

Doubly fed induction motors control in positional electrical drives

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Abstract. The article discusses the phase control of doubly fed induction motors for positional electric drives and an assessment of their capabilities. The advantage of all variants of such control is the possibility of fixing the rotor position even in open systems when the windings are powered with nominal voltages and high smoothness of movement at very low speeds. The proposed methods for implementing the phase control of the doubly fed induction motors open up wide possibilities for solving specific problems of developing positional electric drives, providing high dynamic, accuracy and weight and dimensions rates.

1. Introduction

Increasing the requirements for technical and operational characteristics of critical installations, including spacecraft, leads to the need to improve the electromechanical systems used in them. One of the directions of such improvement is the use of AC motors, including doubly fed motors (DFM).

In DFM can be used as all known methods of control of AC motors, and methods that are specific to dual power supply and provide new useful properties to the electric drive.

One of the specific ways to control DFM is phase control. Its application reveals fundamentally new possibilities for using DFM in positional systems, ensuring the achievement of high dynamic and accuracy rates. This paper discusses the general properties and capabilities of the proposed method.

DFIM are a type of inductor motors (electromagnetic reduction motors), which are currently widely used, usually in the form of valve inductor motors, in which the windings are located on the stator, and the winding-free rotor has teeth interacting with the stator teeth. Induction valve motors have one multi-phase winding on the stator, while the DFIM on the stator has two multi-phase windings. The numbers of pairs of poles of the windings differ even number of times, therefore the energy connection between them is carried out not along the main, but by the tooth harmonic of the field. The combination of the principles of dual power supply and electromagnetic reduction in the DFIM provides for the unique functionality of the electric drive based on them.

In modern electromechanical systems, closed-loop control systems are commonly used to improve accuracy [1-4]. At the same time, for some critical installations (for example, for spacecraft) the use of additional elements (in particular, sensors) is not always desirable from the point of view of mass and dimensional parameters and reliability. Therefore, if possible, it is desirable to create open-loop systems or closed, but with a minimum of sensors and mechanical gears. Most motors can't work in positional systems without feedback on the angle of rotation, as they begin to rotate when voltage is applied. The exceptions are stepper motors and dual power motors. The latter, like stepper motors, make it possible to control directly the angle of rotation of the rotor, which, if necessary, can be provided by open-loop control systems.



2. DFIM phase control

The phase control considered in this article is that both windings of the DFIM are powered by alternating current voltages of the same frequency, and then the phase shifts of one or both voltages change. This causes the rotor to move in the right direction. It is possible to build both open and closed positional (including tracking) systems.

The advantage of all variants of such control is the possibility of fixing the rotor position even in open systems when the windings are powered with nominal voltages and high smoothness of movement at very low speeds.

Options of phase control which differ in ways of formation and change of phases, discretization of movements of a rotor are given below.

A generalized block diagram of the DFIM phase control is shown in Figure 1.

The windings of DFIM are connected to two independent voltage (or current) inverters, which form two systems of multiphase voltages (currents).

The frequencies of their first harmonics ω_1 and ω_2 are set for both windings are the same, and the amplitudes U_{1m} and U_{2m} are determined by the technical characteristics of the engine and may vary. The phases of both voltages ε_1 and ε_2 are determined by the technical characteristics of the engine and may vary. The phases of both voltages are set by the appropriate regulators depending on the desired angle of movement of the rotor θ_z , from which the reference signals of these phases ε_{1z} and ε_{2z} are formed. Regulators are dynamic links, the structure and parameters of which are selected taking into account the dynamic properties of the motor (for example, its transfer functions).

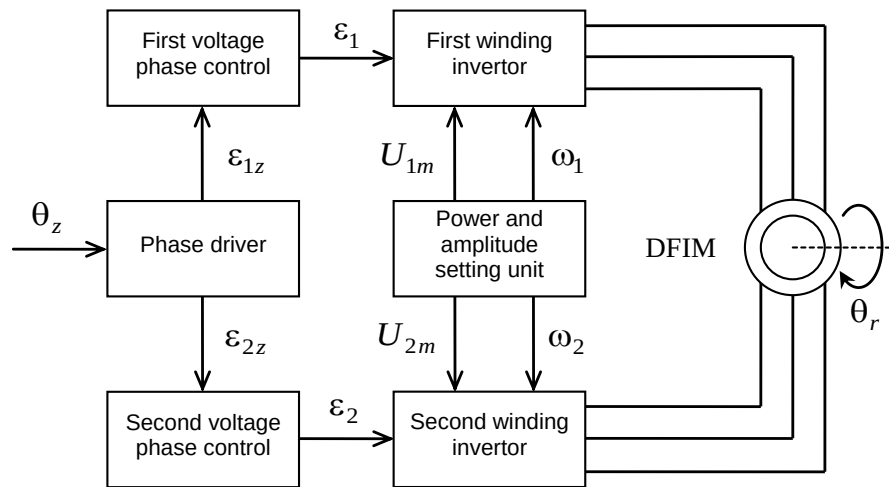


Figure 1. Generalized block diagram of the DFIM phase control.

Mathematical justification of the proposed method of regulation is as follows. The expression for the rotation angle is:

$$\theta_r = \frac{\theta_M + (\theta_1 - \theta_2) + (\varepsilon_1 - \varepsilon_2)}{Z_r},$$

where indexes 1 and 2 correspond to the values of the first and second windings; θ_M — load angle; Z_r — the number of teeth of the rotor; $\theta_1 = \omega_1 t$, $\theta_2 = \omega_2 t$ — current phase shifts of supply voltages; ω_1 , ω_2 — the angular frequency of the supply voltage; t — time.

DFIM is in the mode of synchronous standing, for which the condition is satisfied $\omega_1 = \omega_2$, therefore, always $(\theta_1 - \theta_2) = (\omega_1 - \omega_2)t \equiv 0$ and therefore

$$\theta_r = \frac{\theta_M + (\varepsilon_1 - \varepsilon_2)}{Z_r}.$$

In DFIM, as in all synchronous motors, the auxiliary adjustable parameter is the load angle. In addition to phases, other variables of the alternating voltage — amplitudes and frequencies — can also be control variables.

Among the varieties of phase control can be distinguished phase-independent and phase-dependent control. Phase-independent control will be called such control, in which the phase shifts of both supply voltages do not depend on the rotation parameters of the DFIM (speed and angle of rotation) and are specified from the outside. Then the mathematical representation of the phase-independent control for the DFIM has the form:

$$\begin{aligned}\theta_r(t) &= f[\varepsilon_1(t), \varepsilon_2(t), \theta_M(t)], \\ \theta_M(t) &= f[\omega_1(t), \omega_2(t), U_{1m}(t), U_{2m}(t), M_s(t)],\end{aligned}$$

where the dependence of the load angle on the frequency (the same for both windings) and the amplitudes of the main harmonic of the supply voltages is highlighted.

Phase-dependent control will be called control, in which the phase shifts (one or both) depend on the angle of rotation of the rotor. Then the mathematical representation of the phase-dependent control for the DFIM has the form:

$$\begin{aligned}\theta_r(t) &= f[\varepsilon_1(t), \varepsilon_2(t), \theta_M(t), \theta_r(t)], \\ \theta_M(t) &= f[\omega_1(t), \omega_2(t), U_{1m}(t), U_{2m}(t), M_s(t), \theta_r(t)],\end{aligned}$$

where additionally taken into account the dependence of adjustable values on the angle of rotation of the rotor θ_r , which implies the presence of positive feedback.

It is necessary to distinguish the motor control method and the automatic control system of the electric drive using appropriate regulators - in the latter case, more complex feedbacks are possible, including current, angular velocity, load angle, etc [5]. In this paper, only control methods are considered.

3. Discrete-phase DFIM control with pulse-width modulation by sinusoidal law

For modern digital control systems, the most convenient is the discrete-phase method. It lies in the fact that pulse-width modulation (PWM) is used to form sinusoidal currents in the windings, during which the period of the main harmonic of the supply voltage to be obtained is divided into phase intervals. At each interval, a pulse is formed with a duty ratio proportional to the instantaneous value of the sinusoid for a given value of the phase interval (figure 2).

Thus, it is possible to choose which phase interval should be formed at the moment. For example, you can instantly go from the phase interval $j = 1$ to the interval $j = 5$, and then continue the normal formation of voltage at subsequent intervals $j = 6$, $j = 7$ etc. Therefore, you should have a system for generating pulses with an arbitrary setting of the desired phase shift interval at any time.

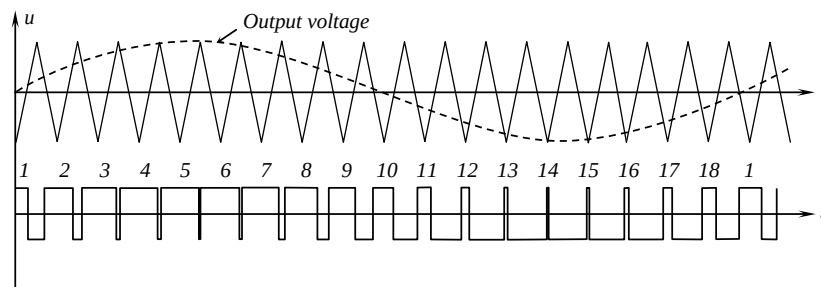


Figure 2. Discrete formation of phase shifts.

Phase control (and, therefore, the angle of rotation of the rotor) is carried out in this case discretely and the DFIM operation resembles the operation of a stepper motor. The minimum value of the discrete angular rotation of the rotor α is determined by the magnitude of the phase interval on which the pulse is formed:

$$\alpha = \frac{2\pi}{NZ_r},$$

where N — the number of phase discretely in the period of the generated voltage.

4. Discrete-phase DFIM control with different number of discretely for the first and second windings

Typical DFIM value of angular discrete α is tens of angular minutes or less. In particular, for one of the variants of the developed electric drive with $N = 24$ and $Z_r = 42$ $\alpha = 21'$. These small discrete values are provided mainly due to electromagnetic reduction. But you can get even smaller values of the angular discretely. For this purpose it is possible to use various number of discretely for the first and second supply voltages. In this case, the value of the angle samples:

$$\alpha = \frac{2\pi}{Z_r} \left(\frac{1}{N_1} - \frac{1}{N_2} \right),$$

where N_1, N_2 — the number of phase discretely of the first and second supply voltages respectively.

The number of discretely may be limited by various considerations. For example, often to ensure ideal symmetry of phase voltages, the number of intervals N is chosen as a multiple of the number of phases m . Sometimes an even number of discretely is additionally required for the symmetry of each voltage relative to 180° . In one of the variants of the electric drive, taking into account such restrictions, it was obtained with $m = 3$, $N_1 = 24$, $N_2 = 36$ and with simultaneous increase in both phase shifts for the DFIM with $Z_r = 42$ $\alpha = 0,12^\circ$. If these restrictions are absent, it is possible to implement the Nonius principle by setting the difference between the numbers of phase intervals to be 1, i.e. $N_2 = N_1 + 1$. Therefore, the minimum angular discrete will be:

$$\alpha_{\min} = \frac{2\pi}{Z_r} \cdot \frac{1}{N_1(N_1 + 1)},$$

that at $Z_r = 42$, $N_1 = 24$, $N_2 = N_1 + 1 = 25$ gives $\alpha_{\min} \cong 0,014^\circ$.

Thus, this method allows to obtain very small step values, provided that the DFIM has a symmetrical system of windings and supply voltages.

5. Regulation of the load angle with phase control

The expressions for the angle of rotation of the rotor with phase control include the angle of the load, which affects the stability of the entire electric drive, and can also affect the control accuracy in open and sometimes in closed systems [6]. Therefore, it is possible to provide in the electric drive with the DFIM the control loops of the load angle using the amplitudes of the supply voltages and leaving their frequencies unchanged. The possibility of such regulation follows from the expression for the angle of load:

$$\theta_{M0} \cong -\frac{\sigma L_1 L_2 \omega_{1.0} \omega_{2.0}}{L_m U_{1m0} U_{2m0}} \arcsin(M_{s0}),$$

where the sign “0” indicates the steady state values; M_{s0} — steady state (average) value of the static moment; L_1 , L_2 , L_m — own and mutual inductances of the windings (after bringing them to a two-

phase machine); $\sigma = 1 - \frac{L_m^2}{L_1 L_2}$.

DFIM has a unique opportunity to adjust the load angle by synchronous changing of both frequencies at constant amplitudes of the first harmonics of the supply voltages. In conventional engines the angular velocity of the rotor also changes simultaneously with the angle of load, which makes it impossible to use this method.

6. Conclusion

A new direction in the creation of automated electric drive systems for positional electromechanical systems with the use of DFIM phase control. The variety of possibilities provided in this case allows relatively simple means to achieve results that are not available or difficult to achieve for other ways to control AC motors. The developed methods of implementation of the phase control of the DFIM open up wide possibilities for solving specific problems of the development of positional electric drives providing high dynamic, precision and mass-dimensional rates.

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