ANALYSIS OF EFFECTIVENESS OF USING WAVELET TRANSFORMATIONS FOR REACTIVE POWER COMPENSATION

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Abstract. In recent years, there has been a significant increase in energy consumption and the algorithmization of the functioning of control devices, protection and diagnostics of electric power facilities and systems, which are based on new methods of analysis and synthesis, coming to the fore. Higher harmonics, which occur due to an increase in the share of electric receivers that have a nonlinear volt-ampere characteristic, lead to additional losses in current-carrying parts, a decrease in the service life of elements, and so on. These negative consequences reduce the energy efficiency of individual energy systems. In addition, there is a decrease in economic interest of consumers in part of reactive power compensation, which leads to a reduced energy supply reliability and efficiency of electricity in general. The mathematical apparatus of the wavelet transform is increasingly being used to analyze and describe the dynamics of complex nonlinear reactive power compensation processes. Wavelets are used as a hierarchical basis for analyzing perturbations in wide frequency ranges under conditions of non-stationary processes under study. In contrast to the Fourier transform, the wavelet transform provides a three-dimensional interpretation of the current (voltage, power) function under study, primarily in physical space (instantaneous value, time) and in frequency space (amplitude, frequency). In this article, the authors analyze the effectiveness of using wavelet transformations in the field of reactive power compensation for non-sinusoidal non-stationary modes of electric power systems.

Keywords: compensation, current, voltage, power, non-stationary loads, reactive power compensation device, energy components of instantaneous current.

Introduction

The topic of the importance of rational energy consumption is relevant all over the world. Currently, energy is a fundamental branch of the world economy, because the process of idustrialization and digitization of modern society depends on the energy component. For the development of economic activity, it is necessary that the energy industry has the following properties: reliability, effective functionality and ensuring uninterrupted supply to the consumer.

Every year the implementation of these properties becomes more difficult due to the changes in the energy supply sector, the rapid development of the energy industry, the process of transition from one energy supply system to another, more innovative types.

There are several official documents regulating all mandatory procedures for participants in the process of generating and consuming energy and issues of electricity quality in Russia.

The main documents are:

- Federal law No. 261-FZ "On energy saving and energy efficiency improvement and on amendments to certain legislative acts of the Russian Federation" [1];
- The State standard of the Russian Federation 32144-2013 " Electric energy. Compatibility of technical means is electromagnetic standards of quality of electric energy in general-purpose power supply systems" [2].

In recent years there has been a significant increase in energy consumption. The process of algorithmization of the functioning of control devices, protection and diagnostics of electric power facilities and systems based on new methods of analysis and synthesis is becoming more relevant.

The concept of electromagnetic compatibility in terms of ensuring the quality of electricity covers all interactions between various devices and systems that use electromagnetic phenomena.

There are harmonic components of the current in modern networks. Harmonics are generated by electrical equipment with a non-linear load, which leads to malfunctions, including the equipment itself, and also negatively affects technological processes, which leads to losses.

Higher harmonics resulting from an increase in the proportion of electric receivers that have a non-linear volt-ampere characteristic lead to additional losses in current-carrying parts, a decrease in the service life of elements, and so on.

In this article, the authors analyze the efficiency of using wavelet transformations in the field of reactive power compensation for non-sinusoidal non-stationary modes of electric power systems.

Materials and methods

Correlation functions of a random process are usually interpreted as a measure of the extent to which knowledge of the past of a random process makes it possible to predict its future.

Accordingly, in the proposed approach, the autocorrelation function of a random process of changing the active power at a prehistory interval is used to predict the active power at subsequent intervals.

In other words, by predicting the correlation function and the mathematical expectation of the current random process, you can also predict the random process itself [3; 4].

The mathematical apparatus of the wavelet transform is increasingly used to analyze and describe the dynamics of complex nonlinear processes of reactive power compensation. Wavelets are used as a hierarchical basis for the analysis of disturbances in wide frequency ranges in the conditions of non-stationary processes under study.

In contrast to the Fourier transform, the wavelet transform provides a three-dimensional interpretation of the current function under study (voltage, power), primarily in physical space (instantaneous value, time) and in frequency space (amplitude, frequency) [5-7].

When solving the issue of reactive power compensation, we keep in mind that the load is not stationary (the values of currents and voltages are random values).

Failure to take this feature into account (namely, the use of known solutions that are used in sinusoidal modes) leads to an increase in energy losses due to the growth of errors in the load power values.

For example, the well-known Frieze expression for determining the orthogonal component of the nonlinear load current (compensator current) requires that the active load power and the active network voltage remain constant over the averaging interval (network voltage period), i.e., the mode is stationary [5; 8].

The development of a tool that allows to work with mathematical models in each specific case is of fundamental importance for practice. Such tools can be a modified algorithm for controlling the reactive power compensator, the essence of which is to determine the law using probabilistic and statistical characteristics of the load operation in real time over an observation interval that is commensurate with the period of supply network voltage [9].

For non-stationary mode, it is proposed to introduce the use of the predicted value of active power at subsequent observation intervals P_{pred}.

$$P_{pred} = \sqrt{(M[P])^2 + \sigma^2 \cdot r(\tau)}, \qquad (1)$$

where $M[P]$ – mathematical expectation of a random process of changing the active powers;
σ – standard deviation;
$r(\tau)$ – normalized autocorrelation function.

The current voltage of the network U for further consideration will be considered unchanged.

For a visual representation of the proposed algorithm functioning, mathematical modeling was performed in the MathCad environment.

During the experiment, the network voltage was set as $u(t) = 100\sin(\omega \cdot t)$, the current is generated with an interference in the form of a random variable

$$i(t) = 3\sin(\omega \cdot t) + \frac{rnd(100) - 5}{10}, \; \omega = 314 \text{ s}^{-1}, \; t = 0\ldots0.2 \text{ s}.$$

The current change graph is shown in Figure 1.

The active power was determined by the expression
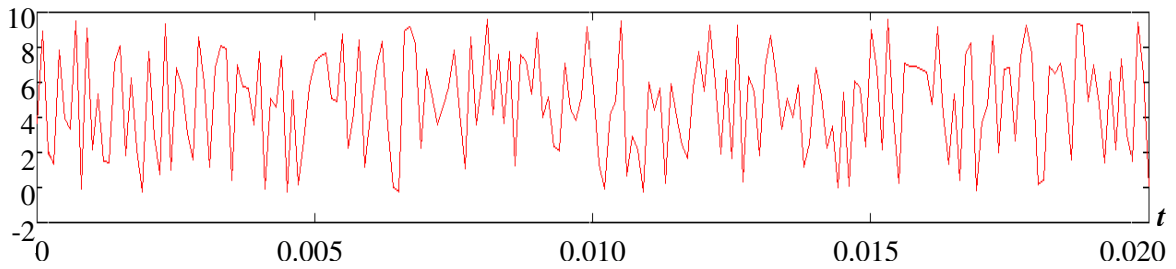
$$P = \frac{1}{T}\int_0^T u(t)i(t)dt \cdot$$

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Fig. 1. **Current change graph**

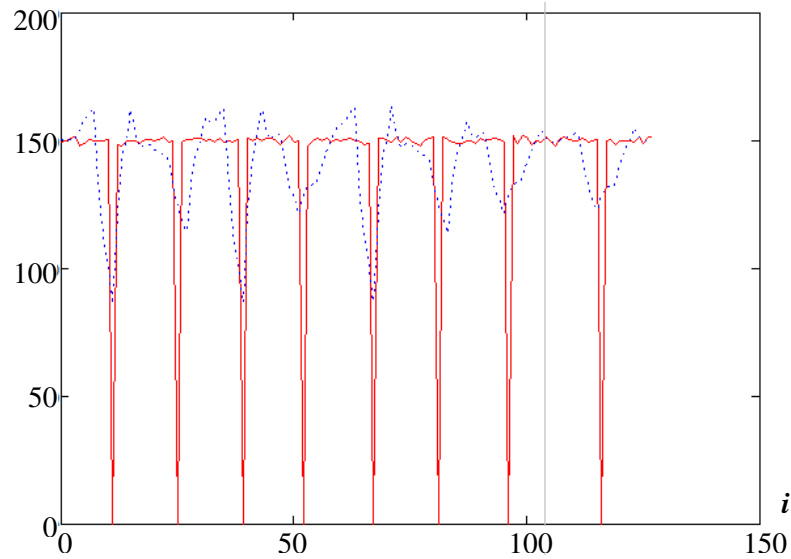Figure 2 shows the graph of wavelet transformations.

Fig. 2. **Active power change graph:** red – y_i, blue dashed – s_i

Table 1 shows a fragment of the final table of simulation results: random sequences of changes in active power over ten periods, mathematical expectation, standard deviation, values of autocorrelation functions of random sequences of changes in active power over ten periods with a lag of 0 and 1, respectively, the value of the normalized autocorrelation function.

The result of calculations is the predicted value of the active power for the eleventh period P_{pred}.

Based on the data shown in Table 1, a mathematical simulation of the process of changing the active power was performed. The graph of active power changes is shown in Figure 3.

The red line shows the change of the power values based on finding the power values by the integrated values, the blue line shows the change of the power values, applying the proposed algorithm.
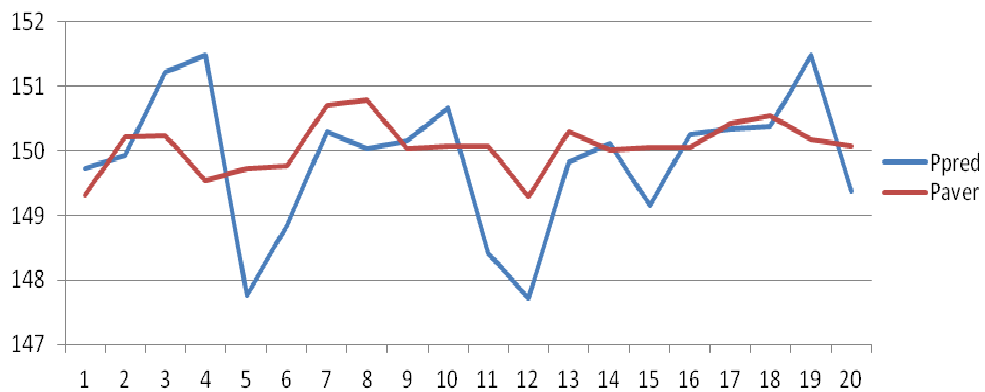

Fig. 3. **Power change graph**

Table 1

Simulation result

Period No.	1	2	3	4	5	6	7	8	9	10
P_1, W	149.71898	149.93014	151.22719	151.48696	147.76142	148.85234	150.30353	149.91551	149.73622	150.15278
P_2, W	150.10996	149.27813	149.71533	150.47401	150.62369	150.83843	151.2447	150.33375	146.85617	151.50084
P_3, W	148.54589	150.39918	152.25218	149.45961	149.8472	148.07884	150.18135	148.87615	148.88397	149.16816
P_4, W	149.31736	151.67108	149.18313	148.07925	150.01178	151.12662	151.48376	148.17195	150.82659	149.66424
P_5, W	149.19304	152.09279	151.37985	149.35953	148.48563	149.93929	149.42248	148.95745	149.08437	150.3378
P_6, W	148.59571	149.95641	150.0923	149.70105	151.49295	148.83877	151.54336	149.94368	151.9818	149.75265
P_7, W	147.94446	150.1502	151.58957	148.05015	150.52189	148.22514	149.26016	150.34223	151.18153	152.1758
P_8, W	149.91551	150.33375	148.87615	148.17195	148.95745	149.94368	150.34223	149.79836	150.3098	150.81787
P_9, W	149.73622	146.85617	148.88397	150.82659	149.08437	151.9818	151.18153	149.91941	151.20631	150.11305
P_{10}, W	150.15278	151.50084	149.16816	149.66424	150.3378	149.75265	152.1758	149.90673	148.9001	148.81741
P_{aver}, W	149.32299	150.21687	150.23678	149.52733	149.71242	149.75776	150.71389	150.53521	150.18374	150.06328
P_{pred}, W	149.32465	150.22335	150.24152	149.53149	149.71619	149.76266	150.71661	150.53605	150.18564	150.06976
σ	0.7096913	1.4021171	1.20024	1.123484	1.0691425	1.2201439	0.910469	0.506206	0.760223	1.401488

Results and discussion

Analysis of the obtained results of mathematical modeling for 500 possible implementations of a random sequence of changes in active power shows that the variance of the predicted values (result) does not exceed the variance of the original data – a random sequence of changes in the active power at intervals of prehistory.

As shown by the analysis, methods of nonlinear mathematical programming provide the required optimization accuracy in conditions of completeness and reliability of the original information flow.

Conclusions

1. An approach to mathematical modeling of a random sequence of changes in active power is proposed, which allows to obtain predicted values of active power at any time intervals. The authors' proposed algorithm for calculating the compensator current can be used in tracking control systems of compensating installations. The proposed algorithm is valid for non-stationary modes of nonlinear loads, when using an interval of observation and control that is commensurate with the period of the supply network voltage.
2. A mathematical model of a random sequence of changes in the active power of the electric network is obtained. The main difference between this model and the existing ones is the ability to accurately describe any change in the load on various space-time hierarchies.

Acknowledgements

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