Assessment of the consumers’ contribution to the deterioration of the electrical power quality

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Abstract. The article presents the rationale for the further development of the methods that uniquely identify consumers making a major contribution to the deterioration of the quality of electricity in power supply systems of enterprises. A new method that gives an unambiguous result is proposed. This feature is a significant difference from the known methods. The given statements are confirmed by the results of computer simulation that are presented in the article. The method is based on the principle of changing the input resistance of the system implemented by varying the impedance of the transformer windings. An on load tap changer can be used for this purpose. The prospects for applying the method to determine the contribution of individual consumers to the changes in the quality of electric power of the enterprises supply systems in terms of percentage are shown.

1. Introduction
At present, as the manufacturers of modern industrial equipment (Siemens, ABB, Schneider Electric), as the scientists [1–5] are highly interested in the problem of voltage compensation of higher harmonics in electrical networks of various levels. This relevance is caused by several factors. The distortion in the electrical network caused by the increasing spread of non-linear loads, such as a frequency-controlled drive [6] and others [7-12] is the first factor. The second one is the need to comply with the global power quality standards as IEEE 1159-1995, IEEE 519-1992. The third reason is the incompletely solved problem of harmonic compensation. In addition, there is no well-reasoned approach to the development of a unified methodology for assessing the effect of higher harmonics on the electrical equipment operation as well as the methodology for choosing the criteria for this assessment [13-16]. The last case includes the issue of identifying the sources of distortions that make the dominant contribution to the deterioration of the quality of electric power [17-20].

There are some methods to define the contribution of consumers to distortions. The most well-known methods, are listed below:

- active two-pole method [21] implies a change in the contribution of the distortion either by the consumer or by the system that leads to calculation errors when it is possible to simultaneously change both of the above factors;
- active power flow method [22] requires high-precision measurements of amplitudes and initial phases of higher harmonics for further calculation of active power;
- inactive power method [23] based on difference between Frieze’s reactive power and Sharon’s root mean square power when non-sinusoidal voltage and current. As a result, the ratio of these powers can determine the level of the load’s non-linearity and the voltage’s
nonsinusoidality but it is highly difficult to estimate the contribution of both the system and the load itself to the total distortion.

It follows that none of them gives precise information about the contribution of each consumer to the distortions of the system in a percentage correlation. Moreover, none of the existing methods is officially approved by the state or international standard. On the other hand, the correct determination of the higher harmonics sources that make the major impact on the network operation modes is an extremely important and urgent issue since it is connected with the further selection of the most effective ways of higher harmonics compensating.

2. Computer simulation

To develop a method for determining the contribution of consumers to the deterioration of electric energy quality indicators studies have been conducted using Matlab Simulink software.

An equivalent circuit of the power supply system with two equivalent customers was compiled (Figure 1). The parameters of all elements are given to the 6 kV phase-to-phase voltage of the distribution network.

Figure 1. The equivalent circuit of the power supply system.

The parameters of power lines are listed in Table 1.

| Line   | Length, km | Specific resistance R, Ohm / km | Specific reactance X, Ohm / km | Active resistance R, Ohm | Reactance X, Ohm |
|--------|------------|---------------------------------|--------------------------------|--------------------------|-----------------|
| Line 2 | 2          | -                               | 0.217                          | -                        | 0.435           |
| Line 1 | 1.33       | 0.253                           | 0.090                          | 0.336                    | 0.120           |
| Line 2 | 1.5        | 0.125                           | 0.077                          | 0.188                    | 0.116           |

Each enterprise consists of a linear load represented by a Load block and a non-linear load, replaced by current sources. Furthermore, a capacitor for reactive power compensation with a series inductance tuned to the resonance at a frequency of 134 Hz is installed at the first consumer. The structure of the second consumer is similar to the first one and the measurement block calculates the
root mean squared value and the total harmonic distortion of the voltage and current of the first consumer. The parameters of the above elements are listed in Table 2.

**Table 2. Consumers’ parameters.**

|                  | Linear load | Nonlinear load | Power factor correction capacitor |
|------------------|-------------|----------------|-----------------------------------|
|                  | Active power | Reactive power | Active power | Reactive power | Reactive power |
|                  | P, kW        | Q, kvar        | P, kW        | Q, kvar        |
| Consumer 1       | 1300         | 975            | 1000         | 425            | 300            |
| Consumer 2       | 2700         | 2000           | 2700         | 800            | -              |

To conduct the research, it was suggested the upstream inductance of the line that includes the input transformer inductance can affect the parameters of the load when it varies. Also load’s parameters depend on the coupling point of the higher harmonics source.

In this regard, the model was calculated while the following parameters changes:

- the resistance of the first consumer input transformer was varied within ± 15% of the nominal value,
- the total power of the nonlinear load of the first and second consumers was taken as 100%, the ratio between the power of the non-linear load of the first consumer and the total non-linear power, in percentage correlation, was varied within 0-100%. At the same time, the contribution of the second consumer to network distortions was varied within 0-100%. Thus, the total power of the non-linear network load remained constant.

As a result, a graph of the first consumer bus voltage 1 was obtained depending on the change in impedance of the input transformer and the contribution of the first consumer.

Analyzing the obtained data, it was established that when 0% contribution of the first consumer to the network distortions its dependence decrease (Figure 2a). At the same time, with a 100% contribution of the first consumer the voltage has an upward trend (Figure 2b).

![Graph](image)

**Figure 2.** The first consumer bus voltage: a) – 0% contribution to non-sinusoidality, b) – 100% contribution to non-sinusoidality.

In order to determine the contribution when the type of the dependence is changing, the derivatives of the voltage U by the change in the resistance of the transformer Z were calculated for each of the contributions of the first consumer. Making a conclusion from the calculated results, the derivative of
the consumer's voltage by the input transformer resistance's change has similar values for all resistances. Based on this, the average value of the voltage derivative was calculated (Figure 3).

![Image]

Figure 3. The average value of the consumer’s voltage derivative.

Analyzing the obtained dependence it can be concluded that it is nonlinear. Consequently, it cannot be used as a convenient criterion for determining the quantitative contribution of the consumer to total distortion in a percentage correlation. However, the resulting dependence clearly indicates the major source of distortion relative to the point of common coupling.

3. Results

As a result of the research, a dependence of the first consumer's bus voltage was obtained depending on the input transformer resistance and the contribution of the first consumer to the distortion of the system. Then, the derivatives of this voltage by changing the transformer resistance for each of the consumer's contributions were calculated.

In sum, a method that determines the dominant source of higher harmonics relative to the point of common coupling was formulated. Also the basis for the further criterion development was determined which shows the consumer's contribution to the deterioration of electric power quality indicators in percentage correlation. Namely, it is the dependence of the higher harmonics voltage derivative by the resistance change of the input transformer.

The developed method allows to determine a consumer who makes a dominant contribution to the distortions of the power supply system of enterprises that are fed from a common network. Besides, it should be highlighted that in comparison with conventional methods, the proposed one is unambiguous and practically does not dependent on measurement accuracy, since it is based only on the type of the dependence.

References

[1] Bunteev Yu E and Shklyarskiy Ya E 2016 Analysis of methods for determining the sources of higher harmonics in electrical networks J of Scientific Publications of Graduate and Doctoral Students 1(115) 88–91
[2] Gamazin S I and Petrovich V A 2003 Determination of the actual contribution of the consumer to the distortion of the parameters of the electrical energy quality J of Industrial Energy 1 32–8
[3] Mayer V Ia 1994 Methods for determining the contribution of consumer and energy supplying organizations in the deterioration of the electricity quality J Electricity 9 19–24
[4] Smirnov S S 2010 Higher harmonics in high voltage networks (Novosibirsk: Nauka)
[5] Shklyarskij Ya E and Pirog S 2016 Impact of the load curve on losses In the power supply network of the company Journal of Mining Institute 222 859-63 (in Russian)
[6] Ivanchenko D I, Salov R A and Yakovleva E V 2018 Analysis of Z-source inverter control system for asynchronous drive for gas compressor Proc. of the 2018 IEEE Conf. of Russian Young Researchers in Electrical and Electronic Engineering, ElConRus 636–40
[7] Obraztsov N V and Frolov V Y 2018 A two-dimensional axisymmetric model of an AC arc Proc. of the 2018 IEEE Conf. of Russian Young Researchers in Electrical and Electronic Engineering, ElConRus 1203–4
[8] Denisova O V, Belitskiy A A and Shelkovnikova I V 2018 Technology of manufacturing the materials for biomedical sensors Proc. of the 2018 IEEE Conf. of Russian Young Researchers in Electrical and Electronic Engineering, ElConRus 977–80
[9] Malarev V I, Kopteva A V and Koptev V Y 2018 Electric power supply system development for down-hole electric steam generators to produce high-viscosity oil Proc. of International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon) 1(1) 1–8
[10] Kanygina E D, Denisova O V and Rastvorova I V 2019 Optical and electrical control in printed circuit board manufacturing Proc. of the 2019 IEEE Conf. of Russian Young Researchers in Electrical and Electronic Engineering, ElConRus 536–8
[11] Ivanchenko D I and Smirnov A I 2019 Simulation of interwire short circuits in transformer windings by means of Simulink MATLAB Proc. of the 2019 IEEE Conf. of Russian Young Researchers in Electrical and Electronic Engineering, ElConRus 977–80
[12] Frolov V Y, Bystrov A V and Neelov A A 2017 Imitating model of a microprocessor trip unit of a circuit breaker Proceedings of the 2017 IEEE Russia Section Young Researchers in Electrical and Electronic Engineering Conference, ElConRus 838–40
[13] Artyukhov I I, Solomin M A and L’vova E V 2016 A method of reactive power measurement in industrial alternative current mains supplies Int. Conf. on Actual Problems of Electron Devices Engineering (APEDE) 2 7879029
[14] Skamyin A N and Kovalchuk M S 2018 Energy efficiency improving of reactive power compensation devices Proc. of the 2018 IEEE Conf. of Russian Young Researchers in Electrical and Electronic Engineering, ElConRus 780–3
[15] Shklyarskiy Y E, Bardanov A I and Shklyarskiy A Y 2018 Novel approach to control of active rectifier during voltage dips IOP Conf. Ser. Earth Environ. Sci. 194 052022
[16] Bardanov A I and Pudkova T V 2019 Control of D-STATCOM for asymmetric voltage dips compensation Proc. of the 2019 IEEE Conf. of Russian Young Researchers in Electrical and Electronic Engineering, ElConRus 430–3
[17] Korotkov A and Frolov V 2016 Calculation methods for determination of electrical load schedules of residential consumers and their indicators Acta Technica CSAV (Ceskoslovensk Akademie Ved) 61(1) 73–9
[18] Shklyarskiy A Y, Zamyatin E O and Rastvorova J V 2018 Developing of electric power quality indicators evaluation and monitoring intellectual system Proc. of the 2018 IEEE Conf. of Russian Young Researchers in Electrical and Electronic Engineering, ElConRus 761–2
[19] Solovev S V, Kryltsov S B and Voytyuk I N 2018 Static load characteristics consideration for determination of transmission line power capacity Proc. of the 2018 IEEE Conf. of Russian Young Researchers in Electrical and Electronic Engineering, ElConRus 803–6
[20] Batueva D E and Shklyarskiy J E 2019 Increasing efficiency of using wind diesel complexes through intellectual forecasting power consumption Proc. of the 2019 IEEE Conf. of Russian Young Researchers in Electrical and Electronic Engineering, ElConRus 434–6
[21] Yang Hong Geng 1992 Assessment for harmonic emission level from one particular customer (Liège: University of Liege)
[22] Sasdelli R et al 1993 Considerations on power definitions on nonsinusoidal conditions IMECO TC-4 5th Int. Symp., Vienna, Austria
[23] Barbaro P V et al 2007 A novel approach based on nonactive power for the identification of disturbing loads in power systems *IEEE Transactions on Power Delivery* **22** 1782–9