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THERMAL COMPUTER MODEL OF TM-160/10 POWER TRANSFORMER

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ANNOTATION

Simulation results of thermal characteristics of dry-type and oil-filled power transformer TM-160/10 in no-load and short-circuit modes are presented. Electrical, geometrical and thermal characteristics of TM-160/10 transformer have been determined. Computer modeling was performed in ANSYS17.1 software package. 2D distributions of temperature and heat flux density in transformer in longitudinal and transverse sections were determined. It is shown that the use of transformer oil for transformer cooling significantly reduces temperatures in the active part. The temperature distribution occupies the range of 67-91 °C. Accordingly, the temperature of the most heated part is 91 °C and also corresponds to the low voltage winding. The dependence of the most heated point of the transformer on the operating mode has been studied. A formula for calculation of maximum transformer temperature depending on power loss has been proposed.

Keywords: power transformer, dry and oil-filled, heat fluxes, maximum temperature, computer simulation.

INTRODUCTION

Power transformers represent the largest part of the capital investment in transmission and distribution substations of industrial enterprises. In addition, power transformer outages cause significant economic damage to the power grid and process equipment. One of the most important parameters determining the lifetime of a transformer is the value of the temperature of the hottest point, which, in turn, is determined by the density of heat fluxes. It has been shown in [4-6] that the maximum temperature is a function of loads, overloads, cooling modes and time. It has also been observed [1, 7, 2] that traditional calculation methods give underestimated values of maximum temperatures, especially in cases where thermal transients have not reached steady-state conditions. An important task is to improve the quality of transformers and to reduce energy losses during their operation [3, 8]. The solution of these problems is impossible without a thorough understanding and study of the thermal modes of the transformer.

At transformer operating modes with elevated temperatures relative to the standard values, the technical and economic indicators decrease: the wear of insulation increases, the reliability decreases and the service life decreases. Protection of transformers against overheating due to unacceptable operating temperatures is connected either to the need to reduce the load, i.e. to the violation of its basic function, or to the application of means of forced cooling.

The aim of this work is to simulate the thermal conditions of the transformer, to study the distribution of heat flows and temperatures in the transformer under different cooling modes and power losses.

According to current standards, the temperature excess of any part of the transformer is the temperature difference between this part and the cooling medium. Exceeding the temperature of the active part of the transformer within the permitted limits influences the technical and structural parameters of the transformer - dimensions, internal construction, load capacity, modes of operation and cost of the product.

Exceeding the average winding temperature over the ambient temperature according to the standard, corresponding to the IEC recommendations 76, should not exceed 65 °C [5]. The maximum excess temperature of the oil under the transformer tank cover over the ambient temperature shall not exceed 60 °C.

The maximum permissible ambient temperature for air is +40 °C, and for water - +25 °C. If the temperature of the environment (air or water) exceeds the threshold value, the heating rate is reduced by the corresponding interval of degrees. Insulation wear, determined by the temperature of the most heated point of the winding and the duration of its exposure, according to IEC recommendations is referred to a temperature of 98 °C. This temperature is typically typical for an ambient air temperature of 20°C and prolonged loading. It is allowed to reach the maximum temperature of the hottest point up to 115°C for insulating materials of heat-resistance class A.

However, control of compliance of the maximum temperature of the most heated point of the transformer with the permissible degree of heating is a very difficult task. Therefore, its determination by experimental methods or by simulation is an actual problem.

An oil-filled three-phase core transformer TM-160/10 was chosen as an object of research, its parameters have been determined according to the methodology [1] and are presented in the table

As the high voltage (HV) and low voltage (LV) windings cylindrical multilayer windings of round wire were adopted.

For HV test voltage Uisp1 = 35 kV insulation distances were determined [6]: a_{12} = 9 mm, l_{02} = 30 mm, a_{22} = 10 mm, δ_{12} = 3 mm (Fig. 1).

Electrical characteristics of transformer TM-160/10

Transformer type	TM-160/10
Power	160 kVA
Frequency	50 Hz
Number of phases	3
Primary voltage	(10000±3×2 %) V
Secondary voltage $^{U}2$	3150 V
Cooling system	oily natural
Diagram and winding connection group	Y/Y
Short circuit voltage	4,5 %
No-load current	2,4 %.
No-load losses	510 W
Short circuit losses	2650 W

For LV test voltage U_{isp2} = 18 kV insulation distance: a_{01} = 15 mm, l_{01} = 30 mm (Fig. 1).
The rod design with number 6, k_{cr} = 0,913 without pressing plate is chosen. At capacity of 160 kVA cooling channels in the magnetic core are not provided [2, 3]. As the material of magnetic system of transformer is accepted cold-rolled 3404 electrical steel with a density of 7650 kg/m^3 is used as a material of the transformer magnetic system.

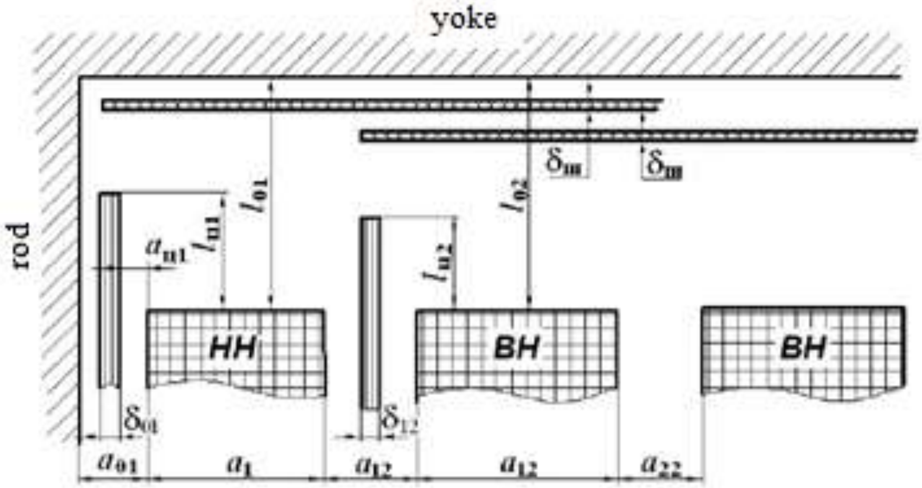


Fig. 1. Main winding insulation

Core rod diameter d = 0.150 mm. The coefficient of conversion of the ideal scattering field to the real field k_r =0.95. Short-circuit losses P_{k2} = 382.78 W, LV winding wire mass G_2 = 18.16 kg. Heat flux density on the surface of LV winding q_2 = 1,183 kW/m^2. A multilayer cylindrical winding made of a round PB copper wire with diameter d_1 = 1.9 mm, cross-section 3.14 mm^2 was accepted. Total cooled surface of HV winding P_1 = 0,888 mm^2. Short-circuit losses P_{k1} = 514.96W. Heat flux density on the surface of HV winding q_1 = 0.58 kW/m^2.
Modelling of heat exchange and hydrodynamics was performed in the transformer environment in the software package of the freeware version Ansys 17.1 (ANSYS Free Student Product Downloads) [9, 10]. As the exact calculation of an oil-filled transformer is limited by the computing resources of the computer, a simplified model of the TM-160/10 transformer was used.

Cylindrical surfaces were used as LV and HV windings, as well as insulation windings, which are created in the DesignModeler geometry module of Ansys 17.1. A sketch is created beforehand, which is then transformed into a three-dimensional figure by using the Extrude operation. The transformer LV and HV winding and single-phase insulation models created in this way, according to the calculated geometry, are shown in Fig. 2.
Next, using the Translate tool, models of two more transformer phases are created, and the yoke was added to the model. The resulting model of the active part of the transformer is shown in Fig. 2.
After that the model is "placed" in the oil-filled tank.

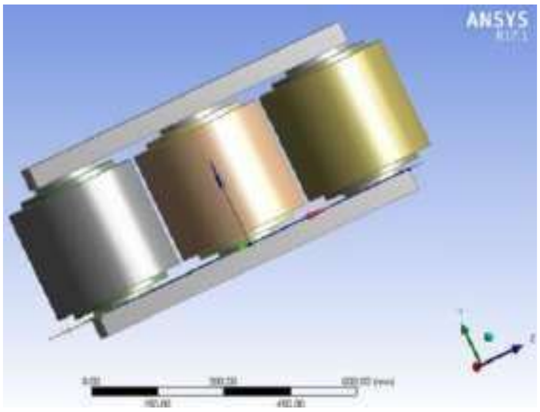
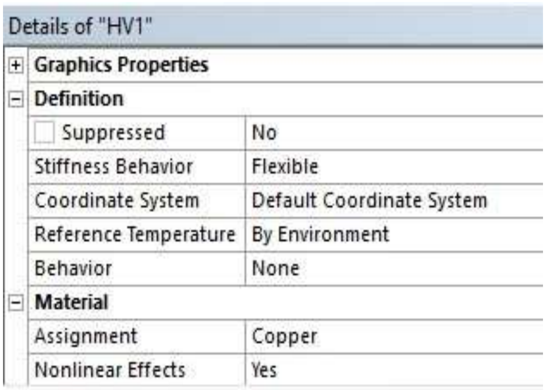


Fig. 2. Model of the active part of the transformer TM-160/10, created in the Design Modeler program Ansys 17.1

Then, the characteristics of the physical model are set in the program. For this purpose, in the module ModelAnsysSteady-StateThermal the characteristics of materials of windings, rods, core, insulation and their environment are set (Fig. 3). As the winding material we take copper (Copper), the core material - steel (StructuralSteel), the cooling medium - transformer oil (Engineeroil).



Details of "HV1"	
Graphics Properties	
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Behavior	None
Material	
Assignment	Copper
Nonlinear Effects	Yes

Fig. 3. Window for setting the material properties of the winding
Next, in AnsysSteady-StateThermal, a Mesh computational mesh region is defined, which is calculated automatically based on the geometric model (Fig. 4).

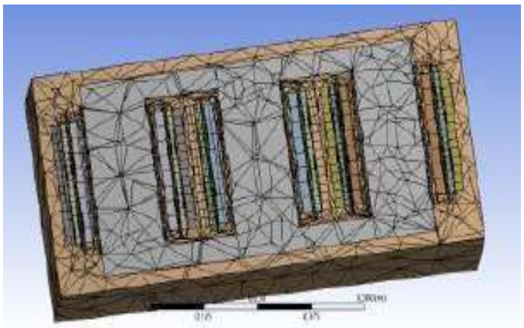
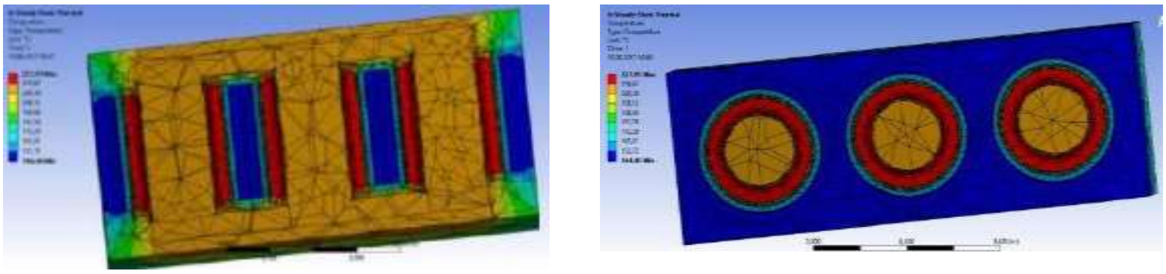


Fig. 4. Calculation grid area of a Mesh transformer (cross-section) In AnsysSteady-StateThermal

The short-circuit mode is set in AnsysSteady-StateThermal by setting the specific heat fluxes q (HeatFlux). On the surface of LV winding the heat flux density in the short-circuit mode is set q_{2kz} = 1183,0 W/m², on HV winding - q_{2kz} = 580,0 W/m².

Also for correct modeling, the condition of heat transfer by convection is introduced into the model, and all boundaries between liquid and solid are marked with the tool FluidSolidInterface.

First, in order to check the performance of the core and the longitudinal insulation, a simulation is carried out without filling the transformer with oil, i.e. with air cooling. The temperature distribution in different areas of the transformer in the vicinity of the core, obtained from the simulation, is shown in Fig. 5.



a б

Fig. 5. Temperature fields in the longitudinal (a) and transverse (b) section in the short-circuit mode. The cooling medium is air

From the screenshots shown, it is clear that the temperatures at which the transformer operates when cooled by air are significantly higher than the allowable 144-235 °C. The temperature of the hottest points corresponds to about 225 °C and is typical for the LV winding, and the core temperature t = 210 °C is also high.

Due to the insulation, the HV winding temperature is significantly lower, but nevertheless also exceeds the permissible value. The highest heat flux density, as it should be expected, is near the windings, and the intensity of heat fluxes decreases rapidly with distance from them.

A similar simulation of short-circuit operation with oil-filled transformer has been performed. Temperature distribution and heat flux density are shown in Fig. 6, 7.

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Figure 6 shows that the use of transformer oil for filling significantly reduces the temperatures in the active part. The temperature distribution occupies the range of 67-91 °C. Accordingly, the temperature of the most heated part is 91 °C and also corresponds to the LV winding.

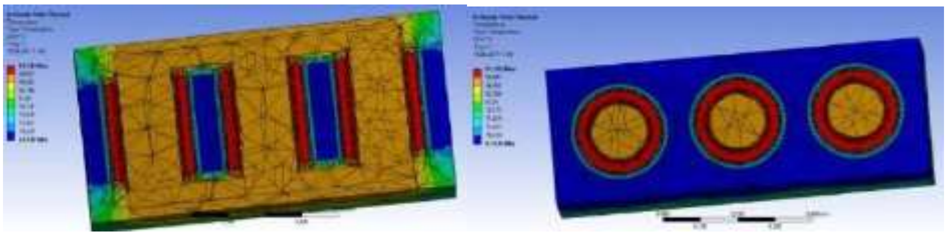

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Fig. 6. Temperature distribution in the transformer in the longitudinal (a) and transverse (b) section during short-circuit operation. Cooling medium - transformer oil

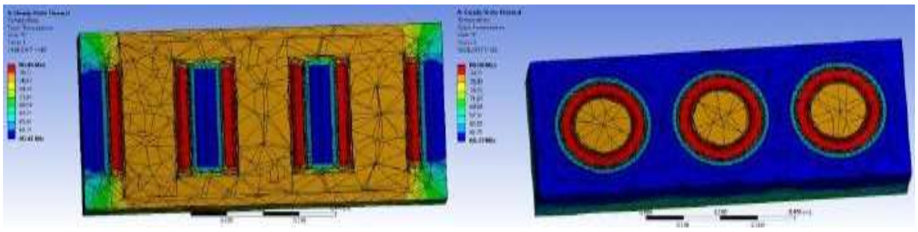

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Fig. 7. Temperature distribution in an oil-filled transformer in longitudinal (a) and transverse (b) section for losses P = 2240 W

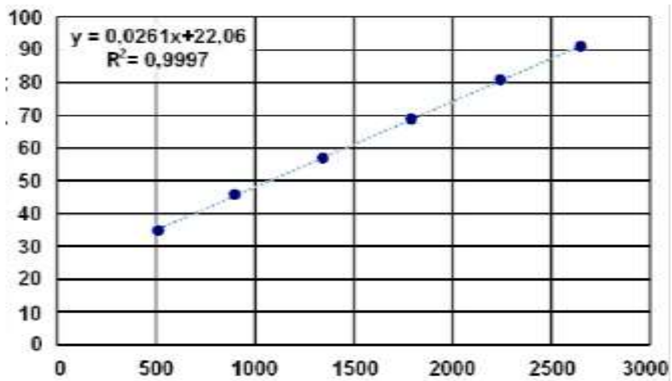

Fig. 8. Dependence of the maximum transformer temperature on the power loss

The lifetime of a transformer is determined by the maximum temperature of its windings, which depends on the transformer's operating mode. In order to investigate the dependence of the maximum temperature of a TM-160/10 transformer on its operating mode, a simulation was carried out in the range of losses from no-load (510 W) to short-circuit (2650 W). The corresponding temperature distributions are shown in Fig. 7.

On the basis of the data obtained, the temperatures of the most heated points of the transformer are determined and a graph of the maximum temperature of the transformer as a function of the losses is plotted. The calculated values of the power losses, the heat flux density of the windings are shown in Fig. 8.

Considering that, as shown in [2, 3], the insulation life decreases exponentially as a function of temperature, we can conclude that a similar dependence will be true for the relationship between insulation life and transformer loss capacity.

Thus, Ansys 17.1 simulation of transformer thermal conditions in both "dry" and oil-filled versions has been performed. The temperature distribution in and near the active part of the transformer, as well as the heat fluxes have been determined, and the dependence of the maximum temperature (the hottest point) on the power loss in the range of no-load and short-circuit modes, which determines its service life, has been determined.

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