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ENERGY CHARACTERISTICS OF ASYNCHRONOUS ELECTRIC DRIVE

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Abstract:
Energy aspects are fundamental to the design of electric drive systems. This article describes energy performance for asynchronous electric drives based on various control methods. These electric drives comparison shows that vector control methods have a significant advantage over scalar control methods. The asynchronous electric drive mathematical description is based on vector control theory and main component method. Equations, obtained by mathematical description, allow calculating of the currents, voltages and electric power at the output when the electromagnetic torque and speed machine are set. Energy characteristics of the asynchronous drive were obtained with the use of the MATLAB-SIMULINK simulation program.

Key words: *energy characteristics, asynchronous electric drive, scalar control methods, vector control methods*

INTRODUCTION

For power industrial drives the significant is not only dynamic but mainly energy characteristics. Energy characteristics of closed loop asynchronous electric drive as well as dynamic characteristics are depended on its structure, selected laws and management ways. Problem analysis shows that in modern power systems there are still unused reserves for increasing energy efficiency when converting electromechanical energy. The greatest potential for increasing the efficiency of electromechanical energy conversion can be obtained by optimizing the operating modes of the system [15].

This article presents the calculation and of energy performance comparison asynchronous electric drive for different laws and ways of management.

Asynchronous machine with squirrel-cage rotor (AMSCR) is significant non-linear control object. Building the electric drive with AMSCR requires a structural and parametric synthesis.

Selection of control method the AMSCR is the first step of structural synthesis.

According to control method analysis all squirrel-cage machine drive can be divided into two broad control classes:

1. Scalar control methods.
2. Vector control methods.

Implementing scalar control methods carried out use nonlinear regulators.

These regulators provide a nonlinear relationship between voltage (current) and frequency on output inverter [7, 11]. For scalar control method is not strict requirements to dynamic process. Vector control method implementation is performed through the phase control of the voltage or current at the output of the inverter [1, 3, 4, 6, 9, 11, 13, 14]. Basis building asynchronous electric drives with vector control serves as a structural synthesis method. This method described in the work of Boychuk [2]. Further development of this method was implemented in the work of the O.S. Popov for solving inverse dynamic problems [10].

METHODOLOGY OF RESEARCH

The main condition for structural synthesis asynchronous electric drive is choice of base vector [12]. The choice of the base vector defines the relationship between electromagnetic variables of AMSCR and angular frequency (coordinate rotation speed). In [12] are represented by six main structures of the asynchronous electric drive, which are marked in accordance with the selected baseline vector as:

- Base vector is stator voltage – $\bar{U}_S$,
- Base vector is rotor voltage –$\bar{U}_R$,
- Base vector is stator current – $\bar{I}_S$,

- Base vector is rotor current – $\bar{I}_R$,
- Base vector is stator flux – $\bar{\Psi}_S$,
- Base vector is rotor flux - $\bar{\Psi}_R$.

The asynchronous vector systems torque is determined as product of pairs spatial vectors.

Equations of torque for all vector combinations was present in monograph [12].

Here are the equations of the torque only for two combinations vectors, which are most prevalent in asynchronous electric drive. The first of these equations is correspond system with the base vector of the rotor magnetic flux, (FOC – Field Oriented Control). The second of these equations corresponds to direct torque control, (DTC – Direct Torque Control).

For the powerful asynchronous electric drives are essential not only dynamic properties, but also the energy characteristics. Energy characteristics of asynchronous electric drives are calculated in the static operation modes. In this article assessment is performed when sets the torque and speed on the shaft of asynchronous motor in the closed loop electric drive.

CALCULATION AND MODELING

Study on energy characteristics of asynchronous electric drive with field oriented control

Study on energy characteristics of asynchronous electric drive with base vector of rotor magnetic flux (FOC-field oriented control) implemented for asynchronous machine power 15kW with the following passport data and parameters:

Nominal power – S_n(VA), RMS-voltage (line-line) – U_n(Vrms), frequency - f_n(Hz):

$$Sn = 1.845e + 04(VA), U_n = 400V, (U_{1m} = 310V),$$
$$f_n = 50Hz, \left(\omega_1 = \frac{3141}{s}\right).$$

Stator resistance and inductance Rs(ohm) Ls(H): $R_S = 0.2147\Omega, L_S = 0.06518$ H.

Rotor resistance and inductance (R_R(ohm) L_R(H)): $R_R = 0.2205\Omega, L_R = 0.06518$ H.

Mutual inductance Lm (H): $L_m = 0.06419H.$

Inertia, pole pairs: $J = 0.102$ kgm^2, $p = 2.$

The basis of the mathematical asynchronous electric drive description is the method of the base vector [8] and main component method [5].

A mathematical description electric drive in the static mode base vector of magnetic flux must meet several conditions:

- Magnetic flux of rotor is set and it is maintained a constant by regulator.
- The rotational speed of the motor shaft is set and maintained a constant by regulator.
- Rotation speed of coordinates is constant, and is determined by the flux of the rotor and the torque.
- Mathematical description of the system is carried out in a rotating coordinate system "x" and "y".
- Orientation of the coordinate system ensures maintenance of flux projections of rotor are equal: $\psi_{Ry} = 0$, $\bar{\psi}_R = \Psi_{Rx} = const$:

$$\begin{aligned}
U_{sx} &= rI_{sx} - \omega_k L'_s I_{sy} - \frac{k_R}{T_R}\Psi_{Rx},\\
U_{sy} &= rI_{sy} + \omega_k L'_s I_{sx} + k_R p\omega_m \Psi_{Rx},\\
I_{sx} &= \frac{1}{L_R k_R}\Psi_{Rx},\\
\omega_k &= \frac{k_R R_R I_{sy}}{\Psi_{Rx}} + p\omega_m,\\
M_e &= 1.5pk_R\Psi_{Rx}I_{sy}.
\end{aligned} \quad (1)$$

where:

$U_{sx}, U_{sy}, I_{sx}, I_{sy}, \Psi_{Rx}$ – projection on axis of voltage, currents, magnetic flux,

ω_m – the angular velocity of the rotor,

$M_e = M_{load}$ – electromagnetic torque and load torque,

p – number pairs poles of machine,

$r = (R_s + k_R^2 R_R), L'_s = \left(L_s - \frac{L_m^2}{L_R}\right), k_R = \frac{L_m}{L_R},$

$T_R = \frac{L_R}{R_R}$ – parameters.

For the selected motor the ratios in equations (1) were calculated, it are placed in the Table 1.

Table 1
Calculated ratios in equations (1)

Parameters	r	T_S^1	T_R	k_R	L'_S
Unit of measurement	Ω	s	s	-	H
Value	0.4285	0.0046	0.2956	0.9848	0.00196

Equations (1) allow calculating of the currents, voltages and angular frequency at the output of the inverter when the electromagnetic torque and speed machine are set. Energy characteristics of the electric drive are calculated according to the equations:

$$\begin{aligned}
P_s &= 1.5(U_{sx}I_{sx} + U_{sy}I_{sy}),\\
Q_s &= -1.5(U_{sx}I_{sy} - U_{sy}I_{sx}),\\
cos\,\varphi &= \frac{P_s}{\sqrt{P_s^2 + Q_s^2}},\\
\eta &= \frac{p\omega_m M}{P_s},
\end{aligned} \quad (2)$$

where:

P_S – active power,

Q_S – eactive power,

cosϕ – power factor,

η – efficiency

RESULTS

On Fig. 1, Fig. 2 are shows the calculated dependencies the active and reactive power in asynchronous electric drive when you change the torque and speed.

Projections of the surface on the basic plane represents dependency between speed and torque at a constant power on output of drive. According to these projections can be judged about restrictions on the variation range of speed and torque on the output of asynchronous drive. Active and reactive electric power are nonlinearly depend on speed and torque output.

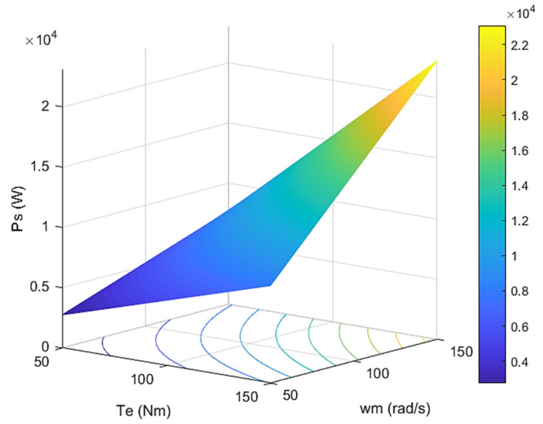

Fig. 1 Characteristics of active power in asynchronous electric drive with field oriented control

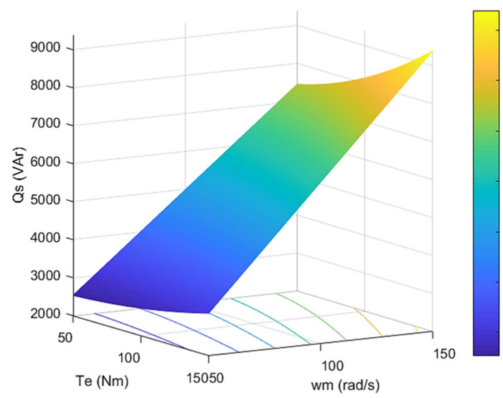

Fig. 2 Characteristics of reactive power in asynchronous electric drive with field oriented control

Mathematical description of asynchronous electric drive with direct torque control (DTC)

On the system with DTC torque is defined as the product of the rotor and stator flux.

$$M_e = \frac{3}{2} p \frac{k_R}{L_S'} \psi_R \psi_{sy} \tag{3}$$

Which means that the increment sign of moment can be positive or negative depending on the sign of the increment ψ_{Sy}. Electric drive control system designed in the rotating coordinate system as dual-channel. In the channel "x" is supported by a permanent module of the stator flux $|\bar{\Psi}_S| = const$.

The torque control carried out in the channel "y". Inverter control is carried out in accordance with the table of optimum switching [13].

The table of optimum switching is recorded in the microprocessor control and depending on the position of vector $\bar{\psi}_S$ and on the sign $\Delta M$is determined what transistors of the invertor have to unlocking. All the above enables to begin to develop the mathematical description asynchronous direct torque control system.

- Firstly, it should be noted, that the with direct torque control carried out vector modulation in the inverter. This allows to replaced output voltage of inverter by first harmonica.
- Secondly, when describing the electromagnetic processes as state variables are chosen by $\bar{\psi}_S$and $\bar{\psi}_R$, then the original equations takes the form:
- Third, the base vector in DTC, is set of rotor magnetic vector $\bar{\psi}_R = \psi_{Rx} = \psi_R$ Fourthly, electric control system is build dual channel in the rotating coordinate system. In the channel "x" is supported by a permanent module of stator magnetic flux. In the channel "y" is carried out control of the torque.
- Fifthly, the conversion of control signals into signals switching of inverter is done using a table of optimum switching.

When the mathematical description of the system becomes:

$$\begin{aligned}
U_{sx} &= \frac{1}{T_s'} \Psi_{Sx} - \frac{k_R}{T_s'} \Psi_R - \omega_k \Psi_{Sy}, \\
U_{sy} &= \frac{1}{T_s'} \Psi_{sy} + \omega_k \Psi_{sx}, \\
\Psi_{sx} &= \frac{1}{k_s} \Psi_R - \frac{T_R'(\omega_k - p\omega_m)}{k_s} \Psi_{sy}, \\
\omega_k &= p\omega_m + \frac{k_s}{T_R'} \frac{\Psi_{sy}}{\Psi_{sx}}, \\
I_{sx} &= \frac{(\Psi_{sx} - \Psi_R)}{L_s'}, \\
I_{sy} &= \frac{\Psi_{sy}}{L_s'}, \\
M_e &= \frac{3}{2} p \frac{k_R}{L_s'} \Psi_R \Psi_{sy}.
\end{aligned} \tag{4}$$

Energy characteristics of asynchronous electric drive with direct torque control are showed on Fig. 3 and Fig.4.

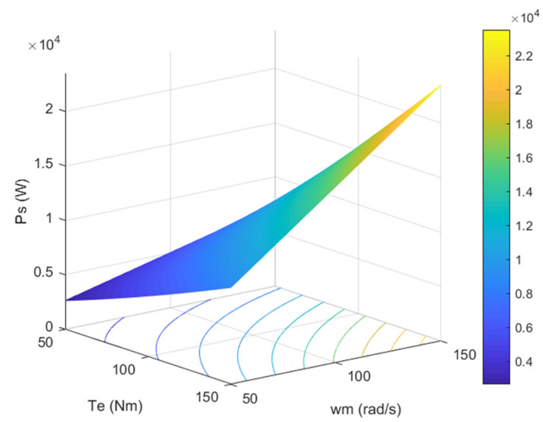

Fig. 3 Characteristics of active power in asynchronous electric drive with DTC

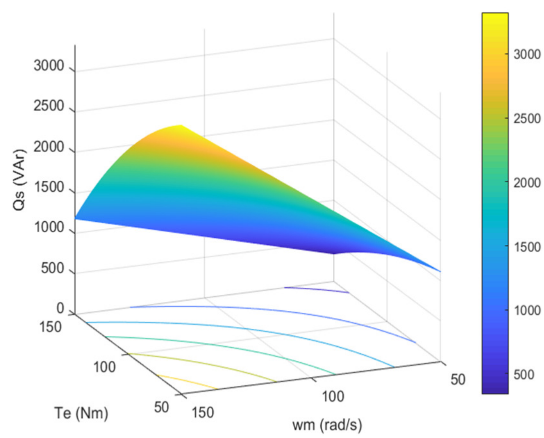

Fig. 4 Characteristics of reactive power in asynchronous electric drive with DTC

DISCUSSION

In article is carried out calculation of power characteristics of the asynchronous electric drives with vector control. These characteristics are constructed in spatial coordinates, where the speed and torque at the output of the electric drive are given state variables. Active power, reactive power are calculated as functions of speed and torque. The authors reviewed a large number of publications on asynchronous electric drive with different control laws and did not find a similar approach in the study of their energy characteristics. Therefore, comparison of the obtained results with the known ones is not possible. Most of the works is devoted design of asynchronous electric drive and investigation it dynamic properties.

CONCLUSION

Asynchronous electric drives with vector control have not only significantly improved dynamic characteristics, but also, as shown by the above studies, improved energy characteristics.

These advantages are the most prominent when comparing the reactive power consumed by the electric drive. At the same mechanical output power, the electric drive with DTC control consumes approximately 3-3.5 times less reactive power compared to the electric drive with FOC control.

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