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DIFFERENT APPROACHES TO POWER TRANSFORMER THERMAL MODELLING

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ABSTRACT
The failures of transformer 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 essential to predict thermal behaviors of transformer during normal operation.
In this paper will be investigated different approaches to power transformer modelling. For this purpose is created a 2D model of real TN-6300/35, 6300 kVA, 35/10,5 kV power transformer, using program package FLUX2D. The results of this model are based on thermal (temperature) field calculation on the 2D finite element model.
The second, thermo-hydraulic model is intended to provide essential information about the status of a transformer, represents the thermal behaviour of core, windings and oil, for transient and steady state conditions. A third model is thermal model of a power transformer in the form of an equivalent circuit, based on fundamental heat transfer theory. In this paper will be presented hot-spot and top-oil temperature thermal models for more accurate temperature calculations during transient states. Results of all thermal models will be compared with results of analytical calculation.
Keywords: power transformer, thermal model, hot-spot temperature, top-oil temperature, thermal factors

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.

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

Figure 1 shows geometry of oil imerssed transformer and in table I are given data about geomtry of oil transformer.

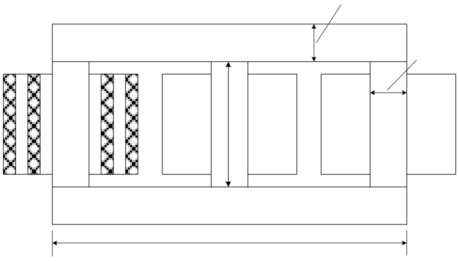

Figure 1. Transformer geometry

Table 1: Transformer geometry data

Parametar	Opis	Veličina u 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

COR_TK

2. MATEMATICAL MODEL OF THERMAL PROCESSES IN POWER TRANSFORMER

COL_TK

Electromagnetic field is defined by equations:

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

COL_HT

Total current density is determined by equation:

$$\mathbf{J}_{\mathbf{uk}}=\mathbf{J}_{\mathbf{iz}}+\sigma(\mathrm{T})\frac{d\mathbf{A}}{d\mathrm{T}}=\sigma(\mathrm{T})\left(\mathrm{Eiz}+\frac{\partial\mathbf{A}}{\partial t}\right) \qquad (2)$$

COR_LH

Temperature field is defined by equation:

$$\nabla\cdot(\lambda\nabla T)-\rho c\frac{\partial T}{\partial t}+q_v=0, \qquad (3)$$

This equation presents partial differential equation of non-stationary heat transfer, where is:
T [K] – function of temperature distribution in space and time,
$c\left[\frac{J}{kgK}\right]$ - specific heat capacity,
$\rho\left[\frac{kg}{m^3}\right]$ - specific material density,
$\lambda\left[\frac{W}{mK}\right]$ - coefficient of heat conduction,
q_v - thermal capacity of eventualy heat sources in determined point,
t [s] – time,

All of this functions arefunctions of space and temperature. Heat exchange between surface of conductor, core, oil and surrounding air is defined by equation:

$$-\lambda\frac{\partial \mathrm{T}}{\partial t}=\alpha\left(\mathrm{T_p}\text{-}\mathrm{T_f}\right). \qquad (4)$$

3. NUMERICAL CALCULATION OF TEMPERATURE FIELD OF OIL TRANSFORMER

Presented model of oil core transformer is intended to provide essential information about the status of a transformer.

It provided information about important thermal data for prognosis, simulation and analysis of the transformer operation.

The electromagnetic field has been calculated using magnetodynamic model. The nonlinearity of the transformer core magnetizing characteristic is taken into account.

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 softwre package.

Results of finite element method are shown on figure 2 and 3.

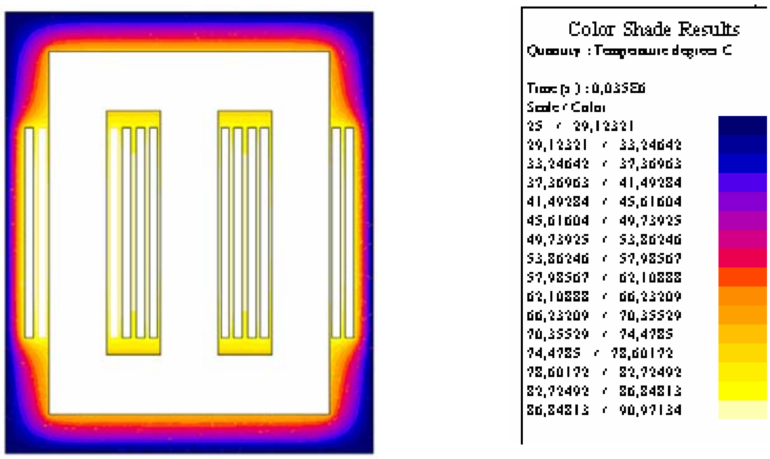

Figure 2. Temperature distribution during 35 000 sec

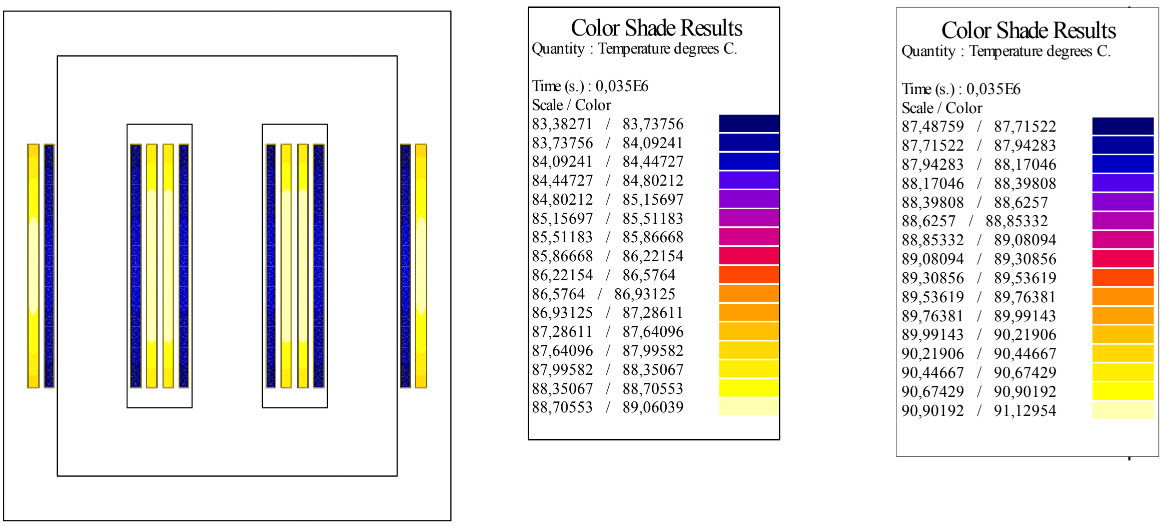

Figure 3. Temperature distribution in the coils of all three phases during 35 000 sec

Using thermal-electrical analogy, RC model of transformer is realised by PSPICE software package, figure 8. Average temperature on the oil surface as a result of simulation is 65 ^{0}C.

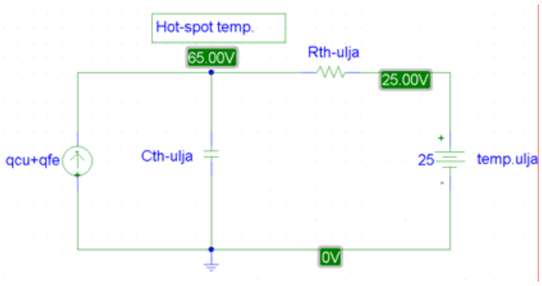

Figure 4. PSPICE model for calculation of average temperature on oil surface

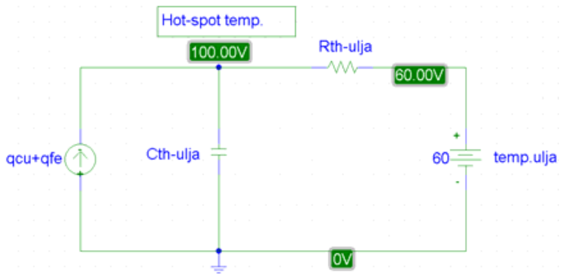

Figure 5. PSPICE model for calculation of hot-spot temperature

Hot-spot temperature as result of simulation is 100 ^{0}C.

4. RESULTS OF ANALITICAL CALCULATION

Results of numerical calculation are compared with results of obtained analytical calculations. Temperatures of LV and HV coils in comparition 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: $\Theta_{V,D} \leq 65^0C$.

5. CONCLUSION

By the analysis of results of temperature field distribution in the oil transformer cross section, also and characteristics of temperature changes in particular points during period of 35 000 sec, 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.

This type of calculation is very practical, by application of adequate software model of any kind of machines, including transformer can be realised. On that way need for very expensive laboratory measurements and repairs are reduced.

Conclusions based on analytical and numerical calculations are:

- The most warm up parts of transformer are coils, LV coil with maximum temperature 91.12 ^{0}C. According analitical 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.

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.

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