

Fuzzy Logic Controller Performance in Vector Control of Induction Machine

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Abstract—Fuzzy logic based controllers for various applications have been largely acknowledged due to their robust performance and model-free characteristics. Popularity of induction motors in major industrial applications has inspired the application of Fuzzy logic based controllers in control industrial drives. This paper presents the study of different topologies of Fuzzy logic based controller for the speed control of induction motors. The analysis is being done in MATLAB/SIMULINK environment. The performance of the controllers has been compared with conventional PI controller for different operating conditions and results has been presented.

Keywords— *Fuzzy Logic Controller, Induction Motor, Field Oriented Control, MATLAB/SIMULINK*

I. INTRODUCTION

Due to simple construction, high reliability and lesser maintenance, induction motors are very widely used in industrial applications. For high performance applications, precise speed control of induction machine is very primary requirement. Indirect field oriented control technique [1] allows the control the machine similar to DC machine. This method decouples the torque and field operations. This method gives the facility to control the speed of induction machine by designing a controller.

PI (Proportional Integral) control method is conventional control method of designing. It gives satisfactory performance for major of the applications [2][3]. But, this design method is machine parameter dependent. For a misadjusted PI controller values, controller is unable to give desired performance in the presence of internal and external disturbances [4][5]. The disturbances mainly include variations in machine parameters and load disturbances.

Fuzzy logic controllers has been proposed for vector control on induction machines [6] [7]. Embedded human intelligence enable Fuzzy Logic Controllers to perform better in speed control applications compared to PI controllers. Different schemes of Fuzzy Logic Controllers has been applied on vector control of induction machines [8][9].

In this paper, two Fuzzy Logic Controller topologies are implemented in MATLAB for FOC of induction machine. In first topology, the increment or decrement in reference torque for inner loop is generated by fuzzy controller itself, however

in second one, fuzzy controller generates PI controller gains called fuzzy PI controller. The transient and steady state performance of both the controllers for various operating conditions has been analyzed and presented.

II. VECTOR CONTROL OF THREE PHASE INDUCTION MOTOR

The indirect field oriented control of three phase induction motor has been a well-established technique [10]. The block diagram of field oriented control is presented in Fig. 1. Three phase currents are decoupled into d -axis and q -axis currents in rotor flux orientation frame. On the q -axis, speed control loop is performed and flux control loop operated in d -axis. In the outer speed loop, speed error ($\omega_{ref} - \omega_r$) passes through speed controller and generates reference torque which generates q -axis reference current i_q and flux control loop generates d -axis reference current i_d . The reference d -axis and q -axis currents are transformed again in three phase currents. The inner current control loop compares the reference and actual three phase currents and generate the switching pulses for three phase voltage source inverter (VSI) switches by hysteresis control.

III. FUZZY LOGIC SPEED CONTROLLERS

The speed controller block in Fig. 1 is normally a conventional PI controller. The PI controller can be replaced with Fuzzy logic based controllers. In this paper, the Fuzzy logic controller with constant parameters has been implemented. The speed controller is replaced with two Fuzzy based controllers as described as following.

A. Fuzzy Speed Controller

The Fuzzy speed controller is based on basic structure of Fuzzy logic and shown in Fig.2. The speed error e and change in speed error ce are the input linguistic variables and reference torque T_e^* is output linguistic variable. According to the fuzzy rules, fuzzy controller gives the increase or decrease required in torque reference (ΔT_e^*). The error and change in error are represented mathematically as

$$e(n) = \omega_r(n) - \omega_r(n-1) \quad (1)$$

$$ce(n) = e(n) - e(n-1) \quad (2)$$

The reference torque is non-linear function of e and ce and is

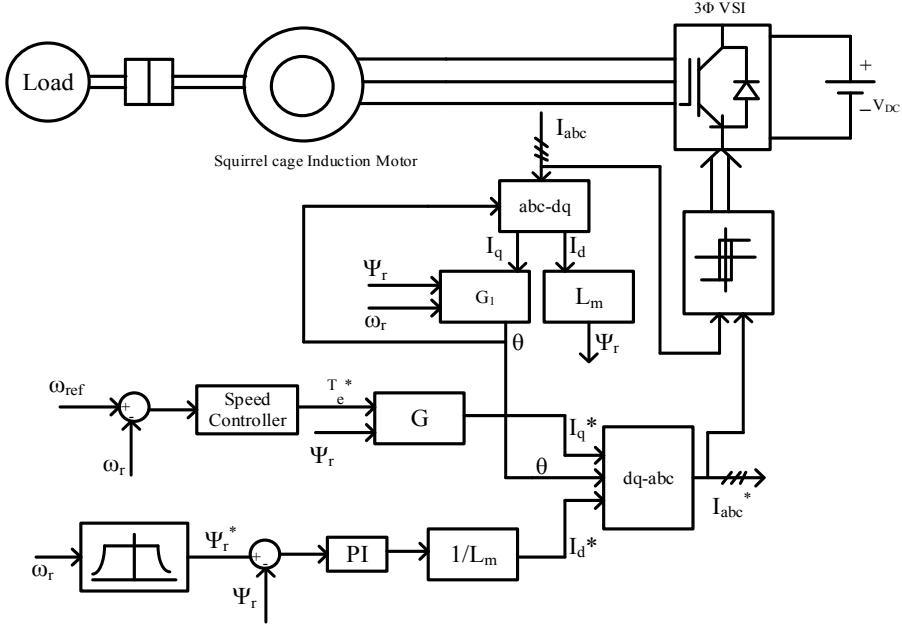


Fig. 1 Block Diagram of Field Oriented Control of Induction Machine

shown as following

$$T_e^* = \int_{discrete} \Delta T_e^*(n) = f(e(n), ce(n)) \quad (3)$$

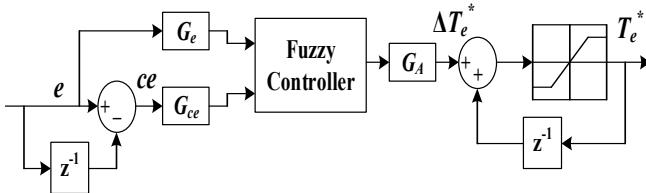


Fig. 2 Fuzzy Speed Controller

The gains G_e , G_{ce} and G_A are scaling factors.

B. Fuzzy PI Speed Controller

The topology of Fuzzy PI speed controller is shown in Fig. 3.

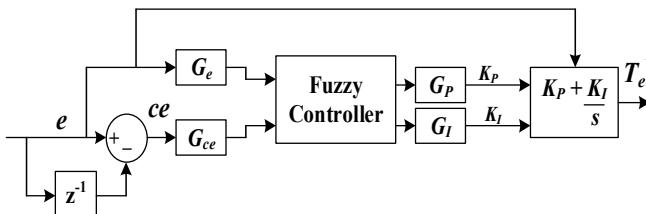


Fig. 3 Fuzzy PI Speed Controller

In this Fuzzy control structure, controller output are the PI gains: proportional controller gain K_p and integral controller gain K_I . The error is being given input to PI controller and PI gains come from Fuzzy controller output. The advantage of the topology is that it has merits of both FUZZY and PI controller. The PI gains in this controller are dynamic and change according to the current e and ce . The gains G_e , G_{ce} are

scaling factors of e and ce before fuzzification. The gains G_p , G_I are scaling factors of K_p and K_I after defuzzification.

IV. DESIGN OF FUZZY LOGIC BASED CONTROLLERS

There are four basic components of Fuzzy logic based controllers – fuzzification, rule base, decision making logic and defuzzification. The design of each component is described as following.

A. Fuzzification

In the fuzzification process, the fuzzifier takes the crisp numeric input and output variables, and converts them into fuzzy form needed by the decision making logic. The linguistic terms for fuzzification are defined as: N, P – Negative, Positive. H, A, L, XL are High, Average, Low and Extra Low. So, NB mean Negative High, PA means Positive Average and so on. For both the control topologies, inputs are e and ce . The inputs are first passed through scaling factors. After scaling, e and ce are in the range of -1 and 1. Then the e and ce are being fuzzified with the help of triangular membership functions. The fuzzification of e and ce are same for both fuzzy based controller and fuzzy PI controller as shown in Fig 4.

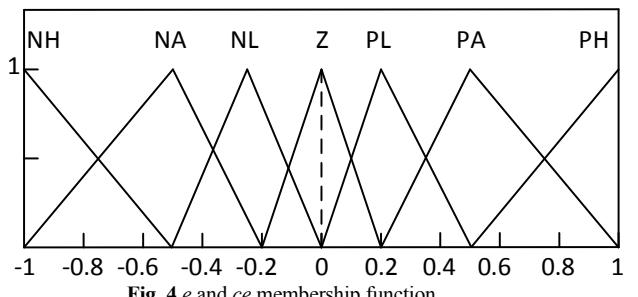


Fig. 4 e and ce membership function

The membership functions for output variable (ΔT_e^*) for fuzzy speed controller which is having a single output is shown in Fig. 5.

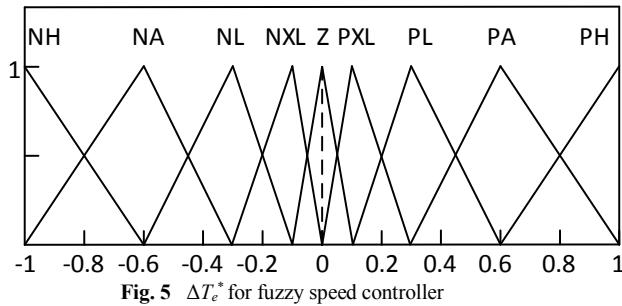


Fig. 5 ΔT_e^* for fuzzy speed controller

The Fuzzy PI speed controller has two output variables which are PI gains. The fuzzified output variables K_P and K_I are shown in Fig. 6a and Fig. 6b.

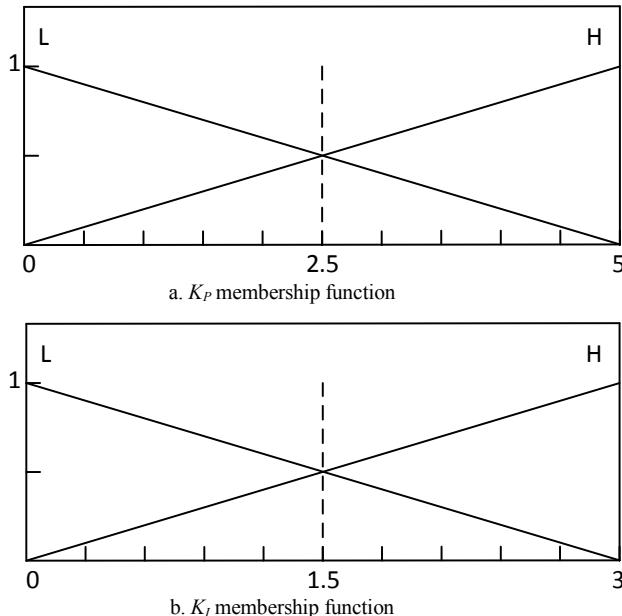


Fig. 6 Output variables for Fuzzy PI Controller

B. Rule Base

The Fuzzy controllers used in this work of are Mamdani's type. The 'IF...THEN' rules for e and ce governs the relationship of output variables in terms of membership functions [11]. The rule base for Fuzzy speed controller is shown in Table I.

TABLE I. RULE BASE FOR FUZZY SPEED CONTROLLERS

$ce \downarrow, e \rightarrow$	NH	NA	NL	Z	PL	PA	PH
NH	NH	NH	NA	NA	NL	NXL	Z
NA	NH	NA	NA	NL	NXL	Z	PXL
NL	NA	NA	NL	NXL	Z	PXL	PL
Z	NA	NL	NXL	Z	PXL	PL	PA
PL	NL	NXL	Z	PXL	PL	PA	PA
PA	NXL	Z	PXL	PL	PA	PA	PH
PH	Z	PXL	PL	PA	PA	PH	PH

The Rule base for Fuzzy PI Speed controller is shown in Table II and III for K_P and K_I respectively. As the output has only two membership functions, the output has only two linguistic variables.

TABLE II. RULE BASE FOR FUZZY PI SPEED CONTROLLER (K_P)

$ce \downarrow, e \rightarrow$	NH	NA	NL	Z	PL	PA	PH
NH	H	H	H	H	H	H	H
NA	L	H	H	H	H	H	L
NL	L	L	H	H	H	L	L
Z	L	L	L	H	L	L	L
PL	L	L	H	H	H	L	L
PA	L	H	H	H	H	H	L
PH	H	H	H	H	H	H	H

TABLE III. RULE BASE FOR FUZZY PI SPEED CONTROLLER (K_I)

$ce \downarrow, e \rightarrow$	NH	NA	NL	Z	PL	PA	PH
NH	L	L	L	L	L	L	L
NA	H	L	L	L	L	L	H
NL	H	H	L	L	L	H	H
Z	H	H	H	L	H	H	H
PL	H	H	L	L	L	H	H
PA	H	L	L	L	L	L	H
PH	L	L	L	L	L	L	L

For both the controllers, the **AND** operator is used in rule base for decision making.

C. Defuzzification

For the defuzzification of output of both the fuzzy controllers, centroid method is being used [11]. After defuzzification, the output is passed through respective scaling factors for fuzzy based controller and fuzzy PI based controller.

V. SIMULATION RESULTS

Both the Fuzzy controllers and PI controller are implemented with vector control of induction motor in MATLAB/SIMULINK. The simulation is done on 3 phase, 415 V, 5HP induction machine. The machine parameters are – $R_s = 4.5 \Omega$, $R_r = 4.5 \Omega$, $L_{ls} = L_{lr} = 8.3 \text{ mH}$, $L_m = 592.6 \text{ mH}$, $J = 0.29 \text{ Kg-m}^2$. the results for all the controllers have been compared. For the fuzzy speed controller, the value of G_e , G_{ce} and G_A are 1/1500, 1/20 and 1 respectively. For the fuzzy PI speed controller, the value of G_e , G_{ce} , G_P and G_I are 1/1500, 1/100, 6 and 1000 respectively. The K_P and K_I values for PI controller are 1 and 20 respectively.

The machine has been started at $t=0.5$ s from zero speed to 1000 rpm at no load and at $t = 5$ s, a load torque of 15 N-m is applied to observe the performance of controllers. Fig. 7 shows the performance of machine. Fig. 8a and 8b show the starting transient performance of controllers. Fig. 8a shows the control signal T_e^* and Fig. 8b shows the transient speed response. In Fig. 8a, control signals before $t=1.55$ sec are at maximum possible torque reference as it is an acceleration period. From response in Fig. 8b, it can be observed that PI controller has

maximum and Fuzzy PI has lowest overshoot of 18 rpm and 2 rpm respectively. The settling time for fuzzy PI is lowest (1.06 sec) while fuzzy speed controller and PI controller have the settling time of 1.15 and 1.35 sec respectively. Also, the torque reference for Fuzzy PI settles fast. Fig. 9 shows the phase a current from the starting till it reaches steady state of 1000 rpm.

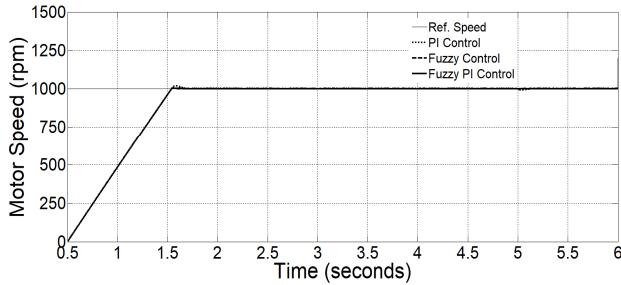
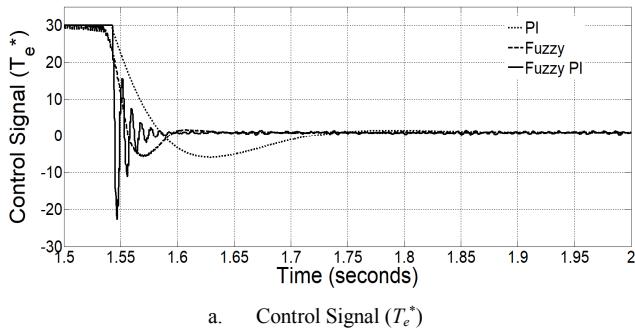
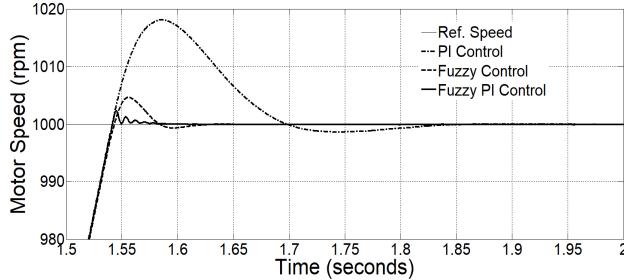


Fig. 7 Speed response of Motor



a. Control Signal (T_e^*)



b. Speed transient response

Fig. 8 Starting transient response

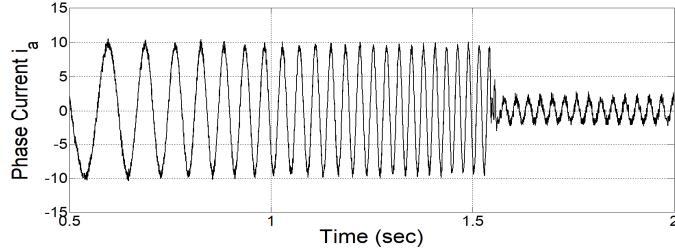
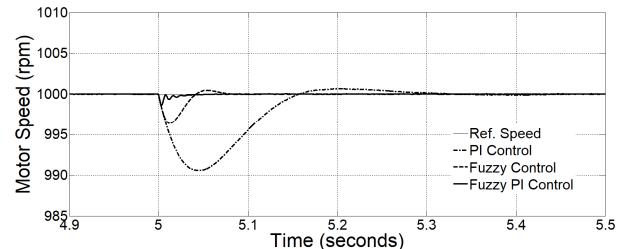


Fig. 9 Starting current phase 'a'

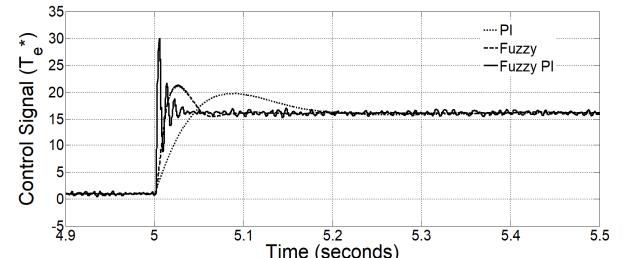
At $t = 5$ s, the load of 15 N-m has been suddenly applied to the running machine. The transient response has been shown in Fig. 10a and 10b. Fig. 10a shows the transient speed response of controller. The settling time for PI controller, Fuzzy speed controller and Fuzzy PI controller is 0.3 sec, 0.1 sec and 0.05 sec respectively. The dip in speed is minimum for fuzzy PI

controller (1 rpm) and maximum for PI controller (9 rpm). Fuzzy speed controller is having dip of 4 rpm. Fig. 10b shows reference torque (control signal). The reference torque for fuzzy PI controller settles quickly at load torque value of 15 N-m.

At $t = 8$ sec, the reference speed is changed from 1400 rpm to 400 rpm while the load to 15 N-m is still active. The transient response near 400 rpm is shown in Fig. 11a and 11b. The overshoot for PI controller is 28 rpm while for fuzzy PI and fuzzy speed controller, it is 4 rpm and 10 rpm respectively. The settling time for fuzzy PI, fuzzy speed controller and PI controller is 0.7 s, 0.8 sec and 9 sec respectively.

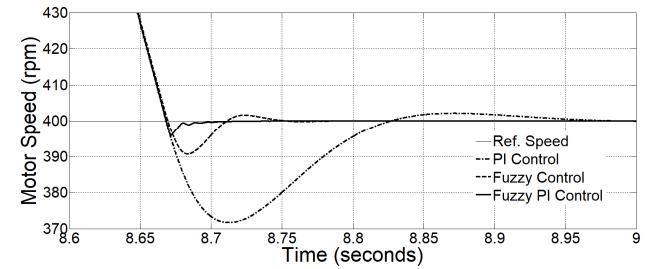


a. Speed transient response

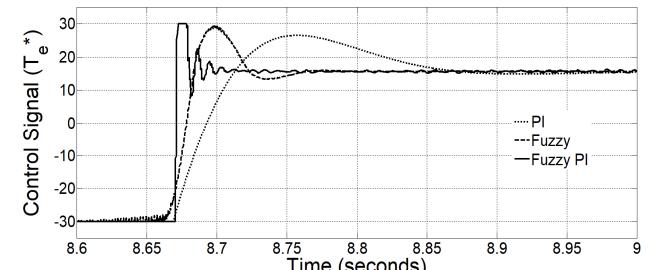


b. Control Signal (T_e^*)

Fig. 10 Response for load disturbance



a. Speed transient response



b. Control Signal (T_e^*)

Fig. 11 Response for speed decrease

VI. CONCLUSION

Both the Fuzzy controllers and PI controller are implemented with vector control of induction motor in MATLAB/SIMULINK. From the speed responses, it is evident that performance of Fuzzy PI speed controller has less overshoot, less settling time for various operating conditions. The fuzzy PI controller has advantage of having dynamic K_P and K_I values which results in dynamic tuning of PI controller. And this controller is giving better performance than both PI and Fuzzy speed controllers. However, proper tuning of gains of Fuzzy controller and Fuzzy rules is required to get the better performance than PI or Fuzzy speed controllers.

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