MODELLING OF THERMAL PROCESSES OF A HYDRAULIC COOLING SYSTEM FOR A POWER TRANSFORMER

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Abstract. *This paper describes the Finite Elements Analysis of the hydraulic cooling system for electric power transformer by type TTU 630 kVA 20/0.4 kV. The Finite Elements Analysis was performed using SolidWorks 3D CAD Design and COSMOSFlow Works 2008 Software based on the designed data. Results from Finite Elements Analysis and experimental tests were compared. The obtained results offer useful information for optimal design of the electric power transformers to improve transformer efficiency, safety, reliability and to reduce manufacturing costs.*

Keywords: *power transformer, hydraulic cooling system, thermal modelling, engineering design*

1. INTRODUCTION

The power transformer is an essential and expensive component in a power system, so that their proper and continuous function is important to system reliability. Due to the complexity of design and manufacture process of a power transformer a collaboration of many experts and complex studies is required [1].

In actual energetic context, the power transformer optimization is of great industrial interest and many optimal design methods have been promoted [2].

The optimum design through the Finite Elements Analysis of a power transformer has become a necessity in order to reduce the weight, the power consumption, the cost of manufacturing, and increase security and even the reliability of the entire transformer unit [3].

The optimization of the hydraulic cooling system from a power transformer requires the correct calculation of losses, hot spot temperature and position.

2. THE HYDRAULIC COOLING SYSTEM FOR ELECTRIC POWER TRANSFORMER BY TYPE TTU 630 kVA 20/0.4 kV

The power transformer by type TTU 630 kVA 20/0.4 kV is shown in Fig. 1 from ICMET Craiova, Romania [4].

The transformer system cooling is a hydraulic circuit with natural convection. The cooling system is made by: walled metal tank fitted with radiators (frontal radiators T1 39 920 V13 placed front-back and lateral radiators T1 40 406 V20 placed side left-right); system isolated for oil cooling circulating. The transfer of heat from cooling hydraulic system radiators is made as follows: - convection process between heated oil and interior of radiator metal surface; - conduction process in the radiator metallic body; - free convection process between the radiator outer surface and the ambient air. The transformer oil has a turbulent flow characteristic.

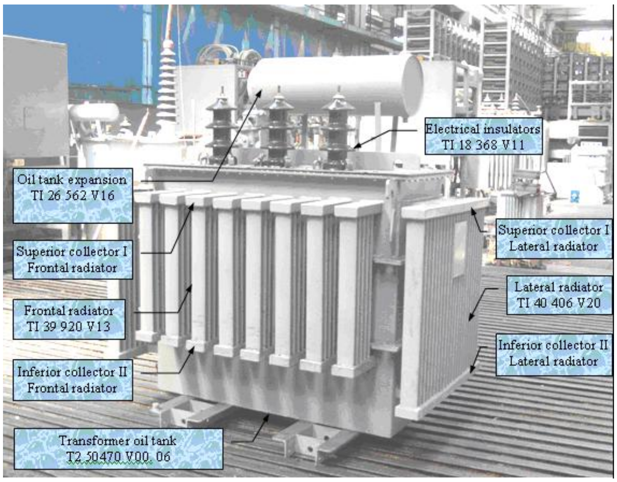


Figure 1. The power transformer by type TTU 630 kVA 20/0.4 kV.

3. 3D MODELLING OF THE HYDRAULIC COOLING SYSTEM

The Finite Elements Analysis was performed using SolidWorks 3D CAD Design and COSMOSFlow Works 2008 software based on the designed data.

The location and number of radiators and the direction of cooling oil flow through them are shown in longitudinal (Fig. 2a) and transversal section (Fig. 2b).

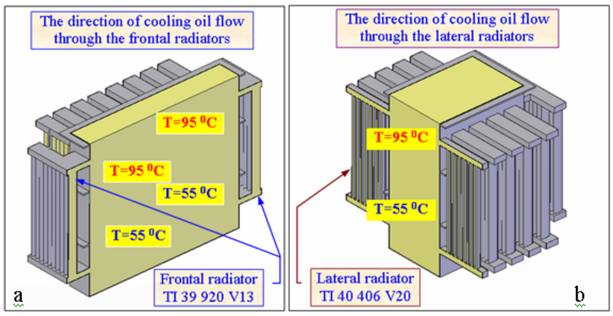


Figure 2. The direction of cooling oil flow through: a) the frontal radiators; b) lateral radiators.

The ceramic insulators (Fig. 3) designed to circulate cooling oil through them are located on top of the oil tank. The isolating fitting is shown in Fig. 4.

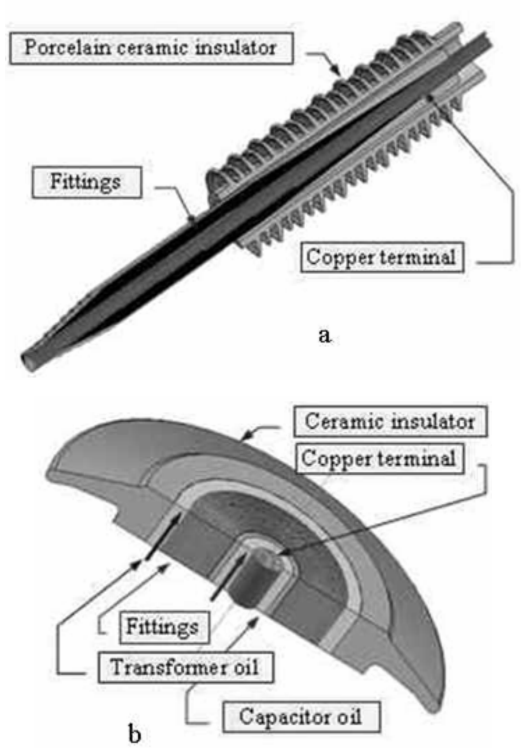


Figure 3. The axial section through: a) a porcelain ceramic insulator; b) a ceramic insulating ring.

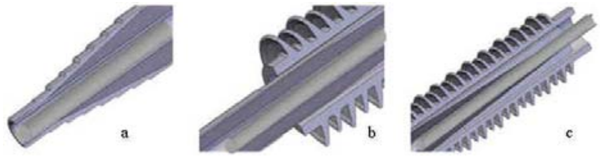


Figure 4. The isolating fitting is made of 20 layers, as are shown in different sectors a) input sector; b) medium sector; c) final sector.

The 3D geometrical model consists of two subregions: a) the first subregion (the transformer) was discretised into 350,000 Hex8 elements; b) the second subregion (the surrounding air) was discretised into 400,000 Hex8 elements.

4. THE ANALYSIS OF HYDRAULIC COOLING SYSTEM USING THE FINITE ELEMENTS METHOD

4.1 The analysis of heat exchange for radiators

a) The initial data for simulation

The simulation was made considering that in a high thermal functioning the input oil into the superior collector of radiators is at a temperature *Toil* = 95 ºC. Also was considered the worse functioning situation, when the ambient air moving to the outer radiators surfaces has the highest temperature value *Tair* = 55 ºC.

The input oil speed into radiators is considered *v* = 10 [mm/s] at a pressure *p* = 35 [kPa].

a1) The FEM analysis of heat exchange for frontal radiator

In Fig. 5 is shown the frontal radiator with the direction of cooling oil flow through it and the isotherm surface for T = 328 K shown in Fig. 6.

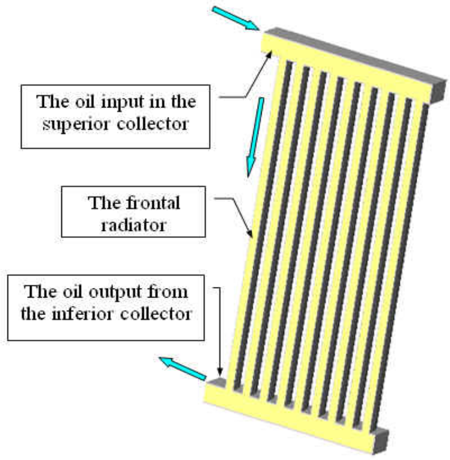


Figure 5. The frontal radiator.

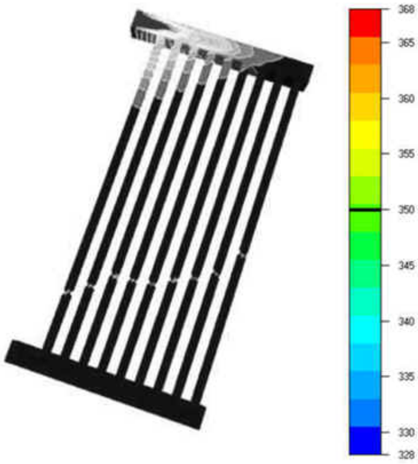


Figure 6. The isotherm surface for T = 328 K.

Conclusions concerning the FEM of the heat exchange in this case are:
- the minimum isotherm lines (for constant temperature), traced in white line and confirmed by the numerical values of temperature, tend to leave oil in the circuit;
- the oil cools to a temperature equal to air flowing around the radiator outside, but this temperature is cooling down before attending full length of elements leading to the conclusion that these elements may be reduced in terms of length;
- the first element has the most heating load;
- the thermal load distribution on the whole assembly is differentiated from first to last element, being thermal loaded only the first 6 elements;
- the elements 7, 8 and 9 have a much reduce contribution in the heat exchanger;
- To optimize the frontal radiator is possible by changing the elements length in a proper dimensioning or by adding auxiliary elements. The oil flow can be more evenly spread to each element in the first group of 6 elements (which are heat load), leading to a more

uniform thermal loading, and could then possibly reduce the number of them;
- Based on the isotherm surfaces the optimal length of the radiator elements, for known values of cooling oil input data, can be determined;
- Extreme temperatures are reached in the radiator plane of symmetry where the flow velocity is higher and decreases to the radiator outer surface where heat transfer takes place mostly through convection.

a2) The FEM analysis of heat exchange for lateral radiator

In Fig. 7 is shown the lateral radiator with the direction of cooling oil flow through it and the isotherm surface for T = 327.04 K shown in Fig. 8.

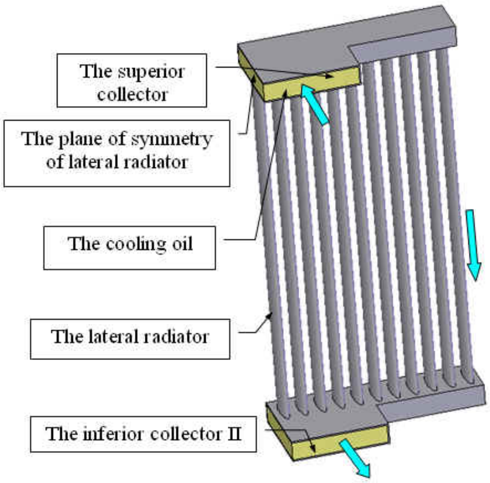


Figure 7. The lateral radiator.

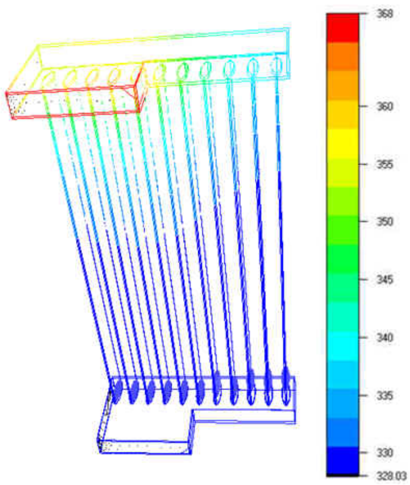


Figure 8. The isotherm surface for T = 327.04 K.

Conclusions concerning the FEM of the heat exchange in this case are:
- the oil reaches to the air temperature (at the temperature T = 55 [°C]), even to limit of the radiator output section;
- for areas where there is an intense exchange of heat (especially to the radiator input), there is a greater variation of temperature gradient;
- the lateral radiator is sized correctly in terms of heat transfer efficiency compared with the frontal radiators.

4.2 The analysis of heat exchange for isolated system

a) The stationary functioning regime

The analysis of temperature distribution in the first ceramic insulator is made according the cases from the Table 1.

Table 1. The FEM study cases for isolated system

Case no.	The transformer oil temperature Toil [°C]	The environment air temperature Tair [°C]
C1	90	-30
C2	90	0
C3	90	55

The results obtained from simulation concerning the average temperature on the outer surface of the item, are shown in [4].

Graphical representation of the average temperature corresponding for the 24 items of the isolated system, subjected to heat exchange study is shown in Fig. 9.

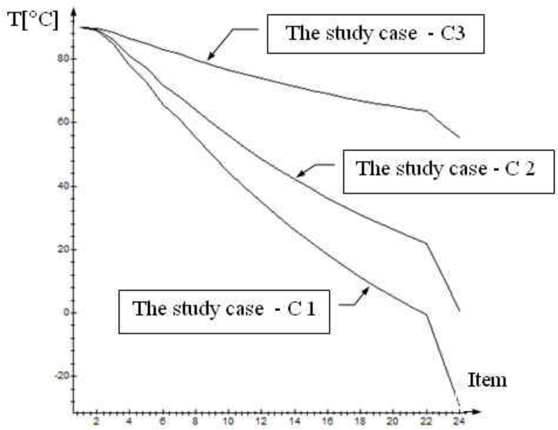
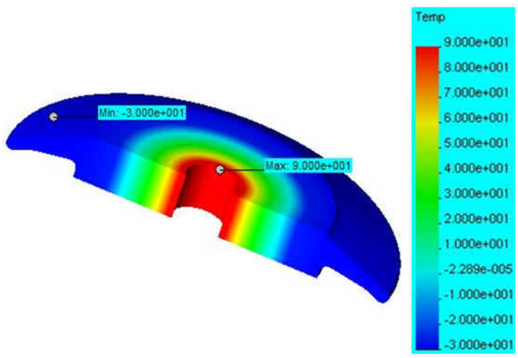
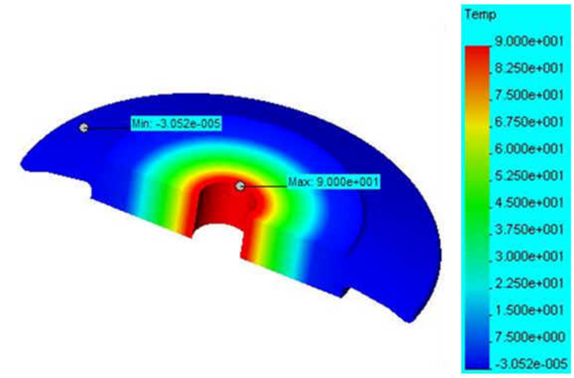


Figure 9. The average temperature corresponding for the 24 items of the isolated system.

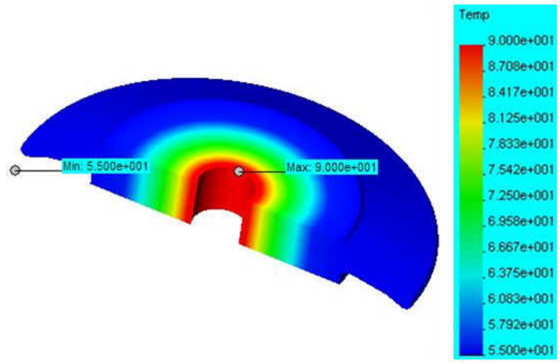
As conclusion it is noted that the average temperature value on the isolating fittings surface decrease in the radial direction, outwards, with decrease of air temperatures in working isolating fitting and heat exchange is more intense at lower environmental temperatures. The temperature distribution and extreme temperatures that occur in the isolated system for the study cases: C1, C2 and C3, with the removal of copper terminal are shown in Fig. 10, a, b and c.



a) C1



b) C2



c) C3

Figure 10. The temperature distribution in the isolated system for the study case: a) C1; b) C2; c)C3.

b) The nonstationary functioning regime

The thermal study is made during a summer day (the period t = 0 .. 24 hours). The temperature variation in time in the environment was registred and noted in [4] and represented in Fig. 11.

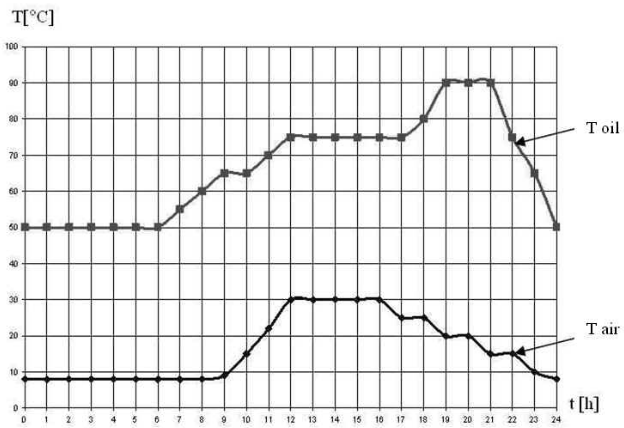


Figure 11. The temperature variation in time for oil and air [4].

The most thermal loaded section of the isolated system is the section corresponding to the first wing which is adjacent to the clamping flange of insulating transition on the oil tank.

In Fig. 12 is shown a temperature distribution in radial section, corresponding to a peak hour (t [h] = 20) in which the network is a maximum coupling of energy consumers.

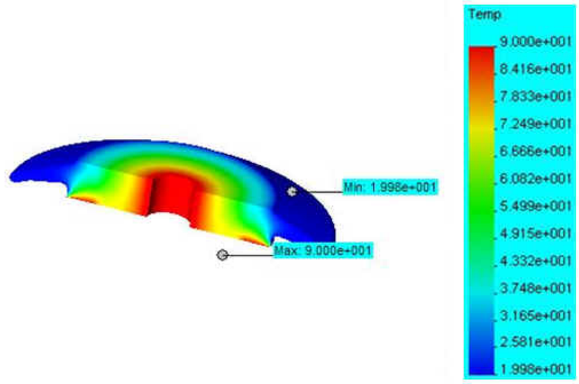


Figure 12. The temperature distribution in the isolated system for a peak hour (t[h] = 20).

5. CONCLUSIONS

The Finite Elements Analysis of the hydraulic cooling system for electric power transformer by type TTU 630 kVA 20/0.4 kV was performed using SolidWorks 3D CAD Design and COSMOSFlow Works 2008 software based on the designed data.

Results from Finite Elements Analysis and experimental tests were compared. The errors between experimental and theoretical values was less than 0.5 %.

The obtained results offer useful information for optimal design of the electric power transformers to improve transformer efficiency, safety, reliability and to reduce manufacturing costs.

6. ACKNOWLEDGMENTS

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