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Uncertainty Reproduction of the Three-phase Voltages System's Asymmetry Analysis

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Abstract **– Methods of reproduction of one-phase alternative voltage is widely known in measuring techniques. Developers apply the same methods to reproduce electric power quality indexes (EPQI) of three-phase networks, which consist of direct, reverse and zero symmetrical sequences. However these parameters depend not only on the amplitude of one vector of voltage of three-phase networks but on amplitudes of all of them and also on the phase angle between them, which is not taken into account by developers. It generates substantial disparity between the real uncertainty and uncertainty, caused only by inaccuracy of value of the amplitude of one vector of voltage of the network. On paper, the uncertainty of reproducing one of the parameters of quality of electric power was analysed in detail, taking into consideration its complex character. The result of comparing the uncertainty, which was calculated with consideration her complex character and without it, is given.**

Keywords – electric power quality indexes, uncertainty, reproduction, network

I. INTRODUCTION

The Electric Power Quality Indexes (EPQI) measurement is the part of the main problem of electric power consumption with parallel estimation of electric power quality and with elucidation of culprit of change to worse this quality. The problem has many peculiarities in the case of measurement of the following static Electric Power Quality Indexes – the three phase voltage fluctuation, the asymmetry factor, the shift of neutral point. It is necessary to take into account that a non-informative parameter (for example, a positive symmetrical sequence) may exceed many times an informative one (for example, negative symmetrical component).

That is why the accuracy of calibration of measurement equipment for informative parameters should be rated higher than the accuracy of calibration of measurement equipment for non-informative parameters.

Solving this problem is possible only when taking into account the complex character of uncertainty of reproducing the EPQI.

II. RELATED RESULTS IN THE LITERATURE

Most of the publications devoted to methods of reproduction of power quality parameters [1-5] existing only in three-phase systems of voltages and currents do not take into account the complex nature of the uncertainty of their reproduction.

III. DESCRIPTION OF THE METHOD

These parameters include the components of the forward, reverse, and zero sequences. Let us dwell on the definition of the uncertainty of the component of the zero sequence. Based on the expression [1]

$$\dot{U}_0 = \frac{1}{3}\left(\dot{U}_R + \dot{U}_S + \dot{U}_T\right), \qquad (1)$$

where $\dot{U}_0$ - the vector of the zero component of the voltage; $\dot{U}_R$, $\dot{U}_S$, $\dot{U}_T$, - the vectors of the three-phase system of voltages, it can be asserted that the uncertainty of reproduction of $\dot{U}_0$ depends both on the amplitudes of the voltage vectors in phases R, S, T and on the deviations of the phase angle between these vectors from the values $2\pi/3$. In other words, the uncertainty $\Delta\dot{U}_0$ of reproduction of $\dot{U}_0$ consists of the amplitude $\Delta\dot{U}_{0U}$ and phase $\Delta\dot{U}_{0\varphi}$ components: $\Delta\dot{U}_0 = \Delta\dot{U}_{0U} + \Delta\dot{U}_{0\varphi}$.

We first estimate the phase component. When $U_R = U_S = U_T = U_N$ and $\varphi_{RT} = \varphi_{RS} = 2\pi/3$, as shown in Fig. 1, the uncertainty $\Delta\dot{U}_0$ of reproduction of the symmetric component $\dot{U}_0$ is equal to zero. The phase component of the uncertainty $\Delta\dot{U}_{0\varphi}$ arises when the equality $\varphi_{RT} = \varphi_{RS} = 2\pi/3$ is violated. In this case, expression (1) is transformed to the form

$$\Delta\dot{U}_{0\varphi} = \frac{\dot{U}_N}{3}\left(e^{j\Delta\varphi_R} + e^{j\Delta\varphi_S} e^{j4\pi/3} + e^{j\Delta\varphi_T} e^{j2\pi/3}\right), \quad (2)$$

were, $e^{j2\pi/3}$, $e^{j4\pi/3}$ - are the rotation operators on $2\pi/3$, $4\pi/3$ respectively, $\Delta\varphi_R, \Delta\varphi_S, \Delta\varphi_T$ - are the deviations of the angles of the displacement of the voltages vectors in the phases R, S, T from the values 0, $2\pi/3$, $4\pi/3$, respectively.

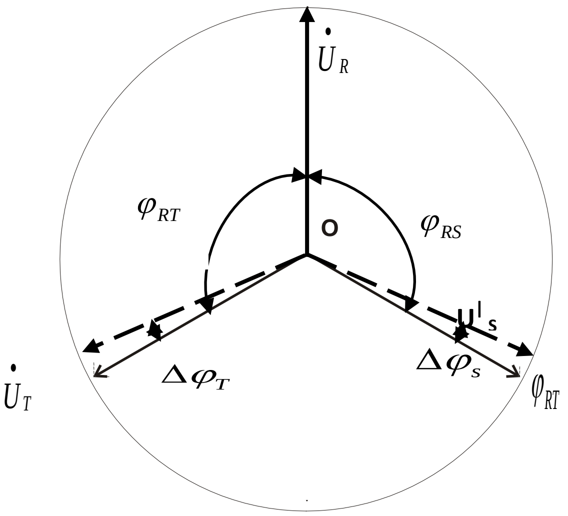

Fig. 1. Vector diagram of forming phase component uncertainty of asymmetry reproduction

Since to create a symmetrical three-phase system of voltages with the same amplitudes it is sufficient to ensure angles $2\pi/3$ between any two pairs of vectors, we assume that $\Delta\varphi_R = 0$. Then from (2) we have

$$\Delta\dot{U}_{0\varphi} = \frac{\dot{U}_N}{3}\left(1 + e^{j\Delta\varphi_S} e^{j4\pi/3} + e^{j\Delta\varphi_T} e^{j2\pi/3}\right). \quad (3)$$

Taking into account that when $\Delta\varphi_S \to 0$ and $\Delta\varphi_T \to 0$, $\cos\Delta\varphi_S \to 1$ and $\cos\Delta\varphi_T \to 1$, after decomposition $e^{j\Delta\varphi_S}$ and $e^{j\Delta\varphi_T}$ into the imaginary and real components according to the Euler formula we obtain from (3)

$$\Delta\dot{U}_0 = \frac{1}{3}\dot{U}_N\left(e^{j2\pi/3}\sin\Delta\varphi_S + e^{j4\pi/3}\sin\Delta\varphi_T\right). \quad (4)$$

The worst case of the effect of the presence of angles of phase shift $\Delta\varphi_S$, $\Delta\varphi_T$ on the asymmetry of the three-phase system of voltages is their multisigned increments. Let $\Delta\varphi_S = -\Delta\varphi_T$ and $\Delta\varphi_S = \Delta\varphi_T = \Delta\varphi$, (by the dotted line in Fig. 1). Then expression (4) is transformed to the form

$$\Delta\dot{U}_{0\varphi} = \frac{1}{3}\dot{U}_N \sin\Delta\varphi\left(e^{j2\pi/3} - e^{j4\pi/3}\right) \quad (5)$$

Expanding the brackets in (5), we obtain the following expression for the phase component of the uncertainty in the reproduction of the asymmetry

$$\Delta\dot{U}_{0\varphi} = -\frac{1}{\sqrt{3}}\dot{U}_N \sin\Delta\varphi. \quad (6)$$

To the phase component of uncertainty it is necessary to add a peak component $\Delta\dot{U}_{0A}$ that at presence of phase symmetry ($\varphi_{AC} = \varphi_{AB} = 2\pi/3$) arises up in case of violation of equality: $U_R = U_S = U_I = U_N$. The worst case of peak asymmetry is a negative increase of one of vectors of network on $-\Delta\dot{U}$ and positive increase of two other vectors on $\Delta\dot{U}$.

Consider this case using the vector diagram shown in Fig. 2.

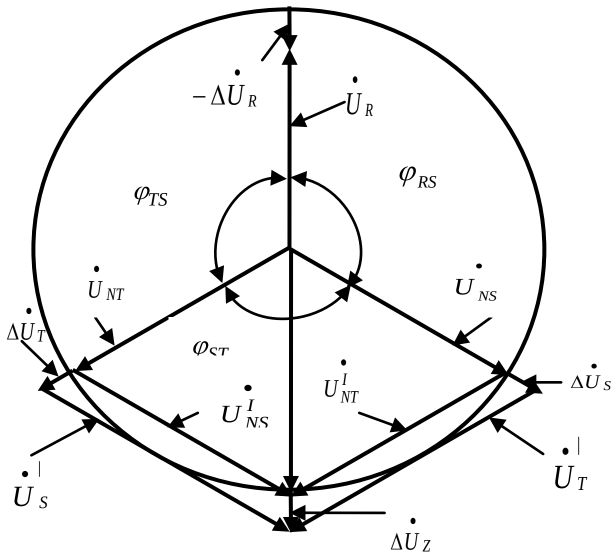

Fig. 2. Vector diagram of forming amplitude component uncertainty of asymmetry reproduction

As can be seen from the diagram, under the conditions $\varphi_{RT} = \varphi_{RS} = 2\pi/3$ and $U_{NR} = U_{SN} = U_{NT} = U_N$

after the summation of the vectors $\dot{U}_R, \dot{U}_S, \dot{U}_T$ we obtain the resultant vector $\dot{U}_\Sigma$ equal to

$$\dot{U}_\Sigma = -\Delta\dot{U}_R + \Delta\dot{U}_Z \,, \quad (7)$$

where $\Delta\dot{U}_Z = \Delta\dot{U}_S + \Delta\dot{U}_T$.

Taking $\Delta U_R = \Delta U_Z = \Delta U_T = \Delta U$, from (7) we obtain

$$\Delta U_{0A} = U_\Sigma = 2\Delta U \quad . \quad (8)$$

Consequently, the amplitude component of the uncertainty of asymmetry reproduction is twice higher than the uncertainty declared in the passports of some devices for reproducing the EPQI.

To obtain a complex expression for the amplitude component of the uncertainty, we substitute in (1) the real values of the vectors $\dot{U}_R, \dot{U}_S, \dot{U}_T$. Suppose that $\dot{U}_R = \dot{U}_{NR} - \Delta\dot{U}_R$, $\dot{U}_S = \dot{U}_{NS} + \Delta\dot{U}_S$ and $\dot{U}_T = \dot{U}_{NT} + \Delta\dot{U}_T$ (see Fig. 2). After setting these values in (1), we obtain the amplitude component of the uncertainty

$$\Delta\dot{U}_{0A} = \frac{1}{3}\left(\dot{U}_{NR} + \dot{U}_{NS} + \dot{U}_{NT} - \Delta\dot{U}_R + \Delta\dot{U}_S + \Delta\dot{U}_T\right), \quad (9)$$

Since $U_{NR} = U_{NS} = U_{NT} = U_N$, for the validity of the equality $\varphi_{RT} = \varphi_{RS} = 2\pi/3$, the sum of the vectors $\dot{U}_{NR} + \dot{U}_{NS} + \dot{U}_{NT} = 0$, and expression (9) takes the form

$$\Delta\dot{U}_{0A} = \frac{1}{3}\left(-\Delta\dot{U}_R + \Delta\dot{U}_S + \Delta\dot{U}_T\right). \quad (10)$$

Let the deviations of the phases voltages are equal to each other $\Delta\dot{U}_R + \Delta\dot{U}_S + \Delta\dot{U}_T = \Delta\dot{U}$, then the amplitude component of the uncertainty of reproduction $\dot{U}_0$ becomes equal to

$$\Delta\dot{U}_{0U} = -\frac{2\Delta\dot{U}}{3} \,. \quad (11)$$

And the total uncertainty

$$\Delta\dot{U}_0 = -\frac{1}{\sqrt{3}}\dot{U}_N \sin\Delta\varphi - \frac{2\Delta\dot{U}}{3} \,. \quad (12)$$

If the uncertainty of reproduction of the asymmetry of the three-phase system of the calibrator vectors is formed only on the basis of the uncertainty of reproduction of one vector, we obtain from (10) the next equation of total uncertainty

$$\Delta\dot{U}_0 = -\frac{\Delta\dot{U}}{3} \,. \quad (13)$$

Dividing (13) by (12), we obtain the coefficient of toughening of the accuracy requirements to the means of reproducing the quality parameters of three-phase electrical networks

$$\dot{K} = \sqrt{3}\frac{\dot{U}_N}{\Delta\dot{U}}\sin\Delta\varphi + 2 \,. \quad (14)$$

Expression (14) allows us to assert that the uncertainty in which its complex character is taken into account is several times higher than the uncertainty, which is determined only by the deviation of the amplitude of one of the vectors.

Calibrator [4], which has the uncertainty ΔU of reproduction of basic value of voltage, that is equal to $0.0005U_N$, and the uncertainty of reproduction of displacement of phase between the vectors of three phase network, that is equal to 0.03 degree, has, taking into account (14), the uncertainty of reproduction of unsymmetry of three- phase networks, which is equal 3.8 ΔU . It is $0.0019U_N$ or 0.19 % of basic value U_N of phase voltage. Coming from the requirements of standard [2], such uncertainty of reproducing does not allow to calibrate facilities of measuring of unsymmetry, as their error must not exceed 0.1% of basic value U_N of phase voltage.

Calibrators must have an uncertainty of reproducing three times less than an uncertainty of measuring means, assumed by a standard. In other words, the uncertainty of unsymmetry reproduced by calibrator must not exceed 0.033% of basic value U_N of phase voltage.

The calibrator Fluke 6101A [5], which has the uncertainty of reproducing of phase voltages, equal to $0.01U_N$, and the uncertainty of reproducing of displacement of phase between the vectors of three phase network, equal to 0.001 degree, satisfies to this requirement.

The uncertainty of reproducing of unsymmetry of this calibrator, taking into account equation (14), is equal $0.024U_N$.

Thus, attained exactness of calibration of facilities of measuring of EPQI is on the border of possibilities of measuring technique.

IV. RESULTS AND DISCUSSIONS

Advantages of method of adjusting of norms for EPQI uncertainty reproducing means wich take into account the features of the three-phase system of voltages in relation to the method of adjusting of norms for EPQI uncertainty reproducing means based on the method of precision task of amplitudes of network vectors are proved.

V. CONCLUSIONS

The described method allows in several times more precisely to estimate the uncertainty of reproducing of the unsymmetry and show that for the decision of problem of further increase of exactness of reproducing of the EPQI it is necessary to create more precise methods of their reproducing.

VI. ACKNOWLEDGMENT

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