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ARCHITECTURE OF COMPUTER-BASED MONITORING SYSTEM OF NON-SINUSOIDAL MODES OF ELECTRIC NETWORK

New concept of non-sinusoidal modes of electric network system monitoring, based on indirect measurements of mode parameters is suggested. For evaluation of voltage non-sinusoidality indices on the buses of the electric network with non-linear loads artificial neural network is used. The example of the suggested monitoring system is suggested.

Key words: *electric network, non-linear loads, non-sinusoidal mode, energy quality monitoring, artificial neural network, modeling.*

Actuality of the problem

In current decade the problem of energy quality in electric network attracts more and more attention. Among electromagnetic disturbances, determining the quality of electric energy, important, role is played by higher harmonics (further harmonics). This can be explained by the fact, that share of loads with non-linear voltage current characteristics constantly grows. Actuality, it can be explained by rapid growth of semiconductor equipment and considerable economic efficiency of its application both in industry and in municipal sphere, On the other hand, practically all electric networks are characterized by constant variations of the load. Such variations can be of daily or seasonal character as well as of random character – i. e., depending on the requirements of industry, and occur even several times a minute. If in energy supply system of variable non-linear loads capacitors are used for improvement of power factor, then due to resonance amplification of harmonics in such conditions along with possible damage of power equipment, other harmful impacts on control systems and technological processes can take place.

According to estimation of European research institutions losses as result of low quality of electric energy in industry and business are about hundreds of milliards € annually [1]. At the same time, additional expenditures for facilities, designed for prevention of the damage do not exceed 5 % of damage cost. Till now Ukraine does not succeed in implementing the existing requirements regarding norms of electric energy quality, control procedure over electric energy quality indexes does not have legislative support, systems of claims is not efficient. Operating and maintenance staff of utility companies and commercial consumers can not solve the problem of substantiation of the volume of investments to be directed for preventive measures and means to avoid possible harmful consequences of the problem. Organizational and technical provision of non-sinusoidal modes of electric networks monitoring system is the task to be solved for realization of the given problem.

Principle of organization and tasks of monitoring

Monitoring of electric energy quality in electric networks is performed to study variations of quality indexes during certain time interval. Depending on the specific features of electric network monitoring can be carried out continuously (on the base of stationary devices), periodically (within certain intervals, for instance, once year) or as requires (in the process of connection of new powerful loads, compensating devices, etc.)

Prior to monitoring of voltage nonsinusoidality on the subject of its conformity with norms of energy quality it is necessary to perform initial analysis of electric network and underline problems to be investigated.

These problems include determination of the points where monitoring is to be performed and values to be controlled. It enables to use rationally available facilities and reduce expenditures for monitoring. The following information must be collected before monitoring [2]

1) characteristic of equipment, generating harmonics;
2) characteristic of equipment, sensitive to harmonics;
3) time, when adverse condition occur;
4) accompaning problems or phenomena, occurring in the network when problems of harmonics aggravate (for instance, connection of capacitor bank);
5) real state of equipment, used in the network;
6) rated values of equipment, used in the given electric network.

It should be noted, that according to the requirements of valid standard [3], supervision over the level of nonsinusoidality mode of electric network should be performed at least during one week. It is expedient to choose the points of harmonics monitoring as close as possible to the equipment (consumers) sensitive to nonsinusoidality.

It is important to have information regarding all changes of electric network configuration (connection/disconnection of capacitor bank, harmonics filters, buses sections, transformers etc.). In distributive networks monitoring of voltage harmonics is mainly performed. In the process of analysis of filtering-compensating devices operation modes we have to measure current harmonics. For current analysis of the problem, measurements of voltage harmonics and current harmonics are to be performed simultaneously.

To provide electromagnetic compatibility in electric network indexes of voltage non sinusoidality in "common point" must be within the norms of existing standard. Testing procedure is carried out on the basis of corresponding measurements, such measurements are performed by certified laboratories in accordance with standard technique, described in [3], by certified specialized measuring instruments – harmonics analyzers. It is obvious, that such measurements are carried out rather seldom, that is why information regarding real state of the system may not be available for a long period of time, hence, the network and consumers will experience negative (in case of non conformity with the norms) influence of harmonics.

Introduction of energy saving technologies results in constant growth of non-linear loads in electric networks. Constant variations loading, leading to changes of compensating devices operation modes, provoke changes of voltage harmonics and current harmonics values in time.

This substantiates the expediency of continuous control of electric network mode nonsinusoidality. Changes of mode nonsinusoidality indexes, in distributive network requires the application of special measuring instruments, which are seldom installed at the stations due to their high cost. Besides at node substations there is permanent operating staff for servicing of these devices and supervision for indications. The analysis of the problem shows that is desirable to perform continuous monitoring of the network operation mode. Monitoring performed with minimum instruments and telemeasurements allows the dispatcher to evaluate voltage nonsinusoidality in control points and, in case of dangerous modes, perform necessary steps to eliminate the problem.

Unlike measurements, performed by certified laboratories using special measuring instruments in order to establish the correspondence of quality norms indexes, such monitoring is performed to obtained information regarding the character of nonsinusoidal mode changes and determination of possible perform points in the network.

Important feature of the suggested monitoring is the possibility to perform observation in real-time over the change of preset part of the network mode, and not only over one substation. Besides, such monitoring does not impose rigid demands regarding the accuracy of measuring devices and allows definition of nonsinusoidal modes indexes on the basis of measurement available at substations. After collection and analysis of data, obtained as a result of monitoring the decision can be made concerning the necessity of measurements on the buses of the consumer applying specialized harmonics analyzers.

In literature we can find references to already known methods of adequate identification of higher harmonic sources in conditions of incomplete provision of the network with measuring facilities. In [4, 5], solutions, based on conventional approaches, are suggested. Some approaches using methodology of artificial neural networks for determination of characteristics of harmonics sources in electric network, are suggested in [6, 7]. In research, published in [7], structural neural network is used for determination of harmonics values in electric network with non- linear loads. The network is supplied with several stationary installation, indeed for harmonics measurement.

Principle of construction of intelligent monitoring system

The expression “intelligent system” is often used to denote any combination using neural networks (further neural networks), expert systems, fuzzy logic systems and other technologies, in particular, such as genetic algorithms. Unlike conventional control, intelligent strategies of control do not require mathematical models of real objects. As compared with human being, the computer with artificial intelligence can rapidly solve problems. Computer operates continuously “tirelessly”, it is not influenced by emotions and other human drawbacks. These systems are constructed on mathematical relations, which inherit “intelligence” of “knowledge” from specialist-experts of field data of observations, presented, as a rule, in the form of input/output pairs.

Convectional engineering approaches provide description of any physical phenomena, regard less of the level of their complexity, on the basis of relations, which can be developed directly from physical principles on the level of separate element or component. Two main problems, emerging while considering real engineering tasks are connected with such approach:

1) the problem is so complicated that creation of exact mathematical model is not a real task and for the solution of this problem, on the basis of generally accepted technical assumptions approximated analysis is applied;

2) complexity of the problem can bring uncertainty, that must be taken into account by certain approximation.

In general case, relation between input and output variables are known only approximately, and many efforts must be applied to find acceptable approximate correspondences. Systems of neural networks enable to “learn” automatically approximated relations between inputs and outputs, by-passing the overcoming the problem of the size complexity of the task. These approximated relations are often more efficient than, those, which are obtained on the basis of physical description of the phenomenon. It happens since these relations usually connect real values of input and output variables (for instance, measurements data) and are free from assumptions of certain theories, based on some human prejudices.

Besides, neural network does not require any information regarding dependences themselves or their efficiency, which is defined by the chosen law of phenomenon description. Approximation error can be gradually reduced due to large volume of input information. Theoretically neural network can be trained to provide exact correspondence between input and output data. In general, systems of neural networks are able to “study” dependences in preset volume of data and establish input-output relations, based exclusively on certain subset of data. Thus, it is expedient that subset data, the systems uses for “training” represent complete set of data.

Dependences, which are not “seen” in the selected subset, will not be “studied” by the neural network. It should be noted, that the same restriction concern conventional algorithms of regression and classification.

As it was stated above, continuous observation over the level of harmonics in electric networks can be performed by specially created information network, that transfers measurement data from harmonics analyzers, located in different parts of electric system to the sires of on-line control.

The authors suggested the concept of construction the system intended for monitoring of nonsinusoidal mode. The system does not require harmonics analyzers to be installed in controlled points of the network and creation of special network for measurements results transfer in observation point [8, 9].

For this purpose it provides the usage of, existing channels of telemeasurements and measuring devices available at electric network substations. For realization of this method we suggest to use neural network, the task of which is “recognition” (identification) of the values of nonsinusoidal modes indices on the buses of distribution substations of electric network, if only the values of electric network mode parameters are available in the point of observation (corresponding active and reactive powers, currents power factors, etc.). Schematic diagram of such system operation is shown in Fig. 1.

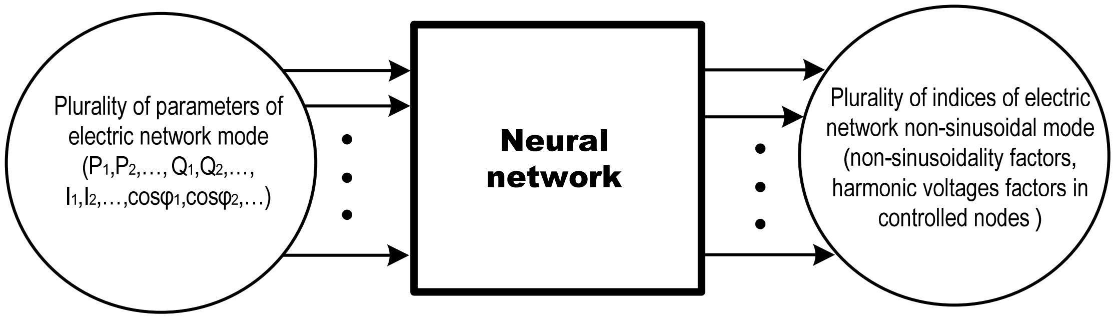

Fig. 1. Schematic diagram of the system of nonsinusoidal mode identification

In fact, this is indirect measurement of mode nonsinusoidality indices, since their values are obtained not on the basis of analysis of voltage curve form, but by means of “recognition” using the relations, imposed by neural network, between values of powers, currents, etc., measures in different points of electric network.

It is known that the spectrum of harmonics and their values in electric network depend on real consumption of active and reactive powers by non-linear loads, operation mode of compensation. It is obvious that in conditions of constant changes of these factors it is difficult to define functional dependence between them and values of harmonics in various paints of electric network. That is why, the possibility to apply for the solution of this problem the intelligent system, which can define the required relations is very attractive idea.

In the process of construction of such intelligent system the most difficult problem is task dealing with obtaining data sets for training of such system using field measurements, it is rather difficult to get needed data for neural network training. In this case, it is a complicated problem to collect sets data for all characteristic operation mode during short period of time. The authors suggested to obtain these data of the basis of modeling in time domain of a certain set of electric network mode with non-linear loads.

Correspondence of input and output data, obtained in such a way, compose the required set for neural network training.

The next problem is the selection of neural network structure and expedient method of its training. As it is known, there are no exact criteria regarding the selection of optimum structure of neural network and the last method of its training. That is why, the most widely applied approach is chosen. For problems, connected with the sphere of electric energy generation neural network of direct propagation are mainly used, their training is performed on the base of training algorithm of “back propagation”. Training algorithm of “back propagation” is the method of interactive choice of weight coefficients to the moment of attaining the desired accuracy. This algorithm is based on the method of optimized search of error function gradient. Typical error function is the function of mean square root error; it is illustrated by the expression (1), where N is total number of output data $y_1, y_1, \dots, y_N$, that are used in training process:

$$e = \sum_{i=1}^{N} (y_{icalc} - y_{idesired})^2. \qquad (1)$$

Set N and outputs, connected with it, represent “training set” that is ordinary subset of complete data set. To obtain the best results, training set must adequately represent all expected changes in complete data set. That is why, the correct choice of the boundaries of loading parameters and electric network configuration changes in the process of modeling is very important.

Greater part of neural networks can be made very accurate (on the basis of training data) by means of increasing the number of hidden layers and nodes in these layers. But in any method of non-linear functions approximation there are cases, when the increase of independent variables makes the system more vulnerable to changes, occurring in output data. Thus, large number of hidden layers and hidden nodes of the layer can make neural system more accurate for training data, but changes, which will be presented in the following data (not included in training process), can be the reason of considerable deviations from expected result at the output. In such cases, we say, that the network "memorized" relations, found in training data, faster than it "learnt" more general relations. Thus it is necessary to find the compromise between the number of layers, nodes and degree of accuracy, attainable with these training data.

For this problem, several rules are formulated, which are to be followed while choosing the configuration of neural network for considered case:

– Input set of neural network is chosen experimentally, taking into account telemeasurements available at network substations and data obtained from stationary devices of harmonics measurement. The choice of sufficient number of input data is performed by iteration and its aim is to define optimum volume of telemeasurements needed for adequate functioning of neural network. Neither excess nor insufficiency of input information is desirable. Excess of data can lead to the influence on evaluation result of minor factors, where as insufficiency of information can make neural network nonsensitive to certain changes.

– For long-distance electric network it is sufficient to use two-layered neural network of direct propagation. The number of neurons in hidden layer is assumed to be equal to half sum of the number of input and output signals. Powers, actual values of currents, power factor of non-linear loads of network substations transfer of active and reactive powers along the lines, indices off non-sinusoidality on buses of the main substation with stationary device for harmonics measurement can be input data of such neural network.

– Training data set of neural network is formed so that to comprise the whole range of possible operation modes of electric network with a certain step, and, if possible, to include character modes. The dimension of training set is also defined experimentally and is corrected to provide the desired accuracy of neural network.

– Using the characteristic features of analysis of harmonic processes in electric network, it is expedient to form common structure, composed of separate parallel neural network for each of possible harmonics. This considerably simplifies the structure of neural network and facilitates the process of its training.

The example of construction of intelligent monitoring system

For investigation, the fragment of electric network with traction substations, which are sources of harmonic is chosen: supply of such substations is performed, as a rule, from main lines by 3-6 substations from 110 kV buses of node substations. This can be explained by the fact, that operation of distributed networks should be avoided in closed mode in order to prevent non-desirable transient transfers and to improve reliability of consumers supply. Supply of traction system is carried out from the circuit of 6 pulse noncontrolled semiconductor converter. Single-line circuit such main distribution electric network of 110 kV is shown in Fig 2

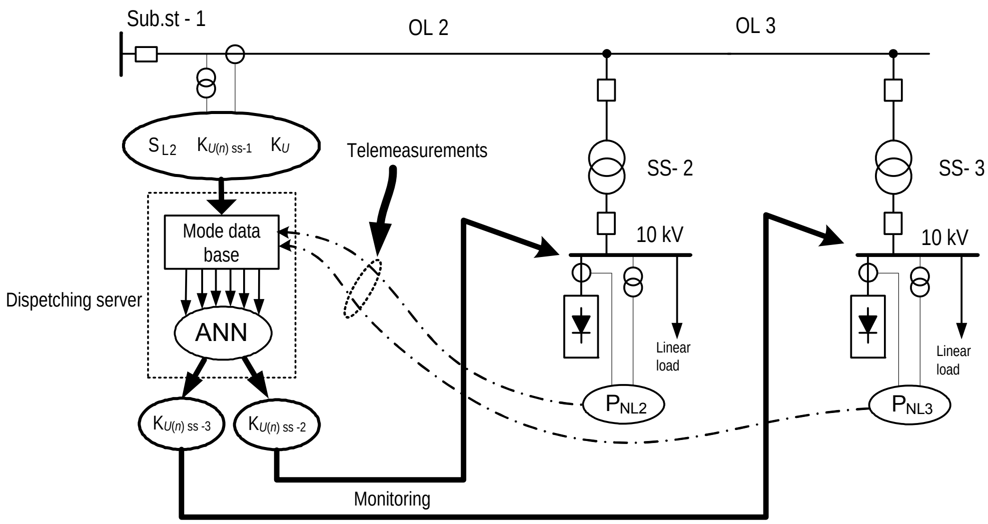

Fig. 2. Structural diagram of monitoring realization in the investigated electric network

Load of traction substation converters is of probabilistic character and can vary depending on the traffic schedule. Operation modes both with practically zero loading of converters and with close to nominal are possible. Variation of load mode can occur both constantly and discontinually (stop-start of the locomotive). The value of harmonics, generated in the network, increases proportionally to the increase of converters load. Substations in the investigated network are provided with standard measuring devices, including wattmeters, which are stationary installed on 10 kV buses of network substations and perform power measurements of the feeders of non-linear loads. Substations are not equipped with stationary devices for harmonics measurements. In the given electric network the installation of stationary device for measurement of non-sinusoidality mode indices in provided only on substation 1 on PL-2 110 kV at substation 1 permanent staff of power supply company performs on-line control of the given section of electric network.

The dispetcher can observe the dynamics of substations load change in time by means of telemeasurements. Fig. 3 shows structural diagram of artificial neural network (ANN) for the system of harmonics monitoring taking into account the transfer of telemeasurements available at substations to substation 1.

Linear load of electric network substations changes in accordance with daily schedule of consumption. Since the value of non-linear load is of probabalistic character. Then there is no strict correspondence between the power of network load and variation of harmonics in the network.

On the basis of experimental research for given neural network minimum necessary quantity of input signals (measurements) to perform execution of the task was defined. The possibility of obtaining such measurements at substations of electric network and their transfer to control point of substation 1 is taken into account.

The structure of neural network of direct propagation contains only one hidden lawyer. The amount of neurons in this layer is assumed to be equal to half-sum of the number of input and output signals.

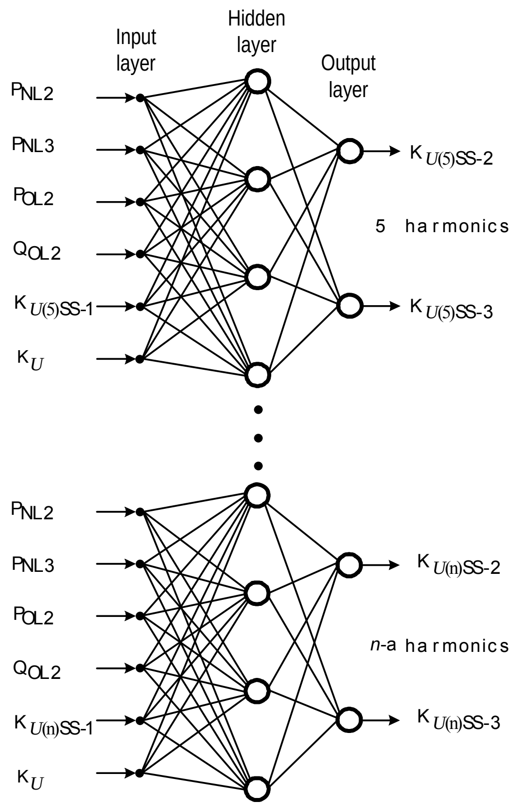

Fig. 3. Neural network for monitoring of nonsinusoidal modes

Taking into account the given features, the following input signals were chosen for neural network: active powers of non- linear loads at substations 2 and substation 3 ($P_{NL}2$, $P_{NL}3$) power transfer from substation 1 to OL-2 ($P_{OL}2$ i $Q_{OL}2$) and sinusoidality distortion factor value of voltage curve and n[th] harmonic component of voltage ($K_{U(n)\,ss\text{-}1}$ i K_U) on 110 kV buses of substation 1. All the data arrive from stationary installed on network substations measuring units.

Neural network was created by means of subprogram NNTool from tools panel Neural Network of programming compel MatLab. For neurons of the hidden layer transfer function in the form of hyperbolic tangent (tensing) is chosen, for variable n it is calculated by the formula

$$\text{tansig}(n) = \frac{2}{(1+e^{-2n})} - 1 . \qquad (2)$$

Function “pureline” is chosen as transfer function of output layer neurons, since such function can transfer any values in vide range. Weight coefficients were adjusted to minimize complete root-square error between training set of outputs and the set of real values.

For training neural network, in accordance with the procedure of training algorithm of “back propagation” the function of scaled conjugate gradient with back propagation of error (TRAINSCG – Scaled conjugate gradient) is used.

Neural network was trained to evaluate coefficients of n[th] harmonic component of voltage on 10 kV buses of SS-2 та SS-3 ($K_{U(n)\,ss\text{-}2}$, $K_{U(n)\,ss\text{-}3}$) of the given electric network. As it was stated above, due to peculiarities of harmonic calculation, that allow to analyze electric network separately for each harmonic, to improve convergence and increase of information memory, neural network is divided into number of parallel networks (separately for each harmonic) with similar inputs and two outputs each, as it is shown in Fig. 3.

In the given case, only harmonics, which are characteristic for non-linear loads of this electric network – 5^{th}, 7^{th}, 11^{th} etc.

The choice of such structure and training algorithms of neural network was preceded considerable volume of research, dealing with the search of possible alternatives. Usage separate neural for each output. Various types of available training functions (in particular, such as TRAINGDM, TRAINGDA, TRAINGDX), different combinations of mode input parameters. As comparative research showed, the chosen variant provides the most rapid convergence of iteration process and simple realization.

In accordance with the suggested concept of intelligent system of monitoring for formation of training set of data input/output modeling of analyzed electric network modes was performed in time domain by means of programming complex MatLab (subprogram Simulink). As a result of computations in instant coordinates voltage curves are obtained, which are decomposed in Fourier series for various loading modes, coefficients of voltage distortion are computed for preset operation mode, which is characterized by corresponding values of powers, chosen for neural network. Set of mode, chosen for modeling comprised possible range of change and combinations of loads powers with discreteness of their change. Table 1 contains the fragment of the set of training data for neural network, shown in Fig. 3, which illustrates the principle of formation of training data set.

The table also contains testing set of data, which do not belong to training set. Testing set of data is used for checking of neural network operation. On the basis of input and output data sets, obtained in such a way, training of corresponding neural networks is performed Table 2 contains the fragment of results of neural network training. Testing of neural network was performed by means of monitoring of “known sources of harmonics” in electric network for checking the ability of neural network to define indexes of voltage curve distortion at the buses of substations, using the data, that did not enter the training set, due to discreteness of these parameters choice.

Table 1

Example of training data set for 5th harmonic

№	P_{NL2}, MW	P_{NL3}, MW	S_{OL2}, MVA	$K_{U(5)\ ss\text{-}1}$, %	$K_{U(5)\ ss\text{-}2}$, %	$K_{U(5)\ ss\text{-}3}$, %	K_U, %
1	1	0	5,4+j1,6	0,09	1,34	0,12	0,56
2	3	0	7,2+j2,2	0,25	3,80	0,34	0,99
3	5	0	8,9+j2,9	0,41	6,30	0,56	1,46
4	7	0	10,5+j3,7	0,56	8,47	0,75	1,78
5	0	1	5,5+j1,6	0,09	0,11	1,31	0,90
6	0	3	7,3+j2,1	0,26	0,34	3,85	1,61
7	0	5	9,0+j2,8	0,43	0,55	6, 23	2,23
8	0	7	10,7+j3,6	0,58	0,74	8,61	2,66
9	1	1	6,4+j1,8	0,17	1,41	1,50	1,04
10	3	1	8,2+j2,4	0,34	3,77	1,74	0,95
11	5	1	9,9+j3,1	0,49	6,11	2,01	1,91
12	7	1	11,5+j3,8	0,62	8,21	1,93	1,54
...	...	...	...	...	...	...	...
21	1	7	11,6+j3,8	0,65	1,95	8,69	2,3
22	3	7	13,3+j4,5	0,82	4,52	8,94	2,11
23	5	7	15,0+j5,2	0,99	6,75	9,15	2,44
24	7	7	16,6+j6,0	1,13	8,80	9,28	3,53
Testing set							
25	2	5	10,8+j3,4	0,59	3,07	6,55	1,56
26	5	2	10,8+j3,4	0,58	6,14	3,21	1,71
27	4	6	13,3+j4,5	0,84	5,57	7,99	2,10
28	6	6	15,1+j5,3	0,97	7,15	7,68	2,22

Lines 25 – 28 in Table 2 show the results of evaluation of voltage curve distortion indexes at the buses of substation by the data of testing set. Absolute error in Table 2 is calculated as the differences between real values, obtained as a result of electric network. Operation modes modeling and data, obtained as a result of neural network training.

Table 2

Results of neural network training using the data of the set, presented in Table 1.

№	Real values		Training results		Absolute error	
	$K_{U(5)\ ss\text{-}2}$, %	$K_{U(5)\ ss\text{-}3}$, %	$K_{U(5)\ ss\text{-}2}$, %	$K_{U(5)\ ss\text{-}3}$, %	$\Delta K_{U(5)\ ss\text{-}2}$, %	$\Delta K_{U(5)\ ss\text{-}3}$, %
1	1,34	0,12	1,35	0,20	-0,01	-0,08
2	3,80	0,34	3,70	0,44	0,1	-0,1
3	6,30	0,56	6,17	0,65	0,13	-0,09
4	8,47	0,75	8,49	0,81	-0,02	-0,06
. . .	. . .	. . .	. . .	. . .	. . .	. . .
23	6,75	9,15	6,82	9,31	-0,07	-0,16
24	8,80	9,28	9,02	9,42	-0,22	-0,14
Results for testing set						
25	3,07	6,55	2,92	6,60	0,15	-0,05
26	6,14	3,21	6,27	3,11	-0,13	0,1
27	5,57	7,99	5,60	8,05	-0,03	-0,06
28	7,15	7,68	7,19	7,85	-0,04	-0,17

Analysis of training results and testing shows that the chosen structure of neural network, set of input data and discreteness of change of training pairs of data allow to provide satisfactory accuracy of monitoring of voltage nonsinusoidicality indexes at the buses of substations of investigated electric network.

Conclusions

1.As a result of research new concept of the system of nonsinusoidal modes of electric networks monitoring was suggested and substantiated on the basis of indirect measurements of modes parameters. The concept allows to reduce considerably application of expensive specialized devices for control of mode nonsinusoidality in electric networks.

2. Principles of construction of intelligent system of nonsinusoidal modes monitoring and method of its adjustment for electric networks with variable non linear loads are elaborated. The system enables to control indexes of mode nonsinusoidality in preset points of electric system by the data of one or several stationary devices for harmonics measurements and data available at substations of electric network measurement (P, Q, U, I etc.).

3. The type of neural network for developed monitoring system and method of possible input and output sets of training data is substantiated. The expediency of obtaining sets of training data for adjusting neural network based on the modeling of characteristic modes of electric networks is proved

4. On the example of the chosen fragment of electric network with non-linear loads practical approach to structure selection and intelligent system monitoring regulation is shown, the efficiency of the elaborated system application and methods of its setting for monitoring of electric systems nonsinusoidal modes is proved.

REFERENCES

1. Manson J. , Targosz R. European Power Quality Survey Report. November 2008 // [Електронний ресурс] http://www.leonardo-energy.org/european-power-quality-survey-report. – 29c.

2. Roger C. Dugan. Electrical Power System Quality / Roger C. Dugan, Mark F. McGranaghen, H. Wayne Beaty. – USA, 1996. – 265 p.

3. ГОСТ 13109-97. Нормы качества электрической энергии в системах электроснабжения общего

назначения.
4. Najjar M., Heydt G. T., A hybrid nonlinear least squares estimation of harmonic signal levels in power systems // IEEE Trans. Power Delivery. – 1991. – vol. 6, no.1. – P. 282 – 288.
5. Farach J. E., Grady M. V., Arapostathis A. An optimal procedure placing sensors and estimating the locations of harmonic sources in power systems // IEEE Trans. Power Delivery. – 1993. – vol. 8, no.3. – P. 1303 – 1310.
6. Hong R. K., Chen Y. C. Application of algorithms and artificial-intelligence approach fo locating multiple harmonics in distributin systems // IEEE Trans. Industry Appl., – 1993. vol. 29, no.1. – P. 202 – 208.
7. Hartana R. K., Richards G. G. Constrained neural network-based identification of harmonic sources // EEE Trans. on Ind. Application. – 1993. – vol. 29, № 1. – P. 202 – 208.
8. Спосіб моніторингу вищих гармонік у розподільчій електричній мережі: Пат. 35180 України, МПК[7] G01R 23/16/ Ю. О. Варецький, Т. І. Наконечний; – № u200802024; Заявл. 18.02.2008; Опубл. 10.09.2008, Бюл. № 17. – 4 с. іл.
9. Varetsky Y., Nakonechny T. Monitoring Harmonic Sources in Distribution System by Neural Network Estimator // Proc. of 9 Int. Conf. "Electric power quality and utilization". – Barcelona, 9-10 October, 2007. – [Електронний ресурс] www.leonardo_energy.org/archive/all/2007 Paper 1219, 4 P. 2007.

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