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Mathematical Model of a Frequency-Controlled Electric Drive of Drilling Rigs for Geological Exploration, Taking into Account the Category of Rocks

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ABSTRACT: This paper presents the mathematical equations of all elements included in the electric drive system of a drilling rig with an asynchronous motor controlled by a frequency converter. In addition, the laws of speed control of an asynchronous motor using a frequency converter for a condition below the rated speed are described. The above equations and the stator winding direct current coupling law were calculated and constructed using the MATLAB program for the mechanical characteristics of an asynchronous motor controlled by a frequency converter, using $e1/\omega1=\psi1=$const.

KEY WORDS: frequency converter, mathematical model, electric drive, voltage margin, uncontrolled rectifier, mathematical equations.

I.INTRODUCTION

Particular attention in the world is paid to the management of existing technological processes in the mining, metallurgical and oil and gas industries, improving their technical characteristics, and increasing energy efficiency during drilling. Currently, in developed countries, the drilling process is being improved on the basis of a frequency control device to improve energy efficiency and optimally control the operating mode of electric motors [1-3].

Research is underway to improve energy efficiency based on frequency control of the speed of the drilling rig. In this direction, drilling rigs regulate the speed of the operating mode, taking into account the composition of the rock, i.e. drilling rig rotation speed depending on the hardness and softness of the drilled rock [4].

Improving energy efficiency through change is an urgent task. The purpose of the study was to improve the efficiency of using electricity in the drilling process.

The system of asynchronous electric drive of the frequency converter includes the following elements (Fig. 1): KIM-AVI - autonomous voltage inventory with wide pulse modulation and squirrel-cage asynchronous motor. The voltage source for the CMM is an uncontrolled rectifier with a switching reactor at the input and an LC filter at the output. The stator winding of the induction motor is star-connected and connected to the zero wireless inventory output through the reactor [1, 5-8].
Before creating a mathematical model of the power part of the frequency converter-asynchronous motor (FC-AM), let's start with creating a constructive model of individual elements. They consist of:

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AM - asynchronous motor, AVS - autonomous voltage storage device with output voltage reactor and uncontrolled rectifier with input switching reactor and LC filter at the output.

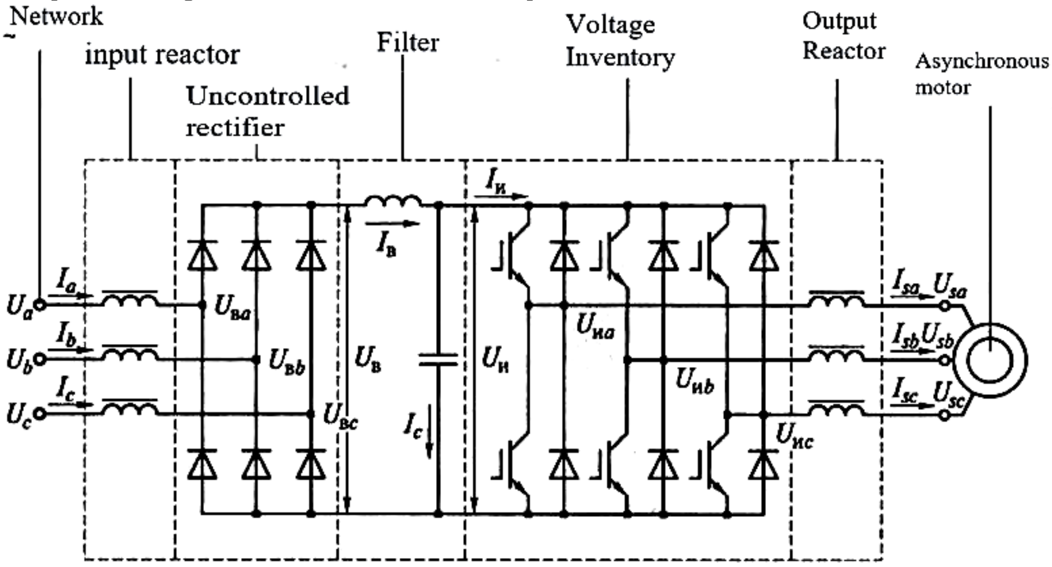

Fig. 1. Power circuit of an asynchronous electric drive system with a frequency converter

II. RESEARCH PROBLEM AND METHOD

Equations for an induction motor with a squirrel-cage rotor [2]:

$$\left.\begin{aligned}
u_{1\alpha} &= r_1 i_{1\alpha} + \frac{d\psi_{1\alpha}}{dt} \\
u_{1\beta} &= r_1 i_{1\beta} + \frac{d\psi_{1\beta}}{dt} \\
0 &= r_2 i_{2\alpha} + \frac{d\psi_{2\alpha}}{dt} + \omega_p \psi_{2\beta} \\
0 &= r_2 i_{2\beta} + \frac{d\psi_{2\beta}}{dt} + \omega_p \psi_{2\alpha} \\
\frac{di_\alpha}{dt} &= \frac{u_{1\alpha} - r i_\alpha}{L} \\
\frac{di_\beta}{dt} &= \frac{u_{1\beta} - r i_\beta}{L} \\
M &= \frac{mpM}{2(L_1 L_2 - M^2)}\left(\psi_{1\beta}\psi_{2\alpha} - \psi_{1\alpha}\psi_{2\beta}\right) \\
\frac{d\omega_p}{dt} &= \frac{p}{J}(M - M_c)
\end{aligned}\right\} \quad (1)$$

Where $u_{1\alpha}=U_m\cos(\omega t)$, $u_{1\beta}=U_{ms}\sin(\omega t)$ – α,β stator voltage along axes a, b;

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$i_{\alpha 1}, i_{\beta 1,} i_{\alpha 2}, i_{\beta 2}$ α,β stator and rotor currents along the axes; $\psi_{\beta 1}, \psi_{\alpha 1}, \psi_{\beta 2}, \psi_{\alpha 2}$, current coupling of the stator and rotor; r_1, r_2 – active resistance of the stator and rotor; ω, ω_p – mains frequency and rotor speed (el. rad/s); L_1, L_2 – total inductance of the stator and rotor; L_m – взаимная индуктивность между обмотками; M, M_C – AD electromagnetic torque and static load moment; m – number of phases; p – number of pole pairs; J – moment of inertia of the motor and mechanism[2].

Voltage Inventory Equations:

$$\left.\begin{aligned} f_\alpha &= \frac{1}{2U_0} u_\alpha^* \\ f_\beta &= \frac{1}{2U_0} u_\beta^* \\ u_{и\alpha} &= u_и f_\alpha \\ u_{и\beta} &= u_и f_\beta \\ i_и &= \frac{3}{2}\left(i_{1\alpha} f_\alpha + i_{1\beta} f_\beta\right) \end{aligned}\right\} \tag{2}$$

Where u_α^* and u_u_β^* — affected variables, $f_\alpha$and f_β medium switching functions, U_0- base signal amplitude, $i_и$- average stock supply current, $u_{и\alpha}$ and $u_{и\beta}$- average inventory output voltage, $i_{1\alpha}$ and $i_{1\beta}$- inventory average output current.
The output reactor is modeled by the following equations:

$$\left.\begin{aligned} pi_{1\alpha} &= L_{\text{р.чик}}^{-1}\left(u_{и\alpha} + \omega_k L_{\text{р.чик}} i_{1\beta} - R_{\text{р.чик}} i_{1\alpha} - u_{1\alpha}\right) \\ pi_{1\beta} &= L_{\text{р.чик}}^{-1}\left(u_{и\beta} - \omega_k L_{\text{р.чик}} i_{1\alpha} - R_{\text{р.чик}} i_{1\beta} - u_{1\beta}\right) \end{aligned}\right\} \tag{3}$$

Where $R_{\text{р.чик}}$ and $L_{\text{р.чик}}$ – active resistance and inductance of the output choke.

The input reactor equations of an uncontrolled rectifier are as follows:

$$\left.\begin{aligned} u_\alpha &= u_{\text{в}\alpha} + L_{\text{р.кир}} p i_\alpha - \omega_k L_{\text{р.кир}} i_\beta - R_{\text{р.кир}} i_\alpha \\ u_\beta &= u_{\text{в}\beta} + L_{\text{р.кир}} p i_\beta + \omega_k L_{\text{р.кир}} i_\alpha + R_{\text{р.кир}} i_\beta \\ f_{\text{в}\alpha} &= \frac{2\sqrt{3}}{\pi}\cos(\theta_i - \theta_k) \\ f_{\text{в}\beta} &= \frac{2\sqrt{3}}{\pi}\sin(\theta_i - \theta_k) \\ u_{\text{в}} &= \frac{3}{2}\left(u_{\text{в}\alpha} f_{\text{в}\alpha} + u_{\text{в}\beta} f_{\text{в}\beta}\right) \\ i_\alpha &= i_{\text{в}} f_{\text{в}\alpha} \\ i_\beta &= i_{\text{в}} f_{\text{в}\beta} \\ \omega_{\text{к}} &= p\theta_k \end{aligned}\right\} \tag{4}$$

Where u_α, u_β, i_α, i_β- modified main harmonics of mains voltage and current; $u_{\text{в}\alpha}$, $u_{\text{в}\beta}$- fundamental harmonics of the altered voltage at the power input of the unregulated rectifier; $f_{\text{в}\alpha}$, $f_{\text{в}\beta}$- switching function of the modified fundamental harmonic of the uncontrolled rectifier; θ_i- angle of rotation of the generalized rectifier turn-on vector or angle of rotation of the resulting mains current relative to the phase voltage; θ_k- angle of rotation of the ordinate system; $u_{\text{в}}$, $i_{\text{в}}$- voltage and current at the rectifier output; $R_{\text{р.кир}}$ and $L_{\text{р.кир}}$ – active resistance and inductance of the output choke.

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The LC filter equations at the output of an uncontrolled rectifier are as follows:

$$\left.\begin{aligned} pi_{\text{в}} &= L_{\text{р.ф}}^{-1}\left(u_{\text{в}} - R_{\text{р.ф}} i_{\text{в}} - u_{\text{и}}\right) \\ pu_{\text{и}} &= \mathrm{C}_{\text{б.ф}}^{-1} i_c \\ i_c &= i_{\text{в}} - i_{\text{и}} \end{aligned}\right\} \qquad (5)$$

Where $R_{\text{р.ф}}$, $L_{\text{р.ф}}$-LC active resistance and filter inductance; $\mathrm{C}_{\text{б.ф}}$- filter capacitor bank capacity; i_c- filter capacitor current.

III. RESULTS

There are the following types of speed control laws for an asynchronous motor using a frequency converter for a mode below the rated speed [3, 7-9]:

1) The law of proportional control u_1/ω_1=const;
2) The law of constant connection for the current of the stator winding $e_1/\omega_1=\psi_1$=const;
3) The law of continuity of the main magnetic flux $e_0/\omega_1=\psi_0$=const;
4) DC Coupling Law of Rotor Coil $e_2/\omega_1=\psi_2$=const.

Taking into account the above equations, Using the MATLAB program, we calculate the mechanical characteristics of an asynchronous motor controlled by a frequency converter, according to the law of constant coupling of the stator winding $e_1/\omega_1=\psi_1$=const [3].

```
clear; clf;
R1=0.2; R2=0.3; X1=0.754; X2=0.754;
Rc=110; Xm=33.9;
p=4; fR=50; VR=460; nmLim=1600; % nmLim is max allowable speed
% Thevenin resistance & inductance
Zm=j*Xm*Rc/(Rc+j*Xm);
ZTh= Zm*(R1+j*X1)/(R1+j*X1+Zm);
RTh=real(ZTh); LTh=imag(ZTh)/2/pi/fR;
L1=X1/2/pi/fR; L2=X2/2/pi/fR; Lm=Xm/2/pi/fR;
% Frequencies for analysis in addition to rated
nf=14; f=linspace(nmLim/nf, nmLim, nf)*p/120;
% Rated frequency calculations( Base curve )
npts=50; ws=2/p*2*pi*fR; wm=linspace(0, ws-0.01, npts);
w=2*pi*fR; VTh=abs(VR/sqrt(3)*Zm/(R1+j*X1+Zm));
for i=1:npts
s=(ws-wm(i))/ws;
TTd( i )=3 * VTh^2*R2/s/ws/((RTh+R2/s)^2+w^2*(LTh+L2)^2);
end
plot(wm*30/pi, TTd); grid;
Title («Mechanical characteristics of asynchronous motor with frequency converter»)
xlabel('Тезлик, айл/мин');ylabel('Момент, Нм');
fdev=f(2)-f(1);
text(0.65, 0.95, ['Frequency increment: ', num2str(fdev),'Hz'], 'sc')
text(0.65, 0.92, ['Basecurve(solid1ine): ',num2str(fR),'Hz'], 'sc')
hold on; % Hold base curve for overplotting
for k=1:nf % Other than rated frequency calculations
ws=2/p*2*pi*f(k); wm=linspace(0, ws-0.01, npts);
w=2*pi*f(k);
% Set voltage-frequency control
```

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if  f(k)/fR <=1; b=0.06*VR; VL=(VR-b)*f(k)/fR+b; else; VL=VR; end
% Empirical adjustment of core loss resistance
Rcf=0.5*Rc*(VR/VL*f(k)/fR)^2*(fR/f(k)+(fR/f(k))^2);
Zm=j*w*Lm*Rcf/(Rcf+j*w*Lm);
ZTh=Zm*(R1+j*w*L1)/(R1+j*w*L1+Zm);
RTh=real(ZTh); LTh=imag(ZTh)/2/pi/f(k);
VTh=abs(VL/sqrt(3)*Zm/(R1+j*w*L1+Zm));
for i=1:npts
s=(ws-wm(i))/ws;
TTd(i)=3*VTh^2*R2/s/ws/((RTh+R2/s)^2+w^2*(LTh+L2)^2) ;
end
% Determinationof points above nmmax for plot
smax=R2/sqrt(R1^2+w^2*(LTh+L2)^2); wmmax=(1-smax)*ws;
for m=1:npts; if wm(m)>=wmmax; break; end; end
plot(wm(m:npts)*30/pi,TTd(m:npts),'--');
end
% Activate to superimpose load torque plot
%TL=50+0.004052847*wm.^2;
%plot(wm*30/pi, TL, '-.');
hold off.
```

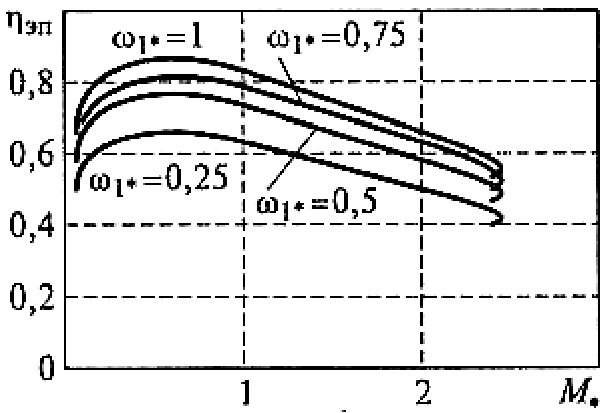

Fig. 2. The stator winding direct current coupling law is the efficiency of an asynchronous motor controlled by a frequency converter, according to the formula $e_1/\omega_1=\psi_1$=const [1].

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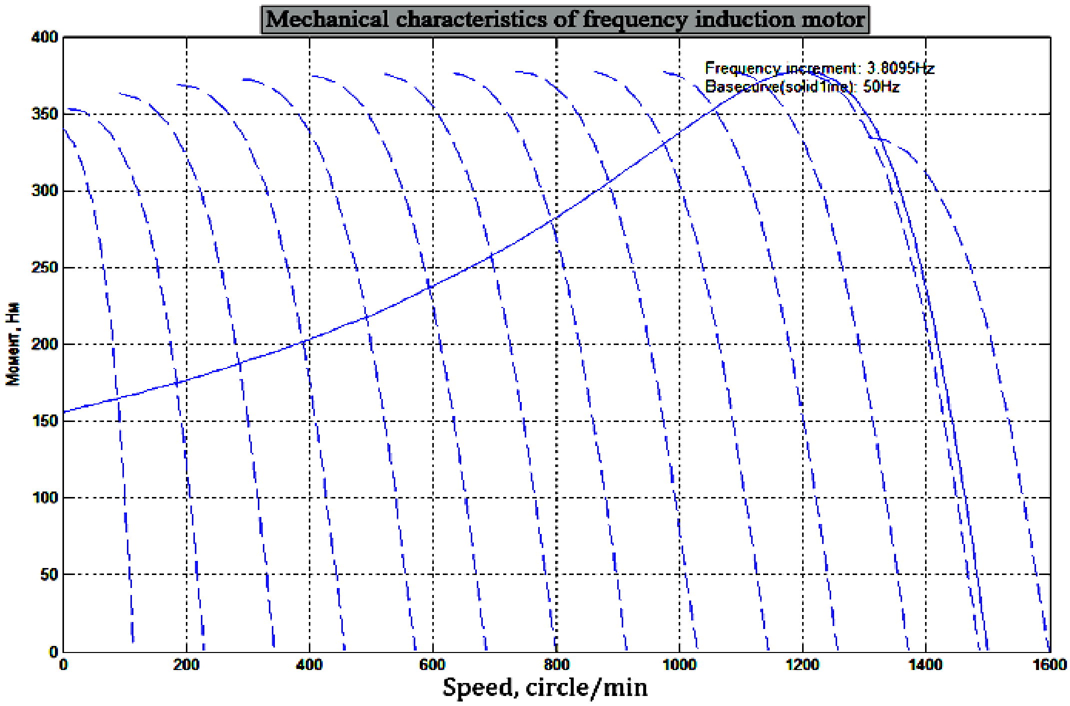

Fig. 3. Mechanical characteristics of an asynchronous motor with a frequency converter

Taking into account the frequency control law for the direct current of the stator winding, the efficiency of an asynchronous motor controlled by a frequency converter is shown in Fig. 2. And also the mechanical characteristics of an asynchronous motor with a frequency converter based on MATLAB are obtained (Fig. 3).

IV. CONCLUSION

1. According to the result obtained, when starting asynchronous motors using a frequency converter and adjusting the speed, its starting torque increases, and the maximum torque is maintained. This leads to a soft start of the electric drive and its recuperation and energy savings.

2. The law of direct current coupling of the stator winding. The efficiency of an asynchronous motor controlled by a frequency converter at $e1/\omega1=\psi1=const$ is much higher than that controlled by the proportional control law $u1/\omega1=const$. Therefore, when driving asynchronous motors, with the correct choice of the control law, depending on the mode of their operation, the energy efficiency of the frequency-converting asynchronous electric drive will increase.

REFERENCES

[1] Braslavsky I.Ya., Ishmatov Z.Sh., Polyakov V.N., Energy-saving asynchronous electric drive, M: Academy, 248 s, 2004.
[2] Ilyansky N.F., Moskalenko V.V., Electric drive energy and resource saving, M: Academy, 201s, 2008.
[3] Jimmie J. Cathey, Electric machines: analysis and design applying MATLAB, International Edition, 2001.
[4] Abramov B.I. Frequency-controlled electric drive of drilling rigs BU-4200/250 / B. I. Abramov, A. I. Kogan et al. Electrical Engineering, No. 1, P. 8-13, 2009.
[5] Kamalov T.S. Frequency-controlled electric drive of pumping stations of machine irrigation systems. Monograph. Tashkent: Fan, 368 p, 2014.
[6] Арипов Н.М., Тоиров О.З., Усмонов Ш Ю., Кучкарова Д.Т. Основные технические требования по диапазону и точности регулирования скорости перемотки шелка-сырца с применением интелектуального электропривода, Вестник Казанского государственного энергетического университета, № 1 (49). С. 218–225, 2021.

[7] Kamalov Tolyagan, Toirov Olimjon, Ergashev Shahboz Modern condition and possibilities of program management of frequency-adjustable electric drives, European research. 2016. №6 (17). URL: https://cyberleninka.ru/article/n/modern-condition-and-possibilities-of-program-management-of-frequency-adjustable-electric-drives (дата обращения: 16.05.2022).

[8] Olimjon Toirov, Tulyagan Kamalov, Utkir Mirkhonov, Sardor Urokov, Dilnoza Jumaeva The mathematical model and a block diagram of a synchronous motor compressor unit with a system of automatic control of the excitation, E3S Web of Conferences, SUSE-2021, 288, 01083 (2021).

[9] Olimjon Toirov, Sardor Urokov, Utkir Mirkhonov, Hadha Afrisal, Dilnoza Jumaeva Experimental study of the control of operating modes of a plate feeder based on a frequency-controlled electric drive, E3S Web of Conferences, SUSE-2021, 288, 01086 (2021).