Considerations Regarding Asynchronous Motors Control by the Stator Flux

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Abstract—**This paper analyzes the transient regime evolutions of the most important quantities characterizing the operation of the asynchronous motors controlled by the stator flux. In this purpose there are detailed the mathematical model when considering the saturation, the simulation program and several graphic results. The paper finishes with experimental results confirming the simulations validity and with conclusions regarding the motor parameters influences on the analyzed transient processes.**

Index Terms—**Control, asynchronous motor, mathematical model, experimental results, industrial robot**

I. INTRODUCTION

The asynchronous motors are ones of the most used motors for driving industrial robots. They have to be controlled so that to allow to obtain an as fast and precise as possible answer. One of the control methods ensuring this desideratum is the one of the on field orientation, particularly on the stator flux.

In order to catch correctly the machine behaviour in this case it is imposed first of all to use an as complete as possible mathematical model, preferably considering the magnetic saturation.

The consideration of the saturation on the main field way is a major preoccupation in the literature [5], [6], [9] etc. The saturated machines analysis usually operates with the currents or the stator and rotor fluxes as state variables.

Mixed combinations of state variables currents-fluxes have been also taken into consideration. The mixed mathematical models are proved to be most suitable in the effective vectorial control of the induction machine or to the implementation of some types of estimators.

II. MATHEMATICAL MODEL

Further on the mathematical model of the induction machine saturated on the main flux way will be used in the general form [1]

$$U_{dq} = A\frac{dX_{dq}}{dt} + BX_{dq} \qquad (1)$$

where

$$U_{dq} = [u_{ds} \quad u_{qs} \quad 0 \quad 0]^T \text{ and}$$
$$X_{dq} = [X_{sd} \quad X_{sq} \quad X_{rd} \quad X_{rq}]^T,$$

X_{sd}, X_{sq}, X_{rd}, X_{rq} being the projections on the d, q axes of the currents and fluxes taken as state variables.

By considering

$$\underline{i}_m = i_{md} + ji_{mq}$$
$$\underline{\Psi}_s = \Psi_{sd} + \Psi_{sq}$$
$$X_{dq} = [i_{md} \quad i_{mq} \quad \Psi_{sd} \quad \Psi_{sq}]$$

and the matrix A and B get the form

$$A = \begin{vmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ L_{r\sigma} + K_\sigma L_{dd} & K_\sigma L_{dq} & 1 - K_\sigma & 0 \\ K_\sigma L_{dq} & L_{r\sigma} + K_\sigma L_{qq} & 0 & 1 - K_\sigma \end{vmatrix} \qquad (2)$$

$$B = \begin{vmatrix} -R_s\frac{L_m}{L_{s\sigma}} & 0 & \frac{R_s}{L_{s\sigma}} & -\omega_B \\ 0 & -R_s\frac{L_m}{L_{s\sigma}} & \omega_B & \frac{R_s}{L_{s\sigma}} \\ R_r\frac{L_s}{L_{s\sigma}} & (\omega_B - \omega)(L_{r\sigma} + K_\sigma L_m) & -\frac{R_r}{L_{s\sigma}} & -(\omega_B - \omega)(1 - K_\sigma) \\ (\omega_B - \omega)(L_{r\sigma} + K_\sigma L_m) & R_r\frac{L_s}{L_{s\sigma}} & (\omega_B - \omega)(1 - K_\sigma) & -\frac{R_r}{L_{s\sigma}} \end{vmatrix}$$

where $K_\sigma = 1 + \frac{L_{r\sigma}}{L_{s\sigma}}$.

The inductivities L_{dd}, L_{qq}, L_{dq} are computation quantities dependent on saturation and reference frame having the forms

$$\begin{aligned} L_{dd} &= L_{mt}\cos^2\varphi + L_m\sin^2\varphi \\ L_{qq} &= L_{mt}\sin^2\varphi + L_m\cos^2\varphi \\ L_{dq} &= (L_{mt} - L_m)\sin\varphi\cos\varphi \end{aligned} \qquad (3)$$

In the previous equations there have been noted:

$\underline{u}$, $\underline{i}$, $\underline{\psi}$ - the representative proper phasors of the voltages, currents and fluxes; the index *r, s* refer to the stator and rotor; the index *m*, σ refer to the main field and the leakage field respectively; L_s, L_r, L_m are the main cyclical inductivities and L_{mt} the differential cyclical inductivity; R_s, R_r the phase windings resistances; ω_B, ω - the electrical angular speed of the d, q, orthogonal axes system and of the rotor, respectively.

The rotor quantities are related to the stator and the rotor winding is considered in short-circuit.

In addition, the following relation gives the electromagnetic torque:

$$M = \frac{3}{2} p \operatorname{Re}(j\underline{\psi}_s \underline{i}_s^*) = \frac{3}{2} p \operatorname{Re}\left(j\underline{\psi}_s \cdot \frac{\underline{\psi}_s^* - L_m \underline{i}_m^*}{L_{s\sigma}} \right)$$

and by computing

$$M = \frac{3}{2} p \frac{L_m}{L_{s\sigma}} (\psi_{sq} i_{md} - \psi_{sd} i_{mq}) \qquad (4)$$

The relations (1) – (4) are general valid and applicable to the analysis of a large range of dynamic regimes. They ensure a high precision for the determinations by taking into consideration the saturation in a relative simple way. The matrixes A, B from (1) get a convenient form for numerical solutions.

III. RESULTS AND CONCLUSIONS

The block scheme of such a drive system is depicted in the Fig. 1.

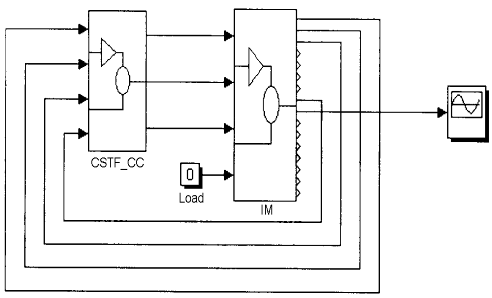


Fig. 1 Block scheme of drive system with induction motor in the studied case

The IM block structure, corresponding to the induction (asynchronous) motor, has been obtained with the help of the equations (1)-(4).

The block CSTF_CC has the structure from the Fig. 2.

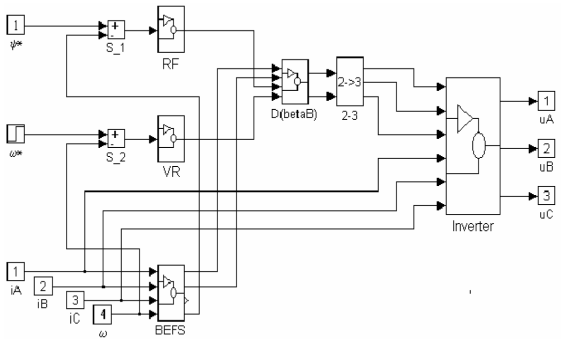


Fig. 2 Simulink model of the analyzed converter

The inverter that has been used is a PWM one with sinusoidal currents (Fig. 3). It compares the reference currents on the three phases with the real values of the measured currents (the blocks S_A, S_B and S_C), the obtained errors supplying further on some hysteresis comparators (H_A, H_B, H_C) that control the commutation of the inverter elements.

For a safe commutation of the elements belonging to a bridge phase it is necessary to achieve a delay by means of the blocks TD_A, TD_B and TD_C.

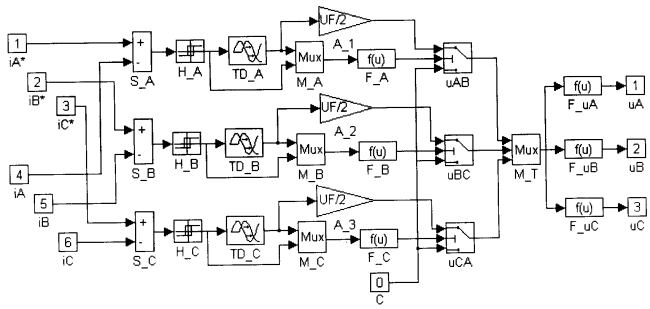


Fig. 3 Structure of the PWM inverter with sinusoidal currents

The waveforms of the line voltages are provided to the output of the commutators uAB, uBC and uCA and those ones of the phase voltages to the connectors 1, 2 and 3. In order to obtain these waves, the functions implemented in the structures of the blocks F_A, F_B, F_C, respectively F_uA, F_uB and F_uC, have the following forms:

F_A, F_B, F_C:	1-abs(u[1]-u[2])
F_uA:	(2*u[1]-u[2]-u[3])/3
F_uB:	(2*u[2]-u[1]-u[3])/3
F_uC:	(2*u[3]-u[1]-u[2])/3

The justification of the forms for the functions F_A, F_B and F_C is given in Fig. 4.

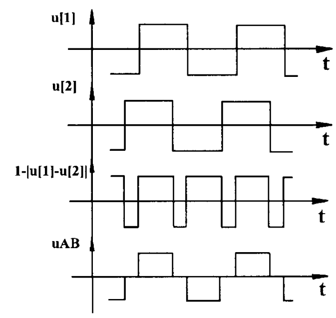


Fig. 4 Explanatory regarding the line voltages modeling

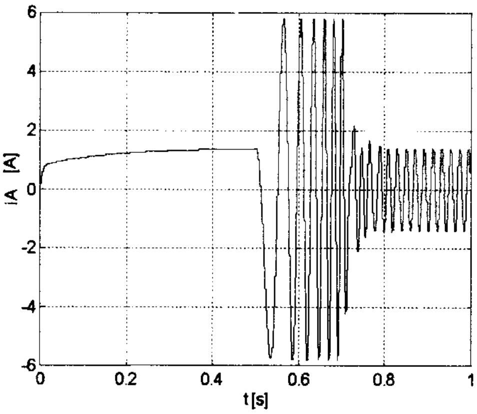
IV. SIMULATIONS

By using the program we presented before there has been simulated the studied system behavior for the case of the no-load starting by saltus variation of the speed reference.

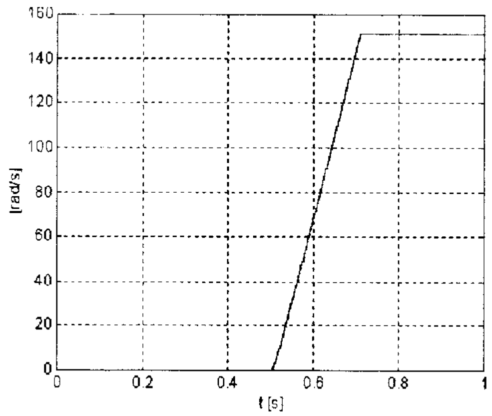
This way, the following representations have been obtained (Fig. 5).

Further on the induction motor parameters have been modified by turns and their influences on the dynamic regime have been analyzed.

Thus, for example, the following figure presents the time evolutions of the A phase current for two values of the rotor resistance (Fig. 6).



a) i_A=f(t)



b) Ω =f(t)

Fig. 5 Variations of the main electrical and mechanical quantities of the converter-motor system during the transient regime

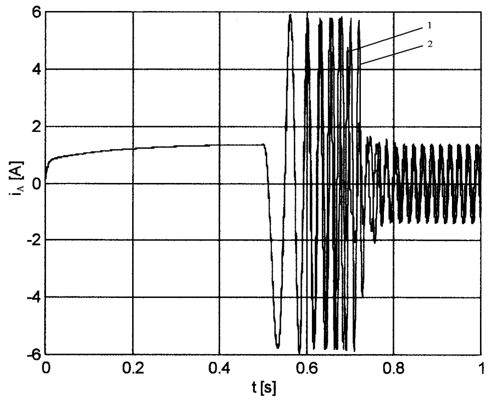


Fig. 6 Current variations for two values of the rotor resistance

By analyzing these representations it is observed that a decrease of the rotor resistance leads to the increase of the stabilization time.

By doing analogously with the other parameters the following conclusions may also be emphasized:

- the increase of the leakage rotor inductivity value also involves the increase of the transient process duration;
- the main inductivity decrease determines a faster stabilization of the process;
- at the same time with the increase of the leakage stator inductivity value, the duration of the transient process increases;
- the stator resistance decrease increases very little the duration of the currents transient process.

V. EXPERIMENTAL RESULTS

The Figs. 7 and 8 present the stator experimental rotor speed and the current obtained at the starting command by the stator flux.

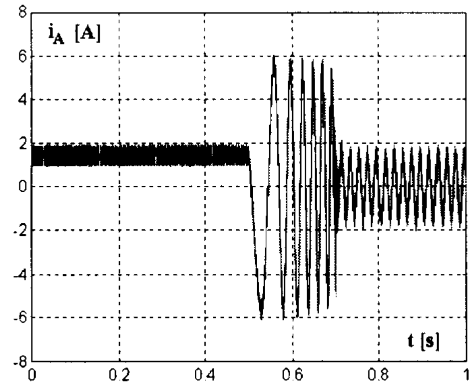


Fig. 7 Time variation of the A phase current

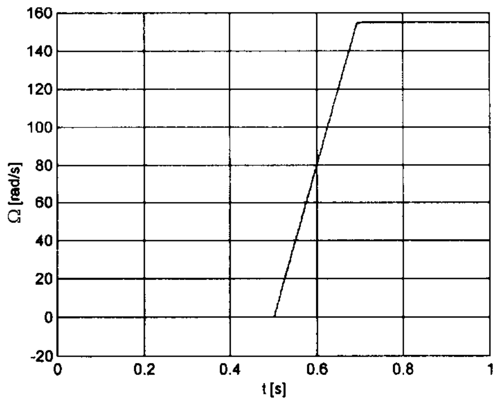


Fig. 8 Speed characteristic

By comparing these graphics with those from the Fig. 5 the validity of the conclusions presented before is confirmed.

Both the simulations and the experimental tests have been carried out for an induction motor having the following data: $R_s = 8{,}35\ \Omega$, $R_r = 5{,}92\ \Omega$, $L_{s\sigma} = 0{,}032$ H, $L_{r\sigma} = 0{,}032$ H, J=0,014 $kg \cdot m^2$, rated voltage U_{1N}=220/380 V, rated current $I_{1N} = 5{,}02/2{,}9A$, rated frequency f_{1N}=50 Hz, rated speed n_N=1405 r.p.m.

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