Application of Fuzzy Logic for Regulation Speed Strategy in Direct Torque Control Scheme of Induction Motor

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***Abstract*— In this article we describe the improved direct torque control of induction motor fed by a voltage inverter with two levels, then we propose a mechanism of optimization (supervisor) earnings of PI, enabling the regulator to root classic by introducing a degree of intelligence in the control strategy. Indeed, this approach involving the PI controller and the supervisor consists of fuzzy rules, offers the possibility of using the mathematical precision of the PI algorithm with the adaptability, flexibility and simplicity of the fuzzy linguistic formalism.**

The validity of the proposed methods is confirmed by the simulation results.

Keywords- Induction motor; Direct torque control; Fuzzy PI controller.

I. INTRODUCTION

The asynchronous motor (also called induction) is the machine most used in industry, it is more robust, reliable, efficient and low cost compared to other machines for similar applications. For cons, the command of this process is complicated by its nonlinear nature, its fast dynamics, changes its parameters during operation and is subject to unknown perturbations. In addition, some of his statements are not accessible by measurement. Huge technological advances have solved this problem and develop appropriate controls for this engine. One of the most recent steps in this direction is the direct torque control-DTC, which provides excellent properties of regulation without rotation speed feedback. Proposed by I Takahashi and T Noguchi and of Depenbrock [1][2], this method appeared in second half of the eighties, competing with the methods of vectorial control. In contrast with these last, which are based on sharp but accurate mathematical formalisms, the techniques of direct torque control were originally based on qualitative and simplified knowledge of the machine behavior.

Today, the setting of fuzzy logic with its nonlinear structure presented good performance and robustness in the control of the MAS, it is a new technique addressing the digital control of processes and decision making. Fuzzy logic based on fuzzy set theory developed by Lotfi Zadah [5]. Besides a mathematical formalism developed strong interest in fuzzy logic control is the fact that the theory of fuzzy sets can handle and reasoning using variables that incorporate the notion of imprecision, uncertainty assessments or subjective quantifications language, which allows the controller to be fuzzy designed to replace a skilled human operator. The fuzzy controllers can be considered as non-linear PID or their parameters are determined in real time is based on the error and its derivative, the disadvantage of FLC controllers is that they need a lot of information to compensate for non-linearity when the parameters change, more if the number of inputs of FLC increases the size of the basic rules increases [6][9]. To overcome the disadvantages of corrective PID and FLC, we combine them together. Corrective PID parameters can be adjusted by a controller based on fuzzy logic (FLC).

This paper is organized as follows: The principle of classical DTC is presented in the second section, the speed PI fuzzy logic controller design is performed in the third section, and section four is devoted to illustrating by simulation the performances of this control strategy, a conclusion and reference list end the paper.

II. PRINCIPLE OF DTC

The principle of the command DTC is different. The objective is the direct regulation of the couple of the machine, by the application of the various vectors of tension of the inverter, which determines her state. The two controlled variables are: the flow statorique and the electromagnetic couple which who are usually commanded by regulators in hysteresis [1][2]. It's about maintaining the greatnesses of statorique flux and the electromagnetic couple inside these bands of hystérésis. The output of this regulator determines the voltage vector of the optimal inverter to be applied to each switching instant. The use of this type of regulators supposes the existence of a frequency of switching in the variable converter requiring a step of very low calculation[2][3].

A. *Principle of the vector control of torque*

We use the vector expressions of the machine in the frame of reference linked to the stator:

$$\begin{cases} \bar{v}_s = r_s \bar{i}_s + \dfrac{d\overline{\Psi}_s}{dt} \\ \dfrac{L_m}{L_s}\overline{\Psi}_s = \sigma\tau_r \dfrac{d\overline{\Psi}_r}{dt} + (1 - j\omega\sigma\tau_r)\overline{\Psi}_r \end{cases} \tag{1}$$

With $\sigma = 1 - \dfrac{L_m^2}{L_s L_r}$ (2) (dispersion coefficient)

The electromagnetic torque is proportional to the vectorial product between the stator and rotor flux vector:

$$\Gamma = p_p \frac{L_m}{\sigma L_s L_r} \Psi_s \Psi_r \sin(\overbrace{\overline{\Psi}_s \overline{\Psi}_r}) \tag{3}$$

B. *Principle control the stator flux*

During the switching interval, each voltage vector is constant and is then rewritten as in [4]:

$$\overline{\Psi}_s(t) = \overline{\Psi}_s(0) + \bar{v}_s t_e - \int_0^t (r_s \bar{i}_s) dt \tag{4}$$

$$\text{Or} \quad \Delta\overline{\Psi}_s = \bar{v}_s t_e \tag{5}$$

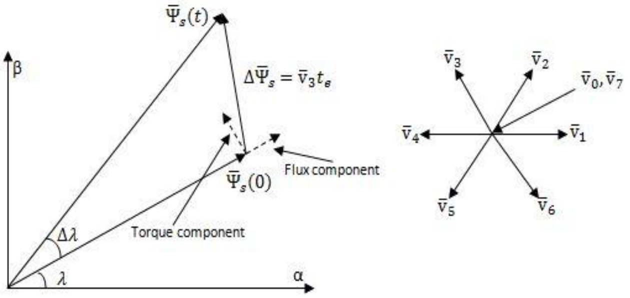


Figure1. Example of stator flux vector end when the resistive term is negligible

C. *Stator flux and torque estimation*

The magnitude of stator flux, which can be estimated by:

$$\begin{cases} \Psi_{s\alpha} = \displaystyle\int_0^t (v_{s\alpha} - r_s i_{s\alpha}) dt \\ \Psi_{s\beta} = \displaystyle\int_0^t (v_{s\beta} - r_s i_{s\beta}) dt \end{cases} \tag{6}$$

The stator flux linkage phasor is given by:

$$\Psi_s = \sqrt{\Psi_{s\alpha}^2 + \Psi_{s\beta}^2} \tag{7}$$

In stationary reference frame, the machine stator voltage space vector is represented as follows:

$$\bar{v}_s = v_{s\alpha} + j v_{s\beta} \tag{8}$$

$$\begin{cases} v_{s\alpha} = \sqrt{\dfrac{2}{3}} U_0 (S_a - \dfrac{1}{2}(S_b + S_c)) \\ v_{s\beta} = \dfrac{1}{\sqrt{2}} U_0 (S_b - S_c) \end{cases} \tag{9}$$

The stator flux sector is determined by the components $\Psi_{s\alpha}$ and $\Psi_{s\beta}$. The angle between the referential and $\overline{\Psi}_s$ is equal to:

$$\lambda = arctg \frac{\Psi_{s\beta}}{\Psi_{s\alpha}} \tag{10}$$

D. *Electromagnetic torque estimation*

Torque can be calculated using the components of the estimated flux and measured currents:

$$\Gamma = p_p (\Psi_{s\alpha} i_{s\beta} - \Psi_{s\beta} i_{s\alpha}) \tag{11}$$

E. *Switching table*

The control table is built according to the state of variables $d\Psi$ and $d\Gamma$ and to the S_i zone and $\overline{\Psi}_s$ position, and so, it is shaped as presented in the table 1.

TABLE1. SWITCHING TABLE FOR CONVENTIONAL DIRECT TORQUE CONTROL

		Sectors (S_i : i = 1 to 6)					
dψ	dΓ	S_1	S_2	S_3	S_4	S_5	S_6
1	1	V_2	V_3	V_4	V_5	V_6	V_1
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_6	V_1	V_2	V_3	V_4	V_5
0	1	V_3	V_4	V_5	V_6	V_1	V_2
	0	V_0	V_7	V_0	V_7	V_0	V_7
	-1	V_5	V_6	V_1	V_2	V_3	V_4

III. FUZZY SPEED CONTROLLER

This controller has two inputs, the error (which is the difference between the setpoint ωref and the output ω of the process) and derivative of error, the controller output is the command that must apply to the input of the process. The majority of controllers developed using the simple structure that is shown in Figure 3.

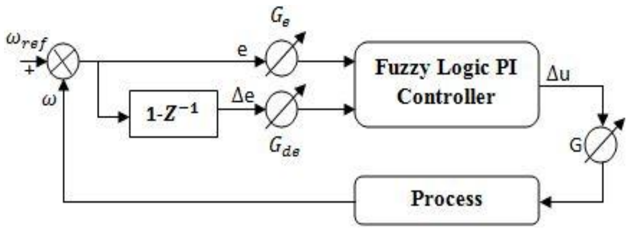


Figure2. Structure of the fuzzy controller

Our controller has two inputs and one output. To apply the fuzzy algorithm, we must define a set of control strategy based on error between a predetermined setpoint and the actual output of the process and the derivative of the error, this to adjust the control variable.

At each sampling period, the inputs of the fuzzy controller are:

The error e, expressed by:

$$e(k) = \omega_{ref}(k) - \omega(k-1) \tag{12}$$

The derivative of error, expressed by:

$$\Delta e = \frac{e(t) - e(t-1)}{t_e} \tag{13}$$

With: t_e is the sampling period.

The output of fuzzy controller is the increment of the torque reference is obtained as follows:

$$\Gamma_{ref} = \Gamma_{ref}(k-1) + du(k) \tag{14}$$

The output u represents the command that must be applied to the system. At each sampling period Te, the fuzzy controller delivers the control u corresponding to a pair of input (error (e) and its derivative (Δe)).

The fuzzy controller is composed of three blocks: fuzzification, rule bases, and defuzzification. The increase in the number of fuzzy sets to seven (NG, NM, NP, Z, PP, PM, PG) requires the processing of 49 rules. The distribution of these sets on the universe of discourse of each variable must be made from a judicious choice.

The linguistic values: NG: Negative Large, NM: Negative Medium, NS: Negative Small, Z: Zero (zero), PP: Positive Small, PM: Positive Medium and PG: Positive Big.

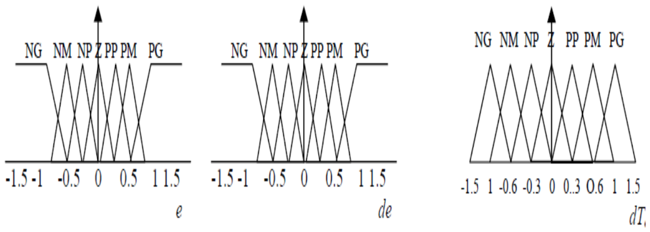


Figure3.Fuzzy partitions for fuzzy PI-seven sets

TABLE2.FUZZY RULES

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

IV. SIMULATION RESULTS

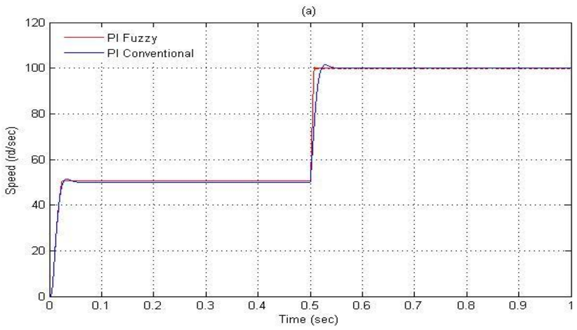
Induction motor parameters:

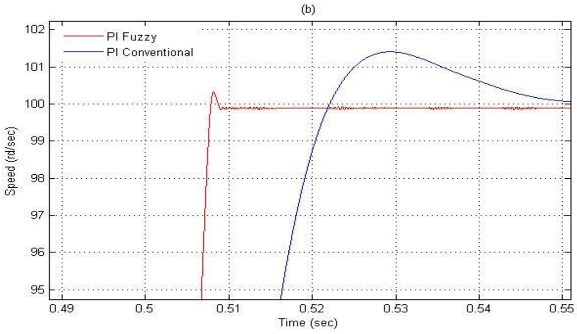
Pn=3Kw, Vn=230v, Rs=5.27Ω, Rr=5.07Ω, Ls=0.416H, Lr=0.423H, Lm=0.458H, J=0.2Kg.m², P=2.

To show the performance obtained by the optimized fuzzy PI compared to conventional PI, we simulated the dynamic behavior after booting empty then an insertion of a load torque and a change of reference speed.

First, the drive is run at no load to verify the performance of the fuzzy PI under no load condition at various operating speeds. The drive is started at no-load and is run at various speeds by increasing it in steps to 50 rad/s, and 100 rad/s at 0 sec, and 0.5 sec,

Indeed, the rotation speed reaches its reference after a response time of 0.02 s at start, then vacuum 0.5076s when changing speed of 50 rd / sec to 100 rd / sec. This response is fast enough compared to that obtained by the conventional PI, this demonstrates the effectiveness of the fuzzy controller.





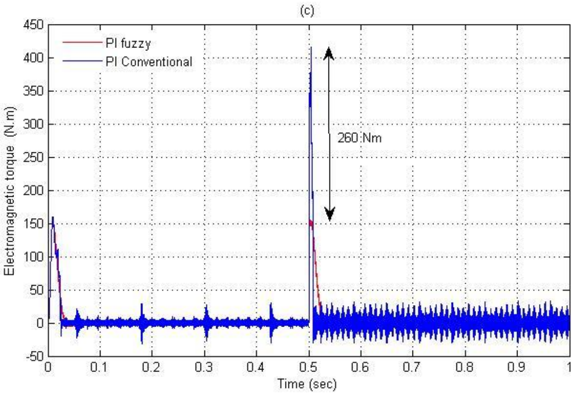
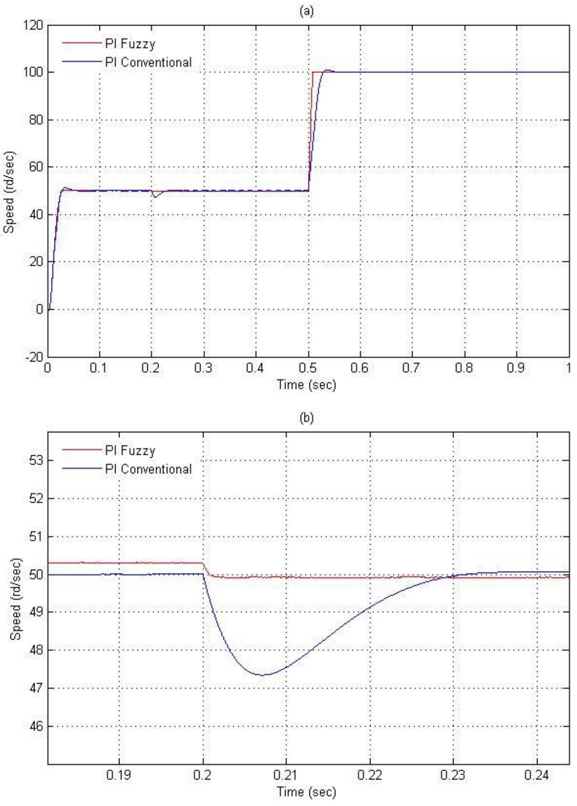


Figure.4 No-load operation at various speeds; (a) PI Fuzzy and PI Conventional (b) The zoom of the dynamic response of the speed (c) Electromagnetic torque.

And in the second test on the application of a load torque of 50 Nm at the moment t = 0.2 s, we obtain the simulation results shown in Figure 5. According to these results, we also note a significant improvement in terms of deviations occurred in the response speed during application and removal torque. These are reduced compared to those of classical PI.



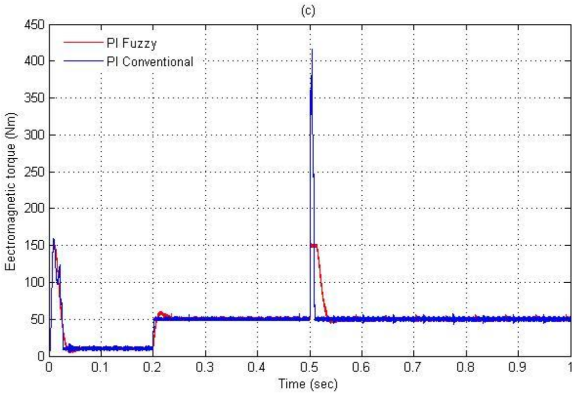


Figure.5 Application of load operation at various speeds; (a) PI Fuzzy and PI Conventional (b) The zoom of the dynamic response of load (c) Electromagnetic torque.

Similarly for the test set change, we simulated the dynamic load at startup for a design speed of 100 rd / s followed by a reversal of the direction of rotation of -100 rd / s from t = 0.5 sec. The figure 6 shows the simulation results. According to this figure, another improvement is observed when changing the set characterized by the reduction of time to pout this change.

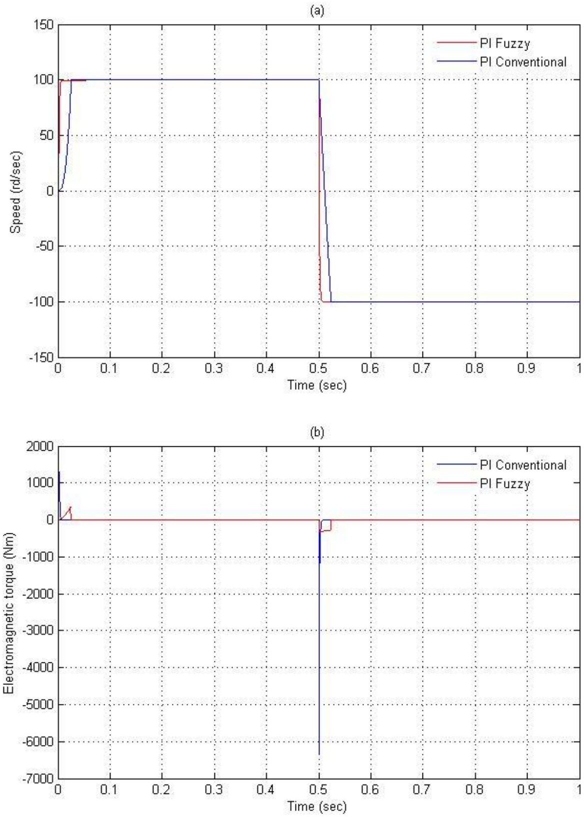


Figure.6 No-load operation at reversal speeds; (a) PI Fuzzy and PI Conventional (b) Electromagnetic torque.

V. CONCLUSION

In this paper we proposed a direct torque control of induction motor with a fuzzy speed controller

The purpose of the study is to develop a fuzzy supervisor that allows to control the effect of disturbance and adjust the gains of PI controller when the change in instructions. It is clear that this combination results make improvements in:

- The robustness of the control chain vis-à-vis the change in charge and the reversal of rotation of the machine;
- The successful operation of the supervisor can detect areas of adaptation gains and evaluate their values of PI controller according to the desired performance.

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