ISSN 1068-3712, Russian Electrical Engineering, 2025, Vol. 96, No. 4, pp. 306–311. © Allerton Press, Inc., 2025.
Russian Text © The Author(s), 2025, published in Elektrotekhnika, 2025, No. 4, pp. 47–52.

Determination of Optimal Options for Connecting and Combining Compensating Devices in an Electrical Network with a Voltage of 0.38 kV

M. A. Yundin[a], K. M. Yundin[b, *], and A. M. Isupova[c]

[a] *Azov–Black Sea Engineering Institute of the Don State Agrarian University, Zernograd, 347740 Russia*
[b] *Don State Technical University, Rostov-on-Don, 344010 Russia*
[c] *Stavropol State Agrarian University, Stavropol, 355017 Russia*
**e-mail: ukm_61@rambler.ru*

Received May 17, 2024; revised November 16, 2024; accepted November 17, 2024

Abstract—The results of experimental studies of various options for connecting technical means for limiting current in the neutral wire to the physical model of a 0.38-kV network are presented. During the study, both the places of connection of technical means to the network and various combinations of their connection to the network model varied. A transformer with a "star/double zigzag with zero wire" winding connection scheme, a "star with zero wire/triangle" transformer group and an inductive coil were considered as technical means. Based on the experimental results, conclusions were drawn about the most rational switching location and the combination of technical means in the 0.38 kV network at asymmetric and nonlinear load.

Keywords: 0.38-kV electric networks, compensating devices, power losses, asymmetry and nonsinusoidality
DOI: 10.3103/S1068371225700403

One of the main problems of energy efficiency in the transmission of electrical energy through a network with a voltage of 0.38 kV, regardless of the specifics of their affiliation (rural, urban, industrial), is additional power losses caused by asymmetry currents and higher harmonics. The reasons for the appearance of these currents are associated with the unevenness of the connection of loads by phases, a large number of single-phase electric receivers, as well as their nonlinear nature.

Various technical means are used to reduce power losses caused by asymmetrical and nonlinear loads, but their combined effect on the energy efficiency of electrical energy transmission under conditions of asymmetry and nonsinusoidality has not been studied in detail. There are also no recommendations regarding the most suitable places for the installation of compensating devices in the 0.38-kV network.

Laboratory studies of the operating modes of technical facilities were continued by developing a model of the electric network [1] by forming an additional section with a nonlinear load modeled by mercury arc fluorescent lamps (Z_{n1}–Z_{n3}) and sodium arc tube lamps (Z_{n4}–Z_{n6}) with different rated power. Figure 1 shows a diagram of connecting a nonsinusoidal and nonlinear load to the physical model of the network; measurements of electrical quantities were performed at points *S*1 and *S*2.

The power supply of the network model is made from power transformer T of the TS-1.5 type with a "star/star with zero wire" winding connection scheme (Y/Y_n) [2]. Electrical measurements are made with a certified HIOKI 3196 instrument in both static and dynamic conditions. Total resistances Z_1–Z_4 and Z_5–Z_8 simulated the resistances of the line sections, and resistances Z_{n1}–Z_{n3} and Z_{n4}–Z_{n6} simulated a nonlinear asymmetrical load.

As compensating devices during the tests, a dry power transformer with a capacity of 1.5 kVA with a scheme for connecting windings "star/double zigzag with zero wire" ($2Z_n$) was used, with a transformer group of single-phase transformers with a "star with zero wire/triangle" winding connection scheme (Y_n/Δ) and an inductive coil placed on an armored core.

The ratio of the number of turns in the windings and half-windings of the load circuit on each of the bars of the transformer magnetic core with the $2Z_n$ winding connection scheme was equal to 1 : 0.5 : 0.5. The transformer group Y_n/Δ was formed by three single-phase transformers with transformation coefficients equal to 1, with a capacity of 250 VA each, and the number of turns of the inductive coil made with a PET-2 wire with a diameter of 1 mm is 50.

During the tests, the load was performed asymmetrically and nonlinearly, throughout all the tests, its

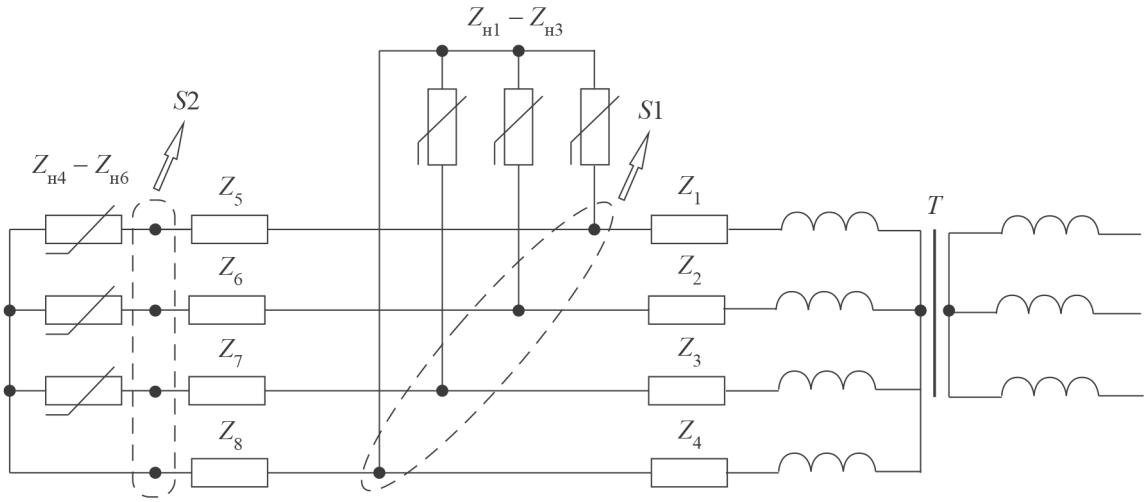


Fig. 1. Schematic wiring diagram of a physical model of a 0.38-kV network.

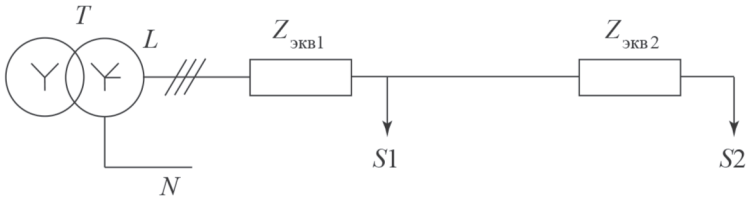


Fig. 2. Simplified representation of the network model.

parameters did not change. In the first test, the technical means were not included in the circuit, the electrical values were measured in the section of the network closest to transformer T (conditionally, Z_{eq1}), and then in the far section (conditionally Z_{eq2}). A simplified version of the image of the original network model is shown in Fig. 2.

It should be noted that these resistances correspond to the overhead sections of the line with a voltage of 0.38 kV, made of wire of AN or AZh grades with a cross section of 35 mm^2 with a length of 450 m each.

During the measurements, the following values were recorded: total load power S_Σ in the network sections, kVA; average value of phase voltages U_{av}, V; and current in the neutral wire I_N, A. To assess the efficiency of technical means, the efficiency criterion was calculated—the ratio of additional power losses from asymmetry and nonsinusoidality currents to technical power losses from the fundamental harmonic in each section of the network ($\Delta P_{add}/\Delta P_1$):

$$\frac{\Delta P_{add}}{\Delta P_1} = K_{i2}^2 + 4K_{i0}^2 + 3.2K_{i(3)}^2,$$

where K_{i2} is the coefficient of current asymmetry in the reverse sequence of the fundamental frequency, K_{i0} is the coefficient of current asymmetry along the zero sequence of the fundamental frequency, and $K_{i(3)}$ is the coefficient of the third harmonic component of the current in the neutral wire.

In the next series of tests, each of the technical means was alternately connected to load node $S1$, and the coil on a closed magnetic core was separately connected to the neutral wire of the network model. During the tests, the same values were measured and calculated as in the first test before the technical means were connected to the network model. The results are shown in the Table 1.

Oscillograms of currents in the line and neutral wires recorded before and after the connection of each of the technical means in load node $S1$ are shown in Figs. 3–5.

In Table 1, the positive dynamics of changes in the mode parameters are highlighted in black font on a gray background, and the negative dynamics of changes in the indicators relative to the basic mode are highlighted in white font on a dark background, when the compensating devices were not connected.

The results showed that the inclusion of an inductive coil in the neutral wire reduces additional power losses from asymmetry and nonsinusoidality currents

Table 1. Results of tests on a physical model

Test number	Electrical quantities on line sections							
	section Z_{eq1}				section Z_{eq2}			
	S_Σ, kVA	U_{av}, V	I_N, A	$\frac{\Delta P_{add}}{\Delta P_1}$	S_Σ, kVA	U_{av}, V	I_N, A	$\frac{\Delta P_{add}}{\Delta P_1}$
1	1.75	214.9	1.81	0.316	1.05	215.6	1.36	0.476
2	1.71	214.2	1.51	0.22	1.04	215.5	1.19	0.414
3	2.08	213.6	0.75	0.059	1.08	215.1	1.89	0.880
4	2.12	215.1	0.74	0.06	1.24	215.3	2.17	0.872
5	2.19	214.5	0.33	0.01	1.06	210.2	1.87	0.826
6	2.13	215.5	0.30	0.009	1.13	216.1	1.94	0.872
7	1.75	208.6	1.22	0.101	0.99	209.6	1.56	0.659
8	1.66	211.7	1.20	0.116	1.01	211.5	1.59	0.669
9	1.66	211.5	0.76	0.056	1.0	211.2	1.54	0.634
10	1.67	209.1	0.69	0.044	0.98	209.4	1.53	0.633
11	2.01	210.9	0.68	0.054	1.01	210.6	1.75	0.799
12	1.96	208.2	0.65	0.049	0.98	208.4	1.70	0.777

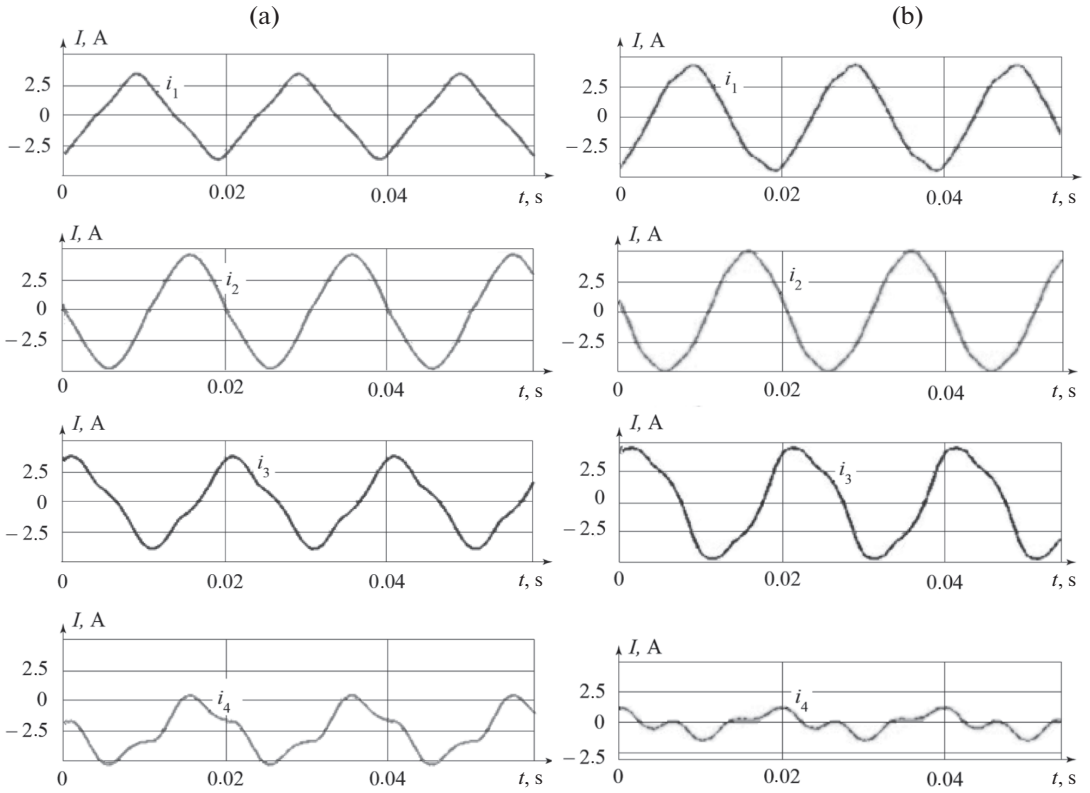


Fig. 3. Oscillograms of currents in the Z_{eq1} section of the network model before and after connecting the transformer $2Z_n$ in the load node $S1$: (a) before connecting the technical means; (b) after connecting the transformer $2Z_n$.

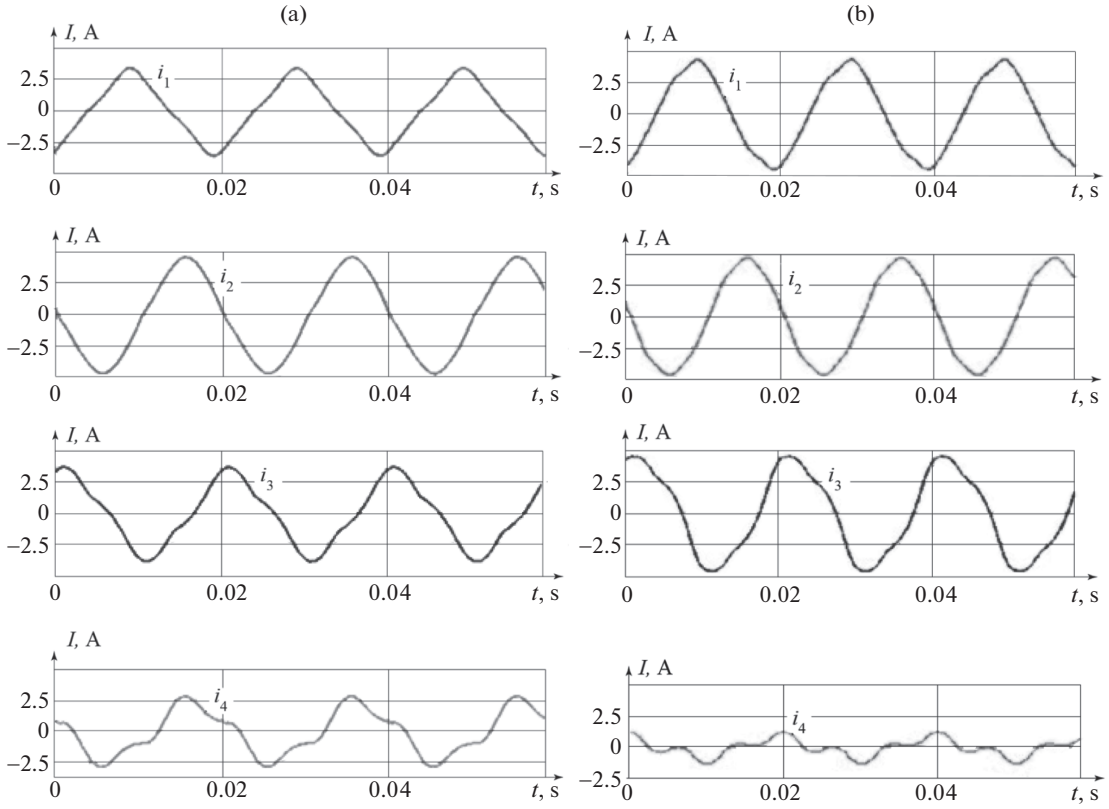


Fig. 4. (б). Oscillograms of currents in the Z_{eq1} section of the network model before and after connecting the transformer group Y_n/Δ in load node $S1$: (a) before connecting technical means; (b) after connecting the transformer group Y_n/Δ.

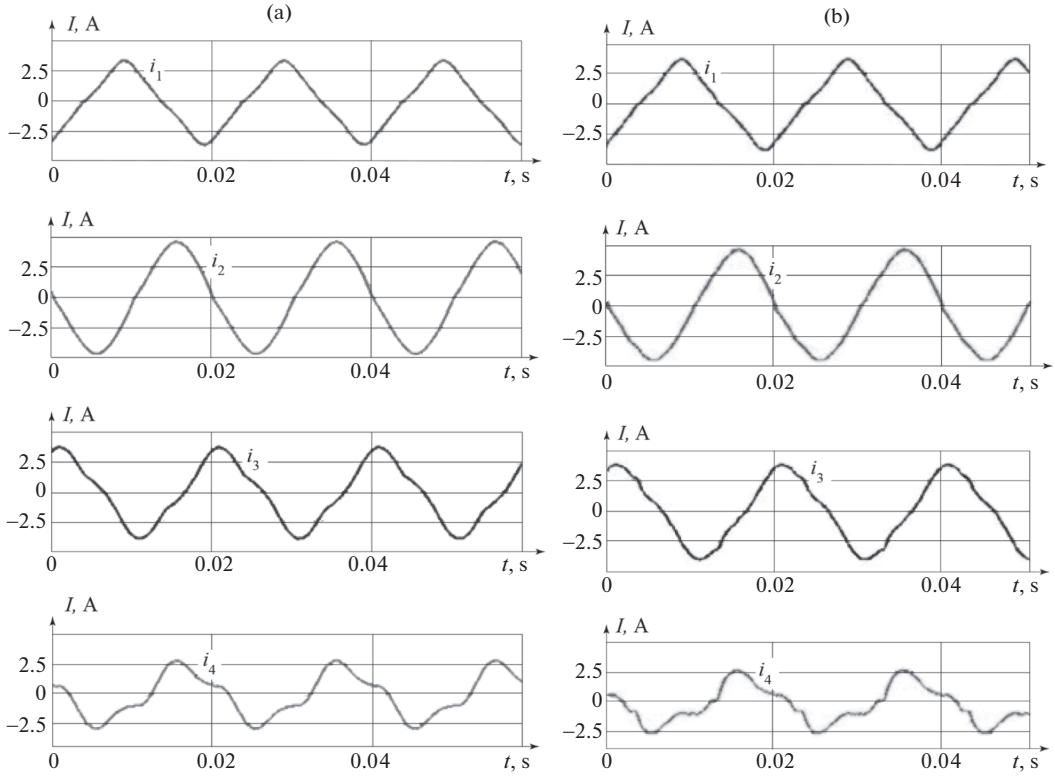


Fig. 5. Oscillograms of currents in Z_{eq1} section of the network model before and after connecting the inductive coil to the neutral wire: (a) before connecting the technical means; (b) after connecting the inductive coil.

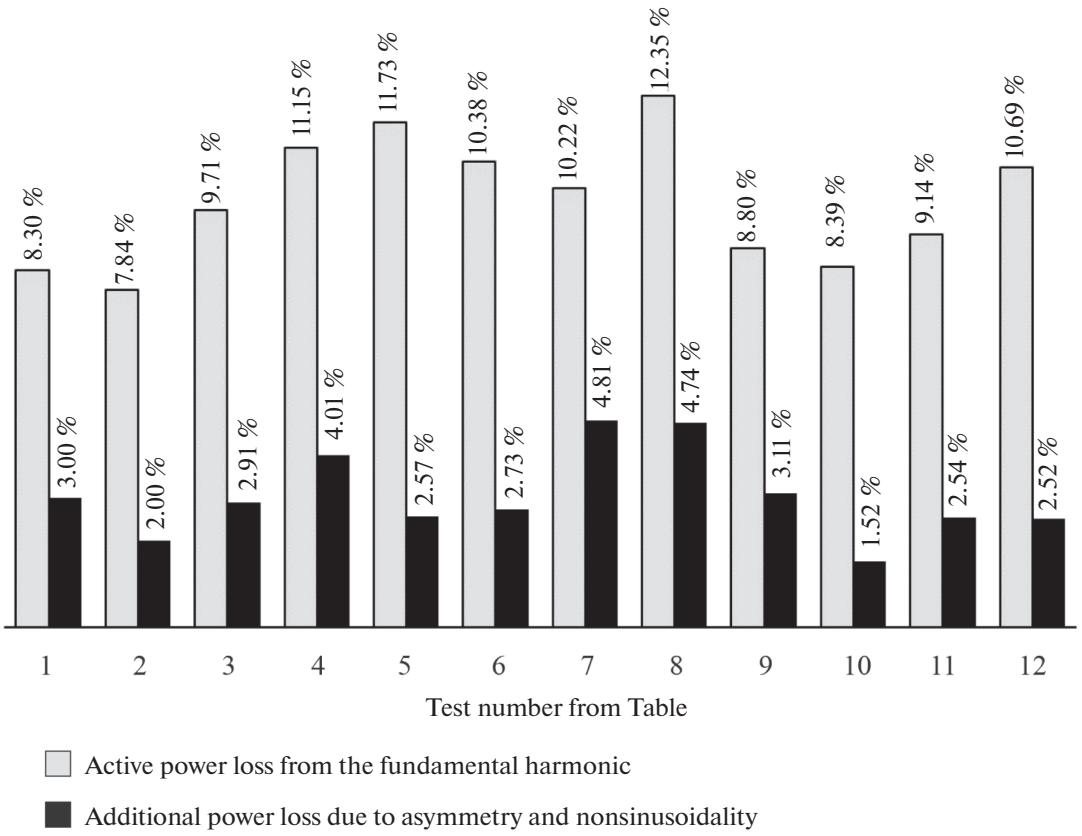


Fig. 6. Active power losses from the fundamental harmonic and additional power losses from asymmetry and nonsinusoidality with respect to the power consumed by the network model in different ways of switching on compensating devices.

in all parts of the network model. At the beginning of the line, additional power losses are reduced from 31.6 to 22%, and at the end of the line from 47.6 to 41.4% (test no. 2); however, in comparison with other technical means, the effect of limiting the current in the neutral working wire in the network section closest to the supply transformer with this method is much smaller.

The greatest reduction in the current in the neutral working wire at the beginning of the line at a nonlinear asymmetrical load is provided by simultaneously connecting the inductive coil to the neutral wire of the network and a transformer with winding connection scheme $2Z_n$ in far load power supply node $S2$ (test no. 6), but this method does not guarantee a decrease in current in all sections of the network. Thus, with this method of switching on technical means, the current in the neutral working wire at the end of the line increased by 42.6% compared to the base level; an increase in active power losses at the end of the line from 47.6 to 87.2% was also recorded.

Analysis of the table data made it possible to establish that, at the end of the line, the loss of active power increased with any option of connecting technical means to the network model. However, the losses increased to a lesser extent when the inductive coil was connected together to the neutral wire of the network model and the transformer group when the windings Y_n/Δ were connected in far load power supply node $S2$ (test No 10).

To determine the optimal connection scheme of compensating devices for all sections of the network model under consideration, a calculation of active power losses from the fundamental harmonic ($\Delta P_{1\Sigma}$) and additional power losses from asymmetry and nonsinusoidality currents ($\Delta P_{add\Sigma}$) in relation to the power consumed by the network model was carried out (Fig. 6). Analysis of the data presented in Fig. 6 indicates that the smallest value of additional power losses due to asymmetry and nonsinusoidality (1.52%) is observed when the inductive coil is connected together to the neutral wire of the network model and the transformer group when the windings Y_n/Δ are connected in the far power supply node $S2$ (test no. 10). At the same time, the losses of active power from the fundamental harmonic in this test (8.39%) are commensurate with similar losses in the basic version (8.3%), when there were no technical means in the circuit.

Based on the results obtained, it can be concluded that the optimal scheme for reducing additional power losses from asymmetry and nonsinusoidality is the scheme of joint connection of the inductive coil to the neutral wire of the network model and the transformer group when connecting the windings Y_n/Δ in far load power supply node *S*2.

FUNDING

This work was supported by ongoing Don State Technical University funding. No additional grants to carry out or direct this particular research were obtained.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

REFERENCES

1. Yundin, M.A., Yundin, K.M., and Isupova, A.M., The influence of a transformer with "double zigzag with zero output" windings on the level of asymmetry and nonsinusoidal currents in a 0.38-kV network, *Russ. Electr. Eng.,* 2023, vol. 94, no. 11, pp. 855–861.
2. Yundin, M.A., Yundin, K.M., Isupova, A.M., et al., On the effectiveness of the use of transformers with a "star/double zigzag with zero wire" winding-connection scheme under nonlinear nonsinusoidal load, *Russ. Electr. Eng.,* 2023, vol. 94, no. 2, pp. 111–116.

Translated by M. Astrov

Publisher's Note. Allerton Press remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.
AI tools may have been used in the translation or editing of this article.

SPELL: 1. OK