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# Non-linear Electrical Load Location Identification

**Stanislav PIROG**[1], **Yaroslav E. SHKLYARSKIY**[2] ✉, **Aleksandr N. SKAMYIN**[2] ✉
[1] *AGH Scientific and Technical University, Krakow, Poland*
[2] *Saint-Petersburg Mining University, Saint-Petersburg, Russia*

The article discusses the issues of identifying the location of non-linear loads in electrical networks which makes the main contribution to the distortion of the non-sinusoidal voltage and current in the distribution network of an industrial enterprise, including mining enterprises. The existing methods for determining the location of the source of higher harmonic components in voltage and current are considered, their advantages and disadvantages are revealed. The main disadvantages of the methods used include the low accuracy and incorrectness of their use in existing enterprises. When developing a new method, the authors were faced with the task of simplicity of its use in the conditions of industrial operation of electrical equipment and the absolute correctness of the results obtained. The proposed method of identifying the source of higher harmonics is based on the variation of the parameters of the power system, in particular, the change in resistance of power transformers taking into account their transformation ratio. It is shown that by varying the transformation ratio during regulation under load, the total coefficient of the harmonic components of the voltage changes. Based on the constructed dependencies, the variation of the derivative of this function with different variations of the parameters of sources of higher harmonics is analyzed and a method is developed that allows determining the share contribution of consumers to the total harmonic component of the voltage.

***Key words*:** higher harmonics; electrical network; consumer; electrical load; source of distortion; total harmonic voltage component; power quality

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**Introduction.** Intensive distribution has been received by electrical receivers with non-linear current-voltage characteristics, in which semiconductor converter technology is used in order to save energy and increase labor productivity [2, 10, 17]. The functioning of their main modules is based on the operation of high-speed semiconductor switches and is the cause of complex transients in systems. As a result, non-linear current is consumed from the network, which creates a non-sinusoidal voltage drop and leads to the appearance of higher harmonic components in the supply voltage [4, 5]. Non-sinusoidality in the supply voltage can occur both due to the consumption of non-linear current by the electrical complex of the enterprise itself, and due to the consumption of non-linear current by other consumers connected to the common connection point [3]. The issues of identification of non-linear electrical loads, as well as their percentage in total indicators of power quality are particularly relevant and unresolved at the moment in Russia, as there are still no regulatory documents regulating the procedure for imposing penalties for both consumers and representatives of electrical networks.

The aim of the work is to develop a method for identifying the location of the electrical load, which degrades the quality indicators of electricity, relative to the point of general connection with the determination of the percentage content in the total indicators of the quality of electricity.

**Formulation of the problem.** In [12, 16], a method for determining the source of harmonic distortion, based on the active two-terminal method is presented. This method has a drawback – when it is used, the data on the equivalent resistances of the network and the consumer which are determined during the measurements and on the basis of which the location of the consumer deteriorating the power quality is detected are initially unknown. A well-known method for single-phase networks is based on determining the sign and power values of higher harmonics (active power flux method) transmitted from the source of distortion to the network [14]. Based on the power theory [6, 9] such a method was refined and applied to multi-phase a system which is reflected in [7, 8, 13]. The application of the method is associated with the determination of the phase angles of volt-

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age and current at higher harmonics. In conditions with low distortion, such measurements should be carried out with means with a very high accuracy class. In addition, this method does not allow determining the percentage content and the contribution of the distorting consumer in the diversified occurrence of higher harmonics relative to the point of common connection.

From which it follows that at the moment there is no well-established and unambiguous method for determining the source of harmonic distortions in electrical networks, especially under the condition of their diverse occurrence relative to the common connection point, which indicates the relevance of research in this area.

**Research methods.** As a rule, in large-scale production, input power transformers are equipped with means for regulating voltage under load, and transformers of outgoing substations with switching devices without excitation. Since the resistance of the transformer windings is predominantly inductive, varying the transformation ratio will lead to a significant change in the resistance to current flow at frequencies higher than the main one, which will affect the total harmonic component of the voltage ($K_U$).

When simulating non-sinusoidal modes, the known equivalent circuits of a transformer [1] were used, namely, a magnetic coupling and a classical T-equivalent circuit with a parallel representation of the magnetization branch. The simulation did not take into account phenomena arising from the saturation of the transformer core [11].

The basis for the calculations was adopted by the established scheme of replacing the electrical network of the enterprise, taking into account the occurrence of distortions on the part of the consumer and the power supply network, presented in Fig.1 [15].

Sources of distortions on the part of the supply network are represented as a series of connected sources of voltage at the corresponding frequency. The sources of distortions on the part of the consumer are presented in the form of parallel-connected current sources at the corresponding frequency. Equivalent linear electrical load is replaced by parallel connection of active and inductive resistances. The transformer is presented in the form of a T-shaped equivalent circuit.

**Scientific and practical results.** The simulation was carried out using the application package MathCAD. Initially, the mode of operation of the network was modeled with the separate occurrence of higher harmonic components relative to the consumer of electrical energy and the electrical network. The dependences of the total harmonic components of the voltage on the transformation ratio $K_т$ were constructed. These dependences for the secondary winding of the transformer ($K_{U2}$) are presented in Fig.2.

According to the graphs obtained, the following conclusions can be drawn. The nature of dependencies is almost linear with a minimum proportion of convexity and concavity of the curve. Increasing or decreasing the function allows detecting the culprit of voltage sine wave violation, i.e. in the presence of a source of distortions on the part of the consumer with an increase in the transformation ratio, the total coefficient of harmonic voltage components increases (the change varies within 25 %) and vice versa if there is a source of distortion on the network side (the change varies within 3 %). The coefficient $K_{U2}$ varies within 25 % in the case of a consumer degrading the quality

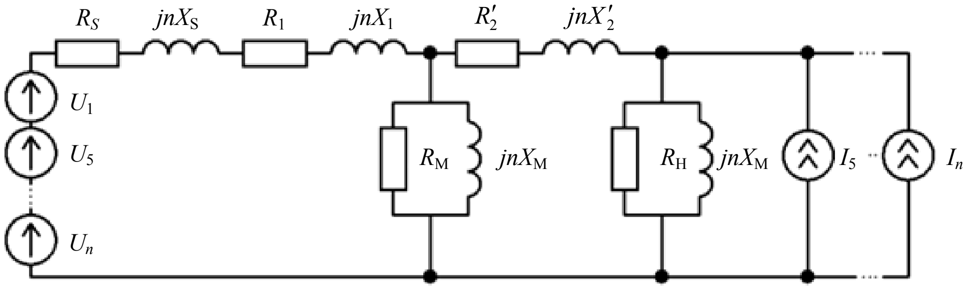


Fig.1. The equivalent circuit of the electrical network, taking into account the occurrence of distortions on the part of the consumer and the mains

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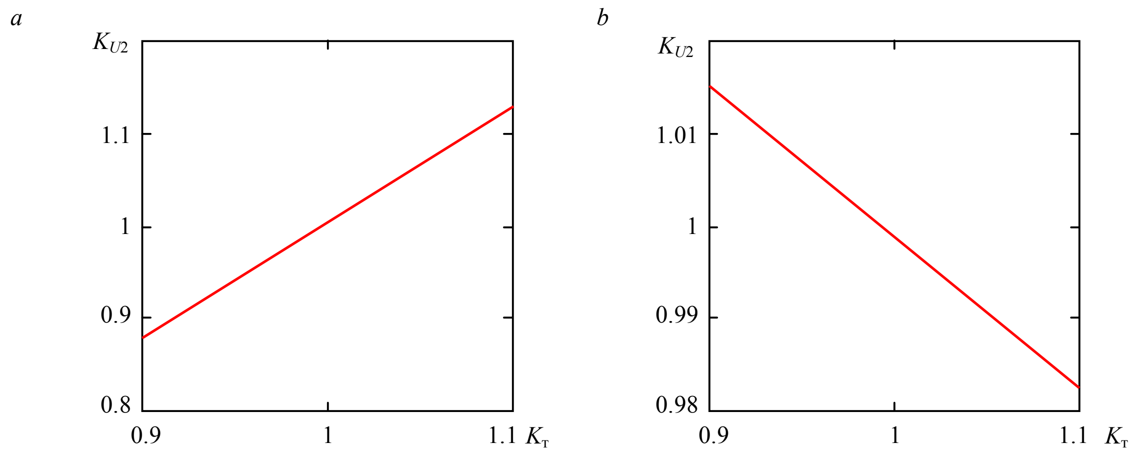


Fig.2. Dependences of $K_{U2}$ from $K_T$ in the presence of distortions on the supply side (*a*) and on the consumer side (*b*)

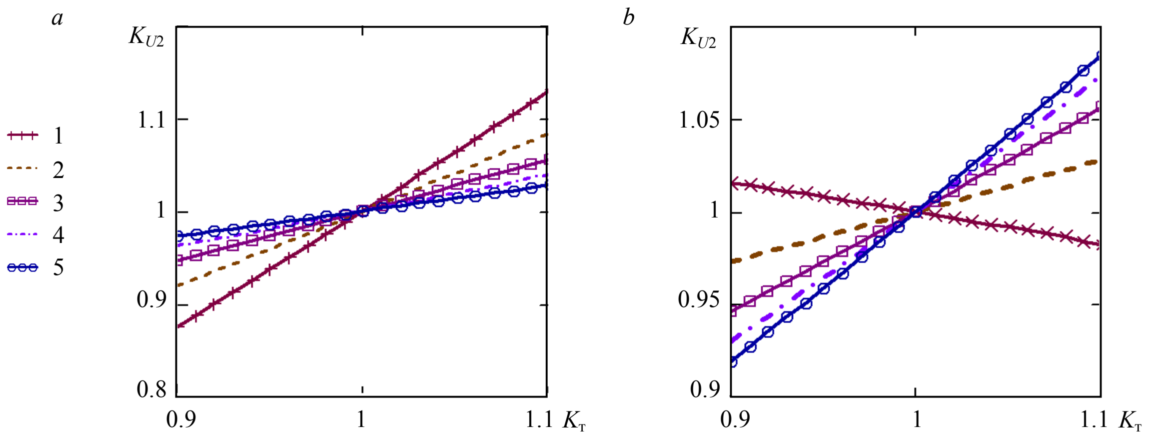


Fig.3. Dependences of $K_{U2}$ in per unit values on $K_T$ at varying the source of distortion from the supply network (*a*) and varying the source of distortion from the load (*b*)

1 – $K_{U2oe}(0, k)$; 2 – $K_{U2oe}(0{,}5, k)$; 3 – $K_{U2oe}(1, k)$; 4 – $K_{U2oe}(1{,}5, k)$; 5 – $K_{U2oe}(2, k)$

of electrical energy, and within 3 % in the case that the cause of distortion is the supply network. In this case, the transformation ratio varied within 0.9-1.1 of the nominal transformation ratio. When modeling the processes, the parameters of nonlinear electrical loads were chosen based on the equality of the total harmonic voltage component in the secondary winding.

Since the aim of the work is to detect the cause of harmonic distortions with the determination of their percentage in total indicators of power quality, similar dependencies were constructed while simultaneously varying the parameters of non-linear electrical load from the network and the consumer. The graph corresponding to the change in the parameters of the source of distortions on the power supply side with a constant source of distortions on the load side in relative units is shown in Fig.3. A similar graph corresponding to the change in the parameters of the source of distortion on the load side with a constant source of distortion on the supply side in relative units is presented in Fig.4.

Using the plotted graphs, it is rather difficult to determine the percentage content and the percentage contribution of the source of distortions to the total indicators, therefore, changes in the derivative of this function with different combinations of parameters of non-linear electrical load were additionally analyzed (Fig.4). In this case, an additional coefficient d was introduced, which characterizes the contribution of the source of distortions to the total indicators. In other words, this is a coefficient in proportion to which the contribution of the source of distortions from the network (consumer) increases with the constancy of distortions that arise from the consumer (network).

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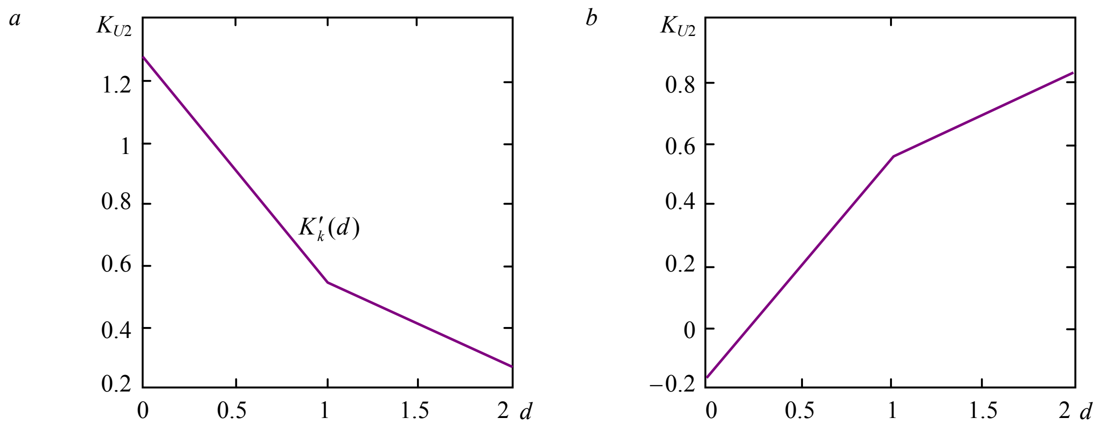


Fig.4. The dependences of the derivative $K_{U2}$ from the coefficient *d* with increasing distortion from the system (*a*) and load (*b*)

From the graphs obtained, it follows that the derivative $K'(d)$ is an increasing function (the angle of inclination of the function increases) with an increase in the fraction of distortions on the part of the consumer and is a decreasing function with an increase in the proportion of distortions from the supply network. It is established that the derivative $K'(d)$ oes not change with a simultaneous proportional change in distortion on the part of the network and the consumer, only the quantitative indicators of the total harmonic components of the voltage change. Thus, we can conclude that the derivative $K'(d)$ is a criterion that allows us to determine the percentage and equity contribution to the total distortion.

**Conclutions.** Analysis of the change in the $K_{U2}$ derivative by $K_{\text{т}}$ depending on the introduced coefficient *d*, corresponding to the contribution of the source of distortions to the total indicators, revealed that the derivative is minimal and has a negative value if there is a source of distortion exclusively from the system, as the percentage of harmonics increases from the consumer the derivative increases and takes the maximum value when distortions occur solely on the load side. It should be noted that the values of the derivative correspond to the type and parameters of the transformer under study, and also depend on the system parameters and the linear electrical load, however, they always have a positive tendency with an increase in the percentage of harmonics from the consumer and (or) a decrease in the contribution from the system.

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***Authors*: Stanislav Pirog,** *Doctor of Engineering Sciences*, *Professor*, *pirog@agh.edu.pl* (*AGH Scientific and Technical University*, *Krakow*, *Poland*), **Yaroslav E. Shklyarskiy,** *Doctor of Engineering Sciences*, *Professor*, *js-10@mail.ru* (*Saint-Petersburg Mining University*, *Saint-Petersburg*, *Russia*), **Aleksandr N. Skamyin,** *Candidate of Engineering Sciences*, *Assistant Professor*, *skamin_an@pers.spmi.ru* (*Saint-Petersburg Mining University*, *Saint-Petersburg*, *Russia*).

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