Analysis of complex structures of marine systems with attraction methods of neural systems

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Abstract
We have given the results of developing of a method of neuro-fuzzy structures self-organization in intelligent process control systems. The proposed modification of the basic algorithm can improve the control performance index of intelligent automated control systems at a reduced volume of calculations and corresponding increase of system performance. In classical training rule, fuzzy neural networks and the number of production rules, type of membership functions, fuzzy inference of algorithm type, etc. is given a priori and does not change during the network training. In the case of an incorrect choice of these parameters fuzzy neural networks can be ineffective in the field of automation. Operation of the developed algorithm is based on the theory of sampling frequency and training frequency distribution. In traditional adaptive control systems parameters are adjusted once every sampling period, thus the sampling rate and update rate are not separated. In order to reduce the algorithm running time and improve its efficiency when performing parametric synthesis of asymptotically stable intelligent control systems, the experts determine method of the concentration coefficient of membership functions and sampling limits for further adjustments to the base of the adaptive-established rules.

One of the most essential tasks for a number of systems of the automatic controls in the autonomous electric power systems of water transport is accurate calculation of variable harmonic components in the non-sinusoidal signal. In the autonomous electric power systems being operated with full semiconductor capacity, the forms of line currents and voltages are greatly distorted, and generator devices generate voltage with inconsistent frequency, phase and amplitude. It makes calculation of harmonic composition of the distorted signals be a non-trivial task. The present paper provides a mathematical set for solution of the outlined problem including the realization in the discrete form. The simplicity and efficiency of the system proposed make possible to perform its practical realization with the help of cheap FPGA. The test of the developed system is performed in the Matlab medium.

Keywords: POWER SYSTEMS, MODELING ALGORITHM, FUZZY LOGIC, INTELLECTUAL SYSTEMS, HARMONIC COMPONENTS, SHIP

Introduction

Today developments in the field of computer science are becoming increasingly important - data processing algorithms are hardware/firmware implemented. Neural networks, fuzzy logic, genetic algorithms and a number of other information technologies, recently known only to a narrow circle of specialists, have become widely used in the last decade. Problems, solved by information systems, in most cases are reduced to a series of typical ones, among which are [1] the following: classification of images; clustering; approximation of functions; forecast; optimization; associative memory; management.

From the above mentioned problem management is complicated, in most cases, it is necessary to solve complex solutions of the above objectives in order to solve it.

In classical training rule, fuzzy neural networks the number of production rules, type of membership functions, fuzzy inference algorithm type, etc. is given a priori and does not change during the network training. In the case of an incorrect choice of these parameters fuzzy neural networks can be ineffective in the field of automation. To avoid this situation adaptive algorithms (self-ogranization) of fuzzy neural networks are applied, which set up in training not only the parameters but also the structure of the network. A few basic principles of self-organization algorithms of fuzzy systems have been defined [1, 2]: copying of training set; optimization of the number of production rules as a single parameter; overall optimization in the number of production rules and fuzzy network weights; gradually growing partitioning algorithm (Incremental Decomposition Algorithm).

The above stated algorithms are distinguished by very high requirements to computing resources. Significant computational costs are required for the procedure of parametric optimization search. In this regard, in terms of reducing the computational complexity, algorithms that do not require a repeated reset in case of removing or adding production rules are of value. Algorithms, which belong to this type, are stated [1, 2, 3]: reduction algorithms of fuzzy neural networks (reduction algorithms); constructive algorithms of fuzzy neural networks (constructive algorithms); fuzzy complementative adaptive algorithm of fuzzy inference. The goal of this article is to develop scientific and technical solutions aimed at improving the quality and reliability of the automatic control of dynamic objects based on improving the adaptive algorithm of fuzzy neural networks, functioning as part of intelligent automatic control systems (ACS).

Theoretical analysis of the intelligent ACS synthetics methodology [5] has led to the conclusion that the development and introduction of hybrid intelligent control systems that use dynamic intelligent database to convert generic concepts will allow to record specified quality parameters when exposed to uncontrollable external perturbations through intellectual correction of the system parameters.

The modern ship's electric power systems (SEPS) are characterized by the presence in its composition of a great number of the conversion load, including frequency transformer, uninterruptive power supply, inverters, rectifiers and other consuming devices varying in their non-linear volt-ampere features. Similar load has a negative impact on the supplying network of the alternating current, generating into it highest harmonic components of currents and voltages.

At the same time a great deal of ship's automation systems apply the line currents and voltages to form the reference signal. Thus, for example, an automatic voltage regulator (AVR) of ship's synchronous generators (SG) performs regulation by an average value of voltages and currents in the circuit. However, with the distorted form of the variable signals (that is caused by the presence of a wide range of highest harmonics) their average value increases and an automatic voltage regulator (AVR), correcting the error, decreases the exciting current of the synchronous generator that results in loss of voltage in the ship's electric power systems (SEPS). Consequently, decrease in relative value and increase in highest harmonics take place and so electromagnetic moment of non-synchronous motors decreases, the level of interferences influencing the systems of ship's automatic controls becomes higher, and losses in power supply lines enlarge. Practically such an error is corrected by adjustment of the voltage corrector (VC). However, as harmonic composition periodically varies depending on the regime of operation and the composition of load of the electric power station, the setting of the voltage corrector should be changed constantly. This problem should be solved by measuring the level of the basic harmonics of the current and voltages of the ship's circuit.

On the other side it is known that filter-compensating devices (FCD) are the most efficient means to increase the quality of electric energy in the ship's power supply systems at the moment. Their efficiency in higher harmonic suppression and compensation of their volt-ampere reactive may be provided only with high accuracy of the calculation of parameters in the target harmonics of the line currents and voltages.

The setting of the problem

Thus, the required functional set of the systems taken as an example determining their efficiency in particular and their operational performance in general, is a set for identification of external parameters of the control system. The major function of the block is extraction of harmonic components required for their analysis, calculation of their parameters from the distorted signal and application of results of that analysis in control of means of the increasing values for quality of the electric energy in the ship's electric power systems. With this, such parameters as levels of target harmonics of currents and voltages, values of summary harmonic distortions, values of distortion capacity, volt-ampere reactive, etc. are regulated [1,2,3,4]. If sources of energy for a ship's electric power station may be represented as a generator of the sinusoidal signal

$$x(t) = a_1(t)\sin\left(\omega_1(t)t + \varphi_1(t)\right) \quad (1)$$

where a1(t) – amplitude, ω1(t) – rate of phase change and φ1(t) – phase – non-stationary parameters of the generator.

The proposed filter (fig.1) is based on the elements of the theory of extreme systems and adaptive systems.

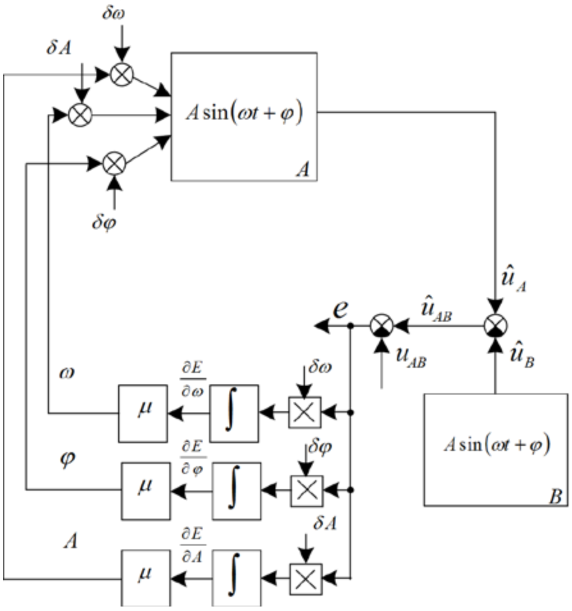

Figure 1. Adaptive harmonic approximation

Generated from the parent function and incrementing signals, the result of this sum is reduced adaptive filter signal that represents phase A voltage. And a difference signal obtained at the output of the adaptive filter will represent signal that is equivalent to line voltage. The difference between the real and the reconstructed signal gives an error signal. From this signal energy function is performed to find the signal increments. Limiting the number of functions derived from the parent function in each channel of the adaptive filter allows us to recover the desired signal (or fundamental harmonic) as close as possible to the original, without any delay and without the presence of higher harmonics.

Filter in each channel can determine the magnitude, phase and frequency of corresponding phase voltage signal. Passing through adders of incrementing, these signals are fed to respective function generators ωh(t), to increment the corresponding coefficients (fig. 2).

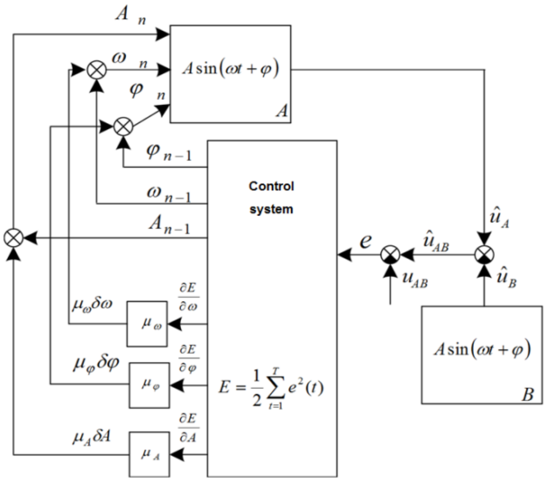

Figure 2. The structure of adaptive approximation

As it would seem, this standard for the theory of the automatic control on the form structural scheme cannot be analyzed by tools of the classical frequency criteria as the sense itself for the frequency characteristics of non-stationary element is lost. With this the non-linear element WHE itself generally is non-stationary as the main semi-conductor load of the ship's electric power system is a set of a closed system (for example, autonomous inverters and converters) described by commutation functions and consequently containing periodically varying coefficients.

In the view of the problem being solved it is required to determine the harmonic composition of the non-stationary signal in order to use it as a set of reference signals in the system of the quality management for the electric energy in the ship's electric power system. The present paper proposes to use certain function approximating the target harmonics of the distorted signal. The structural sketch of such a system is given in Figure 3.

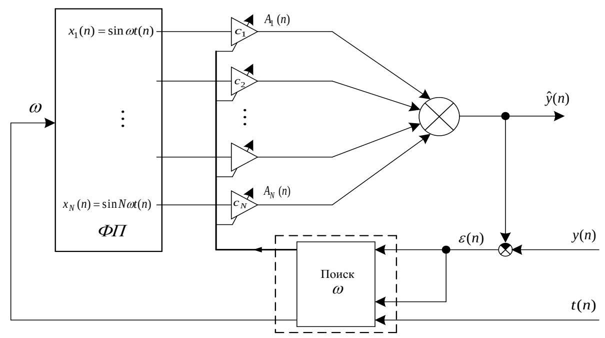

Figure 3. The structural sketch of the approximator, performing monitoring of the frequency ω and components of the harmonics of the signal y

Identification of the target non-stationary harmonics of the distorted signal is made by adjustment of the parameters of the relevant function-prototype (FP). In its general form the input signal y(t) of the identification system being a signal proportional to the circuit current or voltage in the ship's electric power system may be described by Fourier's series:

$$y(t)=\sum_{k=1}^{N} a_k(t)\sin\left(k\omega_k(t)t+\varphi_k(t)\right)=x(t)+\xi(t)$$

where $a_k(t)$ is amplitude, $\omega_k(t)$ is a rate of phase change and $\varphi_k(t)$ is a phase angle of k-harmonics, N is a number of harmonics (in general $N=\infty$), $\xi(t)=\sum_{k=2}^{N} a_k(t)\sin\left(k\omega_k(t)t+\varphi_k(t)\right)$ is a set of non-approximated (i.e. non-recoverable by the device being designed) harmonics.

Let's introduce the vector for the parameters $\phi(t)=\left[a(t),\omega(t),\varphi(t)\right]^T$, which belongs to the space of parameters $\mathbf{\Phi}(t)=\left\{\left[a,\omega,\varphi\right]^T\right\}$.

The approximation error is exhibited by the expression

$$\varepsilon=y-\hat{y}, \qquad (2)$$

where $\hat{y}(t)=\hat{a}_1(t)\sin\left(\hat{\omega}_1(t)t+\hat{\varphi}_1(t)\right)$ is a recovered harmonic component. Moreover, it is evident that the more components ξ(t) of the function will be recovered by the relevant generators of the approximating functions the less error (2) will be.

And also let the energetic function of the error be exhibited by the mean square error

$$E=\frac{1}{2}\varepsilon^2. \qquad (3)$$

The function (3) is the function of three variables, that is E(A, ω, φ) or E(ϕ). The task of the approximation is to seek such an algorithm of variation of elements of vector ϕ, with which minimization of the function (3) takes place, i.e. the search for such value $\overline{\phi}$ of the vector ϕ, to which extreme value of the function E (minimum), where the condition would be realized:

$$E(\phi)\geq E(\hat{\phi}), \quad \forall E\in\mathbf{\Phi}, \qquad (4)$$

where Φ is a permitted area or an area of the possible values for the vector ϕ, determined by the limitations

$$a\in\left[a_{\min},a_{\max}\right], \qquad \omega\in\left[\omega_{\min},\omega_{\max}\right] \quad \text{and} \quad \varphi\in\left[\varphi_{\min},\varphi_{\max}\right]. \qquad (*)$$

At this stage we have approached to the task of seeking the extreme (4) (minimum) of the energetic function (3). The function is differentiable by all the elements; however the expression (2) assumes non-linear conversion of the elements for the input vector ϕ. The latter circumstance challenges the possibility to apply gradient algorithms mostly recommended by themselves in the extreme systems.

Let's consider mathematical aspects of the possibility to apply gradient methods in the task outlined for the case of recovery of one target harmonics. Let's write down the gradients for the recovered parameters in the vector ϕ:

$$\begin{aligned}\frac{d\hat{a}(t)}{dt}&=-\mu_A\frac{\partial\left[E(t,\phi(t))\right]}{\partial\hat{a}(t)}\\ \frac{d\hat{\omega}(t)}{dt}&=-\mu_\omega\frac{\partial\left[E(t,\phi(t))\right]}{\partial\hat{\omega}(t)}\\ \frac{d\hat{\varphi}(t)}{dt}&=-\mu_\varphi\frac{\partial\left[E(t,\phi(t))\right]}{\partial\hat{\varphi}(t)}\end{aligned} \qquad (5)$$

The energetic function may be represented as follows

$$E(t,\phi(t))=\frac{1}{2}\varepsilon(t,\phi(t))^2=\frac{1}{2}\left[y(t)-\hat{a}(t)\sin\left(\hat{\omega}(t)t+\hat{\varphi}(t)\right)\right]^2$$

Substituting it into (5) and differentiating the right-hand part, we will have

$$\begin{aligned}\frac{d\hat{a}(t)}{dt}&=-\mu_A\varepsilon(t)\sin\left(\hat{\omega}(t)t+\hat{\varphi}(t)\right)\\ \frac{d\hat{\omega}(t)}{dt}&=-\mu_\omega\varepsilon(t)\hat{a}(t)t\cos\left(\hat{\omega}(t)t+\hat{\varphi}(t)\right)\\ \frac{d\hat{\varphi}(t)}{dt}&=-\mu_\varphi\varepsilon(t)\hat{a}(t)\sin\left(\hat{\omega}(t)t+\hat{\varphi}(t)\right)\end{aligned} \qquad (6)$$

As it is clear, the time parameter outside the cosine mark appears in the second equation of the system (6). Thus, for this energetic function the expression of the gradient for the angle velocity contains combined, i.e. secular (age) and simultaneously non-linear term. When applying Newton-Raphson's method (or similar ones), using a hessian, several such terms will appear. So whatsoever small the function of the error ε(t) would be, in the course of time the secular term will be increasing without limits.

This fact explains the failures in realization of the numerical techniques on the basis of similar algorithms created by using common approaches of adaptive systems and gradient methods in particular, practical realization of which in the described cases of application faces with the divergence of the process when monitoring the changes in signal phase and frequency.

Consequently, it is necessary to develop such an algorithm for identification of the harmonic composition of signals proportional to currents and voltages in the circuit which makes possible to provide the convergence of the process with existing non-linear features and non-stationary character of the system under review and at the same time to support the implementation of the up-to-date digital systems especially under the necessity to identify a set of harmonic components of the signal that requires parallel and pseudo-parallel operation of a number of copies or nuclei of the algorithm sought.

The solution of the task outlined

The core of the proposed principle of the approximation of every harmonics of the measured signal is in the formation of the periodical function basing on the function-prototype Rk(ωk(t),φk(t),t), where k is a number of the approximated harmonics (or simply Rk(k,t)); so changing its parameters we will strive to approach the minimum of the error between the input signal and periodical function [3, 4]. Proceeding from the physical sense of the processes under the review, as it was stated above, it is reasonable as FP to use the function Rk(t)=sin(ωk(t)t+φk(t)). Thus every harmonics will be approximated by the weight function (Dirac response) $\hat{x}_k(t) = \hat{a}_k(t)R(k,t)$.

Thus the frequency ω(t) and phase function φ(t) of the target function are variable, so let's go to the notion of the complete phase ψ(t)=ω(t)t+φ(t), taking into account all the variations of the function phase. The system (6) will be expressed as

$$\frac{d\hat{a}(t)}{dt} = -\mu_A \varepsilon(t)\sin\hat{\psi}(t) \qquad (7.1)$$

$$\frac{d\hat{\omega}(t)}{dt} = -\mu_\omega \varepsilon(t)\hat{a}(t)t\cos\hat{\psi}(t) \qquad (7.2)$$

$$\frac{d\hat{\psi}(t)}{dt} = \hat{\omega}(t) + \mu_\psi \frac{d\hat{\omega}(t)}{dt} \qquad (7.3)$$

The energetic function would be expressed in the form of the following expression: $E(t) = \frac{1}{2}\left[y(t) - \hat{a}(t)\sin\hat{\psi}(t)\right]^2$, i.e. for the error of the approximation we will have $\varepsilon(t) = y(t) - \hat{a}(t)\sin\hat{\psi}(t) = y(t) - \hat{x}(t)$.

It should be noted that the change in the phase of the input signal may be compensated by the similar change in the initial phase of the approximating function (that will exactly correspond to the behavior of the signal being approximated), short-time change in the frequency of the same function or by the combination of these processes. Let's pass on the integral of the function (7.2) and the final interval [ti – T/2, ti + T/2] of T duration, where one more interval of FP is determined. As one can see, FP used by us is 2π-periodical (i.e. T=2π/ω) and odd-symmetrical in respect of the middle of the interval where it was determined and integrated. Let's assume that the amplitude of the approximated harmonics for the time of the FP period does not change (or changes slowly). So for the basic harmonics we will have

$$\hat{\omega}_1(t) = -\mu_{\omega 1}\int_{t_i-\frac{T}{2}}^{t_i+\frac{T}{2}} \varepsilon(t)\hat{a}_1 t\cos\hat{\psi}(t)dt \qquad (8)$$

Considering (1)-(2) and taking into account that according to the experimental research [1-4] odd harmonics are predominant in the ship's circuit в, express (8) in the following form

$$\hat{\omega}_1(t) = -\mu_{\omega 1}\int_{t_i-\frac{T}{2}}^{t_i+\frac{T}{2}} [a_1(t)\sin\psi_1(t) + a3(t)\sin\psi_3(t) + a_5(t)\sin\psi_5(t) + ...]\hat{a}_1(t)t\cos\hat{\psi}_1(t)dt \qquad (9)$$

If the frequency of the period for the Function-Prototype coincides with the period of the approximated harmonic, i.e. $\hat{\omega}_1(t) = \omega_1$ so (9) will be transformed into:

$$-\mu_{\omega 1}\int\limits_{t_i-\frac{T}{2}}^{t_i+\frac{T}{2}} t\left[\frac{a_1\hat{a}_1}{2}\sin\left[2\omega_1(t)t+\varphi_1(t)+\hat{\varphi}_1(t)\right]+\frac{\hat{a}_1 a_3}{2}\left[\sin\left[4\omega_1(t)t+\hat{\varphi}_1(t)+\varphi_3(t)\right]+\right.\right.$$

$$\left.\left.+\sin\left[2\omega_1(t)t+\hat{\varphi}_1(t)-\varphi_3(t)\right]+.....\right]-\frac{\hat{a}_1 a_1}{2}\sin\left[2\omega_1(t)t+\varphi_1(t)+\hat{\varphi}_1(t)\right]\right]=$$

$$=-\mu_{\omega 1}\int\limits_{t_i-\frac{T}{2}}^{t_i+\frac{T}{2}} t\frac{\hat{a}_1 a_3}{2}\left[\sin\left[4\omega_1(t)t+\hat{\varphi}_1(t)+\varphi_3(t)\right]+\sin\left[2\omega_1(t)t+\hat{\varphi}_1(t)-\varphi_3(t)\right]+.....\right] \quad (10)$$

In the connection with that only odd harmonics will take place in the input signal, so under the mark of the integral vice versa only even harmonics with frequencies 2ω1, 4ω1, 6ω1 etc. will remain, and the integral of their sum in the interval T will be equal to 0 due to the even non-symmetry of the sine components.

With appearing the error δ between the real and recovered frequencies of the main harmonics under-integral expression in (9) will also contain the given even harmonics.

In fact the calculated integral conversion in a general form will represent the resultant of the function of the approximator error ε(t) by means of the window (or using the terms of scanning systems, weight) function $\hat{r}_k(t)$. Thus, the result of integrating the expression (9) is the value of correlation FP and ε(t). If δ tends to zero, (9) will also tend to zero irrespective of he phase shift between FP and every harmonics of the input signal or their amplitudes. The latter feature of the expression enables to simplify it to the form

$$\hat{\omega}_1(t)=-\beta_{\omega 1}\int\limits_{t_i-\frac{T}{2}}^{t_i+\frac{T}{2}}\varepsilon(t)r(t)dt,$$

where r(t) – even- or odd-symmetric in respect of the interval of integration of FP (derivative of R(t)). The form of this function determines the dynamic qualities of the tracking system for the frequency of the basic harmonic. It should be noted that T is a variable value. It is this circumstance that enables to synchronize the FP with the period of the target harmonic and reject the standard measure of time (frequency), having the long-term stability with due necessity.

Taking the above-mentioned into account, the function will be expressed as follows:

$$\hat{\omega}_1(t)=-\beta_{\omega 1}\int\limits_{t_i-\frac{\pi}{\hat{\omega}_1}}^{t_i+\frac{\pi}{\hat{\omega}_1}}\varepsilon(t)r(t)dt.$$

Otherwise, expressing the period by means of frequency FP we will have

$$\omega_{i+1}=\omega_i+\frac{\beta_{\omega 1}\tau\omega_i}{\pi}\varepsilon_i r_i.$$

Substituting $\alpha_\omega = \tau\beta_{\omega 1}/\pi$, we will have

$$\omega_{i+1}=\omega_i+\alpha_\omega\omega_i\varepsilon_i r_i. \quad (!)$$

Coefficient α_ω also determines the dynamic features of the frequency tracking system and depends on the form of the FP. Product $\alpha_\omega\omega_i$ in the expression (!) enables to preserve these specific features with changing the frequency of the input signal, i.e. in fact it describes the reconfigurable filter as it determines constant value of the time of the integrator adapting to the non-stationary frequency of the restorable harmonic.

In the same way we express in the discrete form the expression (7.3), describing the complete phase of the FP

$$\psi_{i+1}=\psi_i+\tau\omega_i+\tau\alpha_\psi\alpha_\omega\omega_i\varepsilon_i r_i. \quad (!!)$$

The complete description of the approximator calculated on the basis of the expressions (!) and (!!), in the discrete form will be represented by the system

$$\begin{gathered}\omega_{i+1}=\omega_i+\alpha_\omega\omega_i\varepsilon_i\cos(\psi_i)\\ \psi_{i+1}=\psi_i+\tau\omega_i+\tau\alpha_\psi\alpha_\omega\omega_i\varepsilon_i\cos(\psi_i)\\ a_{i+1}=a_i+\tau\alpha_a\varepsilon_i\sin(\psi_i)\\ \varepsilon_i=y_i-R_i\\ R_i=a_i\sin(\psi_i)\end{gathered} \quad (11)$$

The key role in the solution of the implementation of the solution (11) is given to the coefficients α, the selection of which is the compromise between the velocity of the approximator adjustment in accordance with the changes of an input signal and the accuracy of approximation. Virtually, large values of coefficients make possible to lessen the time of transition processes, however at same time non-linear distortions start prevailing in the approximating signal. Therefore, in order to improve the values it is possible to apply additional filters for FP parameters or adaptive readjustment of coefficients. The hybrid variant of the tracking system in which internal DFP with high velocity of approximation is used for tracking and output signal of the approximator is taken from the additional external DFP, arguments of which are renewed only in the characteristic points mentioned above. Renewal takes place only by current (or filtered) parameters of the internal DFP.

Results of the modeling and practical implementation

A number of existing solutions with which the proposed system may be compared is rather limited. For example, such distributed methods as fast or discrete Fourier transform are beyond the comparison in connection with the fact that with the frequency shift the component of the input signal is expressed itself as so-called effect of leakage as a result of which the frequency deviation for 5 Hz causes the appearance of errors in the evaluation of amplitude more than 10%.

The comparative analysis of the operation of the designed system and extended Kalman filter produces the following results of modeling. Application of extended Kalman filter with availability of the 5th and 7th harmonics besides the main harmonic with amplitudes 10% and 5% respectively, does not allow having an error less than 4%. At the same time proposed by the author system under the same conditions has an error not exceeding 0.2% by the frequency. And if to use a filter of low frequencies by the signal of the restored frequency, the error reduces to the level less than 0.04%. The simplicity of the proposed algorithm allows to implement multivariable approximator with minimum requirements to the computational hardware of the device. The simplest and the most effective algorithm with computational function or a FP tabular model may be implemented in the FPGA. FPGA architecture, its flexibility and possibility to implement parallel computational processes makes them the most promising platform for the practical implementation of the reviewed tracking system.

Modeling of the scheme operation (Fig.4,5), realizing the system (11) by means of FPGA and generation of the firmware code were made by means of software Xilinx System Generator in Matlab 14. Spartan 6 in Xilinx was chosen as FPGA. Fig.8 provides the report about the number of FPGA resources required while creating the tracking system for the parameters of one harmonic of the input signal, produced by means of block Xilinx Resource Estimator. This realization of the described algorithm is used for acquisition of the main harmonic of the circuit voltage in order to provide correct operation of automatic voltage regulators of the ship's synchronous generators (AVR for the SG) under the conditions of high distortion of voltages and currents in the ship's circuit [5,6].

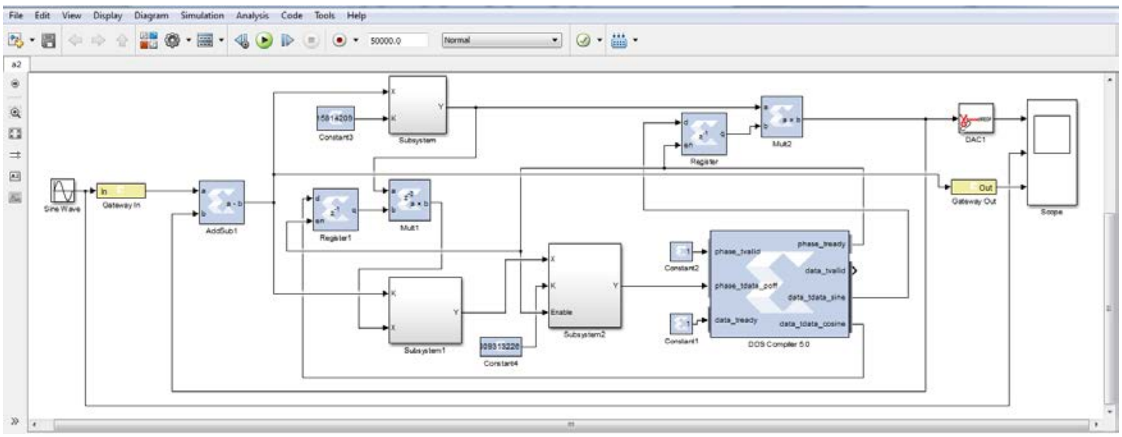

Figure 4. Configuration of FPGA for implementation of the system (11)

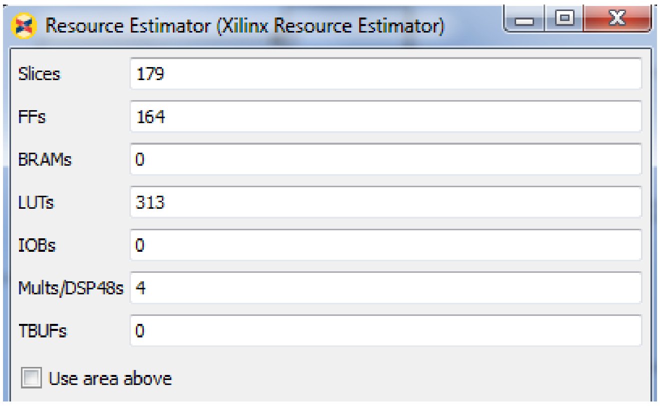

Figure 5. Report of Xilinx Resource Estimator about applied FPGA resources

As it is seen from a small number of the required computational resources, not exceeding even 2% of the available ones in applied FPGA, a multivariable system of parallel restoration of a number of harmonic components of the distorted signal may be developed on the basis of one microscheme.

Conclusions

A task of acquisition of non-stationary harmonics of currents and voltages in the autonomous circuits of water transport craft was solved. Simple and effective mathematical tools were found making possible to solve the outlined task by means of FPGA. It allows restoring simultaneously dozens of target components.

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