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Analysis of thermal state of power transformer of captive power plant

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Abstract

It has been proven that the introduction of the systems for continuous control of the power transformer technical state predetermines the need for improvement of the methods for calculation of the thermal modes, insulation wear and remaining service life of the equipment. Disadvantages of the existing methods recommended by domestic and foreign regulatory documents are noted. It is appeared to be practically to consider parameters of the environment, thermal mode retention and non-linearity of the thermal characteristics. The structure of algorithm for calculating temperature charts according to the load parameters with regard to the influence of the above factors is proposed. The developed software is briefly specified, too. The ultimate purpose is to develop and study the improved model for thermal characteristic calculation designed for the systems of on-line monitoring transformer technical state.

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Keywords: Power transformer; technical state; thermal mode; the hottest spot; temperature; useful lifetime; algorithm; software program; analysis

1. Introduction

It is famously urgent to create robust methodological procedures for calculation and forecast of the remaining transformer component lifetime. This is due to the issue of the necessary renewal of the great number of transformers due to their operating life. That is why it is practically important to substantiate objectively the priority and time sequence of this reorganization of the electric power industry. Furthermore, important diagnostic

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characteristics in the on-line monitoring systems introduced at high-voltage power transformers are temperature values, remaining lifetime and servicing life of insulation [1]. In this regard, the issues of the accurate calculation of temperature of the hottest spot according to the transformer load parameters become more critical and essential.

Regulatory documents define principal items of the methodology and algorithms for calculation of the transformer's thermal modes [2]. However, the proposed algorithms have essential disadvantages reducing calculation accuracy. So, the thermal model of the cooling system suggested in GOST 14209-97 does not consider the following physical features being specific for unsteady thermal modes:

– temperature of the transformer components changes during unsteady processes according to the non-linear dependencies;

– winding temperature has its own heat retention and changes due to the non-linear dependency;

– temperature of the cooling medium influences the thermal mode of the power transformer with due regard to the time constant of its heating.

[3] shows that during monitoring transformer parameters at the temperature determination θ_h it is reasonable to take into account a time lag of the thermal processes in the winding and winding-oil section at presence of step changes of great amplitude in the load current trending. The above suggests elaborating existing methods and improving analysis algorithms aimed to the elimination of these disadvantages.

2. Main Part

At operation of the oil-filled power transformers one face the problem which is connected with temperature θ_h of the hottest spot of the winding insulation; it has an adverse effect on the insulation condition and may result in its fatal failure. That is why the temperature θ_h should be continuously monitored at the transformer operation. Direct measurement of this temperature has not become a frequent practice; consequently, it is determined due to the temperature rise in the upper oil layers.

To calculate temperature θ_h it is proposed to apply the heat equation of the winding sections neighboring to the hottest spot of insulation. Initial data for calculating θ_h are: current of the winding, temperature of the transformer oil upper layers and type of cooling (natural or forced one). In the mode of the stationary load of the transformer the formulas substantiated in [2] are used: For natural cooling (ON):

$$\theta_h = \theta_a + \Delta\theta_{br}\left[\frac{1+RK^2}{1+R}\right]^x + H_{qr}K^y, \tag{1}$$

For forced cooling (OF):

$$\theta_h = \theta_a + \Delta\theta_{br}\left[\frac{1+RK^2}{1+R}\right]^x + H_{qr}K^y + 2(\Delta\theta_{imr} - \Delta\theta_{br})K^y, \tag{2}$$

where θ_a – temperature of the cooling medium; $\Delta\theta_{br}$ – oil temperature rise in the bottom winding part; $\Delta\theta_{imr}$ – average oil temperature rise; K – load ratio; H_{qr} – heat gradient of the hottest spot; R – loss rate; x – oil exponent; y – winding exponent.

2.1. Temperature Calculation in the Unsteady Thermal Mode

From formulas (1) and (2) it follows that the change of the transformer load results in changing the difference between temperatures of the hottest spot and upper oil layers. These dependencies do not reflect transient processes occurring at the change of this temperature but they may be obtained with the model as per [3].

During monitoring transformer parameters at the temperature determination it is reasonable to take into account a time lag of thermal processes in the winding and winding-oil section at presence of step changes of great amplitude