Investigations of the undamped field effect to the electromagnetic processes in the induction machines

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Abstract- **The results of effect of induction motor un-damped field on transient electromagnetic torques in motor switching regime research are presented in these investigations.**

I. INTRODUCTION

Electric drive during its historical evolution proceeded along the path from common mechanical energy source for one machine or machines group up to "intelligent facility" setting in motion machines and mechanisms parts and these motions control.

However it is to be noticed that nowadays 20-25% of all electric drives only require precise adjustment of speed and torques on continuous and transient regimes under conditions of technological processes. This type of electrical drive evolves towards creation of "intelligent power electromechanical module" [1].

At the same time we'd like to draw your attention to circumstance that the price of power converter in controllable electric drive is 3-5 times more expensive than electric drive itself [2].

Swift development of the electronics and microprocessor technology affected electrical drive information recourses improvement with decreasing of the attention to the energy conversion electromechanical processes in the power circuits [3].

Demands made currently to induction motor drives are linked to motor switching high frequency, operation pulse mode, often reverses and different types of breaking under conditions of stop high accuracy. Neglect to electromagnetic transient processes making analysis of these regimes leads to wrong evaluation of torques acting in electric drive system, considerable mistakes in evaluation of motor losses, accordingly of permissible switching frequency, to inaccuracy in electric drive breaking way estimation etc.

Detailed investigations of electromagnetic transient processes allow more efficiently design induction motor drive systems.

In electric motor drive operation practice there are often happens repeated motor switching in very short time after breaking [8]. For example, using repeated switching regime motor after breaking is fed again. In these conditions electromagnetic transient processes course entailing by number of particular features.

II. PARTICULAR FEATURES OF INDUCTION MOTOR SWITCHING REGIME.

In a number of transient appears the need of registration of electromagnetic processes when stator windings are switched off power supply. Inductive motor during transients creates huge electromagnetic torque which might increase multiple nominal torque even more critical. Thus, it is necessary to investigate torques under transients since in particular these torques initiate appearance of dangerous mechanical exertion in electrical drive kinematical chain [7]. After stator switching off the feeding source the current in the windings rapidly drops to zero. Contrary flux doesn't decrease so rapidly to zero. Accumulated in machine electromagnetic energy is unable to be removed instantly and the trial of the circuit opening leads to overvoltage on the breaking contacts and destroy risk of the equipment. Therefore in rotor windings appear free currents sustaining magnetic flux which existed before switching off. These currents damps in time. If motor switched on again when rotor currents and accordingly magnetic linkage currents not yet damped, naturally these residual or so called undamped rotor currents will influence electromagnetic transient processes flow.

Rotatory and damping rotor magnetic flux induce on the stator terminals an EMF, which damps and having frequency equals to rotor speed of rotation. So, remaining EMF and feeding power voltage might many times coincides in phase (initiating overvoltages) during damping time and comes upon antiphase (minimal voltage on induction motor stator terminals) [5].

For switching devices semiconductor U_{max} might be critical and course death of this device [2]. These circumstances illustrate the necessity of nowadays electrical drives rundown process investigation.

III. INDUCTION MOTOR MATHEMATICAL MODEL INTENDED FOR INVESTIGATIONS OF START UP RUNDOWN AND REPEATED SWITCHING PROCESSES.

For the electromagnetic transient processes investigations it was created multi-purpose program, which allows to research different inductive motor operating regimes: inductive motor start-up regime, inductive motor rundown and induction motor reclosing or switching over.

For listed above regimes modeling it was selected induction motor mathematical model based on complete equations of

Park-Gorev, which are putted down in coordinates rotating synchronously with stator field (coordinates d, q) [4]:

$$U_{1d} = R_1 i_{1d} - \omega_{0el}\psi_{1q} + \frac{d\psi_{1d}}{d\tau}$$

$$U_{1q} = R_1 i_{1q} + \omega_{0el}\psi_{1q} + \frac{d\psi_{1q}}{d\tau}$$

$$U_{2d} = R_2 i_{2d} - (\omega_{0el} - \omega)\psi_{2q} + \frac{d\psi_{2d}}{d\tau}$$

$$U_{2q} = R_2 i_{2q} + (\omega_{0el} - \omega)\psi_{2q} + \frac{d\psi_{2q}}{d\tau}$$

(1)

$$T_M \frac{d\omega}{d\tau} = [M_{em} - M_l],$$ (2)

$$\psi_{1d} = X_1 i_{1d} + X_{ad} i_{2d}$$
$$\psi_{1q} = X_1 i_{1q} + X_{ad} i_{2q}$$
$$\psi_{2d} = X_2 i_{2d} + X_{ad} i_{1d}$$
$$\psi_{2q} = X_2 i_{2q} + X_{ad} i_{1q}$$

(3)

Where:

T_M - time constant of the machine in electrical radians;

$M_{em} = X_{ad}(i_{2d}i_{1q} - i_{2q}i_{1d})$ - the electromagnetic torque;

$u_{1d}, u_{1d}, u_{2d}, u_{2q}$ - are components of stator and rotor voltage;

$u_{2d} = u_{2q} = 0$ for induction motor with a squirrel-cage rotor;

$\psi_{1d}, \psi_{1q}, \psi_{2d}, \psi_{2q}$ - are components of flux linkages;

$i_{1d}, i_{1q}, i_{2d}, i_{2q}$ - are components of stator and rotor currents;

ω - is angular rotation speed of rotor;

ω_{0el} - is angular rotation speed of coordinate system;

$X_1, X_2, X_{ad}, R_1, R_2$ - are parameters of the induction motor;

M_{em}, M_l - are electromagnetic torque and load torque.

Solving equation (1) using substitutions (3) relative to current derivative and using signed numbers we get:

$$\frac{dI}{dt} = AI + CU_1,$$ (4)

$$\frac{d\omega}{dt} = \frac{1}{T_M}[X_{ad}(i_{1q}i_{2d} - i_{1d}i_{2q}) - M_l],$$ (5)

where I - column matrix of the induction machine current components;
U_1 - column matrix of the stator voltage components.
A, C - matrixes of coefficients.

$$A = \begin{bmatrix} -c_1 r_1 & +c_1 f_1 & +c_2 x_{ad} & +c_1 x_{ad} \\ -c_1 f_1 & -c_1 r_1 & -c_1 x_{ad} & +c_2 x_{ad} \\ c_3 r_1 & -x_1 & -c_2 x_1 & -f_3 \\ x_1 f_2 & +c_3 r_1 & +f_3 & -c_2 x_1 \end{bmatrix};$$

$$C = \begin{bmatrix} c_1 & 0 & 0 & 0 \\ 0 & c_1 & 0 & 0 \\ 0 & 0 & -c_3 & 0 \\ 0 & 0 & 0 & -c_3 \end{bmatrix}.$$

Where:

$$C_1 = \frac{1}{x'_d} = \frac{1}{x_1 - \frac{x_{ad}^2}{x_2}}$$

$$f_1 = (x_1 - \frac{x_{ad}^2}{x_2})\omega_{0el} - \frac{x_{ad}^2}{x_2}\omega$$

$$C_2 = \frac{r_2}{x_2}C_1$$

$$f_2 = \omega C_3$$

$$C_3 = \frac{x_{ad}}{x_2}C_1$$

$$f_3 = (C_1 x_1 \omega - \omega_{0el})$$

For rundown regime modeling we make following admission: stator current losing power supply drops to zero, i.e.

$$i_{1d} = i_{1q} = 0.$$ (6)

From combined equations which are modeling induction motor start up we get differential equations, defining induction motor rundown regime:

$$\frac{di_{2d}}{dt} = -c_2 x_1 i_{2d} - f_3 i_{2q};$$ (7)

$$\frac{di_{2q}}{dt} = f_3 i_{2d} - c_2 x_1 i_{2q};$$ (8)

$$\frac{d\omega}{dt} = -\frac{1}{T_M}M_l.$$ (9)

Voltage inducted by rotor damping field on the terminals of stator windings we get from first two equations (4):

$$U_{res_d} = -x_{ad}\omega i_{2q} - \frac{r_2 x_{ad}}{x_2}i_{2d};$$ (10)

$$U_{res_q} = x_{ad}\omega i_{2d} - \frac{r_2 x_{ad}}{x_2}i_{2q}.$$ (11)

This multi-purpose model using allows researching the electromagnetic, mechanical and energetic parameters of inductive motors, and complete electric drives as well.

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IV.   MODELING AND ANLYSIS OF GOT RESULTS

For modeling of induction motor start-up regime, induction motor rundown and induction motor reclosing regimes it was applied catalog data of induction motor (4A355M4У3) with following parameters [6]: P_{2N}=315kW, n_N=1500min-1, X_μ=5.7, R'_1=0.012, X'_1=0.099, X_S=5.799, R''_2=0.014, X''_2=0.14, $X_{k.p.}$=0.16, R_{2p}=0.027, $R_{k.p.}$=0.039.

Investigations shows that after induction motor switching off from power supply rotor continue to rotate. Thus damping field inducts on the stator terminals electromotive forces, which also damps in time. On the figure 1 it is presented hodograph of residual voltage on the stator terminal. On the figure 2 we could see that the residual voltage permit damping nature.
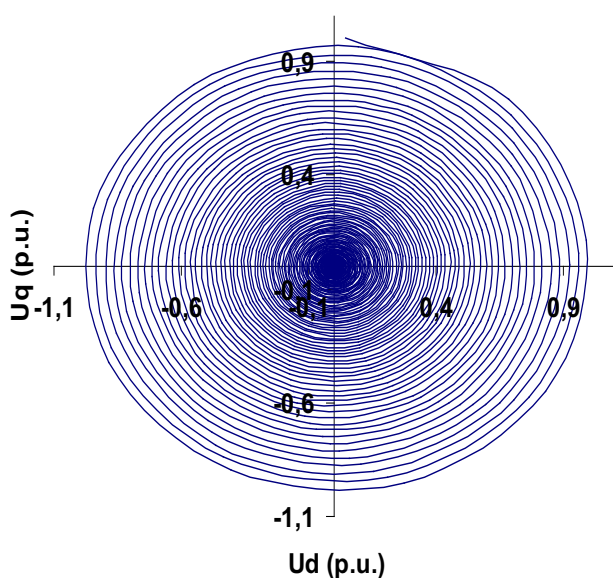
processes. For that let us consider effect of power supply switching phase on electromagnetic transient processes.

After induction motor switching off feeding voltage vector continue to rotate with constant synchronous rotation speed. Therefore depending on switching interval duration (interval without current) feeding power and residual voltage on the induction motor terminals vectors at the moment of repeated switching might takes stand in the area various mutual matching , but after repeated induction motor switching on they always return to stable mutual matching accordingly to run position of regime for concrete rotor rotation speed. The less mutual matching in repeated switching moment differ from stable regime mutual matching, the less is motor magnetic flux alteration and consequently the less transient components of the torque.

Fig. 1. Residual voltage hodograph.

Fig. 2. Residual voltage curve

Fig. 3. Electromagnetic torque alteration curve for inductive motor repeated switching after 0.005s

Fig. 4. Electromagnetic torque alteration curve for inductive motor repeated switching after 0.01s
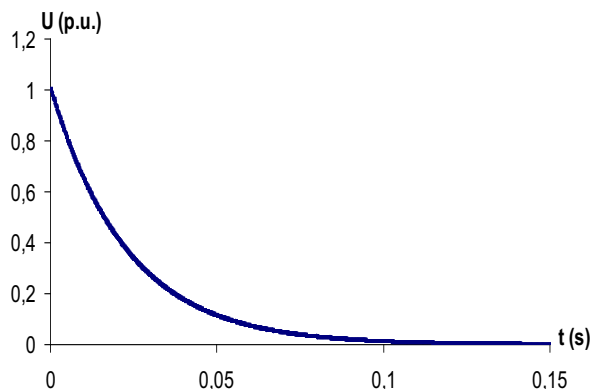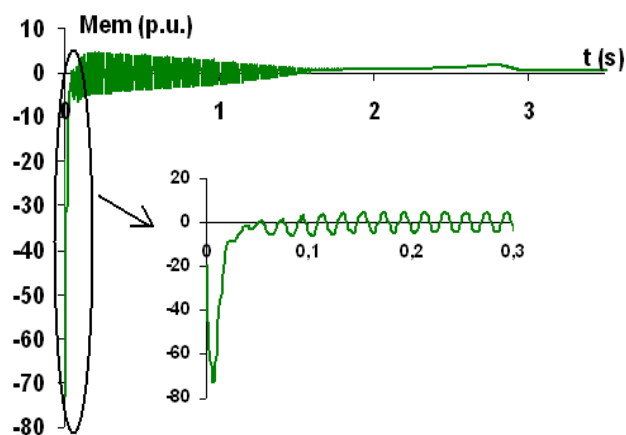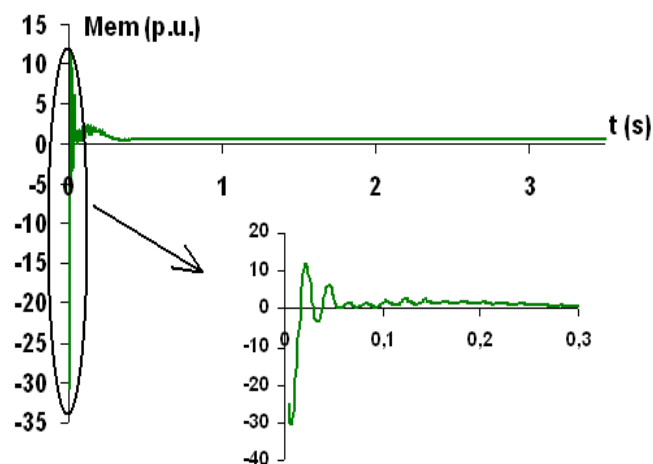
In purpose to evaluate the effect of damping field let us make analysis of influence of electromotive force on transient

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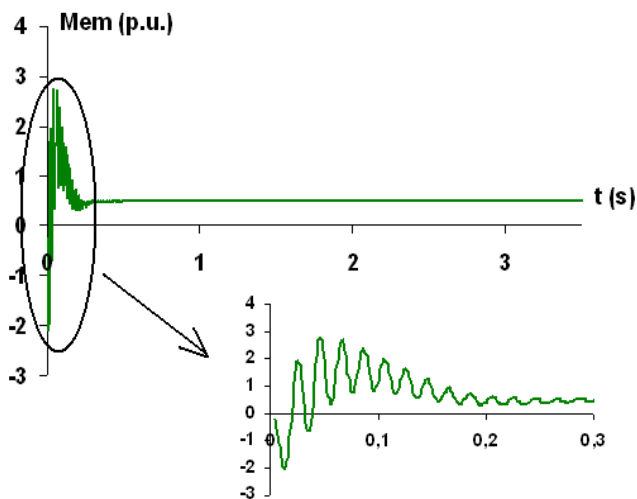Electrical Machines and Apparaturs / Elektriskās Mašīnas un Aparāti

Fig. 5. Electromagnetic torque alteration curve for inductive motor repeated switching after 0.1s

Presented on the figures 3 – 5 curves reflect torque alteration character for repeated motor switching on. Investigations show that rotor rotation speed alteration on repeated switching on regime (Fig. 6) effects only transient process first peak amplitude and torques transient components decay time. It is distinctly seen on the fig. 3. The less drive inertia and the more acceleration in repeated switching on process, the less is transient torque first and following peaks amplitude and peaks quantity.
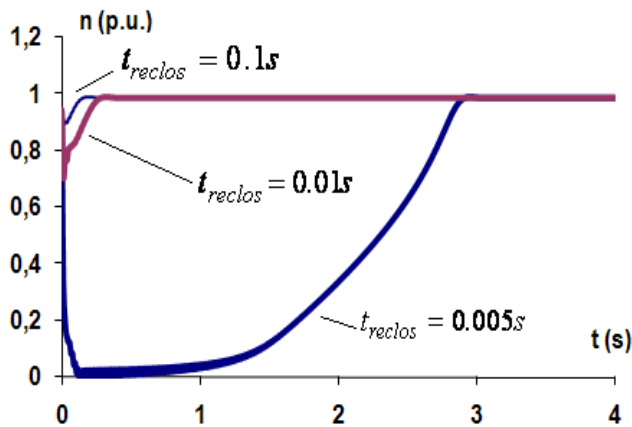

Fig.6. Rotor rotation speed alteration curve for inductive motor repeated switching

Appearance of negative transient torque on repeated switching on might be clarified by occurrence that during the time between switching on and switching off rotor damping flux vectors have time to substantially change mutual matching. Effected by this breaking torque motor rotation speed substantially decelerates, and after torque come in plus appears similar transient process like at the start up ending stage.

V. CONCLUSIONS

Created multi-purpose program allows make complete analysis of the electromagnetic transient processes for induction motor on repeated switching on for different type of switching.

Executed investigations analysis shows that electromagnetic transient process nature on repeated switching on is effected by magnetic flux value, which couldn't decrease instantly to zero after motor switching off power supply.

Fast-acting automation usage is advisable if there is opportunity to control power supply voltage phase and its comparison with residual voltage phase. Otherwise fast-acting automation is not advisable because of for every motor depending on its internal parameters, load characteristic there exists individual time interval during which appears residual EMF damp. If fast-acting switching automation applied, there is possibility to meet antiphase. That could lead to induction motor accident.

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