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The magnetic field map of the power transformer under extreme operating conditions

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In the paper is done the calculation of the magnetic field of the three-phase power transformer with three columns in extreme conditions. The calculation is performed with FEMM application based on finite element theory. The distribution of the magnetic flux from the transformer's magnetic core was obtained. It has been demonstrated the possibility of specifying of the winding and the magnetic system parameters of the transformer.

Keywords*: magnetic flux, transformer, extreme operating conditions*

1. Introduction

With the extensive implementation of numerical calculation methods in power system devices, the difference between the results of the magnetic field calculation and the real magnetic field are minimal. Due to the application of these methods, the parameters of these devices are respected. This ensures the correct and optimal selection of the protection elements, ensuring the stable operation and the quality of the energy production in the given system.

Here is taken into consideration the basic element of the power system, the operator of transport and distribution of electricity between consumers and the electric transformer.

The electric field is a particular aspect of the matter [1]. In electro technical devices, electrical appliances, electromechanical magnetic field converters have the basic function of transforming energy from one form to another. For these reasons, profound knowledge and mathematical interpretation is a difficult problem. Up to now, it is acceptable to estimate and graphically interpret this particular aspect of matter. If we abandon fundamental theoretical prerequisites related to the magnetic field of matter and use the current methods of interpretation of the magnetic field through lines, then the calculation technique ensures that we obtain a picture suitable to this magnetic field [2], [3].

In the specialized sources [4], [5] are given magnetic field calculation programs, such as the FEMM program, based on the finite element theory. Using this program, in the paper is do attempts to determine the graphical interpretation of the magnetic field in the magnetic system and the surrounding area of the power transformer when operating under extreme conditions.

2. Interpretation of the magnetic field in the power transformer

To achieve the correct application of this method, the three-phase transformer with the power P_n=160 kVA, U_{1n}=10 kV, U_{2n}=0.4 kV, was subjected to the experimental tests, according to the following schemes.

Figure 1 shows the transformer magnetic field in nominal mode, calculated using the FEMM method.

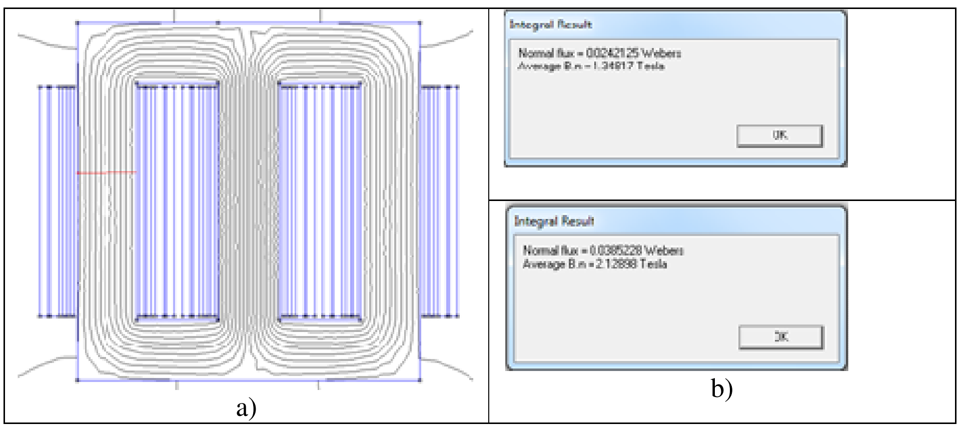


Figure 1. Magnetic field distribution to nominal transformer operation. a) the map of the magnetic field, b) values of magnetic flux and induction in columns.

The obtained images are close to the actual ones, so the parameters of the transformer can be specified.

From Figure 1 a, b it is observed that the magnetic induction in the middle column of the transformer is 1.58 times higher than the value of the induction in the lateral columns. Thus, we observe that the magnetic core of the middle column is very saturated.

Figure 2 show the magnetic field picture in three-phase short-circuit regime. From this it can be seen that it is similar to the magnetic field map in the load regime, but the magnetic induction values differ essentially.

In the lateral columns the magnetic induction in short-circuit mode is B=0.87T, that is, the columns are demagnetized. The magnitude of the magnetic induction of the middle column is 2 times higher than the other columns, and then this column is supersaturated. In the specialty literature it is emphasized that the magnetic system of the short-circuit transformer is demagnetized. The picture shows that the magnetic system is magnetized unevenly.

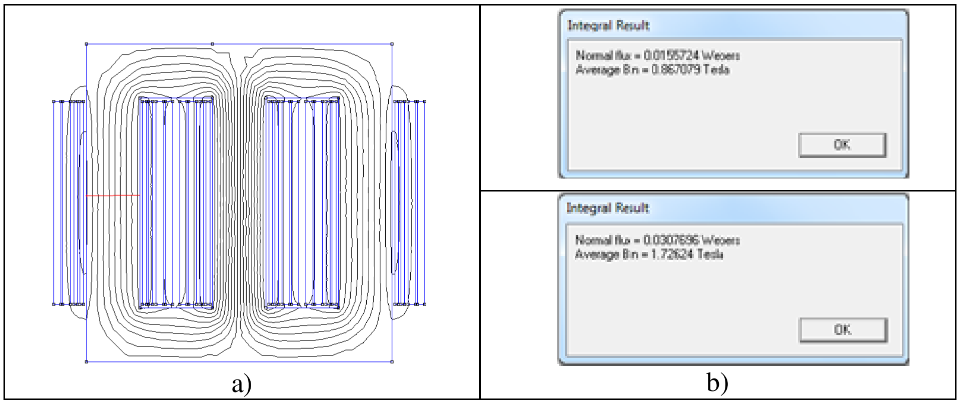


Figure 2. Magnetic field distribution in three-phase transformer short-circuit. a) the map of the magnetic field, b) values of magnetic flux and induction in columns.

In Figure 3 is show the magnetic field to the short-circuiting of two transformer phases.

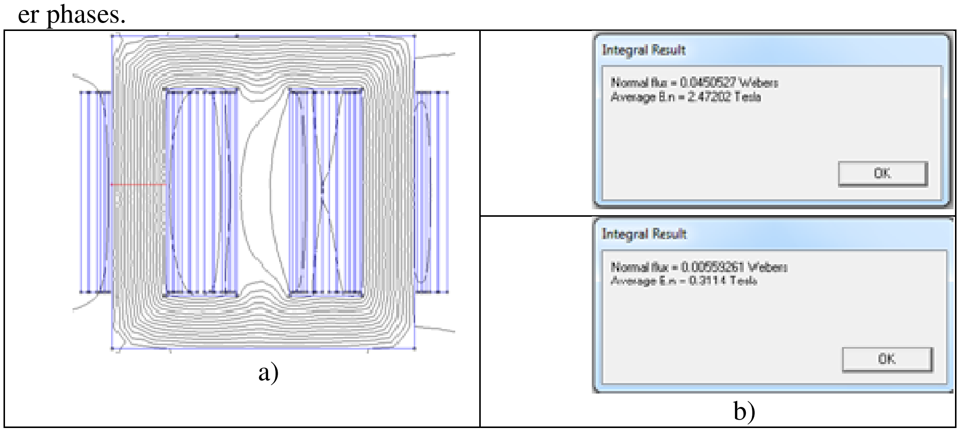


Figure 3. Magnetic field distribution to short-circuit of 2-phase transformer. a) the map of the magnetic field, b) values of magnetic flux and induction in columns.

It can be seen from Figure 3 that the magnetic induction of the middle column decreases substantially and constitutes B = 0.31 T, indicating that the magnetic core of this column is practically demagnetized, while in the lateral columns the magnetic induction value is approximately 2.5 T. In this case we cannot say that the system is demagnetized.

Figure 4 shows the magnetic field map in load mode on a single phase.

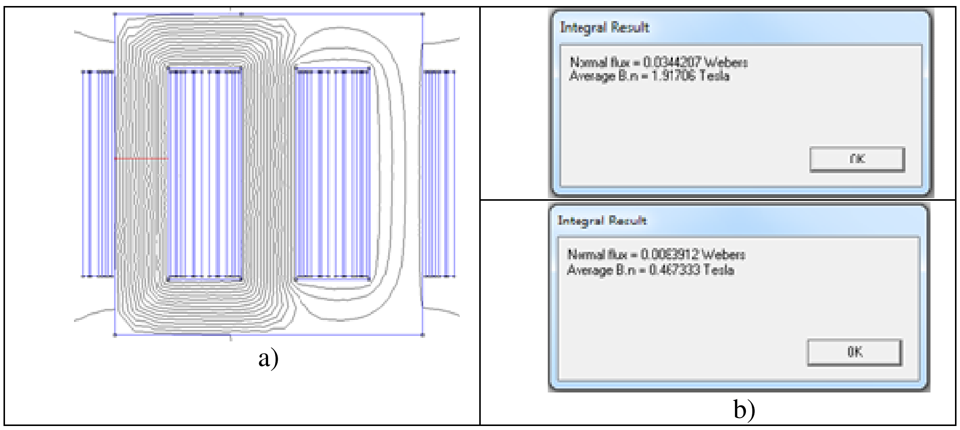


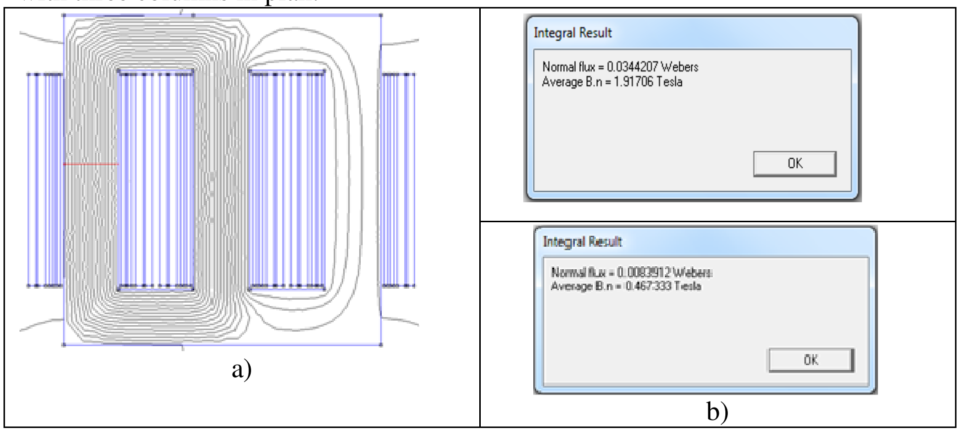
Figure 4. Magnetic field distribution to single-phase transformer operation. a) the map of the magnetic field, b) values of magnetic flux and induction in columns.

When operating the transformer in single-phase load mode, the magnetic flux is distributed unevenly (Figure 4). In this case two columns are oversaturated, and in the third column the magnitude of the magnetic flux is insignificant.

In the case of the operation of the two-phase transformer connected to the load, the magnetic field map is similar to the magnetic field map in the single-phase load regime, but in this case the over-saturation in the two columns is increased (Figure 5). This indicates that the magnetic core is over-saturated.

The magnetic fields of the three-column transformer in nominal and asymmetric short-circuit conditions demonstrate that the magnetic field is essentially deformed. In short-circuit mode and in asymmetric load mode, the magnetic system is over-saturated unevenly.

It is known that the magnetic system of the three-column transformer is magnetically asymmetric. Based on the above, this asymmetry, in the over-saturation mode, further deforms the magnetic field. This influences negatively the correct and accurate determination of the parameters of windings, magnetic losses, currents and so on. The FEMM program based on the theory of the finite element gives the possibility of specifying the degree of deformation of the magnetic field, thus determining or optimizing the magnetic system of the three-phase transformer with three columns in plan.



a) b)

Figure 5. Magnetic field distribution to the operation of the two phase loaded transformer. a) the map of the magnetic field, b) values of magnetic flux and induction in columns

3. Specifying winding parameters

Previously, it has been demonstrated that the magnetic field map makes it possible to determine the flux and magnetic induction in any section of the magnetic core and in the space enclosed by the outer shell of the transformer.

Being known fascicular flux, it can be verified with expression:

$$\Phi = B \cdot S, \tag{1}$$

where S is the surface where the magnetic flux passes.

Then total flux can be determined as such

$$\Psi = \Phi \cdot W, \tag{2}$$

where W is the number of turns of that phase.

The mutual inductance of a phase is then determined

$$L_{mf} = \frac{\Psi_m}{I_m}, \tag{3}$$

after which the phase reactance can be determined

$$X_{mf} = \omega_1 \cdot L_{mf}, \tag{4}$$

where ω_1 is the electrical pulse.

Analogously, the dispersion reactants can be determined for each phase.

Using this method, the construction of the magnetic system can be optimized and the parameters of the windings are determined, determined by the electromotive voltages, which sufficiently exceed the nominal voltages of the single-phase load operation.

4. Conclusion

The FEMM program makes it possible to determine the distribution of the magnetic field from the three-phase power transformer, which is more accurate and precise.

The graphs of the magnetic field distribution are presented in the short-circuit and non-symmetrical load of the transformer.

It was found that the distributions of the magnetic field is uneven and even in a short circuit a column or two are over-saturated.

The magnetic field in short-circuit is calculated according to real currents, but not nominal, as is usually done in the short circuit of the transformer.

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