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The ways for the improvement of the information value of the methods for the assessment of the quality of electric energy as a part of its technical accounting systems

Abstract. *The paper deals with the possibilities of the improvement of the accuracy and the information value of the assessment of the quality of electric energy, based on separate components of instantaneous power. We proved the efficiency of the use of the singled-out component of the distortion power and the coefficients for the identification of the consumers causing nonlinear distortions in the supply network, calculated with the use of the introduced value of the effective power. The obtained results can be used as a part of the systems of technical accounting of electric energy for the creation of the efficient systems of the compensation for nonlinear distortions.*

Streszczenie. *W artykule przedstawiono możliwości poprawy dokładności i wartości informatywnej oceny jakości energii elektrycznej, bazując na składnikach mocy chwilowej. Udowodniono skuteczność użycia pojedynczych składników mocy zniekształceń oraz współczynników do identyfikacji odbiorców, powodujących nieliniowe zniekształcenia w sieci zasilającej obliczane przy użyciu wartości wejściowej mocy skuteczne. Otrzymane wyniki mogą być użyte jako część systemów technicznej ewaluacji energii elektrycznej dla stworzenia efektywnych systemów kompensacji zniekształceń nieliniowych.* ***(Sposoby poprawy wartości informatywnej metod oceny jakości energii elektrycznej jako część ewaluacji systemu technicznego)***

Keywords: electric energy, quality factors, electromagnetic compatibility, active power, reactive power, distortion power.
Słowa kluczowe: energia elektryczna, współczynnik jakości, kompatybilność elektromagnetyczna, moc czynna, moc bierna, moc zniekształceń

Introduction

The irreversible growth of energy consumption and the increase of the index of the nonlinearity of the typical load of electrical networks at industrial enterprises, municipal service objects and household consumers, existing during the recent decades, make topical the problems of the assessment of the electric energy quality and the identification of consumers introducing various distortions into the networks [1]. The existing normative acts providing penalties regulate only the distortion of voltage. It does not give practically any idea of the real character of the energy exchange processes in electric circuits. Besides, the application of these acts in practice is opposed by the impossibility to part both the separate consumers influence on each other and their individual and (or) joint action on the mains supply. The above said is the main cause of the violation of electromagnetic compatibility manifested in the increase of energy consumption, the levels of reactive energy interchange, the distortion of electric networks currents and voltages, the disoperation of relay protection and automation devices. The principles of electric network designs in Ukraine often do not enable quick and reliable determination and localization of the sources of such distortions, which results in periodic occurrence of particular engineering problems as well as conflict situations in the relationship of the consumers and energy supplying organizations.

Thus, the solution to the problem of the improvement of the information value of the method and the means of the assessment of the quality of electric energy for different types of load and operation modes of the consumers is an important research and technical task. The present paper deals with the solution to this problem.

Theory

The main consumers with a nonlinear character of the load include, first of all, arc steel-smelting furnaces, frequency converters and other semiconductor converters and for low-voltage systems additionally – electromechanical devices with saturated magnetic systems, impulse supply sources, especially at their mass use, LED lamps, etc. [1, 2].

A nonlinear character of the load practically causes a non-sinusoidal form of the consumed currents as well as the supply voltage distortions in some cases. It sharply decreases the number of the methods used for the solution of the posed problem. The most accurate and informative of them imply preliminary spectral analysis of both consumed power on the whole and the consumed current in particular [3]. It is practically impossible to solve this problem without the use of multifunctional technical means of energy consumption control and the determination of the electric energy quality.

As a rule, such problems are solved based on automatic systems of commercial accounting of electric energy (ASCAE). However, the software and the algorithms of information processing, being part of them, are practically meant for sinusoidal currents and voltages and cannot be applied to the considered case. Their readjustment for the posed problems is unreasonable due to the high cost of such solutions. The automatic systems of technical accounting of electric energy (ASTAE) are an alternative variant. They differ from ASCAE in a lower cost combined with high functionality and readjustment of the software, but they are often inferior as to the simplicity of adjustment, accuracy and the absence of metrological attestation. Typical microcontrollers with a digital signal processor are the center of such systems. They analyze the information coming from the current and voltage external sensors.

The improvement of the information value of the assessment of the indices of the energy processes as a part of ASTAE is possible at the analysis of the parameters of the instantaneous power of electric signals with singling out the following components:

– the active power constant component;
– the active power sign-variable components;
– the reactive power from the voltages and currents of one frequency;
– the distortion power in the form of a sum of products of different-frequency signals of voltage and current.

In this case the mean-root-square or effective power is assumed as the basic value for the determination of the energy indices.

If the voltage and current are non-sinusoidal and represented by the dependences of the form

(1) $$u(t)=\sum_{n=1}^{N}u_n(t), \quad i(t)=\sum_{m=1}^{M}i_m(t),$$

where $u_n(t)$, $i_m(t)$– instantaneous values of the corresponding voltage and current harmonics, the instantaneous power is described by expression

(2) $$p(t)=\sum_{n=1}^{N}u_n(t)\sum_{m=1}^{M}i_m(t).$$

In accordance with the rules of the multiplication of harmonic series we obtain

(3) $$\begin{aligned} p(t) &= P_{k0\Sigma}+\sum p_{ka}(t)+\sum p_{kb}(t)= \\ &= P_{k0\Sigma}+\sum\left(p_{kac}(t)+p_{kacs}(t)\right)+ \\ &+\sum\left(p_{kbc}(t)+p_{kbcs}(t)\right)+p_{kas}(t)+p_{kbs}(t), \end{aligned}$$

where k– the number of the instantaneous power harmonic determined by expression $k=m\pm n$; $P_{k0\Sigma}$ – the total value of the active power obtained from the products of voltage and current harmonics of the same name ($m=n$) taking into account their phase shift; p_{kac} – the active power harmonics obtained from the product of the voltage and current single-frequency harmonics ($k_c=m+n$); p_{kbc}– the reactive power harmonics obtained from the product of the voltage and current single-frequency harmonics ($k_c=m+n$); p_{kacs}– the instantaneous power harmonics obtained from the product of the voltage and current different-frequency harmonics ($k_s=m\neq n$) provided equality $k_s=k_c$ is true; P_{kbcs} – the instantaneous power harmonics obtained from the product of the voltage and current different-frequency harmonics ($k_s=m\neq n$) provided equality $k_s=k_c$ is true; p_{kas} – the instantaneous power harmonics obtained from the product of the voltage and current different-frequency harmonics, for which $m\neq n$; $k_s=m\pm n$; $k_s\neq k_c$; p_{kbs} – the instantaneous power harmonics obtained from the product of the voltage and current different-frequency harmonics, for which $m\neq n$; $k_s=m\pm n$; $k_s\neq k_c$.

In all the given dependences, index "*a*" designates the cosine orthogonal components, and index "*b*" – the sine ones.

The effective power of non-sinusoidal signals

(4) $$\begin{aligned} P_e &= \sqrt{\frac{1}{T}\int_0^T u(t)i(t)}=\sqrt{P_{k0\Sigma}^2+\frac{1}{2}\sum\left(P_{kac}+P_{kacs}\right)^2+} \\ &\overline{+\frac{1}{2}\sum\left(P_{kbc}+P_{kbcs}\right)^2+\frac{1}{2}\sum\left(P_{kas}+P_{kbs}\right)^2}= \\ &=\sqrt{P_{k0\Sigma}^2+\frac{1}{2}\sum P_{kac}^2+\frac{1}{2}\sum P_{kbc}^2+\sum\left(P_{kas}P_{kacs}\right)+} \\ &\overline{+\sum\left(P_{kbs}P_{kbcs}\right)+\frac{1}{2}\sum P_{kacs}^2+\frac{1}{2}\sum P_{kbcs}^2+\frac{1}{2}\sum P_{kas}^2+} \\ &\overline{+\frac{1}{2}\sum P_{kbs}^2}=\sqrt{P_{k0\Sigma}^2+\frac{1}{2}\sum P_{kac}^2+\frac{1}{2}\sum P_{kbc}^2+P_d^2} \end{aligned}$$

where

$$\begin{aligned} P_d &==\sqrt{\sum\left(P_{kas}P_{kacs}\right)+\sum\left(P_{kbs}P_{kbcs}\right)+\frac{1}{2}\sum P_{kacs}^2+} \\ &\overline{+\frac{1}{2}\sum P_{kbcs}^2+\frac{1}{2}\sum P_{kas}^2++\frac{1}{2}\sum P_{kbs}^2} \end{aligned}$$

the real power of distortion for the case of polyharmonic signals.

Expression $P_{k0\Sigma}^2+\frac{1}{2}\sum P_{kac}^2+\frac{1}{2}\sum P_{kbc}^2$ in the dependence for P_e represents the sum of the effective values of power without taking into account the power of distortion.

The use of ASTAE is aimed at the possibility of the determination of the consumers distorting the quality of the energy. Therefor it is necessary additionally use the following indices:

– the instantaneous power at the buses of group consumers

(5) $$p_n(t)=u_n(t)\sum_{i=1}^{\infty}i_{ni}(t),$$

where $p_n(t)$ – the consumer's power measured by ASTAE at time moment *t*; $u_n(t)$ the voltage of the consumer (power system); $i_{ni}(t)$ – current of the i-th consumer. The consumers' currents are summed up if they are supplied via the same input, i.e.

(6) $$\sum_{i=1}^{\infty}i_{ni}(t)=i_n(t).$$

Further processing of the information bases on the representation of the instantaneous power in the electric network or at its separate section for every phase by the sum

(7) $$p(t)=P_{k0\Sigma}+p_{ka\Sigma}(t)+p_{kr\Sigma}(t)+p_{kd\Sigma}(t),$$

where $p_{ka\Sigma}(t), p_{kr\Sigma}(t), p_{kd\Sigma}(t)$– respectively active and reactive powers, total by harmonic components, and distortion power.

– the power of a separate consumer

(8) $$\begin{aligned} p_{cj}(t) &= u_n(t)i_{ni}(t)= \\ &= P_{0j}+\frac{1}{2}\sum_{i=1}^{k}p_{kai}(t)+\frac{1}{2}\sum_{i=1}^{k}p_{kbi}(t) \end{aligned},$$

where P_{0j} – the constant component of the power (active power); $p_{kai}(t)$ – the cosine component of the power of the k-th order; $p_{kbi}(t)$ – the sine component of the power of the k-th order; k – the number of the power component;

– the effective power of a separate consumer

(9) $$\begin{aligned} P_{ej}(t) &= \sqrt{\frac{1}{T}\int_0^T p_{ni}^2(t)dt}= \\ &= \sqrt{P_{0j}^2+\frac{1}{2}\sum_{i=1}^{k}P_{kai}^2+\frac{1}{2}\sum_{i=1}^{k}P_{kbi}^2} \end{aligned};$$

– the coefficient of the quality of power conversion by a separate consumer

(10) $$K_{tqj}=\frac{P_{0j}}{\sqrt{P_{0j}^2+\frac{1}{2}\sum_{i=1}^{k}P_{kai}^2+\frac{1}{2}\sum_{i=1}^{k}P_{kbi}^2}};$$

– the coefficient of the negative influence of a separate consumer (including the influence of the reactive power and high-frequency components of the instantaneous power):

(11) $$K_{negj}=\frac{\frac{1}{2}\sqrt{\frac{1}{2}\sum_{i=1}^{k}P_{kai}^2+\sum_{i=1}^{k}P_{kbi}^2}}{\sqrt{P_{0j}^2+\frac{1}{2}\sum_{1}^{k}P_{kai}^2+\frac{1}{2}\sum_{1}^{k}P_{kbi}^2}}.$$

The above given power components, their harmonic composition, calculation coefficients as well as additionally determined harmonic composition of the consumed phase currents $i_a(t), i_b(t), i_c(t)$ allow the unambiguous solution of the posed problem. At present, only one problem remains unsolved. It is the improvement of the trustworthiness of the separation of the influence on the quality of the electric energy of the supply mains and separate consumers at their group connection.

Experimental research

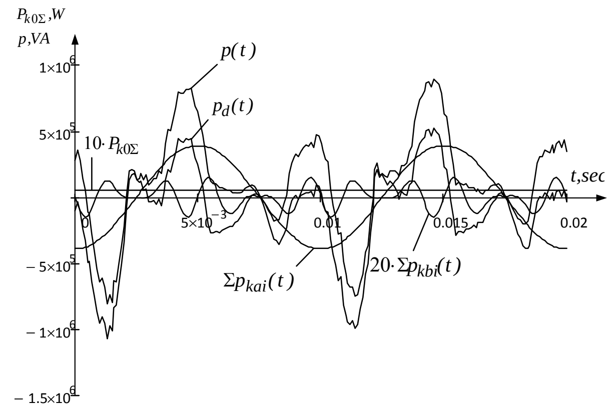
To confirm the theoretic postulates of the paper we assessed the power components and the indices of the quality of electric energy according to the above given relations in electric networks at PJSC "Kriukivskyi Railway Carriage Building Plant" (the city of Kremenchuk). For the research, we used ASTAE variant based on the certified measuring module E14-440 made by company LCard with the pass band of 400 kHz and the reduced error of the current and voltage measuring channels not exceeding 1 %.

In this case, the basic solved problem consisted in the determination of the cause of the occurrence of nonlinear distortions of the current and voltage in 35 kV networks at the decrease of the level of energy consumption by the enterprise. As there is no direct connection of the load to 35 kV network at the enterprise and its subscribers, the research was performed in 6 kV and 0.4 kV electric circuits. They consisted in the measurement of phase voltages and currents by means of ASTAE before and after branching, starting from the outputs of the secondary winding of the transformer.

The primary assessment of the energy processes was performed by the fact of the growth of the power distortion at the decrease of coefficient K_{tqj} and the growth of coefficient K_{negj}. The mentioned measures allowed the determination of the source of nonlinear distortions at the input of 6 kV on the side of the subscriber. A more detailed analysis of the obtained data (Fig. 1) made it possible to concretize their cause – the absence of smoothing chokes at the inputs of the used low-voltage (0.4 kV) three-phase frequency converters.

During the research we additionally explained the admissible decrease of the quality of the electric energy at another internal enterprise input (Fig. 2) resulting from the group influence of the computer supply impulse units of the enterprise engineering structure that are supplied from 220V network, which explains the results obtained in [1].

Besides, we confirmed a higher informative value of the parameters and coefficients calculated according to (7) – (11) as well as their sensitivity to the presence of nonlinear distortions.



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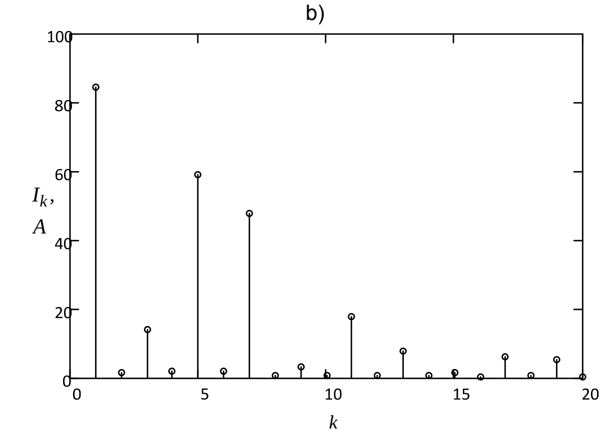

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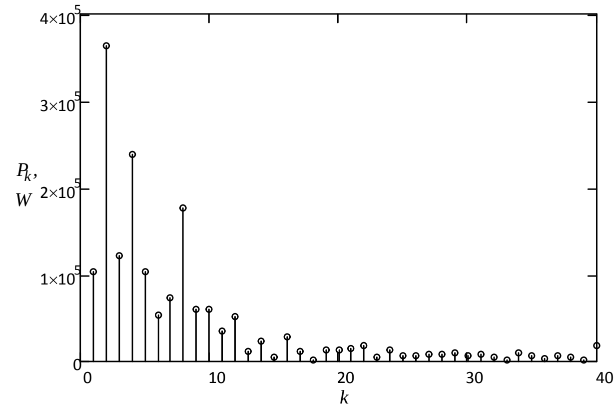
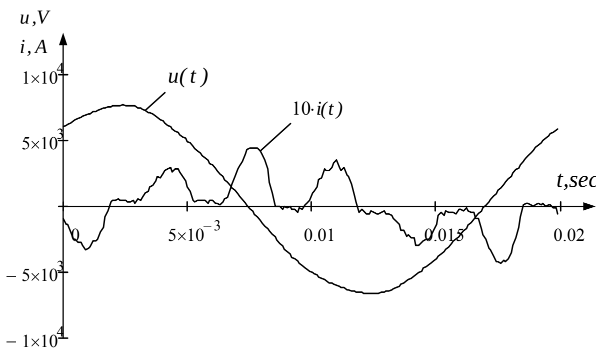


d)

Fig. 1. The results of the analysis of the energy processes and the quality of the electric energy of the influencing consumer of the subscriber: a) the consumed voltage and current curves; b) the instantaneous power components; c) the frequency spectra of the consumed current; d) the frequency spectra of the power



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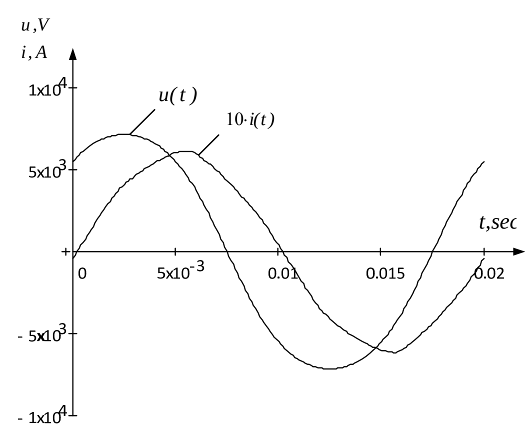

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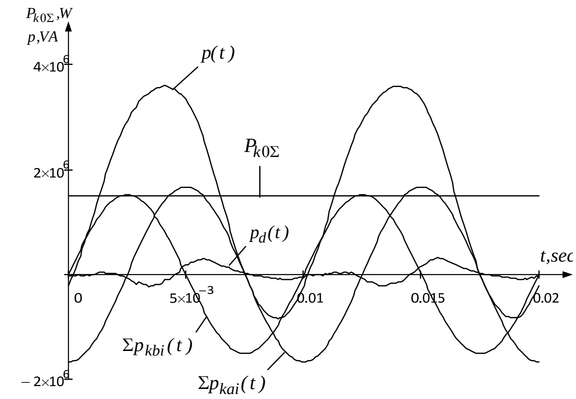

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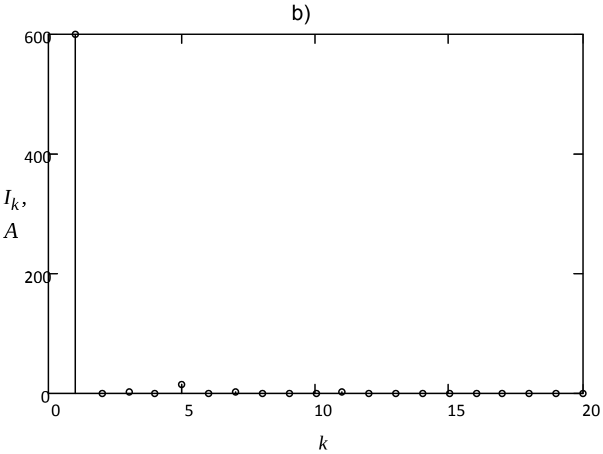

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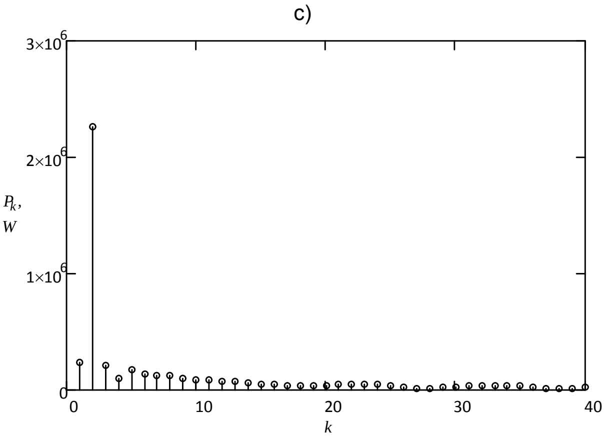

d)

Fig. 2. The results of the analysis of the energy processes and the quality of the electric energy at the enterprise internal input: a) the consumed voltage and current curves; b) the instantaneous power components; c) the frequency spectra of the consumed current; d) the frequency spectra of the power

One can use the obtained results for the substantiation of the introduction of energy-efficient measures as well as for the installation and adjustment of the techniques of compensation for the nonlinear load influence [4, 5].

Conclusions

1. We have proved the prospects of the use of the instantaneous power components obtained via the measured signals of the phase voltages and currents at the assessment of the energy consumption and the indices of the quality of the electric energy in the electric networks.

2. We have confirmed the possibility and the efficiency of the assessment of the quality of the electric energy in the presence of nonlinear distortions with the use of the presented relations for the actual power of distortion.

3. We have obtained the calculation relations allowing the determination of the consumers influencing the quality of the electric energy and have experimentally approbated these relations.

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