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Variable Speed Control for Rotor Field Oriented Control of a Doubly Fed Induction Machines

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Abstract **- In this paper a speed control of doubly fed induction motor is studied. The aims of this paper are the modeling and analyzed the proportional integral and artificial neural network controllers under the load variation of operating in four quadrants of doubly fed induction motor. A computer simulation is developed to demonstrate the effectiveness of the proposed intelligent speed controller and the simulation results are presented for different operating points in order the tested the performance control of the system. The simulation results shows that the control by artificial neural network provides better performances and robustness independently of load disturbances.**

Index Terms - Variable speed, doubly fed induction machine, vector control, feedback state control, neural network.

I. INTRODUCTION

In the industrial applications, there are several reasons for using variable speed operating of motor [1, 2]. Indeed, the theory of vector control [3] has long since been applied successfully, to three- phase induction machine. However, the control performance depends by the variation of motor parameters [4, 5]. Today, in the area of the control of the electric machines, the research works are oriented more and more towards the application of the modern control techniques. These techniques involve in a vertiginous way with the evolution of the computers and power electronics and the interest of using high power applications in the energy renewable industry. This has favoured the use of doubly fed induction machine (DFIM) to be the perfect competitor to other induction machines (IM). Despite the several methods of control are used to control the IM among which the field orientation control (FOC) that allows a decoupling between the torque and the flux [4]. In this paper, the decoupling by feedback state control is used [6].

Recently, artificial neutral network (ANN) has become a popular research topic and has been successfully used for a few numbers of nonlinear and complex processes [7-10]. The ANN is insensible to parameter variations contrary to conventional controllers.

The paper is organized as follows. In section 2, modelling of de machine and decoupling method are given. Sections 3 present the principle and structure of ANN control. The simulation results are presented and discussion in section 4. Finally, conclusion is presented in section 5.

II. FIELD ORIENTED CONTROL

The DIFM equations are described as follow [6, 11]:

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx \end{cases} \tag{1}$$

With, $x = \begin{bmatrix} i_{ds} & i_{qs} & i_{dr} & i_{qr} \end{bmatrix}^t$ is the state vector and $u = \begin{bmatrix} V_{ds} & V_{qs} & V_{dr} & V_{qr} \end{bmatrix}^t$ is input vector.

$$A = \begin{bmatrix} \frac{-R_s}{\sigma L_s} & \frac{(1-\sigma)\omega+\omega_s}{\sigma} & \frac{R_r L_m}{\sigma L_s L_r} & \frac{L_m \omega}{\sigma L_s} \\ \frac{(1-\sigma)\omega+\omega_s}{\sigma} & \frac{-R_s}{\sigma L_s} & \frac{L_m \omega}{\sigma L_s L_r} & \frac{R_r L_m}{\sigma L_s L_r} \\ \frac{R_s L_m}{\sigma L_s L_r} & \frac{-L_m \omega}{\sigma L_r} & \frac{-R_s}{\sigma L_s} & \frac{\sigma \omega_s - \omega}{\sigma} \\ \frac{L_m \omega}{\sigma L_r} & \frac{R_s L_m}{\sigma L_s L_r} & \frac{\omega - \sigma \omega_s}{\sigma} & \frac{-R_s}{\sigma L_s} \end{bmatrix} \tag{2}$$

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$$B = \begin{bmatrix} \frac{1}{\sigma L_s} & 0 & \frac{-L_m}{\sigma L_s L_r} & 0 \\ 0 & \frac{1}{\sigma L_s} & 0 & \frac{-L_m}{\sigma L_s L_r} \\ \frac{-L_m}{\sigma L_s L_r} & 0 & \frac{1}{\sigma L_r} & 0 \\ 0 & \frac{L_m}{\sigma L_s L_r} & 0 & \frac{1}{\sigma L_r} \end{bmatrix} \quad (3)$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

The dynamical equation and electromegnetical torque are given by "(5)," and "(5)," respectively:

$$J\frac{d\Omega}{dt} = T_{em} - T_l - k_f \Omega \quad (5)$$

$$T_{em} = p.L_m (i_{qs}.i_{dr} - i_{ds}.i_{qr}) \quad (6)$$

The aim of the vector control is to ensure control decoupled of the flux and torque [3]. In the synchronous reference frame whose axis d is aligned with the rotor flux vector ($\Phi_{dr} = \Phi^*$ and $\Phi_{qr} = 0$) [6, 12]. Fig. 1 shows the vector representation of vector control.

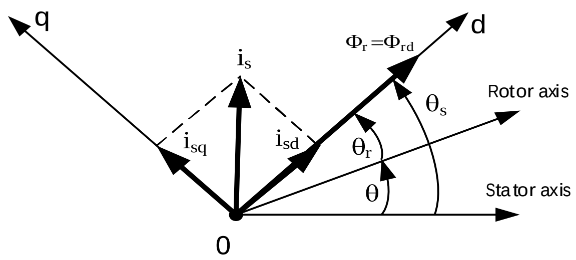

Fig. 1. Orientation rotor flux

The principle of the decoupling by feedback state control is defined by [6, 13]. Let the multi variable system:

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx \end{cases}$$

$$\begin{cases} x \in \Re^n & x = [x_1\ x_2\ \dots\ x_n]^t \\ u \in \Re^m & u = [u_1\ u_2\ \dots\ u_m]^t \\ y \in \Re^m & y = [y_1\ y_2\ \dots\ y_m]^t \end{cases} \quad (7)$$

The loopback by feedback state control desired state feedback is of the following form:

$$u = -K_d x + L_d v \qquad v \in \Re^m \quad (8)$$

Where $\boldsymbol{v}$ is the new input vector of the system. This command law should be such that the input v_i acts only on the output y_i ($i=1$ to m). The output y_i is written:

$$y_i = C_i x \quad (9)$$

Where C_i is the i^{th} row of the matrix C. Must derives y_i until the command appears. We called characteristic index noted σ_i, the number of times that must derived to bring up the command. Where then successively for each output:

$$\dot{y}_i = C_i \dot{x} = C_i(Ax + Bu) = C_i Ax + C_i Bu$$

$$\ddot{y}_i = C_i A\dot{x} = C_i A^2 x + C_i ABu$$

$$y_i^{(3)} = C_i A^2 \dot{x} = C_i A^3 x + C_i A^2 Bu \quad (10)$$

.

.

$$y_i^{(\sigma_i)} = C_i A^{\sigma_i} x + C_i A^{\sigma_i - 1} Bu$$

with ,

$C_i Bu = 0$; $C_i ABu = 0$; $C_i A^2 Bu = 0$ and $C_i A^{\sigma_i} Bu \neq 0$.

This can still be written in matrix form:

$$\begin{bmatrix} y^{(\sigma_1)} \\ y^{(\sigma_2)} \\ \vdots \\ y^{(\sigma_m)} \\ y^* \end{bmatrix} = \begin{bmatrix} C_1 A^{\sigma 1} \\ C_2 A^{\sigma 2} \\ \vdots \\ C_m A^{\sigma m} \\ A^* \end{bmatrix} = \begin{bmatrix} C_1 A^{\sigma 1 - 1} B \\ C_2 A^{\sigma 2 - 2} B \\ \vdots \\ C_m A^{\sigma m - 1} B \\ B^* \end{bmatrix} u \quad (11)$$

So, $y^* = A^* x + B^* u$ (12)

With $y^* \in \Re^m$, $A^* \in \Re^{mxm}$, $B^* \in \Re^{mxm}$

$u = K_d x + L_d v$ as $y^* = v$

$$y^* = A^* x + B^*(-K_d x + L_d v)$$

$$y^* = (A^* - B^* K_d)x + B^* L_d v \quad (13)$$

(13)

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For $\boldsymbol{y}^* = \boldsymbol{v}$; $B^* L_d = I$ et $A^* - B^* K_d = 0$

$$K_d = \left(B^*\right)^{-1} A^* \text{ and } L = \left(B^*\right)^{-1} \tag{14}$$

Therefore,

$$y^* = v \text{ and } Y_i(P) = \frac{1}{s^{\sigma_i+1}} V_i(P) \tag{15}$$

In Fig. 2, the structural current control state feedback is presented:

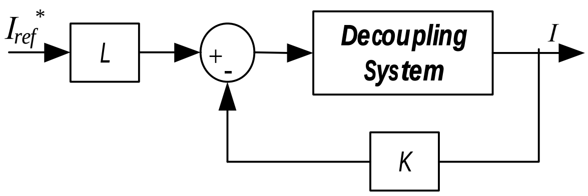

Fig. 2. Current control by state feedback

For the doubly fed induction motor, we obtained:

$$\forall \boldsymbol{i} : \sigma_i = 0 \quad \text{and} \quad \begin{cases} L_d = B^{-1} \\ K_d = B^{-1} A \end{cases} \tag{16}$$

$$y^* = v \qquad G(P) = \frac{Y_i(P)}{V_i(P)} = \frac{1}{P} \tag{17}$$

$$L = K = \begin{bmatrix} k & 0 & 0 & 0 \\ 0 & k & 0 & 0 \\ 0 & 0 & k & 0 \\ 0 & 0 & 0 & k \end{bmatrix} \tag{18}$$

$$\Phi_{qr} = L_r i_{qr} + L_m (i_{qs} + i_{qr}) = 0 \tag{19}$$

$$i_{qr} = \frac{L_m i_{qs}}{L_r + L_m} \tag{20}$$

And,

$$\Phi_{dr} = \Phi_r^*, \qquad \frac{d\Phi_{dr}}{dt} = 0 \tag{21}$$

$$\omega_s - \omega_r = \frac{R_r i_{qs}}{(L_r + L_m) i_{ds}} \tag{22}$$

However, with using the torque equation can be expressed as:

$$T_e = K_m \Phi_{dr} i_{qr} \tag{23}$$

Where K_m is torque constant. So, if the rotor flux is constant, the stator current i_{qs} can be control the torque and the rotor flux can be controlled with direct component of stator current.

The dynamical equation is given by:

$$\frac{J}{p}\frac{d}{dt}\omega_r = K\Phi_{dr} i_{qr} - T_l - \frac{k_f}{p}\omega_r \tag{24}$$

Thus, the transfer function will be expressed by the speed:

$$w_r(P) = \frac{K_m \Phi^* i_{qr}(P)}{K_f + JP} - \frac{T_l(P)}{K_f + JP} \tag{25}$$

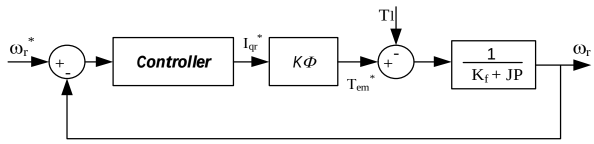

Fig. 3. Speed loop

The proportional action (P) ensures the performance criteria required by speed loop. So an integral action (I) cancel the error in study state. The controller parameters are chosen by the imposed poles method, as [14]:

$$k_i = j2\rho^2 \quad ; \quad k_p = 2jp - K_f \tag{26}$$

Where ρ is the module of the real part.

B. *Artificial Neural Network*

The control speed use a controller based on ANN (20 multiphase). The multi layer preceptor, the number of hidden layers and hidden neurons is not known a priori. Furthermore, there is no general rule for predicting the number of hidden Fig. 3 Scheme of neural fuzzy-speed control neurons necessary to achieve a specified performance of the model. One of the most popular programs is the back-propagation. So for the proposed application, an ANN with a single layer with activation function tansig type is used. In this step, the authors execute several tests and analyzing the performance of the system [20]. The neural network controller considered is shown in Fig. 4. Two neurons in input layer, 30 neurons in hidden layer and one neuron in output layer.

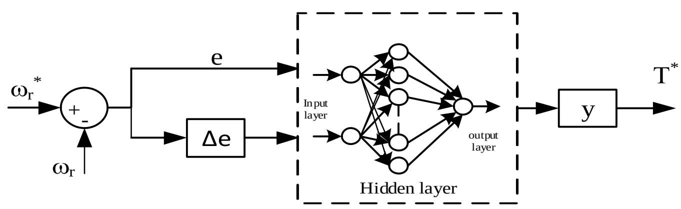

Fig. 4. Scheme of speed control using ANN

III. Results and Discussion

The proposed ANN controller for the DFIM drive is tested using a Matlab/Simulink. The scheme system shown in Fig. 5 consists of the following elements: three-phase doubly fed induction machine, a two three-phase voltage-source inverter. The parameters machines are shown in appendix.

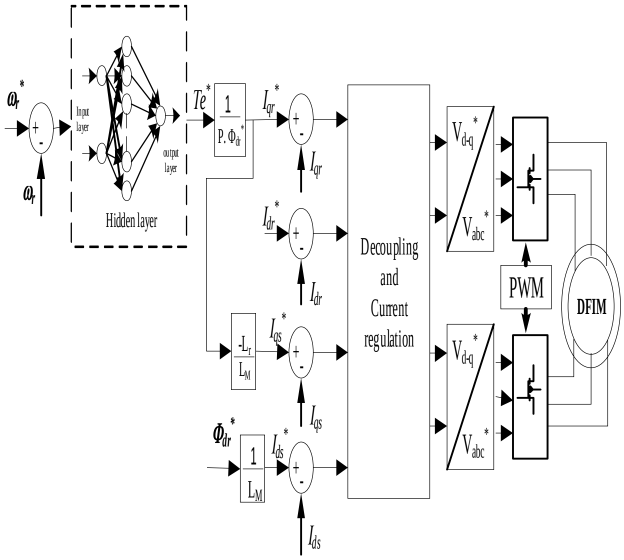

Fig. 5. Scheme of control

In order to evaluate the performances of the proposed control scheme at different operating conditions. The simulated responses are shown in Fig. 6 and Fig. 7. The control system operated properly according to Fig. 5. The rotor speed has successfully tracked the command speed while the rotor flux is fixed at its reference value. Rotor speed, electromagnetic torque, rotor flux, and stator current are shown in Fig. 6(a,b and c), respectively. Moreover, the system is tested for low speed (see Fig. 7). It can be seen that the proposed controller gives regulated responses in terms of fast tracking, small overshoot, and zero steady-state errors. The rotor flux has successfully followed the rotor command flux, while the rotor speed increases linearly to its rated value. The Fig. 6(a) and Fig. 7(a) shows that the speed converges to +/-150 rad/s and +/-25 rad/s , and the electromagnetic torque is shown in Fig. 6(b) and Fig. 7(b). Also, the rotor flux value shown in Fig. 6(c) and Fig. 7(c) converges to its reference properly. By comparing the simulation test results, it can be stated that the intelligent control required performances for the DFIM drive. Another important advantage of the proposed intelligent controller is that it is relatively easy to tune the gain parameters of the controllers effectively and efficiently for high-performance DFIM drive systems.

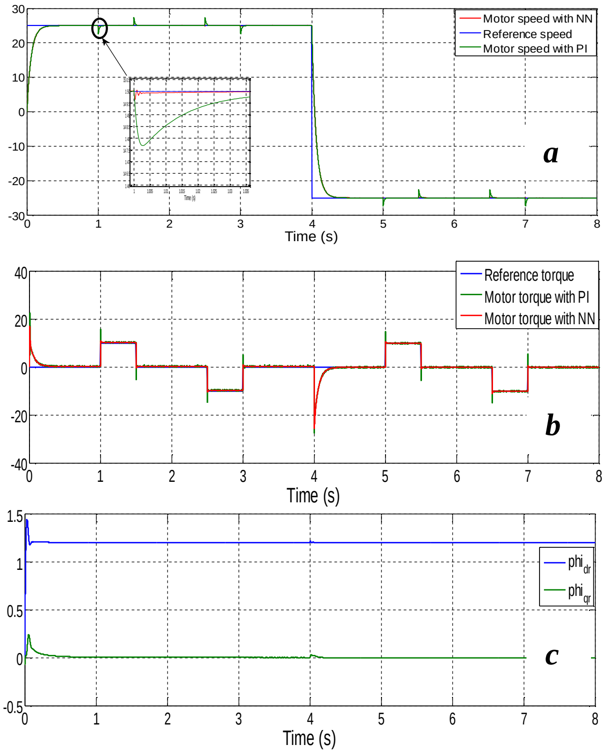

Fig. 6. Simulation results

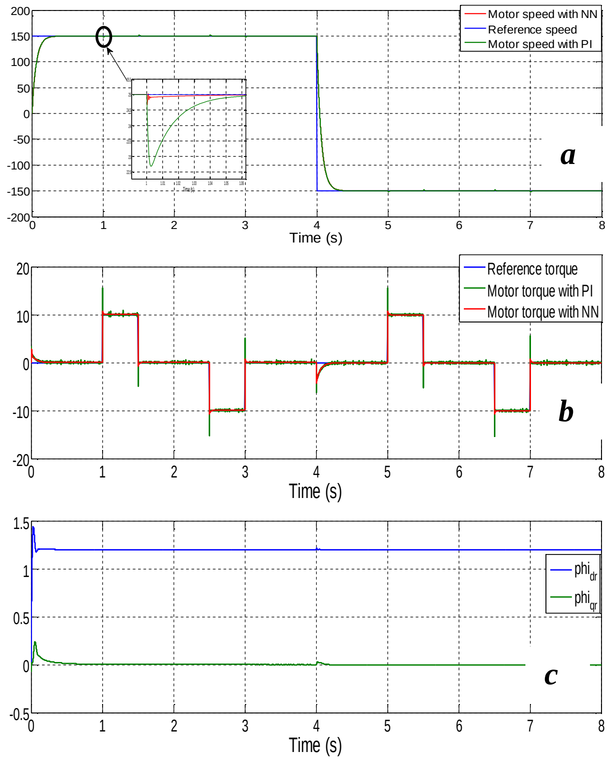

Fig. 7. Simulation results for lower speed reference

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IV. Conclusion

This paper has presented a study to show improvement obtained by using ANN controller for the DFIM drive. The system is tested for low speed. The results shows the proposed controller gives regulated responses in terms of fast tracking, small overshoot, and zero steady-state errors and good control performance in terms of robustness and adaptability. Another important advantage of the proposed intelligent controller is that it is relatively easy to tune the gain parameters of the controllers effectively and efficiently for high-performance DFIM drive systems. The intelligent technique can be easily adopted for industrial applications

Appendix A : *Doubly fed Induction Motors Parameters*

Rated power:	1.5 kW
Rated speed	1420rpm
Rated frequency	50Hz
Stator resistance	4.85Ω
Rotor resistance	3.805Ω
Stator inductance	0.274H
Rotor inductance	0.274H
Magnetizing inductance	0.258H
Number of poles	1
Rotor inertia	0.031Kg.m^2
Friction Coefficient	0.001136N.m.s/rd

Appendix B: *Principal Symbols*

V_{ds}, V_{qs}: stator voltages d-q axis components
i_{ds}, i_{qs} : stator currents d-q axis components
V_{dr} , V_{qr} : rotor voltages d-q axis components
i_{dr} , i_{qr} : rotor voltages d-q axis components
Φ_{ds}, Φ_{qs}: stator flux d-q axis components
Φ_{dr} , Φ_{qr}: rotor flux d-q axis components
Φ^*: flux reference
R_s: stator resistance
R_r :rotor resistance
L_s: stator inductance
L_r :rotor inductance
L_m: mutual inductance
ω_s : speed of the synchronous reference frame
ω_r :rotor electrical angular speed
ω_{sl}:slip speed
J : moment of inertia
p: number of pole pairs
Ω : mechanical speed
T_{em}: electromagnetic torque
T_l : load torque
k_f : friction coefficient

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