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DIFFERENT HOT-SPOT AND TOP-OIL TEMPERATURE MODELS FOR MONITORING OF TRANSFORMERS

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ABSTRACT
One of the most important parameters governing a transformer's life expectancy is the hot-spot temperature value. This paper presents accurate temperature calculation methods taking into account the above mentioned findings to estimate life of transformer form hot spot temperature. An attempt to find a proper dynamic top-oil temperature model to be used in an monitoring and diagnostic system for transformer is the aim of this paper. Through comparison of a measured value such as top-oil temperature, analizing thermal image of transformer, and calculated value top-oil temperature which is obtained by means of a physical model, operational problems can be detected. The experimental base of this research are the measurements on air core transformer realised with thermovision camera.

Key words: Top-oil temperature, Hot-spot temperature, power transformer, air core transformer, model

1. INTRODUCTION

Prediction of the electromagnetic and thermal phenomenas in the structural metal parts of transformer is important step in design process.

The failures of transformers always cause irreversible internal damage. The basic criterion, which limits the transformer loadability and usable life is partially determined by the ability of the transformer to dissipate the internally generated heat to its surroundings. It is therefore essential to predict thermal behaviours of a transformer during normal loadings.

Construction of a transformer model is one of the great importances in transformer condition monitoring.For numerical calculation of distribution of temperature and electromagnetic fields is used finite element method.

Power transformer data:

Producer	БТЗ, Rusija
Type	ТМ – 6300 / 35
Rated power	6300 kVA
HV coil	35±(2x2,5%)kV
LV coil	10,5 kV
Type of connection	Y/Δ – 11
Frequency	50 Hz
Short circuit losses	Pk = 46 500 W
Open circuit losses	Px = 7600 W
Short circuit voltage	u_k = 7,5%
Open circuit current	i_0 = 0,6 %

Air core transformer data:

Producer	Koncar,Croatia
Type	DP/0-9896,
Rated power	2,4 kVA,
HV coil	500 V,
LV coil	380 V,
Frequency	50 Hz,
Rated current-primary	3 A,
Rated current-secondary	3,6 A,

2. MATEMATICAL MODEL OF THERMAL PROCESSES IN POWER TRANSFORMER

Electromagnetic and temperature fields are defined by equations:

$$\nabla\times\mathbf{H}=\sigma(\mathrm{T})\mathbf{E},$$
$$\nabla\cdot\left[\mu(\mathrm{H,T})\mathbf{H}\right]=0, \qquad (1)$$
$$\nabla\times\mathbf{E}=-\frac{\partial\left[\mu(\mathrm{H,T})\mathbf{H}\right]}{\partial \mathrm{t}}.$$
$$\nabla\cdot(\lambda\nabla T)-\rho c\frac{\partial T}{\partial t}+q_v=0, \qquad (2)$$

This equation presents partial differential equation of non-stationary heat transfer, where is:
T– function of temperature distribution in space and time,c- specific heat capacity, ρ- specific material density, λ - coefficient of heat conduction, q_v - thermal capacity of eventually heat sources in determined point, and t – time.
All of these functions are functions of space and temperature.
In table 1 are given data about geomtry of oil transformer, and in a table 2 are given data about air core transformer.

Table 1. Power transformer geometry data

Parameter	Description	Value in cm
COL_HT	Height of columns	143
COR_TK	Thickness of uperr and lower part of the core	34.84
COL_TK	Thickness of the column	34.84
COR_LH	Lenght of the core	168.84
INS_TK1	Thickness of insulator	1.75
INS_TK2	Thickness of insulator	2.7
C1_TK	Coil 1 thickness	4.86
C2_TK	Coil 2 thickness	5.27
COIL_HT	Coil height	123
R_INT	Inner diametter od calculation domen	222x258
R_EXT	Outer diametter od calculation domen	222x258

Table 2. Air-core transformer geometry data

Parameter	Description	Value in mm
COL_HT	Height of columns	145
COR_TK	Thickness of uperr and lower part of the core	50
COL_TK	Thickness of the column	30
COR_LH	Lenght of the core	250
INS_TK	Thickness of insulator	7
C1_TK	Coil 1 thickness	7,5
C2_TK	Coil 2 thickness	7,5
COIL_HT	Coil height	145
R_INT	Inner diametter od calculation domen	2000
R_EXT	Outer diametter od calculation domen	2300

3. NUMERICAL CALCULATION OF TEMPERATURE FIELD OF OIL AND AIR CORE TRANSFORMER

Presented model provided information about important thermal data for prognosis, simulation and analysis of the transformer operation.
Sources of electromagnetic and temperature field are currents in the coils, Joules losses which are consequence of current flow through transformer coils. Numerical calculation of temperature field is realised on two modes: finite element method in CAD software package FLUX2D and using thermal-electrical analogy by PSPICE software package. The experimental base of this research are the measurements on air core transformer realised with thermovision camera. Results of finite element method are shown on figure 2 and 5.

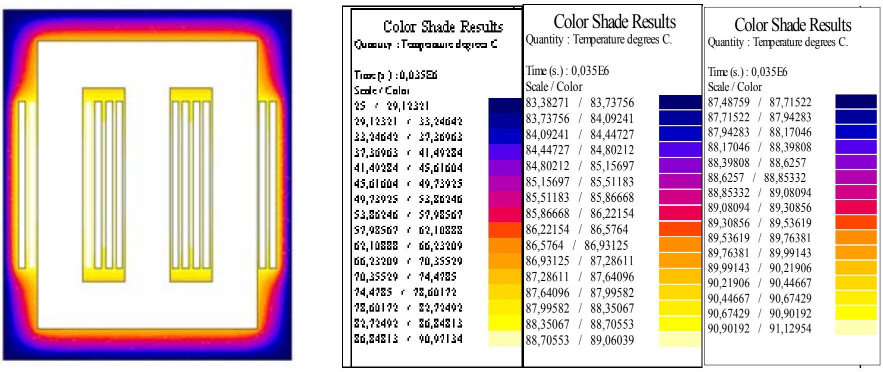

Figure 2. Temperature distribution in power transformer during 35 000 sec

Using thermal-electrical analogy, RC model of transformer is realised by PSPICE software package, figures 3 and 4. Average temperature on the oil surface as a result of simulation is 65 ^{0}C.

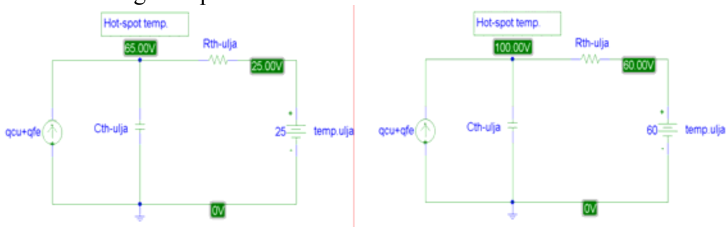

Figure 3, 4. PSPICE models for calculation of average temperature on oil surface and hot –spot temperature

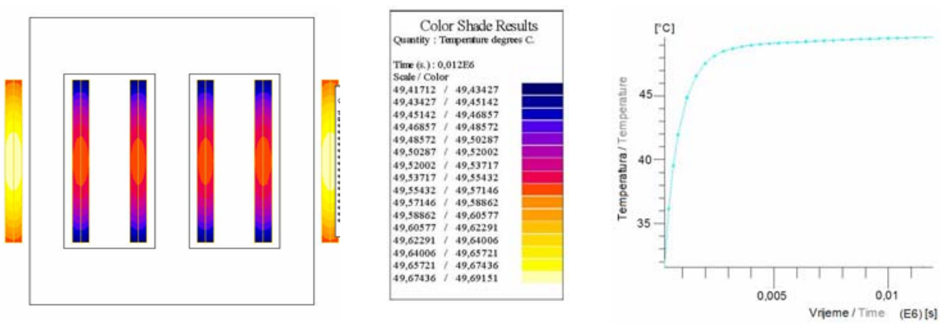

Figure 5. Temperature distribution in the coils of air core transformer during 12 000 sec

4. RESULTS OF ANALITICAL CALCULATION AND MEASUREMENTS

Results of numerical calculation of power transformer are compared with results of obtained analytical calculations. Temperatures of LV and HV coils in comparison with oil temperature are:

$\Theta_{V,NN} = \Theta_{U,NN} + \Theta_{U,V} = 25+39 = 64^0C$, $\Theta_{V,VN} = \Theta_{U,VN} + \Theta_{U,V} = 24.5+39 = 63.5^0C$,

and this is in area of allowed temperature $\Theta_{V,D} \leq 65^0C$.

Results of numerical calculation of air core transformer are compared with results of obtained measurements.

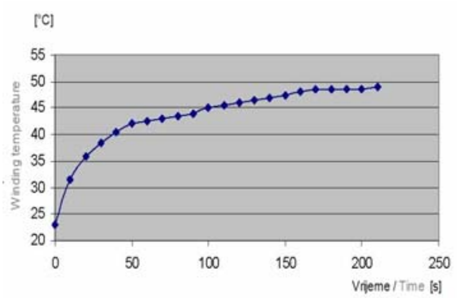

Figure 7. Temperature distribution in the center of coil of air core transformer during 12 000 sec

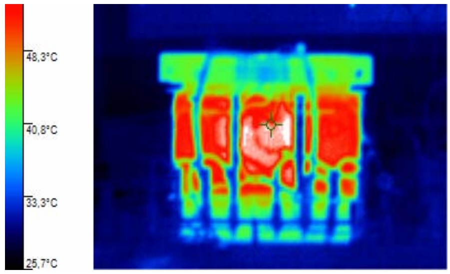

Figure 8. Temperature distribution in the coils of all three phases of air core transformer with thermovision camera.

Coil temperatures in steady state after numerical calculation and measurement are:

$T_{n,np} = 49{,}69\ °C$, and $T_{n,mj} = 49\ °C$.

Relative error is: $\partial T_n = \frac{\Delta T_n}{T_{mj}} 100 = \frac{0{,}69}{49} 100 = 1{,}408\ \%,$.

5. CONCLUSION

By analysis of results of temperature field distribution in the oil and air core transformer cross section, also and characteristics of temperature changes in particular points during calculation period, can be concluded:

- Temperature of surrounding air is 25 ^{0}C,
- The most warm up parts of transformer are coils, and then core and oil (air).

Conclusions based on analytical and numerical calculations are:

- The most warm up parts of power transformer are coils, LV coil with maximum temperature 91.12 ^{0}C. According analytical and numerical calculations temperature of LV and HV coils over temperature of oil is 64 ^{0}C. Allowed temperature for class of insulation used in this transformer is 65 ^{0}C, and this is in harmony with analytical and numerical calculation results.
- On the figures 6-9 are showed temperature distribution in the coils of air core transformer. Maximum value of coil temperature as a result of numerical calculation is 49,69 $^{\circ}$C, and as a result of measurement is 49 $^{\circ}$C.

Results accuracy of numerical and analytical calculation is very good. This shows importance of development of these numerical calculations for practical problems.This is very practical by economic reasons, expensive laboratory experiments, measurements and repairs are reduced.

6. REFERENCES

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