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# MODELING AND SIMULATION OF ROTOR FLUX OBSERVER BASED INDIRECT VECTOR CONTROL OF INDUCTION MOTOR DRIVE USING FUZZY LOGIC CONTROL

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**Abstract** - The indirect vector controlled inductor motor (IM) drive involves decoupling of the stator current into torque and flux producing components. This paper proposes the implementation of fuzzy logic control scheme applied to a two d-q current components model of an induction motor. A Fuzzy logic Controller is developed with the help of knowledge rule base for efficient and robust control. The performance of Fuzzy Logic Controller is compared with that of the PI controller with rotor flux observer in terms of the settling time and dynamic response to sudden load changes. The harmonic pattern of the output current is evaluated for both fixed gain proportional integral controller and the Fuzzy Logic based controller. The performance of the IM drive has been analyzed under steady state and transient conditions. Simulation results of both the controllers are presented for comparison

**Keywords** - *Indirect Vector Control(IVC), PI Controller, Fuzzy logic Controller.*

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## I. INTRODUCTION

Induction motors have been used for over a century because of their simplicity, ruggedness and efficiency. The asynchronous or induction motor is the most widely used electrical drive motor whose invention has given a strong thrust for the transition from DC to AC in the field of generation, transmission and distribution of electrical energy. Its main advantage is the elimination of the sliding contacts, resulting in an exceedingly simple and rugged construction [1][2].

Even though investigations have been carried out for decades for the efficient control of the speed of induction motors, all solutions realizable until a few years ago were unsatisfactory with regard to complexity, efficiency, dynamic performance or cost. The progress of semiconductor technology in the last two decades has laid suitable thrust that the static frequency converters can now be obtained at acceptable cost, making the induction machine the most promising and robust adjustable speed drive for many applications [3]. Separately excited dc drives are simpler in control because independent control of flux and torque can be brought about [4]. In contrast, induction motors involve a coordinated control of stator current magnitude and the phase, making it a complex control. The stator flux linkages can be resolved along any frame of reference. This requires the position of the flux linkages at every instant. Then the control of the ac machine is very similar to that of separately excited dc motor. Since this control involves field coordinated it is also called field oriented control. The requirement of the phase angle of the flux linkages in the control process gives the name vector control.

The drive control generally involves a fixed gain proportional-integral controller [5]. However, the fixed controllers involve parameter sensitivity. Also load disturbances cause delay in setting. Hence a number of adaptive techniques have been proposed [6][7].

During the past many years fuzzy control has given great impulsion to active and fruitful research applications of fuzzy set theory. A survey of FLC is presented and a general methodology for constructing an FLC and assessing its performance is described in [8] and [9]. Procedures and guidelines to define the input parameters and to build fuzzy logic rules are discussed comprehensively in [10]. Also methodologies are proposed to design fuzzy logic controllers [11][12]. A theoretical explanation is given for the relationship between the control resolution and fuzziness of input and output variables. The guidance for designing and tuning the scaling gains is also given.

The present paper discusses a Fuzzy Logic Based Intelligent Controller. A FLC does not need appropriate mathematical algorithms. It is based on the IF-THEN linguistic rules.

## II. MODELING OF INDUCTION MOTOR

The dynamic performance of an ac machine is somewhat complex because the three-phase rotor windings move with respect to the three phase stator windings and description of revolving field machines is supported by well established theories [13],[14]. The saturation effect and parameter changes are neglected.

The dynamic model of the Induction motor is derived by transforming the three phase quantities into two phase direct and quadrature axes quantities. The equivalence between the three-phase and two-phase machine models is derived from the concept of power invariance: the power must be equal in the three phase machine and its equivalent two-phase model [1].

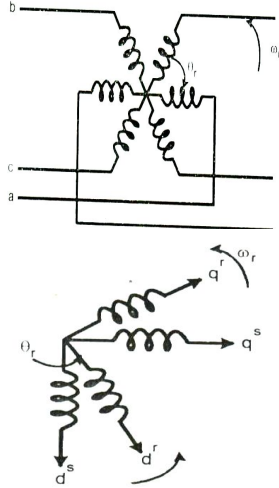


Fig. 1 : Coupling effect in three-phase stator and rotor windings Fig.2. Equivalent two phase machine

The d and q axes mmfs are found by resolving the mmfs of the three phases along the d and q axes. The relationship between d-q and a-b-c axes currents is given by

$$i_{ds} = \frac{2}{3} V_d \left( i_{as} - \frac{i_{bs}}{2} - \frac{i_{cs}}{2} \right) \quad (1)$$

$$i_{qs} = \frac{1}{\sqrt{3}} (i_{cs} - i_{bs}) \quad (2)$$

Where  $i_{as}$ ,  $i_{bs}$  and  $i_{cs}$  are the three phase currents and  $V_d$  is the dc link voltage at the inverter input. These equations are also applicable to the voltage and flux linkage transformation. Applying this transformation to the three phase quantities the electrical model of the induction motor is expressed by the matrix equation (3) is stationary reference frame.

$$\begin{pmatrix} v_{ds} \\ v_{qs} \\ v_{dr} \\ v_{qr} \end{pmatrix} = \begin{pmatrix} R_s + L_s p & 0 & L_m p & 0 \\ 0 & R_s + L_s p & 0 & L_m p \\ L_m p & \omega_r L_m & R_r + L_r p & \omega_r L_r \\ -\omega_r L_m p & L_m p & -\omega_r L_r & R_r + L_r p \end{pmatrix} \times \begin{pmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{pmatrix} \quad (3)$$

Where  $V_{ds}$ ,  $V_{qs}$ ,  $i_{ds}$ ,  $i_{qs}$ ,  $R_s$ ,  $L_s$ ,  $R_r$ ,  $L_r$ ,  $L_m$ , and  $\theta_r$  are the d-q axes voltages and currents, stator resistance, stator inductance, mutual inductances between the stator and rotor windings and the rotor windings and the rotor position respectively.

The stator and rotor flux linkages in the synchronous reference frames are defined as

$$\begin{cases} \Psi_s = L_s \bar{i}_s + L_m \bar{i}_r \\ \Psi_r = L_s \bar{i}_r + L_m \bar{i}_s \end{cases} \quad (4)$$

Where  $\Psi_s$ ,  $\Psi_r$ ,  $\bar{i}_s$ ,  $\bar{i}_r$ , are the stator and rotor flux-linkage space vector and the stator and rotor current space vector, all in stationary reference frame. The electromagnetic torque obtained from machine flux linkages and currents is as:

$$T_e = \frac{3P}{2} L_m (i_{qs} \Psi_{dr} - i_{ds} \Psi_{qr}) \quad (5)$$

Where,  $T_e$ ,  $P$ ,  $\Psi_{dr}$ ,  $\Psi_{qr}$ , are the electromagnetic torque, number of poles, rotor d-q axes fluxes respectively. The electro magnetic dynamic equation describing the mechanical model of the induction motor is given by

$$T_e = J \frac{d\omega_m}{dt} + T_L + B\omega_m \quad (6)$$

Where  $J$ ,  $T_L$ ,  $B$ ,  $\omega_m$  are the moment of inertia of motor and load, the load torque, the friction coefficient and the mechanical speed. The equations (3) and (6) form the mathematical model equations of a three phase induction motor.

### III. INDIRECT VECTOR CONTROL (FEED FORWARD METHOD)

Indirect vector control method is depicted in the Fig.1. It involves the indirect estimation of the slip speed and is a feed forward method of control as compared to the direct vector control.

The speed error, with the help of a PI controller or any other intelligent controller, is converted into a torque controlling current component  $i_{qs}^*$ , of the stator current. This current component is used to regulate the torque along with the slip speed [1]. The control equation which the PI controller involves is given as:

$$i_{qs}^* = k_p \Delta\omega_r + k_i \int \Delta\omega_r dt \quad (7)$$

Similarly, the flux producing current component  $i_{ds}^*$ , is obtained from the stator flux linkage reference value and is given by the following equation,

$$\Psi_s^* = \frac{R_r L_m}{R_r + L_r p} i_{ds}^* \quad (8)$$

For the given flux level, the required torque is

$$T_e = \frac{3}{2} \frac{L_m}{L_r} \Psi_s^* i_{qs}^* \quad (9)$$

From the d-q current components and rotor time constant the slip speed relation is obtained as:

$$\omega_{sl} = \omega_e - \omega_r = \frac{R_r}{L_r} \frac{i_{qs}^*}{i_{ds}^*} \quad (10)$$

The slip speed, together with the feedback rotor speed, is integrated to obtain the stator reference flux linkage space vector position  $\theta_e$ .

$$\theta_e = \int (\omega_{sl} + \omega_r) dt \quad (11)$$

The stator flux space vector position is used to convert the two phase d-q axes current components into the three phase currents. The currents so obtained act as reference values while the real currents from the induction motor are compared with the reference currents. The current errors are fed to two level hysteresis controllers. The hysteresis

current controller allows the induction motor currents to vary within a hysteresis band such that the required performance of the machine is obtained. The rotor flux is calculated from the Blaschae model circuit shown below.

#### IV. FUZZY CONTROLLER

Fuzzy logic implementation requires no exact knowledge of a model. The block diagram implementation of FLC is shown in Fig.2. It involves the use of the concept of fuzzy subset and rule based modeling. By permitting certain amount of imprecision, complex solutions are modeled with ease.

##### A. Concept of Fuzzy Logic

The idea of formulating the control algorithms by logical rules introduced the implementation of human understanding and human thinking in control algorithms. The lack of analytical description makes

the fuzzy control conceptually different from conventional control.

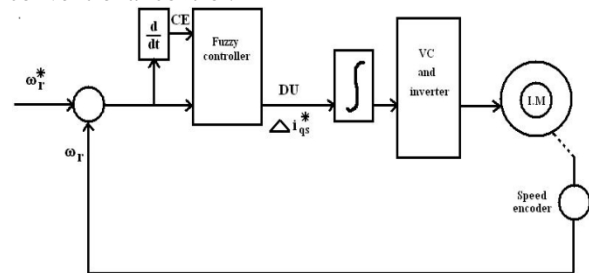


Fig. 3 : Fuzzy speed controller for Indirect Vector Control of IM

One defines a subset with the aid of a characteristic function which describes membership in the subset. Let  $X$  is the universe of discourse and let  $S$  be a subset of  $X$ . The characteristic function associated with  $S$  is a mapping.

$$F_s: X \rightarrow [0,1] \quad (12)$$

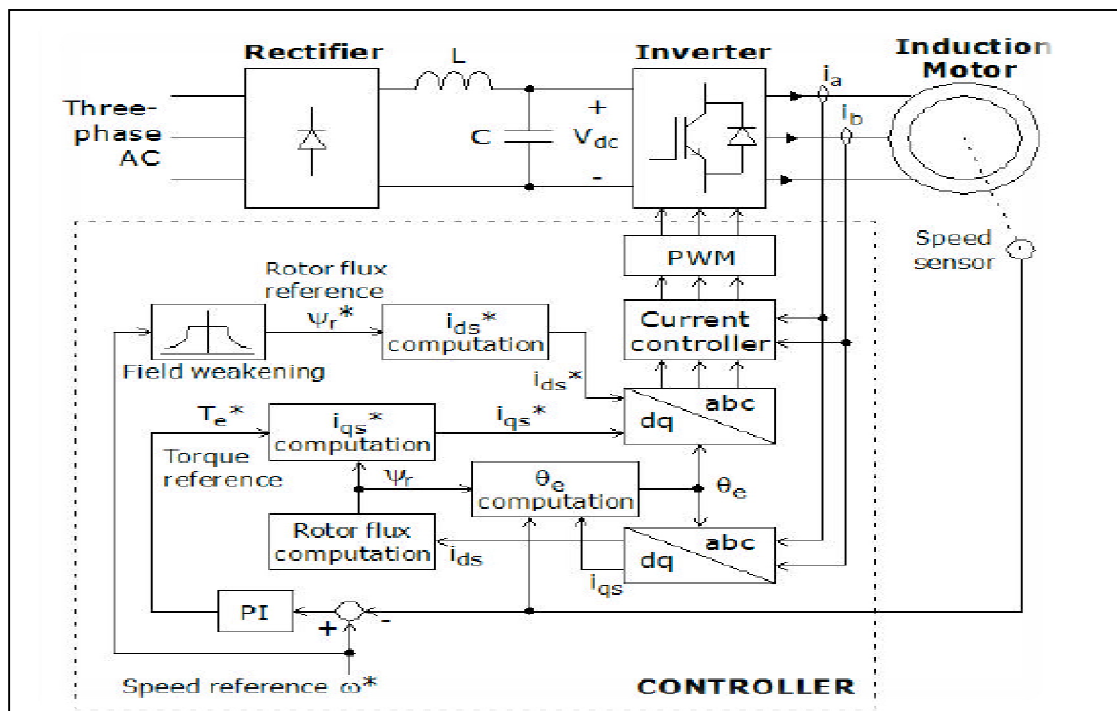


Fig. 4 : Block diagram of Indirect Vector Control

In the framework of fuzzy set theory the characteristic function is called the membership function associated with the fuzzy subset  $A$ . A fuzzy logic controller is described by a knowledge based system consisting of IF... THEN rules with vague predicates and a fuzzy logic inference mechanism. The present fuzzy logic controller adapted is of the Mamdani Controller type [15]. The speed error and the change in the speed error are given as inputs to the FLC. The torque producing current component is the output. A knowledge rule base which simulates the performance of the system is defined. The rule

base acts upon the inputs to produce the given outputs.

##### B. Membership Functions

The Fuzzy Controller initially converts the crisp error and change in error variables into fuzzy variables and then are mapped into linguistic labels. Membership functions are associated with each label as shown in the Fig which consists of two inputs and one output.

The linguistic labels are divided into seven groups. They are: NB-negative big, N-Negative, NS-negative small, Z-zero, PS-positive small, P-positive, PB-

positive big, each of the inputs and the output contain membership functions with all these seven linguistics.

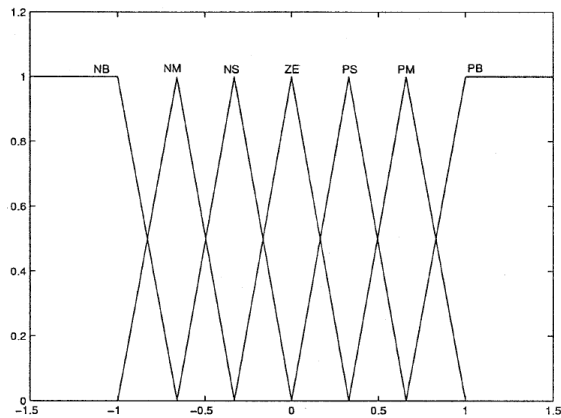


Fig. 5: Membership function of e and Δe, Δu

This method of formulation of control algorithms allows implementing heuristic strategies [16]. A straightforward source of deriving the linguistic control strategies are human experience and understanding, which essentially contain the model of the control system in an implicit form.

C. Knowledge Rule Base

The mapping of the fuzzy inputs into the required output is derived with the help of a rule base as given in Table 1.

Each rule of the FLC is characterized with an IF part, called the antecedent, and with a THEN part called the consequent. The antecedent of a rule contains a set of conditions and the consequent contains a

conclusion. If the conditions of the antecedents are satisfied, then the conclusions of the consequent apply. Considering the first rule, it can be interpreted as: IF change in speed error is NB and change in speed is NB, THEN the output will be NB.

TABLE I : FUZZY RULES FOR COMPUTATION OF ΔU

e/Δe	ΔU						
	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NM	NS	NS	ZE
NM	NB	NM	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PM	PB
PB	ZE	PS	PS	PM	PB	PB	PB

D. Defuzzification

Generally the output obtained is fuzzy in nature and has to be converted into a crisp value by using any Defuzzification technique.

V. RESULTS AND DISCUSSION

The current response of the machine for both case i.e. PI and FLC is presented in the fig.8 &fig.9. It can be see that

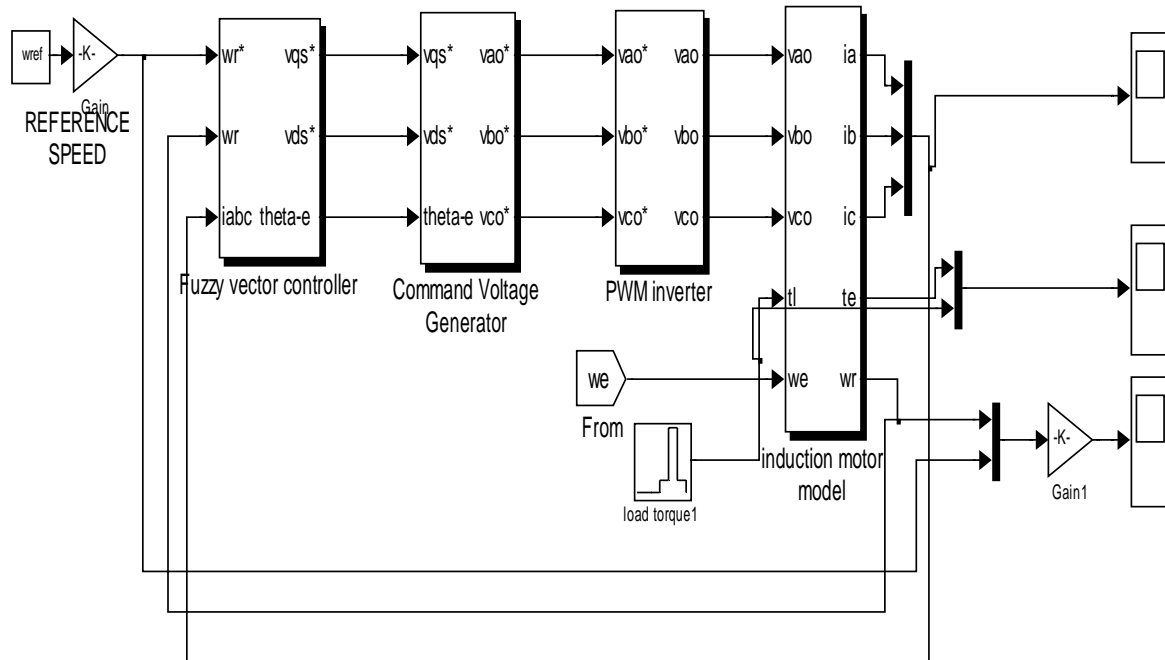


Fig. 6 : Simulink diagram of Indirect vector control with rotor flux observer

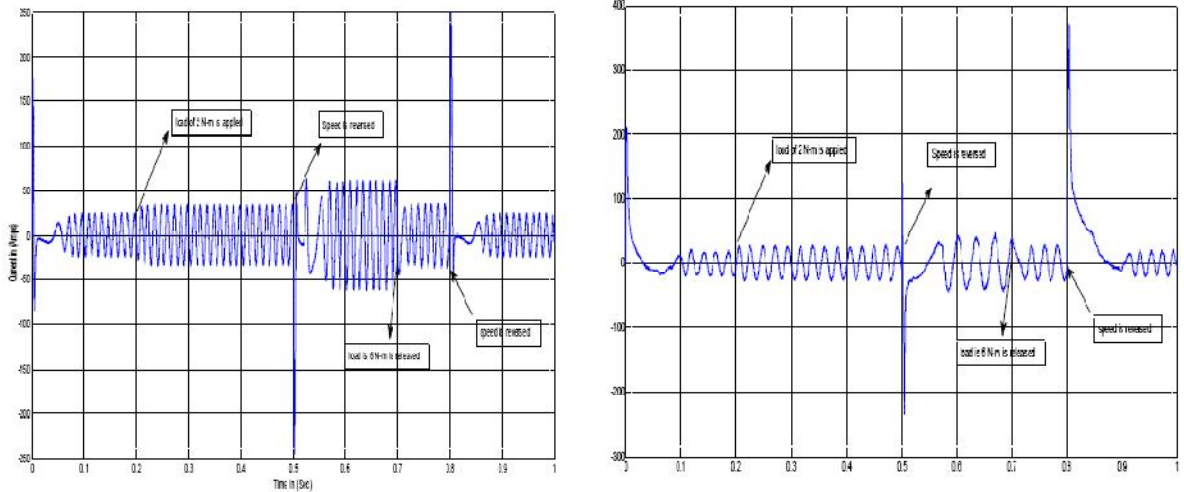


Fig. 7 : Stator phase currents of FLC and PI Controller

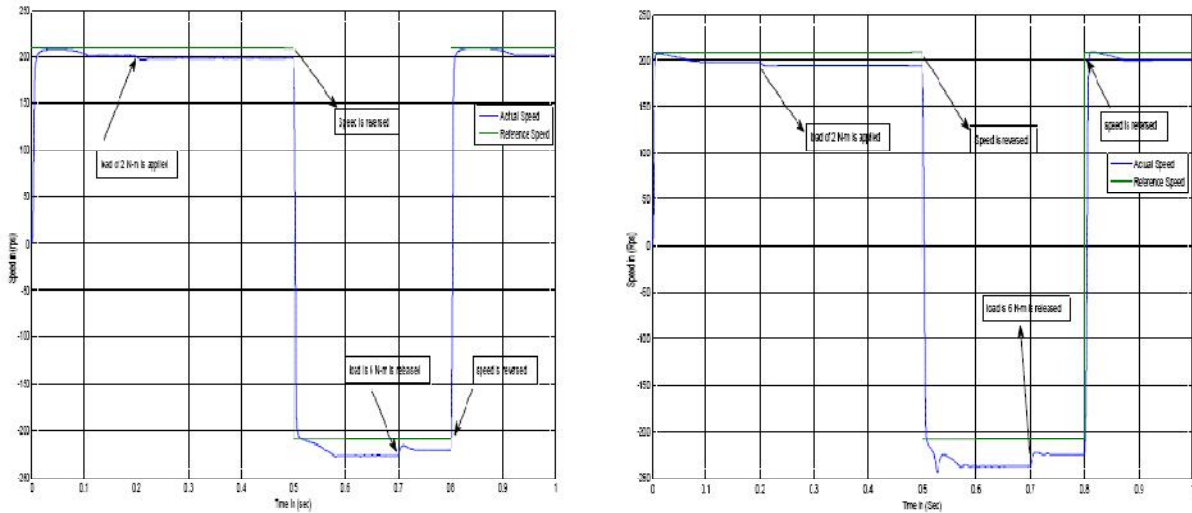


Fig.8. Response of speed with FLC and PI Controller

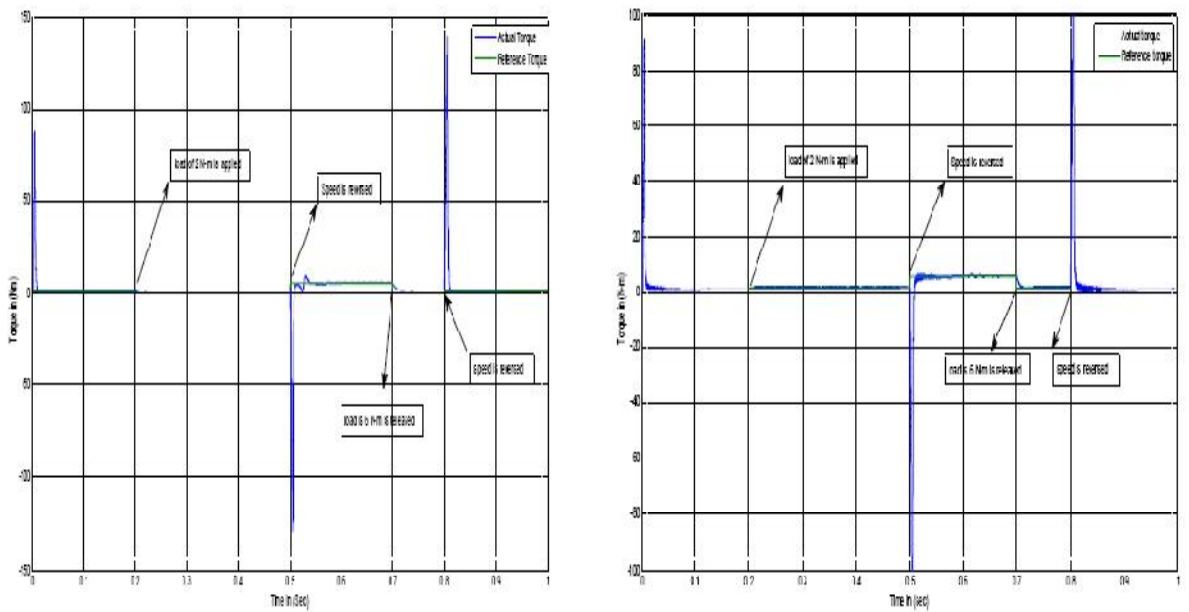


Fig. 9 : Response of torque with PI and FLC Controller

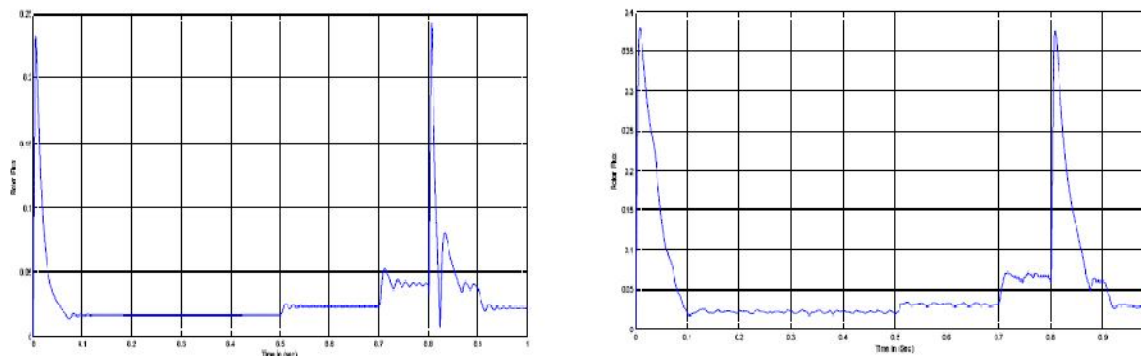


Fig. 10 : Response of Rotor Flux with PI and FLC

the response of FLC is robust to load disturbance even during the speed reversals. The torque response shown in fig.9 reflects the ripples are less and response in the load condition is quick for the FLC controller. The results shows under the steady and the transient condition i.e. speed reversal state for the PI and FLC controller from which it can be see that speed reached the speed value in very short period for the FLC controller. When a load is applied at 0.2 and 0.5 sec the speed response for both controllers are as shown in fig.8. Responses indicate that the speed drop is less in case of FLC.

## VI. CONCLUSIONS

In the is paper the concept of indirect vector controlled induction motor drive with fuzzy logic has been presented and is simulated using Matlab/simulink for both PI and Fuzzy controller by considering the rotor flux. The results of both controllers under the dyanamic and steady state conditions are compared and analyzed. The simulation result support that the FLC settles quickly and has better response than the PI controller.

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