Frequency control of asynchronous motor for an irrigation pump of machine irrigation systems

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Abstract. The working state of freguency-operated asinchronous motor of irrigation pump in the closed system with feedback by velocity are considered. The system issue coefficient, provided a constancy of given value, loading coefficient of motor for voltage control pro rata control freguency are determined. Let us consider the static mode of operation of a frequency-controlled AM in a closed system with speed feedback. A decrease in the rotation speed in irrigation pumps to regulate their productivity is possible up to a certain minimum value, at which the pump head (H) becomes equal to the static head (H_{st}). The pump output (Q) then drops to zero. The value "k" has been determined, which ensures the constancy of the AM overload factor over the entire range of control frequency change in a closed-loop frequency control system with feedback on the engine speed.

1 Introduction

The Action Strategy for the Priority Areas of Development of the Republic of Uzbekistan for 2017-2021 defines the tasks of "... reducing the energy and resource intensity of the economy, the widespread introduction of energy-saving technologies into production according to the target parameters for reducing energy intensity in sectors of the economy" [1]. The implementation of these tasks, including the development and introduction of frequency-controlled electric drives, and the development of scientifically based decisions for building systems of a frequency-controlled electric drive for a pumping station, taking into account the technological regime of water supply and the rational use of water and energy resources, is relevant and of great practical importance.

This article, to a certain extent, serves to fulfill the tasks provided for in the Decrees of the President of the Republic of Uzbekistan No.PP-3012 dated May 26, 2017 "On the program of measures for the further development of renewable energy, energy efficiency in the sectors of the economy and the social sphere for 2017-2021", No. PP-3238 of August 23, 2017 "On measures for the further introduction of modern energy-efficient and energy-saving technologies" and Resolution of the Cabinet of Ministers of the Republic of Uzbekistan

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No.1042 of December 26, 2018 "On measures for the phased modernization and replacement of physically and morally obsolete pumping stations, automation of operation and management of pumping stations of organizations in the system of the Ministry of Water Resources of the Republic of Uzbekistan", as well as in other legal documents adopted in this area [2,3].

2 Research methods

The methodological provisions are based on the results of theoretical and practical research, in a broad generalization of practical experience in assessing the total energy intensity of products, scientific works of Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University and the Institute of Energy Problems of the Academy of Sciences of the Republic of Uzbekistan. Practical research was carried out using standard and special developed techniques, the reliability of the results was evaluated by verifying the research results.

3 Results and discussion

The mode of operation of an asynchronous motor (AM) in the system of an electric drive with frequency control is determined by the mutual change of the following interconnected parameters: input parameters - frequency and voltage; stator and rotor internal currents, flux and absolute slip parameter; output parameters – rotation speed and torque of the shaft. The values of the input parameters - frequency and voltage must be changed in such a way that the specified speed is provided at any moment of resistance on the shaft under the effect of internal parameters.

The voltage to frequency ratio determines the law of frequency control.

Known laws of control of the voltage to frequency ratio are mainly investigated based on the principle of control in an open-circuit system. In such an open-circuit frequency control system, as the control frequency decreases, the flux, maximum torque, mechanical stiffness, and motor control range decrease [4,5].

In a closed-loop control system, the voltage to frequency ratio in the sense it is understood in an open-circuit system is of no practical importance, since it ignores the real feedback of the system and the limitations of its amplification gain [4,6].

Let us consider the static mode of operation of a frequency-controlled AM in a closed system with speed feedback. The block diagram of such a closed system is shown in Fig. 1. Here FrC, FContr., VR, FuncC and P are the frequency converter; frequency controller; voltage regulator; functional converter and pump; K_f and $K_{дf}$ are the transmission coefficients of the FC and AM over the frequency channel; K_γ and $K_{д\gamma}$ - are the transmission factors of the FC and AM over the voltage channel; $K_{фп}$ and K_{oc} are the transmission factors of the FC and the speed meter; $U_з$ – is the voltage setting the rotation speed of the AM [7,8,9]; U_{yf} and $U_{y\gamma}$ are the control voltages for frequency and voltage channels; U_{oc} is the feedback voltage; ω, ω_o and Δω are the angular velocities of rotation of the rotor, stator fields and absolute slip of AM; $F=F/F_н$ and $\gamma=U/U_н$ are the relative frequency and voltage.

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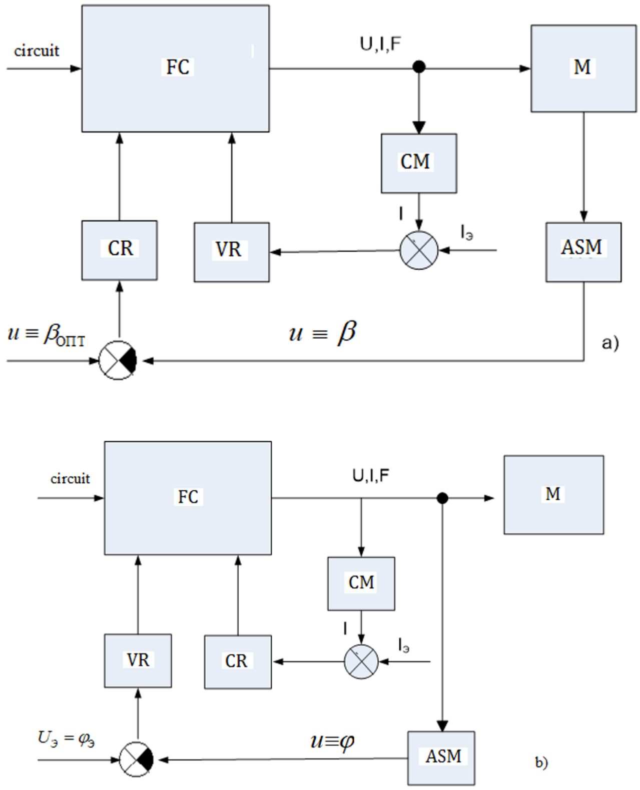

Fig. 1. Block diagrams of the frequency start system using the absolute slip parameter (a) and the angle φ (b).

Figure 1 shows block diagrams of the frequency start system using the absolute slip parameter (a) and the angle meter between current and voltage (b). Here: FC - frequency converter, M - motor, CR and VR - current and voltage regulators, CM and ASM - current and absolute slip meters, and $I_э$ and $\varphi_э$ - reference values of current and angle between current and voltage of the motor.

The first scheme contains two closed current control systems and absolute slip parameters.

According to the figure, the AM transmission coefficient over the voltage channel is [5,10]:

$$K_{Д\gamma} = \frac{\Delta\omega}{U_{н}\gamma} = \frac{\omega_{он}}{U_{н}\gamma} S \tag{1}$$

where *S* is the relative slip of the AM.

As seen from (1), the transmission coefficient $K_{Д\gamma}$ is variable and depends on S and frequency to voltage ratio.

In [11,12,13,14], it is shown that to control the performance of an irrigation pump, it is appropriate to control the voltage in proportion to the frequency, that is, γ=F. In this case, the FC characteristic is linear, and (1) is written up to accuracy to a slip in the form

$K_{ДУ}=\omega_{он}S_{н}/U_{н}$=const. Thus, the given values of all the transmission coefficients of the system are constant.

The control frequency channel determines the synchronous angular velocity, and the voltage channel determines the absolute slip of the motor. The difference ω_o-$\Delta\omega$ gives the angular velocity of rotation of the AM shaft. A feature of this system is that the motor rotation speed through the feedback circuit simultaneously affects the frequency and voltage [15,16,17].

Note that when regulating the necessary ratio between frequency and voltage with the FuncC, in the general case, frequency and voltage can be taken as initial parameters. However, from the point of view of the influence of disturbances in the supply network and the load on the engine speed, a system in which the initial parameter is frequency, and the voltage is regulated as a function of frequency, will be a more rational one. In such a system, the dynamic change in rotation speed is less since the rotation speed of the motor depends primarily on the frequency, determined by the inverter control system and does not depend on disturbances in the supply network and load; the voltage is a parameter determined not only by the inverter control system but also by the entire power circuit. That is why in the closed system presented, the frequency is the initial parameter [18,19].

According to the figure, the angular velocity of rotation of the motor is $\omega=KU_3$,

where
$$K=\frac{K_f K_{\partial f}-K_{фп}K_\gamma K_{l\gamma}}{l+(K_f K_{\partial f}-K_{фп}K_\gamma K_{l\gamma})K_{oc}} \tag{2}$$

is the transmission coefficient of a closed system. Here, the given constant values of coefficients K_f, K_γ, $K_{фп}$, K_{oc} can be selected based on the required conditions set for the system, and the remaining coefficients are constant [18,20].

Let us find the transmission coefficient of a closed-loop system with speed feedback so that the AM overload coefficient in this system in the operating range of rotation speed control from F_{min} to F=1 of the pumping unit is not lower than the nominal overload coefficient ($\lambda_н$) of the motor in the natural circuit of switching. To do this, it is necessary, first, to find the minimum frequency and torque of the motor [21,22,23].

A decrease in the rotation speed in irrigation pumps to regulate their productivity is possible up to a certain minimum value, at which the pump head (H) becomes equal to the static head (H_{st}). The pump output (Q) then drops to zero. Based on this condition, we determine, up to slip, the minimum control frequency [21,24,25]:

$$F_{\min}=\sqrt{\frac{H_{cm}}{H_o}} \tag{3}$$

where H_o – is the head for Q=0 and $\omega=\omega_н$.

The AM torque at the applied frequency, obtained on the basis of the T-shaped equivalent circuit, taking into account (2) for γ=F, is written as

$$M=\frac{K_{\rm M} r_2^{`} X_{\mu\rm H}^2 (F-\beta)}{KU_3\beta D^2} \tag{4}$$

where $$D=\sqrt{\left(\frac{r_1r_2^`}{F\beta}-X_sX_r\sigma\right)^2+\left(\frac{r_2^`}{\beta}X_s+\frac{r_1}{F}X_r\right)^2} \tag{5}$$

$X_s=X_{1н}+X_{\mu н}$; $X_r=X^`_{2н}+X_{\mu н}$ ; $\sigma=1-X^2_{\mu H}/X_sX_r$; $r^`_1$ and $X^`_{1н}$ are the active and nominal inductances of the phase of the stator winding; $r^`_2$ and $X^`_{2н}$ are the active and nominal inductances of the phase of the rotor winding; $X_{\mu н}$ – is the nominal inductance of the magnetizing circuit [26,27,28,29]; β=FS is the absolute slip parameter; $K_м=mU_н/9{,}81$; m is the number of phases.

Exploring (4) to the maximum, we obtain

$$a\beta^2+b\beta+c=0 \tag{6}$$

Where

$$a=\left[\left(\frac{r_1}{F}\right)^2+(X_s\sigma)^2\right]X_r^2+2r_1r_2^`X_{\mu н}^2/F^2$$

$$b=2\left[\left(\frac{r_1}{F}\right)^2+X_s^2\right]r_2^`/F, \qquad c=-Fb/2$$

From (6) we determine the critical value of the absolute slip parameter

$$\beta_{k1,2}=\frac{b}{2}\left(-1\pm\sqrt{\frac{1+2aF}{b}}\right) \tag{7}$$

As seen from (7), the roots of (6) are positive. The positiveness condition of the required real root (the critical value of the absolute slip parameter is found) if the sign in front of the radical is positive [30,31,32,33,34,35], is

$$\beta_k=\frac{b}{2}\left(-1+\sqrt{\frac{1+2aF}{b}}\right). \tag{8}$$

Introducing this expression into (4) instead of β, we find the maximum torque (M_k) of the motor.

The overload coefficient of AM at the minimum control frequency is:

$$\lambda_{(F=F\min)}=\frac{M_{k(F=F\min)}}{M_н} \tag{9}$$

where $M_н$ is determined from (4) for F=1 and $\beta=S_н$.

From the condition $\lambda_{(F=F\min)}=\lambda_н$, we obtain

$$k=\frac{S_H D_H^2\left[F_{\min}-\beta_{k(F=F\min)}\right]}{\gamma_3\lambda_H(1-S_H)D^2_{(F=F\min)}\beta_{k(F=F\min)}} \tag{10}$$

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where $\gamma=U_3/U_{3н}$ and $k=K/K_н$ are relative voltage and transmission coefficient of the system closed in speed; $\lambda_н$ is the nominal overload coefficient of AM in an open-loop system, determined from the catalog; $D_н$ is determined from (5) for F=1 and $\beta=S_н$.

4 Conclusion

Thus, according to (10), the value of *"k"* is determined, which ensures the constancy of the AM overload coefficient over the entire range of control frequency change in a closed-loop frequency control system with feedback on the motor speed.

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