ROBUST TRACKING SPEED CONTROL FOR INDUCTION MOTOR DRIVE BASED FUZZY LOGIC

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Abstract:
The subject of this paper is the implementation of fuzzy logic to control the speed of the induction motor drive. Some fundamentals of the FLC are preliminary illustrated. The introducing of fuzzy logic in the control system helps to achieve good dynamical response, disturbance rejection and low sensibility to plant parameter variations of the A-C motor drive. It also assures precise trajectory tracking with the prescribed dynamics. The effectiveness of this controller is demonstrated through simulation for different operating conditions of the motor drive system and a qualified speed tracking and load regulating responses can be obtained by the proposed scheme of controller.

Index terms: *Induction motor, fuzzy control, speed control, robustness.*

Résumé:
Dans cet article l'implémentation de la logique floue pour la commande en vitesse d'un moteur à induction est considérée. Les résultats fondamentaux d'un régulateur flou sont préliminairement illustrés. La commande floue pour ce type de moteurs semble une alternative intéressante comparativement au régulateur classique de type PI. L'introduction de la logique floue dans les systèmes de commande, permet de réaliser une meilleure réponse dynamique, de rejeter les perturbations et de traiter correctement la sensibilité due aux variations paramétriques du processus à contrôler. Elle assure également un bon suivi de consigne pour les boucles de vitesse et de flux. L'efficacité de ce contrôleur est démontrée par la simulation sous différentes conditions de fonctionnement du moteur à induction et les résultats obtenus montrent la supériorité de la stratégie envisagée vis-à-vis de la robustesse en performance face aux dérives du moteur à induction considéré.

Mots clés : *Moteur à induction, logique floue, contrôle de vitesse , robustesse.*

1. Introduction

AC motors have many chances for application in controlled drives due to there inherent low cost, high torque per volume and useful flux weakening capability. However, for high dynamic performance industrial applications, their control remains a challenging problem because they exhibit significant non linearities and it is now well known that uncertainties of plant parameters and influence of unknown external disturbances can degrade significantly the performance of the system with linearizing feedback. Filed oriented control [1,5,7] methods are attractive, but suffer from one major disadvantage. They are sensitive to uncertainties parameter of the induction motor caused by the thermal variations and load torque disturbances. Consequently, performance deteriorates and adaptive control scheme can be appropriate technique for controlling the induction motor by where the parameters are constant or change very slowly [8]. The need to control complex dynamic systems when the available knowledge on the system and its environment it insufficient or vague let first to the development of fuzzy logic control which has proved very effective in controlling large-scale industrial processes [5]. In the last few decade fuzzy logic based control systems have witnessed a rapid growth in industrial applications. They proved that such control can achieve satisfactory results in dealing with systems whose behaviour is difficult to describe mathematically or is highly nonlinear. Many researches works proved that fuzzy logic techniques could be very helpful in solving compound problems on a range processes as well as used in industrial controllers[5,6,7,8]. However, applications of fuzzy logic control has been reported mainly in the field of control on electrical motors [7]. The fuzzy set theory gives the tools to represent and manipulate the linguistic variables. This approach provides an effective mean for describing systems with are too complex or too uncertainties defined to admit a precise mathematical model fuzzy logic control is one of the most interesting fields to which the fuzzy logic theory can effectively applied. Recently, some applications of fuzzy logic control's to motor drives have been also reported. In our case an induction motor has been to explore the design of FLC drive system and to investigate by simulation and experiment its performance. The motor drive is preliminary simulated and experimented with conventional digital PI speed regulator in order to establish a term of comparison. The paper is organised as follows. Section 2 describes a mathematical of induction motor drive, Section 3 gives the structure of the proposed control scheme. The fuzzy logic approach and fuzzy PI regulator design are discussed in section 4. Section 5 provides the simulation results for demonstrating the performance of the proposed control strategy. Concluding remarks are provided in Section 6.

2. Model of Induction Motor

The dynamics of the induction motor in the d-q motor reference frame, which is rotating at the synchronously speed, can be simply described by a set electrical and mechanical non-linear differential equations (Marino, Peseda and Valigi, 1993).

$$J\frac{d\omega_r}{dt}=\frac{n_pM}{L_r}(\psi_{rd}i_{sq}+\psi_{rq}i_{sd})-T_L \quad (1)$$

$$\frac{di_{sd}}{dt}=\frac{MR_r}{\sigma L_sL_r^2}\psi_{rd}+\frac{n_pM}{\sigma L_sL_r}w_r\psi_{rd}-\frac{M^2R_r+L_r^2}{\sigma L_sL_r^2}i_{sd}$$

$$\frac{di_{sq}}{dt}=\frac{MR_r}{\sigma L_sL_r^2}\psi_{rq}-\frac{n_pM}{\sigma L_sL_r}w_r\psi_{rd}-\frac{M^2R_r+L_r^2}{\sigma L_sL_r^2}i_{sq}+\frac{1}{\sigma L_s}u_{sq}$$

(2)

$$\frac{d\psi_{rd}}{dt}=-\frac{R_r}{L_r}\psi_{rd}-n_pw_r\psi_{rq}+\frac{R_r}{L_r}Mi_{sd}$$

$$\frac{d\psi_{rq}}{dt}=-\frac{R_r}{L_r}\psi_{rq}+n_pw_r\psi_{rd}+\frac{R_r}{L_r}Mi_{sq}$$

(3)

$$\sigma=1-\frac{M^2}{L_sL_r}$$

where i, u, ψ denote current, voltage and flux linkage respectively. Subscripts r and s stand for rotor and stator. ω_r is the rotor speed, d and q denote direct and quadratic components of the vectors with respect to the fixed stator reference frame, L and R are the auto-inductances and resistances, M is the mutual inductance and T_L is the load torque. In the following, we plan to design an fuzzy controller which should stabilize the system and cause $\omega_r(t)$ to track a bounded reference $\omega_r^*(t)$ asymptotically.

3. Proposed Fuzzy Control System

Most of the problems in control of electrical motor drives are due to their highly complicated dynamic models. These drive systems today employ a conventional regulator such as a PI-type controller. This strategy works well, but only under a specific set of known system parameters and load conditions. Thus, the need for other types of controllers which can account for nonlinearities or are somewhat adaptable to varying conditions in real time without the need for operator reprogramming. Other methods are now being employed, such as Fuzzy Logic, in order to achieve a desired performance level. These controllers, as currently demonstrated by a number of experimenters, [4,6]. The main preference of the fuzzy logic is that is easy to implement and that it has the ability of generalization. The proposed Fuzzy Logic Controller is shown in figure 1.

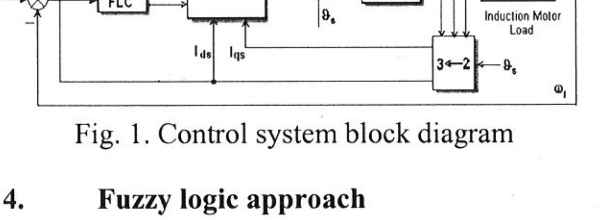


Fig. 1. Control system block diagram

4. Fuzzy logic approach

Using fuzzy logic principles in induction motor speed control has described in [3]. The fuzzy control system architecture is shown as figure 2.

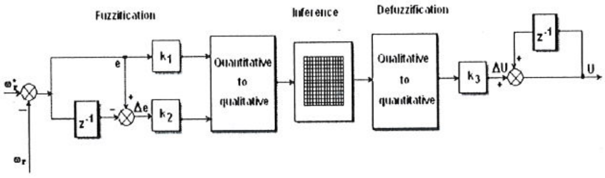


Fig.2. Fuzzy control system architecture

As fuzzy system, we are considering a fuzzy PI controller. The control algorithm is represented by fuzzy rules [3,6]. The first step in designing the fuzzy controller is to generate the fuzzy rules based on the knowledge of the expert. According to the expert, three situations can be distinguished for the motor speed, namely, above, around and below the desired reference speed. The linguistic representation of the motor speed with respect to a given desired reference speed can be easily translated into a linguistic characterisation of the system error. By defining the system error between the measured speed and the desired speed, the propositions, higher, around and beneath the desired reference speeds are otherwise expressed as Positive, Zero and Negative errors. Furthermore, for given system state variables, the expert can express how he would act if he was controlling the system. For example, a typical rule reads as follows:

IF speed error is Positive Small (**PS**),
AND rate of change in speed error is negative small (**NS**)
THEN change in motor voltage (Output of fuzzy controller is Zero (**Z**))

The second step consists of modifying the rule-base in order to satisfy the requirements induced by the proposed strategy. The fuzzy controller has to produce a null action when the system has a normal behaviour. In the system presented in this study, Mamdani type of Fuzzy Logic Controller FLC is used for speed controller. The command signals to the speed controller are the error 'e' and its change 'Δe' while the output is the change of control signal 'Δu'. Fuzzy controllers are based on four well known stages. The fuzzification stage takes crisp numerical values and determines their degree of membership in each collection of sets which are given linguistic labels that are meaningful in terms of the problem to be solved. The second part is the fuzzy rule base which expresses relations between the input fuzzy sets A and B and the output fuzzy sets C in the form of: ' **IF** A and B **THEN** C'. The fuzzified inputs are combined using these rules in the third part, the fuzzy inference engine. This produces a combined fuzzy output set. The final part, the deffuzzifier produces a crisp output from the combined fuzzy output set. Inputs and the output are non-fuzzy values. In this work, a simple Proportional-Integral (PI) speed control scheme was implemented and used to assess the basic performance of the system. The output of the fuzzy controller $u_f(k)$ is given by:

$$u_f(k) = F_f\left(e(k) - \Delta e(k)\right) \qquad (4)$$

Where F_f is a non linear function determined by fuzzy parameters, e(k), Δe(k) are the error and change-of-error respectively. A type of those controllers is fuzzy PI controller whose input is the error e(k).

$$e(k) = \omega_r^*(k) - \omega_r(k) \qquad (5)$$

where $\omega_r^*(k)$ is the reference model and $\omega(k)$ is the process output at time k. The fuzzy logic controller was used to produce and adaptive control so that the motor speed $\omega_r(k)$ can accurately track the reference command $\omega_r^*(k)$.

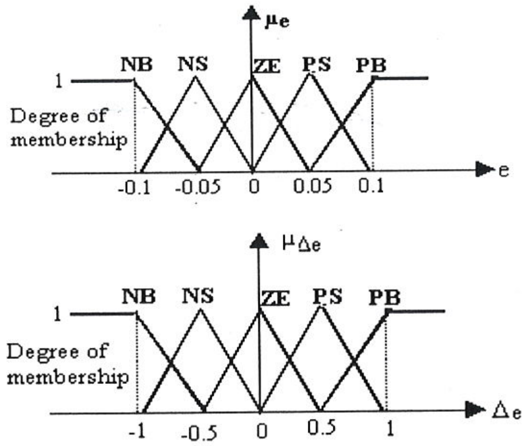


Fig.3. Degree of membership of error and its change

For the proposed fuzzy controller, the universe of discourse is first partitioned into the five linguistic variables. The controller treats each measurements as a fuzzy singleton and fuzzifies it using the fuzzy sets shown in fig.3.

where **NB**: Negative Big, **PB**: Positive Big, **NS**: Negative Small, **PS**: Positive Small and **ZE**: Zero Equal.

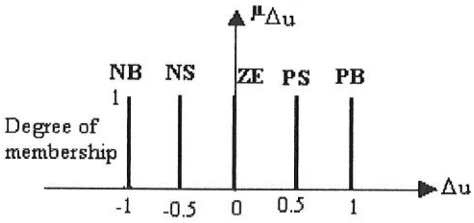


Fig.4. Output membership functions

Triangular shapes were chosen as the membership functions due to the linear equation in evaluation of membership functions. and the output of the fuzzy controller is illustrated in figure 4. The fuzzy rules based on speed error e(k) and its variation change Δe(k) are presented in Table 1. This implies an inference engine based on 5 implications rules for each of the speed error and its variation, thus a total 25 combinations take place. One can see on Table 1. the rules sets of the fuzzy controller. Every combination is associated to a condition instruction as follows:

If e(k) is **NB** And Δe(k) is **PB** , Then Δu(k) is **ZE**

e \ Δe	**NB**	**NS**	**ZE**	**PS**	**PB**
NB	NB	NB	NS	PB	PS
NS	ZE	NS	ZE	PS	ZE
ZE	PB	PB	ZE	PS	NB
PS	ZE	PS	PB	NS	NB
PB	PB	PS	NS	NS	NB

Table 1. Control rules for proposing system

Figure 5 shows the equivalent control surface for the rules in Table 1.

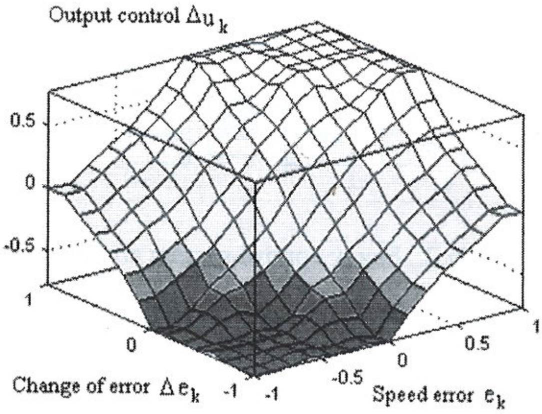


Fig.5. The control surface corresponding to the fuzzy controller

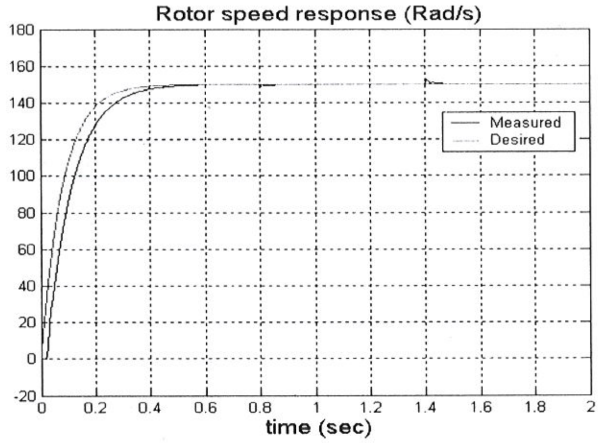
5. Results and comparative analysis

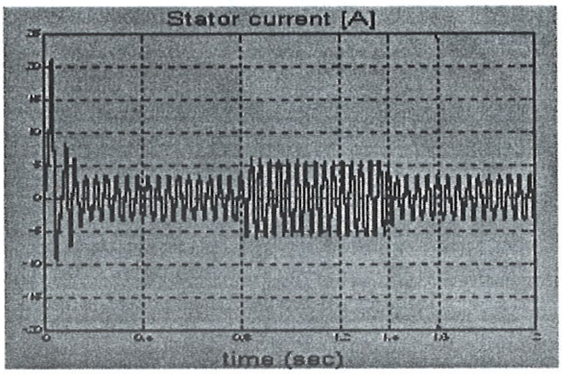
The Fuzzy Logic based speed control system has been studied by simulation in order to validate the design an to evaluate the performance. For the simulation results used in this paper, the numerical values for the tested induction motor are summarized in Table II. The performance of the proposed controllers are evaluated under a variety of operating conditions. The controller algorithm is housed inside the personal computer with Pentium IV microprocessor and all numerical values of the simulation model are obtained either by measurements or identification from laboratory experiments. The software environment used of these simulation experiments is MATLAB with Simulink Toolboxes.

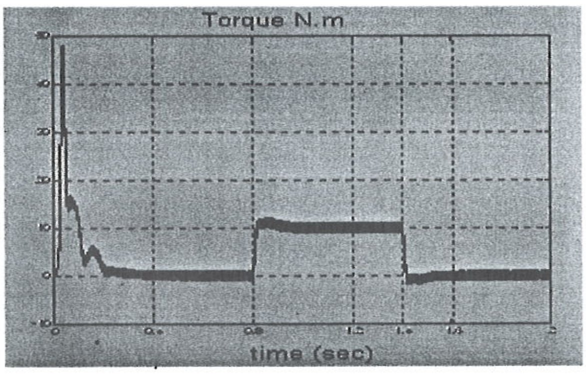
TABLE II
RATING OF TESTED INDUCTION MOTOR

Rated values	Power	1.5	kW
	Frequency	50	Hz
	Voltage Δ/Y	220/380	V
	Current Δ/Y	11.25/6.5	A
	Motor Speed	1420	rpm
	pole pair (p)	2	
Rated parameters	Rs	4.85	Ω
	Rr	3.805	Ω
	Ls	0,274	H
	Lr	0,274	H
	M	0,258	H
Constant	J	0,031	kg,m²

The response of the system using Fuzzy-Logic Controller obtained by simulation in shown in figures 6 to 10. In this simulation, we compare results gotten by a Fuzzy-Logic regulator and a classic regulator. Results of simulation corresponding to the working in tracking in the two cases of regulation (Fuzzy and Classic regulator) are shown in figures 6,8,9,10, while analyzing the different curves, we can note that the fuzzy regulator iqs more robust and permits to have a better dynamic that the classic regulator. Fig.6 shows the behaviour of the system screw to screw of resistant torque T_L= 15 [N.m] all in maintaining the constant speed command (ω_r*=150 rad/s).







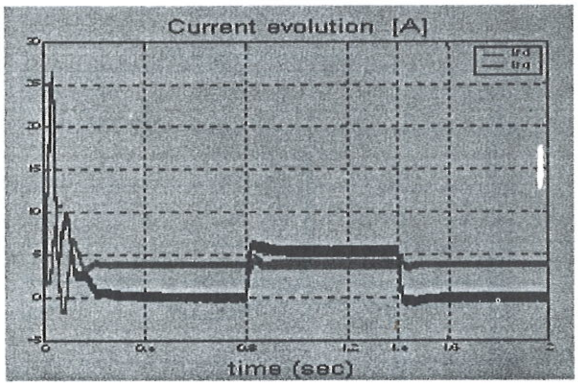
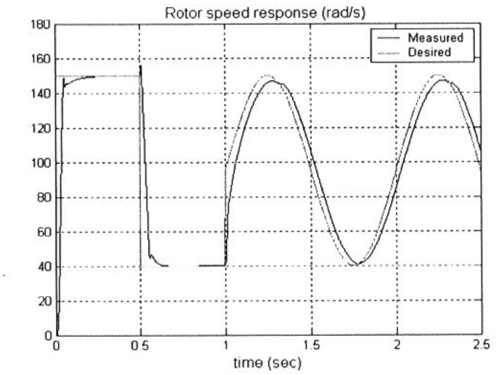
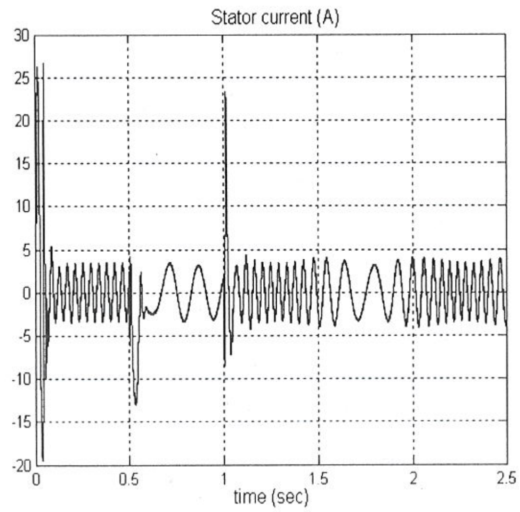


Fig.6. Speed control with load torque

To demonstrate the robustness of the proposed controller, a different type of trajectory (a square followed by sinusoidal wave reference track) was considered in this test. In this experiment, the motor is under the same dynamic load. Fig. 7 displays the speed tracking performance of the hybrid controller. High tracking accuracy is observed at all speeds. One can see from this figure that the results were very successful.





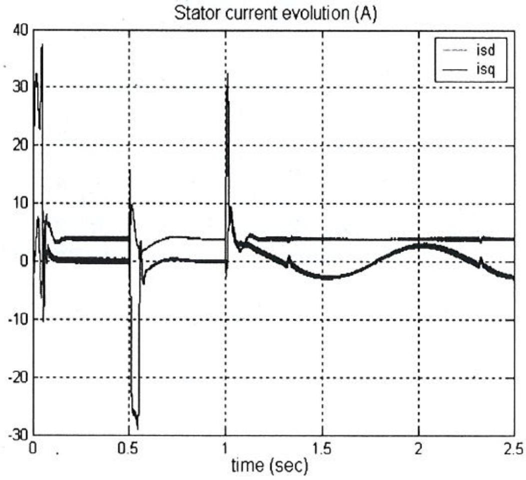
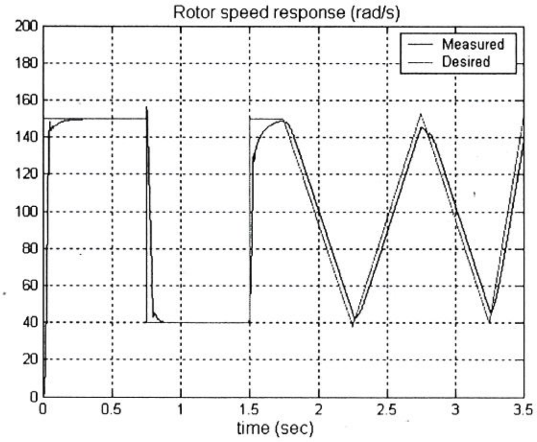
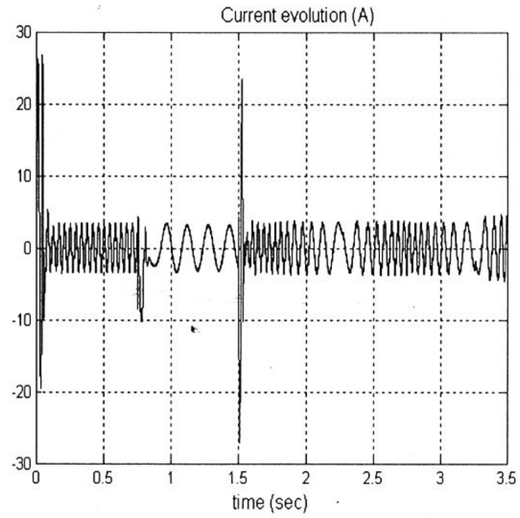


Fig.7. Speed control of a square – sinusoidal wave reference track

Fig.8 shows the results of the proposed control scheme in the case of a combined square-triangular reference speed track, for which ω_r^* has an amplitude of 110 (rad/s) . One can see from this figure that the results were very successful. High tracking accuracy is observed at all speed.





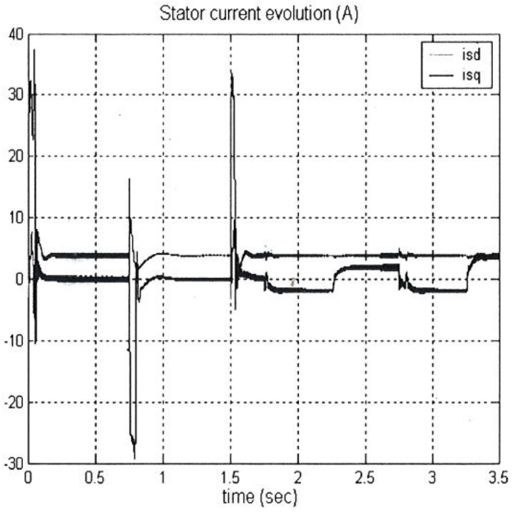
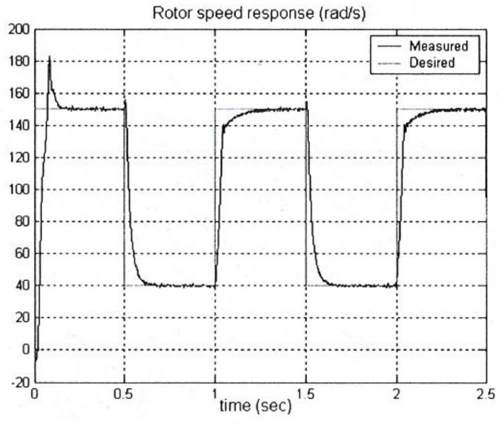


Fig.8. Speed control of a square – triangular wave reference track

Fig.9 shows the performance for motor speed tracking with the desired speed changing from the square wave track, for which ω_r^* has an amplitude of 110 (rad/s) and a wavelength of 0.5 (sec), with randomly induced impulsive changes in torque. It is observed that, in every case, the fuzzy controller brings the measured speed to the desired value smoothly and without the overshoot. Clearly, the fuzzy controller reduces both the overshoot and extent of oscillation under the same operating condition.



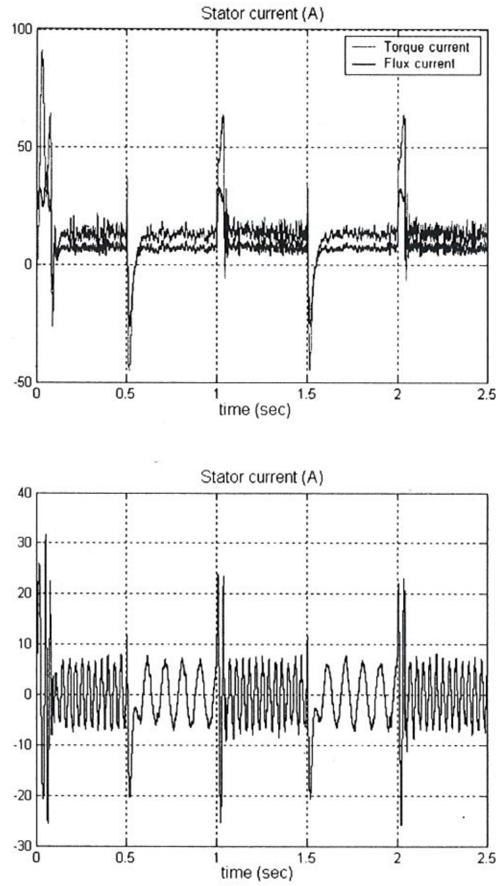
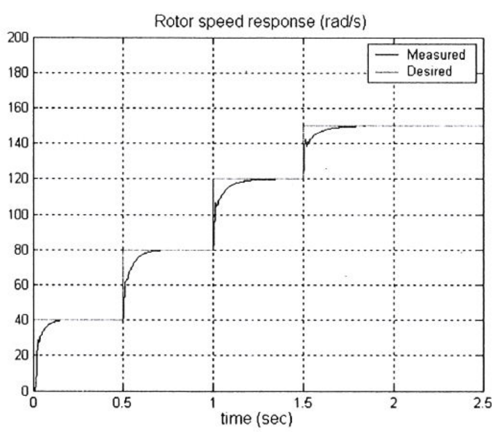


Fig.9. Speed control with stochastic load changes

As shown in Fig.10 the ability of the fuzzy controller in tracking the reference speed is illustrated. A series of 40 (rad/s) and a wavelength of 0.5 (sec), speed command step superimposed on each other respectively are applied as shown in Fig.10. One can be seen that smooth and fast tracking of the actual speed with the reference speed in the whole of the operational range without any overshoot or additional oscillation.



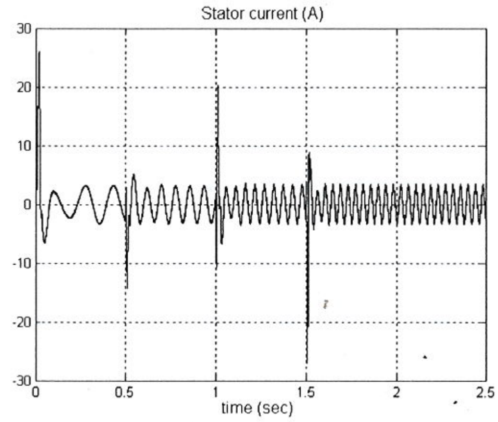


Fig.10. Speed and stator current responses following a variable reference

A comparative analysis of the control strategies in terms of performance and robustness has been conducted. The obtained results have compared to the conventional controller such as PI-type controller. This method works well, but only under a specific set of known system parameters and load conditions. There are two major differences between the tracking ability of the conventional PI controller and the fuzzy logic controller. Both the PI and FLC controllers produce reasonably good tracking for steady-state or slowly varying operating conditions. However, when there is a step change in any of the operating conditions, such as may occur in the set point or lead, the PI controller tends to exhibit some overshoot or oscillations. The fuzzy controller reduces both the overshoot and extent of oscillations under the operating conditions.

6. Concluding remarks

This paper has presented a fuzzy logic scheme for controlling the speed of an induction motor. The proposed control system was analyzed and designed and implemented and its effectiveness in tracking application was verified. From the above results it's clear that, the proposed control scheme had a good speed response, regardless of parameter variations. It despite of its simple structure, has all of the features of a high precision speed controller for operating in the whole of speed range and for any loading and environmental conditions. Advantages of fuzzy logic control are that it is parameter insensitive, priovides fast convergence and accepts noisy and inaccurate signals. System performances, both in steady state and dynamic conditions, were found to be excellent.

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