Performances of Gopinath Flux Observer Used in Direct Field Oriented Control of Induction Machines

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***Abstract*—In this paper there are outlined the automatic speed adjusting control system performances of a two-phase induction machine (TPIM) with direct field oriented control and using adaptive methods for the estimation of the rotoric flux spatial vector. Starting from the linear model of the two-phase induction machine, there are studied in comparison two solutions used in automatic speed adjusting control: one using the deduction of the spatial vector components of the rotoric flux by indirect field determination and the second using adaptive methods for rotoric flux spatial vector estimation from the two-phase components of the stator voltage and current. Thus there are emphasized the performances of the reduced order Gopinath observer. The operation of the automatic speed adjusting control system, based on solid adaptive estimation of the rotoric flux and indirect determination of the field, was studied using Matlab/SIMULINK real time simulation.**

***Index Terms*—two-phase induction machine, direct field oriented control, Gopinath flux observer, adaptive estimation, Matlab/Simulink.**

I. INTRODUCTION

In the area of asynchronous motor operation, the achievement of a competitive product is based on using complex adjusting control designs. These systems are implemented digitally. The digital solution can be applied directly on numerous digital control systems just by modifying the programs. In this category of actuation there are used solid adaptive estimators, a more recent method for determining the rotoric flux spatial vector. The design for such type of observers is based on the combination of a simulator with an error corrector, [1].

In this paper it will be detailed the problem of rotoric flux estimation for a two-phase induction machine and to obtain a direct field oriented control of this flux. This method consists in independent control of rotoric flux and speed using a reference system tied with this flux, [2]. An essential role in this adjusting control is played by the flux observer which calculates the position of the rotoric flux towards the reference mark and its module, used as a closed-loop value in the flux loop.

The performances of the system will be shown using the comparison with the situation in which the rotoric flux results from indirect determination of the air gap field.

II. MATHEMATICAL MODEL

The design of the direct field oriented control with flux observers is implemented considering the linear model of the induction machine represented into a d-q reference system tied with the stator and considering the rotoric speed steady, [2]-[3].

For evaluating the model of the two-phase induction machine using complex values, we start from the state equation definition,

$$\begin{cases} \dfrac{dX}{dt} = A \cdot X + B \cdot u \\ Y = C \cdot X + D \cdot u \end{cases} \tag{1}$$

where,

$$A=\begin{bmatrix} -\dfrac{R_s}{\sigma L_s}-\dfrac{R_r(1-\sigma)}{\sigma L_r} & \dfrac{L_m}{\sigma L_s L_r}\left(\dfrac{R_r}{L_r}-j\omega_r\right) \\ \dfrac{L_m R_r}{L_r} & -\dfrac{R_r}{L_r}+j\omega_r \end{bmatrix},$$

$$B=\begin{bmatrix} \dfrac{1}{\sigma L_s} \\ 0 \end{bmatrix}, \qquad X=\begin{bmatrix} i_s \\ \Psi_r \end{bmatrix} \tag{2}$$

it is considered $\sigma = 1-\left(\dfrac{L_m^2}{L_s L_r}\right)$

The state variables used in (1) are,

$$\begin{aligned} i_s &= i_{sd} + j i_{sq} & i_r &= i_{rd} + j i_{rq} \\ \Psi_s &= \Psi_{sd} + j\Psi_{sq} & \Psi_r &= \Psi_{rd} + j\Psi_{rq} \\ u_s &= u_{sd} + j u_{sq} \end{aligned} \tag{3}$$

The mathematic model of the two-phase induction machine was expressed using the matrix equation because this approach can be easily implemented and simulated using Matlab/SIMULINK.

The two-phase induction machine is directly fed by a voltage power supply which delivers the necessary stator current for each winding.

The structure of a direct field oriented control system based on adaptive estimation of the rotoric flux is represented in Fig.1. The measured closed-loop values are the two-phase components of stator voltage and current and the rotor speed. They are applied to the entry of the Gopinath flux observer. The flux analyzer "AF" computes the module and instantaneous position of the rotor flux

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spatial vector, based on which it is done the field orientation. The module of the rotoric flux and the rotor speed are closed-loop values in the two independent adjusting control loops of the field oriented control system.

The expression for the rotor speed is expressed in terms of torque [4] as,

$$p\omega_r = \frac{P}{2J}\left(T_e - T_L\right) \tag{4}$$

where T_e, T_L are the electromagnetic and the load torque.

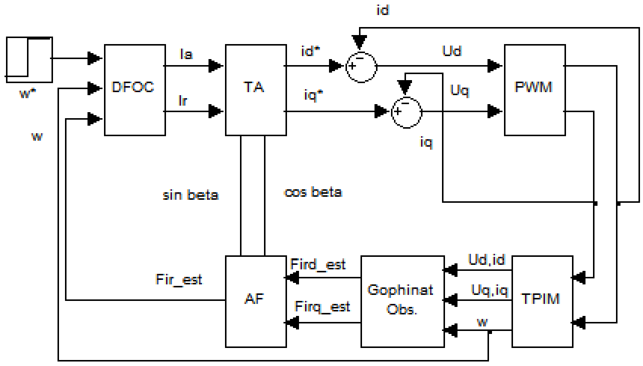

Figure 1. Proposed DFOC block diagram for two-phase induction machine drive system

In Fig.1 it can be observed the presence of the DFOC (Direct Field Oriented Control) block, [5] and its design is presented in Fig.2.

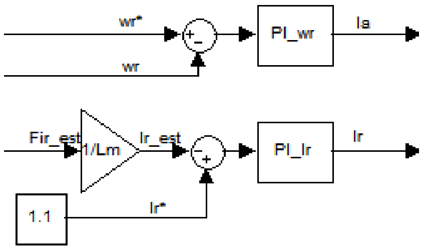

Figure 2. The block diagram of DFOC

As opposed to indirect field oriented control, in the case of direct field oriented control, [6] it is used a closed-loop for the rotoric current, [7]-[8]. The rotoric current controller takes as input the current error, seen as difference between the imposed rotoric current I_r^* and the rotoric current I_r_est which is computed from the estimated rotoric flux. The speed adjusting control takes as input the error computed as difference between the imposed and the measured speed. At the output of the direct field oriented control block there are delivered the active and reactive components of the stator current.

The axes transformer block "TA", computes the rotation with the angle β of the active I_A and the reactive I_R components, (5), supplying as output the control signal for the PWM.

$$\begin{cases} i_d^* = I_R \cos\beta - I_A \sin\beta \\ i_q^* = I_R \sin\beta + I_A \cos\beta \end{cases} \tag{5}$$

It was preferred to keep as correcting condition for the execution element the statoric current because we have less computation effort and it can be avoided the influences due to estimation errors or variations of the statoric circuit parameters. The power supply is a PWM, which represents a special class of invertors with direct current intermediate circuit.

Another block from Fig.1 is the flux analyzer "AF", the one which computes the module and instantaneous position of the rotoric flux spatial vector used for realizing the field orientation.

The estimated rotoric flux results from the block "Gopinath Obs", Fig.3 realized with the help of the simulator based on the current model. The estimator has also a corrector based on statoric equations and the closed-loop value is the statoric current derivative [1].

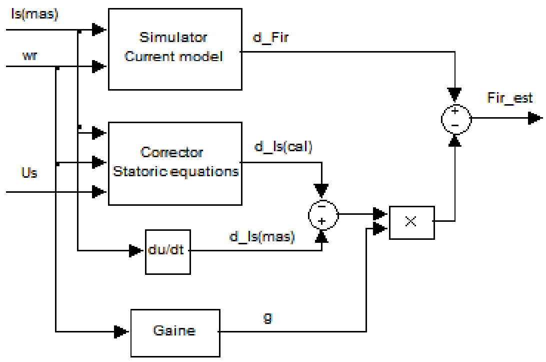

Figure 3. The block diagram of Gopinath Observer

This estimator is known in the specialty literature as the reduced order Gopinath observer [1] and its expression can be deduced by replacing the relations (1)-(3) into (6),

$$\frac{d\Psi_r}{dt} = \textit{simulator} + \textit{gate}\ (\textit{closed-loop value - output estimation corrector}) \tag{6}$$

resulting,

$$\frac{d\Psi_r}{dt} = \Psi_r \cdot \left[-\frac{R_r}{L_r} + j\omega_r - g \cdot \frac{L_m}{\sigma L_s L_r}\left(\frac{R_r}{L_r} - j\omega_r\right)\right] + $$
$$+ i_s \cdot \left[\frac{L_m R_r}{L_r} + g \cdot \left(\frac{R_s}{\sigma L_s} + \frac{R_r(1-\sigma)}{\sigma L_r}\right)\right] - g \cdot \frac{1}{\sigma L_s} u_s + g \cdot \frac{di_s}{dt} \tag{7}$$

In the above equation there were used state variables according to relation (3). With g it was designated the gate, the essential element which determines the stability of the flux observer and the insensitivity at motor parameters variation. It is a complex number having the expression,

$$g = g_a + jg_b \tag{8}$$

where a and b represent the imposed coordinates for the two poles of the observer.

For each value of the rotoric speed we must determine the coefficients for the estimator gate (g_a, g_b). The two poles must follow the stability condition of the system, meaning that a system is stable if and only if the poles belong to the complex negative half plane.

The estimator gate coefficients are determined by equalizing the real and imaginary part from the estimation error relation,

$$\dot{\varepsilon} = \left(a_{22} - g a_{12}\right) \cdot \varepsilon = -\alpha + j\beta \tag{9}$$

where we used ε for the difference between the estimated flux and the real one. This way it results the special case in which the poles are placed on the real negative axis,

$$g_a = \left(\frac{\frac{R_r}{L_r}\alpha}{\left(\frac{R_r}{L_r}\right)^2 + \omega_r^2} - 1 \right) \frac{\sigma L_s L_r}{L_m} \tag{10}$$

$$g_b = \frac{\omega_r \alpha}{\left(\frac{R_r}{L_r}\right)^2 + \omega_r^2} \frac{\sigma L_s L_r}{L_m}$$

where,

$$\alpha = k\sqrt{\left(\frac{R_r}{L_r}\right)^2 + \omega_r^2}\ ,\ (k > 0).$$

III. COMPUTATION RESULTS

The simulations where realized on a two-phase induction machine $(P_N = 35W; U_N = 230V; n_s = 1500 rot/\min)$ with automatic speed adjusting control system with known parameters, Table 1.

TABLE I

p =2	Rr =252,33 Ω
Z_S =16	Ls =1,841 H
Z_S =17	Lr =1,538 H
$m = 2$	Lm =1,161 H
Rs =415 Ω	J =3,3x10^{-5} kgm^2

In Fig.4 it is represented the model of the motor implemented using SIMULINK environment, described by the equations (1)-(4).

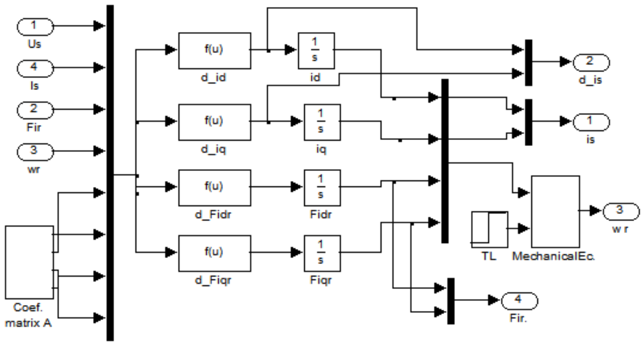

Figure 4. Dynamic model of TPIM

Simulation is the only way in which we can compare the estimated rotoric flux with the one from the motor. In Fig.5 there are drawn the variation of the rotoric flux module computed (Fir_real) from the equations (1)-(4) and the module of the estimated rotoric flux (Fir_est) using the Gopinath flux observer. This comparison is possible due to the fact that the TPIM model supplies the components of the rotoric and statoric current using a two-phase axes system, d-q.

One of the essential properties of the Gopinath flux observer is the robustness at variations of the rotoric resistance, which depends exclusively on the value of the coefficient k.

This way, in the Fig.6 there are drawn the variations of the estimated rotoric flux module for different values of the rotoric resistance: $(R_r = 252{,}33\Omega; R_r = 400\Omega)$, respectively $(R_r = 252{,}33\Omega; R_r = 100\Omega)$ and $k = 0{,}1$.

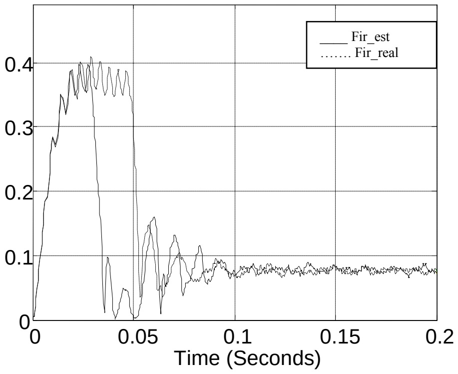

Figure 5. The real and estimated rotor flux

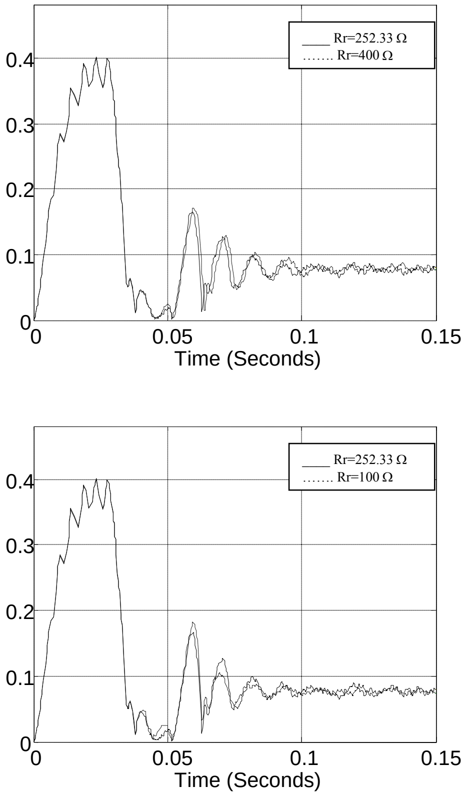

Figure 6. Variation of estimated rotor flux for $R_r = 400\Omega$ and $R_r = 100\Omega$

The results of the simulation confirm the fact that the initial error of estimation reduces rapidly and that the estimated value converges towards the real one even at significant variations of the rotoric resistance, Fig.5 and Fig.6.

The system was tested in transient regime at no-load start of the machine, and after 0.04s it was applied a resistance torque of 0.03 Nm. For the control system it was used a specified value for the speed 157.07rad/s, corresponding to the rated value of the TPIM. In the direct control block the regulators are of type PI, with saturation. During the saturation the integral part is limited.

In Fig.7 it is drawn the system response at a reference speed step $(\omega_r *)$. It can be observed that the system speed has a rapid and linear evolution towards the reference value at no-load $(\omega_r .no-load)$ running . If it was applied at axle a load of 0.03 Nm $(\omega_r .load)$, the evolution is slowed down because of increased inertia of the system.

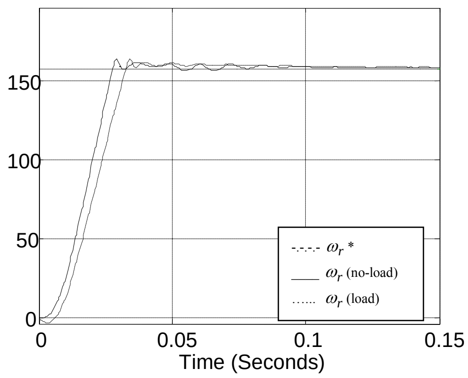

Figure 7. Speed system response for the reference, at no-load and at load running

During the simulated process the flux obtained using computation or estimated using the Gopinath observer is independent on what is happening in the speed loop, but, as it can be seen from the bellow figures, this flux influences the response of the system. This way, in the Fig.8 we can observe that in the case in which the estimation of the rotoric flux is made using the reduced order Gopinath observer $(\omega_r - Fir\_est)$, the speed of the system has a more rapidly evolution towards the reference value than in the case when the rotoric flux is computed $(\omega_r - Fir\_real)$ from the running equations of the two-phase induction machine.

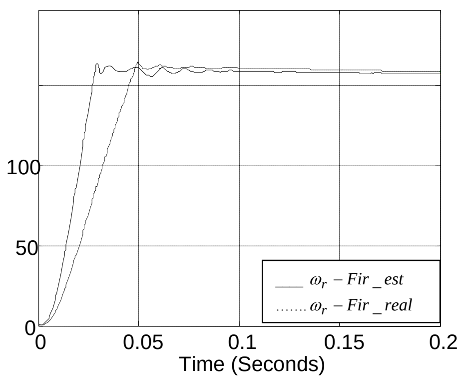

Figure 8. The real and estimated speed for reference speed value 157.07rad/s

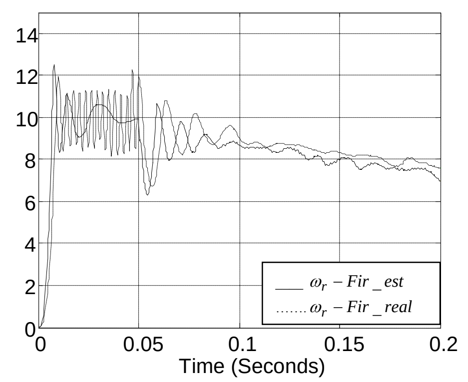

Figure 9. The real and estimated speed for reference speed value 10rad/s

To investigate the behavior of the control system at very low speeds it has been applied a reference step of 10 rad/sec. and the result can be seen in Fig.9.

It can be observed that the speed is highly oscillatory because the rotoric flux is strongly deformed, Fig.10.

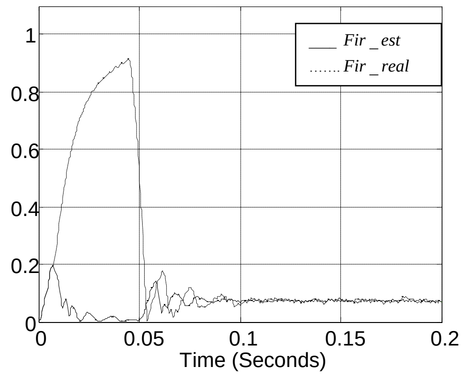

Figure 10. The real and estimated rotor flux for reference speed value 10rad/s

IV. Conclusion

From this paper we can draw the conclusion that the performances of the direct field oriented control depend highly on the precision of the rotoric flux estimation.

The main advantage of the direct field oriented control consists of the fact that the control system gets as input information the module and position of the rotoric flux. From this point of view the design is provided with an estimation block for these values. Comparing the results of the simulations we can see that it is recommended to use the solid adaptive flux observers for rotoric flux estimation. One of the main properties of these observers is the robustness at variations of the rotoric resistance. For a better stability the poles where placed on the real negative axis making the computation in real time much easier.

In conclusion we can assert that the performances of digital designs of the direct field oriented control using the solid adaptive Gopinath observer are superior to the ones based on the computation of the rotoric flux from the machine equations.

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