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Mathematical Expressions and Methods for Calculating Energy-Saving Modes in an Asynchronous Motor

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ABSTRACT: As a result of the analysis, the energy-efficient optimal expressions of the induction motor were considered through mathematical expressions and methods for their calculation.

KEYWORDS: induction motor, frequency, magnetization current, electric current, absolute slip, electromagneticlosses.

I.INTRODUCTION

Other methods of automatic asynchronous drive control, which are widely used today and control the speed, are a special case of frequency control. The method of analysis and calculation of an induction motor with minimal power loss in automated speed-controlled electric drive systems by changing the frequency is described.

II. SIGNIFICANCE OF THE SYSTEM

The analytical dependences expressed by the magnetic flux are given for calculating the working, adjustment characteristics and analysis of the adjustment characteristics of frequency-controlled electric motors by changing the frequency. We determine that the loss of electricity in electric motors is the smallest, which depends on determining the optimal value of the magnetic flux. To simplify the analytical relationship obtained for the T-shaped equivalent circuit and the vector diagram, we give only for k = 1 harmonics. The relative magnitude of the magnetic flux of an induction motor

$$\varphi = \frac{F}{F_N},$$

the relative values of frequency and moment are denoted by the formulas

$$F = \frac{f}{f_N}, \mu = \frac{M}{M_N}$$

Reduced rotor current:

$$I_{RF\varphi} = \sqrt{\frac{P_{EM.N}}{m_1 r_R}\beta\varphi}, (1)$$

where $P_{EM.N}$ is the nominal electromagnetic power, m_1 is the number of stator phases;

$$\beta\varphi = d\varphi^2 - \sqrt{(a\varphi^2)^2 - c}$$

$s = \frac{r_R^{`2}}{x_R^{`2}}$, absolute glide; $a = \frac{m_1 E_{SN} r_R^{`}}{2P_{EM.N} x_R^{`2}}$;

E_{SN} - nominal value of the EMF stator

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Magnetic current $I_{OF,\varphi} = \frac{E_{ON} F \varphi}{\sqrt{r_{O1}^2 + x_{O1}^2 \gamma}}$. (2)

Active and inductive resistances of the magnetic circuit are determined from equation (2):

$$r_{OF,\varphi} = \frac{r_\mu F - \sqrt{(r_\eta F - 4x_{OF,\varphi})^2}}{2}$$

here $x_{OF,\varphi} = F\sqrt{\frac{E_{SN}^2 \varphi^2}{I_{O\varphi}^2} - \left(\frac{\Delta P_{PN} \varphi^2}{m_1 I_{OF}^2}\right)}$

P_{PN} - nominal losses in motor steel

At I_{OF} - $F = 1$ (determined by the magnetization characteristic)

K = 1,315 is a coefficient depending on the steel grade of the magnetic system of the induction motor.

stator current $I_{SF.\varphi} = E_{SN.\varphi}\sqrt{\frac{(x_{OF.\varphi} + x_R^{`} F)^2 + (r_{OF.\varphi} + \frac{r_R^{`} F}{\beta\gamma})^2}{(r_{OF.\varphi} + x_{OF.\varphi}^2)(\frac{r_R^{`2}}{\beta^2 \varphi} + x_R^{`2})}}$, (3)

slip $s_{F.\varphi} = \frac{\beta\varphi}{F}$.

III. LITERATURE SURVEY

Electromagnetic loss:

$$\Delta P_{SM.F.\varphi} = m_1 r_S E_{SN.\varphi}^2 \frac{(x_{OF.\varphi} + x_{\mu F}^{`})^2 + \left(r_{OF.\varphi} + \frac{r_R F}{\beta\varphi}\right)^2}{(r_{OF.\varphi}^2 + x_{OF.\varphi}^2)\left(\frac{r_R^{`2}}{\beta^2\varphi} + x_R^{`2}\right)} + \Delta P_{EM.N}\beta_\gamma + \Delta P_{P.N}\varphi^2 F^K. \quad (4)$$

Total losses

$$\sum \Delta P_{F,\varphi} = E_{SN.\varphi}^2 {}^2\left(m_1 r_S + \frac{\Delta P_{ofadd.N}}{I_{S.N}^2}\right) \frac{(x_{OF.\varphi} + x_R^{`} F)^2 + \left(r_{OF.\varphi} + \frac{r_R^{`} F}{\beta\varphi}\right)^2}{(r_{OF.\varphi}^2 + x_{OF.\varphi}^2)\left(\frac{r_R^{`}}{\beta^2\varphi} + x_R^{`2}\right)} + \Delta P_{EM.N}\beta_\gamma + \quad (5)$$

$$\Delta P_{P.N}\varphi^2 F^K + M_N \omega_N (F - \beta_\gamma),$$

where I_{CN}, ω_N, M_N, $\Delta P_{of\ additional\ N}$ - stator current, speed, mechanical moment and additional losses.

Useable power $P_{useableF.\varphi} = M_N \omega_{ON}(F - \beta_\gamma)$, (6)

where M_N is the rated torque on the motor shaft

Required power

$$P_{NF.\varphi} = E_{ON}^2\left(m_1 r_S + \frac{\Delta P_{ofadd.N}}{I_{SM}^2}\right)\varphi^2 \frac{(x_{OF.\varphi} + x_{\mu F}^{`})^2 + \left(r_{OF.\varphi} + \frac{r_R^{`2} F}{\beta\varphi}\right)}{(r_{OF.\varphi}^2 + x_{OF.\varphi}^2)\left(\frac{r_R^{`2}}{\beta^2\varphi} + x_R^{`2}\right)} + \Delta P_{EM.N} F + \Delta P_{P.N}\varphi^2 F^K \quad (7)$$

Expression of efficiency and power factor using an engine:

$$\eta_{F,\varphi} = \frac{P_{useableF\varphi}}{P_{NF,\varphi}} = \frac{M_N \omega_{ON}(F - \beta_\varphi)(x_{OF,\varphi} + x_R^{`} F)^2 + (r_{OF,\varphi} + \frac{r_R^{`} F}{\beta_\varphi})^2}{\Delta P_{EM.N} F + \Delta P_{P.N}\varphi^2 F^2 + E_{SN}^2 \varphi^2 (m_1 r_S + \frac{\Delta P_{ofadd.N}}{I_{SH}^2})(r_{OF,\varphi}^2 + x_{OF,\varphi}^2)(\frac{r_R^{`} F}{\beta\varphi} + x_R^{`2})} \quad (8)$$

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$$\cos\varphi_{F,\varphi}=\frac{P_{NF,\varphi}}{m_1 UI_{SF,\varphi}}=\left[\frac{E_{SN\varphi}(m_1 r_S+\frac{\Delta P_{E.N}}{I_{SN}^2})(x_{OF,\varphi}+x_{RF}^{`})^2+(r_{OF,\varphi}+\frac{r_{RF}^{`}}{\beta\varphi})^2}{m_1 U(r_{OF,\varphi}+x_{OF,\varphi}^2)(\frac{r_R^{`2}}{\beta\varphi}+x_R^{`2})}+\frac{\Delta P_{EM.N}F+\Delta P_{P.N}\varphi^2 F^K}{m_1 UE_{SN.\varphi}}\right]x \quad (9)$$

$$x\sqrt{\frac{(r_{OF,\varphi}^2+x_{OF,\varphi}^2)\left(\frac{r_R^{`2}}{\beta\gamma}+x_R^{`2}\right)}{(x_{OF,\varphi}+x_R^{`}F)^2+\left(r_{OF,\varphi}+\frac{r_R^{`2}F}{\beta\varphi}\right)^2}}$$

Energy indicator

$$\eta_{F,\varphi}\cos\varphi_{F,\varphi}=\frac{P_{NF,\varphi}}{m_1 UI_{SF,\varphi}}=\frac{M_N\omega_{ON}(F-\beta\varphi)}{m_1 UE_{SN}\varphi}x\sqrt{\frac{(r_{OF,\varphi}^2+x_{OF,\varphi}^2)\left(\frac{r_R^{`2}}{\beta_\varphi^2}+x_R^{`2}\right)}{(x_{OF,\varphi}+x_{RF}^{`})+\left(r_{OF,\varphi}+\frac{r_p^1 F}{\beta\varphi}\right)^2}} \quad (10)$$

IV. METHODOLOGY

The voltage U corresponding to certain values of F and φ can be determined as follows:

$$U=\sqrt{2x_S^2F^2I_{SF,\varphi}^2-A_{F,\varphi}+(2x_S^2FI_{SF,\varphi}^2-A_{F,\varphi})^2-A_{F,\varphi}^2-\frac{4}{m_1^2}x_S^2F^2P_{NF,\varphi}^2} \quad (11)$$

here $A_{F,\varphi}=I_{SF,\varphi}^2(x_S^2F^2+r_S^2)-E_{SN}^2F^2\varphi^2-\frac{2}{m}r_S P_{NF,\varphi}$.

The optimal value of current φ_{opt} for different frequencies F can be determined analytically with sufficient accuracy (error of not more than 2%) without studying the function $AP_{EMF}\varphi=\psi(\varphi)$.

In this case, the square of the stator current of the induction motor is equal to the sum of the square of the rotor current and the square of the magnetic current.

$$I_{SF,\varphi}^2=I_{R\varphi}^{`2}+I_{O\varphi}^2 \quad (12)$$

The reduced rotor current is inversely proportional to the magnetic flux.

$$I_{R\varphi}^{`}=\frac{\Delta P_{EM.N}}{m_1 E_{SN}\varphi}, \quad (13)$$

To express the magnetization squared current by magnetic flux, we use the formula given in 2:

$$I_{O\varphi}^2=I_{ON}^2\frac{\gamma^2}{K_M-(K_M-1)^2\varphi}, \quad (14)$$

where K_M is the selection coefficient for the right side of the I^2 OX curve, to be more precise.

Based on the above initial cases, we obtain an approximate expression of electromagnetic loss:

$$\Delta P_{EM.\varphi}=\frac{B}{\varphi^2}+C\frac{\gamma^2}{K_M(K_M-1)\varphi^2}+D\varphi^2F^2, \quad (15)$$

here $B=(r_S+r_R^{`})\Delta P_{E\check{E}.N}/m_1E_{SN}^2 : C=3r_S^2I_{OH}^2 : D=\Delta P_{PN}$.

Taking the result of the stream from the 14th expression and making it equal to zero, we make some changes:

$$\varphi^2+в\varphi^2+c_\varphi\varphi^2+d_F\varphi^2+e_\varphi=0 \quad (16)$$

here $в=\frac{2K}{1-K_\mu};c_F=\frac{cr_\mu+DF^kK_\mu^2-B(K_\mu-1)}{DF^K(K_\mu-1)^2}$;

$$d_F=\frac{2BK_\mu}{DF^k(K_\mu-1)};e_F=\frac{B}{DF^K}\left(\frac{K_\mu^2}{K_\mu-1}\right);$$

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Solving equation (16), we obtain a general analytical expression of the optimal current at which the power dissipated in an induction motor in frequency-controlled systems is the smallest, and the efficiency is the greatest:

$$\varphi_{OPT} = \sqrt{\frac{в + A}{4} + \sqrt{\left(\frac{в + A}{4}\right)^2 - y\frac{в\varphi - dF}{A}}}, \text{ (17)}$$

in that

$$A = \sqrt{8\varphi + в^2 - 4c_F}; \varphi = \sqrt[3]{-q + \sqrt{q^2 - p^2}} + \sqrt[3]{-q - \sqrt{q^2 + p^3}} + \frac{c_F}{6},$$

here $q = -\left(\frac{C_F}{6}\right)^3 + \frac{C_F(4d_F - в^2) - d_F^2}{16}, p = -\left(\frac{C_F}{6}\right)^2;$

Substituting the obtained values into expressions (1), (11), we can obtain the values of the quantities and indicators of interest to us in the optimal mode. In this case, the electromagnetic loss will be minimal.

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