https://doi.org/10.33271/nvngu/2022-4/071

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THE ELECTRICAL POWER QUALITY INDICATOR – INTERFERENCE POWER FACTOR

Purpose. Substantiation of the methodology for calculating an indicator characterizing the pulsating current power distortion.

Methodology. When analyzing the power of direct and alternating sinusoidal currents, the features of the ratio of a root-mean-square norm to its mean value, known as the invariance power factor, are noted. In this case, the root-mean-square power value acts as a normalizing parameter. Using a combination of direct and sinusoidal (pulsating) current, the dependences of the invariance power factor on the ratio of direct and alternating components are obtained.

Findings. Taking into account the interaction of the current and voltage components of different frequencies, the corresponding power component is highlighted, called "interference power". With its use, by analogy with the invariance power factor, the interference power factor is introduced. The interference power factor behavior for AC non-sinusoidal current circuit and DC pulsed current circuit of rectifier was investigated, as a result of which a difference was established in the interference power factor dependence in these circuits.

Originality. The obtained dependences of the interfere power factor on the ratio of DC and AC components for current and voltage prove the versatility of its application for assessing power distortion in both DC and AC circuits, as proved by the example of a circuit with a single-phase controlled rectifier.

Practical value. The results obtained can be used to assess the electrical power distortion level in electric complexes and systems of various kinds of current and kind of energy, including when it is taken into account. This is a prerequisite for the measures development to improve the electricity quality.

Keywords: *traction substation transformer, current and voltage harmonics, power loss, electrical power quality*

Introduction. Modern electric power systems and complexes are actively equipped with semiconductor devices for regulating or converting electrical energy. Together with electrical installations such as arc furnaces, welding units, etc. the specified loads refer to the consumers group with non-linear volt-ampere characteristics. The distortions in current and voltage that they cause lead to an electrical energy distortion.

In electric power systems and complexes in the generation, transportation, distribution and consumption conditions of electric energy, the power balance is maintained. Energy tends to accumulate, therefore, with the uncertainty of its initial volumes in the system elements, it is impossible to draw up a correct balance. The energy derivative – power is a parameter by which a balance is made in electrical engineering and the electric power industry. Accounting for electrical energy using power allows solving financial issues related to electrical energy as a product. This process is predominantly carried out by active power (kW/h). In some cases, reactive power (kVAr/h) [1, 2] is taken into account, the presence of which indicates a deterioration in the electrical energy quality. In this case, the reactive power value in a certain way reflects the level of quality deterioration.

Electromechanical complexes can be attributed to a separate consumers category. In such complexes, electrical energy, before being converted into mechanical energy, goes through one or more stages the current type converting (rectifiers, inverters, frequency converters, pulse converters). At the same time, the network power balance, the mechanical motor DC pulsating current circuit is maintained, taking into account the power of each element of the specified link.

If for three-phase alternating current circuits the electrical energy indicators, reflecting its distortion, are disclosed in a certain way in [3], then for direct current circuits, or rather pulsating current, such indicators are not used at all. Although, as stated above, these circuits, in certain cases are united by a single energy process.

Literature review. The authors of studies [1–3] emphasize the reactive power importance in the losses analysis in the electrical network. To determine the losses level, it is proposed to take into account the components proportional to the square of the RMS value of the reactive power and the square of the RMS value of the active power variable component. At the same time, in [2], the instantaneous power theory for three-phase systems [4] is used as a basis. But the results obtained cannot be extended to other energy transfer elements and conversion process, such as pulsating current circuits.

For networks with a linear and time-invariant load, it is shown by means of the Hilbert transform, the analytical signal associated representation [5] and instantaneous power that its reactive component according to Budeanu can be associated with energy fluctuations, but only in the average value. In addition, the distortion power is decomposed into a part representing the fluctuation degree around the active power, and a part representing fluctuations around the Budeanu reactive power [6]. Works [5, 6] have commonality in the structure of power analysis and its components using trigonometric series. At the same time, the authors focus on criticizing well-known solutions without providing an alternative.

An alternative option for determining the electric power distortion implies its decomposition into components depending on the current and voltage harmonics combination [7]. However, such a division into even and odd components is not enough due to the combination of different frequencies harmonics in certain components.

The selection of the active, reactive component in the instantaneous power and the assessment of the corresponding root-mean-square norms, according to the authors [8], can be used as a tool for the alternative indicator formation, which reflects the electrical energy distortion level [9], both in alternating current and pulsating current circuits [10]. In this case, the indicator can be used for all links in the electrical energy conversion, and possibly other types of it, for example, mechanical, for electrical machines [11, 12].

Purpose. To substantiate the methodology for calculating an indicator which characterizes the pulsating current power distortion.

Results. Let us analyze the power for several elementary cases, corresponding to stationary processes of energy transfer in idealized systems of direct and alternating current at the same time.

Consider a circuit section with the known voltage and current

$$u = U_0; \quad i = I_0.$$

The energy transferred through a circuit section is determined by the power

$$p = ui = U_0 I_0,$$

and by the time interval T during which it is transferred

$$W = \int_0^T p dt = \int_0^T ui dt = \int_0^T U_0 I_0 dt = U_0 I_0 t \Big|_0^T = U_0 I_0 T.$$

If we divide the energy by the observation time interval, we obtain the average value, active power

$$P = \frac{1}{T}\int_0^T p dt = U_0 I_0.$$

If we consider p as a signal, then it can be characterized by the RMS value, or the quadratic norm on the interval T

$$P_{rms} = \sqrt{\frac{1}{T}\int_0^T p^2 dt} = U_0 I_0 = P.$$

Thus, in the case of a circuit section with direct current and voltage, the average power value (active power) is equal to the norm, and the energy is transferred evenly. There are no ripples in the circuit section. Let us assume that in this case the electrical energy quality is ideal, and there are no distortions in its transmission process. Therefore, the time derivative of energy, power, can also be considered ideal.

In signal processing technology, electronics, power supply, to characterize the unevenness of the load curve, among other things, an indicator called the "shape factor" is used [13]. In this case, to characterize the electrical energy quality, we use a similar ratio known as the "invariance power factor" [14]

$$q_{inv} = \frac{P}{P_{rms}}.$$

In the case of direct current and voltage $q_{inv} = 1$.

Consider a circuit section under the following condition

$$i = \sqrt{2} I_1 \sin\left(\omega t + \psi_i\right); \quad u = \sqrt{2} U_1 \sin\left(\omega t + \psi_u\right),$$

where U_1, I_1, ψ_u, ψ_i are RMS values and phases shift of voltage and current, respectively; ω is angular frequency.

Then

$$p = P_{a.1-1}\cos 0\omega t + P_{b.1-1}\sin 0\omega t + P_{a.1+1}\cos 2\omega t + P_{b.1+1}\sin 2\omega t,$$

where $P_{a.1-1} = U_1 I_1 \cos(\psi_u - \psi_i) = P$ is active power; $P_{b.1-1} = -U_1 I_1 \sin(\psi_u - \psi_i) = Q$ is reactive power; $P_{a.1+1} = -U_1 I_1 \cos(\psi_u + \psi_i)$ is an oscillation cosine quadrature component; $P_{b.1+1} = U_1 I_1 \sin(\psi_u + \psi_i)$ is an oscillation sine quadrature component.

Accordingly, the energy change over time during period T is

$$W = \int_0^T p dt = \int_0^T \big(P_{a.1-1}\cos(0) + P_{b.1-1}\sin(0) + P_{a.1+1}\cos 2\omega t + P_{b.1+1}\sin 2\omega t\big) dt = \left(P_{a.1-1} t + \frac{P_{a.1+1}}{2\omega}\sin 2\omega t - \frac{P_{b.1+1}}{2\omega}\cos 2\omega t\right)\Bigg|_0^T = P_{a.1-1} T.$$

That is, the resulting dependence of energy includes a component that provides an increase in energy in proportion to time, as in the previous case, and two harmonic quadrature components that cause harmonic energy fluctuations over a period of time. These fluctuations do not affect the resulting value of the transferred energy.

The average value, active power is

$$P = \frac{1}{T}\int_0^T p dt = U_1 I_1 \cos(\psi_u - \psi_i) = P_{a.1-1}.$$

The RMS value is

$$P_{rms} = \sqrt{\frac{1}{T}\int_0^T p^2 dt} = U_1 I_1 \sqrt{\frac{1}{2} + \cos\left(\psi_u - \psi_i\right)^2}.$$

Thus, for a section of an alternating sinusoidal current circuit, the RMS power value differs from the average value. Accordingly, the invariance power factor [15]

$$q_{inv} = \frac{P}{P_{rms}} = \frac{U_1 I_1 \cos(\psi_u - \psi_i)}{U_1 I_1 \sqrt{\frac{1}{2} + \cos\left(\psi_u - \psi_i\right)^2}} = \sqrt{1 - \frac{1}{2\cos(\psi_u - \psi_i)^2 + 1}},$$

is different from 1. The maximum value of this indicator can be achieved under the condition $\psi_u - \psi_i = \varphi = 0$

$$q_{inv.\max} = \sqrt{1 - \frac{1}{2\cos(0)^2 + 1}} = \sqrt{\frac{2}{3}} = 0.817,$$

which corresponds to the process of energy transfer exclusively by active power, while reactive power is equal to zero. If the energy transfer process is accompanied exclusively by reactive power, i. e. $\psi_u - \psi_i = \phi = \pm\frac{\pi}{2}$, then

$$q_{inv.\min} = \sqrt{1 - \frac{1}{2\cos\left(\frac{\pi}{2}\right)^2 + 1}} = 0.$$

Given the above, we note that under the condition of a sinusoidal voltage and current, the energy transfer process differs from the ideal one. Both power and energy have fluctuations. This affects the transmission process of the latter depending on the current and voltage phase shift.

Is it reasonable to consider electrical energy in this case as distorted? The answer is yes. The change in energy over time is uneven, the rate of its transfer is not constant. Is it possible to achieve in this case the power fluctuations minimization? Yes, but not higher than the level $q_{inv} = 0.817$ corresponding to $\psi_u - \psi_i = \varphi = 0$, provided that the oscillations amplitude coincides with its constant value, i.e. $P_{a.1+1} = P_{a.1-1} = P$, and $P_{b.1+1} = P_{b.1-1} = 0$.

It is important to note that it is impossible by nature to achieve a $q_{inv} = 1$ value in the case of harmonically current and voltage. The design of electric power systems and power supply systems, their operation involves the action of a sinusoidal current and voltage. Thus, it should be considered that the sinusoidal current and voltage acting in such systems are initial. Accordingly, electrical energy is considered not distorted and is characterized by active, reactive power and invariance power factor. But in terms of the electrical energy quality, a certain contradiction arises at direct and alternating currents.

Consider a circuit section in which there are harmonic voltage and current oscillations around a direct value

$$i = I_0 + \sqrt{2} I_1 \sin\left(\omega t + \psi_{i1}\right); \quad u = U_0 + \sqrt{2} U_1 \sin\left(\omega t + \psi_{u1}\right),$$

where U_0, I_0, U_1, I_1 are RMS values of direct components and harmonical components of voltage and current, respectively; ψ_{u1}, ψ_{i1} are phase shifts of harmonical voltage and current.

Then

$$\begin{gathered} p = U_0 I_0 + \\ + U_1 I_1 \cos(\psi_{u1} - \psi_{i1}) \cos 0\omega t - U_1 I_1 \sin(\psi_{u1} - \psi_{i1}) \sin 0\omega t + \\ + \left(\sqrt{2} U_0 I_1 \sin(\psi_{i1}) + \sqrt{2} U_1 I_0 \sin(\psi_{u1})\right) \cos 1\omega t + \\ + \left(\sqrt{2} U_0 I_1 \cos(\psi_{i1}) + \sqrt{2} U_1 I_0 \cos(\psi_{u1})\right) \sin 1\omega t - \\ - U_1 I_1 \cos(\psi_{u1} + \psi_{i1}) \cos 2\omega t + UI \sin(\psi_{u1} + \psi_{i1}) \sin 2\omega t. \end{gathered}$$

Let us represent the latter with three components in accordance with their frequency

$$p = p_0 + p_1 + p_2,$$

and separated by orthogonal components

$$\begin{gathered} p = \left(P_{a.0+0} + P_{a.1-1}\right) \cos 0\omega t + P_{b.1-1} \sin 0\omega t + \\ + \left(P_{a.0\pm1} + P_{a.1\pm0}\right) \cos 1\omega t + \left(P_{b.0\pm1} + P_{b.1\pm0}\right) \sin 1\omega t + \\ + P_{a.1+1} \cos 2\omega t + P_{b.1+1} \sin 2\omega t, \end{gathered}$$

where $P_{a.1-1} = U_0 I_0 + U_1 I_1 \cos(\psi_{u1} - \psi_{i1}) = P$ is active power; $P_{b.1-1} = -U_1 I_1 \sin(\psi_{u1} - \psi_{i1}) = Q$ is reactive power; $P_{a.0\pm1} + P_{a.1\pm0} = \sqrt{2} U_0 I_1 \sin(\psi_{i1}) + \sqrt{2} U_1 I_0 \sin(\psi_{u1})$ is oscillation with unit frequency cosine quadrature component; $P_{b.0\pm1} + P_{b.1\pm0} = \sqrt{2} U_0 I_1 \cos(\psi_{i1}) + \sqrt{2} U_1 I_0 \cos(\psi_{u1})$ is oscillation with unit frequency sine quadrature component; $P_{a.1+1} = -U_1 I_1 \cos(\psi_{u1} + \psi_{i1})$ is oscillation with double frequency cosine quadrature component; $P_{b.1+1} = U_1 I_1 \sin(\psi_{u1} + \psi_{i1})$ is oscillation with double frequency sine quadrature component.

Thus, in contrast to the direct current circuit, where there is only constant power, and the alternating harmonical current circuit, where there is a constant power component and an oscillating component with a double frequency, in this case an additional oscillating component with a unit frequency is formed. This component is due to the component interaction of currents and voltages with different frequencies, and is called "non-canonical" [16].

In this case, the RMS power value is

$$\begin{gathered} P_{rms} = \sqrt{\frac{1}{T} \int_0^T p^2 dt} = \sqrt{U_0^2 I_0^2 + U_1^2 I_1^2 \cos^2(\psi_{u1} - \psi_{i1}) +} \\ \overline{+ 4 U_0 I_0 U_1 I_1 \cos(\psi_{u1} - \psi_{i1}) + U_0^2 I_1^2 + U_1^2 I_0^2 + 0.5 U_1^2 I_1^2}. \end{gathered}$$

Accordingly,

$$\begin{gathered} q_{inv} = \frac{P}{P_{rms}} = \left[U_0 I_0 + U_1 I_1 \cos(\psi_{u1} - \psi_{i1})\right] \times \\ \times \left[\sqrt{U_0^2 I_0^2 + U_1^2 I_1^2 \cos^2(\psi_{u1} - \psi_{i1}) +}\right. \\ \left.\overline{+ 4 U_0 I_0 U_1 I_1 \cos(\psi_{u1} - \psi_{i1}) + U_0^2 I_1^2 + U_1^2 I_0^2 + 0.5 U_1^2 I_1^2}\right]^{-1/2} = \\ = \frac{1}{\sqrt{1 + \dfrac{U_0^2 I_1^2 + U_1^2 I_0^2 + 2 U_0 I_0 U_1 I_1 \cos(\psi_{u1} - \psi_{i1}) + 0.5 U_1^2 I_1^2}{\left[U_0 I_0 + U_1 I_1 \cos(\psi_{u1} - \psi_{i1})\right]^2}}}. \end{gathered}$$

Let us determine the ratio of the RMS value of pulsating components to the direct components of current and voltage as follows: $I_1 = K_I I_0$, $U_1 = K_U U_0$; we introduce them into the previous expression and perform the reduction and we get

$$q_{inv} = \frac{1}{\sqrt{1 + \dfrac{K_I^2 + K_U^2 + 2 K_U K_I \cos(\psi_{u1} - \psi_{i1}) + 0.5 K_U^2 K_I^2}{\left[1 + K_U K_I \cos(\psi_{u1} - \psi_{i1})\right]^2}}}.$$

For the case when only active power is transferred by the variable component $\psi_{u1} - \psi_{i1} = 0$, the expression for the invariance power factor will look like this

$$q_{inv1} = \frac{1}{\sqrt{1 + \dfrac{K_I^2 + K_U^2 + 2 K_U K_I + 0.5 K_U^2 K_I^2}{\left[1 + K_U K_I\right]^2}}}.$$

For the case when only reactive power is transferred by the variable component $\psi_{u1} - \psi_{i1} = \pi/1$, the expression for the invariance power factor is simplified

$$q_{inv2} = \frac{1}{\sqrt{1 + K_I^2 + K_U^2 + 0.5 K_U^2 K_I^2}}.$$

Fig. 1, *a* shows the dependences q_{inv} on the ratio of the variable component to the direct component of current and voltage, respectively $q_{inv} = f(K_U, K_I)$. At the same time, the surface q_{inv1}, which fits the case $\psi_{u1} - \psi_{i1} = 0$ is not significantly different from the surface q_{inv2}, which fits the case $\psi_{u1} - \psi_{i1} = \pi/2$ provided $K_I \le 1$, $K_U \le 1$. This is evidenced by the zero level of the difference between these surfaces in Fig. 1, *b* in the indicated area "1". The value of the invariance factor at the boundary of this region is $q_{inv1} = q_{inv2} = 0.686$. With increasing K_I and K_U the difference between surfaces grows. Dependence $q_{inv2} = f(K_U, K_I)$ is decreasing with increasing arguments K_I and K_U and tends to 0. At the same time, dependency $q_{inv1} = f(K_U, K_I)$ at the borders ($K_U = 0$ or $K_I = 0$) matches the dependency $q_{inv2} = f(K_U, K_I)$. With the increase in $K_U > 0$, $K_I > 0$, that is, in the case when the variable component increases, q_{inv1} also increases and tends to a value of 0.817. This corresponds to the maximum value of q_{inv} the sinusoidal current and voltage.

Thus, the surfaces q_{inv1} and q_{inv2} limit the range of all possible values for the case under consideration.

Using the distribution of instantaneous power over the components [16], we determine the RMS value of the "non-canonical" oscillating component with a unit frequency

$$P_{1rms} = \sqrt{U_0^2 I_1^2 + U_1^2 I_0^2 + 2 U_0 I_0 U_1 I_1 \cos(\psi_{u1} - \psi_{i1})}.$$

In view of the fact that the specified power is formed by the components of current and voltage of different frequencies, we use the name RMS value of "interference power" for this parameter.

Determine the interference part (interference factor) by a suitable factor

$$q_{int} = \frac{P_{1rms}}{P_{rms}} = \frac{1}{\sqrt{1+\dfrac{U_0^2 I_0^2 + U_1^2 I_1^2\left(0.5+\cos^2(\psi_{u1}-\psi_{i1})\right) + 2U_0 I_0 U_1 I_1 \cos(\psi_{u1}-\psi_{i1})}{U_0^2 I_1^2 + U_1^2 I_0^2 + 2U_0 I_0 U_1 I_1 \cos(\psi_{u1}-\psi_{i1})}}}.$$

Using the parameters K_I, K_U, we obtain the following expression

$$q_{int} = \frac{1}{\sqrt{1+\dfrac{1+K_U^2 K_I^2\left(0.5+\cos^2(\psi_{u1}-\psi_{i1})\right)+2K_U K_I \cos(\psi_{u1}-\psi_{i1})}{K_U^2+K_I^2+2K_U K_I \cos(\psi_{u1}-\psi_{i1})}}}.$$

For the case when only the active power $\psi_{u1} - \psi_{i1} = 0$ is transferred by the variable component, the last expression will look like this

$$q_{int1} = \frac{1}{\sqrt{1+\dfrac{1+1.5K_U^2 K_I^2+2K_U K_I}{K_U^2+K_I^2+2K_U K_I}}}.$$

For the case when only reactive power is transferred to the variable component, $\psi_{u1} - \psi_{i1} = \pi/2$, the last expression will take the form

$$q_{int2} = \frac{1}{\sqrt{1+\dfrac{1+0.5K_U^2 K_I^2}{K_U^2+K_I^2}}}.$$

Fig. 1, *c* shows the dependences of q_{int} on the ratio of the variable component to the direct component of current and voltage, respectively $q_{int} = f(K_U, K_I)$. Both obtained surfaces are closely spaced throughout the study area. The nature of the q_{int1} change corresponding to the $\psi_{u1} - \psi_{i1} = 0$ case differs from the $\psi_{u1} - \psi_{i1} = \pi/2$ surface corresponding to the q_{int2} case by no more than 0.05 under the condition of $K_I \le 1$, $K_U \le 1$. This is evidenced by the corresponding level of difference between these surfaces in Fig. 1, *d*, in the indicated area "1". The maximum difference between the surfaces in the studied range is 0.15 – area "2" in Fig. 1, *d*. At the same time, the dependence $q_{int1} = f(K_U, K_I)$ at the boundaries ($K_U = 0$ or $K_I = 0$) coincides with the dependence $q_{int2} = f(K_U, K_I)$. In this situation, we should note the limiting case, under the conditions $K_U = 0$, $K_I \to \infty$ and $K_U \to \infty$, $K_I = 0$ the value of the interfere power factor tends to unity $q_{int} \to 1$.

Provided that $K_U = 0$ and $K_I = 0$ (direct current and voltage) $q_{inv1} = q_{inv2} = 0$, which is also observed under the condition $K_U \to \infty$ and $K_I \to \infty$ (sinusoidal current and voltage).

We use the proposed indicators to estimate the power of a single-phase elementary semiconductor rectifier in the circuit shown in Fig. 2. The following circuit parameters are set for the experiment. The source has voltage $u_{gr} = U_{m.gr}\sin(\omega t) =$

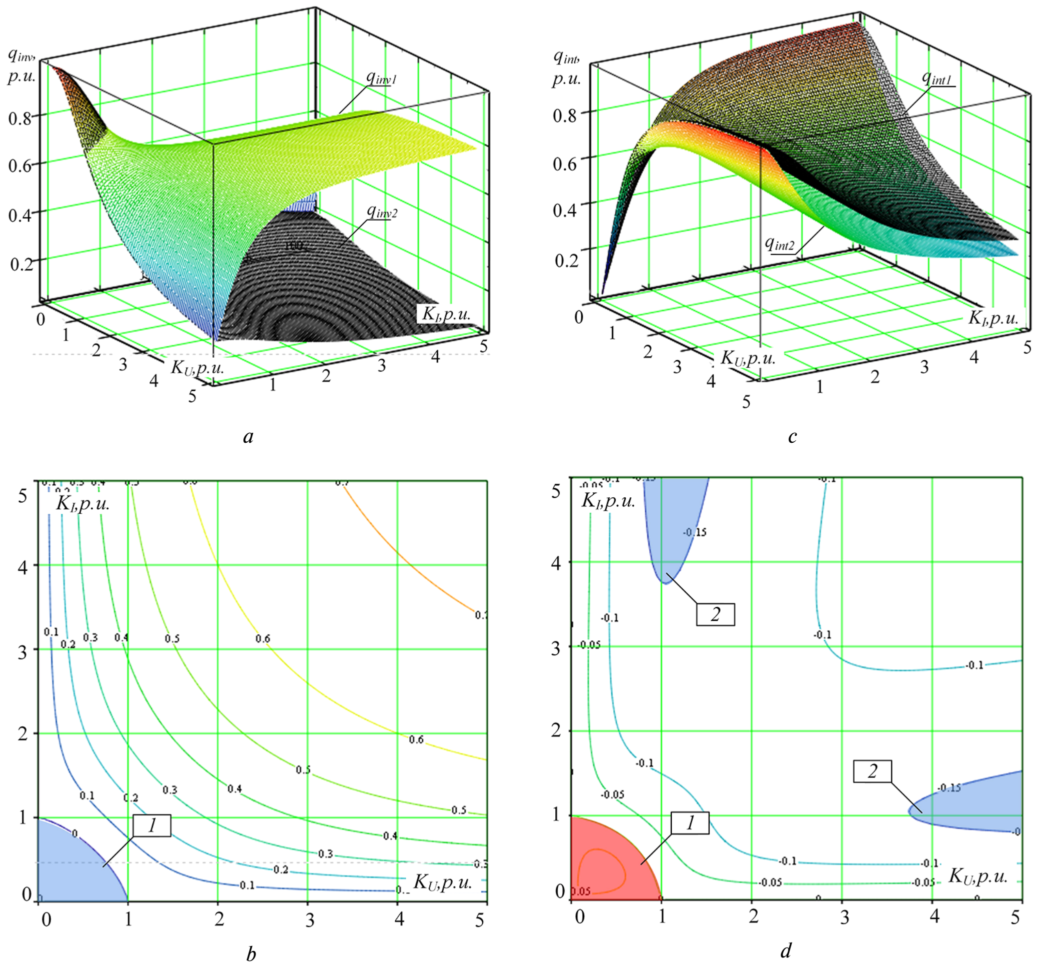


Fig. 1. Dependence diagram $K_I = I_0/I_1$, $K_U = U_0/U_1$:
a – invariance power factor; b – invariance power factor differences; c – interference power factor; d – interference power factor differences

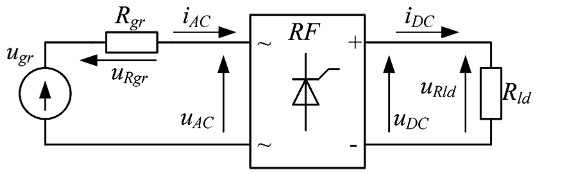
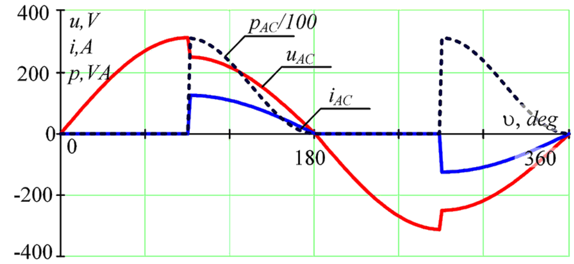


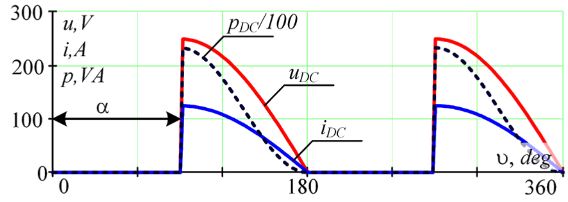
Fig. 2. Scheme of the system under study with a controlled single-phase rectifier

$= 220\sqrt{2}\sin(2\pi 50t)$, where t is time; ω is angular frequency; $U_{m.gr}$ is source voltage amplitude. The network is represented by a lumped resistance $R_{gr} = 1\,Ohm$ of active load with resistance $R_{ld} = 10\,Ohm$. Rectifier semiconductors are assumed to be ideal. Let us assume that the rectifier control angle a of the semiconductors changes. Current, voltage and power under the condition of a control angle 90 degrees are shown in Fig. 3.

The analysis of the diagrams in Fig. 3 shows that the graph of power changes at the input (p_{AC}) and output (p_{DC}) naturally coincides. We use the procedure for calculating the instantaneous power given in [16] with its division into canonical, pseudo-canonical and noncanonical components. As shown in [17], in this case, the components of the last group are absent. A series of experiments was carried out with a change in the rectifier control angle from α = 0 *deg* to α = 120 *deg*. For each case, a discrete spectrum of amplitudes of orthogonal cosine and sine power components was calculated from the harmonics s at the input (p_{AC}) and output (p_{DC}) of the rectifier (Fig. 4).



a



b

Fig. 3. Time diagrams in the rectifier parameter changes:
a – on the AC side; b – on the DC side

The analysis of the diagrams shown in Fig. 4 shows the following. When the valve control angle is changed from 0 to 30 *deg*, the sine orthogonal power components have an insignificant level. Significant amplitudes of the cosine compo-

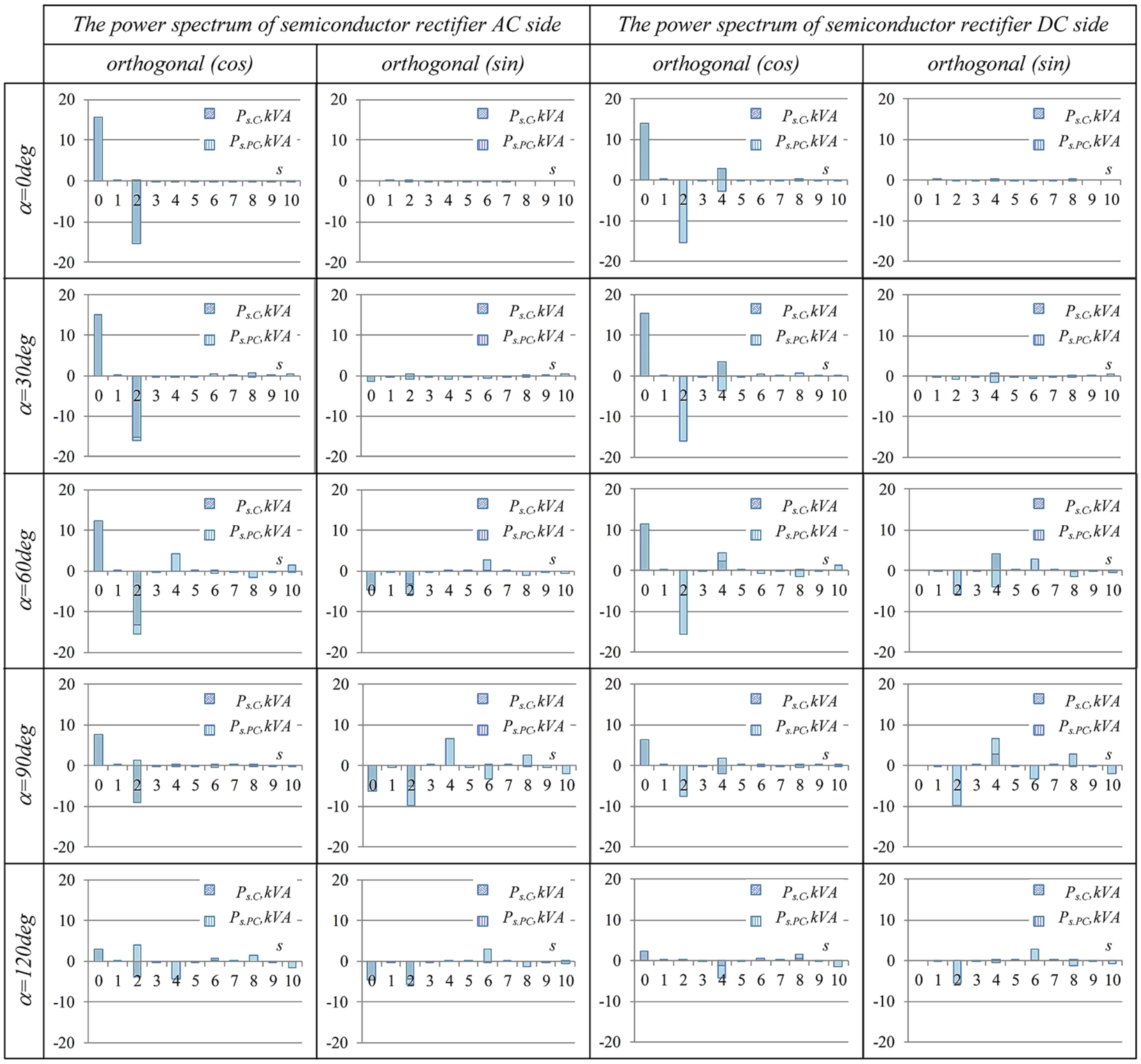


Fig. 4. Discrete amplitude spectrum of orthogonal cosine and sine power components

nents of the zero and second power harmonics are observed. On the AC side, the amplitude of the cosine component refers to the canonical power components, and on the DC side, to the pseudo-canonical ones. On the DC side, the amplitude of the fourth harmonic of the canonical power component is compensated by the harmonic of the pseudo-canonical power component.

Under the condition of an angle of 60 *deg*, the sine orthogonal power components acquire a significant level. Due to the action of the pseudo-canonical components, the second and fourth harmonics of the cosine orthogonal power components are amplified.

In the range of control angle change from 60 to 120 *deg*, there is a decrease in the direct component and the amplitude of the second harmonic, both cosine and sine orthogonal power components at the input and output of the rectifier.

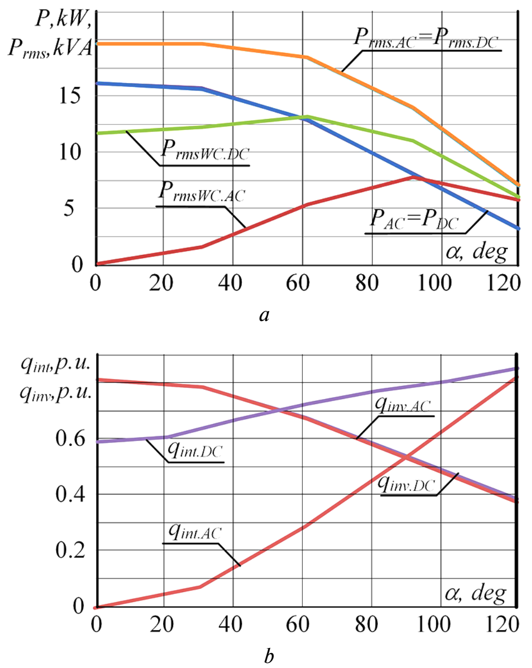
According to the data obtained, depending on the control angle, the integral indicators are determined according to [17] in the AC and DC circuits: active power (P); RMS power (P_{rms}); RMS interference power ($P_{rms.WC}$). The dependences of the invariance power factor (q_{inv}) and the interference power factor (q_{int}) for the indicated conditions are also determined. The results are shown in Fig. 5.

The active power and RMS power (Fig. 5, *a*) at the input and output of the rectifier are equal ($P_{AC} = P_{DC}$ та $P_{rmsAC} = P_{rmsDC}$). But the change in the interference power RMS value has a different pattern of change ($P_{rms.WC.AC} \neq P_{rms.WC.DC}$). At the same time, even at a control angle of 0 *deg*, the interference power RMS value at the rectifier output differs from zero.

Conclusions.

1. Theoretical provisions for estimating electric power using the invariance power factor have been developed due to the possibility of its application for power in both direct and alternating current circuits.

2. Using the factors due to the ratio of the harmonic component RMS value to the direct component for current and voltage, respectively, the surfaces of the invariance power factor are obtained. Its limiting values are established, due to the dominance of the harmonic or direct component, as well as the phase shift of the variable components of voltage and current.



b

Fig. 5. Characteristics when changing the control angle:

a – active and RMS power; b – invariance and interference power factor

3. To assess the power distortion due to interaction of different frequencies current and voltage components for a pulsating current circuit, the rationality of using the interference power factor is substantiated.

4. The interference power factor, as the ratio of the effective value of the harmonic component to the direct component for current and voltage, changes from 0 for direct current and voltage, to 0 for harmonic current and voltage. In this case, the maximum value of the interference power factor is achieved with a combination of direct current/voltage and sinusoidal voltage/current. This case is classified as limiting.

5. The change in the interference power factor in the case under study, depending on the phase shift of the current and voltage harmonic components of (0 and $\pi/2$), does not exceed 0.15 p.u.

6. The behavior of the interference power factor was studied for circuits of alternating non-sinusoidal current and pulsating current of a controlled rectifier. As a result, the difference in the dependence of the interference power factor at the input and output of the rectifier is established.

7. The interference power factor is rational to use, taking into account its universality for an arbitrary power nature, which is especially important for evaluating processes in current/voltage type converters, electromechanical converters and similar devices.

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Показник якості електричної потужності – фактор потужності змішування

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Мета. Обґрунтування методики розрахунку показника, що характеризує спотворення потужності пульсуючого струму.

Методика. Проводячи аналіз потужності постійного та змінного синусоїдального струму відзначені особливості співвідношення середньоквадратичної норми потужності до її постійного значення, відоме як фактор незмінності потужності. При цьому середньоквадратичне значення потужності виступає нормуючим параметром. Використовуючи комбінацію постійного й синусоїдального (пульсуючого) струму отримані залежності фактору незмінності потужності від співвідношення постійних і змінних складових.

Результати. Беручи до уваги взаємодію складових струму й напруги різних частот, виділена відповідна компонента потужності, іменована «потужністю змішування». З її використанням, за аналогією із фактором незмінності потужності, уведено фактор потужності змішування. Поведінка фактору потужності змішування досліджена для кіл змінного несинусоїдального струму та пульсуючого струму випрямляча, у результаті чого встановлена різниця залежності фактору потужності змішування на вході й виході випрямляча.

Наукова новизна. Отримані залежності фактору потужності змішування від співвідношення постійних і змінних складових для струму та напруги доводять універсальність його застосування для оцінки спотворення потужності як у колах постійного, так і змінного струму, що доведено на прикладі схеми з однофазним керованим випрямлячем.

Практична значимість. Отримані результати можуть бути використані для оцінки рівня спотворення електричної потужності в електроенергетичних комплексах і системах різного роду струму й роду енергії, у тому числі при її обліку. Це є передумовою для розробки заходів щодо підвищення якості електричної енергії.

Ключові слова: *трансформатор тягової підстанції, гармоніки струму й напруги, втрати потужності, якість електричної енергії*

The manuscript was submitted 18.10.21.