ABSTRACT

In Parts I and II of the article, the Indian practice (magnetic balance test) and IEEE practice (excitation current test) of detecting defects in the windings and in the core of a power transformer in field conditions were considered. This Part III is devoted to GOST practices (no-load test at reduced voltage).

KEYWORDS:

distribution transformer, GOST, no-load loss at reduced voltage test, power transformer

After the end of the war in 1945, the transformer industry in the Soviet Union developed at a faster pace than the production of synchronous three-phase generators of sufficient power to test power transformers

Simple ageless methods for field testing power transformers of no-load condition at the low induced voltage

(Analytical review with the aid of transformer field service technicians) – Part III

4. The practice of GOST (no-load test at reduced voltage)

4.1. Historical aspect

After the end of the war in 1945, the transformer industry in the Soviet Union developed at a faster pace than the production of synchronous three-phase generators of sufficient power to test power transformers. The MTZ test station had only a single-phase generator, and A. K. Ashryatov proposed a simplified method for determining the no-load losses of a three-phase transformer at a reduced voltage of 5–10 % of the nominal, followed by recalculation to the nominal voltage. It was proposed to carry out three experiments, in each of which power from a single-phase generator is supplied to two phases, and the third phase is short-circuited. The sought value of the losses at the rated voltage was determined from the half-sum of the losses in these three experiments using a special formula [23, 24]. This method became widespread as the "Ashryatov test" was included in GOST 3484-55 and survived in GOST 3484-65. Note that GOST 3484-55 also contained a three-phase experiment at reduced voltage, but in practice, it did not become widespread and was excluded from further editions of this standard.

In subsequent years, new data on the comparison of losses at low and rated voltage showed an unacceptably large spread when using the conversion formulas, and the conversion was excluded from GOST 3484-77 [25]. But the measurement of losses at low voltage as a comparison method is preserved in the current standard GOST 3484.1-88. According to the standard for general requirements for transformers [26], this test is included in the scope of the factory routine tests of transformers 10 MVA and above.

Currently, in post-Soviet countries, this test is used at different stages of transformer production (at ZTZ, low voltage losses are measured four times during the manufacturing process), during commissioning, regularly during the operation of the transformer during diagnostics, tests after an accident and after repair. In the field, testing is used for transformers with a power of 1000 kVA and more, and for transformers of lower power, the test is carried out after a major overhaul with full or partial stripping of the core [27].

Since 2012, extended field tests of transformers with a service life of more than thirty years or in an emergency state have

> **According to GOST, the no-load test is conducted separately for each of the two phases where the remaining phase is short-circuited**

become mandatory in Russia [28]. Online and offline tests are provided. One of the eleven offline tests is the no-load test at reduced voltage.

4.2. The essence of the no-load test at reduced voltage

Testing a three-phase transformer is carried out in the form of the following three experiments. The first experiment - short-circuit the winding of phase A, excite phases B and C of the transformer, and measure the losses (Fig. 12a). The second experiment - short-circuit the winding of phase B, excite phases A and C of the transformer and measure the losses (Fig. 12b). The third experiment - short-circuit the winding of phase C, excite phases A and B of the transformer, and measure the losses (Fig. 12c). If there is a shorted turn on one phase of the transformer, then it will cause a significant increase in losses. If we exclude the phase with such a turn from the measurements, the losses will be lower. If, for example, there is a shorted turn on phase C, then this phase will participate in measurements when phases a and b are short-circuited. Thus, when phase c is short-circuited and voltage is applied to phases a and b, the obtained values will differ little from the factory data, and in two other cases, they will be higher than those indicated in the passport. This will indicate a malfunction of one of the windings of phase c of the transformer.

A short circuit of any phase is usually carried out at the corresponding terminals of the LV winding of the transformer, but you can also short-circuit the terminals of the HV or MV winding. For single-phase transformers, the reduced voltage is simply applied to the LV winding.

According to GOST, the test is carried out at a voltage of 380 (220) V or less with a frequency of 50 Hz supplied to the LV side of the transformer. It is preferable to excite the transformer with a line voltage of 380 V since the phase voltage can have a significant deviation from the sinusoidal shape of the curve, which will lead to distortion of the measurement results. Also, a frequency deviation of more than ± 3 % from the nominal value (50 Hz) can lead to distortion of the results. The test should be carried out before starting other types of tests. The applied voltage must not exceed the rated voltage of the winding.

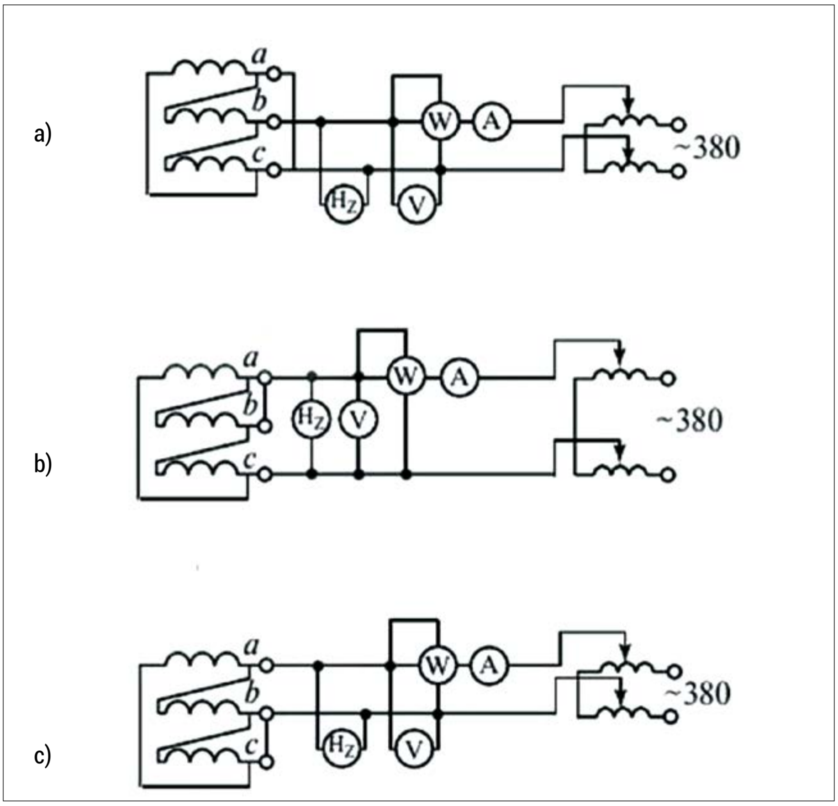

Figure 12. Connection diagrams of the excited windings of a three-phase transformer

For large transformers with voltages up to 380 V, very small values of current (from tens to hundreds of milliamperes) and losses (from units to tens of watts) are measured. For this reason, two measurements are standardized in each experiment. First, it measures the applied voltage, current, and loss P consumed by the tested transformer and measuring instruments in accordance with Fig. 13a. Then the measuring circuit is disconnected from the transformer, and the loss consumed by the measuring devices $\sum P_{dev}$ is measured (Fig. 13b).

Losses in the transformer P_0 are calculated by the formula:

$$P_0 = P - \sum P_{dev}$$

In the schemes of features Fig. 13, it is allowed to use measuring current transformers.

Typical values of measured current and losses in a large transformer are shown in Table 17.

In those cases, when the application of voltage to the LV winding is difficult, the voltage is applied to the MV or HV side. In this case, the voltage value is chosen so that it is equal to the factory voltage of 380 V on the LV side (Table 18).

4.3. Evaluation criteria of the no-load test at reduced voltage

The main criterion for evaluating this test is the comparison of test results with measurements in the factory and with previous measurements in the field. Significantly increased current and losses compared to the previous test usually indicate damage to the winding (s) or closed loops in the active part. A significant increase in only losses can be caused by the deterioration of the insulation between the steel sheets of the core and the beginning of the "steel fire". A significant increase in current usually occurs at the manufacturing plants or after repair of the transformer due to poorly executed core corners or due to the lack of sheets in the upper yoke; the author is not aware of such cases in the field.

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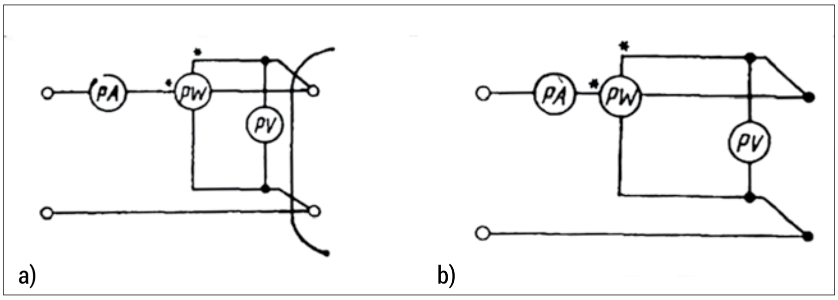

a)
b)

Figure 13. Measurement schemes according to GOST 3848-77

It is generally accepted in the post-Soviet space that the measured field losses should not differ from the factory data by more than 10 %. The author's experience shows that this criterion requires a number of essential refinements. First of all, we note that for old transformers, the cores of which were made of steel 0.35 mm thick, there could be a uniform increase in losses during the first years of operation up to 14–16 % without defects in the transformer [25]. Also, a significant drawback of this practice is the neglect of the current value, which is always measured, is a more reliable value than losses due to the greater ease of measurement but is not used to assess the condition of the transformer.

The author recommends leaving 10 % as an allowable increase in losses only for single-phase transformers and adding the same 10 % for current. If losses and currents increase to about 50 %, first check if the transformer is demagnetized.

In three-phase transformers, losses in experiments with a short circuit of external phases are usually almost equal to each other (no more than 2–4 %), and losses during a short circuit of the middle phase are less by 25–50 % (depending on the core design) from losses a short circuit extreme phases. The specified "correct" difference between the losses between the phases is considered to be evidence that there are no defects in the transformer.

The problem is that measuring tens or even units of watts on a large transformer in the field is not an easy task. Transformer field service technicians often use devices of a low accuracy class, not following the GOST instructions (Fig. 13), they do not always supply 380 V. They often use a more convenient voltage of 220 V. For example, Table 20 shows conflicting current values and losses measured in the field in 2005 and 2019. These results raised doubts, is there a defect in the 200 MVA autotransformer? In such cases of poor-quality measurements, it is necessary to determine the state of the transformer not by the absolute values of currents and losses but by their ratio in different phases. The last two columns of Table 19 show the equality of these ratios at the factory and in two measurements in the field, which indicates that there are no defects in the autotransformer in question.

To confirm the independence of the ratios of current and losses in different phases from the voltage value (up to 380 V according to GOST), the current and losses were measured, and their ratios in different phases were determined in the initial part of the magnetization curve of a 20 MVA 110 kV transformer (Fig. 14a - dependence of current on voltage and Fig. 14b - dependence of losses on voltage).

These figures confirm the independence of the ratios of current and losses between phases from the voltage value, which

Table 17. Autotransformer ZTZ 250 MBA 400/121/38.5 kV, Yn/d-11 serial No. 143648, S/S «Stolnik» disp. No. T403, Bulgaria. The table was formed by the device M 4000 Doble.

No.	Serial No. / Test ID	L C	Circ. Desc.	kV	mA	WATTS
4	lv (b-c) (zakA)	E	UST-R	0.380	83.89	20.052
5	lv (a-c) (zakB)	E	UST-R	0.380	110.4	24.454
6	lv (a-b) (zakC)	E	UST-R	0.380	81.25	20.143

Table 18. Energized side of MV autotransformer ZTZ 250 MBA 400/121/35 kV, Yn/d-11 serial No. 110495, S/S "Metallurgichna", disp. No. AT-2, Bulgaria.

Energized	Shorted out phase	Voltage, V	Current, A	LOSSES, W
Bm – Cm	A	5566	74.86	265.7
Am – Cm	B	5566	97.75	331.0
Am – Bm	C	5566	72.73	259.0

> **In cases with the poor quality of measurements, it is necessary to determine the state of the transformer not by the absolute values of currents and losses but by their ratio in different phases**

makes it possible to recommend, when comparing test results with earlier tests, first of all, focus on the ratio of current and losses between phases, and only secondarily consider their absolute values.

From the experience of factory tests of transformers at ZTZ and field tests after repair of transformers, a 5 % value can be considered as the permissible deviation of the current and loss ratios during tests of three-phase transformers from factory measurements and / or previous field measurements. If these ratios differ up to 10 % or more, first of all, you should check whether the transformer is demagnetized.

In doubtful cases, it is necessary to analyse the results of other tests, if possible, repeat the test at a voltage higher than 380 V, and contact the supervisor.

Conclusions and recommendations

1. The old methods for detecting defects in the core and windings in transformers in the field (magnetic balance test, excitation current test, no-load test at reduced voltage or so-called Ashryatov's test) have not lost their significance in the 21st century. They are simpler, cheaper and, according to the author, in most cases are not inferior in efficiency to modern FRA and SFRA methods, especially for the rapid detection of faults during transformer operation.

It is often ignored that FRA or SFRA is performed at voltages up to 10–12 V, MBT and Ashryatov's test - at a voltage of 220–400 V, excitation current test - at 10–12 kV, and there is a number of voltage-sensitive problems.

For distribution and power transformers of low power, it is enough to use the old methods. At the same time, it is recommended to carry out comparative tests of old and new methods for various defects in transformers, especially such thin ones as one shorted turn in the winding.

2.To eliminate measurement errors, the test circuit, test voltage value and, preferably, devices should be the same as in the previous tests. In unclear cases of MBT and the GOST method, it is recommended to increase the test voltage to 10–12 kV, which is possible when using modern devices.

When performing the SAT or after a repair of the transformer, use factory-specific methods, and if the factory data are not available, use those specified in your national regulations plus FRA or SFRA for fingerprinting.

During periodic preventive maintenance and during diagnostics, use the same methods as for SAT and previous tests plus FRA or SFRA if they were not previously performed.

In case of an accident, use the same methods as in the previous test, plus voltage tip-up test and other classic tests such as TTR, DC-WR, FRA or SFRA if there is a fingerprint, DGA.

3. Evaluation criteria of no-load tests at reduced voltage is recommended: a) supplement with an assessment of the results of current measurements with a permissible deviation of 10 % from measurements at the factory and / or from previous measurements in the field, b) consider the ratio of current and losses between phases as the main criterion for three-phase transformers, and only secondarily con-

Table 19. Autotransformer ZTZ 200 MBA 330/115/10.5 kV, Yn/d-11 serial No. 146232 (source: Pavel Pleskatsevich, Belarus).

Energized	Shorted out phase	Voltage, V	Current, A	Losses, W	Ia-c/Ib-c or Ia-b/Ib-c	Pa-c/Pb-c or Pa-b/Pb-c
ZTZ, 1994						
b - c	a	380	0.53	153		
a - c	b	380	0.83	231	1.57	1.51
a - b	C	380	0.53	153	1.00	1.00
Field, 2005						
b - c	a	220	0.53	84		
a - c	b	220	0.84	124	1.58	1.48
a - b	C	220	0.53	84	1.00	1.00
Field, 2019						
b - c	a	220	0.551	121.2		
a - c	b	220	0.844	185.6	1.53	1.53
a - b	C	220	0.546	120.2	0.99	0.99

sider their absolute values, c) accept the value of 5 % as the permissible deviation of the current and loss ratios from measurements at the factory and/or from previous measurements in the field.

In case of an accident, use the same methods as in the previous test, plus voltage tip-up test and other classic tests such as TTR, DC-WR, FRA or SFRA if there is a fingerprint, DGA.

Evaluation criteria of GOST no-load tests at reduced voltage is recommended: a) supplement with an assessment of the results of current measurements with a permissible deviation of 10 % from measurements at the factory and / or from previous measurements in the field, b) consider the ratio of current and losses between phases as the main criterion for three-phase transformers, and only secondarily consider their absolute values, c) accept the value of 5 % as the permissible deviation of the current and loss ratios from measurements at the factory and / or from previous measurements in the field.

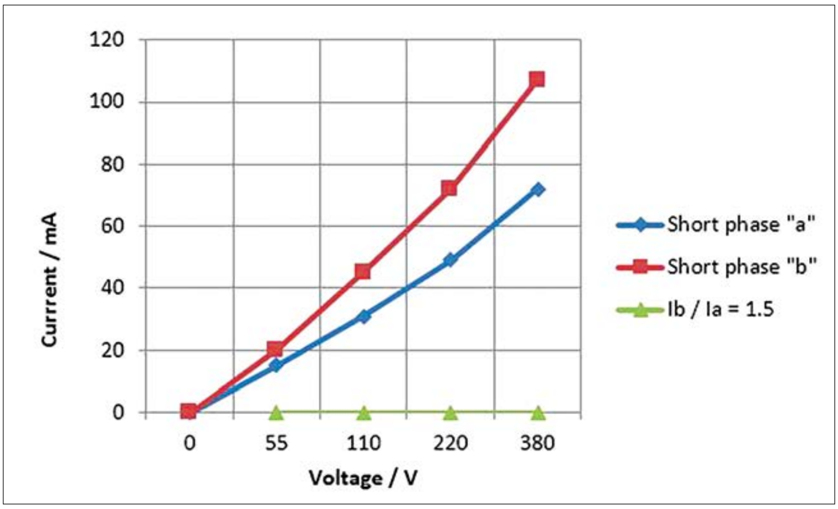

Figure 14a. Transformer ZTZ 20 MVA 115/38.5/11 kV, Yn/Yn/d-11, serial No. 163195, core steel 0.3 mm 1.1 W/kg

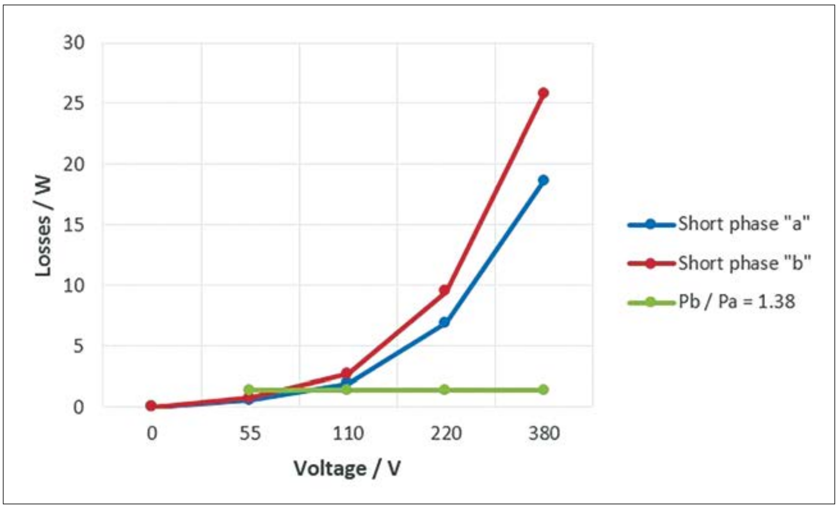

Figure 14b. Transformer ZTZ 20 MVA 115/38.5/11 kV, Yn/Yn/d-11, serial No. 163195, core steel 0.3 mm 1.1 W/kg

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Vitaly Gurin graduated from Kharkov Polytechnic Institute (1962) and graduated from school at the Leningrad Polytechnic Institute. Candidate of technical sciences in the Soviet scientific system (1970). For 30 years, he tested transformers up to 1.150 kV at ZTZ, including the largest one of that time in Europe, and statistically analysed the test results. For over 25 years, he was the Executive Director of Trafoservis Joint-Stock Company in Sofia (the diagnosis, repair and modernisation in the operating conditions of transformers 20–750 kV). He has authored about 150 publications in Russian and Bulgarian and is the main co-author of GOST 21023.