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Ways to Improve the Energy Efficiency of an Electric Drive with Asynchronous Motors.

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Abstract — *This article discusses the analysis of frequency control systems for asynchronous electric motors*

Keywords —asynchronous motor, half-phase operation mode, vector control of the electric drive, torque control, direct torque control.

Introduction

One of the most important tasks of a modern electric drive (ED) is to ensure the energy efficiency of its operation. Research in the field of creating energy-saving algorithms in electric drive control systems is very relevant today. There are the following ways to save energy in an electric drive:

1. First of all, it is a competent choice of an electric motor (EM) in terms of heating and power. After all, most of the mistakes are made precisely at this stage of the development of an electric drive, when the ED load factor is about 50% or less;

2. It is also the modernization of the design and materials of the ED, as well as an increase in the amount of active materials, which can significantly increase the efficiency;

3. Transition to frequency-controlled electric drive;

4. Improving the structure and algorithms of frequency control systems

- regulated EP.

As basic electric drive control systems, on the basis of which
in the future, energy-efficient algorithms are implemented, mainly scalar or relay-vector systems are used.

Materials and methods

So, for example, in work [2] a method for achieving energy saving of an asynchronous electric drive in a scalar control system is proposed. Here, energy efficiency is achieved by reducing power losses using a search algorithm. A feature of the search algorithm is the achievement of the extremum of the minimum power losses with the help of a small negative or positive increment in the voltage amplitude setting until the optimal operating mode of the electric drive is achieved. This method is rather inertial due to large mathematical calculations, but has such an advantage as - it does not depend on the variable parameters of the control object.

To obtain a more specific picture of static and dynamic processes in an induction motor, it is necessary to take into account the change in the resistance value of the stator windings taking into account the effect of current displacement, which has a significant effect when the electric drive operates at low frequencies [3]. An increase in the temperature of the IM windings during the operation of the electric drive entails a change in its electromechanical characteristics and, as a consequence, in the parameters of the control system, which is an important factor in the construction of a control system. The so-called IR - compensation allows to partially solve the problem of reducing the voltage of the magnetic circuit and, accordingly, the magnetic flux at low frequencies, i.e. a slight increase in voltage relative to the frequency control law U / f = const (Figure 1).

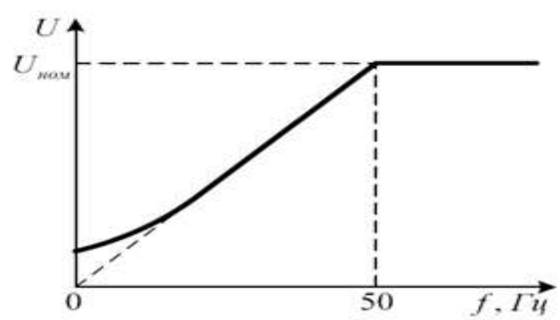

Figure 1. The law of frequency control U / f = const, taking into account IR - compensation

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A change in the resistance value of the stator windings of an induction motor depending on temperature also leads to a deviation of the optimal values of the controlled quantities, in particular, the flux linkages of the stator, rotor, main flux linkage, stator or rotor current, depending on the control system algorithm. In this regard, the DTC direct torque control system is the most optimal solution, since it is less sensitive to changes in the parameters of the electric motor.

In work [1] the analysis of dynamic modes in a frequency-controlled electric drive with vector control systems has been carried out. It was noted that vector control systems with a strict law of implementation of the control algorithm make it possible to increase the energy performance of an electric drive according to the criterion of a minimum of additional losses. The rather high complexity of the classical vector control system with continuous control laws is fully compensated by the use of relay vector control systems and a direct torque control system.

Using the same power part of the electric drive (Figure 2), it is possible to form the output voltage of an autonomous voltage inverter (AVI) in various ways: by pulse-width modulation either in a "relay" way, or with a transition to TPE at certain frequencies for a single switching of keys [5].

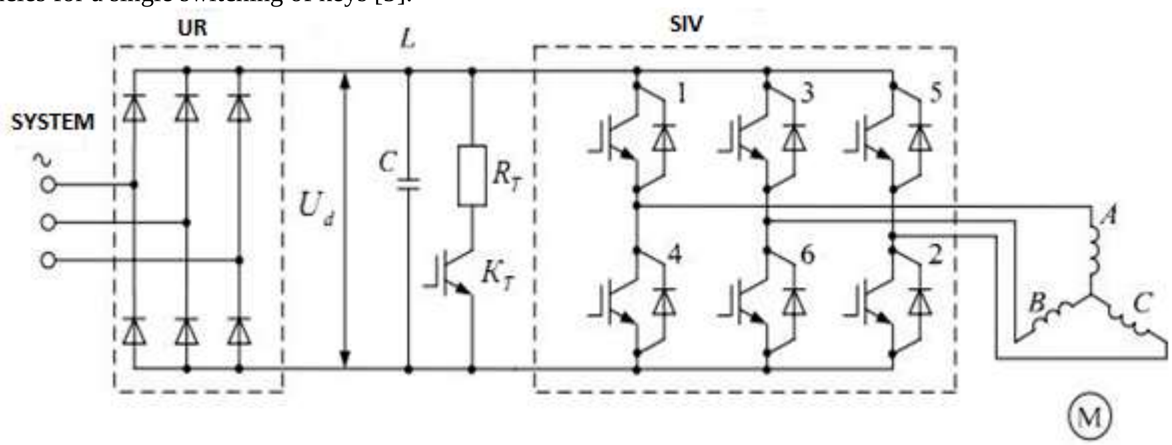

Figure 2. Diagram of the power section of an asynchronous electric drive with a frequency converter including a stand-alone inverter voltage (SIV) and uncontrolled rectifier (UR)

To generate voltage in such systems, PWM (Pulse Width Modulation) is used - classical pulse-width modulation and SVPWM (Space Vector Pulse Width Modulation) - spatial vector pulse-width modulation, relay-vector control, and separately, as a method of generating the output voltage of the inverter, you can indicate its formation in a system with direct torque control, based on tabular calculation and switching the voltage vector [80].

Discussion

In papers [4, 5, 6, 9], a method is described for optimizing classical vector control systems for an asynchronous electric drive in order to save energy according to the criterion of minimum stator current consumption, which is achieved by maintaining the required angle between the moment-generating vectors. The following pairs of vectors are considered as moment generators:

1) rotor flux linkage and stator current;
2) stator flux linkage and stator current;
3) main flux linkage and stator current.

In [4, 43], a geometric calculation revealed that the optimal from the point

In terms of minimizing the stator current, the angle between the vectors of the stator current and the rotor flux linkage is 45°in the absence of saturation of the magnetic circuit. This calculation can serve as a basis for determining the angle between the remaining pairs of moment-generating vectors, using the vector diagram of flux linkages and IM currents (Figure 1.4). Based on this vector diagram, it is possible to determine the minimum stator current at a given value of the induction motor torque [7]. In this diagram, θ_S is the angle between the vectors of current and flux linkage of the stator; θ_Ψ is the angle between the vectors of the stator flux linkage and the rotor flux linkage, ψ_S is the stator flux linkage vector; ψ_R is the rotor flux linkage vector; ψ_m is the vector of the main flux linkage; IS and I′R are the stator current vectors and the reduced rotor current, respectively; E_1 is the stator EMF vector.

Also in [8], an analysis of the construction of a control system in various coordinate systems is carried out. Comparing the three-phase stationary coordinate system a, b, c, the two-phase stationary coordinate system relative to the stator α, β and the rotating coordinate system d, q, oriented along the flux linkage of the rotor, the author points out that in the coordinate system d, q the system is formed much more conveniently equations of an asynchronous motor and describe the electromagnetic processes in the electric motor.

A more detailed implementation of energy-efficient algorithms in control systems of an asynchronous electric drive with direct torque control is presented in works [10]. Control systems for an asynchronous electric drive with direct torque control provide high speed of the torque loop, high speed of response to the torque control [5]. This advantage makes it possible to build algorithms based on the structure of this system that increase the energy performance of an asynchronous electric drive. In [11], a search algorithm based on fuzzy logic is presented, which implements in the direct torque control system the minimization of the stator current and losses due to stabilization of the angle between the torque-generating vectors of an induction motor. The fuzzy logic algorithm presented in [2] with the use of fuzzy controllers takes into account the deviation of the optimal angle by the criterion of minimum losses in the AM between the torque vectors when heating the stator and rotor windings, as well as losses in steel and saturation of the magnetic circuit of the electric motor.

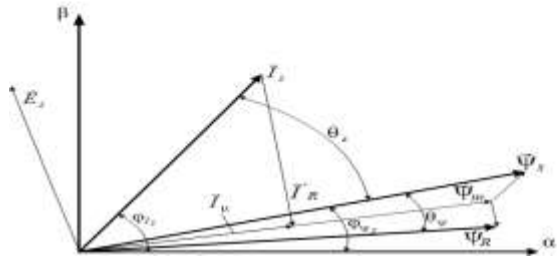

Figure 3. Vector diagram of flux linkages and currents of an induction motor in the α, β coordinate system

Also in this paper, a variant of forcing the stator flux linkage setting is proposed to improve the dynamic processes in an asynchronous electric drive when implementing an energy-saving algorithm.

Noting the features of search algorithms when achieving energy savings, the following should be indicated. Along with the search criterion for the minimum current consumption, there is also a search criterion for the maximum cosφ of an induction machine. Finding the maximum cosφ does not allow getting an advantage over minimizing the power consumption (or minimizing the stator current consumption) in terms of the complexity of mathematical calculations, since the cosφ is also determined by calculating the current and voltage vectors. The current minimization criterion has the advantage of a simpler implementation of the algorithm, especially in a direct torque control system.

Also in [2] it is noted that regulation by the criterion of the minimum stator current and regulation by the minimum losses in the AM (minimum power consumption) do not always correspond to each other. The algorithm for finding the minimum power consumption requires tenths of a second to determine the optimal value, which is unacceptable for high-speed mechanisms with low duty cycles. As a consequence, the search algorithm, optimized according to the criterion of minimum power consumption, can be applied exclusively to electric drives operating with constant load, provided that they are much lower than the rated ones [2].

When implementing an energy-saving algorithm, the problem of reducing the overload capacity of an induction motor with a decrease in the supply voltage arises with all the acuteness. The control system could reduce the magnetic flux in order to save energy when the load torque decreases and, consequently, lower the IM voltage. However, it must be taken into account that the critical moment is proportional to the square of the voltage and is determined by the following formula [12]:

$$M_m = \pm \frac{p m_1 U_1^2}{2\omega_1 \left[\pm r_1 + \sqrt{r_1^2 + (x_{\sigma 1} + x'_{\sigma 2})^2} \right]}, \quad (1)$$

where U_1 is the effective value of the IM phase voltage; $\omega_1 = 2\pi f_1$- angular frequency of phase voltage (current); p is the number of pole pairs; m_1 is the number of phases of the stator winding; r_1, r_2 ', $x_{\sigma 1}$, $x_{\sigma 2'}$ are the parameters of the T-shaped equivalent circuit of the induction motor. From formula (1) it can be seen that with a decrease in the flow (and voltage) of the IM, its overload capacity decreases, and this must be taken into account when building energy-efficient control systems.

In this paper comparative analysis of the classical vector systems and systems of direct torque control from the point of view of the implementation of static and dynamic characteristics of the electric drive. In dynamic modes, the system with direct torque control is preferable due to the faster response to the control action when using relay controllers.

Conclusion

It was revealed that algorithms that increase the energy efficiency of electric drives operation are advisable to apply in certain operating modes of an electric drive, when energy saving will not have a negative impact on the static and dynamic characteristics during the implementation of the required technological process.

Since the direct torque control system has a high speed, is immune to disturbances and inaccuracies of information on the state of engine parameters, it is advisable to use it to implement algorithms aimed at energy-efficient control of a traction electric drive with asynchronous motors, and this will be facilitated by solving the problems formulated in the introduction.

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