Energy-efficient variable frequency asynchronous electric drive

D A Vasilyev, R I Gavrilov, L A Panteleeva

Izhevsk State Agricultural Academy, 11, Studencheskaya Str., Udmurt Republic, Izhevsk 426069, Russia,

E-mail: 79128747827@yandex.ru

Abstract. Currently, there are quite a large number of various scientific papers on the creation of a controlled asynchronous engine and the optimization of its modes, and the availability of acceptable results for practical implementation, but there is still no single generally accepted approach to solving the problem. In this regard, the issue of synthesis of scalar control systems that provide the minimum value of one or another criterion of energy efficiency is relevant. In this paper, we consider the obtained mathematical model of an asynchronous engine (AE), which differs from the known ones in that the parameters of the substitution scheme are expressed in terms of the stator and rotor conductivities. The energy characteristics of the AE in the sliding function are obtained, which make it possible to determine the dependences of the active and reactive components of the AE current and the possibility of their redistribution within the nominal value of the AE phase current. The principle of optimal frequency-current control of AE is formulated, which differs from the known ones in that, as an energy efficiency indicator, the value of the maximum energy efficiency of AE is used, expressed as the ratio of the active resistance of the rotor circuit to the total conductivity of the AE phase.

1 Introduction
Currently, electric drives with an asynchronous engine (AE) are common. One way to reduce energy consumption is to use frequency control. The most interesting for research and promising from the point of view of energy saving, when using control systems with a frequency-controlled drive, are ventilation and water supply systems and other systems with fan load characteristics. This is due to their largest component in the total volume of electricity consumers and the pronounced unevenness of the load. The object of the research is the process of operation of a frequency-controlled alternating current electric drive, which includes an AE with a short-circuited rotor. The subject of the study. Modes of operation of the AE that meet the criterion of energy efficiency. The purpose of the work is to minimize energy consumption in technological processes by implementing energy-efficient modes of frequency-controlled asynchronous engines. The specific feature of frequency control of asynchronous electric engines is that in order to economically control the speed by changing the frequency, it is necessary to change the amplitude of the supply voltage. Despite the fact that there are quite a large number of various scientific works on the creation of a controlled asynchronous engine and the optimization of its modes, and the availability of results acceptable for practical implementation, there is still no single universally recognized approach to solving this problem. In this regard, the issue of synthesis of scalar control systems that provide the minimum value of one or
another criterion of energy efficiency is relevant.

2. Materials and methods

To evaluate the operating modes of the electric engine and the capacity balance in different modes, its replacement scheme is used as a formalized description of the engine. In bibliographic sources, various replacement circuits are used, presented in the form of electrical circuits containing active and inductive resistances.

When studying the steady-state operating modes of an asynchronous engine, it is important to know not only the voltage drop at the individual resistances of the replacement scheme, but also the phase currents, their active and inductive components, by which the active and reactive capacity, the capacity factor and other components of the operating characteristics of an asynchronous engine are determined. In this regard, it is proposed to represent the replacement scheme of an asynchronous engine in the form of a logical set of conductivities: active and inductive, Figure 1.

The transition is carried out on the basis of the known formulas for converting an electric circuit with series connections of resistances into an electrical equivalent circuit with parallel connections, without introducing any additional dependencies or coefficients, as a result of which the conversion is absolutely equivalent, and all the assumptions that are accepted for engine replacement schemes relate to the proposed replacement scheme.

The widely used asynchronous electric engine AIR100S4 was selected for the research. On the developed model, Figure 1, the simulation of the operating mode within the limits of the slip change, \( s = 0 \pm 0.1 \), as a generalized indicator of the AE operation, is carried out. Based on the simulation results, graphs of the conductivity of one phase of the AIR100S4 engine from the rotor slip are constructed, which are shown in Figure 2.

When analyzing the dependences in Figure 2 and theoretically studying the conductivities of an asynchronous engine, it is found that the active conductivity depends directly proportional to the rotor slip, line 3, Figure 2, and the inductive conductivity has a weak dependence, since it contains a constant component, line 1, Figure 2. Taking into account these features, a hypothesis is formulated: in an asynchronous engine, it is possible to change the ratio between the active and inductive components of the current within the nominal value of the phase current, by simultaneously affecting the amplitude and frequency of the mains voltage, and, as a result, to change the energy efficiency indicators of the asynchronous engine.

Evaluation of the efficiency of the AE is carried out using the efficiency factor (efficiency) and the capacity factor, but these indicators do not fully reflect the energy performance of the engine. We propose, as an indicator of the efficiency of the AE in steady-state operating modes, to use the energy efficiency \( \xi \), the value of which is determined as the ratio of the active conductivity of the rotor circuit \( q_{2s} \) to the total conductivity \( y \), expressed in relative units. Thus, it is proposed to estimate the
consumption of the engine not only the active components of capacity, which determine the efficiency, but also the consumption of reactive capacity by asynchronous engines, characterized by the capacity factor $\xi$, o.e.

The target function, the energy efficiency of the AE, is determined by the parameters of the substitution scheme, the voltage frequency and the slip value. Finding the optimal conditions for the operation of an asynchronous engine is to determine the frequency of the network and the slip providing the extremum of this function. In the solution, the sliding dependence corresponding to the maximum energy efficiency of AE is found $s_\xi$, o.e.:

$$s_\xi = \frac{R_2}{2R_0 \cdot R_1 \cdot X_2k + (X_0 \cdot X_2k - R_1^2) \cdot (X_0 + X_2k)}.$$

From this formula, it follows that the engine will operate with minimal losses if you change the amplitude of the supply voltage so that the AE slip is equal to the critical value $s_\xi$ for a given frequency. For the AIR100S4 engine under study, the critical value is $s_\xi = 0.061$ at a network frequency of 50 Hz.
The method of increasing the energy efficiency in the operation of three-phase asynchronous engines of electric drives under varying loads, consider the example of the AIR100S4 engine, working together with a fan BP80-75-6.3. The control law corresponding to the operating mode of the fan with a nominal efficiency is found by jointly solving the equations for the mechanical characteristics of the motor and the load relative to the frequency:

\[
a_1 \cdot M_{n,0} + (1 + b_1) \cdot M_{n,0} \cdot \left(\frac{\omega}{\omega_n}\right)^x = \frac{mR_2pU^2}{2\pi sf \cdot \left(\frac{R_1 + R_2}{S}\right)^2 + (2\pi fL_2)^2}
\]

According to the results of the calculation, the dependence of the voltage on the frequency of regulation of the AIR100S4 asynchronous engine – BP 80-75-6.3 fan system is found according to the conditions of the maximum value of the energy efficiency. The volt-frequency response is represented by the dependence \((U, V)\):

\[
U(f) = 0.1145f^2 - 1.5696f + 22.04.
\]

A program for calculating the optimal parameters of the power supply network for. The simulation was also carried out, the results of which showed that the method is workable and practically implementable. Experimental studies were conducted in the laboratory of the Department of Electrical Engineering, Electrical Equipment and Power Supply of the Izhevsk State Agricultural Academy. To achieve this goal, a laboratory stand was developed and created. Experimental studies were carried out to confirm the hypothesis previously obtained in the theoretical study of the regularities of changes in capacity consumption when varying the speed of rotation, as well as to assess the impact of frequency control methods and the nature of the load on energy efficiency indicators. For the AIR100S4 engine under study, an increase in energy efficiency was obtained from 0.59 to 0.67.

3. Conclusion

A mathematical model of AE has been developed, which differs from the known ones in that the parameters of the substitution scheme are expressed in terms of the stator and rotor conductivities and allows us to determine the components of the AE capacity when varying the frequency of the supply voltage.

The energy characteristics of the AE in the sliding function, as a generalized parameter of the engine operating mode, are obtained, which make it possible to determine the dependences of the active and reactive components of the AE current and the possibility of their redistribution within the nominal value of the AE phase current.

The basic principle of optimal frequency - current control of AE is formulated, which differs from the known ones in that, as an energy efficiency indicator, the value of the maximum energy efficiency of AE is used, expressed as the ratio of the active conductivity of the rotor circuit to the total conductivity of the AE phase.

References

[1] Vasiliev D A, Panteleeva L A, Noskov V A 2018 A mathematical model of capacity losses in an asynchronous engine according to an M-shaped substitution scheme in the Simulink package Vestnik VIESKH 2 (31) 53-56
[2] Vasiliev D A, Panteleeva L A, Lekomcev P L, Martynov K V, Kokonov S I, Shavkunov M L 2019 Improving the efficiency of a variable frequency asynchronous electric drive IOP Conference Series: Earth and Environmental Science 341 012120.
[3] Vinokurov V A, Popov D A 1986 Electric machines of railway transport: a textbook for higher education institutions (Moscow: Transport)
[4] GOST R IEC 60034-2-1: 2007 Electric rotating machines. Part 2-1. Methods of determination of losses and efficiency of rotating electric machines (except for machines for rolling stock)
[5] GOST R 53472-2009. Electric rotating machines. Asynchronous engines. Test methods.