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Voltage Stability in 6-10/0.4 kV Power Networks: Experimental Assessment of Transformer Tap Adjustment

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Abstract: The article discusses the appearance of voltage deviations in the power transmission line as a result of connecting more and more electric consumers with different resistance to the power supply line and the assessment of its negative impact on the efficiency and reliability of power transformers during long-term operation. In the LD DIDACTIC laboratory complex, the connection schemes of the power transformer with a total capacity of 360 VA were changed and the voltage deviation from the nominal value is brought to the supply line. The values of the voltage deviation generated in the power transformer were determined when loads with different resistance is connected to the secondary output terminals of the power transformer. Based on the obtained results, it is possible to evaluate the performance of the power transformer.

Keywords: Power lines, power transformers, voltage deviation, energy efficiency, reliability indicators, power transformer connection diagrams, voltage vector diagrams.

Introduction: In today's modern world, electricity is an integral part of every sector. With the increasing demand for it, providing consumers with uninterrupted and high-quality electricity is particularly important [1]. Electricity supply quality is principally determined by frequency variations, voltage deviations, phase imbalance, and harmonic content [2]. If electricity quality indicators deviate from the values specified in the regulatory documents of the international IEEE std

1159 standard, the technical and economic performance of the electricity supply deteriorates. To reduce this damage and increase the technical and economic efficiency of electricity supply to consumers, it is necessary to maintain electricity quality indicators in an optimal state [3].

The increase in loads with varying resistances in power transmission networks, driven by new generation technologies and electricity consumers, negatively affects the stability of the energy system, as well as the reliability and efficiency of electrical installations [4]. Power losses in long-distance transmission lines and the connection of different types of resistance to power supplies and consumers located far from power transformers cause voltage deviations beyond the limits required by IEEE [5].

Voltage deviations also affect power transformer operation. For example, in power transformers supplying consumers with varying resistances, the voltage deviation in their lower windings differs. Below we will consider the differences in voltage deviations for power transformers with different connection schemes.

METHODOLOGY

For the above keywords, scientific research works carried out over the past 20 years using the resources of Google academy, eLIBRARY, ELSEVER, ResearchGate and other search engines is edited. For this analytical study, articles related to traditional and modern methods of voltage deviation correction in a power transformer, their advantages and disadvantages, is used.

Theoretical part

According to the “Service Order No. 817 on information by district and city” of the Fergana regional power grid enterprise dated 03.01.2024, currently, by region, 667 of the total 709 power transformers with a voltage of 6-10/0.4 kV with a capacity of up to 2500 kVA in the enterprise balance, or 94% of the total transformers, and 550 of the total 572 power transformers with a voltage of 6-10/0.4 kV with a capacity of 25 kVA to 3150 kVA in the consumer balance, or 96% of the total transformers, have a Δ/Y_0 or 〚Y/Y〛 _0 connection scheme [6].

The diagrams of a 6-10/0.4 kV power transformer with the connection schemes "delta-star-neutral" and "star-star-neutral" show in the figure below (Fig. 1).

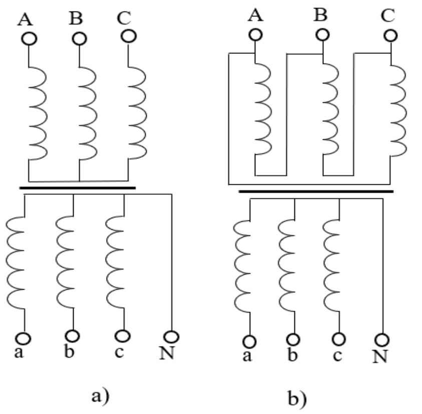

Fig.1. Connection diagram of power transformers with a) Y/Y_0 and b) Δ/Y_0-11

RESULTS

In order to analyze the voltage deviations in power transformers with a voltage of 6-10/0.4 kV, the connection diagram of a laboratory transformer with a capacity of 360 VA as a prototype was changed Δ/Y_0 or 〚Y/Y〛 _0in the LD DIDACTIC laboratory complex, and the working diagrams were assembled, and the voltage deviations of this power transformer were studied in the pure operation and various load modes.

First of all, the maximum input voltages of power transformers with connection schemes Δ/Y_0 and 〚Y/Y〛 _0 are given in the table below (Table 1).

Table 1

Values of high input voltages of power transformers with connection schemes Δ/Y_0 and Y/Y_0

№	Scheme	Phase	U (V)	δU (%)	ϕ
1	Δ/Y_0	A	240.6	4,8	0º
		B	240.6	4,8	120,1º
		C	238,9	4,01	239,6º
2	Y/Y_0	A	240,9	4,9	0º
		B	239,7	4,4	120,2º

		C	239,3	4,2	239,2°

In general, the voltages entering the power transformer for a power transformer with a Δ/Y_0 connection scheme are 230.6 V in phases A and B, and the voltage deviation in the power network itself is 4.8% of the nominal voltage. The voltage in phase C of the power network is 228.9 V or 4.01%.

In the experimental study conducted for a power transformer in the 〖Y/Y〗_0 connection scheme, in phase A of the electrical network, U_A=230.9 V or δU_A=4.9%, in phase B, U_B=229.7 V or δU_B=4.4 %, in phase C, U_C=229.3 V or voltage deviation from the nominal value is δU_C=4.2%.

When the connection schemes and connection groups of a power transformer are changed, the value of the voltages generated in its secondary winding changes according to the phase. It is known that when changing from a delta circuit to a star circuit, the phase voltages change by √3 from each other [6,7,8]

In the next experimental study, the values of the voltages in the secondary winding of power transformers with the Δ/Y_0 and 〖Y/Y〗_0 connection schemes in the single-phase operation mode were obtained (Table 2).

Table 2

The output voltages of the power transformer in the Δ/Y_0 and Y/Y_0 connection schemes on the idle mode

№	Scheme	Phase	U_1 (V)	U_2 (V)	δU (%)	φ
1	Δ/Y_0	A	230.6	228,9	4,4	0°
		B	230.6	229,7	4,4	120,1°
		C	228,9	228,7	4,02	239,6°
2	Y/Y_0	A	230,9	230,5	3,9	0°
		B	229,7	229,3	4,2	120,2°
		C	229,3	228,9	4,04	239,2°

We can see that in the single-phase operation mode, the voltage in the secondary windings of the power transformer practically does not change from the voltage at the input. The deviation of the instantaneous value of the voltage from the nominal is also observed in the secondary winding.

Vector diagrams of high input voltages for the single-phase operation mode of power transformers with connection schemes Δ/Y_0 and 〖Y/Y〗_0 were obtained.

In our further experimental studies, the same number of active, inductive and capacitive resistances were connected to the output side of power transformers with the “delta-star-zero” and “star-star-zero” connection schemes, and the results are presented in the following tables (Tables 3; 4; 5).

When loads with inductive-capacitive resistance are connected to a power transformer, we can see that the voltage deviation in its secondary winding exceeds the values specified in IEEE regulatory documents. In particular, the voltage deviation in power transformers with the 〖Y/Y〗_0 connection scheme changes significantly.

The secondary voltage values were determined during the process of non-contact automatic voltage adjustment in a single-phase power transformer with an inductive-capacitive load. In this case, a non-contact automatic voltage adjustment process was performed in the transformer by connecting an inductive-capacitive load with an inductance of L=6 Gn and a capacitance of C=16μF, and changing the primary voltage of the power transformer from its nominal value as described above (Table 3).

Table 3

The output voltages of the power transformer in the Δ/Y_0 and Y/Y_0 connection schemes when the active load is connected

№	Scheme	Phase	U_1 (V)	R (Om)	I (A)	U_2	δU (%)	φ
1	Δ/Y_0	A	230.6	500	0,812	227,5	3,4	0°
		B	230.6	500	0,766	228,1	3,68	120,2°
		C	228,9	500	0,787	225,6	2,25	239.8°
2	Y/Y_0	A	230,9	500	0,810	227,2	3,9	0°
		B	229,7	500	0,771	226,5	2,9	121,8°
		C	229,3	500	0,799	226,2	2,8	240,5°

In this case, a load with a reactive resistance of X=2.083 k Ohm is connected to the power transformer. The voltage deviation in the secondary winding of a power transformer with an inductive-capacitive load is not more than 2% (Fig.3).

A load with an reactive load of L=2,4 Hn was connected to a single-phase power transformer with a contactless automatic voltage regulator (Table 4). The secondary voltage values were obtained during the contactless automatic voltage regulator process in a single-phase power transformer with an active load.

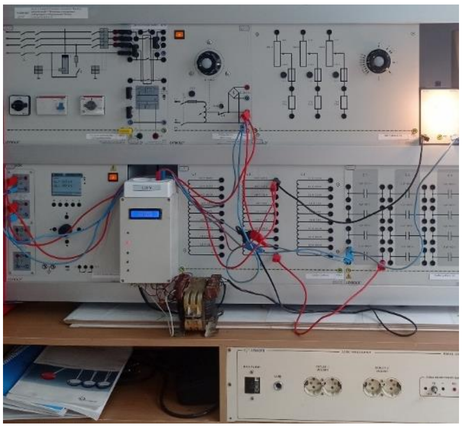

Fig.2. The process of non-contact voltage adjustment in a power transformer with an inductive-capacitive load

Table 4

The output voltages of the power transformer when an inductive load is connected are

№	Scheme	Phase	U_1 (V)	L Hn	I A	U_2	δU %	ϕ
1	Δ/Y_0	A	230.6	2,4	0,183	227,3	3,3	0°
		B	230.6	2,4	0,187	228,4	3,8	120,1°
		C	228,9	2,4	0,174	225,2	2,3	239,6°
2	Y/Y_0	A	230,9	2,4	0,185	227,5	3,4	0°
		B	229,7	2,4	0,185	226,2	2,8	120,6°
		C	229,3	2,4	0,176	226,1	2,7	241,8°

A contactless automatic voltage adjustment process was performed on a single-phase power transformer with a mixed load of active power P=300 W and inductive-capacitive resistance X=2.083 kOhm, and the secondary voltage values of the transformer were determined (Table 4).

Table 5

The output voltages of the power transformer when an inductive load is connected are

№	Scheme	U_1 (V)	L Hn	C mkF	I A	U_2	δU %	ϕ
1	Δ/Y_0	230.6	2,4	16	0,220	230,7	4,8	0°
		230.6	2,4	16	0,226	233,0	5,9	117,7°
		228,9	2,4	16	0,208	230,3	4,6	240,2°
2	Y/Y_0	230,9	2,4	16	0,223	256,7	16,7	0°
		229,7	2,4	16	0,224	249,8	13,5	83,8°
		229,3	2,4	16	0,211	217,5	-1,1	219°

In a single-phase power transformer with an active load and a load factor of kload=1.07, the voltage deviation in the secondary winding during automatic contactless voltage adjustment is within 2% (Figure 3).

A graph of the change in the secondary voltage of a single-phase power transformer with a contactless automatic voltage regulator was obtained in the LD DIDACTIC laboratory complex.

The TRIAC switches of the contactless voltage regulator operate at a speed of 3 seconds.

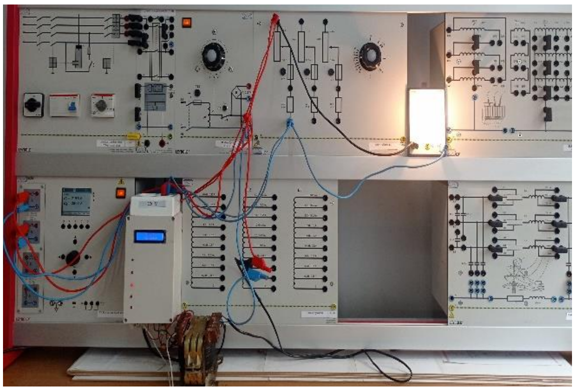

Fig.3. The process of non-contact voltage adjustment in a power transformer with an impendence load

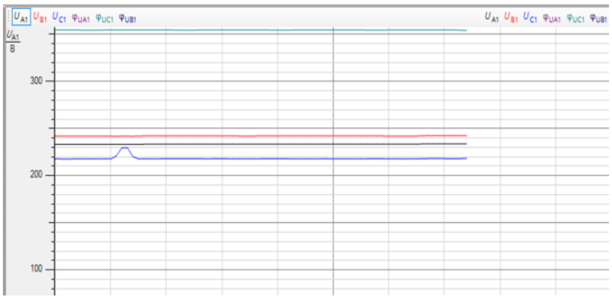

Figure 4. Graph of contactless automatic adjustment of secondary voltage in a power transformer

The secondary voltage values were determined during the process of non-contact automatic voltage adjustment in a single-phase power transformer with an inductive-capacitive load. In this case, a non-contact automatic voltage adjustment process was performed in the transformer by connecting an inductive-capacitive load with an inductance of L=6 Gn and a capacitance of C=16μF, and changing the primary voltage of the power transformer from its nominal value as described above (Table 6).

Table 6

The output voltages of the power transformer when an inductive load is connected are

№	Scheme	U_1 (V)	L Hn	C mkF	I A	U_2	δU %	φ
1	Δ/Y_0	A	230.6	L=2,4 Gn	0,220	230,9	4,9	0°
		B	230.6	R=500 Om	0,658	231,5	5,2	117,7°
		C	228,9	L=2,4 Gn C=16 mk F	0,694	228,4	3,8	240,2°
2	Y/Y_0	A	230,9	L=2,4 Gn	0,278	256,7	16,7	0°
		B	229,7	R=500 Om	0,845	249,8	13,5	83,8°
		C	229,3	L=2,4 Gn C=16 mk F	0,392	217,5	-1,1	219,0°

As can be seen from Table 6, when the primary voltage deviation of a power transformer operating with an active, inductive-capacitive load is within ±10%, its secondary voltage deviation is adjusted within ±2.5%. This indicates that the process of automatic non-contact voltage adjustment in a transformer can also be used for mixed load connection (Figure 5).

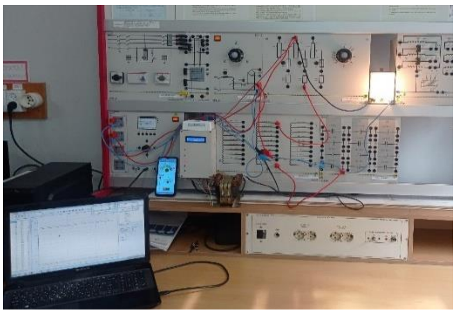

Figure 5. The process of contactless automatic voltage adjustment in a single-phase power transformer with a mixed resistive load

According to the results of the analytical study, the sinusoidality of the voltage in power transformers under operating conditions is often violated when inductive-capacitive loads are connected to the network [7].

A graph of the change in the secondary voltage over time for the process of non-contact voltage adjustment in a power transformer with an inductive-capacitive load was obtained (Fig. 6).

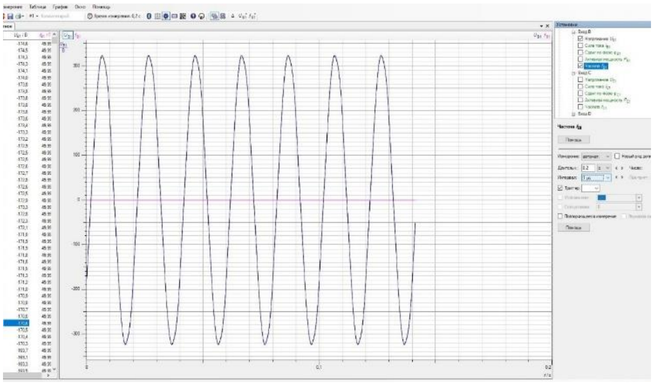

Figure 6. Graph of the change in secondary voltage over time during contactless voltage adjustment in a power transformer with an inductive-capacitive load

Active, inductive, and inductive-capacitive loads were connected to this three-phase power transformer in phases, and the value of the transformer's secondary voltages was determined during the contactless automatic voltage adjustment process.

CONCLUSION

As can be seen from the above graphs, the voltage deviation on the secondary winding of power transformers with the Δ/Y0 and Y/Y0 connection schemes on the high voltage side is present only in the operating mode and the loads with active and inductive resistance have almost no effect on the voltage deviation.

However, capacitive loads directly affect the voltage value, causing the voltage in the secondary winding of power transformers to deviate from the values specified in GOST regulatory documents.

In addition, the voltage deviation at the output of power transformers is directly dependent on its connection scheme. In order to provide uninterrupted and high-quality electricity to electricity consumers and reduce additional power waste and damage caused by voltage deviations in the power transformer in this process, phase-to-phase voltage adjustment in the power transformer is an important practice.

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