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ANALYSIS OF MONITORING OF THE AT-3 AUTOTRANSFORMATOR IN TashTES MODE

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Abstract

The article considers the results of the analysis of autotransformers operation mode monitoring. The time diagram of active load current and oil temperature of autotransformer TashTES AT-3 is established and during one year changes of these variables and basic parameters of autotransformer were observed. Technical faults of the power transformer and high power autotransformer are established and methods of their elimination are determined. Damage of transformers and autotransformers with voltage of 110-500 kV of about 30% of the total number of outages which were accompanied by internal short-circuits and two main causes of damage were determined. The main causes of technological failures, which were not accompanied by internal short-circuits, are as follows: 20% of failures in operation of the on-load tap-changer, 16% of oil leaks from the bushings, 13% of oil leaks and lowering of oil from the transformer due to violation of welded joints and rubber seals, 4% of engine damage to oil pumps of the cooling system, 3% of pressure increase in high-voltage hermetic bushings, 2% of film protection shell damage. The main reasons of technological violations accompanied by internal short-circuit in the transformer are as follows: breakdown of internal insulation of high-voltage bushings, insufficient short-circuit resistance, wear and tear of winding insulation, breakdown of insulation.

Key words: *monitoring, transformer charging circuit, booster transformer, transformation ratio, reliability of power transformers, partial discharge monitoring, power transformer diagnostics, thermal imaging control nomogram.*

Annual observations (monitoring) of current, active power, and dependence of oil temperature on AT-3 time were carried out in TashTPP.

Table. 1.

Data of considered autotransformer AT-3 TashTPP

Type	ATDCS 200000/222/110-U1	
Nominal power HV/MV/LV;kV·A	200000/100000	
Voltages; kV	230/121 10,5	
Current HV/MV/LV; A	502/594 5499	
Frequency ; Hz	50	
CT voltages HV-MV/HV-LV/MV-LV; %	10,5/3,3/20,3	
Winding connection diagram and group	Yauto / D -0-11	
Test voltage; kV: One minute full thunderstorm Prom. pulse frequency	winding HV	325/750
	windingMV	200/480
	total neutrality	85
Gross weight ;T	215	
Mass of oil; T	59	

Mass of active part ;T	111,4
Removable parts of the tank; T	10,5
Transport; T	182
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Calculation of autotransformers parameters

The parameters of this substitution scheme are determined by the following formulas: G[sm] and B [sm] - by the same formulas as for a double winding transformer:

$$\mathrm{Y} = \frac{I_{xx}}{100} \cdot \frac{S_{ном}}{U^2_{ном}}; \; G = \frac{P_{xx}}{U^2_{ном}} \; ; B = \sqrt{\mathrm{Y}^2 G^2} \; .$$

(1)

Total resistances Z[Ω] are determined by formulas:

$$Z_B = \frac{u_{k(BC)} + u_{k(BH)} - u_{k(CH)}}{2} \cdot \frac{U^2_{ном}}{100 S_{ном}};$$

$$Z_C = \frac{u_{k(BC)} + u_{k(CH)} - u_{k(BH)}}{2} \cdot \frac{U^2_{ном}}{100 S_{ном}} \; ;$$

(2)

$$Z_H = \frac{u_{k(BH)} + u_{k(CH)} - u_{k(BC)}}{2} \cdot \frac{U^2_{ном}}{100 S_{ном}} \; .$$

If all three short-circuit loss (КЗ) values between winding pairs are known, the active resistors are

$$R_C = 0{,}5 \cdot \left(P_{кз(BC)} + \frac{P_{кз(CH)}}{k_S^2} - \frac{P_{кз(BH)}}{k_S^2} \right) \cdot \frac{U^2_{ном}}{S^2_{ном}} \; ;$$

(3)

$$R_H = 0{,}5 \cdot \left(\frac{P_{кз(BH)}}{k_S^2} + \frac{P_{кз(CH)}}{k_S^2} - P_{кз(BC)} \right) \cdot \frac{U^2_{ном}}{S^2_{ном}} \; .$$

If only the maximum short-circuit (КЗ) loss value is specified in the catalogue data, the active resistors are defined as follows:

with equal winding power

$$R_E = R_C = R_H = R_k \cdot \frac{U^2_{ном}}{2 S^2_{ном}} \, .$$

(4)

For windings with a capacity of k_s as a fraction of the capacity of the other two windings. For example, if $S_{BH}=S_{CH}=S_{ном}$, a $S_{HH}=k_S S_{ном}$

$$R_E = R_C = R_k \cdot \frac{U^2_{ном}}{2 S^2_{ном}}; \qquad R_H = \frac{1}{k_S} R_B$$

(5)

According to the found Z and R there are inductive resistances X [Ω]:

$$X_B = \sqrt{Z_B^2 - R_B^2}\,;\; X_C = \sqrt{Z_C^2 - R_C^2}\,;\; X_H = \sqrt{Z_H^2 - R_H^2}$$

(6)

The indices of the inductive resistance X are assumed to be the same as those of the corresponding resistances Z determined by formulas (6).

If there is a voltage transformer included in the neutral of the autotransformer, the resistances are corrected according to the formulas (provided that they have been brought to the HV side):

$$\dot{Z}'_B = \dot{Z}_B + \frac{U_{BH} - U_{CH}}{U_{CH} \pm \Delta U} \cdot \left(\frac{\Delta U}{U_{BH}} \cdot \dot{Z}_H - \dot{Z}_{ВДТ} \right);$$

$$\dot{Z}'_C = \dot{Z}_C + \frac{U_{CH} - U_{BH}}{U_{CH} \pm \Delta U} \cdot \left(\frac{\Delta U}{U_{BH}} \cdot \dot{Z}_H - \dot{Z}_{ВДТ} \right); \quad (7)$$

$$\dot{Z}'_H = \frac{\frac{U_{CH}}{U_{BH}} \cdot Z_H + Z_{ВДТ}}{\left(\frac{U_{BH}}{U_{BH}} \pm \frac{\Delta U}{U_{HH}} \right)^2 \cdot \left(\frac{U_{CH}}{U_{HH}} \pm \frac{\Delta U}{U_{HH}} \right)} \cdot \left(\frac{U_{BH}}{U_{HH}} \pm \frac{\Delta U}{U_{HH}} \right)^2.$$

Transformation coefficients are determined by formulas:

1. If there is no under-load control (RVT) or voltage transformer (VVT)

$$k_{TC-B} = \frac{U_{CH}}{U_{BH}};\; k_{TH-B} = \frac{U_{HH}}{U_{BH}}. \quad (8)$$

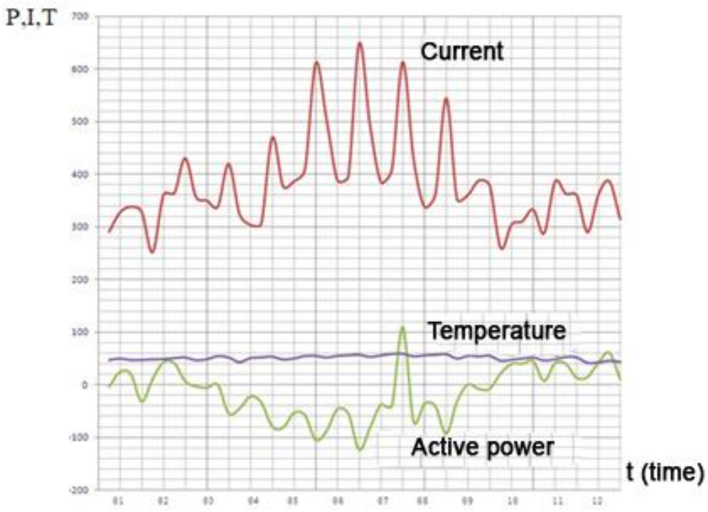

Fig. 1. Dependence of current, active load, and oil temperature on the time of AT-3 of TashTPP for the period of 2018.

2. If there is an RVT or VVT, i.e. Additive is made only to voltage $U_{рег}$, depending on the side of autotransformer at which control is performed, transformation factor is calculated according to the following formula:

$$k_T = \frac{U_{рег} \pm \Delta U}{U_{нр}}; k_T = \frac{U_{нр}}{U_{рег} \pm \Delta U}. \quad (9)$$

(RVT) with control on the middle side, i.e. the addition to both voltages, the conversion factor is calculated by the formula:

$$k_T = \frac{U_{рег} \pm \Delta U}{U_{нр} \pm \Delta U}. \quad (10)$$

(VVT) with neutral regulation, i.e. adding the next phase voltage to both voltages, the conversion factor is calculated by the formula:

$$k_T = \frac{U_{рег} \pm \Delta U \angle 120^0}{U_{нр} \pm \Delta U \angle 120^0}. \quad (11)$$

Transformation factor $k_т$ complex. Usually, it is VVT with the regulation in neutral, voltage addition is taken from the adjacent phase: addition of voltage of the previous phase is made to both voltages; transformation coefficient is calculated according to the formula:

$$k_T = \frac{U_{рег} \pm \Delta U \angle -120^0}{U_{нр} \pm \Delta U \angle -120^0}. \quad (12)$$

Autotransformer conventions:

$U_{ном}$ и $S_{ном}$ – the same thing as a two-winding transformer;

$u_{к(ВС)}$, $u_{к(ВН)}$, $u_{к(СН)}$– short-circuit (КЗ) voltage between high voltage (HV)-average voltage (MV), high voltage (HV)-low voltage (LV), medium voltage (MV) - low voltage (LV), respectively, related to the nominal power of autotransformer " $S_{НОМ}$ -% of the nominal voltage;

$P_{кз(ВС)}$, $P_{кз(ВН)}$, $P_{кз(СН)}$– Losses of short-circuit (КЗ) current between the windings of the HV-MV, HV-LV, MV-LV, respectively. Pкз(HV) in directories it is resulted referred to rated capacity of autotransformer $S_{НОМ}$, and Pкз(HV), Pкз(LV) - to rated capacity of windings LV S_{LV} , therefore it is necessary to use k_S;

k_S - the coefficient showing the share of nominal LV windings in the nominal power of autotransformer S_{LV}, if S_{LV} is not specified, then k_S is assumed to be equal to the coefficient of profitability of autotransformer:

$k_{выг}$=(U_{HV}-U_{MV})/U_{HV}; (13)

Where ΔU is the addition of RVT or VVT voltage. ΔU is specified in reference books or can be defined by a formula:

$N_{ст}$ - step number (antsapfa number) for which the voltage addition ΔU is calculated;

h - step, %

$U_{ном}$ value - nominal voltage of the autotransformer side, with respect to which step h is specified.

Calculation of AT-3 parameters of TashTPP

ATDCS -200000/220/110 autotransformer type. The autotransformer is equipped with RVT ±6×2 % of % of Ra to the party of MV.

Calculation

We will use the three-ray substitution scheme (Fig. 1)

$S_{ном}$=200 MB·A; U_{BH}=230 кВ; U_{CH}=121 кВ; U_{HH}=10,5 кВ; $U_{k\,(BC)}$=10,5 %;

$U_{k\,(BH)}$=3,3%; $U_{k\,(CH)}$=20,3%; $P_{k\,(BC)}$=430 кВт; $P_{x/x}$=105 кВт; $I_{x/x}$=0,24%; Power of LV winding is 50% of rated power of AT-3.

All calculated values will lead to HV side. By formulas

(2) and (3) define G, B, Z:

$$Y = \frac{I_{x/x}}{100} \cdot \frac{S_{ном}}{U_{BH}^2} = \frac{0{,}24}{100} \cdot \frac{250 \cdot 10^6}{\left(230 \cdot 10^3\right)^2} = \frac{0{,}6}{230^2}\left[См\right];$$

$$G = \frac{I_{x/x}}{U_{BH}^2} = \frac{105 \cdot 10^3}{\left(230 \cdot 10^3\right)^2} = 2{,}0 \cdot 10^{-6}\left[См\right]$$

$$B = \sqrt{Y^2 - G^2} = \sqrt{\left(\frac{0{,}6}{230^2}\right)^2 - \left(2 \cdot 10^{-6}\right)^2} = 11{,}1 \cdot 10^{-6}\left[См\right]$$

$$Z_B = \frac{U_{k(BC)} + U_{k(BH)} - U_{k(CH)}}{2} \cdot \frac{U_{BH}^2}{100 \cdot S_{ном}} = \frac{10{,}5 + 3{,}3 - 20{,}3}{2} \cdot \frac{\left(230 \cdot 10^3\right)^2}{100 \cdot 200 \cdot 10^6} = -8{,}6\,[\Omega];$$

$$Z_C = \frac{U_{k(BC)} + U_{k(CH)} - U_{k(BH)}}{2} \cdot \frac{U_{BH}^2}{100 \cdot S_{ном}} = \frac{10{,}5 + 20{,}3 - 3{,}3}{2} \cdot \frac{\left(230 \cdot 10^3\right)^2}{100 \cdot 200 \cdot 10^6} = 3{,}63\,[\Omega];$$

$$Z_H = \frac{U_{k(BH)} + U_{k(CH)} - U_{k(BC)}}{2} \cdot \frac{U_{BH}^2}{100 \cdot S_{ном}} = \frac{3{,}3 + 20{,}3 - 10{,}5}{2} \cdot \frac{\left(230 \cdot 10^3\right)^2}{100 \cdot 200 \cdot 10^6} = 17{,}3\,[\Omega].$$

The initial data indicate that the power of the LV winding is 50% of the rated power of the AT, so:

K_s=S_{HH}/$S_{ном}$=0,5.

Active resistance of AT are determined by formulas (4) since only the maximum losses of К3 $P_{k\,(BC)}$:are given:

$$R_B = R_C = P_k \cdot \frac{U^2_{BH}}{2S^2_{ном}} = 430 \cdot 10^3 \cdot \frac{\left(230 \cdot 10^3\right)^2}{2 \cdot \left(250 \cdot 10^6\right)^2} = 0{,}18\,[\Omega];$$

$$R_H = \frac{1}{k_S} \cdot R_B = \frac{1}{0{,}5} \cdot 0{,}18 = 0{,}36\,[\Omega];$$

By formulas (6.) we find inductive resistances X [Ω]:

$$X_B = \sqrt{Z_B^2 - R_B^2} = \sqrt{(-8{,}6)^2 - 0{,}18^2} = 8{,}6\,[\Omega];$$

$$X_C = \sqrt{Z_C^2 - R_C^2} = \sqrt{3{,}63^2 - 0{,}18^2} = 3{,}6\ [\Omega];$$

$$X_H = \sqrt{Z_H^2 - R_H^2} = \sqrt{17{,}3^2 - 0{,}36^2} = 17{,}3\,[\Omega].$$

Considering that Z_B is negative, finally, we accept XB= -8.6 [Ω].

According to the condition of task 2, the RVT is set on the side of the MV, so when the position of the antsapfa changes only the transformation coefficient between the MV and HV $k_{T\ M–H}$ will change, the transformation coefficient between the HV and HV $k_{T\ M–H}$ will not change when the position changes. Therefore, $k_{T\ M–H}$ must be determined by the formula (12):

$$k_{T\ M-H} = \frac{U_{HH}}{U_{HB}} = \frac{10{,}5 \cdot 10^3}{230 \cdot 10^3} = 0{,}04565$$

Considering that the value of $k_{T\ M–H}$ is determined by the current number of the anchor, we determine only its extreme values. For this purpose it is necessary to define ΔU tension additive in extreme provisions of RVT, in view of that a step concerning the party of MV:

$$\Delta U_1 = N_{cm1} \cdot \frac{h}{100} \cdot U_{CH} = 6 \cdot \frac{2}{100} \cdot 121 \cdot 10^3 = 14520\,[\kappa B]$$

$$\Delta U_2 = N_{cm2} \cdot \frac{h}{100} \cdot U_{CH} = -6 \cdot \frac{2}{100} \cdot 121 \cdot 10^3 = -14520\,[\kappa B].$$

Transformers and autotransformers damage analysis

One of the problems associated with the reliability and development of electrical networks is the reliability of power transformers and autotransformers. The main number of transformers of power systems of the CIS was put into operation in the 70s and early 80s of the XX century. Nowadays there is a large enough experience of operation, which allows to carry out the analysis and give recommendations on increase of reliability of operation of power transformers and autotransformers with voltage of 110 kV and higher.

The analysis of the damageability of transformers and autotransformers with voltage of 110 - 500 kV and more with capacity of 63 MVA and more, operated at the enterprises of electric networks, including intersystem networks of the CIS, for the period 1998 - 2016 shows that the specific number of technological violations in the work of the specified transformers, which led to their disconnection by the action of automatic protective devices or forced disconnection by the personnel on emergency request, is 1.8% per year. At the same time, about

30% of the total number of these technological violations were accompanied by internal short-circuits in the transformer.

The main causes of technological violations that were not accompanied by internal faults, but led to the shutdown of automatic protective devices or forced shutdown by personnel on emergency request, are (as a percentage of the total number of violations):

- RVT's malfunctions are 20%;
- oil leaks from the inlets - 16%;
- Leakage and drain of oil from the transformer due to violation of welded joints and rubber seals - 13%;
- Cooling system oil pump engines damage - 4%;
- Pressure increase in high-voltage sealed bushings - 3%;
- Damage to the film protection shell - 2%.

The main reasons of technological failures accompanied by internal short-circuit in the transformer are (as a percentage of the total number of transformer failures accompanied by internal short-circuits):

- breakdown of internal isolation of high-voltage bushings - 48%;
- insufficient short-circuit resistance - 14%;
- winding insulation wear - 12%;
- breakdown of winding insulation - 7%;
- Punching of insulation of tapes, infringement of contact connection of tapes of a coil, break of a part of conductors of flexible communication, short circuit on a yarm beam of a magnetowire and the tank case - 5 %;
- Damage to the on-load tap-changer - 5%.

Of the internal short-circuit faults, 24% were caused by transformer fires and fires. At the same time, the specific damage rate of 110-500 kV power transformers and autotransformers with the capacity of 63 MVA and more, operated at the enterprises of electrical and intersystem networks, accompanied by internal short-circuits, is 0.45% per year.

Thus, as a result of one year of analysis of the AT-3 autotransformer operation mode monitoring at TashTPP:

1. This characteristic shows that the current in June reached its maximum value, the active load in July reached its maximum value, and the temperature has not changed throughout the year.
2. According to the statistics for transformers and autotransformers with 110-500 kV, about 30% of the total number of trips was accompanied by internal short-circuits (КЗ).
3. The two main causes of damage are insufficient short circuit (КЗ) resistance of the windings and internal insulation breakdown.

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