Electromagnetic and Thermal Analysis of Power Distribution Transformer with Method of Finite Elements

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Abstract: **The paper will be presented the way of obtaining the electromagnetic characteristics of power distribution transformer type ETN 630, a product of EMO Ohrid – Republic of Macedonia, with software that performs simulation calculations based on the method of finite elements. The magnetic field is described by well known system of Maxwell's equations. Because the core materials in the transformer structure are nonlinearity, equations have to be solved iteratively and simultaneously. All computational results presented in the paper are obtained by using the Finite Element Method (FEM).**

Also over the same transformer made him a model for calculating the temperatures in the separate component parts, such as: Core, Coils, refrigeration fluid (the transformer oil) and the transformer container.

Keywords – **Power transformer, ETN 630, Finite Element Method, Electromagnetic characteristics, magnetic field, flux density, calculation of the temperatures.**

I. INTRODUCTION

Object of study is a three phase core – type power transformer with rated data: Sn=630kVA, U_1 / U_2 =10/0.4 kV, f = 50 Hz, Yy0.

In The paper will be given a model of the transformer, its geometry and characteristics of the materials from which it is derived, and obtained distributions of electromagnetic fields in separate regions, at rated load. Also given will be the model for the calculation of temperatures and heat fields in separate regions of the transformer. As tool that made electromagnetic and temperatures analysis in this paper is applicable software package FEM 4.2 which is specialized software for analysis of this type. The algorithm which is basis of the software performs calculations using the method of finite elements.

Once a suitable model of the transformer may to various distinct approximations and test models of which the manufacturer may be offer the results of calculations that would improve some of the basic characteristics. Such analysis is applied in a contemporary production of electrical machinery and equipment for providing the wide range of optimizations without additional which cost would increase the cost of the device. Initial nominal sizes and data distribution transformer ETN 630, which is under consideration in this paper taken are from the test protocol have produced by this type transformer. In making transformer model of the software packages will be observed that all dimensions given in test protocol list of already produced transformer in order to obtain model that will later be analyzed and the results of calculations can be compared with those declared by the manufacturer.

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II. ELECTROMAGNETIC ANALYSIS OF THE POWER TRANSFORMER ETN 630 IN FEM 4.2.

II. 1. MATHEMATICAL MODEL FOR ELECTROMAGNETIC ANALYSIS OF POWER TRANSFORMER ETN 630 IN FEM 4.2

FEM 4.2 software package is a specialized program for designing, modeling and analysis of electric machines and appliances. The program was developed by David Maker, and is the last version that stands out in the previous three versions with that, only the FEM 4.2 is possible despite the Electrostatic and electromagnetic analysis to makes electrical circuit and thermal analysis. FEM 4.2 has possibility to solve magnetic vector potential and consequently magnetic flux density by solving relevant set of Maxwell equations for magnetostatic case as well as for time harmonic case. In magnetostatic case field intensity **H** and flux density **B** must obey:

$$\nabla \mathbf{H} = \mathbf{J} \tag{1}$$

$$\nabla \mathbf{B} = 0 \tag{2}$$

subject to a constitute relation between **B** and **H** for each material:

$$\mathbf{B} = \mu\, \mathbf{H} = \frac{1}{\nu}\cdot \mathbf{H} \tag{3}$$

and for nonlinear material permeability μ is actually function of **B** .

FEM goes about finding a field that satisfies Eq. 1-Eq. 3 via a magnetic vector potential. Flux density is written in terms of the vector potential **A** , as:

$$\mathbf{B} = \nabla x \mathbf{A} \tag{4}$$

This definition of **B** always satisfies Eq. 2. Then Eq.1 can be redefined as:

$$\nabla\, x \left(\frac{1}{\mu(\mathbf{B})} \nabla\, \mathbf{A} \right) = \mathbf{J} \tag{5}$$

II. 2. CHARACTERISTICS OF THE MATERIAL COVERED IN THE MODEL OF THE TRANSFORMER ETN 630.

Magnetic circuit of transformer is made of cold rolled transformer sheet type M-27, its magnetic characteristics is given on Figure 1. Each sheet has a thickness of 0.635mm^2 filling factor is 0.98. Sheet are each insulated with paper thickness 0.25mm, and the total weight of the magnetic circuit is 701.56kg.

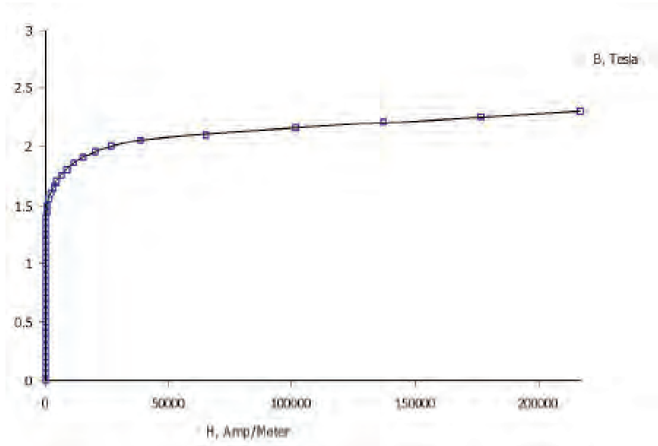

Fig. 1. Magnetic characteristic of transformer sheet M-27

The primary winding of high voltage on transformer is composed of eight layers (on Fig. 2. are presented as rectangular blocks) each of the layers has a 120 turn. Conductor which is made from a copper coil with a cross-section of 7.7931 mm^2. The modeling of the Coils current density recorded in the appropriate phase of the transformer, the value of current density on high voltage winding is J = ± 3.410 (MA/m^2).

The secondary coil of the low voltage is composed of two layers. The two layers are identical and consist of 11 turn. The value of current density on low voltage winding is J = ± 2.903 (MA/m^2).

This model is made ready for electromagnetic analysis in FEM 4.2. after being given, the appropriate boundary conditions.

II. 3. PROCESOR PART – GENERATING MASH OF FINITE ELEMENTS AND SOLOVING EQUATIONS WHICH DESCRIBE THE TRANSFORMER ETN 630

After defining the geometry of the transformer and the complete transfer the materials with their characteristics are accessing the second mode of FEM 4.2. This is the so-called solver mod that automatically draw the mesh of finite elements over which the geometry was introduced [2]. Check the validity is automatically. So if there is any part that is not defined network elements will not be final be drawn.

On Figure 2. is shown finite element mesh in cross section of the power three phase transformer. It contains 33,427 nodes and 66,780 triangular finite elements.

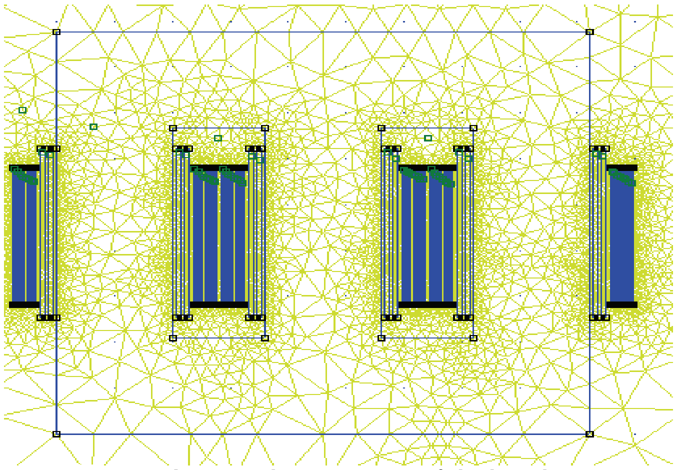

Fig. 2. . Finite element mesh in cross section of the three phase power transformer ETN 630.

The activation of fkern.exe, calculations are carried out equations that describe the transformer. Iterative calculations are made and more repetitions each subsequent faster than the previous, they may begin previous solution is approximately true. The actual analysis is carried out 12 repetitions that takes time is approximately 100 seconds on a PC Pentium 4th. Time that will make the calculation is depend with the number of nodes and triangular finite elements, and the dimensions of the triangle finite elements.

II.4. DESCRIPTION OF ELECTROAMGNETIC ANALYSIS AND PRESENTATION OF RESULTS

Starting with electromagnetic analysis on the model of the transformer, one of ways to get a good representation of the solution for the distribution of magnetic flux with finite element method, is drawing the lines of magnetic flux. They are lines that magnetic flux is established in the geometry of the transformer. When the magnetic flux lines are close to each other, then the flux density have greater value. The solution is initially shown with 19 lines of magnetic flux (which is also selected and it is possible to select and greater or lesser number of lines) - shown in Figure 3.

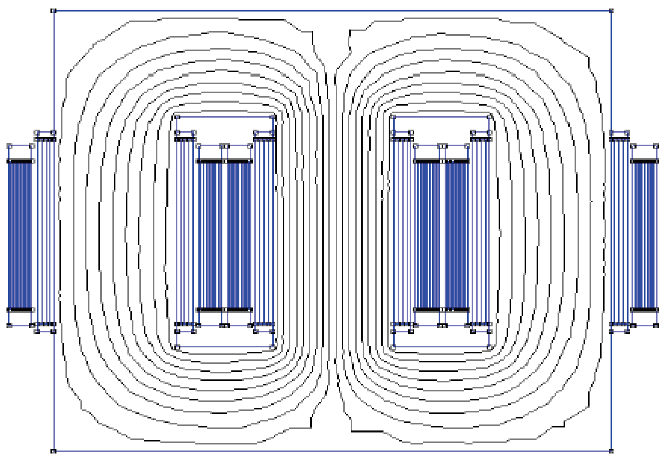

Fig.3. Distribution of magnetic flux in the transformer

In addition on figures 4 and 5, respectively show magnetic field density, and magnetic strength of magnetic field in the separate regions of transformer.

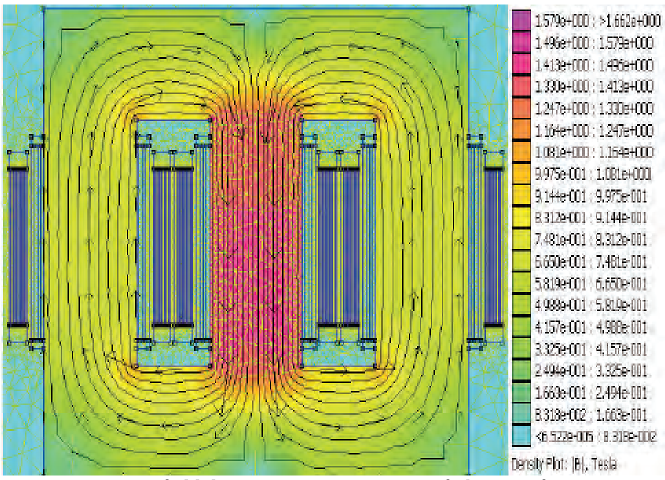

Fig. 4. Magnetic field density in in cross section of the transformer

It may be noted that in the mid-point value of the module magnetic induction is B=1.398 T, and the size of the magnitude of the magnetic field is H=472.535 A/m.

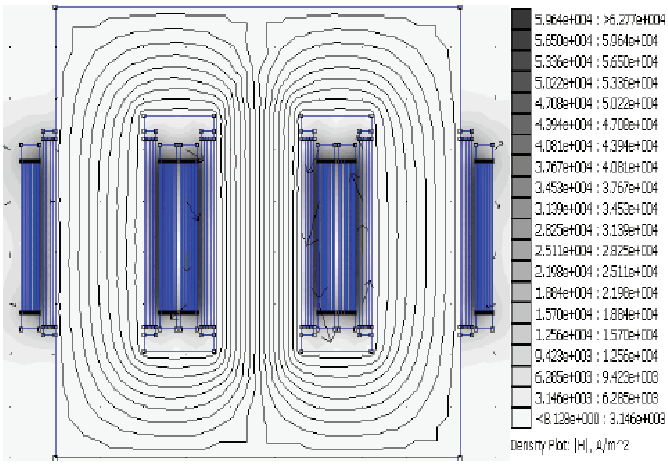

Fig. 5. Distribution of magnetic field in separate regions of the transformer

III. THERMAL ANALYSIS OF POWER TRANSFORMER TYPE ETN 630, IN FEM 4.2

Similarly as in electromagnetic calculations by the method of finite elements and the heat calculations, the system of differential equations are replaced by algebraic equations corresponding to a finite number of variables. The relevance of this method comes to terms with the sudden development of computer technology because only using fast computers it is possible to quickly resolve the large number of equations. Finite element method is very adaptable and powerful tool that enables you to obtain information on models with very complicated structures and arbitrary loads.

III.1 THERMAL ANALYSIS OF THE SIMULATION MODEL OF THE POWER TRANSFORMER ETN 630 WITH FEM 4.2

The temperature analysis is done in several consecutive steps:

1. Initial step in the temperature analysis is defining the geometry of the transformer. In the program package FEM 4.2 enabled directly draw the geometry to be analyzed. Because the transformer is made electromagnetic analysis can be used geometry of that analysis should be further noted that to enter transformatorkiot container with cooling ribs so as to meet the volume of fluid refrigeration. Fig. 6. given intersection pattern ETN transformer 630, the xy plane, ie the appearance of the geometry of the problem is analyzed.

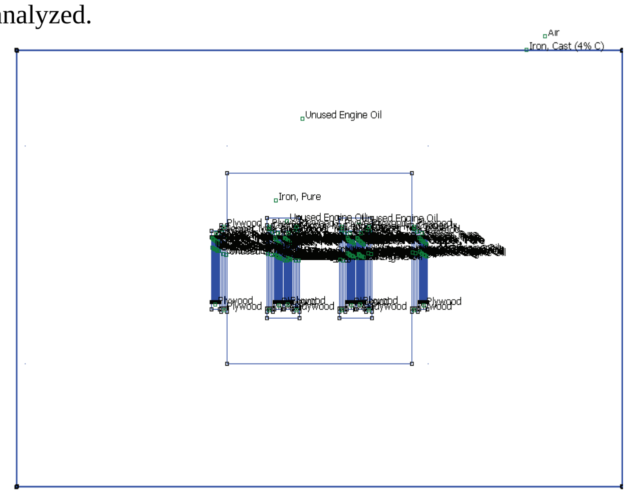

Fig. 6. Geometry of the model for thermal analysis in FEM 4.2

2. Defining characteristics of the material from which the transformer is made.

3. Forming a mesh of finite element - After defining the geometry of the model and characteristics of the materials from which the transformer is made, the following phase in which the model is divided into a number of triangular finite elements. Mesh of finite elements covering the transformer model contains 47,334 nodes and 94,604 triangular finite elements and is presented on figure 7.

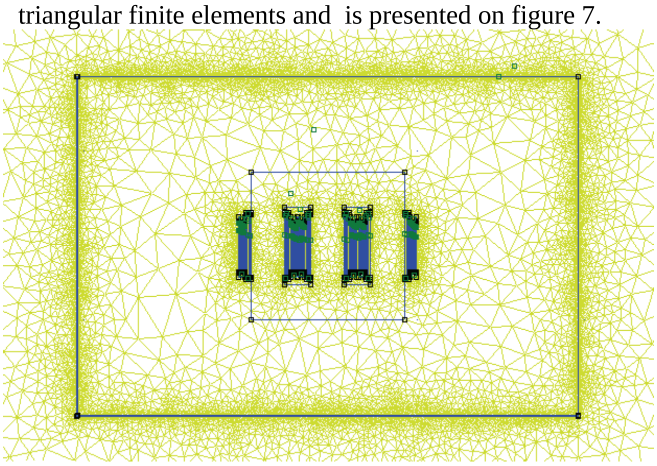

Fig. 7. Finite element mesh in cross section of the transformer ETN 630.

4. Defining the boundary conditions and loads - In order to obtain a solution to the algebraic system of equations necessary for the transformer model to define the boundary conditions and external loads. As is known, the power losses in the transformer primary source of heat that is generated as a thermal load is given heat rate generated per unit volume.

The total losses amounted to 7535.2(W) which are distributed as follows: magnetic core losses in 1300 (W), losses in high voltage coil is 2995.2 (W) and losses in low voltage coil is 3240 (W).

5. Solver, which generates results-Once a definition of all the sizes are approached to solving the problem of thermal analysis system composed of algebraic equations.

6. Post processing part - In this mode, the programming package of the solution obtained data are processed for further calculations of certain characteristic sizes. The results obtained are shown in different ways: graphically, in tables, visual, etc.

At Figure 8. heat distribution is shown in the pattern of distribution power transformer which is subject to this analysis. The legend on the right image shows the values of temperatures in separate regions, stating that temperature program calculated in Kelvin (K), which means that 273.15 (C) correspond to 0 (° C).

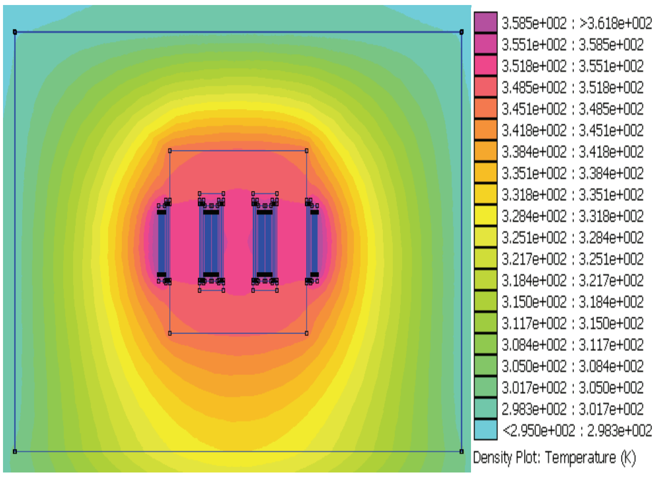

Fig. 8. Distribution of head field in separate regions of the transformer

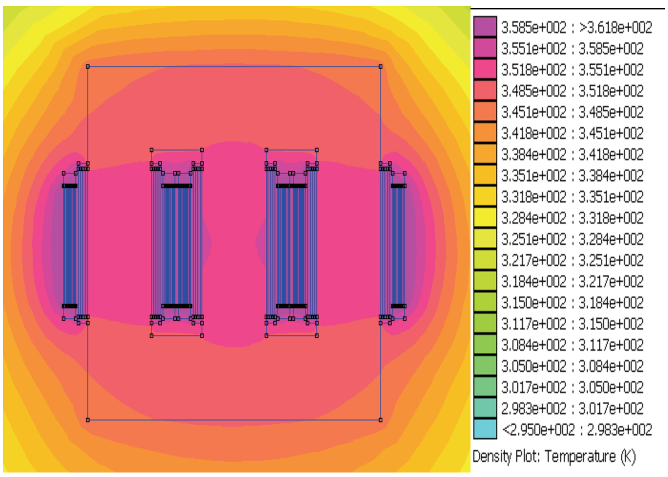

Fig. 9. Distribution of head field in separate regions of the transformer

For better visibility of the Figure 9. is given the distribution of temperatures in the magnetic circuit of the transformer and Coils because they are parts which are active and they are sources of heat.

From the analysis of concrete-made model of transformer, the nominal load, obtained the following average values of temperature: HVC 89,66 (° C), LVC 88,08 (° C), magnetic core 78,11 (° C), transformer oil 48 (° C), pot 32,651 (° C).

IV. Conclusion

From the performed research and made electromagnetic and heat analysis of the model of the energy transformer type ETN 630, may be adopted the following conclusions:

1. Made and honored model of the transformer in the paper is a real picture because the values of sizes that characterize the transformer declared in the test protocol sheet coincide with those obtained by using modified accounting software FEM
2. This type of analysis gives good results and offers the opportunity to conduct further investigations in the future which would be in favor of improving the characteristics of power transformers of this type without additional investment, since the use of the software, do not require additional costs.
3. From the analysis of thermal-made model of transformer in FEM 4.2. can be concluded that this method of calculating the temperatures in the transformer, contribute to optimize the solution for feasibility since the design phase can be made to control heating.

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