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Dynamic Performance Improvement of DFIM based on Hybrid Computational Technique and Artificial Intelligence Control

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Abstract—**The aim of this paper is to design a speed controller by using artificial neural network technique. This controller is destined to the speed control of doubly fed induction motor. It solves the problems associated with the PI (Proportional Integral) conventional controller. In this paper, the performance comparison study of the artificial neural network control and the conventional Proportional Integral (PI) controller is presented. The artificial neural network controller is based on the decoupling control to enhance robustness under different operating conditions such as load torque and in the presence of parameters variation.**

Keywords— DFIM, Decoupling Control, PI, AI, FLC, ANNC

I. INTRODUCTION

The Doubly Fed Induction Motor (DFIM) with wounded rotor has become increasingly used in the industry compared to the direct current (DC) motors and synchronous motors. This type of motor has been neglected by researchers for several years because of its disadvantages, namely its high cost, its volume, the presence of brushes, and the use of converters. However, it has come back to the forefront because of the progression of vector control and the accessibility to its rotor [1].

In the vector control based on conventional controllers, the parameters of the machine must be well known in order to become more efficient[3]. So, this fact has led other researchers to find new method of control. These efforts have been rewarded by the introduction of modern control techniques such as artificial intelligence (AI) [5,6,9].

Different techniques of artificial intelligence exist in the literature today, mainly Genetic Algorithms, Evolutionary Algorithms, Fuzzy Logic, Neural Networks, and Swarm Intelligence, which are increasingly applied in the control of induction machines. In this study we have focused on these last three techniques.

The remainder of this paper is structured as follows: in section 2, the machine model is developed and in section 3, the decoupling control of DFIM is presented. In section 4, PSO is contribution is described followed by speed controllers' synthesis section 5. The simulation results of FL, ANN and the PI controller are shown in section 6. Finally, the conclusions are presented in section 7.

II. MATHEMATIC MODELS OF DFIM

The DFIM model is expressed by its dynamic model in the synchronous reference frame which is given by:

$$V_S = R_S I_S + \frac{d\phi_S}{dt} + j\omega s \phi_S \quad (1)$$

$$V_R = R_R i_R + \frac{d\phi_R}{dt} - j\omega_R \phi_R \quad (2)$$

$$\phi_S = L_S I_S + M_{SR} I_R \quad (3)$$

$$\phi_R = L_R I_R + M_{SR} I_R \quad (4)$$

The equation (5) of motion must be added to the precedent system of equations to present the transient phenomena during the load variation and start up, and shutdown

$$J\frac{d\Omega}{dt} + f\,\Omega = C_{em} - C_r \quad (5)$$

III. STRUCTURE OF DECOUPLING CONTROL

Controlling doubly fed induction machine implies controlling the torque and the flux independently; this is done by using a d-q rotating reference frame synchronously with the rotor flux space vector as shown in Figure 1. The general full order dynamic model of DFIM is given by:

$$V_{Sd} = R_S I_{Sd} + \frac{d\phi_{Sd}}{dt} - \omega_S \phi_{Sq} \quad (6)$$

$$V_{Sq} = R_S I_{Sq} + \frac{d\phi_{Sq}}{dt} + \omega_S \phi_{Sd} \quad (7)$$

$$V_{Rd} = R_R I_{Rd} + \frac{d\phi_{Rd}}{dt} - \omega_R \phi_{Rq} \quad (8)$$

$$V_{Rq} = R_R I_{Rq} + \frac{d\phi_{Rq}}{dt} + \omega_R \phi_{Rd} \quad (9)$$

While The electromagnetic torque is modelled in the Park reference as follows:

$$C_{em} = \frac{3pM}{2L_R}\left(\phi_{Rd} I_{Sq} - \phi_{Rq} I_{Sd}\right) \quad (10)$$

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Then, after the d-axis is aligned with the rotor flux vector as shown in Figure 1, we get:

$$\phi_R = \phi_{Rd}, \quad \phi_{Rq} = 0;$$
$$I_{Rq} = -\frac{M_{SR}}{L_R} I_{Sq}, \quad I_{Rd} = 0; \qquad (11)$$

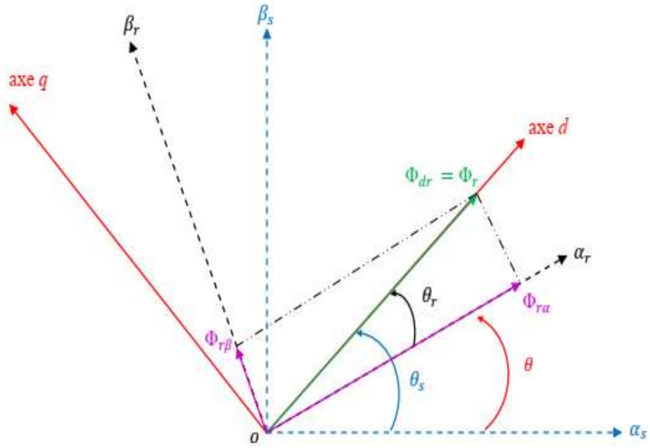

Fig. 1 Rotor field orientation on the d-axis

A. Control of currents and compensation terms

In order to obtain a decoupling between d and q axis we used a method which was introduced by D. LECOQ [9]. It is based on the four current correctors which, imply the new equation of voltages as:

$$\begin{aligned}
V_{tSd} &= V_{Sd} - \frac{M_{SR}}{L_R} V_{Rd} \\
V_{tSq} &= V_{Sq} - \frac{M_{SR}}{L_R} V_{Rq} \\
V_{tRd} &= V_{Rd} - \frac{M_{SR}}{L_S} V_{Sd} \\
V_{tRq} &= V_{Rq} - \frac{M_{SR}}{L_S} V_{Sq}
\end{aligned} \qquad (12)$$

Using equations (3-4),(11) and (12), we can write:

$$\begin{aligned}
V_{tSd} &= R_S I_{Sd} + \sigma L_S \frac{dI_{Sd}}{dt} - R_R \frac{M_{SR}}{L_R} I_{Rd} - \phi_{Sq}\omega_S + \frac{M_{SR}}{L_R}\phi_{Rq}\omega_R \\
V_{tSq} &= R_S I_{Sq} + \sigma L_S \frac{dI_{Sq}}{dt} - R_R \frac{M_{SR}}{L_R} I_{Rq} + \phi_{Sd}\omega_S - \frac{M_{SR}}{L_R}\phi_{Rd}\omega_R \\
V_{tRd} &= R_R I_{Rd} + \sigma L_R \frac{dI_{Rd}}{dt} - R_S \frac{M_{SR}}{L_S} I_{Sd} - \omega_R \phi_{Rq} + \frac{M_{SR}}{L_S}\phi_{Sq}\omega_S \\
V_{tRq} &= R_R I_{Rq} + \sigma L_R \frac{dI_{Rq}}{dt} - R_S \frac{M_{SR}}{L_S} I_{Sq} + \omega_R \phi_{Rd} - \frac{M_{SR}}{L_S}\phi_{Sd}\omega_S
\end{aligned}$$

(13)

Thus:

$$\begin{aligned}
V_{tSd} &= V_{tSdc} + V_{tSdc1} = R_S I_{Sd} + \sigma L_S \frac{dI_{Sd}}{dt} + V_{tSdc1} \\
V_{tSq} &= V_{tSqc} + V_{tSqc1} = R_S I_{Sq} + \sigma L_S \frac{dI_{Sq}}{dt} + V_{tSqc1} \\
V_{tRd} &= V_{tRdc} + V_{tRdc1} = R_R I_{Rd} + \sigma L_R \frac{dI_{Rd}}{dt} + V_{tRdc1} \\
V_{tRq} &= V_{tRqc} + V_{tRqc1} = R_R I_{Rq} + \sigma L_R \frac{dI_{Rq}}{dt} + V_{tRqc1}
\end{aligned} \qquad (14)$$

Where V_{tsdc1}, V_{tsqc1}, V_{tRdc1} and V_{tRqc1} are considered as compensation terms. This method gives us the same transfer function between the currents and voltages of the same axis as shown by the following equation (15):

$$\begin{aligned}
\frac{I_{Sq}(S)}{V_{tSqc}(S)} &= \frac{I_{Sd}(S)}{V_{tSd}(S)} = \frac{1}{R_S + \sigma L_S . S} \\
\frac{I_{Rq}(S)}{V_{tRqc}(S)} &= \frac{I_{Rd}(S)}{V_{tRd}(S)} = \frac{1}{R_R + \sigma L_R . S}
\end{aligned} \qquad (15)$$

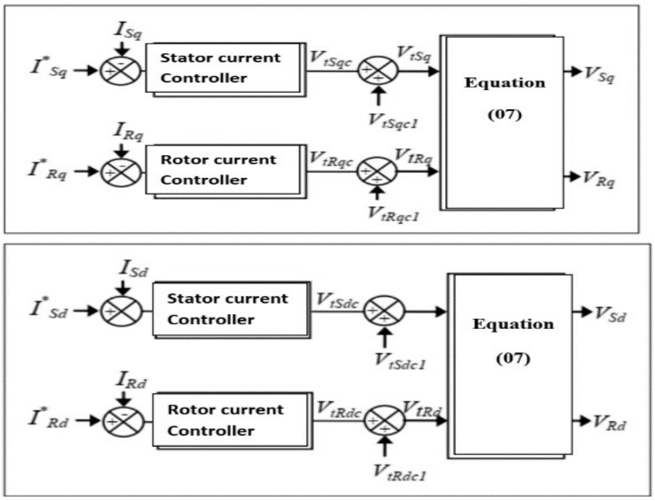

Fig. 2Decoupling and regulation of the currents

The current references are given by:

$$\begin{aligned}
I_{Sd}^* &= \frac{L_R}{M_{SR}} \phi_{Rd}^* \\
I_{Sq}^* &= \frac{L_R}{P . M_{SR} . \phi_{Rd}^*} C_{em}^* \\
I_{Rd}^* &= 0 \\
I_{Rq}^* &= -\frac{1}{P . \phi_{Rd}^*} C_{em}^*
\end{aligned} \qquad (16)$$

The control structure of the currents is shown in Figure 2.

IV. PSO ALGORITHM

The PSO main program has to optimize in this case three parameters, Ke, Kd and β to the fuzzy controller, and search optimal value of the three-dimensional search space. It is well described in [7,8].

V. SPEED CONTROLLERS SYNTHESIS

A. Speed control via PI controller

The PI controller has been applied for the control of induction machine speed. The speed control loop with PI

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type regulator is shown in the Figure 3. It is used for the adjustment of the mechanical variable.

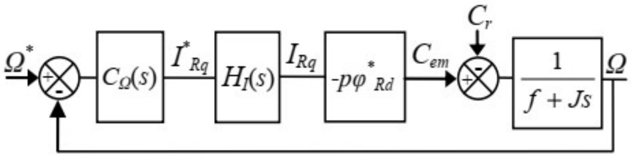

Fig. 3Block diagram of the speed regulator with PI controller

Since, the choice of the parameters of the regulator is chosen according to the choice of the damping constant (ξ) and the natural pulse wn, the proportional and the integral gains can be represented by equation (17).

$$K_p = \frac{(2\xi\omega_n T_m) - 1}{K_m};$$
$$K_i = \frac{T_m \omega_n^2}{K_m}. \quad (17)$$

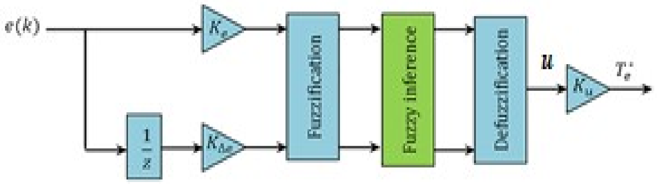

Fig. 4Internal structure of the FLC

TABLE I
INFERENCE MATRIX OF FUZZY RULES

		Δe						
		NG	**NM**	**NP**	**Z**	**PP**	**PM**	**PG**
e	**NG**	NG	NG	NG	NM	NP	NP	Z
	NM	NG	NG	NM	NP	NP	Z	PP
	NP	NG	NM	NP	NP	Z	PP	PP
	Z	NM	NP	NP	Z	PP	PP	PM
	PP	NP	NP	Z	PP	PP	PM	PG
	PM	NP	Z	PP	PP	PM	PG	PG
	PG	Z	PP	PP	PM	PG	PG	PG

The fuzzy rules allow the determination of the regulator output variable according to the input variables that are deduced from the inference table. In this case, there are 49 rules. Table.1

C. Speed control via Neural Network controller

1) *The neural network block design:* After simulating the DFIM by using, the design of artificial neural network model is created through our program in MATLAB/ SIMULINK and databases that are collected from running machine.

The principal diagram of direct vector control (CVD) with rotor flux oriented on the d-q axis is shown the Figure 10.

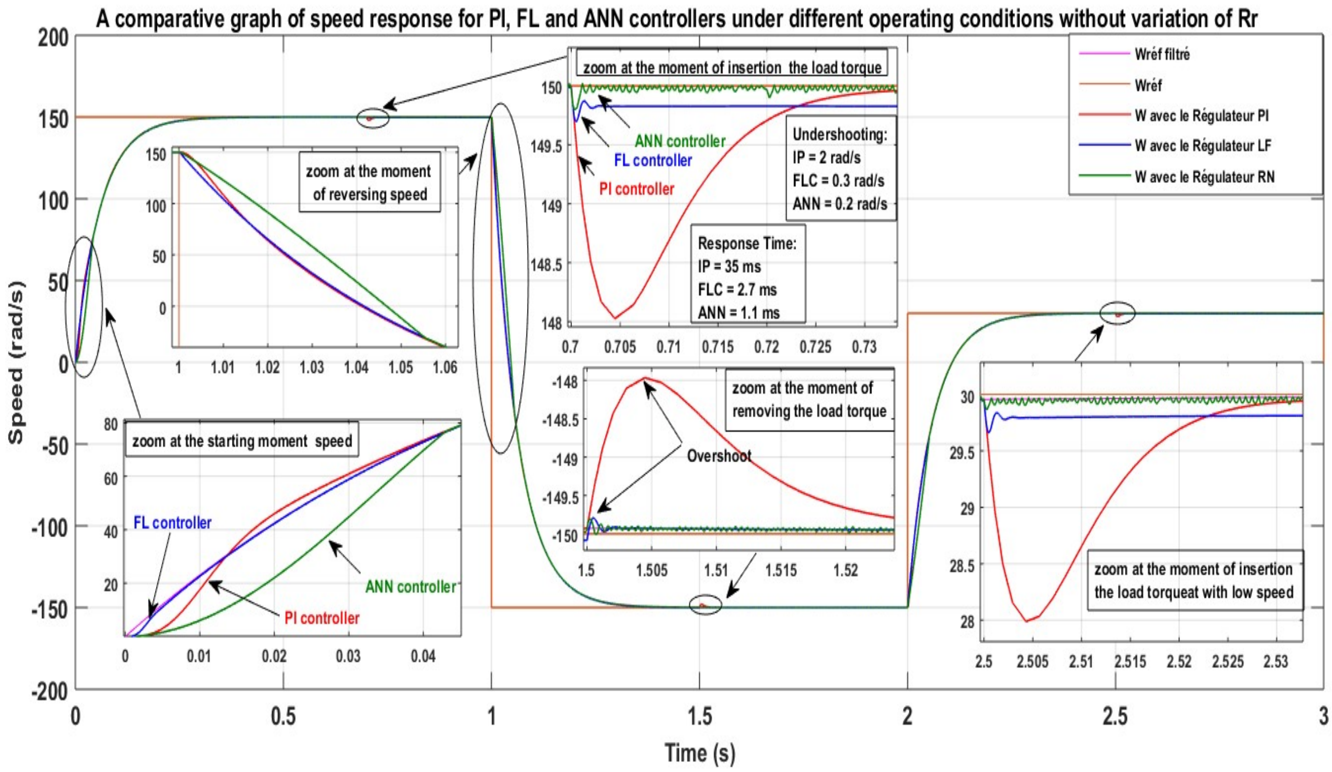

Fig.6 Simulation results of speed variation

B. Speed control via Fuzzy-PSO logic controller

Let us consider the internal schema of the fuzzy regulator in Figure 4[4].

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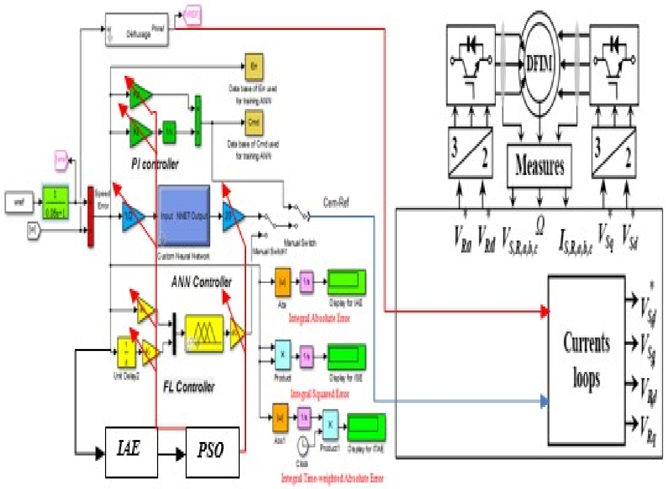

Fig.5 Block diagram of the proposed control scheme of the DFIM

VI. SIMULATION RESULTS

In order to test the robustness of the regulation, two tests are carried out. Firstly, a change in the speed setpoint from (150rd/s), (-150 rd/s) to (30 rad/s) with a cyclic change of different load torque levels was applied to the DFIM by time. The results of this simulation are shown in Figures 6.

The speed and the flux components are represented respectively by Figures 6 All of them contain zooms on moments of constraint changes.

We note that the PSO-ANN controller-based drive system can handle the sudden change in load torque without undershoot, overshoot and without steady state error but with negligible ripples. However, The PSO-FL controller presents negligible steady state error, undershoots and overshoots. The PI controller presents a steady state error, undershoots and overshoots.

VII. ONCLUSIONS

In this paper, the effectiveness of the proposed controllers ANN and FL have been tested in comparison with conventional PI controller under different operating conditions. The results obtained with this PSO-ANN and PSO-FLC are very interesting compared to the PI controller. As aconclusion, the PSO-ANN mode controller has very satisfactory tracking performance than those tuned by the FL and IP controller.

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