Electric drives on the basis of doubly fed induction motor

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Abstract. The article describes the design and principle of operation of a doubly fed induction motor, which is a special class of electrical machines that combine two principles – electromagnetic reduction and doubly fed. The methods of control of this motor are listed. Doubly fed induction motor have six control actions, which allows by their combination to create electric drives with different functional properties and principles of construction. A general assessment of the properties and capabilities of an electric drive on the basis of doubly fed induction motor is given.

1. Introduction
Doubly fed induction motors (DFIM) are a special class of electric machines that combine two principles – electromagnetic reduction and doubly fed. Both of these principles are used to create traditional electric motors [1-6].

The principle of electromagnetic reduction is implemented in synchronous motors with electromagnetic reduction, which are currently widely used in special technology. The principle of doubly fed is used in electric drives based on asynchronous motors with a phase-rotor [7-12].

Each principle has its own positive properties, but in the DFIM they successfully complement each other and give a new positive effect with regard to low-power executive electric drives with high demands on smooth rotation at low speeds. In this case, you can reduce the size of the mechanical gearbox or completely abandon it [13-16].

DFIM have six control actions, which allows by their combination to create electric drives with different functional properties and principles of construction.

2. The design and principle of operation of the DFIM
Doubly fed induction motors is a special class of electromagnetic machines with electric reduction. Currently, this class has a name: inductor motors.

A feature of the stator is that the grooves in which the winding fits have pronounced teeth on the side of the air gap (Figure 1).

The surface of the rotor in the area of the air gap also has clearly protruding teeth.

The presence of teeth in the stator and rotor is fundamentally necessary to ensure the efficiency of the induction motor.
In grooves on the stator of the DFIM there are two three-phase windings, which are powered by their own three-phase AC voltage systems. Each winding generates its own electromagnetic field, which rotates at a frequency equal to the supply frequency of the corresponding voltage.

Both electromagnetic fields exist in the common space of the electric machine (magnetic core and air gap) and therefore are mixed. As a result, a common electromagnetic field is formed, which rotates with a difference frequency:

$$\omega_{\mu} = \omega_1 - \omega_2 = 2\pi f_1 - 2\pi f_2 = 2\pi(f_1 - f_2)$$  \hspace{1cm} (1)

where $\omega_{\mu}$ – the angular velocity of the rotating electromagnetic field; $\omega_1$ – angular frequency of the supply voltage of the first winding, rad/s; $\omega_2$ – the angular frequency of the supply voltage of the second winding, rad/s; $f_1$ – frequency of the supply voltage of the first winding, Hz; $f_2$ – frequency of supply voltage of the second winding, Hz.

Rotor speed:

$$\omega_r = \frac{\omega_{\mu}}{Z_R} = \frac{\omega_1 - \omega_2}{Z_R} = \frac{2\pi f_1 - 2\pi f_2}{Z_R} = 2\pi \frac{f_1 - f_2}{Z_R}$$  \hspace{1cm} (2)

where $\omega_r$ – the angular velocity of the rotor of the engine; $Z_R$ – the number of teeth of the rotor.

At DFIM there are two multi-phase windings on the stator, which are powered by the corresponding multi-phase AC voltages. For interaction between the stator windings, the air gap properties are used. The number of teeth of the stator and rotor cannot be arbitrary, their ratio is determined by the appropriate formulas for various variants of the design DFIM. As a result, the teeth of the stator and the rotor are always offset relative to each other.

Figure 2 shows the conductivity between the stator and rotor teeth. As a result, pulses of different widths are obtained. This pulse shape can be approximated by a sinusoidal one. An important condition is that the maximum of the magnetic conductivity should differ as much as possible from its minimum. This is achieved by reducing the air gap between the stator and the rotor.
3. Basic Methods of control of the DFIM

DFIM by its nature is a synchronous machine. But like all synchronous machines, it can be used both in the synchronous motor mode and in the mode of the brushless DC motor.

DFIM can be controlled by changing the parameters of the supply voltage: frequency, amplitude and phase. Thus, there are 3 basic methods of control: frequency, amplitude and phase. Since the DFIM has two windings, there are 6 control actions.

Frequency control directly follows from the equation (2) for the rotor frequency.

There are various options for changing the frequency of the supply voltage: joint and separate.

Amplitude control implies a change in the amplitudes of the supply voltages.

Phase control is a specific feature of doubly fed motors (including DFIM). Its possibility follows from the equation (2) for the rotational speed, if we integrate the right and left sides of this equation:

$$\theta_r(t) = \theta_1(t) - \theta_2(t)$$

(3)

where $\theta_r$ – the angle of rotation of the rotor; $\theta_1$, $\theta_2$ – current phase shifts of the first and second supply voltages.

Phases $\theta_1$ and $\theta_2$ can be forced to change the analog and discrete (with digital control) method. Phase control allows, in particular, to provide direct control of the angle of rotation without rotor position sensor.

In real control systems, all control methods can be combined depending on the purpose of the drive.

In terms of control capabilities, the DFIM is the most functional among electric motors.

4. General assessment of the properties and capabilities of the DFIM

DFIM has a number of specific properties, which in some cases can have a positive effect. There are three groups of properties:

1) Properties due to the design. Both windings are located on the stator and thus a good heat dissipation is achieved compared to those motors in which one of the windings is located on the rotor. This allows you to choose large values of currents and increase the electromagnetic moment. There are no permanent magnets in the DFIM, which makes it possible to guarantee characteristics that can be changed in permanent-magnet motors due to demagnetization of the magnets.

2) Properties due to the effect of doubly fed. Doubly fed leads to the fact that the rotational speed of the rotor is not proportional to the power frequency of any one winding, but the difference of two frequencies in accordance with equation (2). This makes it possible to obtain very small rotational speeds with significant but close supply frequencies. Doubly fed is important for smooth rotation. Usually, motors are powered by pulsed voltage, for example, using pulse-width modulation (PWM). In single fed motors, the fed frequency is proportional to the rotational speed, and a low fed frequency is specified for low rotational
frequencies. As a result, single fed motors at low frequencies move impulsively (“walk”). But doubly fed motors have significantly smoother rotation.

3) Properties due to the effect of electromagnetic reduction. The effect of electromagnetic reduction is due to the fact that the interaction between the first and second stator windings is due to the movement of the rotor teeth relative to the stator teeth. The angular velocity of the rotor is less than the angular velocity of the magnetic field in the number of teeth of the rotor times according equation (2). At the same time, the electromagnetic moment increases. This effect is called electromagnetic reduction. In some cases, it is possible to create fully gearless electric drives, and in some cases, with a reduced size of mechanical gearbox. In both cases, the reliability of the electric drive associated with mechanical parts is significantly increased.

5. Conclusions
DFIM have a set of specific properties that provide ample opportunities for the construction of executive electric drives of different function. The main advantage of DFIM is the ability to provide low stable rotational speeds without the use of a mechanical gearbox. The simplicity of the design makes it possible to manufacture the DFIM for a specific product.

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