

# dSPACE implementation of Fuzzy Logic based Vector Control of Induction Motor

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*Abstract-* Vector control of induction motor is an efficient approach to control the speed of induction motor used for industrial drives. Although the vector control is very popular method but there lies difficulty in obtaining an accurate model of induction motor (IM) owing to the variation of induction motor parameters, such as resistance, inductance and time constant. Therefore, to cope up with this uncertainty in the model we used a fuzzy logic based vector control approach to speed control of an induction motor. The focus of the paper is to analyze the real-time implementation issued for realizing a vector control in a laboratory set up of induction motor using dSPACE 1104. This fuzzy logic based vector control scheme has been successfully implemented on a 3 hp induction motor drive in the laboratory and the performances of this controller has been checked with a PID control strategy .

*Index Terms--* Induction motor, vector control, fuzzy logic, dSPACE

## I. INTRODUCTION

The vector control method is very effective approach for high-performance control of torque, speed and position of an induction motor [1, 2,3]. By using vector control strategy, we achieve decoupled control of the rotor flux magnitude and the torque-producing current, with a fast torque response. The torque response is achieved by estimating, measuring, or calculating the magnitude and position of the rotor flux in the machine. Usually in most industries, the motor-control issues are traditionally handled by fixed-gain proportional-integral (PI) and proportional-integral-derivative (PID) controllers. However, the fixed-gain controllers are very sensitive to parameter variations and load disturbances, etc. A number of other controller such as model reference adaptive control (MRAC), sliding-mode control (SMC), and self-tuning PI controllers have been proposed for induction motor control [3-8]. Unavoidable parameter variations due to saturation, temperature variations, and system disturbances are some the causes of model uncertainty. Therefore, it is often difficult to develop an accurate system mathematical model. The development of induction motor model due to unknown load variation also becomes a difficult task. To overcome the above problems, the fuzzy-logic technique embedded to vector control is an attractive choice for controlling of induction motor. Further, the real-time implementation of fuzzy vector control to an induction drives necessitates high

performance computing platform for which we have considered a dSPACE to realize the fuzzy vector control strategy in the lab. The contribution of the paper lies in the fact that the developed MATLAB/SIMULINK version of fuzzy vector control can easily be transformed in to dSPACE environment. In the subsequent section of the paper we described the fuzzy logic vector control design, its MATLAB/SIMULINK implementation and dSPACE implementation in real-time and finally compared the fuzzy logic vector control with PID control. The contribution of the paper lies on the real-time implementation of fuzzy logic based vector control on a laboratory scaled induction motor drive system using dSPACE.

## II. DESIGN OF FUZZY INDIRECT VECTOR CONTROL

### A. Indirect vector control

The indirect vector control method is essentially the same as direct vector control, except the unit vector signals ( $\cos \theta_e$ , and  $\sin \theta_e$ ,  $\theta_e$  is the rotating field position) are generated in manner. Indirect vector control is very popular in industrial applications. The  $d^s - q^s$  axes are fixed on the stator, but the  $d^r - q^r$  axes, which are fixed on the rotor, are moving at speed  $\omega_r$ . Synchronously rotating axes  $d^e - q^e$  are rotating ahead of the  $d^r - q^r$  axes by the positive slip angle  $\theta_{sl}$ , corresponding to slip frequency  $\omega_{sl}$ . Since the rotor pole is directed on the  $d^e$  axis we have,

$$\omega_e = \omega_r + \omega_{sl} \quad (1)$$

$$\theta_e = \int \omega_e dt = \int (\omega_r + \omega_{sl}) dt \quad (2)$$

In order to design a fuzzy-logic-based vector control algorithm, the following steps have been followed.

- Development of a suitable rule set
- Selection of input/output variables and their quantization in fuzzy sets
- Definition of membership functions to be associated to the input/output variables
- Selection of the inference method
- Selection of the defuzzification technique.

For the proposed fuzzy logic vector control, we have considered speed error  $\Delta e_w$  and rate of change of the speed

error  $\Delta\omega_r$  are considered as the input linguistic variables and the torque-producing current  $i_q$  component is considered as the output linguistic variable. Thus, the functional relation of the FLC can be expressed as

$$i_q(n) = f(\Delta e_w(n), \Delta w_r(n)) \quad (3)$$

where  $n$  is the discrete step  $\Delta e_w(n) = \Delta w_r(n) - \Delta w_r(n-1)$  is the change of speed error  $\Delta w_r(n) = w_r^*(n) - w_r(n)$ , is the present sample of speed error,  $\Delta w_r(n-1)$  is the past sample of speed error,  $w_r(n)$  is the present sample of actual speed, is the present sample  $w_r^*(n)$  of command speed, and  $f$  denotes the nonlinear function. The main goal of the control system is to track the command speed by providing the appropriate torque-producing current component  $i_q$  depending upon the operating conditions. In real-time, the motor position information and output of the FLC, which is considered as the command q-axis current  $i_q^*$ , as well as the command d-axis current  $i_d^*$  are used to get the command phase currents  $i_a^*$ ,  $i_b^*$ , and  $i_c^*$ . The electrical position of the motor can be expressed as

$$\theta_e = \theta_r + \theta_{sl} \quad (4)$$

where  $\theta_r$  is the rotor position due to slip speed, and  $\theta_{sl}$  is the slip position due to slip speed. In the next step, the scaling factors  $K_\omega$ ,  $K_e$  and  $K_i$  are chosen for fuzzyfication, as well as for obtaining the actual output of the command current. These scaling factors play a vital role for the FLC. The scale factors  $K_e$  and  $K_\omega$  are chosen to normalize the speed error  $\Delta e(n)$  and the change of speed error  $\Delta w_r(n)$ , respectively, so that these remain within the limit of  $\pm 1$ . Factor  $K_i$  is so chosen that one can get the rated current for rated conditions. Here, the constants are taken as  $K_\omega = w_r^*(n)$  (command speed),  $K_e = 10$ , and  $K_i = 100$  in order to get the optimum drive performances. After selecting the scaling factors, the next step is to choose the membership function of  $\Delta w_n$ ,  $\Delta e_n$ , and  $i_{qn}^*$  which perform the important task of the FLC. The membership functions used for the input and output fuzzy sets are shown in Fig.2. The trapezoidal functions are used as membership functions for all the fuzzy sets except the fuzzy set ZE (zero) of the input vectors. The triangular membership functions are used for the fuzzy set ZE of the input vectors and all the fuzzy sets of the output vector [5]. The trapezoidal and triangular functions are used to reduce the computation for online implementation.

## B. Fuzzy-Rule-Based Matrix

TABLE I RULE BASE

$\Delta\omega_n$ / $\Delta e_a$	NH	NL	ZE	PL	PH
NE	NH	NL	NC	PM	PH
ZE	NH	NL	NC	PM	PH
PS	NH	NL	PL	PM	PH

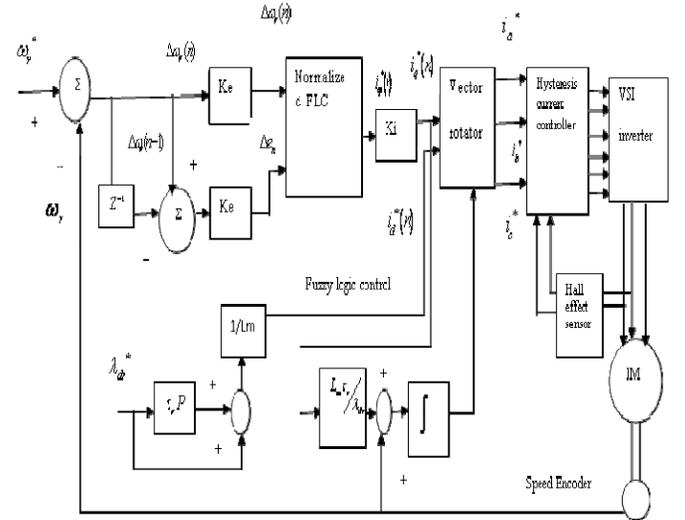


Figure 1. Structure of Fuzzy Logic based vector control system

For the fuzzyfication of  $\Delta e_w$  and  $\Delta\omega$  as defined trapezoidal membership function in equation (5)

$$f(x; a, b, c, d) = \begin{cases} 0, & x \leq a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ 1, & b \leq x \leq c \\ \frac{d-x}{d-c}, & c \leq x \leq d \\ 0 & x \geq d \end{cases} \quad (5)$$

It may be noted that we can obtain the triangular membership functions from trapezoidal function by setting  $b=c$ . The rules used for the proposed fuzzy logic vector control of IM are shown in Table I.

(4)

For this study, Mamdani-type fuzzy inference is used. The values of the scale factors, membership functions, fuzzy sets for the input and output variables, and the rules used in this study are selected by trial and error to obtain the optimum drive performance. In this fuzzy vector control development,

the center of gravity defuzzification given in equation (6) is used

$$i = \frac{\sum_{k=1}^N i \cdot \mu_i(k)}{\sum_{k=1}^N \mu_i(k)} \quad (6)$$

where  $N$  is the quantization levels,  $i$  ( $i_q$  with suffix  $q$  omitted for simplicity) is the crisp output,  $\mu_i(k)$  is corresponding fuzzy membership function.

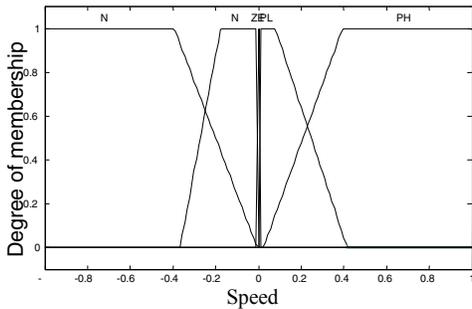


Figure.2.a Membership functions for speed error

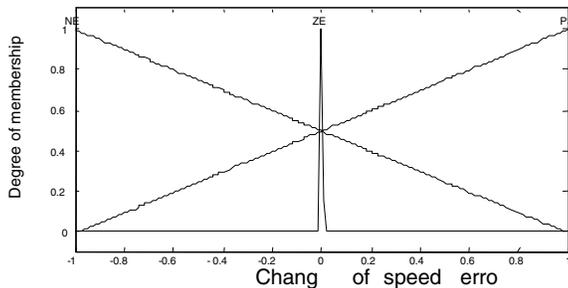


Figure2.b Membership functions for change speed error

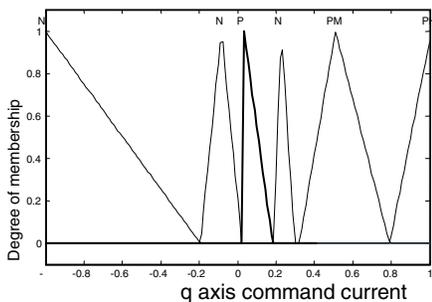


Figure2.c Membership functions for q axis current

### III. EXPERIMENTAL IMPLEMENTATION

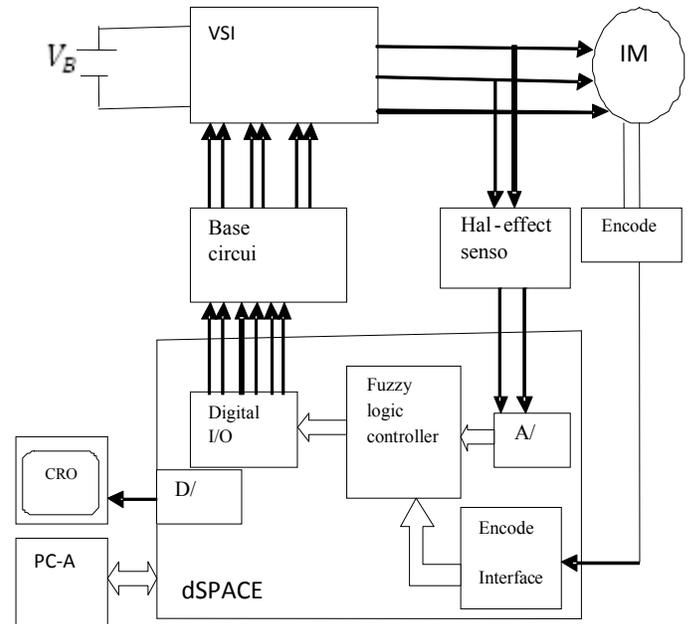


Figure 3 Experimental set up

The proposed FLC-based vector control of IM is experimentally implemented using dSPACE 1104 through both hardware and software. The DSP board is interfaced to PC with uninterrupted communication capabilities through dual-port memory. The hardware schematic for real-time implementation of the proposed FLC-based IM drive is shown in Fig. 3. The DSP has been supplemented by a set of on-board peripherals used in digital control systems, such as A/D, D/A converters, and incremental encoder interfaces. The dSPACE 1104 is also equipped with a TI TMS320C240 16-bit DSP processor. DSP that acts as a slave processor and provides the necessary digital input/output (I/O) ports and powerful timer functions such as input capture, output capture, and pulse width modulation (PWM) waveform generation. In this study, the slave processor is used for digital I/O configuration. The actual motor currents are measured by the Hall-effect sensors, which have good frequency response and are fed to the dSPACE board through the A/D converter. The rotor position is measured by an optical incremental encoder, which is mounted at the rotor-shaft end. It is then fed to the dSPACE board through an encoder interface. The encoder generates pulses per revolution. A 24-bit position counter is used to count the encoder pulses and is read by a calling function in the software. The motor speed is calculated from the rotor position by backward difference interpolation. A digital filter is used to remove the noise from the speed signal. The calculated actual motor speed is compared to the command speed to generate the speed error signal. The input vectors of the FLC are generated from the present and the delayed samples of the speed error. The command currents are generated from the FLC. The hysteresis current controller

compares the command currents with the corresponding actual motor currents and generates the logic signals, which act as firing pulses for the inverter switches. Thus, these six PWM logic signals are the output of the dSPACE board and fed to the base drive circuit of the inverter power module. The D/A channels are used to capture the necessary output signals in a digital storage oscilloscope. The complete IM drive is implemented through software by developing a program in high-level American National Standards Institute (ANSI) "C" programming language. The program is compiled by the TI "C" code generator. Finally, the program is downloaded to the dSPACE controller board using loader program. The sampling frequency for experimental implementation of the proposed FLC-based IM motor drive system is 5 kHz.

In order to verify the feasibility and the performance of the proposed procedure, computer simulations have been carried out using MATLAB software. It is assumed in the following that for simulation purpose a typical 3kW induction machine, fed by a source voltage is already running in steady state at nominal speed conditions. The specifications and parameters of the induction machine are listed in table II

TABLE.II  
Parameters of Squirrel cage type Induction Motor

Parameter	Symbol	Rating	units
Power output	P	3	hp
Line voltage	V	415	volts
Supply frequency	f	50	hertz
Mechanical speed	N	1410	rpm
Stator inductance	$L_s$	2.81	mH
Rotor inductance	$L_r$	4.5	mH
Stator resistance	$R_s$	8.2	ohm
Rotor resistance	$R_r$	2.8	ohm
Pole pairs	p	2	

Some tests such as constant speed and variable speed were performed to evaluate the performance of the proposed FLC-based vector control of the IM drive system both theoretically and experimentally

The speed-control loop of the drive was also designed, simulated, and experimentally implemented with the PID controller. The speed responses are observed under different operating conditions such as a sudden change in command speed, and step change in load, etc. Some sample results are presented in the following section. The PID controller gain is tuned at rated conditions in order to make a fair

comparison. We then conducted two sets of experiments as follows.

#### #Test 1: Constant command speed

In Test 1 we aimed at analyzing the performance of induction motor on constant command speed. Fig.4 shows the simulated performance of constant command response of PID vector control of induction motor. Fig.5 shows the simulated response of constant command speed performance of fuzzy logic vector control of induction motor. Fig 6 shows the experimental response of PID vector control using dSPACE implementation for constant command speed Fig 7 shows the experimental response of fuzzy logic vector control using dSPACE implementation for constant command speed. From these figures it is seen that the fuzzy logic vector control performance is more smoother than PID vector control performance.

#### # Test 2: Variable command speed

Fig. 8 and Fig.9 show the simulation responses of the drive system using the PID vector control and Fuzzy logic vector control respectively, with a change in the reference speed. It is evident from Fig. 8 and Fig. 9 that the proposed FLC-based IM drive system can follow the command speed without any overshoot and steady-state error. The motor speed follows its reference with zero steady-state error and a fast response using a fuzzy controller. Thus, the FLC-based drive system is not affected by the sudden change of the command speed i.e. a good tracking has been achieved by the Fuzzy logic vector control, whereas the PID-control gives more overshoot when there is a sudden change in command speed. On the other hand, there remains a constant steady-state error in the case of PID controlled variable speed tracking experiment. This is the drawback of a PID controller with varying operating conditions. Fig. 11 and Fig. 12 show the performance of the experimentally implemented PID vector control and fuzzy logic vector control variable speed response of induction motor. From Fig 11 and Fig 12 it can be seen that the fuzzy logic vector control has better speed tracking performance.

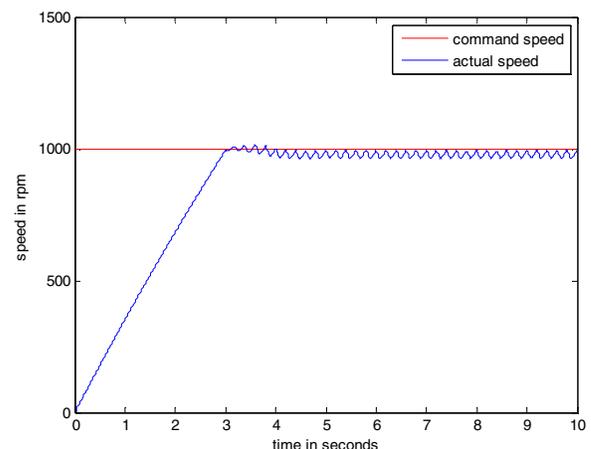


Figure4 Simulation performance of constant speed PID vector control scheme

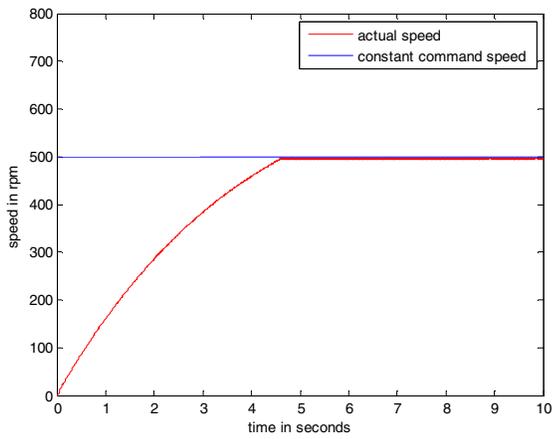


Figure 5 simulation performance of constant speed fuzzy vector control scheme

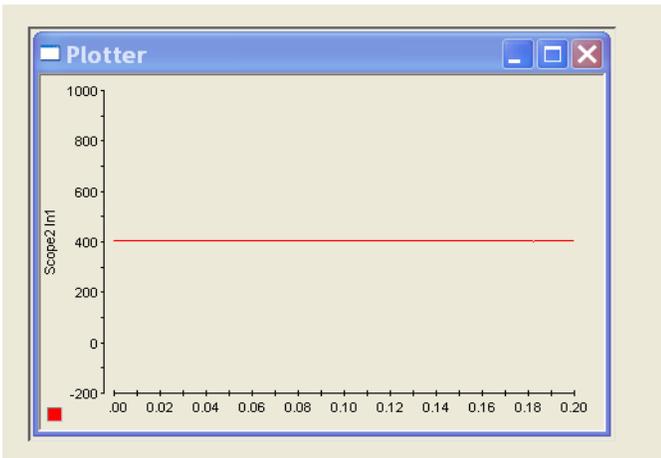


Figure 7 experimental performance PID vector control of actual speed and constant set speed

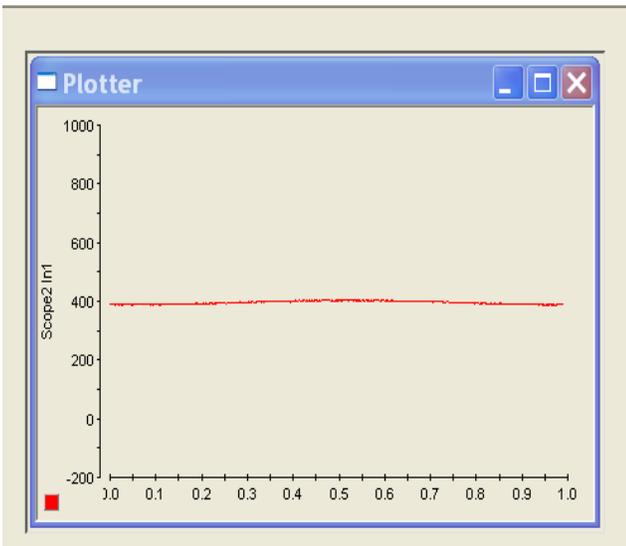


Figure 7 Experimental performance fuzzy vector control of actual speed and constant set speed

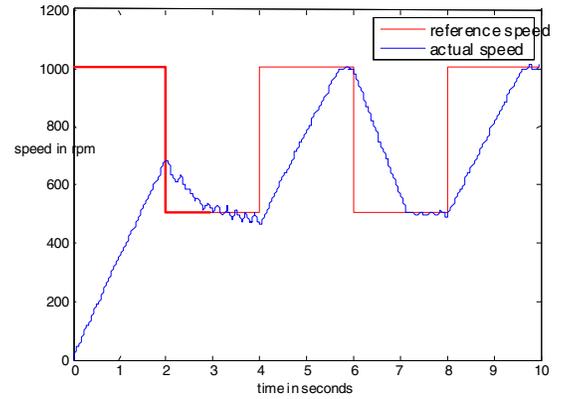


Figure 8 simulation performance of PID variable speed control scheme

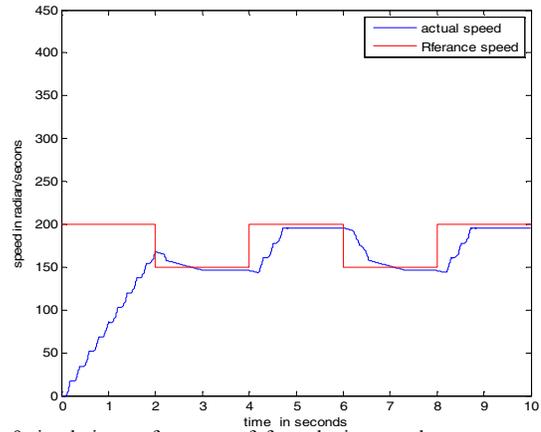


Figure 9 simulation performance of fuzzy logic control vector control scheme

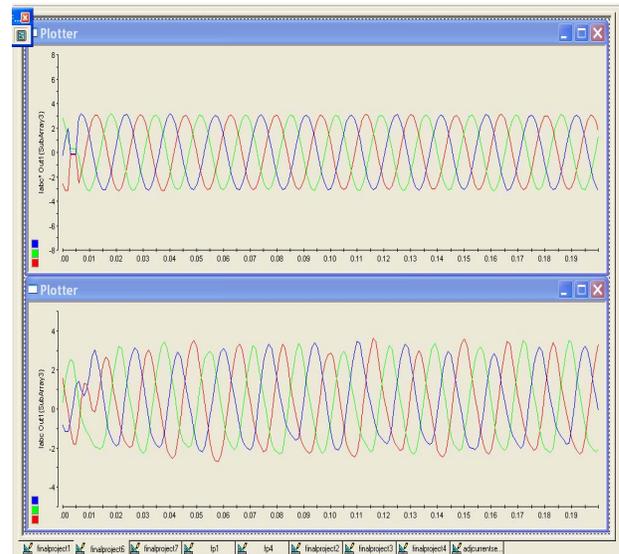


Figure 10. Experimental performance of desired currents and actual currents

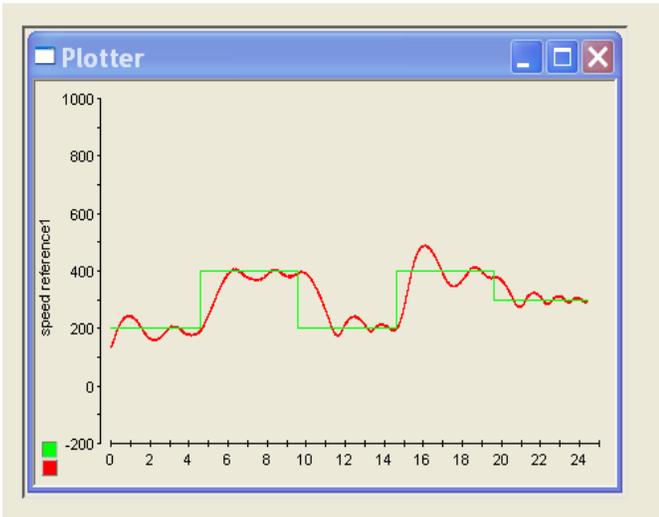


Figure 11. Experimental performance of PID vector control actual speed versus change in command speed

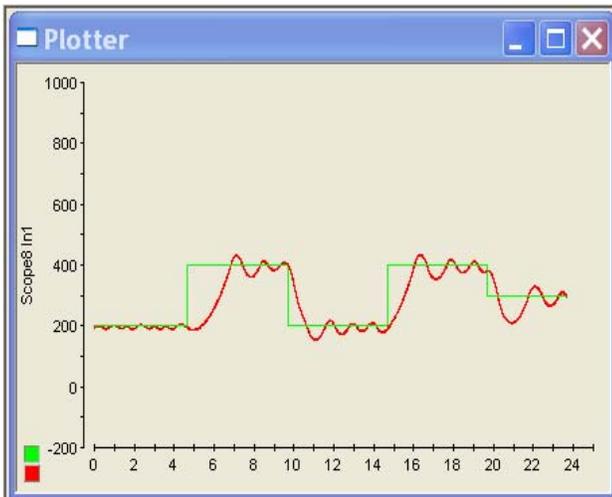


Figure 12. Experimental performance of actual speed versus change in command speed

#### IV. CONCLUSIONS

The paper has described a fuzzy logic based vector control of a laboratory scaled induction motor drive system i.e. the designed FLC acts on the speed-control loop. A hardware set-up of the integrated induction motor drive system has been developed in the laboratory and we have also successfully implemented the fuzzy vector control strategy in real-time by employing a dSPACE controller 1104. The efficacy of the controller has been verified through its hardware and MATLAB implementations.

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