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A Field Oriented Based Method for Speed Control of Asynchronous Motor

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Abstract

Because of development of the power electronics in the branch of frequency converters, the drives with variable speed with asynchronous motors required today a great interest.The systems of vector control of the asynchronous motors, based on the field oriented principle, having accomplished the separate command of the magnetic flux and of the torque.
The paper presents the modeling and simulation of a new system of speed control of the asynchronous motor, oriented by the rotor flux. Followed a Matlab Simulink simulation one can observe the accuracy of the responses in speed and torque of the motor and underline the advantages of the method.

Key words: *speed control, simulation, asynchronous motor*

Introduction

Depending on the technological process in which they function and on the power of the motor, the automatic electric drives must accomplish a large variety of demands as follows:

- the continuous control of the speed and of the torque;
- the reduction to the minimum of the errors and diminishing the transitory process, when the controlling variables and the perturbatory ones modify;
- the stability of the system;
- the maximum efficiency of the energy conversion.

These demands can be satisfied with the help of the automatic control systems of the asynchronous motors, where the electric motor is supplied with the help of the frequency converters.

For the determination of the control circuits structure and the study of their stability as part of the variable speed drives it is necessary to know the static and dynamic behaviour of the driving electric motor. In the same way, for the simulation of the control systems, it is imperative a mathematical model of the asynchronous machine which can determine in an accurate way the dynamic behaviour, but also to use the parameters that can be identified by off-line and on-line methods. The study of the speed control of the asynchronous motor by considering the reference frame (k) rotating synchronously and with the same phase with one of the three space phasors of the fluxes: from stator, from rotor or from air gap, has the name of *flux oriented control*.

The Mathematical Model of the Asynchronous Motor

The mathematical model of the asynchronous motor can be described by the following system:

$$\begin{cases} u_{sq} = R_s i_{sq} + \dfrac{d}{dt}\psi_{sq} + \omega\psi_{sd} \\ u_{sd} = R_s i_{sd} + \dfrac{d}{dt}\psi_{sd} - \omega\psi_{sq} \\ u'_{rq} = R'_r i'_{rq} + \dfrac{d}{dt}\psi'_{rq} + (\omega - \omega_r)\psi'_{rd} \\ u'_{rd} = R'_r i'_{rd} + \dfrac{d}{dt}\psi'_{rd} - (\omega - \omega_r)\psi'_{rq} \\ M = 1{,}5p(\psi'_{rq} i'_{rd} - \psi'_{rd} i'_{rq}) \\ M = J\dfrac{d}{dt}\omega_m + F_v\omega_m + M_2 \end{cases}, \quad (1)$$

where:

$$\begin{cases} \psi_{sq} = L_s i_{sq} + L_m i'_{rq} \\ \psi_{sd} = L_s i_{sd} + L_m i'_{rd} \\ \psi'_{rq} = L'_r i'_{rq} + L_m i_{sq} \\ \psi'_{rd} = L'_r i'_{rd} + L_m i_{sd} \\ L_s = L_{\sigma s} + L_m \\ L'_r = L'_{\sigma r} + L_m \end{cases}. \quad (2)$$

It is given the following notation: u – voltage; i – current; Ψ – magnetic flux; L – inductance; R – electric resistance; M – electromagnetic torque; M_2 – load torque; J – the inertia coefficient; F_v – the viscous friction coefficient; ω – the supply voltage pulsation; ω_r – the pulsation of the electrical rotor quantities; ω_m – the rotor angular speed; p – number of pole pairs.
The used subscripts have the next correlation: q – on the q axes; d – on the d axes; s – stator quantity; r – rotor quantity; σ – of leakage; m – of magnetization.
All electrical rotor variables and parameters are referred to the stator, being noted by ’ sign..

Orientation after the rotor flux

By choosing the rotating reference frame (k) synchronously and in phase with the phasor of the rotor flux $\underline{\psi}'_r$, with the axes d all along this phasor [3], the model of the asynchronous machine becomes particular for $\psi'_{rd} = \psi'_r$ and $\psi'_{rq} = 0$. By eliminating the components of the rotor current phasor, i'_{rq} and i'_{rd}, there are obtained the expressions of the variables ψ'_r , M and ω-ω_r according to the components of the stator current phasor under the form:

$$\begin{cases} \psi'_r = L_m i_{sd} - T_r\dfrac{d\psi'_r}{dt} \\ M = 1{,}5p\dfrac{L_m}{L'_r}\psi'_r i_{sq} \\ \omega - \omega_r = R'_r\dfrac{L_m}{L'_r}\dfrac{1}{\psi'_r}i_{sq} = \dfrac{M}{1{,}5p}\dfrac{R'_r}{\psi'^2_r} \end{cases}. \quad (3)$$

where $T_r = L'_r/R'_r$ is the time constant of the rotor circuit. From the relations (3) one can observe that in the case of the rotor flux orientation, the machine is completely decoupling on the two axis *d-q* and the projections of the $\underline{i}_s$ phasor on these axis are *controlling variables*:

- i_{sd} (reactive current) - is controlling the flux from the rotor ψ'_r;
- i_{sq} (active current) - is controlling the electromagnetic torque *M*.

The Simulation of the Scheme of Variable Speed Electric Drive

To analyze the way in which the rotor flux oriented based method for speed control of the asynchronous motor works, it was realized the Matlab Simulink scheme from Fig.1. A characteristic of the scheme is the fact that it calculates the rotor flux on the ground of the measurement of the stator currents and of the motor speed *n*, after the so called *flux estimation model* ($\underline{i}_s$, *n*) *in field coordinates d-q* [4].

The supply of the asynchronous motor is made from a three phase alternative voltage source with the help of the equipment formed by: *three phase rectifier*, *DC intermediate circuit* and *controlled three phase inverter*, elements which are introduced in Simulink scheme through Sim Power Systems pre-definite blocks.

The command part of the scheme contains principally: *the speed controller* and the system called *Field oriented control*, which calculates the command signals which are applied to activate the inverter switches.

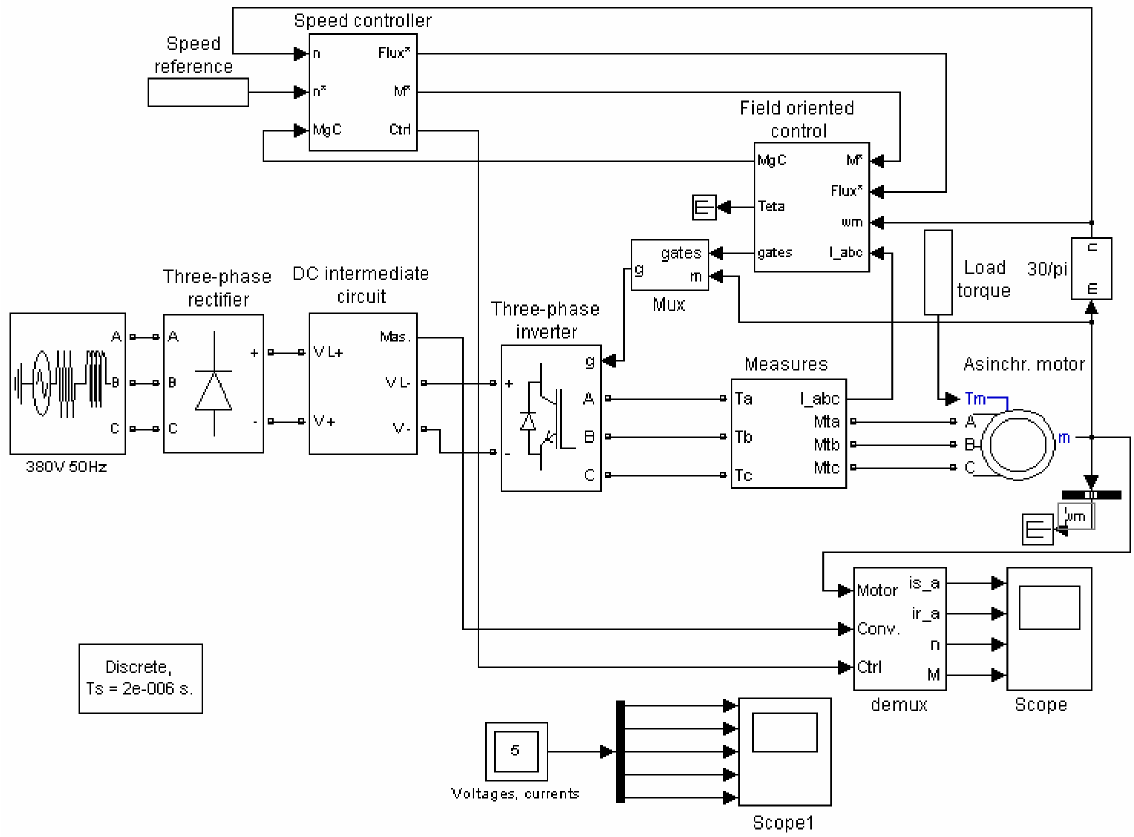

Fig. 1. The Simulink scheme of the electric drive of the asynchronous motor

The speed controller

The speed controller, based on a PI regulator, was simulated on the ground of the operating principle from Fig. 2. It calculates the variable *Torque** on the ground of the absolute error between the prescribed speed n^*, after passing from *the speed ramp* (where the acceleration and deceleration values are established) and the real speed *n* of the motor. The reference value of the rotor flux, notated *Flux**, results at the exit of a *flux generator*. Both variables, *Torque** and *Flux** become input variables for the *Field oriented control system*.

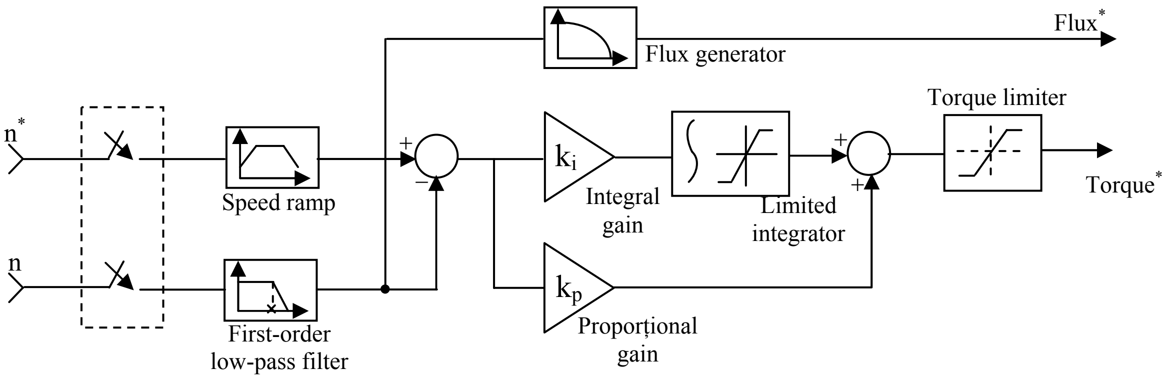

Fig. 2. The operating principle of the speed controller

The field oriented control system

On the ground of the system of equations (3), corresponding to the orientation after the rotor flux, it was realized the simulation scheme of the control system, presented in Fig. 3. It contains a rotor flux estimator, composed of the blocks: *abc-dq, Flux calculation* and *Teta calculation*. The outputs of the estimator are the modulus and the angular position of $\underline{\psi}_r'$.

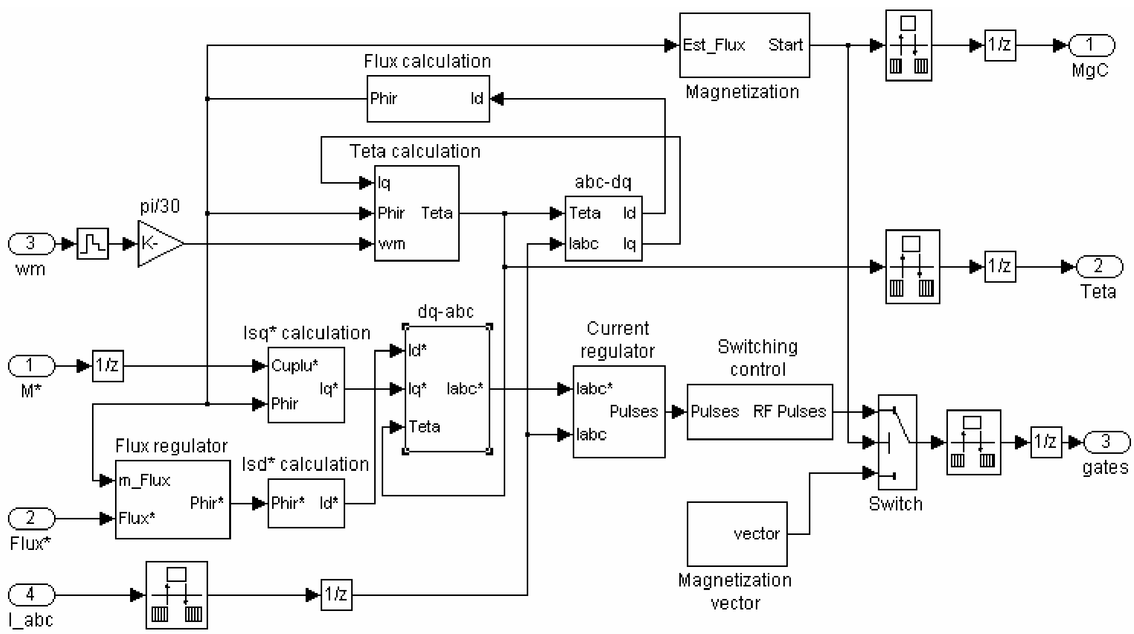

Fig. 3. The Simulink scheme of the *Field oriented control system*

The blocks named i_{sq}^* *calculation* and i_{sd}^* *calculation* compute the quadrature components of the prescribed stator current, using the expression of the torque and flux from (3). The *dq-abc* block calculates the prescribed stator currents i_{sa}^*, i_{sb}^*, i_{sc}^* using *the inverse matrix of Park transformation* [4]. The measured currents i_{sa}, i_{sb}, i_{sc} and those prescribed i_{sa}^*, i_{sb}^*, i_{sc}^* enter in a *current regulator* wich calculate the command pulses of the commutation. Being these pulses or those created by the *Magnetization vector* block (necessary to creation of the motor initial flux) are taken to the output of the control system, being send to the three phase inverter.

The Simulation Results

It was made simulations for an asynchronous motor with squirrel-cage rotor, with following parameters: $P_n = 3$ kW, $U_n = 380$ V, $f_n = 50$ Hz, $p = 3$, $n_n = 965$ rpm, cosφ = 0.79, $J = 0{,}035$kgm^2, $F_v = 0{,}0028$ Nms, $R_s = 1{,}69$ Ω, $L_{\sigma s} = 0{,}0048$ H, $R'_r = 2{,}29$ Ω, $L'_{\sigma r} = 0{,}022$ H, $L_m = 0{,}1579$ H.

The parameters of simulation are:

- *time of simulation*: 2s,
- *the speed reference*: $n^* = [500\ 900]$ rpm at $t = [0\ \ 1]$ s, with acceleration ramp1800 rpm/s
- *the load torque*: $M_2 = [0\ \ 7\ \ 14]$ Nm at $t = [0\ \ 0{,}5\ \ 1{,}7]$ s, with step variation.

The way of variation of the main quantities, specific to the electric drive, is presented in Fig. 4. One can observe that:

- *the motor speed n follows* in an accurate way *the reference speed* n^* on the landing portions but also in the ramp zones; the fluctuations of the *n speed* until the stabilization on a new value are limited in an *oscillating damped regime* that lasts almost 0,02 s;
- all the modifications of the value of the calculated *electromagnetic torque* M^* and of the real one *M* are made in an *oscillating regime* which are *damped* extremely rapid (0,025s).

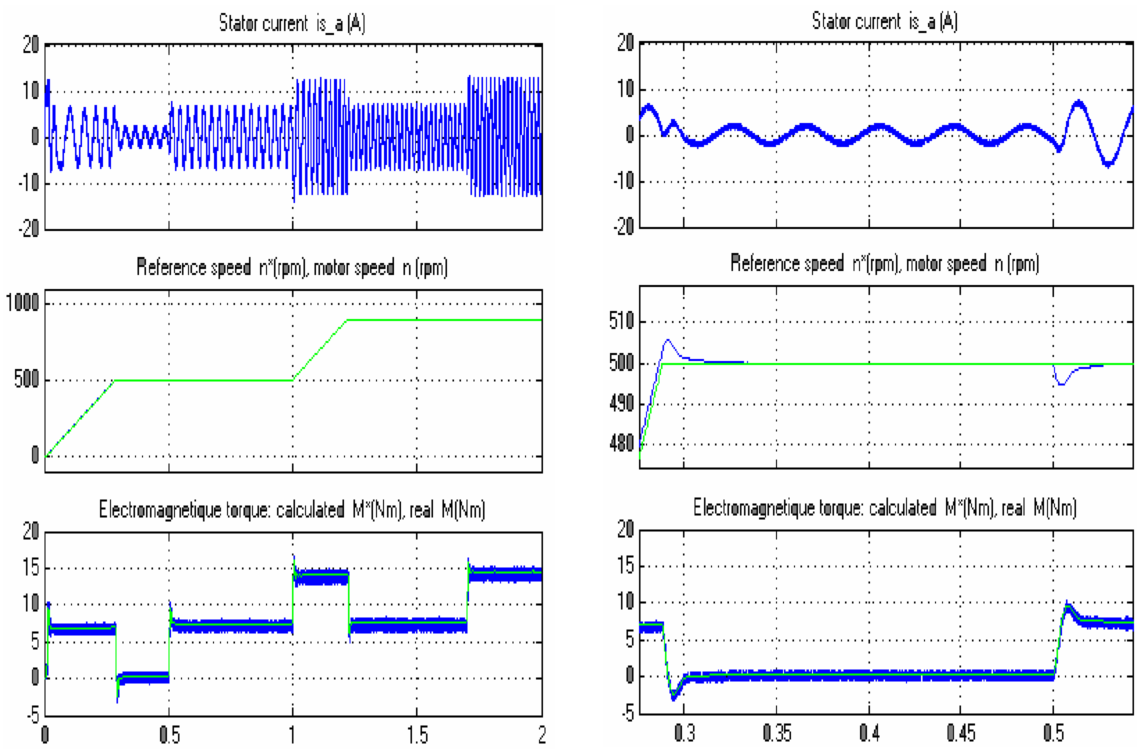

Fig. 4. The variation of the main quantities at the drive simulation: **a.** ensemble **b.** detail

Conclusions

The paper presents a rotor flux oriented based method for speed control of the asynchronous motor, which having accomplished the separate command of the magnetic flux and of the torque by the stator current quadrature components.

Followed a Matlab Simulink simulation it was underlined a few of its advantages:

- the decoupling of the control circuit after *d-q* axis;
- the rapid response of the motor at variations of speed reference or load torque;
- the stability in functioning.

These make the method advisable in precisely drives as there are: the driving of the tool machines with numerical command, the industrial robot driving, the synchronized position driving and others.

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Metodă bazată pe principiul orientării după câmp pentru controlul turaţiei motorului asincron

Rezumat

Datorită dezvoltării electronicii de putere în domeniul convertizoarelor de frecvenţă, acţionările de turaţie variabilă cu motoare asincrone au devenit astăzi de larg interes. Sistemele de reglare vectorială a motoarelor asincrone, bazate pe principiul orientării după câmp, realizează comanda separată a fluxului magnetic şi a cuplului.

Articolul prezintă modelarea şi simularea unui nou sistem de reglare vectorială a motorului asincron, orientat după fluxul rotoric. În urma simulării în Matlab Simulink se remarcă acurateţea răspunsurilor în turaţie şi cuplu ale motorului şi se pun în evidenţă avantajele acestei metode.