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INFORMATION SYSTEM OF MINIMIZATION CONSUMPTION REACTIVE POWER IN ASYNCHRONOUS ELECTRIC DRIVE WITH VECTOR CONTROL

Abstract. *It is known that the energy performance of asynchronous electric drives is extreme nature. However, when stabilizing the magnetic flux of the asynchronous machine at the nominal level and reducing the load moment on the shaft, the power factor becomes less than the nominal, and this reduction can be significant. Therefore, the paper proposes to improve the energy performance of asynchronous electric drives with a fan mechanical characteristic of the production mechanism by changing the magnetic flux as a function of the moment of resistance forces on the shaft of the asynchronous machine. Thus, to optimize the energy processes in the electric drive when regulating the performance of turbomechanisms, it is necessary to build a system with independent speed control and magnetic flux of an asynchronous machine. Since the control systems of turbomechanisms are designed to stabilize the speed in long-term operation, it is first necessary to ensure the maximum energy performance in steady-state operation. In this work, the increase in energy efficiency is achieved by implementing a vector field-oriented control system of an asynchronous machine with the addition of an extreme control circuit. In the article the information system of two-channel vector control of the asynchronous electric drive with the fan moment of loading which contains a contour of extreme regulation on criterion of a minimum of consumption of reactive power is developed. The dependence of the values of the magnetic flux of the rotor, which are extreme for the reactive power function, mainly on the moment of loading and insignificant on the speed, is substantiated. A synthesized state observer, which estimates the moment of static load, is needed to determine the extreme values of the magnetic flux of the rotor on the basis of the obtained functional dependence. Thus, the idea is to use the reactive power channel of an asynchronous machine not to stabilize the magnetic flux, as was the case in classical vector control systems, but to adjust the modulus of the magnetic flux vector as a function of static load by the minimum stator reactive power. A mathematical model in the Matlab/Simulink environment has been developed and the efficiency of the synthesized information system of minimization of reactive power consumption by an asynchronous electric drive with vector control has been confirmed by mathematical modeling.*

Keywords: *asynchronous machine; vector orientation; objective function; control law; state observer; functional converter; reactive power; functional scheme of information system*

Introduction. In connection with the rapid development of information technology in science and technology in recent years, special attention is paid to the modeling of information systems that implement the function of control complex technical objects. Such information systems are synthesized on the basis of a set of known physical and mathematical descriptions, and their modern algorithms allow to solve current multifactor technical problems. One of the main areas of application of information technology in electromechanics is the development and creation of systems that increase the energy efficiency of existing or projected facilities. A special case of such information systems can be considered as vector control systems for asynchronous electric drives, synthesized in order to minimize power losses, reactive power consumption or improve other energy performance [1-5].

The structure of the vector control system of an asynchronous machine (AM) with constant flux coupling may be irrational because the stabilization of the control system of the modulus of the flux coupling vector at the nominal value leads to a decrease in power factor at load times less than nominal. Adjustable electric drives of mechanisms with fan mechanical characteristics have this disadvantage [6-8]. Analytical expressions that allow determining the value of the electromagnetic flux of the rotor of an asynchronous electric drive (ED), at which its energy characteristics reach an extreme, were obtained in [9]. However, in this work, the calculations were performed without taking into account the phenomenon of saturation of the magnetic circuit, which is expressed in the influence of the electromagnetic flux on the value of the inductances of the AM windings. When forming the target control functions and in the algorithms for finding their extreme values to increase the accuracy it is desirable to take into account effect of the saturation of the

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magnetic circuit, [10-13]. It is possible to improve the energy efficiency of an asynchronous electric drive by changing the modulus of the reference vector of electromagnetic flux as a function of the load moment on the AM shaft [14-18]. In [19] it was proved that to optimize the energy efficiency of the ED with rotor control it is necessary to build a multichannel system with independent speed control and electromagnetic flux AM, which can be implemented in a vector field-oriented control system with the addition of an extreme control circuit. The purpose of control is to achieve the extremum of some objective function and to observe the displacement of the extremum point under variations of the state variables of the ED under the action of external coordinate perturbations.

The purpose of the article. The purpose of the article is to develop an information system to minimize the consumption of reactive power by an asynchronous electric drive with vector control.

To achieve this goal it is necessary to solve the following tasks: to form quality functions of static modes of operation the AM with a short-circuited rotor, which reflect the energy performance of the ED; perform an analysis of the properties of these functions to obtain the results necessary for the synthesis of the control information systems, optimal in terms of energy efficiency; to synthesize as a part of vector control system of ED of the mechanism with the fan mechanical characteristic a contour of searchless extreme control; applying methods of mathematical modeling to explore the process of two-channel control of the stator’s state variables of asynchronous ED in the mode of ensuring the lowest consumption of reactive power by the stator circuit AM.

Results of work. Take as a source the following system of equations of the steady-state operation of an asynchronous machine, written in orthogonal axes uv, oriented by the vector of electromagnetic flux of the rotor, [9]:

$$\begin{aligned} U_{su} &= I_{su}R' - \omega_k L'_s I_{sv} - \frac{k_r}{T_r}\Psi_{ru}; \\ U_{sv} &= I_{sv}R' + \omega_k L'_s I_{su} + k_r N\omega_r \Psi_{ru}; \\ \Psi_{ru} &= L_m I_{su}; \\ \omega_k &= N\omega_r + \frac{R_r k_r I_{sv}}{\Psi_{ru}}; \\ M_{st} &= \frac{3}{2}Nk_r\Psi_{ru}I_{sv}, \end{aligned} \qquad (1)$$

where: $T_r = L_r/R_r$; $k_r = L_m/L_r$; $L'_s = L_{s\sigma} + k_r L_{r\sigma}$; $R' = R_s + k_r^2 R_r$; N – is the number of pairs of poles.

Dependencies for the components of the electromagnetic flux of the rotor have the form:

$$\begin{aligned} \Psi_{ru} &= L_m I_{su} + L_r I_{ru}; \\ \Psi_{rv} &= L_m I_{sv} + L_r I_{rv}. \end{aligned} \qquad (2)$$

When orienting the coordinate system on the electromagnetic flow vector of the rotor $\Psi_{rv} = 0$, $\Psi_{ru} = \left|\vec{\Psi}_r\right|$. Then from (2) after simple transformations we obtain:

$$I_{rv} = -k_r I_{sv};\ I_{ru} = \frac{\Psi_{ru}}{L_r} - k_r I_{su}. \qquad (3)$$

From equations (1) follow the relationship:

$$I_{su} = \Psi_{ru}/L_m;\ I_{sv} = \frac{2M_{st}}{3Nk_r\Psi_{ru}}. \qquad (4)$$

Since the rotor parameters in equations (1) are given to the stator and the rotor is not connected to the mains, the active power consumed by the AM is equal to:

$$P_s = \frac{3}{2}Re\left[\vec{U}_s \times \vec{I}_s^*\right] = \frac{3}{2}\left[U_{su}I_{su} + U_{sv}I_{sv}\right]. \qquad (5)$$

The components of the stator voltage vector after the replacement of currents I_{su} and I_{sv} by relations (4) in expressions (1) will take the form:

$$\begin{aligned} U_{su} &= R'\frac{\Psi_{ru}}{L_m} - \frac{2\omega_k L'_s M_{st}}{3Nk_r\Psi_{ru}} - \frac{k_r}{T_r}\Psi_{ru}; \\ U_{sv} &= \frac{2R'M_{st}}{3Nk_r\Psi_{ru}} + \frac{\omega_k L'_s\Psi_{ru}}{L_m} + k_r N\omega_r\Psi_{ru}. \end{aligned} \qquad (6)$$

Substitute the relations (4), (6) into (5) and after the transformations we obtain:

$$P_s = \frac{3R_s\Psi_{ru}^2}{2L_m^2} + \frac{2R'M_{st}^2}{3N^2k_r^2\Psi_{ru}^2} + \omega_r M_{st}. \qquad (7)$$

The reactive power of the AM is determined by the formula:

$$Q_s = \frac{3}{2}Im\left[\vec{U}_s \times \vec{I}_s^*\right] = \frac{3}{2}\left(U_{sv}I_{su} - U_{su}I_{sv}\right). \qquad (8)$$

Substituting relations (4) and (6) into (8), after transformations we obtain:

$$Q_s = \frac{3L_s^{'}\omega_k\Psi_r^2}{2L_m^2} + \frac{2L_s^{'}\omega_k M_{st}^2}{3N^2k_r^2\Psi_r^2} + \\ + \frac{3k_rN\omega_r\Psi_r^2}{2L_m} + \frac{M_{st}}{NT_r}. \quad (9)$$

The rotation speed of the coordinate system is taken from equations (1) and is equal to:

$$\omega_k = N\omega_r + \frac{R_rk_rI_{sv}}{\Psi_r} = N\omega_r + \frac{2R_rM_{st}}{3N\Psi_r^2}. \quad (10)$$

Substitute the obtained expression in (9), simplifying which, we will have:

$$Q_s = \frac{3NL_s^{'}\omega_r\Psi_r^2}{2L_m^2} + \frac{L_s^{'}R_rM_{st}}{NL_m^2} + \frac{2L_s^{'}\omega_rM_{st}^2}{3Nk_r^2\Psi_r^2} + \\ + \frac{4L_s^{'}R_rM_{st}^3}{9N^3k_r^2\Psi_r^4} + \frac{3Nk_r\omega_r\Psi_r^2}{2L_m} + \frac{M_{st}}{NT_r}. \quad (11)$$

Expression (11) can be considered as a quality function of static regimes asynchronous ED. To research this function, it is necessary to introduce the dependence of the inductance of the magnetizing circuit on the magnetic flux $L_m = f(\Psi_r)$. As a result approximation of the universal magnetization curve [6] the form of the function $L_m = f(\Psi_r)$ and its parameters are determined:

$$L_m = 1{,}504L_{mn}(\Psi_{ru}/\Psi_{rn})\mathrm{ctg}(\Psi_{ru}/\Psi_{rn}) = \\ = a\Psi_{ru}\,ctg(b\Psi_{ru}), \quad (12)$$

where: $a = 1{,}504L_{mn}/\Psi_{\mathrm{rn}}$; $\mathrm{b} = 1/\Psi_{\mathrm{rn}}$.

Substituting in (11) instead of the parameter L_m its expression (12), after the transformations we obtain the objective function in the form:

$$Q_s = \left(\frac{3L_s^{'} + 3k_r}{2a^2}\right)N\omega_r tg^2(b\Psi_r) + \\ + \frac{L_s^{'}R_rM_{st}}{Na^2}\frac{tg^2(b\Psi_r)}{\Psi_r^2} + \frac{R_rk_rM_{st}}{Na}\frac{tg(b\Psi_r)}{\Psi_r} + \\ + \frac{2L_s^{'}M_{st}^2\omega_r}{3Nk_r^2\Psi_r^2} + \frac{4L_s^{'}R_rM_{st}^3}{9N^3k_r^2\Psi_r^4}. \quad (13)$$

Fig. 1 and Fig. 2 show the dependences in relative units of reactive power AM on the modulus of the magnetic flux vector of the rotor for different speeds and loads: $\psi_r = \Psi_r/\Psi_{rn}$, $\alpha = \omega_r/\omega_{\mathrm{rn}}$. The graphs show that the extremum of characteristics shifts upwards with increasing speed, and to the right with increasing load. At low speeds, the reactive power function in the vicinity of the minimum is acclivous. As the speed increases, the minimum becomes obviously pronounced. Reactive power is due to two types of magnetic fluxes: the magnetization flux and the scattering flux. The increase in reactive power to the right of the minimum is due to an increase in the reactive magnetizing current at saturation of the AM. The increase in reactive power to the left of the minimum is caused by an increase in the scattering magnetic fluxes and the associated reactive power.

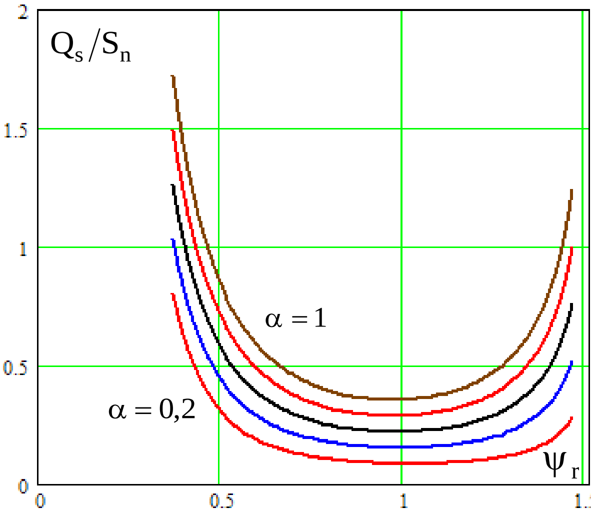

Fig.1. Graphs of changes in reactive power at different speeds and $\mathrm{M} = \mathrm{M_n}$

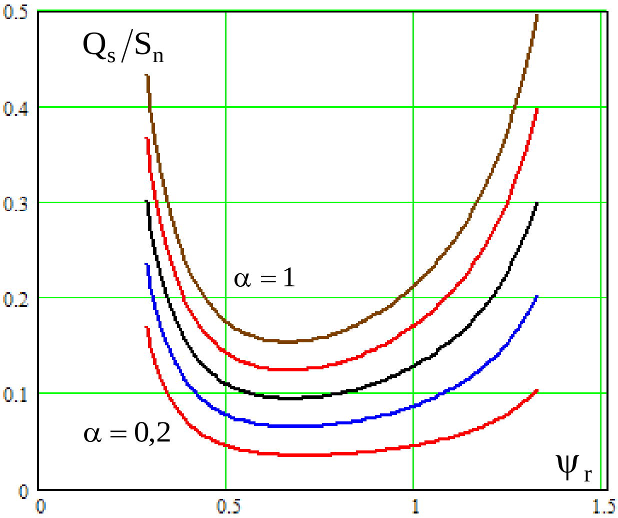

Fig. 2. Graphs of change of reactive power at different speeds and $\mathrm{M} = 0{,}4\mathrm{M_n}$

Let us find the extremum of the objective function (13). To do this, differentiate it by Ψ_r, equal the obtained expression to zero and obtain the following equation:

$$\frac{dQ_s}{d\Psi_r}=\frac{3bN\omega_r}{a^2}\left(L_s^{'}+k_r\right)\frac{tg\left(b\Psi_r\right)}{cos^2\left(b\Psi_r\right)}- -\frac{4L_s^{'}\omega_r M_{st}^2}{3Nk_r^2\Psi_r^3}-\frac{16L_s^{'}R_r M_{st}^3}{9N^3k_r^2\Psi_r^5}+ +\frac{2bL_s^{'}R_r M_{st}}{Na^2\Psi_r^2}\frac{tg\left(b\Psi_r\right)}{cos^2\left(b\Psi_r\right)}- \quad (14)$$

$$-\frac{2L_s^{'}R_r M_{st}}{Na^2\Psi_r^3}tg^2\left(b\Psi_r\right)+\frac{bR_r k_r M_{st}}{Na\Psi_r\, cos^2\left(b\Psi_r\right)}- -\frac{R_r k_r M_{st}}{Na\Psi_r^2}tg\left(b\Psi_r\right)=0.$$

As a result of solving this equation at given speeds ω and different moments of static load M_{st}, a stirps of graphs extreme values of rotor's magnetic flux Ψ_r from the load moment and rotor speed, at which the reactive power of the stator circuit AM reaches a minimum (Fig. 3). The close arrangement of the curves indicates that the values of the rotor magnetic flux extreme for the reactive power of the stator circuit slightly depend on the rotor speed (speed range $\alpha=0{,}2\div 1$).

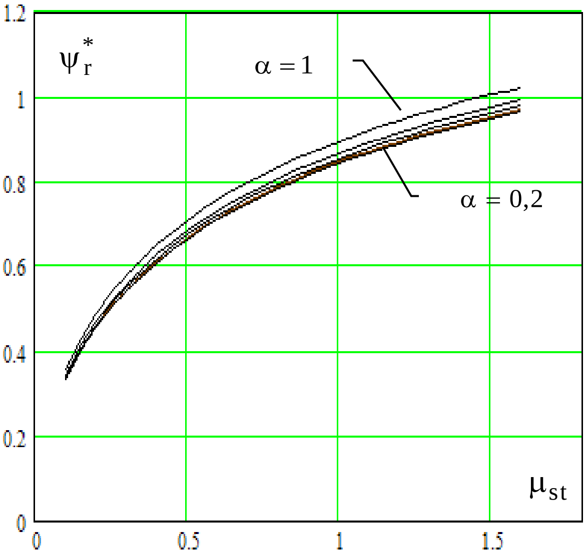

Fig. 3. Dependences of extreme values Ψ_r for Q_s from the moment of loading $\mu_{st}=M_{st}/M_n$ at different speeds

To avoid stepwise algorithms for finding the extremum, which can lead to self-oscillations and reduce the margin of stability of the electric drive, it is advisable to approximate the characteristics in Fig. 3 by analytical expressions and use them in the information control system of the rotor magnetic flux module. To approximate all the curves, it is most convenient to use the arctangential function of the form:

$$\psi_r^*=d_1+d_2\, arctg\left(d_3\,\mu_{st}\right). \quad (15)$$

The coefficients d_i are found by the method of least squares and, for example, for the second curve from above $(\alpha=0{,}8)$ in Fig. 3 are equal to: $d_1=0{,}273,\ d_2=0{,}58,\ d_3=1{,}691.$

Relay regulators with rigid settings implement control algorithms, which are synthesized for the nominal parameters of the ED according to the method described in [20]. Algorithms for controlling stator reactive current and rotor magnetic flux module have the form:

$$U_{rcr}=\mathrm{U_m}\, sign\left[\mathrm{U_{r\psi}}-I_{su}\right]. \quad (16)$$

$$U_{r\psi}=\mathrm{I_{su}^*}\, sign\left[\Psi_r^*-\Psi_r-\gamma_1 p\Psi_r\right], \quad (17)$$

where: $\gamma_1=T_l^{'}T_r/\left(T_l^{'}+T_r\right)$.

The level of limiting the reactive current of the stator is assumed to be equal $I_{su}^*=3I_{sun}=3\Psi_{\mathrm{rn}}/\mathrm{L_m}$. The nominal value of the magnetic flux module of the rotor is equal to:

$$\Psi_{rn}=\frac{U_s}{\omega_0\left(1+L_{s\sigma}/L_m\right)}, \quad (18)$$

where: U_s – stator voltage vector module; ω_0 – circular frequency of the power supply network.

The relay regulator of the active component of the stator current implements the algorithm

$$U_{rca}=U_m sign\left[\mathrm{U_{r\omega}}-I_{sv}\right]. \quad (19)$$

The relay speed regulator in the coordinate basis of the first derivatives implements the control algorithm

$$U_{r\omega}=I_{sv}^* sign\left[\omega_r^*-\omega_r-\gamma_2 p\omega_r\right], \quad (20)$$

where: $\gamma_2=L_s^{'}/R^{'}$; $I_{sv}^*=4\mathrm{M_{stn}}/3\mathrm{Nk_r}\Psi_{rn}$.

The vector control system is two-channel with the implementation of the method of subordinate control in each channel. The external adjustable variable in the active power channel is the speed, and in the reactive power channel – the modulus of the magnetic flux vector of the rotor.

To generate the task signal of the magnetic flux regulator of the rotor (17) by expression (15) it is necessary to estimate the moment of static load, which is not amenable to instrumental measurement. Therefore, it is necessary to use a monitoring device that identifies not only the variables of the state of the control object, but also inaccessible to direct measurement of external influences. The following system of equations, obtained by the method described in [21], determines the structure of the observation device and its algorithm:

$$\begin{aligned}
p\hat{\omega}_r &= \frac{3Nk_r\Psi_r}{2J}\hat{I}_{sv} - \frac{\hat{M}_{st}}{J} + k_1\left(I_{sv} - \hat{I}_{sv}\right);\\
p\hat{I}_{sv} &= -\frac{Nk_r\Psi_r}{L_s'}\hat{\omega}_r - \frac{R'}{L_s'}\hat{I}_{sv} + k_2\left(I_{sv} - \hat{I}_{sv}\right) -\\
&\quad -\frac{R_rk_rI_{sv}I_{su}}{\Psi_r} - N\omega_rI_{su} + \frac{U_{sv}}{L_s'};\\
p\hat{M}_{\mathrm{st}} &= \frac{3Nk_r\Psi_rb}{2J}\hat{I}_{sv} - \frac{b}{J}\hat{M}_{st} + k_3\left(I_{sv} - \hat{I}_{sv}\right).
\end{aligned} \tag{21}$$

Analytical expressions for coefficients of correction feedbacks:

$$\begin{aligned}
k_2 &= A_1\Omega_0 - \frac{R'}{L_s'} - \frac{b}{J};\\
k_1 &= \frac{3Nk_r\Psi_r}{2J} + \frac{bR'}{JNk_r\Psi_r} +\\
&+ \frac{bL_s'k_2}{JNk_r\Psi_r} - \frac{A_2\Omega_0^2L_s'}{Nk_r\Psi_r};\ k_3 = bk_1 + \frac{\Omega_0^3JL_s'}{Nk_r\Psi_r},
\end{aligned} \tag{22}$$

where: $b = \frac{2\left(M_{stn} - M_0\right)\omega_r}{\omega_{rn}^2}$ – coefficient that varies in proportion to the speed of rotation of the rotor; $\Omega_0 = (1 \div 2)Nk_r\Psi_r\sqrt{\frac{3}{2JL_s'}}$ – geometric mean root of the characteristic equation of the observation device; $A_1 = A_2 = 2$ – for distribution by Butterworth.

To correct the values of the state variables (CO), the moment-releasing component of the stator current I_{sv} is controlled, which is compared with a similar variable calculated $\hat{I}_{sv}$ by the observer, and their difference is fed through the blocks of corrective feedbacks to the inputs of the integrators of the observation device $\left(k_1, k_2, k_3\right)$ to adjust the observer parameters. As can be seen from formulas (22), the coefficients of corrective connections k_1, k_2, k_3 depend in the magnetic flux and rotor speed, and also depend on Ω_0 . The dynamic errors in estimating the state variables of the object will be smaller the larger the value Ω_0. However, the possibility of increase is limited because it causes an increase in the feedback coefficients CO, which will lead to fluctuations and further to the loss of stability of the automatic control information system (ACS) with the identification of the moment of static load.

The functional diagram of the information system of automatic control of asynchronous ED is shown in Fig. 4. It represents a relay vector control system of the AM with an additional self-tuning circuit based on the functional converter FC, which implements the dependence (15).

In the functional scheme it is possible to allocate power and regulating parts. The power part contains an asynchronous machine AM and a transistor converter TC. The control part includes a speed controller and regulators of states variable in the rotating frame of reference, the executive part of the ACS: coordinate transducers for communication parts of the control system synthesized in different reference systems, a calculation device for calculating variables entered into the controlled part of the ACS, speed sensors, currents and voltages. The control devices are a speed regulator (SR), a regulator of the modulus of rotor magnetic flux (FR), as well as regulators of reactive (RCR) and active (ACR) components of the stator current.

Consider the elements of the functional diagram designed to organize feedback in a rotating coordinate system. Signals from the sensors of the phase currents of the stator are fed to the phase converter PC3, which determines the projections of the vector of the stator current on the axis α, β by the ratio

$$I_{s\alpha} = I_{sA};\quad I_{s\beta} = \frac{1}{\sqrt{3}}\left(I_{sB} - I_{sC}\right). \tag{23}$$

The vector transformation subsystem includes a vector analyzer VA, designed to determine the modulus of the reference vector of the magnetic flux and its location in space in the form of sine and cosine guides.

The calculation of the modulus and the angle turn of the flow vector of the rotor is in the vector analyzer VA by the formulas:

$$\left|\vec{\Psi}_r\right| = \sqrt{\Psi_{r\alpha}^2 + \Psi_{r\beta}^2}\,;$$
$$\cos\delta = \frac{\Psi_{r\alpha}}{\left|\vec{\Psi}_r\right|}\; \sin\delta = \frac{\Psi_{r\beta}}{\left|\vec{\Psi}_r\right|}\,. \qquad (24)$$

The coordinate converter CC2 translates the stator current vector in the axes α,β in its projection on the coordinate axes u,v. Transformations are carried out by ratios

$$I_{su} = I_{s\alpha}\cos\delta + I_{s\beta}\sin\delta\,;$$
$$I_{sv} = I_{s\beta}\cos\delta - I_{s\alpha}\sin\delta\,. \qquad (25)$$

Coordinate converters CC1 and PC1 convert the control voltage vector $\vec{U}_s^*$ from the coordinate system u,v to the phase coordinate system ABC.

The transformations take place in two stages: first in CC1 the projections of the control voltage from the system u,v are converted into projections in a fixed coordinate system α,β according to the formulas

$$U_{s\alpha}^* = U_{su}^*\cos\delta - U_{sv}^*\sin\delta\,;$$
$$U_{s\beta}^* = U_{su}^*\sin\delta + U_{sv}^*\cos\delta\,. \qquad (26)$$

Next, in the PC1 coordinate converter transitions from a two-phase system of variables control voltages to control signals in the phase axes according to the expressions

$$U_A = U_{s\alpha}^*\,;$$
$$U_B = \frac{1}{2}\left(\sqrt{3}U_{s\beta}^* - U_{s\alpha}^*\right);$$
$$U_C = -\frac{1}{2}\left(\sqrt{3}U_{s\beta}^* + U_{s\alpha}^*\right). \qquad (27)$$

The following calculations are implemented in the PC2 coordinate converter

$$U_{s\alpha} = \frac{2}{3}\left(U_{sA} - \frac{1}{2}\left(U_{sB} + U_{sC}\right)\right);$$
$$U_{s\beta} = \frac{1}{\sqrt{3}}\left(U_{sB} - U_{sC}\right). \qquad (28)$$

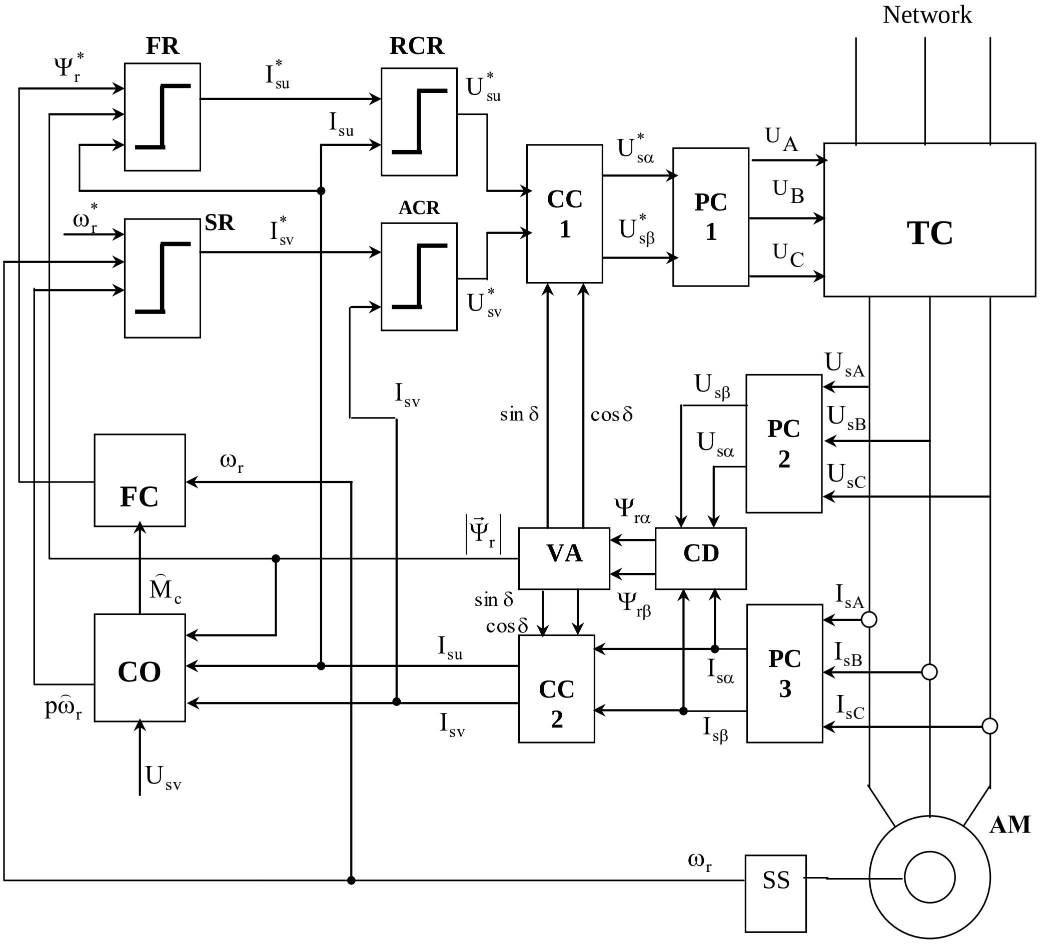

Fig. 4. Functional diagram of the information system of extreme vector control of an asynchronous electric drive

In the calculation device CD projections $\Psi_{s\alpha}$ and $\Psi_{s\beta}$ are defined by expressions

$$\begin{aligned}\Psi_{s\alpha} &= \int \left(U_{s\alpha} - \mathrm{R}_s I_{s\alpha}\right)dt;\\ \Psi_{s\beta} &= \int \left(U_{s\beta} - R_s I_{s\beta}\right)dt.\end{aligned} \tag{29}$$

Here is the definition of the projections of the magnetic flux vector of the rotor on the axis α, β by formulas

$$\begin{aligned}\Psi_{r\alpha} &= \frac{L_r}{L_m}\Psi_{s\alpha} - \frac{L_r L_s - L_m^2}{L_m} I_{s\alpha};\\ \Psi_{r\beta} &= \frac{L_r}{L_m}\Psi_{s\beta} - \frac{L_r L_s - L_m^2}{L_m} I_{s\beta}.\end{aligned} \tag{30}$$

The speed is measured by the speed sensor SS, the information from which is transmitted to the relay speed controller SR and to the functional converter FC.

In the simulation used passport data AM with a phase rotor type 4AK160S4U3, which is used as a short-circuited motor by closing the rotor rings: $P_n = 11kW$, $\mathrm{U}_{\mathrm{ln}} = 380V$, $I_{sn} = 22{,}4\,A$, $I_{rn} = 22\,A$, $\mathrm{n_s} = 1500$ rpm, $J_d = 0{,}125\,kg \cdot m^2$. The GTLF1-040 fan with power $9\,kW$ and moment of inertia $0{,}14\,kg \cdot m^2$ is accepted as the loading mechanism.

Fig. 5 shows the transients in the developed information system to minimize the consumption of reactive power by an asynchronous electric drive with vector control. For comparison, there are also transients in the classical vector control system with stabilization of the magnetic flux vector.

The dynamics of such electric drives at start-up to the nominal speed with two consecutive decelerations to lower speeds has been studied.

The ED state variable control subsystem is a two-channel vector control system with relay controllers that implement control algorithms (16), (17), (19), (20). The internal regulators of the active (19) and reactive (16) components of the stator current are subject to the speed regulators (20) and the modulus of the rotor magnetic flux vector (17), respectively. The external subsystem of extreme control consists of the identifier CO which calculates the moment of static loading, and the functional converter (15) which puts size of magnetic flux in functional dependence on the moment of loading on a shaft AM.

The method substantiated in the article minimizes the consumption of reactive power by the stator circuit of the AM and, therefore, increases the power factor of the ED. In a system with regulation of magnetic flux in all steady modes the smaller reactive current of a stator is consumed than in system with stabilization of flux coupling. It should be noted that in the nominal mode due to the positivity of the objective function of the reactive power in the vicinity of the extremum there is almost the same power factor for both systems, despite the fact that the magnetic fluxes are different. The positive effect from the extreme control is manifests itself in steady modes at speeds below nominal, when the moment of static load is also much less than nominal. In such modes, the power factor is significantly increased by reducing the reactive current of the stator and the reactive power consumed. The active component of the stator current increases, which indicates that the stator current vector rotates closer to the stator voltage. As can be seen, the redistribution of the components of the stator current is carried out in such a way that the reactive power reaches a minimum, which confirms the achievement of set goal.

Conclusions. The article solves the following problems:

1. Taking into account the phenomenon of saturation of the magnetic circuit, received expression of the reactive power of the AM (13) is obtained, which is accepted as a target function for extreme control of asynchronous ED.
2. As a result of solving equation (14) for the production mechanism with fan mechanical characteristics the values of magnetic flux of the rotor AM are found, at which the objective function (13) reaches a minimum. The dependences obtained in this way (Fig. 3) of the extreme values of magnetic flux from the moment of loading are best approximated by arctangent dependences with three parameters.
3. In the system of extreme control stepwise algorithms for finding the extremum of the objective function can be replaced by a functional converter that implements the expressions of the form (15) and is used in the construction of the extreme control system for achievement the minimum reactive power of the stator.
4. The efficiency of the developed system is confirmed by mathematical modeling taking into account the influence of the dynamics of the CO coordinate identifier on the speed control processes in order to minimize the consumption of reactive power from the power supply network under variable load moment on the AM shaft.

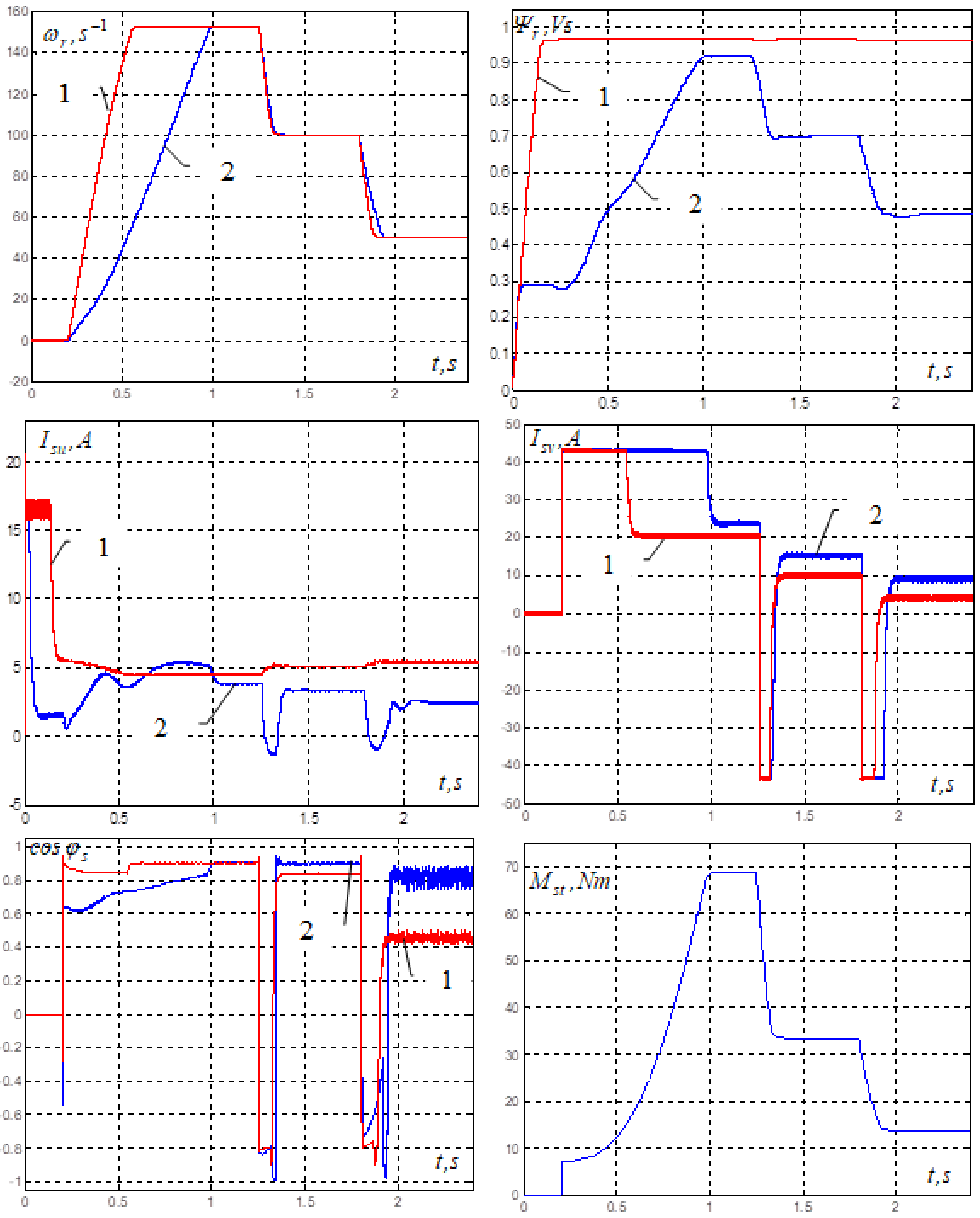

Fig. 5. Graphs of transients in an asynchronous electric drive with vector control:
1 – system with stabilization of magnetic flux at nominal level;
2 – system with a contour of extreme regulation of magnetic flux by the criterion of minimum reactive power of the stator circuit

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ІНФОРМАЦІЙНА СИСТЕМА МІНІМІЗАЦІЇ СПОЖИВАННЯ РЕАКТИВНОЇ ПОТУЖНОСТІ АСИНХРОННИМ ЕЛЕКТРОПРИВОДОМ З ВЕКТОРНИМ КЕРУВАННЯМ

Анотація. *Відомо, що енергетичні показники асинхронних електроприводів мають екстремальний характер. Однак при стабілізації потокозчеплення асинхронної машини на номінальному рівні і зменшенні моменту навантаження на валу коефіцієнт потужності стає менше номінального, і це зменшення може бути значним. Тому в роботі пропонується поліпшити енергетичні показники асинхронних електроприводів з вентиляторною механічною характеристикою виробничого механізму шляхом зміни потокозчеплення в функції моменту сил опору на валу асинхронної машини. Таким чином, для оптимізації енергетичних процесів в електроприводі при регулюванні продуктивності турбомеханізмів необхідно побудувати систему з незалежним керуванням швидкістю і потокозчепленням асинхронної машини. Оскільки системи керування турбомеханізмів призначені для стабілізації швидкості в тривалих режимах роботи, то в першу чергу необхідно забезпечити граничні енергетичні показники в сталих режимах експлуатації. У даній роботі підвищення енергоефективності досягається при реалізації векторної полеорієнтованої системи керування асинхронною машиною з додаванням до її складу контуру екстремального регулювання. У статті розроблена інформаційна система двоканального векторного керування асинхронним електроприводом з вентиляторним моментом навантаження, яка містить в своєму складі контур екстремального регулювання за критерієм мінімуму споживання реактивної потужності. Обґрунтована залежність екстремальних для функції реактивної потужності значень потокозчеплення ротора головним чином від моменту навантаження і незначна від швидкості. Синтезований спостерігач стану, який оцінює момент статичного навантаження, необхідний для визначення екстремальних значень потокозчеплення ротора на підставі отриманої функціональної залежності. Таким чином, ідея роботи полягає в тому, щоб використовувати канал реактивної потужності асинхронної машини не для стабілізації потокозчеплення, як це було в класичних системах векторного керування, а для регулювання модуля вектора потокозчеплення ротора в функції моменту статичного навантаження за критерієм мінімуму реактивної потужності статора. Було розроблено математичну модель у середовищі Matlab/Simulink і шляхом математичного моделювання підтверджена працездатність синтезованої інформаційної системи мінімізації споживання реактивної потужності асинхронним електроприводом з векторним керуванням.*

Ключові слова: *асинхронна машина; орієнтація за вектором; цільова функція; закон керування; спостерігач стану; функціональнй перетворювач; реактивна потужність*

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ИНФОРМАЦИОННАЯ СИСТЕМА МИНИМИЗАЦИИ ПОТРЕБЛЕНИЯ РЕАКТИВНОЙ МОЩНОСТИ АСИНХРОННЫМ ЭЛЕКТРОПРИВОДОМ С ВЕКТОРНЫМ УПРАВЛЕНИЕМ

Аннотация. *Известно, что энергетические показатели асинхронных электроприводов имеют экстремальный характер. Однако при стабилизации потокосцепления асинхронной машины на номинальном уровне и уменьшении момента нагрузки на валу коэффициент мощности становится меньше номинального, и это уменьшение может быть значительным. Поэтому в работе предлагается улучшить энергетические показатели асинхронных электроприводов с вентиляторной механической характеристикой производственного механизма путём изменения потокосцепления в функции момента сил сопротивления на валу асинхронной машины. Таким образом, для оптимизации энергетических процессов в электроприводе при регулировании производительности турбомеханизмов необходимо построить двухканальную систему с независимым управлением скоростью и потокосцеплением асинхронной машины. Поскольку системы управления турбомеханизма-*

ми предназначены для стабилизации скорости в длительных режимах работы, то в первую очередь необходимо обеспечить предельные энергетические показатели в установившихся режимах эксплуатации. В данной работе повышение энергоэффективности достигается при реализации векторной полеориентированной системы управления асинхронной машиной с добавлением в её состав контура экстремального регулирования. В статье разработана информационная система двухканального векторного управления асинхронным электроприводом с вентиляторным моментом нагрузки, содержащая в своём составе контур экстремального регулирования по критерию минимума потребления реактивной мощности. Обоснована зависимость экстремальных для функции реактивной мощности значений потокосцепления ротора главным образом от момента нагрузки и незначительная от скорости. Синтезирован наблюдатель состояния, оценивающий момент статической нагрузки, необходимый для определения экстремальных значений потокосцепления ротора на основании полученной функциональной зависимости. Таким образом, идея работы состоит в том, чтобы использовать канал реактивной мощности асинхронной машины не для стабилизации потокосцепления, как это было в классических системах векторного управления, а для регулирования модуля вектора потокосцепления ротора в функции момента статической нагрузки по критерию минимума реактивной мощности статора.

Ключевые слова: *асинхронная машина; ориентация по вектору; целевая функция; закон управления; наблюдатель состояния; функциональный преобразователь; реактивная мощность*

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