IJCTA, 10(5) 2017, pp. 659-666

Speed Regulation of Indirect Vector Controlled-Induction Motor using Fuzzy Logic Controller

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Abstract: This paper proposes Fuzzy Logic Controller that applies fuzzy logic method in speed regulation of an induction motor drive. Based on the fuzzy set theory, this paper provides the analysis, design and simulation of the fuzzy logic controller for an indirect vector controlled IM drive. The conventional PI controller and the Fuzzy Logic Controller are implemented using Matlab/Simulink software. The performances of the IM drive using FLC are examined and compared with those of the IM drive using conventional PI controller at various conditions such as step change in load, sudden change in command speed, etc. The comparison results tell that the fuzzy logic controller is more robust and is best suitable for industrial drive applications with high performance.

Keywords: Indirect vector control, induction motor, fuzzy logic controller, PI controller, speed control.

1. INTRODUCTION

Electric motors used in industrial and commercial premises consume high electricity. The DC motors were in use earlier for applications like industrial robots, numerically controlled machinery etc in which the control of speed and position is difficult. This is because it is easy to control flux and torque in DC motors. But the main drawback of DC motor is, it uses a commutator because of which the motor size and maintenance cost is increased and motor life is reduced. The improvements in digital technology and power electronics has made the induction motor control a profitable solution, thus induction motors replaced the DC motors in various industrial plants.

Conventionally, the speed of the induction motor is controlled by PI and PID controllers which are fixed gain but are sensitive to variations in parameters, load disturbances, etc. Therefore several other techniques have been considered such as sliding mode control, model reference adaptive control, variable structure control, self tuning PI controller, etc, but all the above need an exact mathematical model of the system which is difficult because of variations in load and parameters, etc. Recently, from studies it is shown that the speed is calculated from the current and voltage across the AC motor thus the need of speed sensors is eliminated. The problems in controlling speed sensorless induction motor is overcome by Field oriented control that helps in providing smooth motion at low speeds and active operation at high speeds [1]. But the performance of the field orientation is largely dependent on exact knowledge of the machine parameters. Therefore Fuzzy logic controller is used that provides the smooth performance of induction motor dynamically [2]. The advantage of fuzzy logic controller compared to conventional controllers is that it does not need any exact mathematical model and is dependent on linguistic rules.

2. INDIRECT VECTOR CONTROL OF INDUCTION MOTOR DRIVE

The field oriented control has been considered as the popular control method of the induction motor drive. With the field oriented control, the induction motor which is complex can be operated as a dc motor

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by simple transformation. Figure 1 depicts the block diagram of an indirect vector control of induction motor drive and following are the equations that help in implementing indirect vector control strategy [3].

$$\theta_e = \int \omega_e dt = \int (\omega_r + \omega_{sl}) = \theta_r + \theta_{sl} \tag{1}$$

The equation of the rotor circuit

$$\frac{d\Psi_{dr}}{dt} + \frac{R_r}{L_r}\Psi_{dr} - \frac{L_m}{L_r}R_r i_{ds} - \omega_{sl}\Psi_{qr} = 0 \tag{2}$$

$$\frac{d\Psi_{qr}}{dt} + \frac{R_r}{L_r}\Psi_{qr} - \frac{L_m}{L_r}R_r i_{qs} + \omega_{sl}\Psi_{dr} = 0 \tag{3}$$

Equations (1) and (2) derives

$$\frac{L_r}{R_r}\frac{d\widehat{\Psi}_r}{dt} + \widehat{\Psi}_r = L_m i_{ds} \tag{4}$$

Where Ψ_r is the total flux.

The following equation gives the slip frequency

$$\omega_{sl} = \frac{L_m R_r}{\widehat{\Psi} L_r} i_{qs} \tag{5}$$

When $d\Psi_r/dt = 0$ is substituted in equation (4), the rotor flux is written as

$$\widehat{\Psi}_r = L_m i_{ds} \tag{6}$$

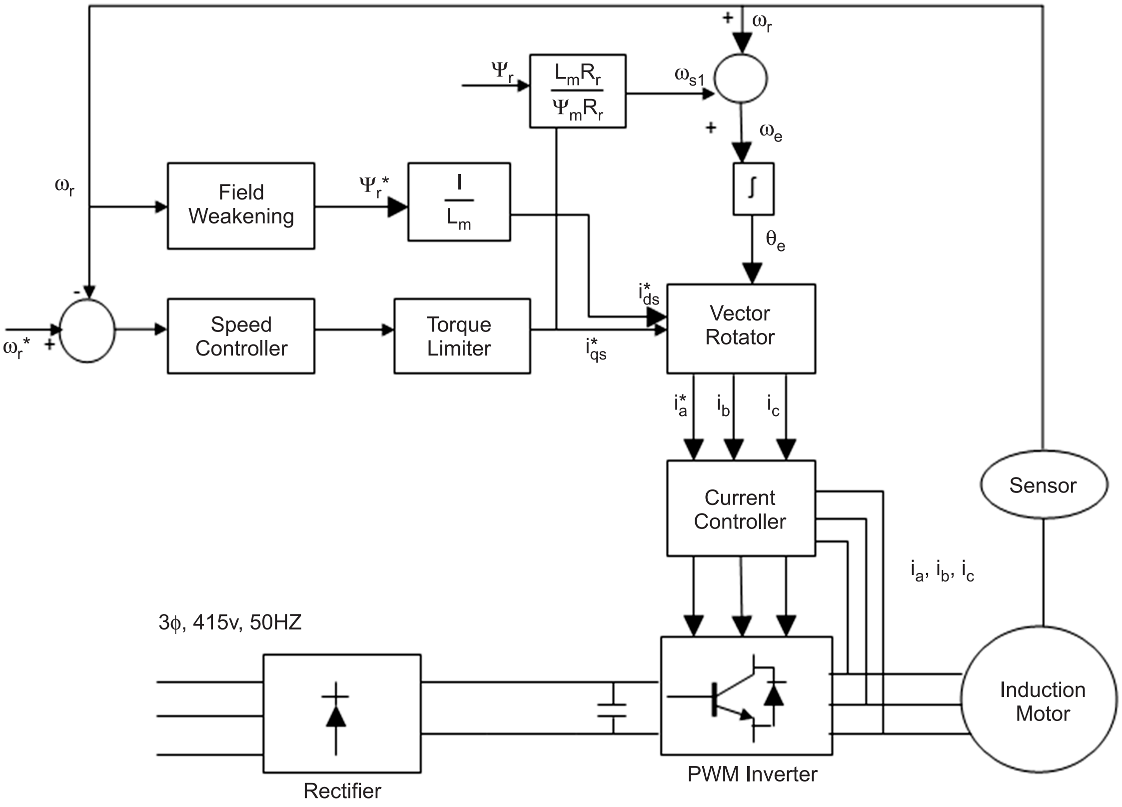

Figure 1: Indirect vector control of Induction Motor Dive

The electromechanical torque that is developed is derived by

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\hat{\Psi}_r i_{qs} \tag{7}$$

3. FUZZY LOGIC CONTROLLER DESIGN FOR INDUCTION MOTOR DRIVE

The functional block diagram of the fuzzy logic controller (FLC) is depicted in Figure 2 [4]. As shown there are two inputs speed error (*e*) and change in speed error (*ce*), of which the former is considered as the first input and later as second input and the calculation of these input variables is done at every sampling time as

$$\begin{aligned} e(t_s) &= \omega_r^*(t_s) - \omega_r(t_s) \\ ce(t_s) &= e(t_s) - e(t_s - 1) \end{aligned} \tag{8}$$

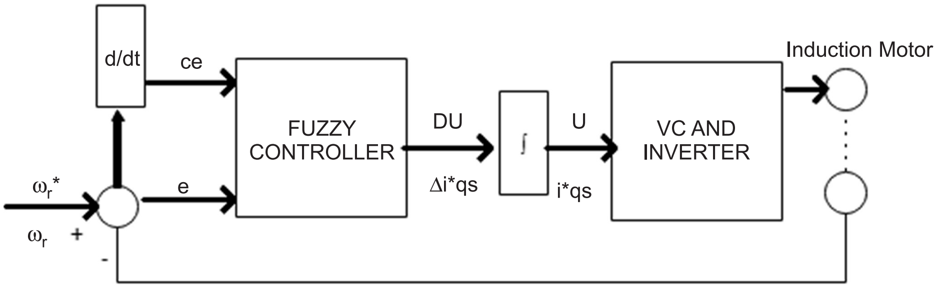

Figure 2: Functional block diagram of Fuzzy Logic Controller

where '*ce*' denotes the change in speed error '*e*', $\omega_r^*(t_s)$ is the reference rotor speed, $\omega_r(t_s)$ is the actual speed, $e(t_s - 1)$ is the value of error at previous sampling time.

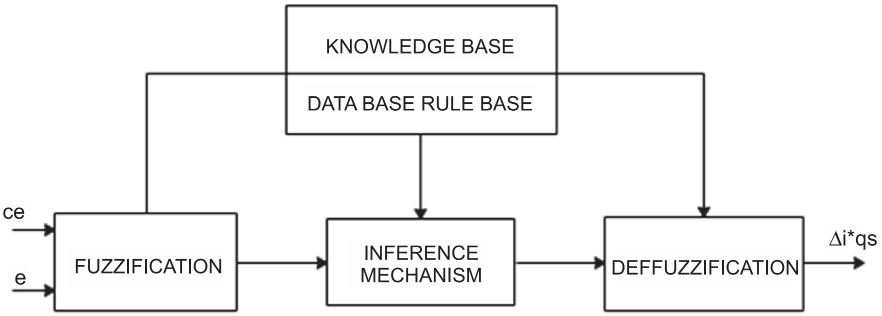

Figure 3: Fuzzy Logic Controller Internal structure

The output variable is the change in torque ΔT which is integrated to get the reference torque as shown in the equation

$$T^*(t_s) = T^*(t_s - 1) + \Delta T \tag{9}$$

Figure 3 shows the internal structure of fuzzy logic controller comprising the four blocks such as fuzzification, inference mechanism, knowledge base and defuzzification.

A. Fuzzification

The fuzzification modifies the variables of input error $e(t_s)$ and change in error $ce(t_s)$ into fuzzy variables and maps them to linguistic labels of fuzzy sets such as NB, NM, NS, ZE, PS, PM, PB. Each label is associated with membership function consisting two inputs and an output.

B. Knowledge base and Inference Mechanism

Knowledge base defines IF-THEN rules which manage the input and output relationship in terms of membership functions. The input variables execute 7*7 rules and are processed by inference mechanism using Mamdani's algorithm. For example if we consider the first rule, IF change in speed and change in speed error is NB, THEN the output is NB.

C. Defuzzification

Defuzzification uses various methods in producing fuzzy set value of fuzzy variable ΔT. Here the centre of gravity or centroids method is used in calculating the final fuzzy value $\Delta T(t_s)$. COA method used in defuzzification generates $\Delta T^*(t_s)$ output with the help of centre of gravity in which $\Delta T(t_s)$ is considered as geometric centre of $\mu_{out}(\Delta T)$ area, the $\mu_{out}(\Delta T)$ is formed by uniting all the contributions of rules satisfying the condition to be greater than zero. The COA expression can be written as

$$\Delta T = \frac{\sum_{i=1}^{n} \Delta T_i \cdot \mu_{out}(T_i)}{\sum_{i=1}^{n} \mu_{out}(\Delta T_i)} \tag{10}$$

The Te^* obtained by integration is used to calculate i^*qs.

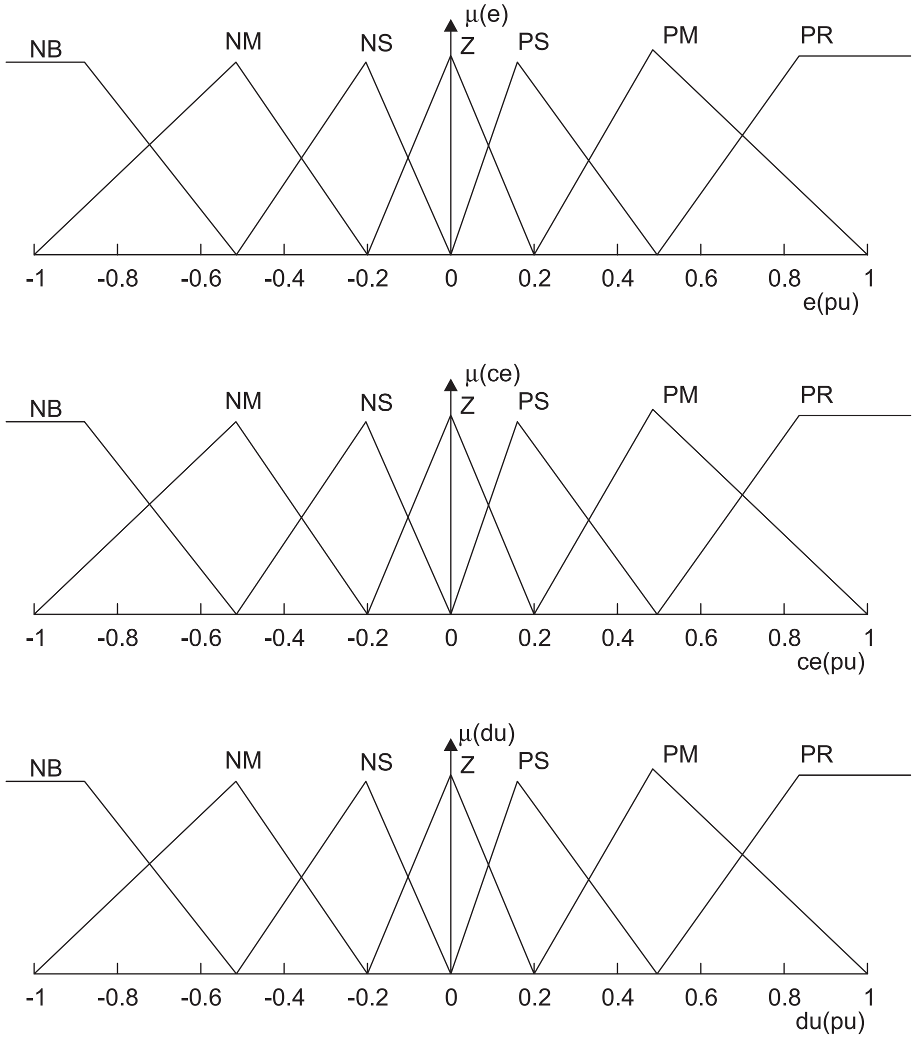

Figure 4. Membership Function of Fuzzy Variables μe, μce and $\mu(du)$

Table 1
Fuzzy Controller Rule Base

e(pu) *ce(pu)*	*NB*	*NM*	*NS*	*ZE*	*PS*	*PM*	*PB*
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
ZE	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

4. SIMULATION RESULTS AND DISCUSSION

The machine will be idle initially when there is no load. The reference speed increases linearly from zero and its rated value is 314 rpm with FLC and PI controller. The simulation was done on both PI and fuzzy logic controllers based indirect-vector control of Induction motor drive. The simulink block diagram of indirect vector control of induction motor drive is depicted in Figure 5.

Figure 6 and Figure 9 shows the stator currents using PI controller and fuzzy logic controller respectively. It is shown that the disturbance in the stator currents using PI controller as in Figure 6 has been reduced when fuzzy logic controller was used as in Figure 9.

Load torque and electromagnetic torque using PI controller and fuzzy logic controller is depicted in Figure 7 and Figure 10 respectively. Here the PI controller was affected when there is a change in load whereas there is no affect on FLC. Figure 10 shows that the proposed FLC is more robust to load disturbance compared to PI controller.

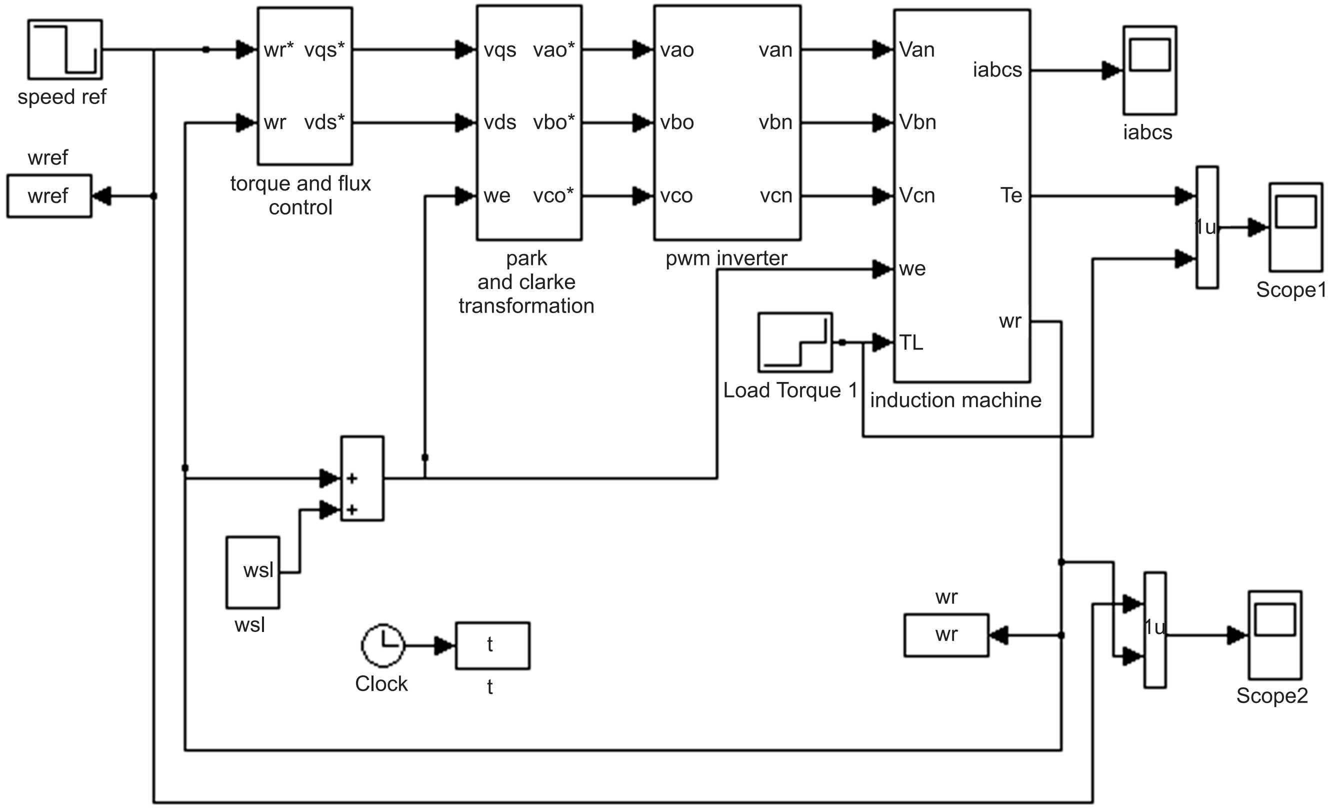

Figure 5: Simulink block diagram of indirect vector controlled induction motor drive

Finally Figure 8 and Figure 11 depicts the reference speed and actual speed response using PI controller and fuzzy logic controller respectively and it is clear that FLC offers faster response in comparison with PI. Therefore FLC based drive system is superior to PI based drive system in all respect such as rise time, settling time and overshoot.

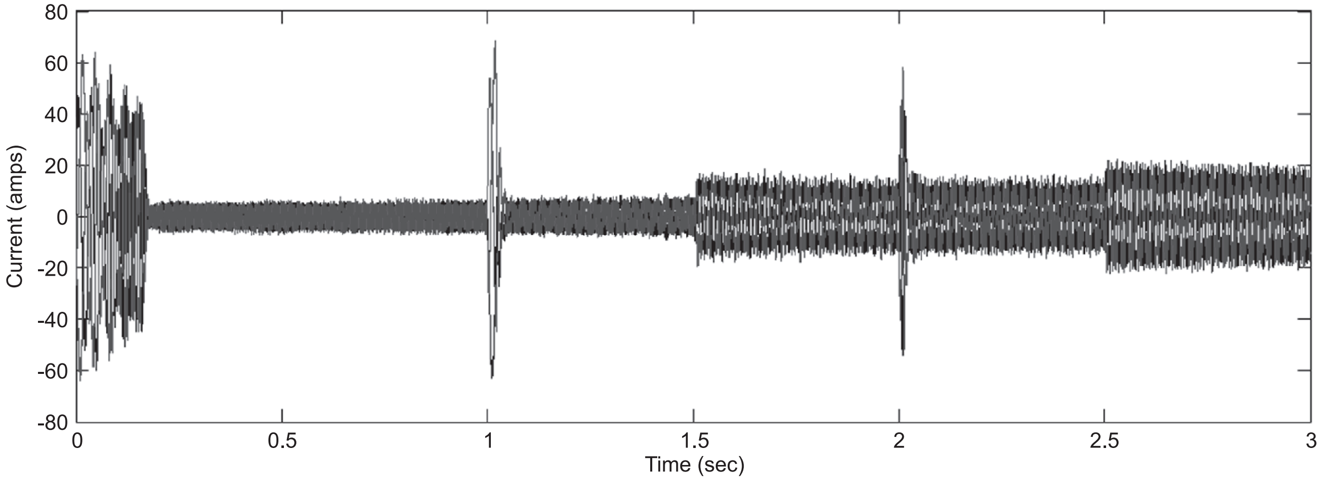

Figure 6: Stator currents using PI controller

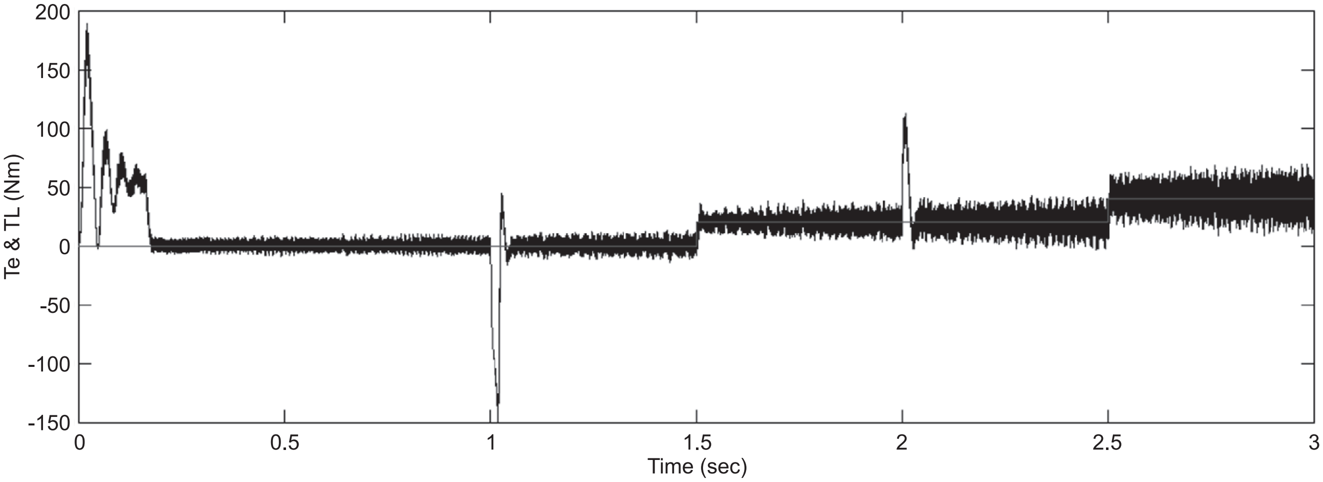

Figure 7: Load torque and electromagnetic torque using PI controller

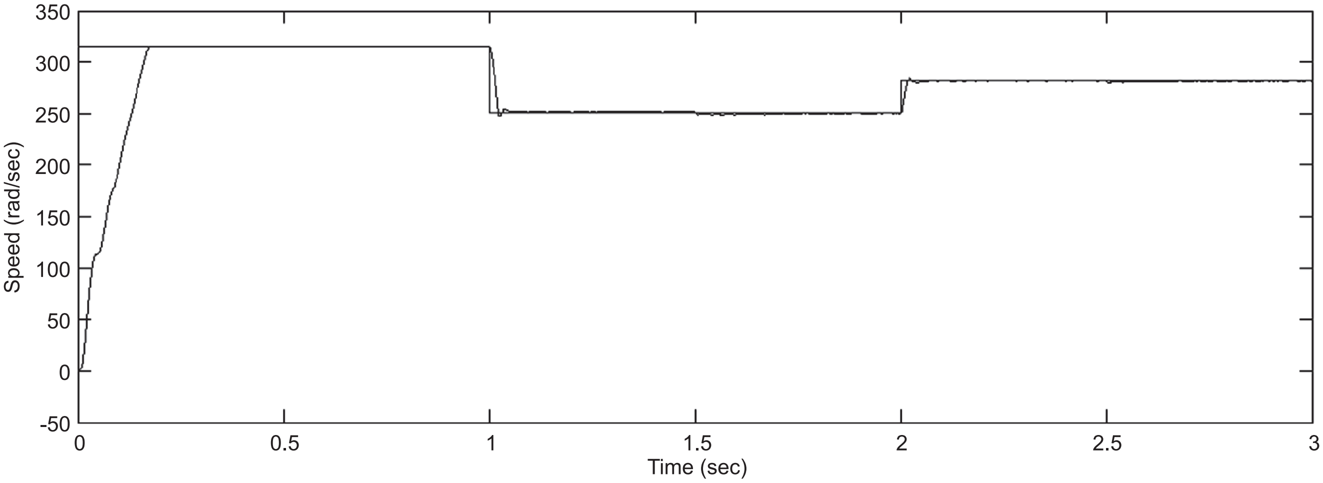

Figure 8: Reference speed and actual speed using PI controller

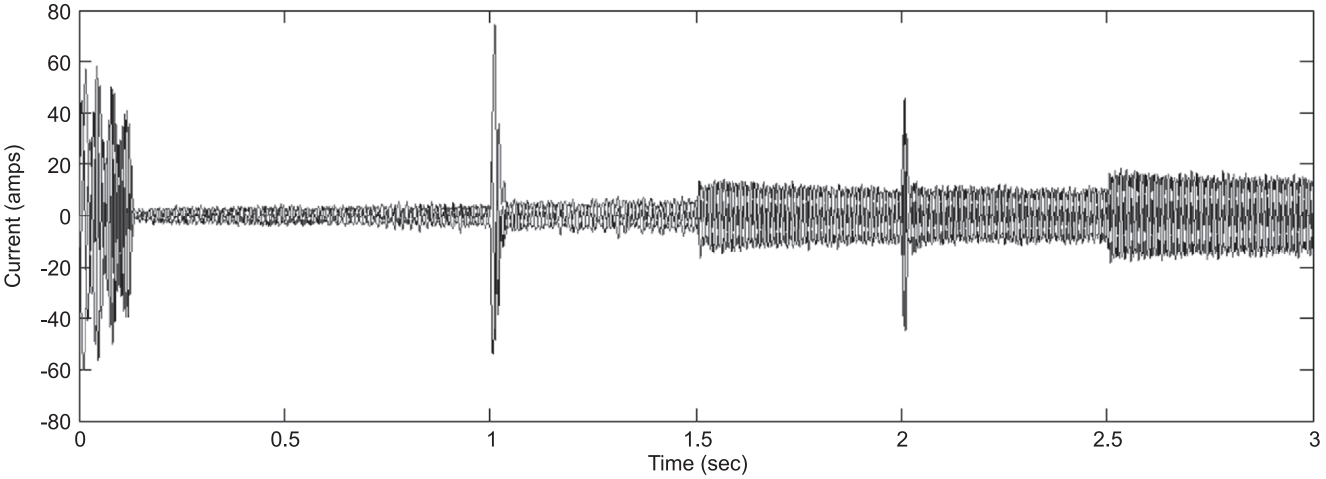

Figure 9: Stator currents using fuzzy logic controller

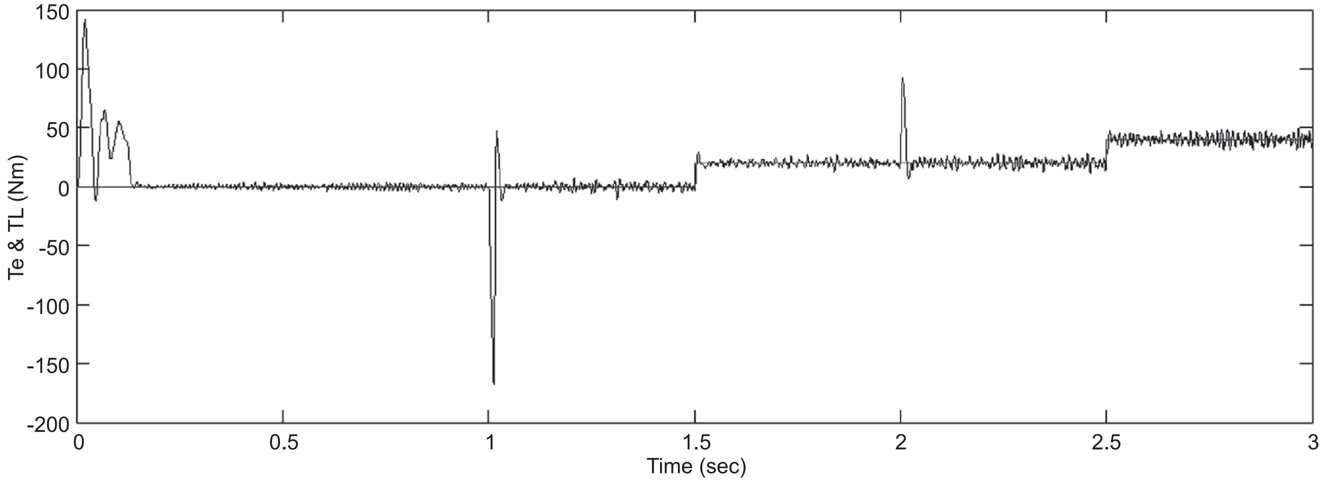

Figure 10: Load torque and electromagnetic torque using fuzzy logic controller

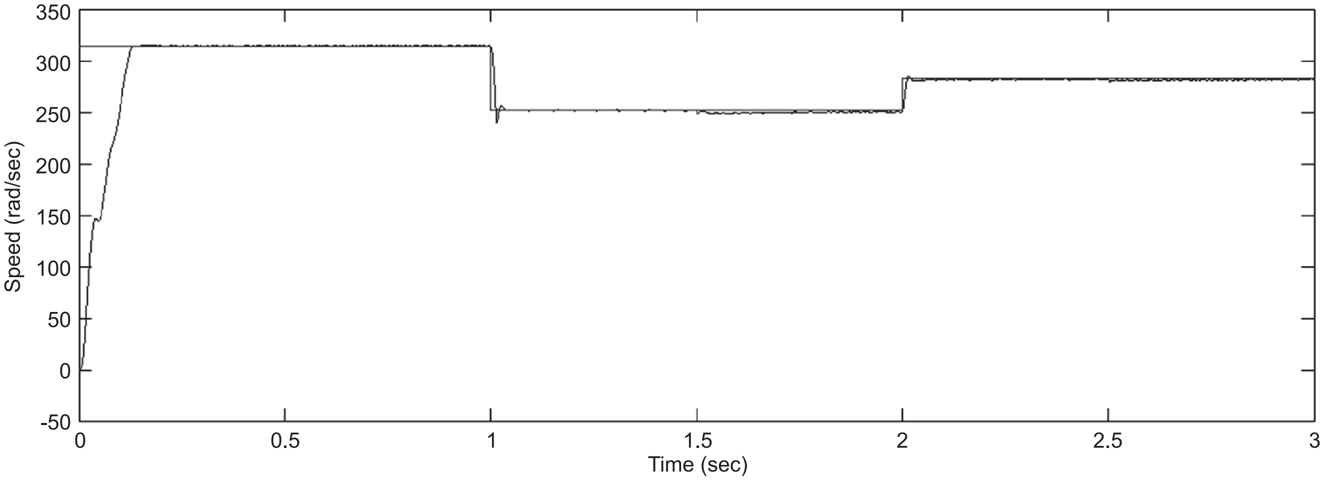

Figure 11: Reference speed and actual speed using fuzzy logic controller

5. CONCLUSION

This paper proposed the fuzzy logic controller for controlling the speed of an indirect vector control of induction motor drive. The performances of the indirect vector control of induction motor drive using fuzzy logic controller was compared with that of IM drive using conventional PI controller at dynamic load conditions. The simulation results show that the designed fuzzy logic controller based induction motor drive performs better than PI controller based induction motor drive at various operating conditions such as rapid change in reference speed, step change in load, etc.

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