A simple model to explain the leakage flux measured around an off line transformer

D. Cavallera(1), J-L. Coulomb(2), O. Chadebec(2), B. Caillault(1) and F-X. Zgainski(1)
(1) EDF/DTG (Electricity of France-Hydro Generation &Engineering), Grenoble, France
(2) Grenoble Electrical Engineering Laboratory (Grenoble-INP, UJF, CNRS), Grenoble, France
didier.cavallera@g2elab.grenoble-inp.fr, didier.cavallera@edf.fr

Abstract —This paper presents a simple model in order to explain the magnetic field observed around an off line transformer. In order to measure the magnetic field, laboratory test measurements have been realized on a single-phase transformer (32 kVA). The purpose of this paper is to propose a simple finite element model to explain the leakage flux presence and topology outside an off line transformer.

I. INTRODUCTION

Many articles deal with the measurements of the level of the induction in operating industrial areas (substations [1] or transformers [2]). For this device in an off-line operation mode, the magnetic flux leakage has been very few studied. The reason is maybe because, it is often assumed that this flux does not exist. In this paper, we show that, contrary to the generally held opinion, we show that a significant flux does exist, even if it is very low in comparison with field range classically encountered in our community. A single-phase transformer (400V/4V, 32 kVA, 2 limbs) is chosen for this study. The first part of this paper describes the measurement process and the second part tries to explain the measurement thanks to simple numerical field models.

II. MAGNETIC FIELD MEASUREMENTS NEAR A TRANSFORMER

A. Description of the measurement process

The measurement system is composed by a data system, commonly used for on site tests, and coupled with high accuracy magnetic field sensors (fluxgate). The electric measurements are the voltage in the primary and secondary transformer windings and the current in the primary winding. Some magnetic sensors are placed outside the magnetic circuit of the transformer. In Fig. 1, a schematic view of the transformer and some of the sensors positions are exposed. For each of the four sensors, the component of the magnetic field, tangential to the magnetic circuit is exploited.

The tank of the transformer is disassembled in order to simplify the comprehension of the phenomena.

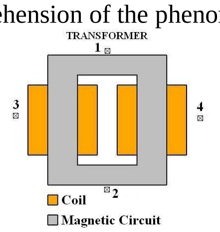
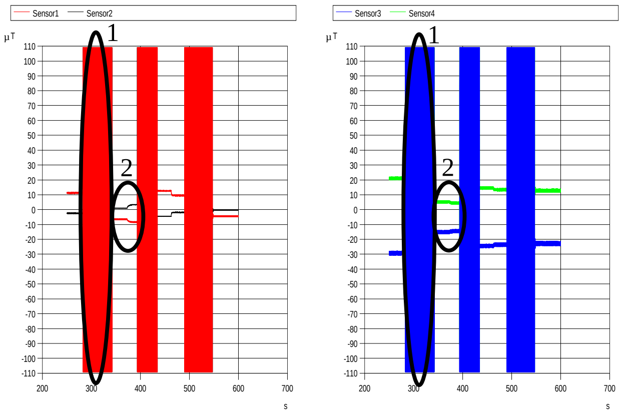


Fig. 1. Schematic view of the device

B. Measurement result

The transformer is suddenly energized with no load. at nominal voltage (400 V_{RMS}) then after one or two minutes, the source voltage is manually lowered (Fig. 2) This sequence is performed several times. The measurement range of the sensor is ±100 µT and the bandwidth is DC of 3 kHz. Measurements results (in microTeslas) for the opposite sensors couples are presented on Fig. 2.



a) Sensors 1 and 2 b) Sensors 3 and 4

Fig. 2. Induction measured during some different switching

At t=0, the transformer is off line (not connected to the network), different values of DC-component of the field are measured on each sensor. A part of this field being certainly composed by the Earth magnetic field (between 40 and 50µT). Another part is certainly due to the induced magnetization got by the magnetic circuit in the Earth's magnetic field. A 3D simulation on Flux software [3] enables the computation of its influence and results will be exposed in the final paper. However, these two contributions not only composed the total field.

Some energizations and de-energizations of the transformer with a voltage level of 400 V_{RMS} are now realized. During the energization phase in the circle 1, the alternative (50Hz) induction amplitude measured by each sensor saturates. This is essentially due to the leakage flux of the coils.

After the energization shown in the circle 2, we can observe that the average DC-component induction has changed on each sensor, compared to the state before the energization. Moreover, an inversion phenomenon dealing with the field values measured on both opposite sensors (1 and 2) has appeared. It shows that the magnetic field in the transformer magnetic circuit has changed and creates a various leakage flux outside. The same phenomenon is less visible on the other sensors (3 and 4).

III. ELECTROMAGNETIC MODELING OF A OFF-LINE TRANSFORMER

The main objective of the modeling consists in verifying that the magnetic circuit of a power transformer in which a remanent magnetization is present has a leakage flux. The magnetic circuit model described here is given for an autotransformer of 357 MVA. Different modelings are exposed hereafter.

A. *Magnetic circuit composed by magnets*

In our case, the transformer is off-line, no current flows through the coils, so there is no magnetic field at 50Hz. However, a residual induction is present in the magnetic circuit [4]. Some simple models can be used to explain the magnetic field observed outside the transformer.

A first model of magnetic circuit has been used, composed by some magnets, each of them having a particular direction of magnetization (Fig. 3). An imposed residual induction is set to 1 Tesla and the material relative permeability is 5000.

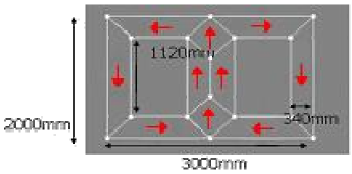


Fig. 3. Transformer magnetic circuit modeling

FEM simulations enable to see that for this configuration, the field created out of the transformer is equal to zero. This first result can be easily explained by a magnetic charge analogy. In this analogy, the outside field is created by magnetic charges located on boundaries of the magnetic circuit where the induction is not tangential. In our case, these surfaces are those where the direction of the induction changes. On them, the flux being uniform, the contribution of charges vanishes so the outside field is null.

B. *Magnetic circuit composed by magnets with gaps*

Of course, the magnetic circuit of a transformer is not composed by one single ferromagnetic material but by a large number of sheets which intersect. The consequence is the creation of unintentional air gaps between the iron sheets.

In a second model, gaps are introduced, located in the corners of the magnetic circuit because the sheets mainly intersect in this location. In this model, the transformer tank is taken into account and modeled as a magnetic shield. The thickness of this tank is set to 10 millimeters. The characteristics of the model are residual induction of 1 Tesla, material permeability of 5000 for the magnetic circuit and of 100 for the tank. In the corners of the structure, 8 air gaps are placed, with a thickness of 0.5 millimeter. The choice of this value is obviously a difficult task because in the reality we can't consider a real measurable air-gap. In this work, this choice is made to ensure the model being in a reasonable adequacy with the observed measurements, the goal of this work being essentially didactic. Simulation results are exposed in Fig. 4

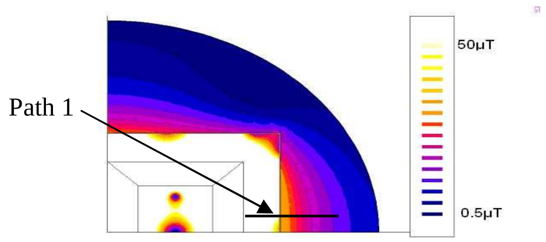


Fig. 4. ¼ Magnetic circuit modeling with air-gaps in the corners

The level of tangential induction near the tank is about 30 µT. The two dimensional models give a good qualitative idea of the magnetic field around the transformer.

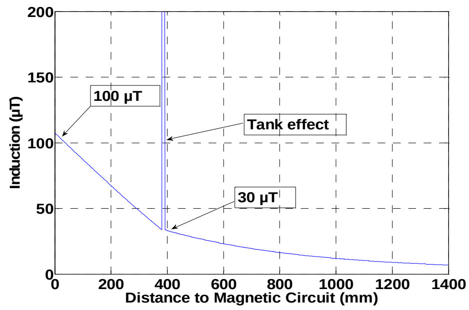


Fig. 5. Induction outside the magnetic circuit (Path 1)

The computed induction along the path 1 is shown in the Fig. 5. The tank has a screen role but not enough to cancel the whole field. Simulations confirm that raising the number of air gaps increases the induction outside the magnetic circuit. A magnetic circuit has leakage fluxes if it has air-gaps or more precisely geometrical imperfections. This is these small imperfections which provide our measurable flux.

C. *Conclusion*

In this paper, magnetic field measures are presented around an off line transformer. Changes in the DC component of the magnetic field measured shows that leakage flux exists in the environment of the transformer. A simple model composed by magnets with gaps in the structure has been realized. It explains the presence of leakage flux when the transformer is off line.

IV. REFERENCES

[1] W. K. Daily, "Measurements and Computations of Electromagnetic Fields in Electric Power Substations", IEEE Transactions on Power Delivery, Vol. 9, No. 1, January 1994.

[2] L. Stac, F. Kelemen, D. Zarko, "Modeling and Calculation of Electromagnetic Field in the Surroundings of a Large Power Transformer", Proceedings, 20th Int.Zurich Symposium on EMC, Zurich 2009. .

[3] Flux®, CEDRAT, www.cedrat.com/

[4] J. H. Brunke, K. J. Fröhlich, "Elimination of Transformer Inrush Currents by Controlled Switching-Part I: Theoretical Considerations", IEEE Transactions on Power Delivery, vol.16, no. 2, pp 276-280, April 2001