DETERMINATION OF THREE-PHASE VOLTAGE S UNBALANCE WITH THE USE OF ANALOG-DIGITAL CONVERTORS OF ITS INSTANTANEOUS VALUES AND MATHEMATICAL TREATMENT OF THE GOT CODES

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Appearance of the asymmetrical, impulsive and stochastic loadings, store inter capacitors and semiconductor modulators in three-phase networks (3phn) substantially worsens their indexes of electric power quality, in particular such static and dynamic indexes, as voltage unbalance, speed and size of its change. Development of analog-digital measuring devices for determination of unbalance of three-phase voltage of fundamental frequency is an complicated problem, as analog blocks and analog-to-digital converters of the phase channels must be realized with identical parameters. For decreasing the parameters dispersion error of phase channels it is being suggested to measure phase voltages instantaneous' values at the output (a, b, c) clamps of the phase channels simultaneously during a period (20 ms) and to memorize it. Farther the input (A, B, C) and output (a, b, c) clamps of the phase cannels are being switched "on a ring" with a phase step of 120^0*. All the operations mentioned above are being executed three times. Thus a vector error caused by dispersion of parameters of the phase channels of measuring device is also being revolved with a phase step of* 120^0*, and the vectors of the negative voltage sequence (NVS) of the fundamental frequency (NVSFF) of the 3phn are not being revolved. Therefore the next adding of the proper instantaneous values of different three tacts selects the instantaneous values of triple NVSFF of the 3phn without the parameters dispersion error of phase channels.* References 12, figures 3.
Key words: three-phase voltage, direct and negative voltage sequence, electric power quality

Using of non-symmetrical semiconductor current modulators [1, 2] and discharging pulse generators [3] having linear and non-linear store capacitors [4, 5], non-linear and stochastic loads [6, 7] and forced limiting of electric current duration [8] considerably worsens indexes of electric energy quality in three-phase mains. Therefore the problem of correct measuring indexes mentioned above, and, in particular, improving of voltages unbalance and the speed of their changing is the urgent and actual one.

The unbalance of mains voltages is being defined by the root-mean square value of the negative voltage sequence (NVS) of the fundamental frequency (NVSFF) and is a random value [9]. Working out of analog-digital measuring system of three-phase voltage's unbalance is a quite complicated task, as it is necessary to have analog units of phase channels with identical parameters. An analog unit of each channel must provide a galvanic isolation, scaling and filtering of low frequencies before analog-digital conversion, the error caused by parameters dispersion of each channel adding to the error caused by measuring of voltage unbalance; usually the total absolute error of each channel must not exceed 0.1 %. For decreasing this shortage of measuring system of electric energy quality it is suggested in this paper to use the analogue-to-digital conversion of instantaneous values of phase voltages in the three-phase mains with following mathematical treatment of obtained codes [10]. This approach is enough universal, because it allows to measure all the current static indexes of electric energy's quality of every period of the fundamental frequency as well as dynamic indexes of the above mentioned quality with necessary accuracy [11].

For measuring the NSV it is necessary to complete two linear procedures – extracting sought symmetrical three-phase voltage system and extracting voltage of the fundamental frequency. As a consequence of the linearity of these procedures the first one to be completed may be any of them. Traditionally the extracting of fundamental frequency's phase voltages is being completed after the analog-to-digital conversion followed by enough complicated calculation of the three-phase voltage symmetric component. After extracting of phase voltages of the fundamental frequency these voltages contain a non-informative dominant positive voltage sequence (PVS) of the same frequency, which exceeds the NVS 25 to 50 times, and it is necessary to process obtained codes in digital devices having a big word memory. These indirect methods of NVS measuring are being characterized by insufficient accuracy.

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Therefore the attraction should be toward the method [2, 3] using at the beginning of processing the analog-to-digital conversion of phase voltages into instantaneous values which are then being memorized. After that codes of instantaneous values of NVSFF and three-phase voltages higher harmonics are being extracted. It is obtained by suppressing of non-informative dominant PVS of the fundamental frequency and majority of higher harmonics. Then codes of the fundamental frequency's NVS are being selected. But under measuring of the NVS with the aim of any method considerable demands to the identity of phase channels' parameters remain. And under the wide scatter of these parameters it is necessary to correct the error caused a scatter.

The aim of this paper is analysis of equations describing conversion characteristics of NVSFF meters and working out correction of dominant errors under NVS measurement. The emphasis is on the correction of errors caused by parameters dispersion of phase channels.

Each of the three channels of the NVS meter contains connected in series analog input units: an analog switching unit (ASU1..3), a galvanic decoupling circuit (GDC1..3), a scale conversion circuit (SCC1..3), a low-pass filter (LPF1..3) for decreasing of possible error caused by time sampling and an analog-to-digital converter (ADC1..3), a digital switch (DS4..6). Such three-phase units [12] are reasonable to be considered together as a linear six-terminal network with three inputs and three outputs. In general case a non-symmetrical three-phase voltage of fundamental frequency is applied to input contacts a, b, c of the three-phase unit having parameters dispersion; this three-phase voltage can be introduced as the sum of a PVS symmetrical system – $\dot{U}_{1(1)}\begin{pmatrix}1\\a^2\\a\end{pmatrix}=\dot{U}_{1(1)}(a+)$ and a NVS one – $\dot{U}_{2(1)}\begin{pmatrix}1\\a\\a^2\end{pmatrix}=\dot{U}_{2(1)}(a-)$ of the fundamental frequency, $a=\exp(j2\pi/3)$, $j=\sqrt{-1}$. Using the principle of superposition (as the circuit which is to be considered is the linear one), the expression for the output voltage of such a three-phase unit one can write that

$$\begin{pmatrix}\dot{U}_{a\Sigma}\\\dot{U}_{b\Sigma}\\\dot{U}_{c\Sigma}\end{pmatrix}=(\dot{U}_{a\Sigma}\quad\dot{U}_{b\Sigma}\quad\dot{U}_{c\Sigma})^T=\dot{\alpha}_\Sigma\dot{U}_{1(1)}(a+)+\dot{\beta}_\Sigma\dot{U}_{2(1)}(a-)+\left[\dot{\gamma}'_\Sigma\dot{U}_{2(1)}(a+)+\dot{\gamma}_\Sigma\dot{U}_{1(1)}(a-)\right],\qquad(1)$$

where; $\dot{\alpha}_\Sigma,\dot{\beta}_\Sigma$ are transfer factors of PVS $\dot{U}_{1(1)}(a+)$ and, accordingly, NVS $\dot{U}_{2(1)}(a-)$, $|\dot{\alpha}|\langle\langle 1$, $|\dot{\beta}|\approx 1$, $\dot{\gamma}_\Sigma,\dot{\gamma}'_\Sigma$ – conversion factors of PVS $\dot{U}_{1(1)}(a+)$ and NVS $\dot{U}_{2(1)}(a-)$ by the three-phase unit into, accordingly, NVS $\dot{\gamma}_\Sigma\dot{U}_{1(1)}(a-)$ and PVS $\dot{\gamma}'_\Sigma\dot{U}_{2(1)}(a+)$, $|\dot{\gamma}_\Sigma|\approx|\dot{\gamma}'_\Sigma|\langle\langle 1$, $|\dot{U}_{1(1)}|\rangle\rangle|\dot{U}_{2(1)}|$.

Coefficients $\dot{\gamma}_\Sigma,\dot{\gamma}'_\Sigma$ characterize the size of phase channels dispersion. It is the latter that is the reason of the opposite sequence of symmetric system's voltages appearance. And the value of the said dispersion sets the value of the opposite voltage. The total vector error due to the phase voltages dispersion is given in (1) in square brackets.

The hardiest demands to this dispersion appear under NVS measurements, that is why we will describe this case more detailed. The first item in (1) shows the effect of the PVS changing ($1/|\dot{\alpha}_\Sigma|$ times), and the second one – changing of NVS ($1/|\dot{\beta}_\Sigma|$ times). Only the second item $\dot{\beta}_\Sigma\dot{U}_{2(1)}(a-)$ in (1) is proportional to the measured NSV. The second item $\dot{\gamma}_\Sigma\dot{U}_{1(1)}$ in square brackets makes the most contribution to the error caused by parameters dispersion; it can be modulo commensurable or even bigger than the second and the only informative item in (1). This part of the error has the same frequency and phase sequence as the voltage to be measured, and it is hard to separate the said part and to reduce its influence on the result. And it is necessary to reduce by all means the error caused by parameters dispersion in phase channels.

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Below the correction method of the error caused by the above mentioned dispersion is suggested. According to this method instantaneous values of three phase voltages are being measured during three periods of the fundamental frequency's voltage (the first three steps).

1st step. . Phase voltages u_A, u_B and u_C are being accordingly applied to phase inputs a, b, c through analog switching units ASU1..3 of galvanic decoupling circuits GDC 1...3 during the first period. Instantaneous values of voltages from outputs A, B and C of according analog-digital converters ADC1...3 through digital switches DS4...6 are being written respectively into memory registers RA, RB and RC. The measurement result is (Fig 1):

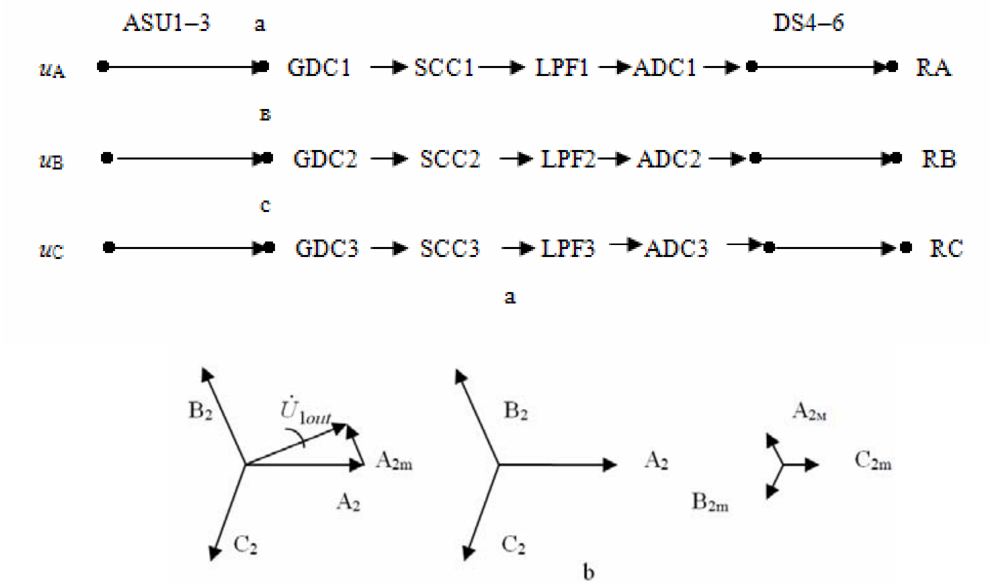

Fig. 1

$$\dot U_{1вих} = (\dot U_{a\Sigma} \quad \dot U_{b\Sigma} \quad \dot U_{c\Sigma})^T{}_1 = \dot\alpha_\Sigma \dot U_{1(1)}(a+) + \dot\beta_\Sigma \dot U_{2(1)}(a-) + \left[\dot\gamma'_\Sigma \dot U_{2(1)}(a+) + \dot\gamma_\Sigma \dot U_{1(1)}(a-)\right] \approx \dot\beta \dot U_{2(1)}(a-) + \dot\gamma \dot U_{1(1)}(a-).$$

2nd step. Phase voltages u_C, u_A and u_B are being accordingly applied to phase inputs a, b, c through analog switching units ASU1..3 of galvanic decoupling circuits GDC 1..3 during the second period. Instantaneous values of voltages from outputs A, B and C of according analog-digital converters ADC1..3 through digital switches DS4..6 are being written respectively into memory registers RC, RA and RB. The measurement result is (Fig 2):

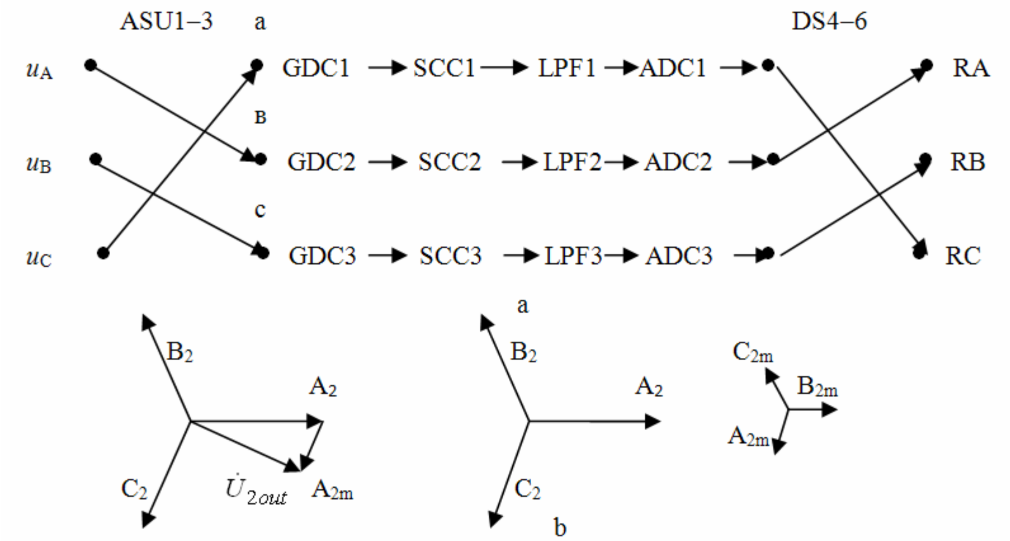

Fig. 2

$$(\dot U_{a\Sigma} \quad \dot U_{b\Sigma} \quad \dot U_{c\Sigma})^T{}_2 = \dot\alpha_\Sigma \dot U_{1(1)}(a+) + \dot\beta_\Sigma \dot U_{2(1)}(a-) + a\left[\dot\gamma'_\Sigma \dot U_{2(1)}(a+) + \dot\gamma_\Sigma \dot U_{1(1)}(a-)\right] \approx \dot\beta \dot U_{2(1)}(a-) + a\dot\gamma \dot U_{1(1)}(a-).$$

Such kind of phase channels commutation gives the circle's rotation of the vector error (with the step of 120^0) caused by parameters dispersion of phase channels. At that vectors of mains NVSFF do not rotate.

3rd step. Phase voltages u_B, u_C and u_A are being accordingly applied to phase inputs a, b, c through analog switching units ASU1..3 of galvanic decoupling circuits GDC 1..3 during the third period. Instantaneous values of voltages from outputs B, C and A of according analog-digital converters ADC1..3 through digital switches DS4..6 are being written respectively into memory registers RB, RC and RA. The measurement result is (Fig 3):

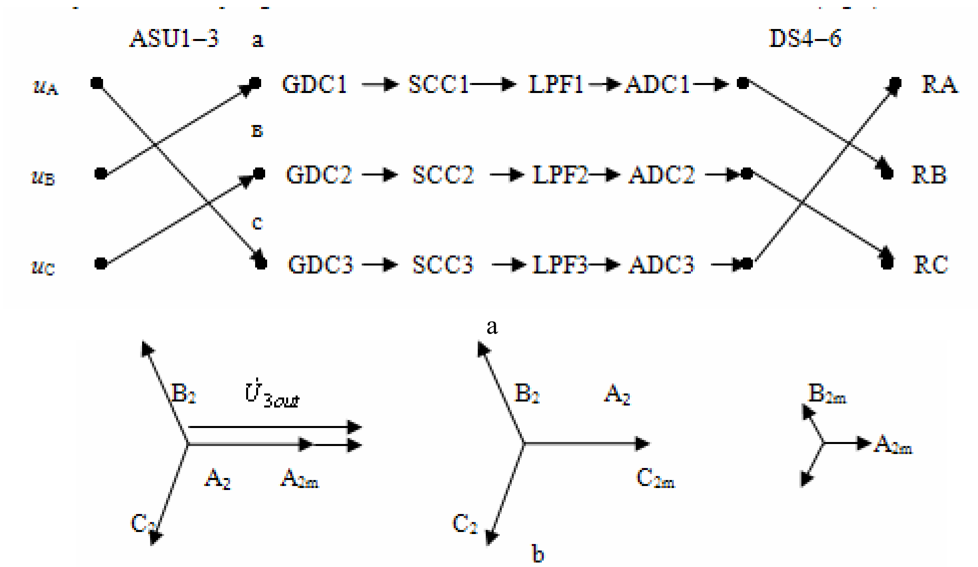

Fig. 3

$$(\dot U_{a\Sigma}\quad \dot U_{b\Sigma}\quad \dot U_{c\Sigma})^T{}_3 = \dot\alpha_\Sigma \dot U_{1(1)}(a+) + \dot\beta_\Sigma \dot U_{2(1)}(a-) + a^2\left[\dot\gamma'_\Sigma \dot U_{2(1)}(a+) + \dot\gamma_\Sigma \dot U_{1(1)}(a-)\right] \approx \dot\beta \dot U_{2(1)}(a-) + a^2\dot\gamma \dot U_{1(1)}(a-).$$

4th step. Every three instantaneous values of according time samples which are accumulated in registers RA, RB and RC during three previous steps are being accordingly added. Results of this adding are respectively stored in memory register $R\Sigma$:

For single phase voltage: $\dot U_{1out} + \dot U_{2out} + \dot U_{3out} = 3\dot\beta \dot U_{2(1)}$ and for three phase voltage:

$$(\dot U_{a\Sigma}\quad \dot U_{b\Sigma}\quad \dot U_{c\Sigma})^T{}_\Sigma = (\dot U_{a\Sigma}\quad \dot U_{b\Sigma}\quad \dot U_{c\Sigma})^T{}_1 + (\dot U_{a\Sigma}\quad \dot U_{b\Sigma}\quad \dot U_{c\Sigma})^T{}_2 + (\dot U_{a\Sigma}\quad \dot U_{b\Sigma}\quad \dot U_{c\Sigma})^T{}_3 =$$
$$= 3(\dot\alpha_\Sigma \dot U_{1(1)}(a+) + \dot\beta_\Sigma \dot U_{2(1)}(a-)) \approx 3\dot\beta \dot U_{2(1)}(a-).$$

5th step. Then the NVSFF is being extracted.

Symmetric voltages of the opposite sequence comparing with the sequence of voltages which are applied to units' inputs also are being appeared at outputs of this measurer.

Conclusion. The obtained result contains the triple value of the sought NVS, and the error caused by parameters dispersion of phase channels completely disappears.

This voltage is being defined by the appropriate conversion factor and characterizes the dispersion value of meter's parameters. It is this component that can produce the one which will be dominant or commensurable with the sought NVSFF. Therefore it is necessary to complete additional correction of this error for increasing of accuracy's measurement of the NVSFF.

In the case of absence of additional correcting the influence of the above described error can be insufferable big. For example, under measuring of the unbalance coefficient in the limits of 2...5 % it is simply impossible to use type HCPL 7850 modules having 5 % gain coefficient's dispersion for galvanic isolation of each phase voltage without additional correcting. Even the use of expensive type AD210 modules having 0.1 % gain coefficients' dispersion makes great limitations on the total error of NSV measuring.

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ВИЗНАЧЕННЯ НЕБАЛАНСУ ТРИФАЗНИХ НАПРУГ З ВИКОРИСТАННЯМ АНАЛОГО-ЦИФРОВИХ ПЕРЕТВОРЮВАЧІВ ЇХ МИТТЄВИХ ЗНАЧЕНЬ ТА МАТЕМАТИЧНОЇ ОБРОБКИ ОТРИМАНИХ КОДІВ

Поява несиметричних, імпульсних і стохастичних навантажень, проміжних накопичувальних конденсаторів і напівпровідникових модуляторів у трифазних мережах електропостачання суттєво погіршує їхні показники якості електроенергії, зокрема такі статичні та динамічні показники, як небаланс напруги та швидкість і величина її змінення. Розробка аналого-цифрових вимірювачів для визначення небалансу трифазної напруги основної частоти є досить складною задачею, оскільки аналогові блоки фазних каналів і АЦП необхідно реалізовувати з ідентичними параметрами. Для корекції похибки від розкиду параметрів аналого-цифрових фазних каналів вимірювачів небалансу трифазних напруг пропонується одночасно один раз за період коливань напруги основної частоти вхідні (А, В, С) та вихідні (а, в, с) затискачі фазних каналів переключати "по кільцю" з фазним кроком 120^0 *та вимірювати вектори вихідної напруги. При цьому векторна похибка від розкиду параметрів фазних каналів вимірювача теж обертається з фазним кроком* 120^0*, а вектори напруги зворотної послідовності (НЗП) основної частоти електромережі не обертаються. Тому наступне складання відповідних кодів миттєвих значень отриманих трьох векторів різних тактів дає потроєну НЗП основної частоти без похибки від розкиду параметрів фазних каналів.* Бібл. 12, рис. 3.
Ключові слова: трифазні напруги, пряма та зворотна послідовності, якість електроенергії.

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ОПРЕДЕЛЕНИЕ НЕБАЛАНСА ТРЕХФАЗНЫХ НАПРЯЖЕНИЙ С ИСПОЛЬЗОВАНИЕМ АНАЛОГО-ЦИФРОВЫХ ПРЕОБРАЗОВАТЕЛЕЙ ИХ МГНОВЕННЫХ ЗНАЧЕНИЙ И МАТЕМАТИЧЕСКОЙ ОБРАБОТКИ ПОЛУЧЕННЫХ КОДОВ

Появление несимметричных, импульсных и стохастических нагрузок, промежуточных накопительных конденсаторов и полупроводниковых модуляторов в трехфазных сетях электроснабжения существенно ухудшает их показатели качества электроэнергии, включая такие статические и динамические показатели, как небаланс напряжения, скорость и величина ее изменения. Разработка аналого-цифровых измерителей для определения коэффициента несимметрии трехфазного напряжения основной частоты является достаточно сложной задачей, поскольку аналоговые блоки фазных каналов и АЦП необходимо реализовывать с идентичными пара-

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 (A, B, C) и выходные (a, в, c) 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