Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online): 0493-2137
E-Publication: Online Open Access
Vol:54 Issue:10:2021
DOI 10.17605/OSF.IO/S3EM9

INFLUENCE OF ASYMMETRICAL MODES ON THE VALUE OF ADDITIONAL POWER LOSSES IN LOW-VOLTAGE ELECTRICAL NETWORKS

ILKHOMBEK KHOLIDDINOV[1], ZAFAR TUYCHIEV[2], ERALIEV KHOJIAKBAR[3] AND MASHKHURA KHOLIDDINOVA[4]

[1,2,3,4]Power engineering Department, Fergana Polytechnic Institute, Fergana, Uzbekistan

Email: i.xoliddinov@ferpi.uz

ABSTRACT

In this article are presented the issues of one of the main power quality indicators of voltage unbalance and ways to solve them. An algorithm for measuring the level of the asymmetry coefficient of the reverse and zero sequence and the influence of the load unbalance on the amount of power and electricity losses are presented, as well as modeling the determination of the values of powers, voltages and currents and, accordingly, their symmetrical components. The use of domestic devices for monitoring the power quality in a separate power system is proposed. The results of measurements of electrical networks are presented. [1]

Index Terms: Power quality, asymmetrical modes, power losses

INTRODUCTION

The energy industry, being one of the basic sectors of the economy of the Republic of Uzbekistan, over the years of independence, developing at an accelerated pace, not only provides the country's needs for electricity, and has become an exporting state [1].

The efficiency of using electrical energy is determined mainly by the creation of such conditions for its consumption, which ensure the required power quality and a minimum of productive losses.

Electricity needs mandatory certification and at the same time has a number of features, including the continuity and simultaneity of production and consumption processes. The transportation of electricity is carried out at the expense of the consumption of a certain part of the product itself, that is, the loss of electricity during its transmission is inevitable.

When determining the value of the PQI for three-phase electrical networks, the requirements set forth in [2, 3] are legally established. Therefore, the analysis of the state and directions of development of methods and means of the state and directions of development of methods and means for measuring the PQI should proceed from the list and rules for measuring the PQI set forth in the above [2, 3]. In view of the above, in the future, the main attention will be paid to standard methods for measuring the PQI, taking into account the capabilities that are provided by modern computing facilities and their information support.

The relevance of the work is due to the constant increase in electricity prices, the need to reduce electricity losses in the process of its production and delivery to consumers. One of the factors that increase the loss of electricity in power distribution networks is the asymmetry of currents in its elements and voltage in the nodes. It is required to develop

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new methods for measuring voltage and current unbalance and associated energy losses. One of the ways of balancing currents and voltages is given in this work [4].

1.Influence of Asymmetrical Modes on the Value of Additional Power Losses

Unbalance of phase voltages noticeably affects the operation of power transformers, causing a reduction in their service life. The analysis of the work showed that at a rated load and a current unbalance ratio of 10%, the transformer insulation service life is reduced by 16% [4,5,7].

A feature of such systems is a fairly simple network structure (Fig. 1), usually consisting of a 6-10 kV medium voltage network, a transformer substation with step-down transformers, and a 0.4 kV low voltage network. As a rule, these are rather long networks, made in the form of overhead lines (less often, cable lines), through which end consumers are supplied, mostly in the form of single-phase loads. This leads to the fact that it is often not possible to sufficiently evenly distribute their load over all three phases, which in turn leads to an increase in losses in the network. Let us consider this issue in more detail [7].

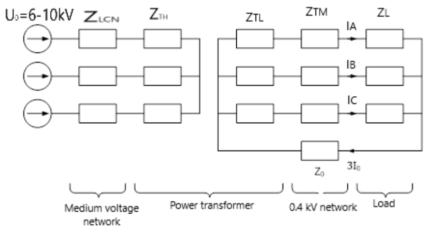

Fig. 1. Fragment of a network of power supply systems

On the example of a symmetrical vector diagram of voltages at the terminals of a 0.4 kV transformer (Fig. 2), it can be seen that voltage unbalance can form with an incorrect distribution of loads between phases in the form of two cases. In the first, the magnitude of the load modulo in one of the phases changes (in this case, let it be phase A), without changing its angle. In the figure, such a situation is shown by the vector U`A, the magnitude of the displacement by the vector ΔU`. For simplicity, we will call such a case "longitudinal" asymmetry. In the second case, the voltage module remains unchanged, but the angle of its rotation changes, which is displayed by the vector U``A and, accordingly, by the vector of voltage change ΔU``. This variant will be called “transverse” asymmetry [7].

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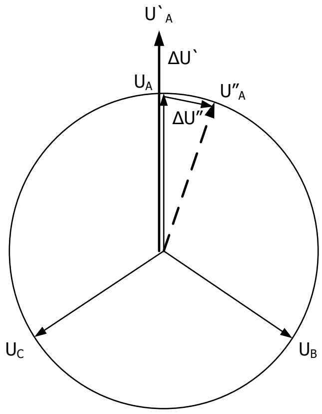

Fig. 2. Original vector diagram and new asymmetrical mode. U`A - "longitudinal" and U"A -" lateral "unbalance

In real life, of course, there is a combination of these two cases for all phases at the same time, but it will be useful to consider them separately, considering them as limiting cases, which make up the real asymmetry in the network.

All that has been said for voltages fully applies to the current load, in this case the network mode is characterized by completely similar vector diagrams. For brevity, we will omit them [7].

The direct sequence with "longitudinal" asymmetry in accordance with the method of symmetrical components is determined in the form (Fig. 3):

U`1 = 1/3*(U`A + cUB + c2UC) =1/3*(ΔU`+ UA
+ cUB +c2UC) = UA + ΔU`/3 (1)

where the operator c denotes the vector rotation by $+120^0$, and the c^2 operator the rotation by $+240^0$.

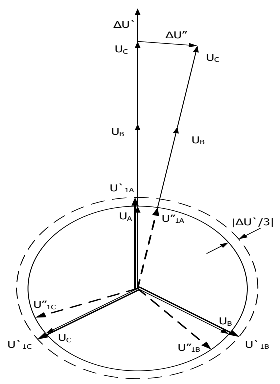

Fig. 3. Direct sequence for "longitudinal" and "lateral" asymmetry

Similarly, for the current we have:

I`1 = IA + ΔI`/3 (2)

In the case of "transverse" asymmetry, similarly to (1), we have:

U``1 = UA + ΔU``/3 (3)

I``1 = IA + ΔI``/3 (4)

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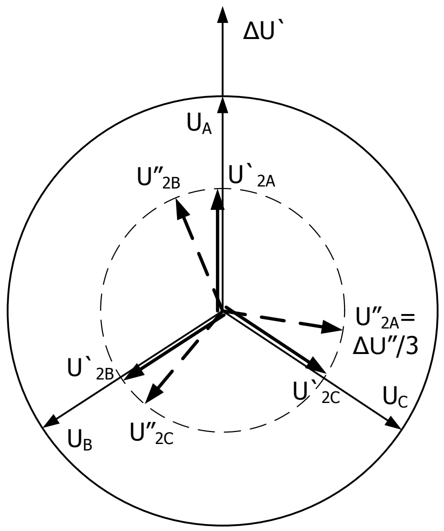

Fig. 4. Reverse sequence for "longitudinal" and "lateral" unbalance

The reverse sequence (Fig.4) in this case will be determined in the form, for the "longitudinal" asymmetry

$$U`_2 = \Delta U`/3 \qquad (5)$$

$$I`_2 = \Delta I`/3 \qquad (6)$$

and for "transverse"

$$U``_2 = \Delta U``/3 \qquad (7)$$

$$I``_2 = \Delta I``/3 \qquad (8)$$

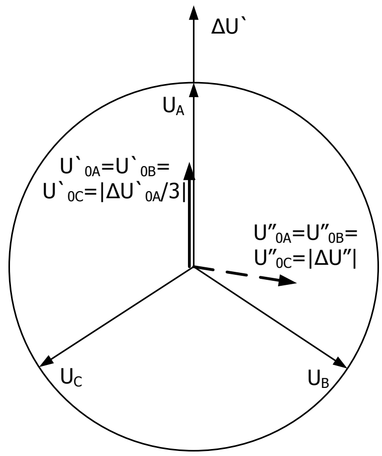

Fig. 5. Zero sequence for "longitudinal" and "lateral" unbalance

$$U`_0 = \Delta U`/3 \qquad (9)$$

$$I`_0 = \Delta I`/3 \qquad (10)$$

$$U``_0 = \Delta U``/3 \qquad (11)$$

$$I``_0 = \Delta I``/3 \qquad (12)$$

In real practice of operation of power supply systems, the asymmetry is measured as the value of the asymmetry coefficient [1] on the reverse

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$$K_{2U} = |U_2| / U_1 * 100 \quad (13)$$

$$K_{2I} = | I_2| / I_1 * 100 \quad (14)$$

and zero sequence

$$K_{0U} = |U_0| / U_1 * 100 \quad (15)$$

$$K_{0I} = |I_0| / I_1 * 100 \quad (16)$$

If measurements are carried out at the terminals of 0.4 kV of a transformer substation, we will evaluate what permissible values **ΔU`** and **ΔU``** can exist to meet the specified requirements. Let us determine these values for the "longitudinal" asymmetry from the following ratio, taking into account (1 and 13).

$$K_{2U} = (\Delta U`/3) / (U_A + \Delta U`/3) * 100 = 2 \quad (17)$$

Having solved this equation, we get,

$$\Delta U` = 0.061\ U_A \quad (18)$$

Thus, we can say with confidence in advance that if the “longitudinal” unbalance at the low voltage terminals of the transformer at any phase exceeds at least 6.1% of the normal voltage (in the case of a voltage of 220 V, this value is 13.5 V), then the power quality may not meet regulatory requirements. With an unbalanced voltage on one of the phases of 27.5 V, the power quality is absolutely accurate in the entire 0.4 kV network goes beyond the permissible limits [7].

Let us consider a similar question for the case of “transverse” asymmetry. As can be seen from Fig. 2, we have the right to write the following expression:

$$\Delta U`` = U_1 * \sin \Delta\varphi = 0,0175 * U_1 * \Delta\varphi \quad (20)$$

To change the value of the angle **Δφ** from 0 to 20 degrees, the error of such an approximation lies within 1%. Then, taking into account (13, 15), we can write

$$K_2 = K_0 = (\Delta U``/3) / U_1 \quad (21)$$

Further equating this expression, respectively 2 and 4, we obtain that when one of the voltage vectors is rotated by 3.44 degrees, we obtain the normally permissible value of asymmetry for the entire network of 0.4 kV, and when this vector is rotated by 6.88 degrees, we obtain the maximum permissible (ie, actually unacceptable) value of this parameter [7].

Thus, we have shown that a change in one of the voltage vectors, both in absolute value and in angle, leads to the appearance of an asymmetric mode in the network. The limiting values of these permissible changes on the low side of the transformer were obtained, at which the quality of electricity in the entire 0.4 kV network ceases to meet the required standards.

All the conclusions made for voltages can be applied to currents in the 0.4 kV network. In this case, it is no longer so important what kind of asymmetry takes place, "longitudinal" or "transverse". Although it is really difficult to expect a large value of the "transverse" current unbalance, since the composition of various loads is still usually quite homogeneous (all electrical receivers are similar - that is, of the same type). Much more real is a fairly large “longitudinal” unbalance caused by the imbalance of the loads of different phases?

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In this case, the main role is played by the value of the current unbalance in phases - □**I**, which determines the value of the current unbalance coefficient for the reverse (14) and zero (16) sequences. At the same time, the value of power losses in the 0.4 kV network can be determined in the following form (see Fig. 1):

$$\Delta P = 3*I_1^2*R_1 + 3*I_2^2*R_2 * 3*I_0^2*R_1 + (3I_0)^2*R_0 \quad (22)$$

Where R1 and $\mathbf{R_2}$ **-** active resistances of positive and negative sequence of a network of 0.4 kV, in this case they are equal to each other; R_0 - active resistance of the neutral wire for currents of the 0-th sequence (phase-zero loop).
It should be borne in mind here that, until recently (under Soviet rule), the neutral wire of cable and overhead lines was made with a smaller diameter (by two sections) compared to the phase one. Now, due to a sharp increase in the amount of distortion in electrical networks, due to the appearance of a large number of non-sinusoidal loads, the cross section of the 0th wire is usually the same as for phase wires. Therefore, at present, the ratio $R_0 = R_1$ can be considered valid [7].
Then, taking into account (14.16), expression (22) can be rewritten as follows:

$$\Delta P = 3*I_1^2*R_{1*}[1 + K_2^2 + K_0^2*(1+3R_0/R_1)] \quad (23)$$

Taking into account expressions (5-16), we obtain

$$K_2 = K_0 = (\Delta I/3) / (I_1+\Delta I/3) \quad (24)$$

Substituting this expression in (23), and proceeding to calculate the relative value of power losses in the network (relative to power losses only by losses from the direct sequence d $(\Delta P) = \Delta P / 3*I_1^2*R_1$), after elementary transformations we get:

$$d(\Delta P) = 1 + 5 * K_U^2 / (3 + K_U)^2 \quad (25)$$

where KU $\mathbf{= \Delta I / I_1}$ **-** coefficient of current load irregularity in phases.

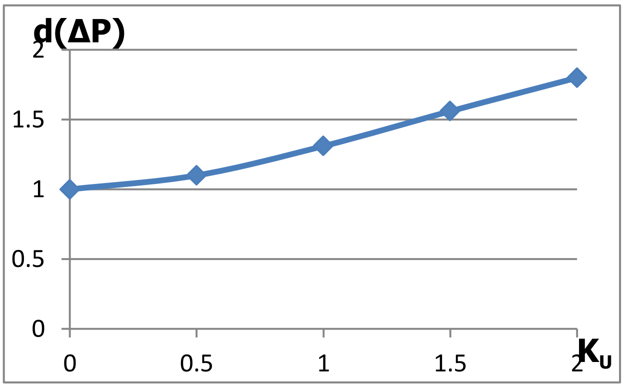

Fig. 6. Change in the relative value of electricity losses in the 0.4 kV network depending on the value of the load imbalance in phases

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Table 1. Dependence of the value of power losses on the coefficient of unevenness loads

Kn	0	0,5	1	1,5	2
d(ΔP)	1	1,1	1,31	1,56	1,8

As can be seen from the graph of this dependence (Fig. 6), with an unbalance of currents in one of the phases of 100% (Ku = 1.0), the value of losses in the network increases by more than 30%. With an unbalance of 200%, it almost doubles. Of course, strictly speaking, such a comparison has a certain methodological error, since with such imbalances, the magnitude of the direct harmonic also changes somewhat, but the qualitative dependence is still displayed correctly [7].
From the above considerations and calculations, we can make an unambiguous conclusion that the imbalance of the load in phases leads to a significant irrational increase in electricity losses in the network. Therefore, special attention should be paid to the correct phasing of loads, in order to prevent significant imbalance, in order to prevent, among other things, significant excess losses in electrical networks [7].

1. Development of power quality indicators

On the basis of the Tashkent State Technical University and the Fergana Polytechnic Institute, a domestic specialized measuring device "Malika-01" has been developed [8]. The device is designed to measure power quality indicators (PQI) in electrical networks with a voltage of 220 - 380 V. This device is used when conducting surveys and evaluating FE using statistical methods, including with a limited range of indicators in accordance with the requirements [2, 3]. The analog part provides simultaneous connection of up to three phases of alternating current, the connection diagram is shown in Fig. 7. The general view of the device is shown in Fig. 8.

As a result of measurements, we obtain the parameters required for the PQ analysis [4].
- Network frequency f (Hz);
- Effective values of voltages U (V) and currents I (A) for each of the 3-phase network;
- Active P (kW) and reactive Q (kVAr) power at the first harmonic for each of the 3-phase network;
- power factor cos φ = arctan (Q / P) (angles between the vectors of currents and voltages) at the first harmonic for each of the 3-phase network;
- Amplitudes of positive sequence U_1 (V) and currents I_1 (A) for each of the 3-phase network;
- Coefficient of voltage unbalance according to the reverse K_{2U} (%) sequence;
- Coefficient of voltage unbalance by zero K_{0U} (%) sequence;
- Coefficient of current unbalance according to the reverse K_{2I} (%) sequence;
- Coefficient of current unbalance by zero K_{0I} (%) sequence;

The device is made in the form of a single device, assembled in a plastic case, which provides mechanical and electrical protection, both for the device itself and for the personnel working with it. The device is equipped with 3 portable current-measuring clamps for connecting current channels in the case of its operation as a portable device

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(Fig. 7, 8) [4, 9]. The built-in non-volatile memory provides storage of the data obtained during the last 10 days of measurements. The front of the instrument has four voltage terminals and six latched current inputs. On the other side of the device there is a data output channel from the device: SD / MMC card reader [4,8,9].

Fig.7. Clamp meter connection diagram

Methods for measuring the quality indicators of electrical energy in electrical networks of power supply systems of alternating three-phase and single-phase current with a frequency of 50 Hz are established by the interstate SSt [2].

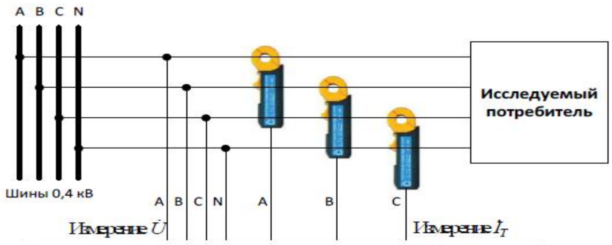

Fig.8. General View of the device "Malika-01"

On the basis of business agreement No. 9/15 dated May 25, 2015 with the “Tashkent TEEN” JSC, measurements were carried out from August 26 to September 1 at TP No. 399 in Zangiata region. The results of measurements of the third feeder of this TP are presented. The feeder provides electricity to the population, more than 50 houses [4].

From the results of PQI measurements given in [4], it follows that the quality of electrical energy:

According to the coefficient of voltage unbalance in the reverse sequence - does not correspond;

• According to the zero sequence voltage unbalance coefficient - does not correspond;

The analysis shows (Fig. 9 and 10) that on this feeder the current asymmetry coefficient in the negative sequence is K_{2i} = 30.3%, and the current asymmetry coefficient in the zero sequence K_{0i} = 33.5%. Obviously, there is a systematic asymmetry on the feeder. Consequently, by equalizing the loads in phases during the hours of the evening maximum load, it is possible to reduce the coefficients of the reverse and zero sequence of currents to 15%. This, in turn, will lead to a decrease in additional losses of more than 30% [8].

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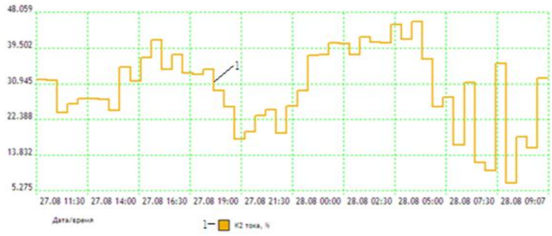

Fig. 9. The graph of the change in the coefficient of unbalance of the current of the negative sequence

Fig. 10. The graph of the change in the coefficient of unbalance of the zero sequence current

4. CONCLUSION

With a voltage unbalance of about 2%, the service life of transformers is reduced by -4%, and with a current unbalance of about 10% or more, the service life of transformer insulation is reduced by 16%. In addition, voltage unbalance leads to a decrease in the reliability of equipment operation at consumers. So with a voltage asymmetry of about 2%, the service life of asynchronous motors due to additional losses of active power is reduced by 10.8%, synchronous - by 16.2%, capacitors - by 20%. With a voltage unbalance ratio of approximately 4%, the service life of three-phase asynchronous electric motors is reduced by 2 times compared to the service life in the symmetrical supply mode [5].
To eliminate the unbalance of currents and voltages in the 0.38 kV network, it is also necessary to use balancing devices.
A prerequisite for effective control of PQ is the use of the proposed domestic device that implements the algorithm for calculating for electricity, taking into account its quality, which is necessary for periodic (summer, winter) and constant measurements.

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