangular cross section. Therefore, each transformer column is composed by two of these windings as shown in Fig. 1. The geometry of the windings is obtained from the manufacturer data (D_{MV}, D_{LV} and D_{ax}). Finally, equal and opposite ampere turns ($N_1 I_1$, $N_1 I_2$) are injected in the relative windings.

The magnetic field of each column is calculated starting from the exact expression of the magnetic field produced by a wire loop [5]. This expression is integrated over the rectangular cross section by assuming a constant current density. An adaptative quadrature rule based on Kronrod coefficient is implemented.

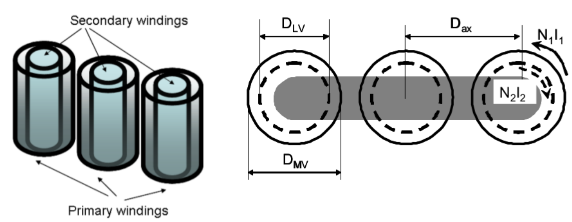


Figure 1. Model of oil transformer: geometry and ampere turns

III. Modelling of the metallic enclosure

The metallic enclosure of an oil transformer is generally made of steel. In this paper the shedding effect of the metallic enclosure is taken into account by considering the magnetic properties of the material and by neglecting the possible eddy currents.

It is well known that, in presence of ferromagnetic materials, the overall magnetic field is

$$\mathbf{H} = \mathbf{H}_\mathrm{s} + \mathbf{H}_\mathrm{m} \quad (1)$$

where $\mathbf{H}_\mathrm{s}$ is the magnetic field generated by the sources, i.e. conductors and windings, and $\mathbf{H}_\mathrm{m}$ is the demagnetizing field generated by the magnetization $\mathbf{M}$ inside the ferromagnetic material, i.e. the metallic enclosure. By assuming that saturation does not occur, the overall magnetic field $\mathbf{H}$ is linearly dependent on the magnetization $\mathbf{M}$. Moreover, the demagnetizing field is related to the magnetization by means of the demagnetizing tensor $\mathbf{N}$ [6]. Therefore:

$$\frac{\mathbf{M}}{\chi} = \mathbf{H}_\mathrm{s} - \mathbf{N}\mathbf{M} \quad (2)$$

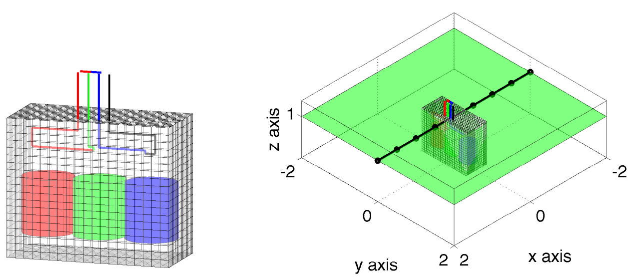
The metallic enclosure of the transformer is thin enough to introduce a thin shell approximation, therefore, the ferromagnetic material is discretized on several surface elements. If (2) is written in the barycenter of each element a linear system of equation where the magnetization $\mathbf{M}$ is the unknown is found [7], [8]:

$$\mathbf{AM} = \mathbf{b} \tag{3}$$

Finally, once the magnetization $\mathbf{M}$ is known the overall magnetic field can be computed with (1).

IV. Model validation

The magnetic field emission of a 630 kVA oil transformer 20kV/400V has been investigated by means of measurements. The same transformer has been analyzed with the proposed integral technique in order to verify the accuracy of the model. In Fig. 2(a) the developed model is shown. In order to compare measurements and simulations one inspection line and one inspection plane have been defined at 1 m from the ground level as shown in in Fig. 2(b). In Fig. 3 it is apparent that the measurement profile is in perfect agreement with the simulation one. In Fig. 4 the isolevel curves at 3 μT and 10 μT are shown with thinner lines for the simulations and with wider lines for measurements.



(a) (b)

Figure 2. (a) Transformer model (b) inspection line and inspection plane at 1 m from the ground level

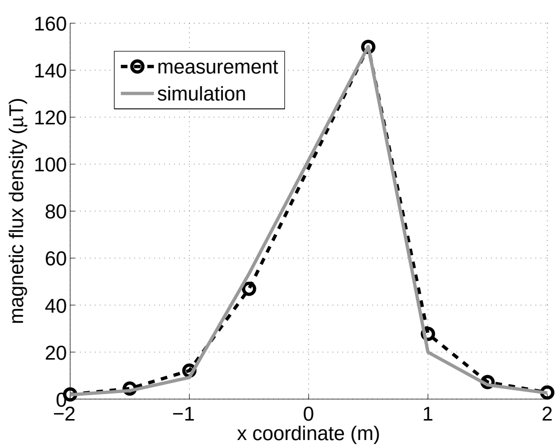


Figure 3. Measurement vs. simulation over the inspection line

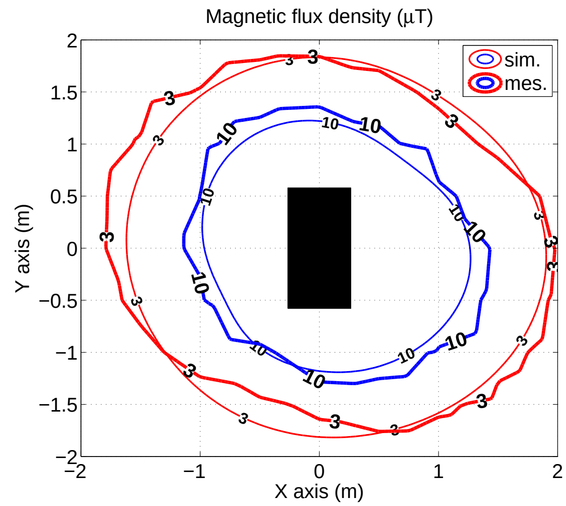


Figure 4. Isolevel curves at 3 μT and 10 μT: thinner lines for simulations and wider lines for measurements

V. Conclusion

In this paper a model for the simulation of the outer magnetic field generated by MV/LV three-phase oil transformer is proposed. The model takes into account the transformer terminals, primary and secondary windings and the shielding effect of the external enclosure. The final comparison of the model performance with measurement validates the model and suggests that the employed simplification hypotheses seems to be acceptable for this purposes.

In the full paper a deeper details of the model will be given. Moreover, other comparisons with measurement on inspection plane at different ground level will be provided in order to enforce the validation of the model in all the transformer surrounding area.

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