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GENERALIZED IDENTIFIER OF THE PRESENCE OF DISTORTIONS IN THE QUALITY OF ELECTRICITY

A.V. Voloshko*, T.E. Dzheria**
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute",
pr. Peremohy, 37, Kyiv, 03056, Ukraine
e-mail: avolosko820@gmail.com, tatyanakurus0202@gmail.com

The development of measures to ensure the quality of electric energy is possible only after assessing the actual state of the quality of electric energy in all nodes of the electric network. Therefore, the basis of the system of ensuring the necessary quality of electric energy should be the system of its monitoring. An approach to the construction of a system for monitoring the quality of electrical energy in real time is presented by developing a generalized identifier for the presence of distortion of the quality of electrical energy, regardless of its type, time of appearance and duration, based on the construction of the spatial-temporal distribution of the information signal and subsequent orthogonal analysis of the frequency-temporal changes of its spectral components. This makes it possible to create a system for monitoring the quality of electric energy in real time, in contrast to existing methods, which use sequential processing of the measurement signal to determine individual indicators of the quality of electric energy, which makes it impossible to conduct it in real time. Ref. 3, fig. 4.
Keywords: power quality, distortion, reliability, artificial neural networks, orthogonal transformation, Lipshytsya's signal, wavelet analysis, Fourier analysis, frequency-time atoms, point smoothness, discontinuities of the first kind, sinusoidal signal.

Introduction. Analysis of the current state of Ukraine's electricity industry shows that its integration with the electricity sector of the EU is possible only if strict requirements for the parameters of power quality, which must be within acceptable levels set in regulations [1]. It should be noted that the quality of electricity significantly affects the reliability of Ukraine's electricity, and is a constant factor that can lead to unjustified economic losses of both direct energy companies and many consumers of electricity..

Literary review. As you know, there are two main groups of distortions in the quality of electricity: stationary (or quasi-stationary) and distortions that change over time. Harmonics and interharmonics, voltage fluctuations and voltage imbalances belong to the first group, and transients of voltage, voltage reduction / excess, voltage interruption and other high-frequency distortions are the second group.

A large number of methods for processing information signals are used to determine the quality of electricity. All of them have both advantages and disadvantages for their application in power quality monitoring systems [2].

The analysis of literature sources allowed to outline the main existing methods of identifying the presence and type of distortions in the quality of electricity:

• artificial neural networks (hidden Markov's models);
• based on expert systems;
• expert systems with fuzzy logic;
• SVM – precedent-based teaching methodology;
• combined methods - artificial neural networks and SVM;
• wavelets and Markov's models, fuzzy logic expert systems, and Fourier analysis.

Analysis of the application of these methods allowed to outline the most important problems in detecting and identifying distortions of electricity, which are not sufficiently resolved at present [3]. Based on the above, to build a system for monitoring the parameters of power quality, it is necessary to develop such methods and algorithms that implement them, which will:

• determine and identify the presence of voltage and current distortion in the electrical network;

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ORCID ID: * https://orcid.org/0000-0002-6867-2060, ** https://orcid.org/0000-0002-9519-2951

• to ensure the definition of certain types of distortion that are simultaneously present in the electrical network;

• develop a generalized identifier for the distortion of power quality, which would allow real-time monitoring of power quality.

This article considers the approach to building a system for monitoring the quality of electricity in terms of developing a generalized identifier to determine the presence of distortions in the quality of electricity, the time of its occurrence and duration in real time.

Development of a method for unambiguous identification of the presence of distortions in the quality of electricity. According to scientific publications, real-time monitoring of power quality (PQ) parameters is currently impossible, as their determination requires time for data collection and statistical processing. Also, in most cases, each PQ parameter requires a separate algorithm and mathematical apparatus to determine. Currently, there is no generalized identifier for determining the presence of an arbitrary type of distortion. Therefore, it is important from a scientific and practical point of view to develop a method for unambiguous identification of deterioration of PQ in real time. As the results of many studies show, frequency-time atoms with different time carriers are needed to analyze the structure of signals of different durations. In orthogonal transformations, the wavelet function is used as a family of such frequency-time atoms $\psi_{u,s}(t)$ as a result of its scaling by the value *s* and offset by the value *u*:

$$\psi_{u,s}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-u}{s}\right), \tag{1}$$

In this case, the orthogonal transformation from the time of *u* and scale *s* is as follows

$$Wf(u,s) = \left\langle f, \psi_{u,s} \right\rangle = \int_{-\infty}^{+\infty} f(t)\frac{1}{\sqrt{s}}\psi\left(\frac{t-u}{s}\right)dt, \tag{2}$$

where $\left\langle f, \psi_{u,s} \right\rangle$ – scalar product.

As follows from expression (2), wavelet transform can focus on local signal structures using the object zoom procedure, which gradually decreases / increases the scale parameter. Features and smooth surfaces of the signal often contain basic information about its characteristics. Since the local signal smoothness is characterized by a decrease in the amplitude of the wavelet transform with decreasing scale, the paper examines the features and differences of the signal by analyzing the local maxima of wavelet transform at small scales, which allowed to detail the "anomalies" in the signal [2].

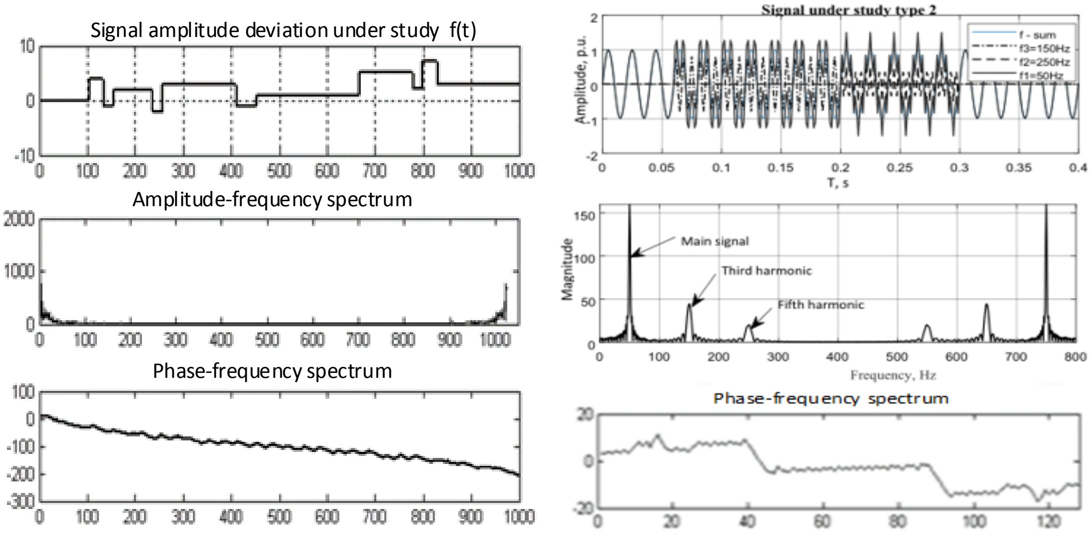
As noted in the scientific literature, the decrease in the amplitude of the wavelet coefficients depending on the scale is due to the uniform and point smoothness of the Lipshytsya's signal better. Measurement of this asymptotic decrease is equivalent to the approximation of signal structures at a scale that goes to zero. That is, if $f \in L^2(R)$ satisfies the condition Lipshytsya *α*, $\alpha \leq n$, on [*a,b*], it exists A > 0 such that

$$\forall (u,s) \in [a,b] \times R^{+} \quad \left|Wf(u,s)\right| \leq As^{\alpha + 1/2}. \tag{3}$$

Inequality (3) is a condition of asymptotic decline $\left|Wf(u,s)\right|$, if *s* goes to zero. At the same time, when reducing the scale *s* function $\left|Wf(u,s)\right|$ characterizes small-scale changes in the environment *u*. The scale *s* must be more than 2, otherwise, the sampling step may be larger than the wavelet carrier. Therefore, when calculating the smallest scale of wavelet transform is limited to the separation of discrete data. As is well known, discrete wavelet transform is calculated on a scale $2^j \geq s \geq \mu^{N-1}$, where μ may be large enough to eliminate the effect of inaccurate sampling on the smallest scale wavelets. Therefore, the largest scale 2^j should be chosen so that it is less than the distance between two consecutive features in time, in order to prevent the influence of other features on $Wf(u,s)$.

At each scale 2^j representation of maxima gives value $Wf(u,2^j)$, where $\left|Wf(u,2^j)\right|$ – local maximum. In this case, when the value of the function *f*(*t*) offset on τ, each *Wf(u,2^j)* also shifted to *τ*, as well as their maxima.

Approbation of research results. To verify the adequacy of the theoretical solution and its practical significance, we will conduct a comparative analysis of the results of signal processing using Fourier and wavelet analysis. The following are selected as information signals: the presence of breaks of the first kind (amplitude differences) and the presence of the third and fifth harmonics (Fig. 1 and Fig. 2).

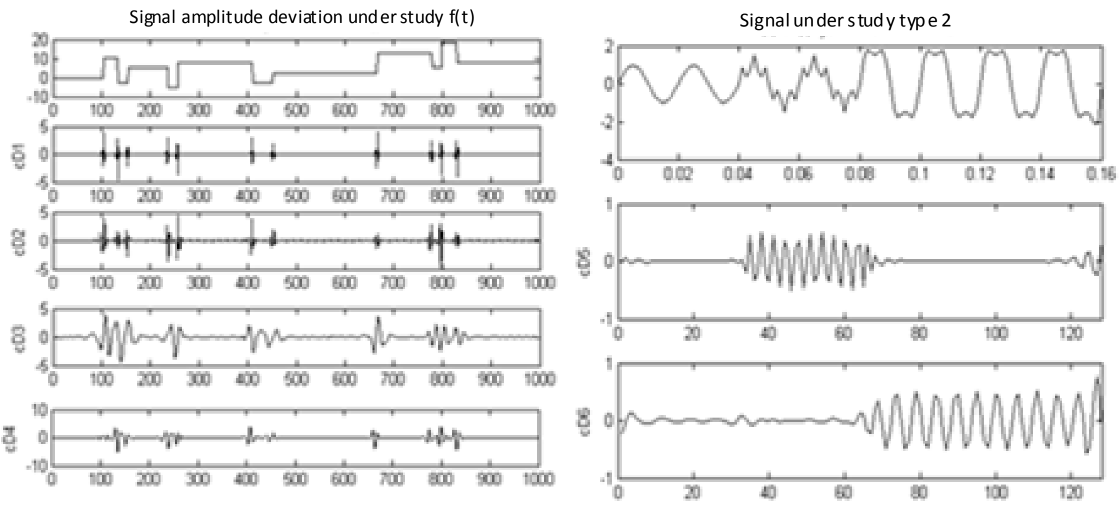


a *b*

Fig. 1

The results of the Fourier analysis indicate the presence of anomalies in the signal (Fig. 1*a*) and the presence of the third and fifth harmonics (Fig. 1*b*), but without identifying the time of their occurrence and duration.

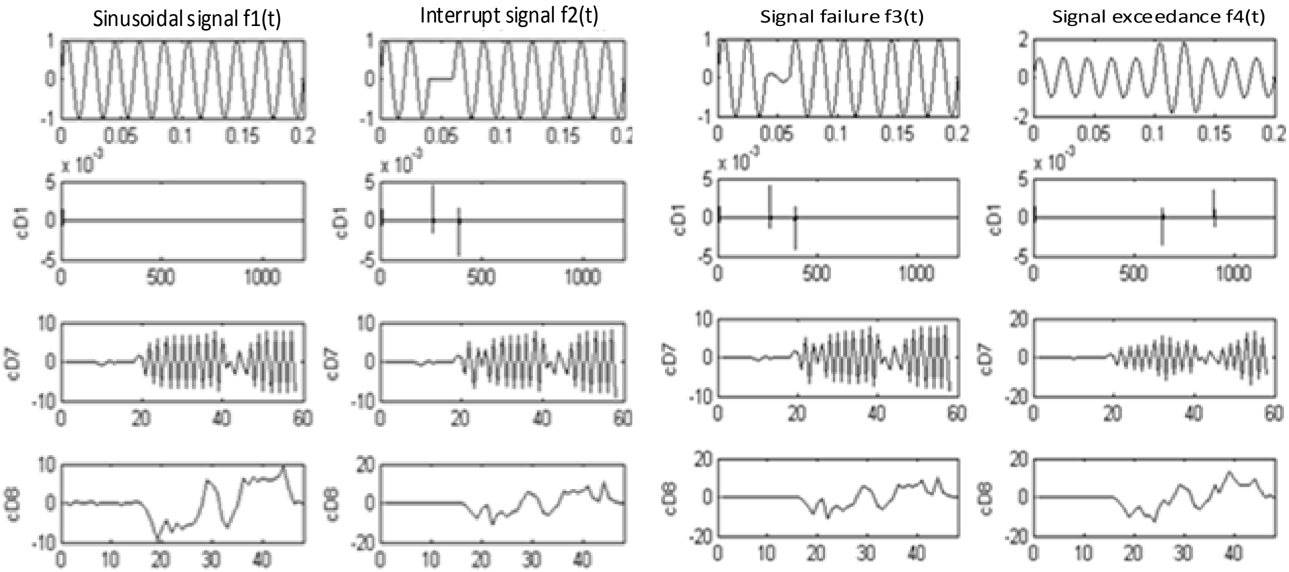
The results of the wavelet analysis, which are presented in Fig. 2 show the following. Values of wavelet coefficients of the first level of wavelet analysis (Wf(u,2j)) – cD1 indicate the presence of anomalies in the signal, characterize the time of their occurrence and duration. Reducing the scale of wavelet transform allows you to detail anomalies (cD2 – cD4).



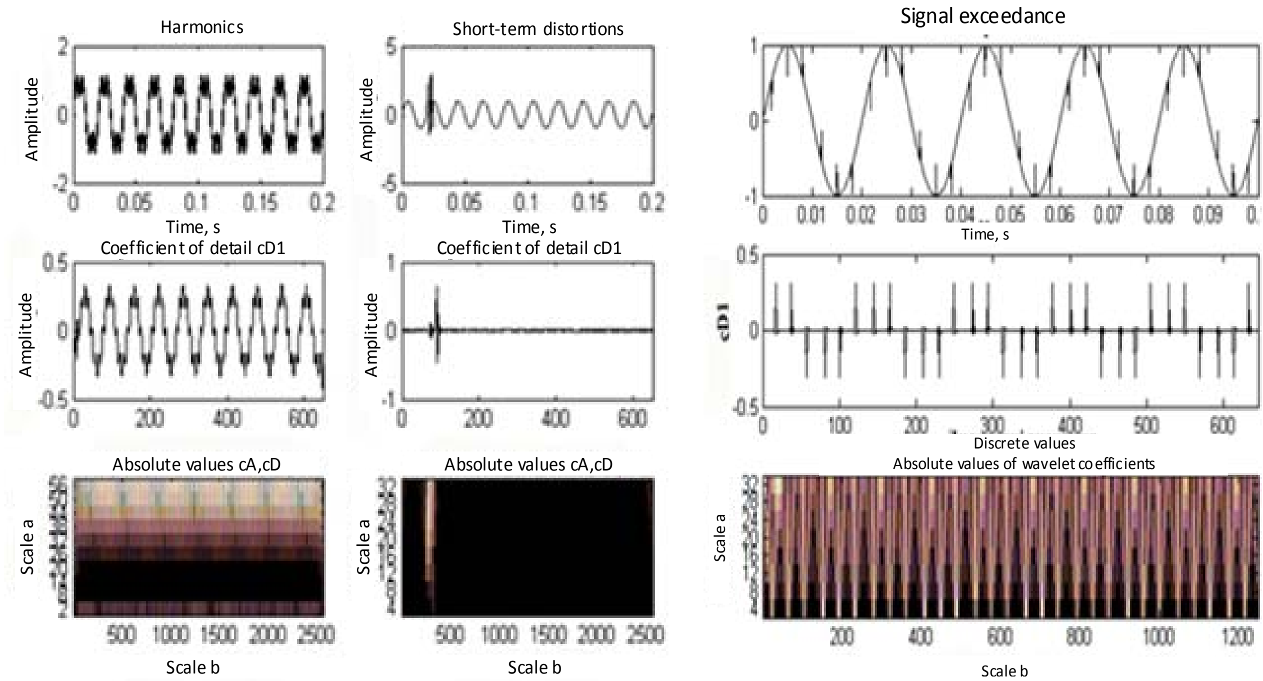
a *b*

Fig. 2

Fig. 3 shows wavelet-conversion of information signals, namely, *a* – sinusoidal signal and the presence of voltage interruption, *b* – lowering and exceeding the voltage. Fig. 4 shows wavelet decomposition of distorted signals, namely, *a* – harmonics, *b* – short-term, and periodic distortions, and their scalograms. Let's analyze the influence of the presence of distortions that are present in the information signal on the results of its orthogonal transformation (Fig. 3 and Fig. 4).



a **Fig. 3** *b*



a *b*

Fig. 4

As follows from the results of the study, the presence in the signals of any type of distortion leads to the value of the detail coefficient of the first level of wavelet decomposition (*cD1*) different from zero.

In the presence of a sinusoidal signal *cD1*=0 – the information signal does not contain distortions. Distortion of the type of undervoltage and overvoltage also leads to the value of the coefficient *cD1* indicating the beginning and end of distortion. The maximum values of wavelet coefficients are observed at the seventh and eighth levels of wavelet decomposition.

Distortions of the type of voltage interruption also lead to the value of the coefficient *cD1*. The presence of harmonic components in the signal is clearly manifested at the first level of wavelet decomposition of the signal. Short-term distortions lead to appearance *cD1* - (short-term changes in its values). Repetitive high-frequency distortions (output voltage of the six-pulse converter) lead to the appearance of the coefficient *cD1* in the form of a sequence of short values.

Conclusion. Analysis of the current state of Ukraine's electricity industry shows that its integration with the electricity sector of the EU is possible only if strict requirements for power quality parameters, which must be within acceptable levels set in regulations. It should be noted that the quality of electricity significantly affects the reliability of Ukraine's electricity, and is a constant factor that can lead to unjustified economic losses of both direct energy companies and many electricity consumers. To achieve this difficult task, first of all, you need clear control over the quality of electricity.

Fuzzy information about the specific amount of signal distortion, in turn, also incurs huge costs. Which becomes a prerequisite for finding solutions to improve the accuracy and speed of measurements of power quality indicators.

Analysis of the obtained results of wavelet transform of sinusoidal signal and distortions of electric energy quality (values of detailed coefficients of the first level of decomposition and scalogram) shows the possibility of direct detection of distortions and determination of the beginning and / or end of the corresponding distortion. This detail wavelength repetition rate has zero values at most points except those where the violation occurs.

That is, the presence of a detailed coefficient of wavelet analysis (*cD1*) can serve as a generalized identifier of the presence of distortion of the quality of electricity, regardless of its type. In other works, the sequential processing of the measuring signal is carried out to determine individual indicators of power quality, which makes it impossible to monitor the quality of electricity in real time.

1. EN 50160:2010&A1:2015&A2:2019&A3:2019 Voltage characteristics of electricity supplied by public electricity networks. (NSAI), 2019, 36 p.
2. Mallat S.A. A theory for multiresolution signal decomposition: The wavelet representation. IEEE Trans. Pattern Anal. Machine Intell. 1989. Vol. 11. Pp. 674–693. DOI: https://doi.org/10.1109/34.192463
3. Volodarsky E.T., Shcherbak L.M., Voloshko A.B. Generalized indicator of the presence of distortions in the quality of electricity. Certificate of copyright registration for the work № 66753 dated 19.07.2016.

УЗАГАЛЬНЕНИЙ ІДЕНТИФІКАТОР НАЯВНОСТІ СПОТВОРЕНЬ ЯКОСТІ ЕЛЕКТРИЧНОЇ ЕНЕРГІЇ

А.В. Волошко, Т.Е. Джеря
Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського»,
пр. Перемоги, 37, Київ, 03056, Україна

Розробка заходів із забезпечення якості електричної енергії можлива тільки після оцінки фактичного стану якості електричної енергії у всіх вузлах електричної мережі. Тому в основу системи забезпечення необхідної якості електричної енергії має бути покладена система її моніторингу. Представлено підхід до побудови системи моніторингу якості електричної енергії у реальному часі шляхом розробки узагальненого ідентифікатора наявності спотворення якості електричної енергії незалежно від його типу, часу появи та тривалості на основі побудови просторово-часового розподілу інформаційного сигналу і подальшого ортогонального аналізу частотно-часових змін його спектральних компонент. Це дає змогу створення системи моніторингу якості електричної енергії в реальному часі на відміну від існуючих методів, задля яких проводиться послідовна обробка вимірювального сигналу для визначення окремих показників якості електричної енергії, що унеможливлює його проведення в реальному часі. Бібл. 3, рис. 4.

Ключові слова: якість електроенергії, спотворення, надійність, штучні нейронні мережі, ортогональні перетворення, сигнал Ліпшиця, вейвлет-аналіз, аналіз Фур'є, частотно-часові атоми, точкова гладкість, розриви першого роду, синусоїдальний сигнал.

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