Journal of Engineering and Applied Sciences 12 (Special Issue 11): 9082-9090, 2017
ISSN: 1816-949X
© Medwell Journals, 2017

Experimental Study of Changes of Active Power Losses of Power Three Phase Two-Winding Transformer in the Idle Mode When Changing the Temperature of its Magnetic System

Sergey Kostinskiy
Electricity and Electric Department, Platov South-Russian State Polytechnic University, Novocherkassk, Russia

Abstract: In this study, researchers conduct an experimental investigation of the changes of active power losses of power three phase two-winding transformer in the idle mode when changing the temperature of its magnetic system. The object of the study was the three-phase two-winding transformer of the brand RP3-380/220V-2, 5 with nominal power of 2.5 kW·A, voltage on the high voltage winding of 380 V, low voltage winding of 220 V. To perform the experiments, a stand was assembled consisting of a personal computer, laboratory autotransformers, measurement unit, universal eight-channel temperature meter, three phase two-winding transformer, analyzer of power quality and interface devices and measuring devices with a personal computer to synchronize measurements. Experimental studies were carried out with conventional phase voltages at the LV winding of the test transformer are respectively 200, 210, 220, 230 and 240 V in accordance with the requirements of GOST 3484.1-88. "Transformers Electromagnetic methods of testing". The study presents graphs corresponding dependencies confirming the compliance of completed experimental studies of the above-mentioned standard. By results of processing of experimental data managed to draw the following conclusions. With increasing temperature the magnetic system the total losses of active power idle in all three-phases of the test transformer are reduced. With increasing temperature the magnetic system when testing three-phase transformers with three-phase excitation transformation ratio is practically unchanged.

Key words: Technical losses, power distribution networks, power three phase two-winding transformer, the temperature of the magnetic system, the power losses of the power transformer, the transformation ratio of three-phase two-winding, power transformer

INTRODUCTION

Currently, errors in determining losses XX transformer considerable as they are calculated according to simplified methods. Required a realistic assessment of these losses on the test results and development ofnecessary recommendations (Bazakov *et al*., 2012).

It is established that "the setting of standards of electric power losses in electric networks can be considered the technical condition of electric grid facilities on the basis of surveys and calculations" (Anonymous, 2005). In the calculations of the losses of the XX transformers shall, as a rule, equal to the nameplate value, but over the life of the real losses of the XX change.

Selective measurement of power losses XX current transformers networks 6-10 kV (Bazakov *et al*., 2012) and compare the resulting measurements with calculated values obtained by recalculation of the certified values according to the method (Kazakov *et al*., 2006, 2007) which takes into account the change in the value of power loss of the XX in the process of transformer operation, suggests that the real loss values of XX for individual transformers can be both above and below the calculated values.

The actual loss, i.e., the difference between supplied to the network and paid electricity, enlarged has four components (Zhelezko *et al*., 2005). Technical losses of electricity due to the physical processes occurring during the transmission of electricity in electric networks and expressed in the conversion of electricity into heat in the elements of the networks (Exposito *et al*., 2016; Masters, 2013).

Electricity consumption for own needs of substations and melting ice, necessary to ensure the operation of the technological equipment of substations and power lines and activity staff. Energy loss due to instrumental errors of measuring it (instrumental losses) (Short, 2014; Shin *et al*., 2014).

Commercial losses due to theft of electricity, not the conformity payment for electricity by consumers of the readings, late payments, not paying bills, etc. reasons in the sphere of organization of control over the electricity consumption (Gonen, 2016; Uraev *et al*., 2016). Business losses are not themselves mathematical description and as a result cannot be calculated offline. Their value is determined as the difference between the actual (reported) losses and the sum of the first three components, representing technological losses.

In addition, part of the electricity generated is consumed in electric networks on the creation of electric and magnetic fields and is the necessary technological consumption for transmission (Short, 2014; Gonen, 2016; Exposito *et al*., 2016).

The electric network is a set of power transformers and transmission lines. Electric power transformers are the most critical elements in the circuit of any electrical substation. The total number of electrical transformers, installed at substations of power systems, industrial and agro-industrial enterprises, urban and rural power grids, hundreds of thousands. This is because electricity is on the way from generators to consumers-the consumers of electricity, usually are repeatedly transformed: first, the voltage of the generators is increased for the transmission of electricity along the lines of high and extra-high voltage and then drops to the nominal voltage of distribution networks in the areas of energy consumption and lowering the voltage to the nominal voltage of most electrical equipment 380 and 220 is not within the transformer and consequently in several transformers that are installed, usually at different substations (Shabad, 1989).

Losses in power transformers consist of two components: the short-circuit loss (copper loss) and load losses (losses in steel). In electrical distribution networks with high voltage 6-10 kV a significant component of technological electricity losses are load losses (XX) transformers (Bazakov *et al*., 2012).

The core temperature affects the value of no-load losses caused by eddy currents. The deviation of the load losses due to temperature changes can be significant (Lizunov and Lokhanin, 2004). So when measuring the temperature at 21°C and at 50°C on the transformer 50 MVA, 110/10.5 kV, it was observed decrease of losses with increasing temperature. At a nominal of TL induction of 1.77, a decline of 1.2% while induction of 1.6 T and 3.3% (Porudominskiy, 1984).

In view of the above pressing issue is clarification of the impact on losses of the XX and the transformation ratio of power transformer core temperature.

MATERIALS AND METHODS

According to Section 6.1.1 of GOST 3484.1-88 when checking the ratio and measurement of losses of idling of one of the windings when the windings fail open the remaining nominal voltage. In accordance with Section 2.1.3 (GOST 3484.1-88) when testing three-phase transformers with three-phase excitation of the measured line voltage corresponding to the eponymous line clamps check the windings. According to Section 1.2 (GOST 3484.1-88), transformers experience with mounted parts and the external support devices that can influence the test results of the transformer.

The object of the study was adopted by the three-phase two-winding transformer brand RP3-380/220 V-2.5 a nominal power of 2.5 kW·A voltage in the winding of the higher voltage 380 V, coil voltage 220 V, made 30.09.2016 g with serial number 1054 and corresponding TU 3413-006-47936447-2002 (Fig. 1and 2).

In accordance with clause 6.1.8 (GOST 3484.1-8) losses, voltage and current in the experience of the XX

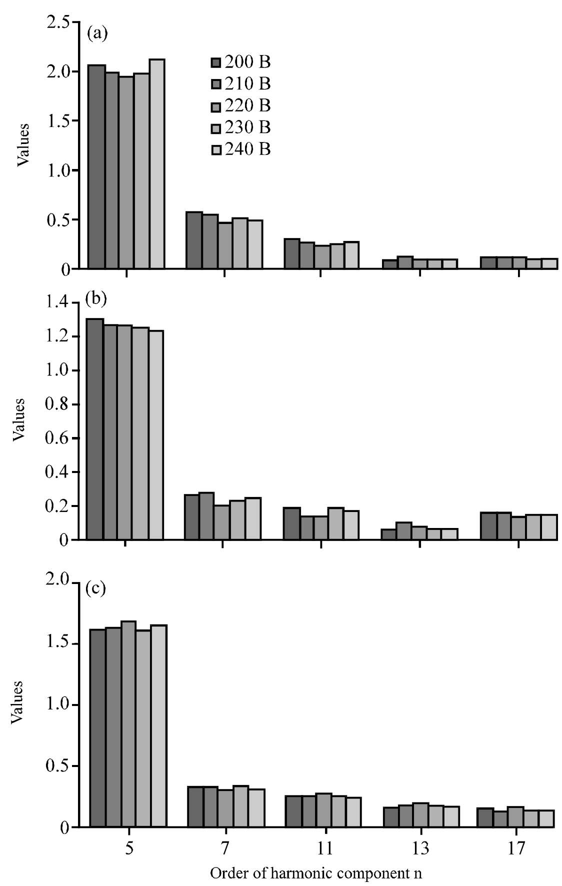

Fig. 1: A graph of the coefficients values of the odd harmonic components of voltage, not divisible by three $K_{U(n)}$ in the conventional voltage of winding of 200, 210, 220, 230, 240 V for: a) Phase L1; b) L2 and c) Phase L3; Translation of elements: B-V

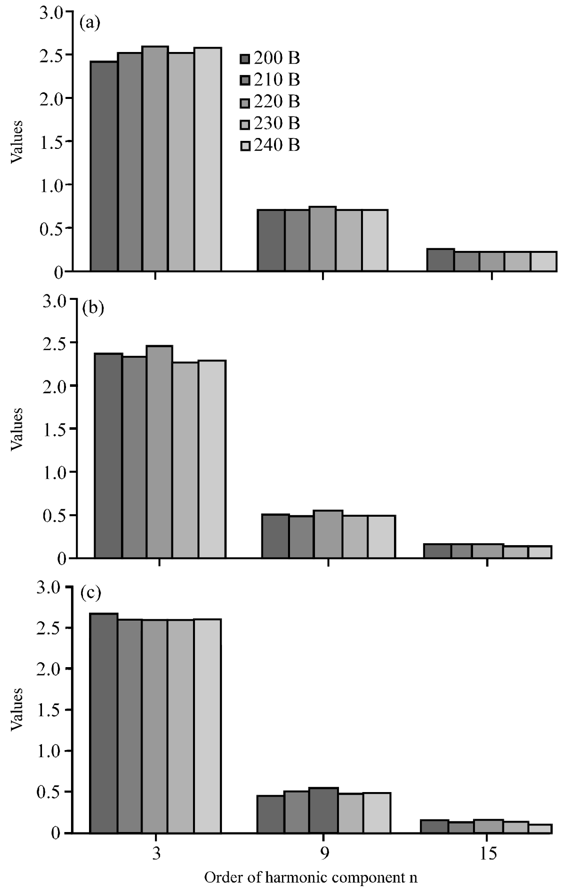

Fig. 2: A graph of the coefficients values of the odd harmonic components of voltage, divisible by three $K_{U(n)}$ in the conventional voltage of winding of 200, 210, 220, 230, 240 V for: a) Phase L1; b) L2 and c) Phase L3; Translation of elements: B-V:

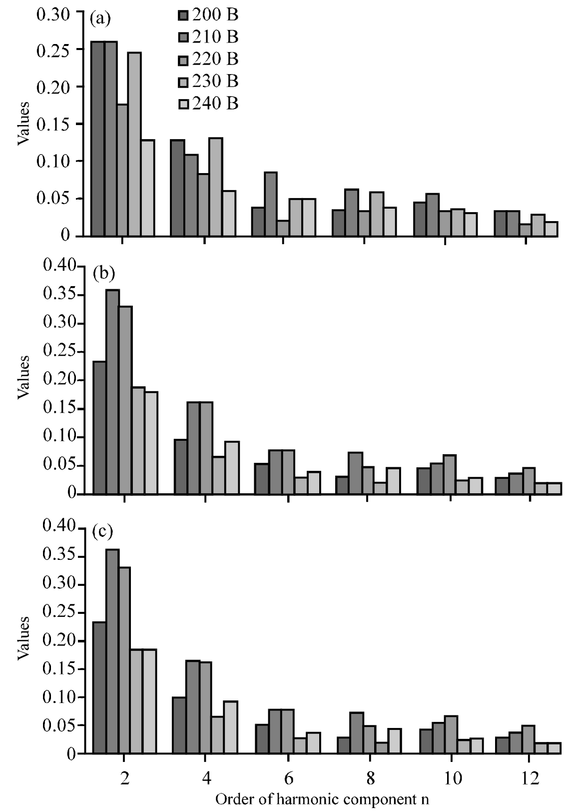

Fig. 3: A graph of the coefficients values of the odd harmonic components of voltage $K_{U(n)}$ in the conventional voltage of winding of 200, 210, 220, 230, 240 V for: a) Phase L1; b) L2 and c) Phase L3; Translation of elements: B-V

should be measured in accordance with the schemes of (Fig. 3 and 4). If the experience of the XX transformer cos $\varphi_{op} \leq 0$, 15, then you should use the schemes of measurement using the three low-power-factor wattmeter class accuracy of 0.5.

Scheme of electrically principled stand for testing transformation ratio and measurement of losses of idling is considered in this study.

For measuring currents, voltages, active power and frequency on the HV side of the transformer is used an electricity meter multifunction PSCH-4TM.05MK.00. released 22.07.2016 with factory room No. 1107160939 corresponding ILGS.411152.167 TU. Electricity meter multifunction PSCH-4TM.05MK.00 designed for commercial and technical accounting of electric energy in three and four-wire AC networks with the voltage 3×(57.7-115)/(100-200) V, frequency (50±2.5) Hz, nominal (maximum) current 5 (10) A. Accuracy class for active energy is 0.5 sec the meter has independent, galvanically isolated interface-optical port. The limit of permissible basic error of measurement of voltages (phase, a phase) ±0.4 in the range from 0.8-1.15 Unom. The limit of permissible basic error of frequency measurement is ±0.05 in the range from 47.5-52.5 Hz.

For measuring harmonic composition of the voltage applied to the analyzer power quality MI 2792A made 15.11.2013 with serial number No. 13140624 entered in the State register of measuring means under number 52911-13. MI 2792A has a certificate of verification No. 206.1-22463-13 valid until 15.11.2017.

Because the primary purpose of the tests was to determine the effect of the temperature of the magnetic core to change the value of the transformation ratio and losses XX the test transformer on the test transformer was installed temperature sensors-thermocouples of type

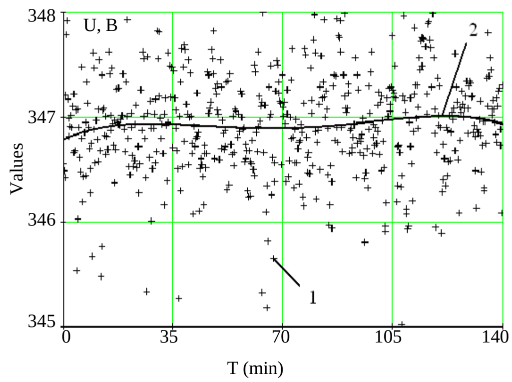

Fig. 4: A graph of the values of the average of the three line voltages of the system during the test: 1: values calculated based on the linear voltage test of the LV windings of the transformer, obtained from the meter PSCH-4TM-05MK; 2: values calculated on the basis of linear voltages of the LV windings, approximated by a polynomial of 4th order; translation of elements: B-V; min

SCI.50M-K10-v3/-50, ..., +100°C, released 04.2014. Thermocouples of type SCI.50M-K10 is designed for temperature control of steel products and supplied by a permanent NdFeB magnet for fixing it on a controlled surface. The range of measured temperatures from minus 50 to plus 100°C. Nominal static characteristics are of 50 M.

Temperature is measured by thermocouples of type SCI.50M-K10-v3/-50,...+100°C is passed to the meter controller eight-channel universal TPM138-R. SCH7 made 30.01.2014 with serial number No. 365901312040733325 corresponding to TU 4211-003-46526536-03. The temperature measurement error is ±0.25%.

Meter-controller the universal eight-channel TPM138-R. SCH7 designed in particular to; measure physical parameters controlled by the input of primary transducers (sensors) with the non-linearity of their NSC; correctmeasured parameters to eliminate the errors of primary transducers (sensors); transfer to computer via. RS-485 interface information on the values of the controlled primary transducers (sensors) units.

To ensure synchronization of measurements of physical quantities on the HV side and LV test transformer and temperature measurement data from electricity meters and multifunction meter controller eight-channel universal TPM138-R. SCH7 transferred to a PC.

For transmitting the measured physical quantities on the HV side of the test transformer with the meter multifunction PSCH-4TM.05MK.04 PC used interface device optical CPI-2 (CPI-2 No. 1), released 24.03.2015 g with serial number No. 03151161 corresponding ILGS.468351.008 TU.

For transmitting the measured physical quantities on the LV side of the transformer under test with the meter multifunction PSCH-4TM.05MK.00 in PC apply device pairing optical CPI-2, released 24.03.2015 g with serial number No. 03151063 corresponding ILGS.468351.008 TU. Interface device optical CPI-2 is designed for contactless connection of the PC to the external device to implement the exchange of information. CPI-2 performs conversion of the signal USB 2.0 into a pulse signal of infrared during data transfer from the PC to the external device and the reverse conversion when transferring data from the external device to the PC. Data transfer is performed at speeds from 300-38400 bits/sec.

To transfer the measured values from the temperature meter-controller eight-channel universal TPM138-R. SCH7 used in the PC interface Converter AC4, made 29.01.2014 g. with serial number No. 10162140102024734 corresponding to TU 4218-003-46526536-06. Interface Converter AC4 is designed for mutual conversion of electrical signals of USB interface and RS-485 with providing galvanic isolation between inputs. Interface Converter AC4 is a device intended for bidirectional communication between USB and RS-485 with automatic determination of the direction of transmission.

RESULTS AND DISCUSSION

Experimental studies were carried out with conventional phase voltages at the LV winding of the test transformer are respectively 200, 210, 220, 230 and 240 V.

According to Section 6.1.1 of GOST 3484.1-88 in the XX to experience one of the windings when the windings fail open the remaining nominal voltage is practically sinusoidal according to claim 6.1.4 (GOST 3484.1-88). In accordance with clause 6.1.4 (GOST 3484.1-88), the voltage curve is allowed being virtually sinusoidal if the ratio of the RMS voltage to average different from 1.11 or no more than ±2%. The definition of medium voltage is performed by the average-reading voltmeter. When performing measurements to determine the harmonic components used in the analyzer of power quality 2792 A MI. Thanks to its application, there is the ability to visually observe waveforms of phase voltages and harmonic components up to 50th order.

In accordance with paragraph 4.2.4 of Anonymous (2013) indicators of quality of electric energy related to harmonic components of voltages are; the values of the coefficients of the harmonic components of the voltage to

Table 1: The values of the coefficients of the odd harmonic components of voltage

Variables	Values
Order of harmonic component (n)	5, 7, 11, 13, 17, 19, 23, 25, >25
The values of the coefficients of the harmonic components of voltage $K_{U(n)}$ (% U_1)	6, 5, 3.5, 3.0, 2.0, 1.5, 1.5, 1.5, 1.5

Table 2: The values of the coefficients of the odd harmonic components of voltage (2)

Variables	Values
Order of harmonic component *n*	3, 9, 15, 21, >21
The values of the coefficients of the harmonic components of voltage $K_{U(n)}$ (% U_1)	5, 1.5, 0.3, 0.2, 0.2

Table 3: The values of the coefficients of the odd harmonic components of voltage (3)

Variables	Values
Order of harmonic component n	2, 4, 6, 8, 10, 12, >12
The values of the coefficients of the harmonic components of voltage $K_{U(n)}$ (% U_1)	2, 1, 0.5, 0.5, 0.5, 0.2, 0,2

40th order $K_{U(n)}$ percentage voltage main harmonic component U1 at the point of transmission of electrical energy the value of total voltage harmonic distortion (the ratio of the RMS sum of all harmonic components up to 40th order for the RMS value of the main component) KU% at the point of transmission of electrical energy.

According to Table 1 (Anonymous, 2013), the values of the coefficients of the odd harmonic components of voltage, not a multiple of three $K_{U(n)}$ at a voltage of electric networks 0, 38 kV should not exceed.

Graph of the coefficients of the odd harmonic components of voltage, not a multiple of three $K_{U(n)}$ in the conventional voltage winding 200, 210, 220, 230 and 240. The values of the coefficients of the odd harmonic components of voltage is not a multiple of three after a 17th order is <0.1% and are not shown on the chart.

According to Table 2 (Anonymous, 2013), the values of the coefficients of the odd harmonic voltage components, a multiple of three $K_{U(n)}$ at a voltage of electric networks 0.38 kV should not exceed.

Graph the coefficients of the odd harmonic voltage components, a multiple of three $K_{U(n)}$ in the conventional voltage winding 200, 210, 220, 230 and 240 shown in Fig. 2. The values of the coefficients of the odd harmonic components of voltage a multiple of three after a 15th order are less than 0.1% and are not shown on the chart.

According to Table 3 (Anonymous, 2013), the values of the coefficients of the even harmonic voltage components $K_{U(n)}$ at a voltage of electric networks 0, 38 kV should not exceed.

Graph the coefficients of the even harmonic components of the voltage $K_{U(n)}$ in the conventional voltage winding 200, 210, 220, 230, 240 shown in Fig. 3.

Table 4: The coefficients values of the odd harmonic components of voltage K_U in the conventional voltage of winding of 200, 210, 220, 230, 240 for phases L1, L2, L3

Conditional voltage	The total coefficient of the harmonic components of voltage K_U (%)		
	Phase L1	Phase L2	Phase L3
2000	7.531	6.042	7.226
210	7.644	6.45	6.525
220	7.1	6.484	6.823
230	7.477	5.672	6.531
240	7.291	5.724	6.276

The values of the coefficients of the even harmonic voltage components after 12th order are <0.1% and are not shown on the chart.

According to Table 4 (Anonymous, 2013), the values of the total coefficients of the harmonic components of the voltage K_U at a voltage of electric networks 0.38 kV shall not exceed 8.0%. The values of the total coefficients of the harmonic components of the voltage K_U with conventional voltage winding 200, 210, 220, 230 and 240 are given in Table 4.

As can be seen from Fig. 1-3 and Table 4 values of coefficients of odd harmonic components of the voltage are not in multiples of three, multiples of three and even $K_{U(n)}$ and the total coefficients of the harmonic components of the voltage K_U with conventional voltage winding 200, 210, 220, 230 and 240 V-L1, L2 and L3 measured in the experiment do not exceed the value specified in Table 1-4 (Anonymous, 2013). Accordingly, the voltage applied to the HV winding in the experiment can be considered practically sinusoidal.

Below are the results of processing of experimental data obtained with conventional phase voltages at the LV winding of the test transformer is 200 V. In accordance with clause 1.3 (GOST 3484.1-88) the ambient temperature during the tests should be from 10-40°C.

During the test, the minimum value for the ambient air temperature was 13.8°C and the maximum of 22.3°C which corresponds to the requirements of item 1.3 of (GOST 3484.1-88). The average ambient temperature for the entire test period amounted to 19.7°C.

According to Section 2.1.3 (GOST 3484.1-88), there is an allowed measuring the transformation ratio at the three-phase excitation if it is established that the difference between the largest and smallest line voltages does not exceed 2%.

During the test, the minimum value of the line voltage of the LV windings of the test transformer is made up 343, 43 V between phases L2 and L3 and the maximum 351, 48 In between phases L3 and L1. Therefore, the difference between the largest and smallest line voltages during the testing was within 2% which meets the requirement of Section 2.1.3 (GOST 3484.1-88).

According to Paragraph 6.1.1 of GOST 3484.1-88, the experience of the XX aimed at measuring the losses of the XX the test of the transformer, applied voltage when testing three-phase transformers shall be substantially symmetrical in Section 6.1.2 (GOST 3484.1-88). In accordance with Clause 6.1.2 (GOST 3484.1-88), the system line voltages should be considered almost symmetric, if each of the line voltages is not more than 3% of the average of the three line voltages of the system. Graph of change values are the average of the three line voltages of the system during the test is shown in Fig. 4. Average value the average of the three line voltages of the system over the entire test period amounted 346.9 V.

During the test minimum deviation of the line voltage relative to the value of the average of the three line voltages of the system was -1.159% for line voltage between phases L3 and L1, the maximum-0, 843% for line voltage between phases L2 and L3.

The average value of the deviation of line voltage between phases L1 and L2 relative to the value of the average of the three line voltages of the system over the entire test period amounted to 0.157 inch% between phases L2 and L3-0.198% between phases L3 and L1-0, 355%.

Given the preceding value of deviation values of the line voltages relative to the values of the average of the three line voltages of the system during the test, we can conclude that each of the line voltages is much <3% of the average of the three line voltages of the system. Accordingly, system the line voltages should be considered as almost symmetric.

According to Section 6.1.1 of GOST 3484.1-88 in the XX experience necessary to determine the losses of the XX the test of the transformer, the input voltage must be the rated frequency with a tolerance of ±1%. A graph of the frequency values applied to the test transformer voltage during the test is shown in Fig. 5.

As can be seen in Fig. 5 during the test, the minimum value of the frequency of the supplied test voltage transformer was 49.97 Hz and the maximum from 50.03 Hz. The average value of the frequency of the supplied test voltage transformer for the entire test period amounted to 49.999 Hz.

Variation in the frequency of the supplied test voltage transformer of the nominal value of 50 Hz in average during the test were 0.002% which is three orders of magnitude <1%. Therefore, the requirement of Clause 6.1.1 of GOST 3484.1-88 is performed.

According to Section 2.1.3 GOST 3484.1-88 with the possibility of measuring the phase voltages, it is allowed to determine the transformation ratio for the phase voltages of the respective phases.

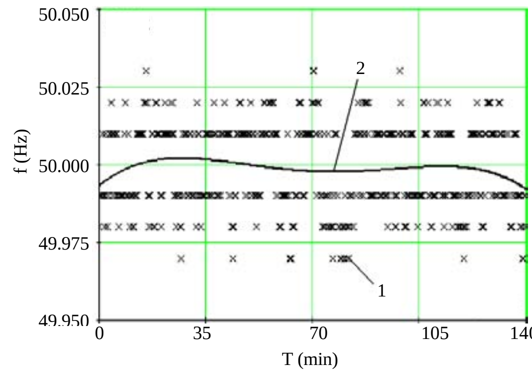

Fig. 5: A graph of the frequency of the voltage supplied to the test transformer during the tests: 1-frequency values obtained from the meter PSCH-4TM-05MK; 2: frequency, approximated by a polynomial of the 4th order; Translation of elements: Hz; min

The average value of the phase voltage of phase L1 during the entire period of testing amounted to 200, 559 V, phase L2-200, 564 V and phase L3-200, 507 V.

During the test, the minimum value of the phase voltages of the LV windings of the test transformer is made 198.76 V in the phase L3 and the maximum 202.12 V in the phase L3. Therefore, the difference between the highest and lowest phase voltages for test time left of 1.69%. Therefore, the phase voltage on all three phases can be considered relatively constant.

The main objective of the tests was to determine the effect of the temperature of the magnetic core to change the value of the transformation ratio of the test transformer. The transformation ratio of the transformer under test is determined when three-phase excitation for the LVDT as the ratio of the phase voltages measured on the LV winding to the phase voltages measured on the windings NN.

The average value of the transformation ratio calculated by the phase voltage of windings HV and LV phase L1 during the entire period of testing amounted to 1.645, phase L2-1.645, phase L3-1.647. During the test, the minimum value of ratio calculated by the phase voltage of windings HV and LV phase L1 amounted to 1.644 and maximum 1.645. Therefore when the average temperature of the magnetic system of 13-45°C, i.e., 32°C or 246%, the change ratio calculated by the phase voltage of windings HV and LV phase L1 amounted to 0.081%.

During the test, the minimum value of ratio calculated by the phase voltage of windings HV and LV phase L2 amounted to 1.645 and maximum 1.646. Therefore, when the average temperature of the magnetic system described above, the change of ratio calculated at the phase voltage of windings HV and LV phase L2 made up 0.067%.

During the test, the minimum value of ratio calculated by the phase voltage of windings HV and LV phase L3 made 1.6468 and the maximum 1.6472. Therefore, when the average temperature of the magnetic system described above the change of ratio calculated at the phase voltage of windings HV and LV phase L3 made up of 0.027%.

According to Section 2.1.3 (GOST 3484.1-88) when testing three-phase transformers with three-phase excitation of the measured line voltage corresponding to the eponymous line clamps check the windings.

The average value of ratio computed according to a linear voltage windings HV and LV phase L1 during the entire period of testing amounted to 1.644, phase L2-1.646, phase L3-1. 646.

During the test, the minimum value of ratio computed according to a linear voltage windings HV and LV phase L1 amounted to 1.644 and maximum 1.645. Therefore, when the average temperature of the magnetic system of 13-45°C, i.e., 32°C or 246%, a change of ratio computed according to a linear voltage windings HV and LV phase L1 made 0.051%.

During the test, the minimum value of ratio computed according to a linear voltage windings HV and LV phase L2 amounted to 1.645 and maximum 1.647. Therefore, when the average temperature of the magnetic system described above, the change of ratio computed according to a linear voltage windings HV and LV phase L2 totalled 0.064%.

During the test, the minimum value of ratio computed according to a linear voltage windings HV and LV phase L3 amounted to 1.646 and maximum 1.647. Therefore, when the average temperature of the magnetic system described above the change of ratio computed according to a linear voltage windings HV and LV phase L3 is estimated to be 0.05%.

Of interest is the relative comparison of the coefficients of transformation computed from the phase and line voltages HV and LV windings. Chart of a relative comparison of the coefficients of transformation computed from the phase and line voltages HV and LV windings during the test was approximated by a polynomial of the 4th order is shown in Fig. 6.

The average value of the relative comparison of the coefficients of transformation of phases L1, calculated by the phase and line voltages HV and LV windings during the entire period of testing amounted to 0.019%, L2- 0.047%, phase L3-0.046%.

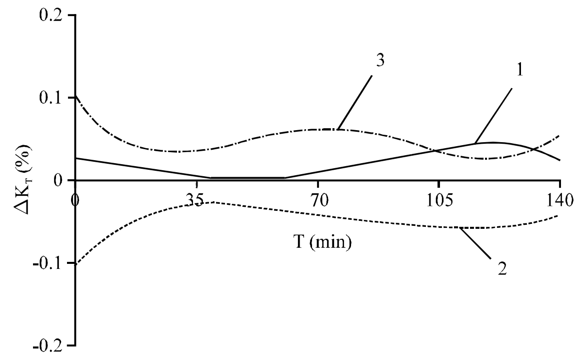

Fig. 6: Graph of relative comparison of the coefficients of transformation computed from the phase and line voltages HV and LV windings during the test was approximated by a polynomial of 4th order: 1: phase L1; 2: L2; 3: phase L3; Translation of elements: min

Therefore, it can be concluded that when testing three-phase transformers with three-phase excitation to calculate the transformation coefficient by the measured line or the phase voltage of windings HV and LV does not matter.

A graph of the values of the coefficients of transformation are calculated for the phase voltages HV and LV windings of the respective phases at conventional voltages of 200, 210, 220, 230 and 240 V on the average temperature of the magnetic system, approximated by a polynomial of 1st order as shown in Fig. 7.

When the average temperature of the magnetic system of 13-45°C, i.e., 32°C or 246%, the change of ratio when performing the experience on the verification of transformation ratio with the conditional voltages of 200, 210, 220, 230 and 240 V averaged for phase L1-0.031%, for L2-0.032% for phase L3-0.072%.

According to Section 6.1.1 of GOST 3484.1-88 in the XX to experience one of the windings when the windings fail the rest of the open-loop nominal voltage nominal frequency nearly sinusoidal according to claim 6.1.4 (GOST 3484.1-88) and when testing three-phase transformers in addition, almost symmetrical in Section 6.1.2 (GOST 3484.1-88).

The main objective of the tests was to determine the effect of temperature of the magnetic change losses XX. During the test, the minimum value of total active power losses in all three phases of the transformer under test as measured by the implementation of the experience of the XX amounted to 81.208 W and a maximum W 83.255.

Therefore, when the average temperature of the magnetic system of 13-45°C, i.e., 32°C or 246%, the change

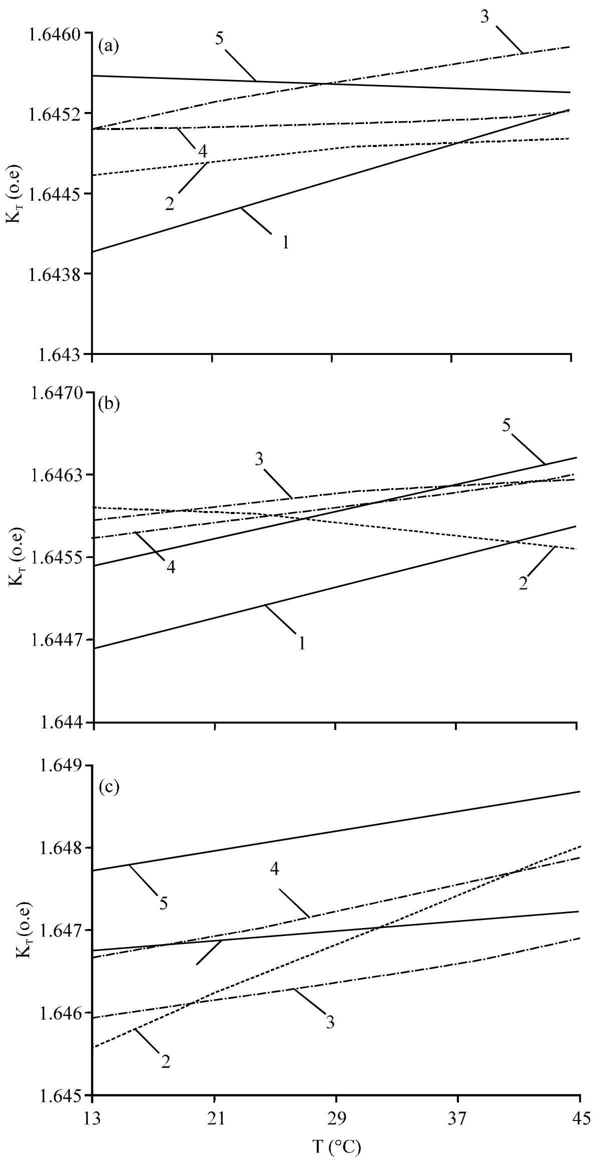

Fig. 7: A graph of changing the values of the transformation coefficients that are calculated at the phase voltage of windings HV and LV on the average temperature of the magnetic system approximated by a polynomial of 1st order: a) for the phase L1; b) L2 and c) Phase L3; 1: at the conditional voltage of 200 V; 2: at the conventional voltage of 210 V; 3: at the conventional voltage of 220 V; 4: at the conventional voltage of 230 V; 5: at the conventional voltage of 240 V

of the total losses of active power on all three phases of the transformer under test as measured by the implementation of the experience of the XX amounted to -2.458%.

When the average temperature of the magnetic system of 13-45°C, i.e., 32°C or 246%, the change of the total losses of active power on all three phases of the transformer under test as measured by the implementation of the experience of the XX when the conditional voltages of 200, 210, 220, 230 and averaged -1.496%. Therefore as in the sources (Lizunov and Lokhanin, 2004; Porudominskiy, 1984) temperature of the magnetic system of the transformer under test affects the value of no-load losses.

Ermakov and Antipanova (2014) carried out a study of low-power transformers under load. On the basis of experimental data it is shown that the transformation ratio of the transformer (when off load) in a range of currents in the primary winding has a constant value. When applying for a HV winding of the transformer voltage in the range ±10% of nominal voltage coil, the relative change of ratio was 0.13%. The disadvantages of this study include the following: a small power transformer used for the study (TN-46-220-50 nominal active power 58 W); the use of single-phase transformers while in power systems used three-phase power transformers, the lack of information on temperature of structural elements of the active part of the transformer, perform spot measurements which affects the reliability of the results.

In the research by Goremykin and Korolev (2006), the dependence of the acceptable level of mismatch of the coefficients of transformation from the load power factor. The difference in the transformation ratio of power transformers included in the parallel work can take place as a result of errors made during their manufacture and after emergency situations. For example, when there are short circuits in the windings.

Research conducted by the researchers show that backup capabilities of modern power transformers in the conditions of coincidence of the values of the coefficients of transformation depend, ceteris paribus, from the nature of the load. Therefore, to evaluate the real load capacity of the block parallel connected transformers it is necessary to have data on typical values of load power factor which can be defined in the presence of the full load curve, both active and reactive power (Shin *et al*., 2014).

According to GOST 11677-97, the parallel operation of transformers is valid with the transformation ratio of more than three, if the relative difference of their coefficients of transformation ΔK does not exceed 0.5%. The value of ΔK can be found from the relationship:

$$\Delta K = [(K_2 - K_1)/K_{aver}].100$$

Where:

K_1, K_2 = The transformation coefficients

K_{aver} = The average ratio of the block of two parallel operating transformers

The inequality of the coefficients of the transformation leads to the appearance of the surge current flowing in the secondary windings of the unit parallel operating transformers. The magnitude of this current is determined by the following expression (Kostenko and Piotrovskiy, 1964):

$$I_{eq} = \Delta K.100/\left[U_{k1}+U_{k2}.(S_{n1}/S_{n2})\right]$$

Where:

I_{eq} = Equalizing current, % of the rated current of the transformer for the secondary winding

$U_{k1}+U_{k2}$ = Short-circuit voltage, respectively of first and second transformers, % of the nominal voltage of the primary winding

S_{n1}, S_{n2} = Full nominal power of transformers (kVA)

CONCLUSION

With increasing temperature the magnetic system, the total losses of active power XX for all three phases of the test transformer are reduced. With increasing temperature the magnetic system when testing three-phase transformers with three-phase excitation transformation ratio is practically unchanged. To calculate the transformation coefficient by the measured line or the phase voltage of windings HV and LV does not matter.

REFERENCES

Anonymous, 2005. On the organization in the ministry of industry and energy of the Russian federation of work on approval of standards of technological losses of electricity during its transmission through electric networks. Ministry of Industry and Trade of the Russian Federation, Russia.

Anonymous, 2013. Electrical energy-electromagnetic compatibility of technical equipment-power quality norms of electric energy in power supply systems of general purpose. GOST 32144, SAI Global, Sydney, Australia. https://infostore.saiglobal.com/store/Details.aspx?ProductID=1750775.

Bazakov, Y.B., V.Y. Frolov and A.V. Korotkov, 2012. The method of determining the power loss of idling transformers with different operating life. Ivanovo State Power Eng. Univ. Bull., 1: 1-4.

Ermakov, I.I. and I.S. Antipanova, 2014. The results of experimental studies of low-power transformers under load. Energy Prob., 1: 74-80.

Exposito, A.G., A.G. Exposito, A.J. Conejo and C. Canizares, 2016. Electric Energy Systems: Analysis and Operation. CRC Press, Boca Raton, Florida, ISBN:978-0-8493-7365-7, Pages: 649.

Gonen, T., 2016. Electric Power Distribution Engineering. CRC Press, Boca Raton, Florida, ISBN:9781498785846, Pages: 1061.

Goremykin, S.A. and N.I. Korolev, 2006. The technical capabilities of the unit parallel operating transformers when the mismatch of the coefficients of transformation. Electrotechnical Complexes Control Syst., 1: 55-57.

Kazakov, Y.B., A.B. Kozlov and V.V. Korotkov, 2006. Accounting of changes in losses of idling of transformers in the period of life when calculating losses in distribution networks. Electr. Eng., 5: 11-16.

Korotkov, V.V., A.B. Kozlov and ?.V. Korotkov, 2007. Quantitative Evaluation of Dependence of Losses of Idling of Power Transformers from the Date of Service. In: Improving the Efficiency of Energy Systems, Shuin, V.A., M.S. Misrikhanov and A.V. Moshkarin (Eds.). Ivanovo State Power Engineering University, Ivanovo, Russia, pp: 351-356.

Kostenko, M.P. and L.M. Piotrovskiy, 1964. Electrical Machines. Energiya Publishing House, Moscow, Russia,.

Lizunov, S.D. and A.K. Lokhanin, 2004. Power Transformers. Energoatomizdat, ?oscow, Russia, Pages: 616.

Masters, G.M., 2013. Renewable and Efficient Electric Power Systems. John Wiley & Sons, Hoboken, New Jersey, Pages: 121.

Porudominskiy, V.V., 1984. Transformer and Reactor Equipment for Voltage Regulation and Reactive Power. VINITI Publisher, Moscow, Russia, Pages: 96.

Shabad, M.A., 1989. Protection of Transformers of 10 KV. Energoatomizdat, Moscow, Russia, Pages: 144.

Shin, J., S. Shin, Y. Kim, S. Ahn and S. Lee *et al*., 2014. Design and implementation of shaped magnetic-resonance-based wireless power transfer system for roadway-powered moving electric vehicles. IEEE Trans. Ind. Electron., 61: 1179-1192.

Short, T.A., 2014. Electric Power Distribution Handbook. CRC Press, Boca Raton, Florida, USA., Pages: 850.

Uraev, N.N., G.F. Mingaleev, A.T. Kushimov and N.A. Kolesov, 2016. Methodological aspects of strategic development of regional socio-economic system (following the example of radio-electronic industry enterprises in the Republic of Tatarstan). Intl. J. Environ. Sci. Educ., 11: 5094-5108.

Zhelezko, Y.S., A.V. Artemiev and O.V. Savchenko, 2005. Calculation, Analysis and Regulation of Electric Power Losses in Electrical Networks: A Guide for Practical Calculations. ENAS Press, ?oscow, Russia, Pages: 280.