метрами. Для коррекции погрешности от разброса параметров аналого-цифровых фазных каналов измерителей небаланса трехфазных напряжений предлагается одновременно один раз за период колебаний напряжения основной частоты входные (А, В, С) и выходные (а, в, с) зажимы фазных каналов переключать "по кольцу" с фазным шагом 120^0 *и измерять векторы выходного напряжения. При этом векторная погрешность от разброса параметров фазных каналов измерителя тоже вращается с фазным шагом* 120^0*, а векторы напряжения обратной последовательности (НОП) основной частоты электросети не вращаются. Поэтому следующие сложения соответственных кодов мгновенных значений полученных трех векторов разных тактов дает утроенное НОП основной частоты без погрешности от разброса параметров фазных каналов.* Библ. 12, рис. 3.

Ключевые слова: трехфазные напряжения, напряжения прямой и обратной последовательностей.

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FEATURES OF INFLUENCE OF THE HIGHER HARMONICS ON CHOICE PARAMETERS USBARS OF WORKSHOP NETWORKS

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The universal criteria, which allows for the effective and calculated values of the network power factor optimally choice the busbar configuration, also the parameters of reactive power compensation devices for reducing of power and voltage losses in three-phase systems of shop electric power supply was developed. The modified technique of preliminary estimation of the voltage losses in busbar trunk lines on the power factor of the network taking into account the higher harmonics content of the busbar current is developed. This will provide a qualified approach to the formation of requirements for the construction of current conductors and converters, which are sources of generation of the current harmonics. References 10, figures 2, table.

Key words: busbar, higher harmonics, compensation, voltage, power factor.

Introduction. The production of metallurgical energy-intensive products, the provision of technological operations applying hoisting and transport mechanisms, including crane electric drives in the shops of enterprises is very powerful. Therefore, for modernization own power systems of enterprises of the Ukrainian metallurgical industry requires the application of modern solutions in the field of energy resource saving. The wide use of power semiconductor converters in all industries allowed increased the energy efficiency of industrial mechanisms, to reduce energy consumption, and to improve the quality of manufactured products. The introduction of frequency-controlled electrical drive systems, rectifiers and other semiconductor converters leads to the generation of higher harmonic components in DC and AC current conductors, and also negatively affects the network power factor, which are standardized by the relevant standards of electromagnetic compatibility [1]. The presence of higher harmonics in the current conductors also provides additional voltage power losses. Therefore, to suppress them to the allowable standards, knowledge of the network configuration and detailed calculation of the power system is required.

Analysis of last researches. Now, there is a significant amount of work devoted to the influence of current higher harmonics on the losses in the main elements of the network: electrotechnical converters [2], semiconductor converters [3], synchronous and asynchronous electric drive systems [4] and etc. The known engineering techniques for selecting and calculating current conductor parameters for shop networks (shape, geometry, relative locations) [5] not allow to taking into account the influence of current higher harmonics on the voltage losses in the shop networks, power losses, changing of balance of active and reactive capacities, network parameters, non-phase symmetry. For determining the reserve of a possible increase efficiency coefficient by compensating pulsations of active and reactive powers, also a constant component of reactive power in electric supply systems in the works [6, 7] by authors were researched. The researches allowing to evaluate

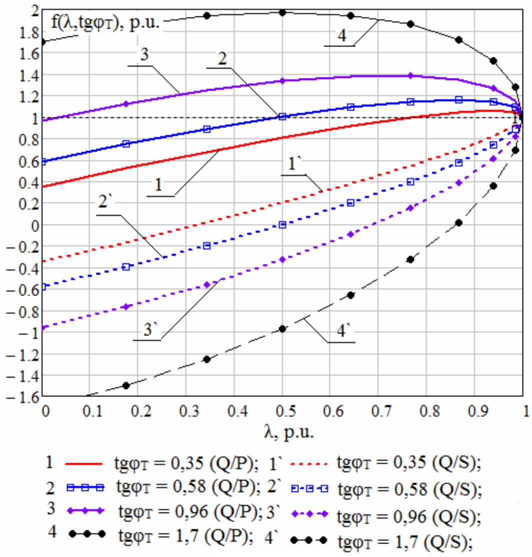

Fig. 1

the influence of the asymmetry of the geometry constructions and type of materials, on the electromagnetic parameters of the electric network is provided. Most of the works is devoted to the research of electromagnetic, energy and thermal processes [8, 9], identification of electrical parameters, electrical stability parameters of busbars, and for graphite furnaces [10], crucible melting furnaces, vacuum plasma electric furnaces by numerical simulation methods. All these researches allowed increasing energy efficiency of technological processes and electromagnetic compatibility between the main elements of three-phase power supply systems. However, problems, which related to the assessment of the effect of higher harmonic current components and asymmetry in three-phase power supply systems on power and voltage losses in shop current conductors, depending on their design parameters are not sufficiently researched. Therefore, the actual problem is to improve the techniques of choice the busbars of AC current, which allow estimating the voltage and power losses in the shop networks, depending on the higher harmonics content of electromagnetic parameters. Also it will provide a qualified approach to the formation of requirements for the construction of current conductors and converters, which are sources of generation of the current harmonics.

The aim of this work is to improve the technique for estimating the voltage losses in three-phase busbar systems of shop power supply, depending on the higher harmonics content of the electromagnetic parameters of the network.

Expounding the main material. The parameters of the reactance (X) and resistances (R) of the current conductor significantly depends on its geometry (the ratio of height and width dimensions, proximity effect, displacement effect, current density and frequency, the presence of protective shieldings, the current conductor materials). Mostly, the increases of the power and voltage losses in busbar systems allowed by the growth of reactance related resistance. Therefore, when designing and choosing of the geometry constructions and busbars placement, designers are trying to minimize reactance, so that the calculated value of the voltage losses corresponds to the value of the voltage loss for λ =1. For this comfortably to use the nondimensional parameters represented as a function which depends from power factor of the network.

The voltage losses in the current busbars is determined by the known expression [5]:

$$\Delta U=\left[\sqrt{3}\cdot I\cdot\left(R\cdot\cos\varphi+X\sin\varphi\right)/U\right]\cdot 100\%\,, \qquad (1)$$

where R, X is the resistance and reactance of current busbar, Om; I is the effective value of busbar current, A; U is the linear value of voltage, V; φ is the angle phase shift between current and voltage, el. deg.

For further analysis, the expression (1) transformed as:

$$\Delta U=\left[R\cdot\sqrt{3}\cdot I\cdot\left(\cos\varphi+tg\varphi_T\cdot\sin\varphi\right)/U\right]\cdot 100\%\,, \qquad (2)$$

where $tg\varphi_T=X/R$ is the design parameter of the current busbar.

If the busbar parameters are expressed in relative units, and assume that R*=1, that according to (2) the character of the voltage losses ΔU will be determined by the behavior of the function:

$$f\left(\varphi,tg\varphi_T\right)=\cos\varphi+tg\varphi_T\cdot\sin\varphi\,. \qquad (3)$$

In fig. 1 shown dependence of the function $f(\varphi,\ tg\varphi_T)$ on the power factor of the network for different values of the design parameter $tg\varphi_T$ for active-inductive (Q/P) and active-capacitive (Q/S) loads. At the active inductive loads, in the Q/P zone, for the eigenvalues of $tg\varphi_T$, the function (3) will be possess the value f_{QP}=1 at two points: at λ = 1, and the defined value λ according to the value of $tg\varphi_T$. For example, for busbar with $tg\varphi_T$ = 0,35 (curve 1, fig. 1) the function (3) will be possess the value f_{QP}= 1, at λ=0,7 and for $tg\varphi_T$ = 0,58 - λ = 0,5 (curve 2, fig. 1.). With decreasing busbar design parameter $tg\varphi_T$, the curve function (3) is shifted to the right side, and the value of power factor λ at the point of intersection of the curve will tend to $\lambda = 1$. At the active-capacitive loads, in the Q/S zone, the curve of the function (3) is symmetrical relative to the function curve (3) with the active-inductive loads. (curves 1`-4`, fig.1). Since in three-phase systems of shop electric power supply used only active-inductive loads, the curves of function (3) need considering for estimation of compensation possibility of voltage dropping in busbar by reactive power compensation devices. For example, for busbar design parameter $tg\varphi_T = 0{,}35$, for a compensation angle $\varphi_c = -5$ °, the voltage drop compensation value $f_{QS} = 0{,}034$; for $\varphi_c = -10$ ° - $f_{QS} = 0{,}076$; for $\varphi_c = -15$ ° - $f_{QS} = 0{,}106$. Thus, the dependences according to (3) are universal criteria, which allows choice the busbar design parameters for the effective and calculated values of the network power factor optimally, also the parameters of reactive power compensation devices for reducing of power and voltage losses in three-phase systems of shop electric power supply was developed.

To estimate the voltage losses taking into account the presence of current higher harmonics, transform equation (1) to the following form [5]:

$$\Delta U_{res} = \sqrt{\sum_{i=1}^{n} \left(\sqrt{3} \cdot I_i^2 \cdot \left(R_{\omega_i} \cdot cos\,\varphi + X_{\omega i} \cdot sin\,\varphi \right) \Big/ U \right)^2} \cdot 100\%; \qquad (4)$$

where I_i is the effective current value i-th harmonics; $R_{\omega i}$, $X_{\omega i}$ is the resistance and reactance of the busbar for the i-th harmonics.

Resistance and reactance values for the i-th harmonics determined from the following expression [5]:

$$R_{\omega_i} = k_{\omega_i} \cdot R_g; \qquad R_g = \rho \cdot \frac{l}{q}; \; X_{\omega i} = i \cdot X_{\omega_1} + 0{,}564 \cdot R_{\omega_i}, \qquad (5)$$

where $k_{\omega i}$ – coefficient, which takes into account the changes resistance at the current frequency of the i-th harmonics; R_g, – resistance for DC; l – active length of busbar, m; ρ – resistivity of the material of the busbar, Ohm·mm^2/m; q – cross-section of busbar, mm^2.

The coefficient which takes into account the change in the resistance from the current frequency of the i-th harmonics for steel busbars can be determined as [5]:

$$k_{\omega_i} = \begin{cases} 1 + 0{,}84 \cdot \beta_i^4, \forall \beta \prec 1; \\ 0{,}758 + \sqrt{1{,}34 \cdot \beta_i^2 - 0{,}183}, \forall \beta \geq 1; \beta \leq 3; \\ 0{,}758 + 1{,}159 \cdot \beta_i, \forall \beta \geq 3; \end{cases}$$

$$\beta_i = 2 \cdot 10^{-2} \cdot \frac{q}{P} \cdot \sqrt{\frac{i \cdot f}{\rho}} \cdot \mu; \qquad (6)$$

where P is the busbar perimeter, mm; f is the current frequency of i-th harmonics, Hz; μ is the мagnetic permeability, H/m.

According to the expressions (4)...(6), in fig. 2 shows the voltage drop on 1m of the busbar length for the first current harmonic, as well as the dependence of the resulting voltage drops for a nonsinusoidal current for the angled steel of busbar (profile 60 × 60 × 6, cross-section = 684 mm^2) from the network power factor, at current load of more than 5000 hours with a current density of 0,3 A/mm^2 (fig. 2 a), and current load up to 3000 hours, with a current density of 1,2 A/mm^2 (fig. 2 b) [5]. The harmonic composition of the current was determined according to for the standard values of the

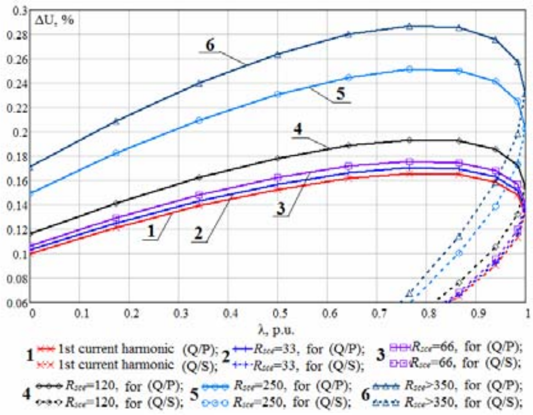

Fig. 2 *a*

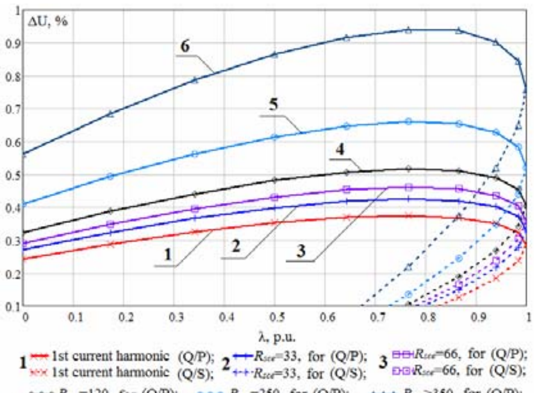

Fig. 2 *b*

short-circuit ratio R_{sce} [1]. To analyze the results of the research and to estimate the degree of influence of higher harmonics on the voltage drop in busbars, we will use the relative value of the voltage drop changes with non-sinusoidal current for the corresponding value:

$$\Delta U^*_{res} = \Delta U_{res} / \Delta U_1 ;$$

where ΔU_{res} is the resulting voltage drop at non-sinusoidal current at the corresponding coefficient R_{sce}; ΔU_1 is the voltage drop from the first harmonic of the current in the busbar.

In table shows the relative values of the voltage drop changes for the corresponding coefficients R_{sce} without and reactive power compensation. To compensate the reactive power, the change was taken into account, when the angle of phase correction varied in the range $0 < \varphi_c \leq -20°$. The analysis shows, that at maximum allowable current load on busbars, full compensation voltage drop, and particular overcompensation voltage drop on the availability of the higher harmonics, at lower values R_{sce} is performed. For large values R_{sce}, the current load on the busbars must be reduced. Thus, the availability of higher harmonics of current exert influence on the voltage drop changes in busbars, the relative value of which, can reach to 1,73...2,51 times, depending on the current load and the short-circuit ratio $R_{sce.}$ Partial or complete compensation of the voltage drop for steel busbars, depending on the value of the current load and the short-circuit ratio $R_{sce.}$, is performed, when the angle of phase correction in the range $0 < \varphi_c \leq -20$ ° is changed. However, providing correction angles $\varphi_c > -10°$, especially for large values of the short-circuit ratio R_{sce}, requires the use of reactive power compensation devices with a larger rated capacity, which is not always possible and reasonable for three-phase shop power systems. Therefore, in order to compensate the voltage drop on availability of the higher current harmonics, it is necessary to take into account not only the features of the busbar design parameters, but also a whole complex of features: related to the choice of the short-circuit ratio; current load conditions; operation modes of converters and limit of the related capacity of reactive power compensation devices. Due to the diversity of the converter technology and the generation by them of higher harmonics with values of amplitudes and frequency spectrum, which differ from the limited values of the standard documents [1]. This problem will be researched in the following aspects: development more accurate technique of determination of the voltage and power losses taking into account the constructive parameters of busbar and their optimization, the proximity effect, the displacement effect, the frequency spectrum and their phase angle shift between current and voltage, electromagnetic asymmetry, the presence of protective shells, etc.

φ_c	Relative values of voltage drop changes ΔU^*_{res}, p.u,									
	current load at J_{min}=0,3A/mm^2					current load at J_{max}=1,2A/mm^2				
R_{sce}	=33	=66	=120	=250	≥350	=33	=66	=120	=250	≥350
without reactive power compensation										
-	1,028	1,061	1,167	1,515	1,733	1,139	1,234	1,382	1,766	2,515
with reactive power compensation										
φ_c =-5°	0,92	0,948	1,044	1,355	1,549	1,013	1,22	1,235	1,578	2,255
φ_c =-10°	0,811	0,837	0,92	1,201	1,371	0,887	0,964	1,082	1,387	1,99
φ_c =-15°	0,708	0,723	0,805	1,05	1,196	0,766	0,834	0,935	1,205	1,744
φ_c =-20°	0,603	0,621	0,684	0,893	1,02	0,64	0,701	0,794	1,015	1,489

Conclusions. The universal criteria, which allows for the effective and calculated values of the network power factor optimally choice the busbar configuration, also the parameters of reactive power compensation devices for reducing of power and voltage losses in three-phase systems of shop electric power supply was developed. With the help of the improved technique, an estimation of the voltage drop in the steel busbars on the availability of higher current harmonics was executed. Depending on the short-circuit ratio and the current load, the relative value of the voltage drop can increase by 1,73...2,51 times was defined. At the maximum allowable current load on the busbars, full compensation, and particular overcompensation of the voltage drops on the availability of higher harmonics is performed at lower values of the short-circuit ratio. In this case, reactive power compensation devices with a smaller related power can be used. For large values of the short-circuit ratio, the current load on the busbars must be reduced.

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ОСОБЛИВОСТІ ВПЛИВУ ВИЩИХ ГАРМОНІК НА ВИБІР ПАРАМЕТРІВ СТРУМОПРОВОДУ ЦЕХОВИХ МЕРЕЖ
Розроблено універсальний критерій, що дає змогу для необхідних значень коефіцієнта потужності мережі оптимально підібрати конфігурацію шинопроводу, а також параметри пристроїв компенсації реактивної потужності для забезпечення зниження втрат і падіння напруги в трифазних системах цехового електропостачання. Удосконалено методику попередньої оцінки падіння напруги в шинопроводах від коефіцієнта потужності мережі з урахуванням змісту вищих гармонік струму, що дає змогу забезпечити кваліфікований підхід формування вимог до конструкцій струмопроводів і перетворювачів, які є їх джерелами генерації. Бібл. 10, рис. 2, таблиця.
Ключові слова: шинопровід, вищі гармоніки, компенсація, напруга, коефіцієнт потужності.

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ОСОБЕННОСТИ ВЛИЯНИЯ ВЫСШИХ ГАРМОНИК НА ВЫБОР ПАРАМЕТРОВ ТОКОПРОВОДОВ ЦЕХОВЫХ СЕТЕЙ
Разработан универсальный критерий, позволяющий для необходимых значений коэффициента мощности сети оптимально подобрать конфигурацию шинопровода, а также параметры устройств компенсации реактивной мощности для обеспечения снижения потерь и падения напряжения в трехфазных системах цехового электроснабжения. Усовершенствована методика предварительной оценки падения напряжения в шинопроводах от коэффициента мощности сети с учетом содержания высших гармоник тока, что позволяет обеспечить квалифицированный подход формирования требований к конструкциям токопроводов и преобразователям, являющихся их источниками генерации. Библ. 10, рис. 2, таблица.
Ключевые слова: шинопровод, высшие гармоники, компенсация, напряжение, коэффициент мощности.

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