Robust Speed Controller of a Bearingless AC Motor type Divided Winding, Based on a Conventional Squirrel Cage Induction Motor

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Abstract— **This paper shows a new approach to control the speed of rotor field oriented for a bearingless AC Motor type divided winding for a conventional squirrel cage Induction Motor of 3.75 kW, 380V, 4-poles, 60Hz, 1.04 Nm. To implement the control strategies, was chosen the rotor flux referential (R-FOC). This referential is based on decomposition of the stator current into two components done in a decoupled manner: flux controlled by stator direct-axis current and torque controlled by quadrature-axis current. To implement the control algorithm, was chosen the rotor flux referential, which is being estimated through the stator winding currents and the rotor speed. The vectorial speed controller operates in synchronism with the radial positioning controller, but these controllers should work with low mutual influence.**

I. INTRODUÇÃO

The advance of technology has leveraged new challenges increasing order to produce goods and consumer products with a high degree of control, security, robustness, and competitive prices and environmentally correct. In the field of engineering of electrical machine has softly improved the quality of these machines, as well as, control methods, searching optimal operation.

In recent decades, due to the great development of microelectronics and computer engineering and control, rotating electrical machines of alternating current began to have greater demand into industrial market, especially the machines with rotors in cage, due to several factors: robustness, dimensions versus-power, reduced maintenance, low cost and simplicity of construction.

However, one of the major limitations to the expansion of the application of induction machines is the number of maintenance of mechanical parts, such as bearings and roll-tires, especially when access to these parts is difficult [1]. Thus, in order to minimize mechanical wear and, consequently, the number of maintenance, an area of research that has progressed is the engine-bearings of induction. It has been developed works involving contact control and radial-position control using different radial windings disposed in the stator (called double winding). Started in the mid-80s, works were developed involving the control strategies of the machine and its stator winding acting as magnetic bearings in alternating current engine.

In 1990s, was carried out a study about the effect of application of tensional load on the radial positioning of a bearing engine, in 2002, the proposal was the machine without bearing three-phase winding divided vertically for operation. In 2004, there were optimizations system radial positioning of the engine shaft with the same running horizontally, and control is accomplished through the DSP and in 2006 was conducted study that dealt with the mathematical modeling of engine-bearing phase based the vector model of the conventional three-phase induction machine. In 2007, was implemented a system of vector control rotational speed DSP via the engine-bearing three-phase winding divided, using two feedforward multilayer neural networks to estimate the magnitude of the magnetizing current and speed of the rotor flux [2].

The main objective of this paper is to present a robust controller for speed control for a Bearingless AC Motor type Divided Winding, Based on a Conventional Squirrel Cage Induction Motor.

In this work, was chosen the rotor flux reference to run the vectorial speed control. To implement the speed control is necessary to do the rotor flux position and magnitude estimation due to this variable presents a difficult measurement, mainly in this machines type [3], [4], [7], [8].

II. MACHINE DESCRIPTION AND MODELING APROACH

The model of bearingless induction machine (*BIM*) is based on the conventional induction machine model. This fact help the analysis and the attainment of the vectorial model, however the currents generated by the positioning control and the unbalancing influence become the machine modeling more complex.

A. Squirrel-cage machine equivalent circuit

For a balanced three-phase, the analysis of a *BIM* can be done by analyzing only one of the phases. Where *ia1* is stator current and *i'a1* is the rotor current refer to stator.

The steady state circuit model for *BIM* is give Fig. 1.

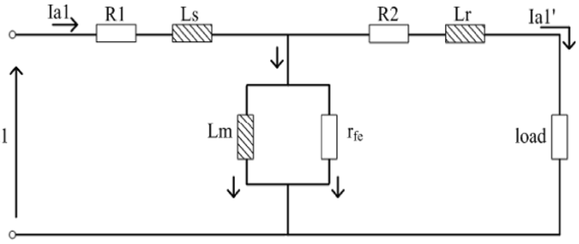

Figure 1. Steady-state equivalente circuit of the *BIM*.

III. THE CURRENT MODEL

To avoid the use the of additional sensors or measuring coils in the *BIM*, method rotor field-oriented-control (*R-FOC*). For generating torque on this machine, is necessary to feed the machine phases with phase currents given by

$$i_{a1} = I_m \cos(\omega_s t) \tag{1}$$

$$i_{b1} = I_m \cos(\omega_s t - 2\pi/3) \tag{2}$$

$$i_{c1} = I_m \cos(\omega_s t + 2\pi/3) \tag{3}$$

$$i_{a2} = I_m \cos(\omega_s t + \pi) \tag{4}$$

$$i_{b2} = I_m \cos(\omega_s t - \pi/3) \tag{5}$$

$$i_{c1} = I_m \cos(\omega_s t + \pi/3) \tag{6}$$

For the rotor flux estimation, is being used the vectorial model of conventional induction machine [3], [4], [7], [8]. For decoupling control, it is desirable that,

$$\Psi_{rd} = \Psi_r \tag{15}$$

$$\Psi_{rq} = 0 \tag{16}$$

Taking into account the previous result, the following equations are defined [3], [4], [7], [8]:

$$\frac{R_r}{L_r}\frac{d\Psi}{dt} + \psi_r \tag{9}$$

$$R_s i_{sd} + \sigma L_s \frac{d}{dt} i_{sd} - \omega_{mR} \sigma L_s i_{sq} - \frac{R_r M^2}{L_r^2}(i_{sd} - i_{mR}) = u_{sd} \tag{10}$$

$$R_s i_{sq} + \sigma L_s \frac{d}{dt} i_{sq} - \omega_{mR} \sigma L_s i_{sd} + \omega_{mR} \frac{M^2}{L_r^2} i_{mR} = u_{sq} \tag{11}$$

$$\frac{d}{dt} i_{mR} = \frac{R_r}{L_r}(i_{sd} - i_{mR}) \tag{12}$$

$$\frac{d\rho}{dt} = \omega_{mR} = p\omega_{mec} + \frac{R_r}{L_r}\frac{i_{sq}}{i_{mR}} \tag{13}$$

$$mM = \frac{2}{3}(1 - \sigma) L_s i_{mR} i_{sq} \tag{14}$$

where

σ	dispersion factor
p	number of pole pairs
i_{sd}	stator current *d* component (field current)
i_{sq}	stator current *q* component (current torque)
L_r	rotor inductance
L_s	stator inductance
M	mutual inductance
ρ	rotor flux angle
ω_{mR}	rotor flux frequency
ω_{mec}	rotor speed
mM	Electromagnetic torque
u_{sd}	*d*-axis stator voltage
u_{sq}	*q*-axis stator voltage
$\imath_{mR}$	flux magnetizing current
Ψ_r	rotor flux linkage
Ψ_{rd}	*d*-axis rotor flux linkage
Ψ_{rq}	*q*-axis rotor flux linkage

IV. SPEED CONTROL

This paper presents a robust speed controller for an Bearingless AC Motor type Divided Winding, Based on a Conventional Squirrel Cage Induction Motor.

For designing the speed controller, the nonlinear model is linearizing around an operating point (op). This control will be realized by state feedback obtained through linearized model.

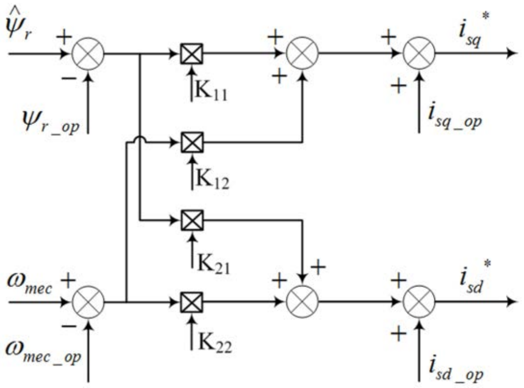

Figure 2. Block diagram of the synchronous PI current controller.

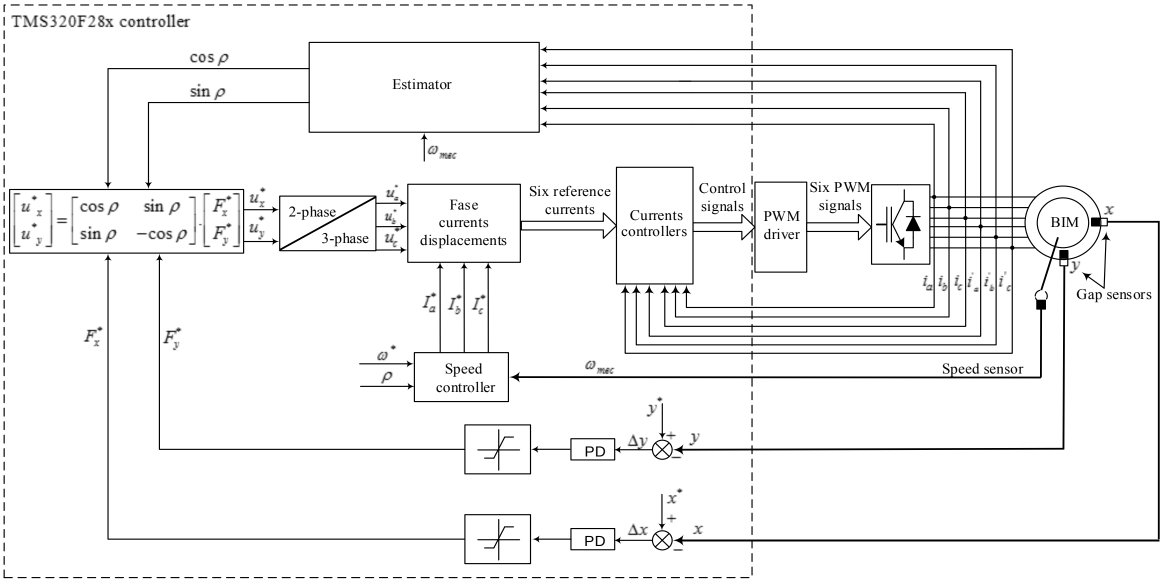

Figure 3. A digital control block diagram of BIM.

The schematically shown controller in Fig. 2 and the architecture of the overall control system is depicted in Fig. 3.

Bearingless motor receives six command currents for motor stator coils. These currents are driven using two parallel IGBTs (Insulated Gate Bipolar Transistors) inverters.

The control of the *BIM* divides in three parts: the current control, the radial positioning control and the speed control. The current controllers are of the type PI and they do the applied currents to the six bearingless machine windings.

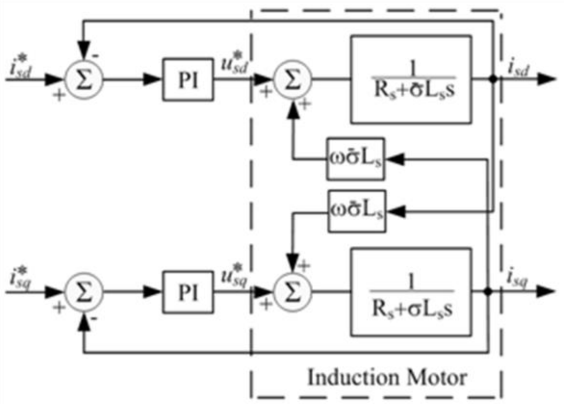

Figure 4. shows a block diagram of proposed bearingless motor control system.

The structure of the PI controller is presented in Fig. 4. To design these controllers is studied a mathematical model based on the impedance of the stator coils, since it is assumed that the currents flowing therein have no significant influence each other [3].

The transfer function of the PI controller is given by

$$G_{PI}(s) = k_{p+}\frac{k_i}{s} \tag{17}$$

The k_p and k_i controller parameters are tuned by (18) and (19) where a value of $\zeta = 0.707$ is chosen and $\omega_n = 631.7$ rad/s.

$$k_p = 2\zeta\omega_n L_s \tag{18}$$

$$k_i = \omega_n^2 L_s \tag{19}$$

The radial position of the rotor shaft is regulated by two digital PD controllers, one for the *x*-axis and another for *y*-axis. Both position controllers are implemented on synchronous reference frame [3], [4], [5], [6].

The ideal transfer function of a PD controller is shown in

$$G_c(s) = k_p + sT_d \tag{20}$$

where, K_p is constant gain of the proportional controller and T_d is time constant of the derivative.

The fig. 5 shows the control system in *x*-direction for this bearingless motor [3], [4].

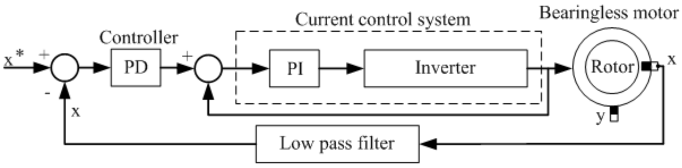

Figure 5. Dynamic model of position.

V. SIMULATION AND EXPERIMENTAL RESULTS

A robust controller is proposed for speed control for a Bearingless AC Motor, due some classical controllers find some difficulties in dealing with the tuning problem.

In order to verify the validity of the proposed controller, the Fig. 6 show the speed response of the robust control.

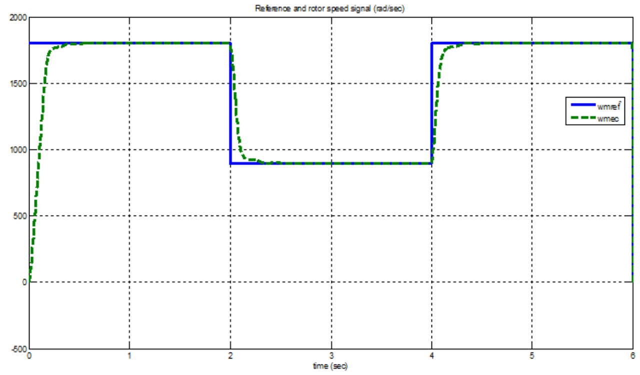

Figure 6. Steady state response.

Fig. 7(a)-(b) present the preliminary experimental results for the proposed BIM motor drive system.

To validate the current control of induction motor drive with PI controller, the following results confirms the satisfactory performance for this controller.

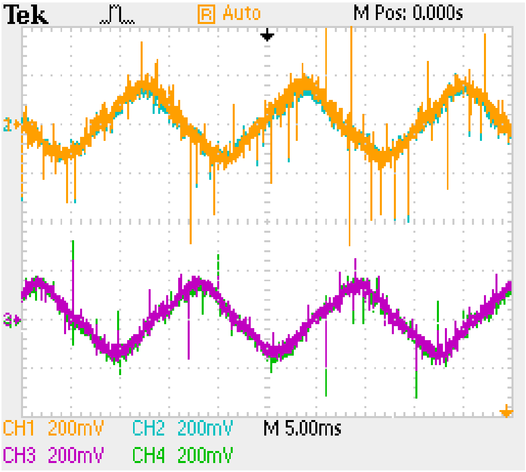

Figure 7(a).Two windings currents of different phases, at 60 Hz.

The Fig.7 (a) shows the currents waveforms in two of the six stator windings corresponding to two different phases, both operating under the nominal frequency of 60 Hz. Fig.7 (b) shows the waveforms the rotor *x*- and *y*-axis direction displacements whit frequency equal to 60 Hz.

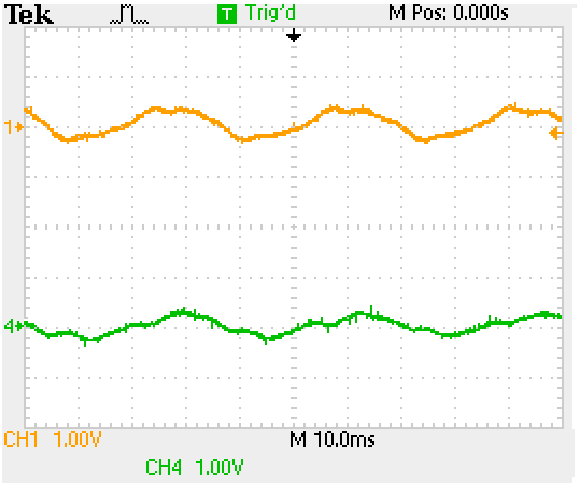

Figure 7(b) Waveforms of rotor displacement for a frequency (60 Hz).

VI. CONCLUSION

This result shows that with the proposed control strategy keeps the machine rotor in almost the center of the possible radial displacement.

According to obtained results, it was possible to confirm the high performance of the system.

An important result is the independent control of the radial forces in relation to the electric torque of the machine. This specific control was obtained through the generation of minimum induced currents.

In order to reduce the implementation costs, a speed observer been developed. This observer is based on the conventional methods of the state estimation.

Experimental results show that the radial forces are sufficient to control the rotor position on the rotating magnetic field.

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