DIGITAL MODELING OF NON-FULL PHASE AND ASYMMETRICAL OPERATING CONDITIONS OF SUBMERSIBLE MOTORS

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For study of open-phase and asymmetrical operating conditions of submersible motors the digital mathematical model of electric motors have been designed, where machine's equations have been recorded in fixed three-phase coordinate system in suitable for personal computer form.

Key words: **Asymmetric mode, open-phase mode, depth electric motor, digital simulation, three-phase system, computer supply.**

The designed by us digital model of three-phase asynchronous motor's submersible electric pump is presented in [1] and a study of symmetrical operating conditions have been carried out on it. The equations of asynchronous motor of submersible electric pump in fixed three-phase coordinate system are presented in the suitable for personal computer form.

$$\left.\begin{aligned}
p\psi_{s\alpha} &= U_{s\alpha} - \left(r_{s\alpha} + r_{B\alpha}\right)\cdot i_{s_\alpha}\\
p\psi_{s\beta} &= U_{s\beta} - \left(r_{s}\beta + r_{B\beta}\right)\cdot i_{s\beta}\\
p\psi_{s\gamma} &= U_{s\gamma} - \left(r_{s\gamma} + r_{s\gamma}\right)\cdot i_{s\gamma}\\
p\psi_{r\alpha} &= 0{,}577\cdot\psi_{r\gamma}\cdot\omega_r - 0{,}577\cdot\psi_{r\beta}\cdot\omega_r - r_r\cdot i_{r\alpha}\\
p\psi_{r\beta} &= 0{,}577\cdot\psi_{r\alpha}\cdot\omega_r - 0{,}577\cdot\psi_{r\gamma}\cdot\omega_r - r_r\cdot i_{r\beta}\\
p\psi_{r\gamma} &= 0{,}577\cdot\psi_{r\beta}\cdot\omega_r - 0{,}577\cdot\psi_{r\alpha}\cdot\omega_r - r_r\cdot i_{r\gamma}
\end{aligned}\right\} \tag{1}$$

It is necessary to express the currents in terms of magnetic-flux linkage, using herewith the inverse matrix of motor's and electric power network's inductive reactance's

$$\begin{bmatrix} i_{s\alpha}\\ i_{s\beta}\\ i_{s\gamma}\\ i_{r\alpha}\\ i_{r\beta}\\ i_{r\gamma}\end{bmatrix} = \begin{bmatrix}
(x_{s\alpha}+x_{B\alpha}) & -0{,}5x_m & -0{,}5x_m & x_m & -0{,}5x_m & -0{,}5x_m\\
-0{,}5x_m & (x_{s\beta}+x_{B\beta}) & -0{,}5x_m & -0{,}5x_m & x_m & -0{,}5x_m\\
-0{,}5x_m & -0{,}5x_m & (x_{s\gamma}+x_{B\gamma}) & -0{,}5x_m & -0{,}5x_m & x_m\\
x_m & -0{,}5x_m & -0{,}5x_m & x_{r\alpha} & -0{,}5x_m & -0{,}5x_m\\
-0{,}5x_m & x_m & -0{,}5x_m & -0{,}5x_m & x_{r\beta} & -0{,}5x_m\\
-0{,}5x_m & -0{,}5x_m & x_m & -0{,}5x_m & -0{,}5x_m & x_{r\gamma}
\end{bmatrix}^{-1} \begin{bmatrix} \psi_{s\alpha}\\ \psi_{s\beta}\\ \psi_{s\gamma}\\ \psi_{r\alpha}\\ \psi_{r\beta}\\ \psi_{r\gamma}\end{bmatrix} \tag{2}$$

It is necessary to add the equations of electromagnetic torque and motion to equations (1) and (2):

$$m_{ЭМ} = 0{,}866\cdot p_m\cdot x_m\left[\left(i_{s\alpha}\cdot i_{r\gamma} + i_{s\beta}\cdot i_{r\alpha} + i_{s\gamma}\cdot i_{r\beta}\right) - \left(i_{s\alpha}\cdot i_{r\beta} + i_{s\beta}\cdot i_{r\gamma} + i_{s\gamma}\cdot i_{r\alpha}\right)\right] \tag{3}$$

$$\frac{J}{p_m}\cdot p\omega_r = m_{em}\cdot m_r \tag{4}$$

In afore–cited equations the following notations need to be explained.

$U_{s\alpha} = U_s \cdot \sin\tau$; $U_{s\beta} = U_s \cdot \sin(\tau - 2{,}09)$; $U_{s\gamma} = U_s \cdot \sin(\tau + 2{,}09)$ – phase voltages, attached to three–phase stator winding of the motor; τ–time in rad.; *p*–a symbol of time differentiation $\tau = 314 \cdot t$; $r_{s\alpha}$, $r_{s\beta}$, $r_{s\gamma}$, $r_{r\alpha}$, $r_{r\beta}$, $r_{r\gamma}$, $r_{в}$ – the resistances of corresponding stator and rotor windings and also a resistance of external circuit;

$x_{s\alpha}$, $x_{s\beta}$, $x_{s\gamma}$, $x_{в}$ – corresponding inductive reactance's of A(α), B(β) and C(γ) phases and as well the inductive reactances of external circuit;

$\psi_{s\alpha}$, $\psi_{s\beta}$, $\psi_{s\gamma}$, $\psi_{r\alpha}$, $\psi_{r\beta}$, $\psi_{r\gamma}$ – accordingly the magnetic-flux linkages of corresponding stator and rotor phases;

$i_{s\alpha}$, $i_{s\beta}$, $i_{s\gamma}$, $\psi_{s\alpha}$, $\psi_{s\beta}$, $\psi_{s\gamma}$, $i_{r\alpha}$, $i_{r\beta}$, $i_{r\gamma}$, $\psi_{r\alpha}$, $\psi_{r\beta}$, $\psi_{r\gamma}$ – accordingly phase currents and magnetic-flux linkages of stator and rotor loops;

x_m, $x_s = x_{\delta s} + x_m$ – an inductive reactance of mutual induction and apparent inductive reactances of stator winding;

$x_{\delta s}$ – a dispersal inductive reactance of stator winding;

ω_r, p_m, J – accordingly rotor speed, the number of pole pairs and moment of inertia of motor's rotor jointly with pump.

A resistance moment of submersible pump is written in the form of [2]:

$$m_r = m_0 + k_M \cdot \omega_r^2 , \tag{5}$$

where m_o – an initial torque of water pump; $k_м$ – a torque proportionality factor.

Thereby, the equations (1), (2), (3), (4) and (5) constitute the digital three-phase model of water pump's asynchronous submersible motor, allowing to research the non–full phase and asymmetrical operating conditions of system.

Modeling the non–full phase mode, under which the loss of phase of supplying motor voltage on presented model is meant, is realized by increase the corresponding additional resistance, switched in corresponding phase.

This mode have been researched on model for water holes' submersible motor of P_n=11 кW, M_n=72Nm, η=0,875, cosφ=0,87, U_{kq}=220V, I_{kq}=21,5A, r_b=0,46Om, r_r=0,312Om, $x_{\sigma s}$=0,831Om, $x_{\sigma r}$=1,262Om, x_M=27,5Om, s_n=0,028, $2p_m$=4, J_{rot}=0,04kgm^2, J_{mech}=0,065kgm^2.

The study results have allowed drawing the following conclusion: when one of the phases is broken, the currents in other phases increase on 30 %, the fluctuations of torque appear, reaching 25% of initial mode value. It is necessary to note, that the obtained on model results conform well to nature studies, where currents value in remained working phases increases on 33 %.

Besides non–full phase mode the studies of asymmetrical operating conditions have been carried out, for all this two modes have been considered: voltage amplitude asymmetry and amplitude-phase asymmetry. Under symmetrical operating condition the phase voltages change according to following correlations:

$$\left.\begin{aligned} U_{s\alpha} &= U_s \cdot \sin\tau = 1 \cdot \sin\tau \\ U_{s\beta} &= U_s \cdot \sin(\tau - 2{,}09) = 1 \cdot \sin(\tau - 2{,}09) \\ U_{s\gamma} &= U_s \cdot \sin(\tau + 2{,}09) = 1 \cdot \sin(\tau + 2{,}09) \end{aligned}\right\} , \tag{6}$$

$\tau = 314 \cdot t$ – time in rad., 2,09 – a angle in rad. corresponding to 120 electrical degree.

Under pure amplitude asymmetry the study have been carried out for following voltages change

$$\left.\begin{aligned} U_{s\alpha} &= 1{,}11 \cdot \sin\tau \\ U_{s\beta} &= 0{,}85 \cdot \sin(\tau - 2{,}09) \\ U_{s\gamma} &= 1{,}027 \cdot \sin(\tau + 2{,}09) \end{aligned}\right\} . \quad (7)$$

Under amplitude–phase asymmetry the phases have also been changed except amplitude changing:

$$\left.\begin{aligned} U_{s\alpha} &= 1{,}11 \cdot \sin\tau \\ U_{s\beta} &= 0{,}85 \cdot \sin(\tau - 2{,}07) \\ U_{s\gamma} &= 1{,}027 \cdot \sin(\tau + 1{,}88) \end{aligned}\right\} . \quad (8)$$

After processing on PC the calculation results of transient and steady–state conditions the following conclusions are allowed to be drawn. For loading factor of the motor equal to $m_r = 0{,}8 \cdot m_n$ for pure amplitude asymmetry the torque fluctuations exceed $\pm$ 0,5m_r, a current in phase A reaches in relative units value $i_{s\alpha}$=1,2, in phase B $i_{s\beta}$=0,9 and in phase C $i_{s\gamma}$=0,8. For amplitude–phase asymmetry the torque fluctuations do not exceed $\pm$0,15m_r, a current in phase A reaches in relative units a value $i_{s\alpha}$=2, in phase B $i_{s\beta}$=1,4 and in phase C $i_{s\gamma}$=1,4. Thus from a point of view of currents growth the most disadvantage variant is under amplitude–phase asymmetry.

R E F E R E N C E S

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