IMPROVEMENT OF MONITORING MEANS OF VOLTAGE UNBALANCE FACTOR IN SHIPBOARD ELECTRICAL POWER SYSTEMS

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Shipboard electrical power systems (SEPS) are isolated and autonomous. Voltage unbalance can occur in a three-phase system due to the non-zero impedance of the power source and differences in phase loads. The power quality by the unbalance factor is considered to be in compliance with the standards if the total duration of its going beyond the normally permissible values (2%) is no more than 1 hour and 12 minutes per day. In addition, there should be no measurements exceeding the maximum permissible value (4%) [1]. In electric machines (e.g. induction motors), due to the appearance of additional magnetic fields rotating in the direction opposite to the direction of the rotor rotation, their service term is reduced by 10-15%. The efficiency of power (synchronous) generators is decreased. Also, voltage unbalance leads to an increase in losses in the neutral wire during power transmission. In this case, disruption of uninterrupted power supply, disruption of computers and other equipment [2] is possible. Therefore, it is relevant to improve the systems for measuring and monitoring the quality of electricity in three-phase networks.

In [3] the increasing useage of electric traction on ships is noted, which leads to a significant increase in nonlinear loads in the system due to the presence of drives with variable frequency. Also, in [3] the calculation of indicators of the power quality, based on the results of modeling, was carried out. At the same time, the options for the hardware implementation of the unbalance rate measurement system and algorithms for the software implementation of signal processing methods, brought to ready-made technical solutions, have not been considered. In [4], a research was made of the effect of a break in the neutral wire on the voltage unbalance ratio and electricity consumers. The importance and necessity of the presence of means for monitoring the voltage unbalance ratio is noted. The solutions proposed in [4] are useful in the design of power systems. The research carried out in this work will provide control and timely detection of the fact of voltage unbalance.

In [5], the influence of voltage unbalance on the magnitude of the moment on the shaft of an induction motor and its operating modes was investigated. Research has been done for 8 different types of asymmetry; the method of symmetric components was used. Analysis of the research results showed that in order to minimize hardware, it is advisable to measure the characteristics of phase voltages with a sequential calculation of the RMS values of line voltages.

The purpose of the research is the development and improvement of methods and means of control, analysis and monitoring of power quality indicators, one of which is the unbalance factor of the three-phase voltage system.

One of the purposes of the power quality monitoring system is the calculation and transfer to the automated control system at the operator's request of the zero sequence asymmetry coefficients:

$$K_{0U} = \sqrt{\frac{\sum_{i=1}^{N} K_{0U(i)}^2}{N}}\ , \tag{1}$$

and reverse sequence:

$$K_{2U} = \sqrt{\frac{\sum_{i=1}^{N} K_{2U(i)}^2}{N}}\ , \tag{2}$$

where $K_{0U(i)}$ and $K_{2U(i)}$ are the corresponding coefficients obtained on the basis of the data of the i-th sample; N is the number of samples in the averaging interval (according to [1], the averaging interval is 3 seconds and N must be at least 9).

The mathematical expression (1) can be written in the form of an analytical expression shown in Fig. 1.

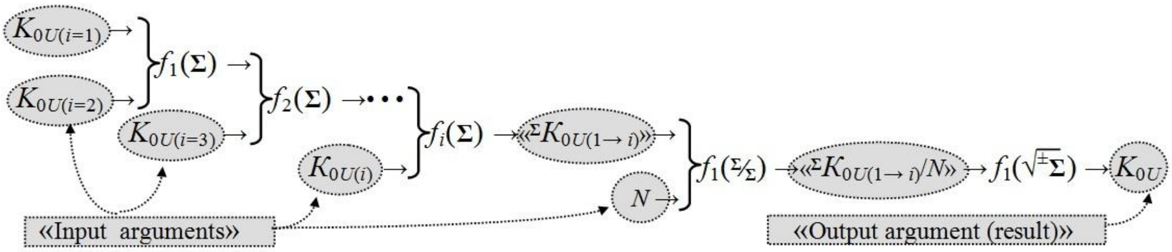

Figure 1 – Analytical expression for calculating K_{0U}

There are the functional structures of adders $f_1(\mathbf{\Sigma})$, $f_2(\mathbf{\Sigma})\ldots f_i(\mathbf{\Sigma})$ in the figure; $f_1(^{\Sigma}\!/_{\Sigma})$ – functional structure of the divider; $f_1(\sqrt{^{\pm}\Sigma})$ is a functional structure for calculating the square root. A feature of the analytical expression shown in Fig. 1 is an unambiguous sequence of actions performed. Similarly, the mathematical expression (2) can be represented.

To calculate the voltage unbalance ratio, an effective method from the point of view of subsequent practical implementation on the basis of a microcontroller or a programmable logic integrated circuit is to use the expressions [6]:

$$K_U = \sqrt{A^2 + B^2}\,, \tag{3}$$

$$A = \frac{2U_{AB} - U_{BC} - U_{CA}}{U_{AB} + U_{BC} + U_{CA}}\,, \tag{4}$$

$$B = \frac{\sqrt{3}(U_{BC} - U_{CA})}{U_{AB} + U_{BC} + U_{CA}}\,, \tag{5}$$

where U_{AB}, U_{BC} and U_{CA} are the measured RMS values of the line-to-line voltages. The mathematical expression (3) can be written in the form of an analytical expression (Fig. 2).

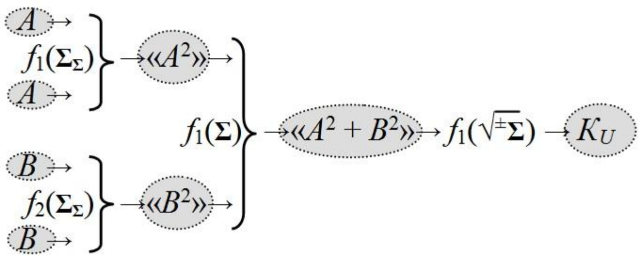

Figure 2 – Analytical expression for calculating K_U

Fig. 2 shows that by means of the functional structures of multipliers $f_1(\mathbf{\Sigma}_\Sigma)$ and $f_2(\mathbf{\Sigma}_\Sigma)$, intermediate arguments «A^2» и «B^2» are obtained for calculating, using the functional structure of the adder $f_1(\mathbf{\Sigma})$, the intermediate argument «A^2+B^2», which is the input argument of the functional structure for calculating the square root $f_1(\sqrt{^{\pm}\Sigma})$ to obtain the output (resulting) argument K_U.

The mathematical expression (4) can be written in the form shown in Fig. 3.

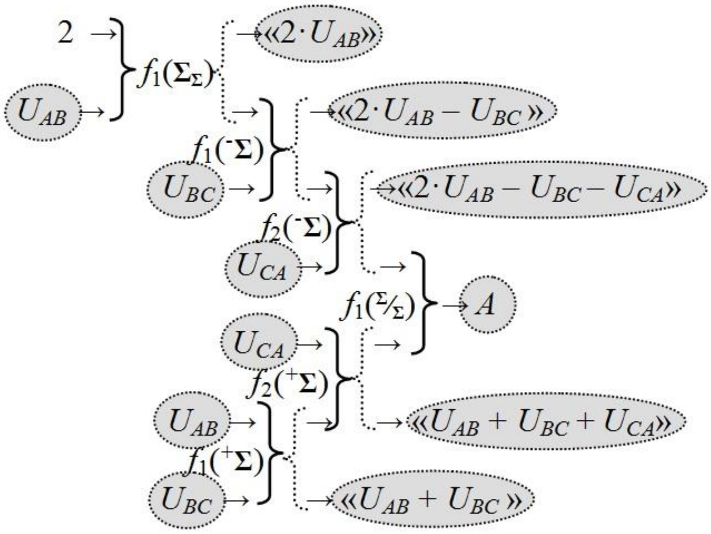

Figure 3 – Analytical expression for calculating the intermediate argument A

Using the functional structure of the multiplier $f_1(\mathbf{\Sigma}_\Sigma)$, an intermediate argument $f_1(\mathbf{\Sigma}_\Sigma)$ is obtained, which, together with the input arguments, is sequentially fed to the second inputs of subtractors $f_1(^{-}\mathbf{\Sigma})$ and $f_2(^{-}\mathbf{\Sigma})$ for obtaining the converted argument «$2\cdot U_{AB}–U_{BC}–U_{CA}$» and feeding it to the first input of the functional structure of the divider $f_1(^{\Sigma}\!/_{\Sigma})$ to obtain the resulting argument A. Simultaneously with this procedure, the second input of the functional structure of the divider $f_1(^{\Sigma}\!/_{\Sigma})$ receives an intermediate result (argument) «$U_{AB}+U_{BC}+U_{CA}$», which is obtained using the functional structures of adders $f_1(^{+}\mathbf{\Sigma})$ and $f_2(^{+}\mathbf{\Sigma})$ from the input arguments U_{AB}, U_{BC} and U_{CA}.

Mathematical expression (5) can be written in the form shown in Fig. 4.

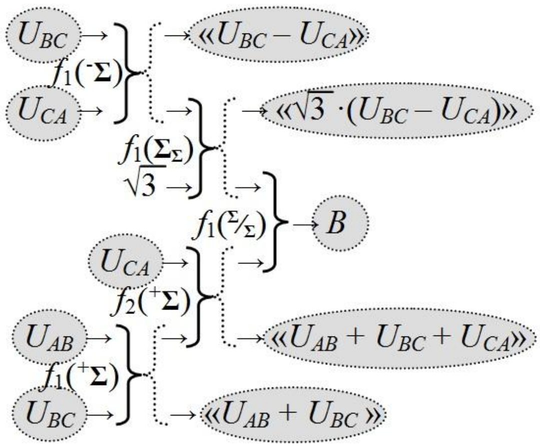

Figure 4 – Analytical expression for calculating the intermediate argument B

Fig. 4 shows that using the functional structure of the subtractor $f_1(^{-}\mathbf{\Sigma})$, an intermediate argument «$U_{BC}–U_{CA}$» is obtained for subsequent calculation using the functional structure of the multiplier $f_1(\mathbf{\Sigma}_\Sigma)$ of the argument «$\sqrt{3}\cdot(U_{BC}–U_{CA})$» to obtain using the first input of functional structure of the divider $f_1(^{\Sigma}\!/_{\Sigma})$ of the resulting argument B. In this case, the second input of the functional structure of the divider $f_1(^{\Sigma}\!/_{\Sigma})$ receives the intermediate argument «$U_{AB}+U_{BC}+U_{CA}$», which is obtained by the functional structures of adders $f_1(^{+}\mathbf{\Sigma})$ and $f_2(^{+}\mathbf{\Sigma})$ from the input arguments U_{AB}, U_{BC} and U_{CA}.

Thus, one of the requirements for the hardware of the power quality monitoring system is the ability to measure the line-to-line voltages of the network. However, to ensure clarity of display of voltage unbalance, it is necessary to have a value of at least one of the angles between the vectors of phase voltages. Since there is an unambiguous relationship between the vectors of phase and line voltages, in order to minimize the hardware, it is proposed to measure the characteristics of the vectors of phase voltages with the subsequent calculation of the effective values of line voltages. The resulting argument $U_{AB(i)}$ can be written in the form of the analytical expression shown in Fig. 5, and the resulting argument $U_{BC(i)}$ can be written as an analytical expression as shown in Fig. 6.

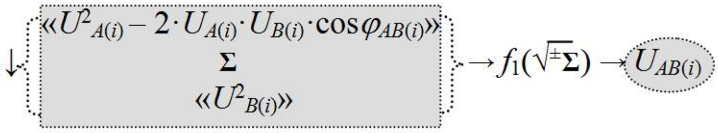

Figure 5 – Analytical expression for calculating the line voltage $U_{AB(i)}$

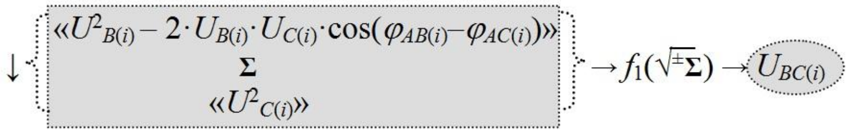

Figure 6 – Analytical expression for calculating the line voltage $U_{BC(i)}$

The obtained analytical expressions were implemented in the automated system of measurement and control of the three-phase voltage system unbalance factor in the network of the ship electrical power system and introduced into production at the LLC "Inter Electro". A distinctive feature of the developed system is a low measurement error in the presence of the voltage frequency variation, which does not exceed 2%, which is achieved by using an optimized structure of the digital signal processing subsystem and using modern hardware.

Conclusion. The obtained expressions for calculating the unbalance factor, in which the RMS values of the phase voltages are used, make it possible to minimize the hardware required to obtain the required signals. It also provides a high speed of the developed system, since it is equipped with three zero cross detectors, the signals from which are fed to the microprocessor for processing and determining the phase shifts. The noise immunity of the system is improved due to the independence of the measured phase displacement angles between line voltages from the shape of the mains voltage. The use of the developed system to determine the voltage unbalance ratio allows taking timely actions to eliminate voltage unbalance and reduce losses in the SEPS network by 10-15%.

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