Power processes quality estimation and compensation for poor quality in low-voltage electric networks

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Abstract – **A method of power processes quality estimation and compensation for poor quality in industrial low-voltage electric networks is substantiated. Calculation relations for spectral presentation of power components and quality factors of electric power are improved in accordance with *p-q-r*-theory of instantaneous power. The structure of compensating device is grounded and a higher efficiency of nonlinear distortions compensation compared with the basic variant of *p-q-r*-theory is confirmed.**

Keywords – **electric power; quality factors; instantaneous power; power active filter.**

I. Introduction

At present practically all real powerful electric power consumers operate under the conditions of single-phase asymmetry of loads when current harmonics are big due to nonlinearity of their characteristics. The same can be said about phase-by-phase loading of appliance communal networks mainly because of the influence of personal computer impulse power supplies, unbalanced networks load, etc. It results in increased power losses in power supply system and occurrence of significant distortion of voltage form, which deteriorates other consumers' operating conditions [1].

The process of voltage form distortion in low-voltage industrial networks has its own particular features and is mainly conditioned by the influence of sharply variable dynamic nonlinear load, mostly, of operating electromechanical transducers including an electric machine and a controlled transducer power unit [2]. In the analyzed case the level of voltage distortions may considerably exceed the values regulated by the standards for the steady state and short duration excess and sometimes reach values as high as 25-30%. Such a situation is undesirable [3].

Besides, practically no difference is made in the estimation of symmetric and asymmetric power consumption. Usually only data of active and reactive powers are used in this case. As a rule, this information is insufficient as it does not take into account the components included into nonsymmetry and distortion powers, according to classic power theories, and, as active and reactive powers, cause losses and decrease the efficiency of operation of all the system links.

Mutual influence of voltage and currents anharmonicity and nonsymmetry results, on the one hand, in the increased losses of voltage and power in the networks, decrease of their capacity and, on the other hand, in irregularity of normal operation and reduction of various electric devices operating life.

Previous research [3] demonstrated that in low voltage networks 40% of the total losses are conditioned by voltage distortions, 40% – by voltage anharmonicity and 20% – by nonsymmetry, which makes the problem of estimation and compensation for nonlinear distortions and nonsymmetry of network voltage topical.

II. Problem Statement

To develop a method for estimation of the quality and compensation for poor quality of power processes in low-voltage industrial electric networks.

III. Research Method and Results

Estimation of electric power quality in low voltage networks is not an independent problem. It is aimed at obtaining the necessary information for efficient compensation for the considered types of poor quality operation. In the process of compensation it is necessary to reach such a level of nonlinear distortions and nonsymmetry coefficients at which total influence of the mentioned types of network voltage poor operation will not result in breach of electromagnetic compatibility of different type consumers.

The disadvantage of the most used methods consists in application of compensated parameters integral values, which is efficient only in case of supply voltage harmonicity and is not applicable to the assigned task. Complete compensation for poor network voltage is only possible when instantaneous power characteristics are taken into consideration. These characteristics include different power components in the load. In this aspect the application of modern theories of instantaneous power and equipment created on their basis make it possible to improve considerably the quality of compensation.

The *p-q-r*-theory of power [4] was chosen as a basic method for solution of the posed problem. It provides the possibility to obtain efficient algorithms of compensation in the considered cases of poor operation. The advantages of this theory include the possibility to control separately phase and zero currents without the need for energy storage system, presenting instantaneous reactive power as separately compensated and not connected linearly q_r and q_q components. When it is used, the possibility of variable active power compensation is easily realized, which, in fact, enables reactive current to be reduced to zero by means of power assignment method, common for all instantaneous power theories [4]. Besides, *p-q-r*-theory provides the possibility of taking into account the spectral composition of instantaneous powers. However, its method of calculating alternating power Z as a separate component of apparent power S does not make it possible to compensate for a part of power variable components.

The authors offered a method of compensating for this disadvantage by using an algorithm of instantaneous power alternating components presentation through phase voltage and current quadratures.

Relationships for power components calculation in this case are as follows:

$$p(t) = p(t)\big|_{const} + p(t)\big|_{\cos} + p(t)\big|_{\sin},$$

where $p(t)\big|_{const} = \sum\limits_{\nu=1,3\ldots}^{n} P_\nu$;

$$p(t)\big|_{\cos} = \sum_{\nu=1,3\ldots}^{n}\Big(P'_\nu + \sum_{\substack{j=1,3..n\\ k=n,n-2\ldots1\\ j+k=2\cdot\nu\\ j\neq k}} P'_{jk} + \sum_{\substack{l=1,3..n\\ m=n,n-2\ldots1\\ l-m=2\cdot\nu\\ m-l=2\cdot\nu\\ l\neq m}} P_{lm}\Big)\cos(2\nu\omega t) +$$

$$+ \sum_{\nu x=1,3\ldots}^{n}\Big(\sum_{\substack{\nu y=3,5\ldots\\ \nu y>\nu x\\ \nu x+\nu y\neq 2\cdot\nu}}^{n}\Big(\sum_{\substack{j=1,3..n\\ k=n,n-2\ldots1\\ j+k=\nu x+\nu y\\ j\neq k}} P'_{jk} + \sum_{\substack{l=1,3..n\\ m=n,n-2\ldots1\\ l-m=\nu x+\nu y\\ m-l=\nu x+\nu y\\ l\neq m}} P_{lm}\Big)\cos((\nu x+\nu y)\omega t)\Big);$$

$$p(t)\big|_{\sin} = \sum_{\nu=1,3\ldots}^{n}\Big(Q'_\nu + \sum_{\substack{j=1,3..n\\ k=n,n-2\ldots1\\ j+k=2\cdot\nu\\ j\neq k}} Q'_{jk} - \sum_{\substack{l=1,3..n\\ m=n,n-2\ldots1\\ m-l=2\cdot\nu\\ l\neq m}} Q_{lm} +$$

$$+ \sum_{\substack{l=1,3..n\\ m=n,n-2\ldots1\\ l-m=2\cdot\nu\\ l\neq m}} Q_{lm}\Big)\sin(2\nu\omega t) + \sum_{\nu x=1,3\ldots}^{n}\Big(\sum_{\substack{\nu y=3,5\ldots\\ \nu y>\nu x\\ \nu x+\nu y\neq 2\cdot\nu}}^{n}\Big(\sum_{\substack{j=1,3..n\\ k=n,n-2\ldots1\\ j+k=\nu x+\nu y\\ j\neq k}} Q'_{jk} -$$

$$- \sum_{\substack{l=1,3..n\\ m=n,n-2\ldots1\\ m-l=\nu x+\nu y\\ l\neq m}} Q_{lm} + \sum_{\substack{l=1,3..n\\ m=n,n-2\ldots1\\ l-m=\nu x+\nu y\\ l\neq m}} Q_{lm}\Big)\sin((\nu x+\nu y)\omega t)\Big).$$

Here $p(t)\big|_{const}$, $p(t)\big|_{\cos}$, $p(t)\big|_{\sin}$ are constant and sign-changing cosine and sine components of instantaneous power; $P_\nu, Q_\nu, P'_\nu, Q'_\nu$, are active and reactive harmonic powers for single-frequency current and voltage components; $P_{lm}, Q_{lm}, P'_{jk}, Q'_{jk}$ are active and reactive powers for various frequency current and voltage components [5].

In this case instantaneous power variable components from combination frequency refer to sine and cosine instantaneous power alternating components.

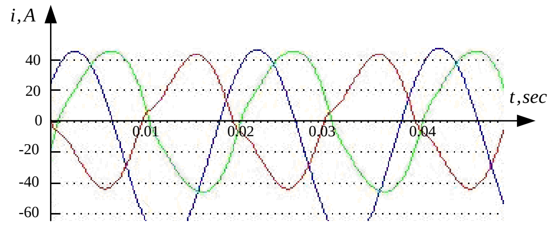
Application of factors used in the accepted theory is grounded for estimation of the quality of power processes in a three-phase system. In this case calculated relations for them were also corrected taking [5] into consideration.

As, according to *p-q-r*-theory, there is no necessity for singling out a network voltage sinusoidal component during compensation, taking into account the particular features of the used mathematical support, the choice of the power active filter structure controlled by the method of power assignment was substantiated.

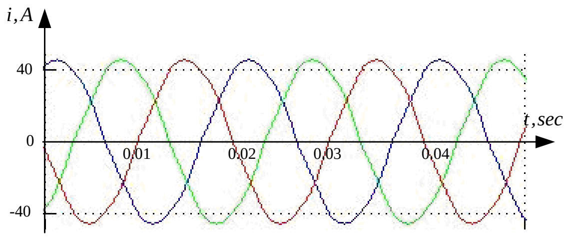
Modeling of the compensation system operation conditions was made in the Matlab SimPower Systems application package. The calculation algorithms are based on the mathematical support developed by the authors. It allows one, basing on the results of system currents and voltages spectral decomposition, to research the special features of formation of instantaneous power components, correlating them with variation of the used indices of electric power quality.

Fig. 1 shows phase voltages and currents curves in the network before and after compensation, which were obtained as a result of modeling.

As a result, the possibility of refining the method of taking reactive electric power into account, estimating power processes poorness on the whole, as well as developing more efficient approaches and devices for compensation for poor energy in low voltage networks, compared with the basic variant of *p-q-r*-theory, was substantiated.



a)



b)

Fig. 1 – Phase currents time dependences in a low-voltage network before (a) and after (b) compensation

IV. Conclusions

1. The efficiency of application of *p-q-r*-theory theses to estimation of power parameters and electric power quality in low-voltage industrial networks has been confirmed. This, along with the assurance of the measurements assigned accuracy, provides the possibility of compensation for the poor quality of the considered types.
2. An approach to modification of *p-q-r*-theory by referring the products of combination frequency voltages and currents to sine and cosine instantaneous power alternating components has been substantiated. As a result, calculation relations for instantaneous power components and electric power quality indices change and instantaneous power variable components compensation is improved in comparison with the basic variant.
3. The obtained results confirm a higher efficiency of the proposed compensation method for low-voltage networks compared with the basic variant of compensation according to *p-q-r*-theory. Besides, it is obvious that, when the existing approach is used, a complete compensation of currents and voltages higher harmonics is impossible. As to a further development of the offered method, use of separate compensation according to sine and cosine instantaneous power alternating components seems to be promising, which will allow compensating for supply voltage distortions.

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