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ANALYSIS OF THE INFLUENCE OF ASYMMETRICAL AND NONLINEAR LOAD ON THE STATE OF INSULATION OF POWER TRANSFORMER WINDINGS IN INCOMPLETE-PHASE MODES OF ELECTRIC NETWORK OPERATION

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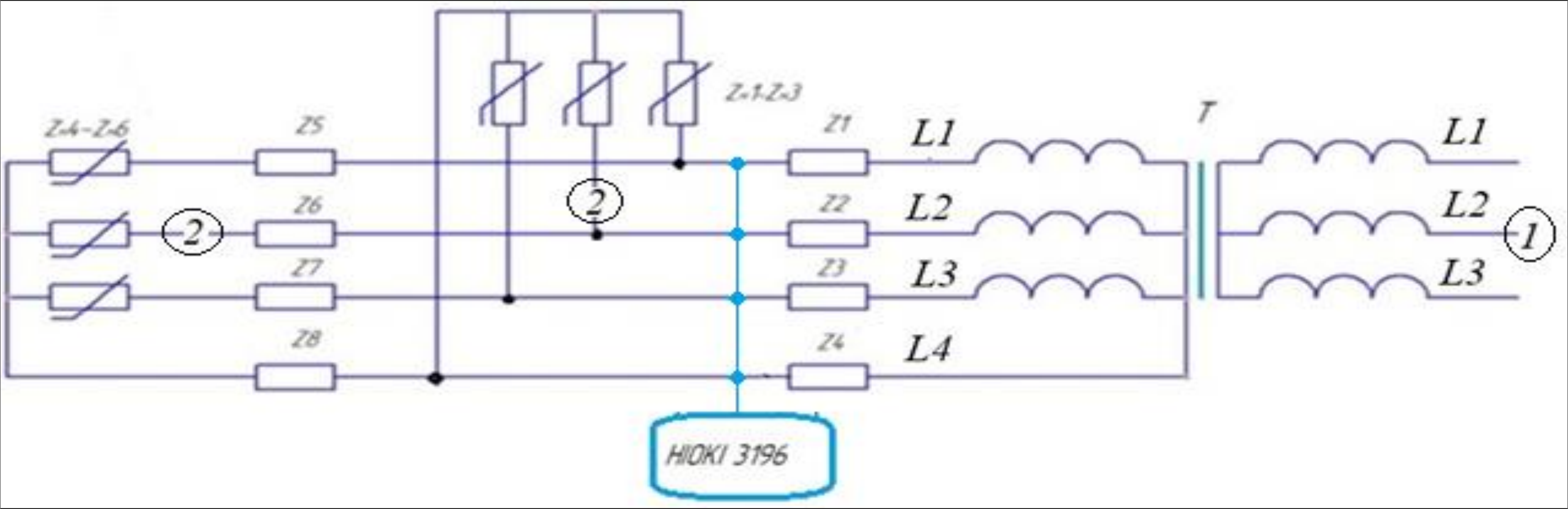
Introduction

- It is known that the last link in the chain of electric energy transformation from the source to the consumer are power transformers with a voltage of 6-10/0.4 kV. As for the power supply system of rural consumers, in Russia, relatively inexpensive three-phase power transformers with a "star/star with zero" winding connection scheme have traditionally been installed en masse for such purposes. With a relatively linear load, which was typical at the initial stages of electrification of agriculture, the operation of such transformers did not cause any particular problems.
- Currently, the nature of the rural consumer load has changed significantly, a large number of non-linear power receivers with pulse power supplies at the input have appeared. Such a change in the nature of the load, together with the natural asymmetry mode that constantly exists in rural electrical networks, due to the mismatch in the connection time of single-phase receivers to the three-phase network, leads to a number of negative impacts associated with both the emergence of additional losses of electrical energy and a reduction in the service life of electrical network equipment.
- The asymmetry and non-sinusoidal currents are the main factors causing an increase in currents in the zero working wire of the network. Harmonic currents of multiples of three are close to common-mode and, when summed in a zero working wire, can form a current exceeding phase currents at a frequency of 150 Hz. Most of the operated cable lines in networks with a voltage of 0.38 kV are made of four-core. At the same time, the zero core of such a cable can be either of a smaller cross-section or of the same cross-section with phase cores. From the point of view of heating, a four-core cable with a zero core of a smaller cross section turns out to be in worse conditions. In power transformers, currents in multiples of three and the zero sequence current of the fundamental frequency lead to an increase in additional power losses and a decrease in the service life of the insulation.

Research objectives



Interest to study the operating modes of a power transformer loaded with a non-linear and asymmetric load, namely under conditions of extreme voltage asymmetry - phase break on the 10 (6) kV voltage side

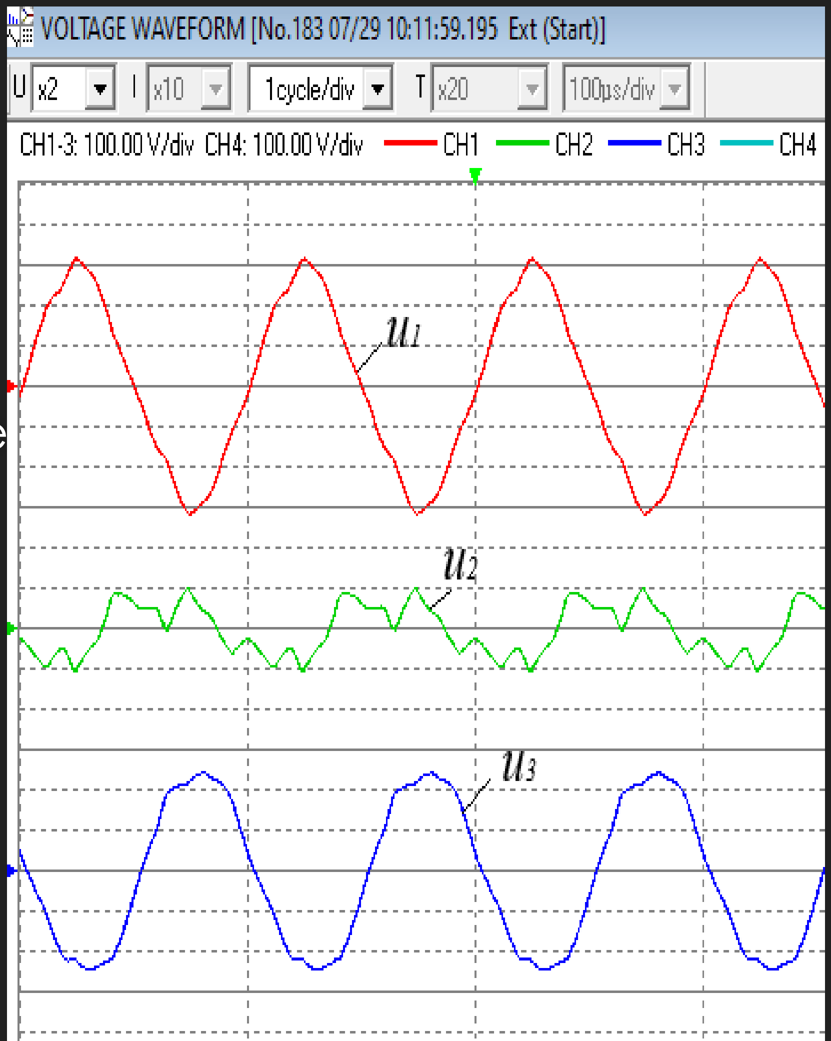
For this purpose, we have collected physical network model.

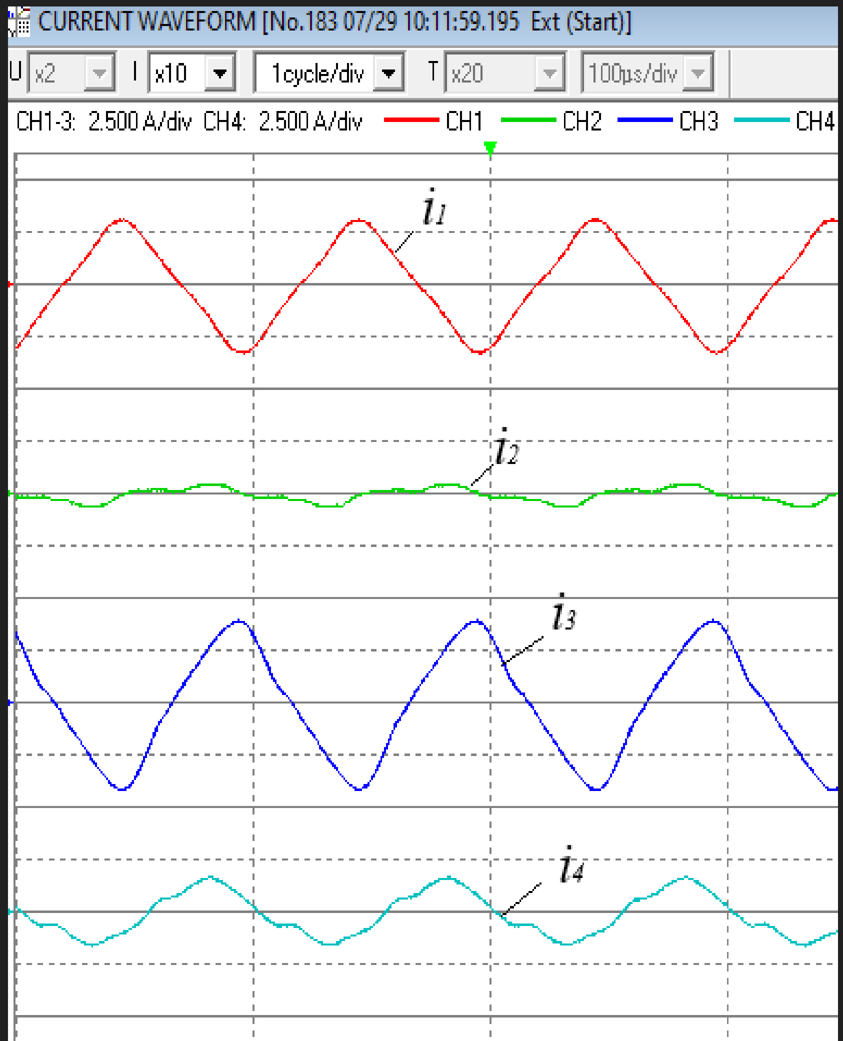
The network model was powered by a power transformer T type TS-1.5 with a star/star with neutral wire (Y/Yn) winding connection scheme. Electrical measurements were performed using a certified HIOKI 3196 instrument at the beginning of the line model, both statically and dynamically.

The total resistances Z1-Z4 and Z5-Z8 modeled the resistances of the line sections, and Zн1-Zн3 and Zн4-Zн6 modeled the nonlinear asymmetric load. The nonlinear load was modeled by mercury arc fluorescent lamps (Zн1-Zн3) and arc sodium tube lamps (Zн4-Zн6) with different nominal power. The load during the experimental studies was set as asymmetrical and nonlinear, and its parameters did not change throughout the experiments.

Methods

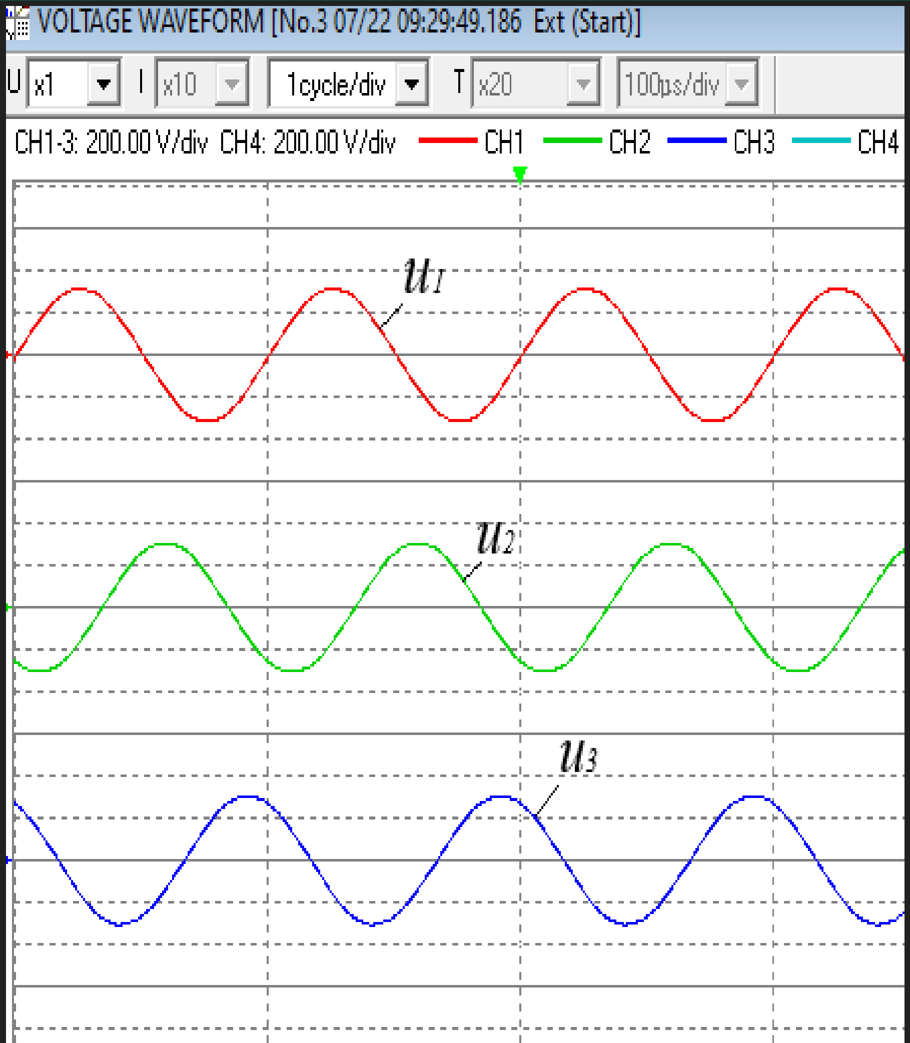
- During the experiments the following were recorded: vector diagrams voltages and currents of fundamental frequency, oscillograms voltages and currents, quantities voltages and currents direct, zero and negative sequences, effective values of phase voltages and currents, as well as current in the neutral wire and the value of k-factor.
- First, phase L2 was broken on the supply line side (at point 1).The recorded oscillograms and vector diagrams of currents and voltages are shown below.

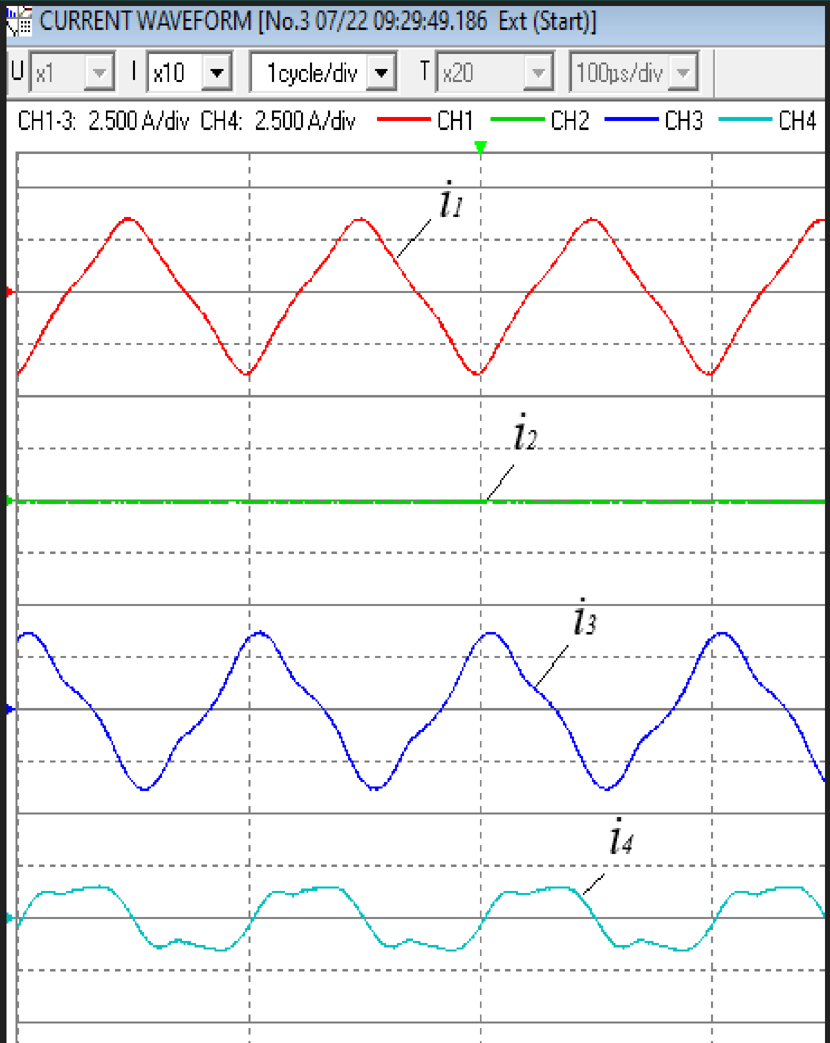




Methods

- During the second experiment, the load was disconnected from the secondary winding of the transformer at points 2.
- The recorded oscillograms and vector diagrams of currents and voltages are shown below





Results

- First, phase L2 was broken on the supply line side (at point 1)
- Vector Diagram Analysis currents and voltages shows a significant increase in the asymmetry of voltages and currents on the 0.4 kV side of power transformer T. In case of breakage of one of the phases on the supply line side and full load the coefficient of voltage unbalance by the negative sequence became 68.23%, the coefficient of voltage unbalance by the zero sequence – 1.14%, the coefficient of current unbalance by the negative sequence – 99.09%, the coefficient of current unbalance by the zero sequence – 25.49%.harmonic current components coefficients THD-I1=11.42%, THD-I2=43.77% and THD-I3=11.86%. Harmonic voltage components coefficients also increased, especially on the line wire L2.
- The k-factor values for each phase were respectively: kF1=1.11, kF2=2.63 and kF3=1.13. A significant increase in the k-factor in the linear conductor L2 is noticeable.
- Second experiment, the load was disconnected from the secondary winding of the transformer at points 2
- During current unloading in one of the Line wires of 0.38 kV line the coefficient of voltage unbalance by the negative sequence decreased to 2.4%, the coefficient of voltage unbalance by the zero sequence decreased to 0.44%, the coefficient of current unbalance by the negative sequence decreased to 74.13%, and the coefficient of current unbalance by the zero sequence increased to 25.87%.The harmonic current components coefficients in this mode are: THD-I1=13.63%, THD-I2=381.46% and THD-I3=16.61%. The harmonic voltage components coefficients have decreased.
- The k-factor values for each of the phases were respectively: kF1=1.15, kF2=0 and kF3=1.32, i.e. there was a slight increase in the linear wires L1 and L3.

Conclusions

When modeling two modes, it was determined that a nonlinear asymmetric load causes a change in the values of higher harmonics of voltage and current in the network under study, and also significantly increases the k-factor value in the mode of a break in one of the phases on the side of the supply line. The study showed that an open-phase mode on the side of the supply line significantly worsens the characteristics of the transformer in terms of the state of the winding insulation and its service life. It should be noted that according to the recommendations of the International Energy Commission (IEC), for normal daily wear of the transformer insulation, the temperature of the hottest point of the windings should not exceed + 98 ° C. If the temperature is increased by 6 ° C, almost half will reduce the service life of the insulation. In this regard, for a power transformer against overheating, especially in the summer, protection is required, either by negative sequence voltage or by negative sequence current with an effect on an independent tripping device of the circuit breaker on the lower side.

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