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SPACE VECTOR MODULATION & FUZZY PID SPEED CONTROLLER FOR DIRECT TORQUE CONTROL INDUCTION MOTOR DRIVE

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ABSTRACT

This paper shows the application of fuzzy PID control technique to reduce torque ripple in an induction motor employing Direct Torque Control (DTC). The performance of the proposed drive system is evaluated through digital simulation using MATLAB-SIMULINK package. The simulation results clearly depict the superiority of devised method over the SVM - DTC.

Keywords: *Fuzzy Logic Control (FLC), Direct Torque Control, Induction Motor, Membership Function, Space Vector Modulation*

1.INTRODUCTION

During the last decade, a lot of modifications in classic Direct Torque Control scheme [1] have been made [8], [9], [10], [11], [12], [13], [14], [15] and [16]. The objective of these modifications was to improve the start up of the motor, the operation in overload conditions and low speed region. The modifications also aimed to reduce the torque and current ripple, the noise level and to avoid the variable switching frequency by using switching methods with constant switching frequency. The basic disadvantages of DTC scheme using hysteresis controllers are the variable switching frequency, the current and torque ripple. The movement of stator flux vector during the changes of cyclic sectors is responsible for creating notable edge oscillations of electromagnetic torque. Another great issue is the implementation of hysteresis controllers which requires a high sampling frequency. When a hysteresis controller is implemented using a digital signal processor (DSP) its operation is quite different to the analogue one. In the analogue operation the value of the electromagnetic torque and the magnitude of the stator flux are limited in the exact desirable hysteresis band. That means, the inverter can change state each time the torque or the flux magnitude are throwing the specified limits. On the other way, the digital implementation uses specific sample time on which the magnitudes of torque out of the desirable limits until the next sampling period. For this reason, an undesirable torque and flux ripple is occurred.

Artificial intelligent controller (AIC) could be the best candidate for IM control. Over the last two decades researchers have been working to apply AIC for induction motor drives [1-6]. This is because that AIC possesses advantages as compared to the conventional PI, PID and their adaptive versions. Mostly, it is often difficult to develop an accurate system mathematical model since the unknown and unavoidable parameter variations, and unknown load variation due to disturbances, saturation and variation temperature.

In this paper a fuzzy PID controller (FPIDC), as an AIC, is considered for motor control purpose [7-10]. The main advantages are that the designs of these controllers do not depend on accurate system mathematical model and their performances are robust. The performance of the proposed drive is investigated in simulation. In order to prove the superiority of the proposed FLC, the performances of the proposed controller are also compared to those obtained by a DTC_SVM controller.

2.CONTROL STRATEGY OF DTC-SVM

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y of DTC_SVM induction motor drive block diagram is shown in Fig.1. It operates with constant rotor flux, direct stator flux and torque control. The speed controller is a classical PID regulator which produces the reference torque. Only the dc-link voltage and two line currents are measured.

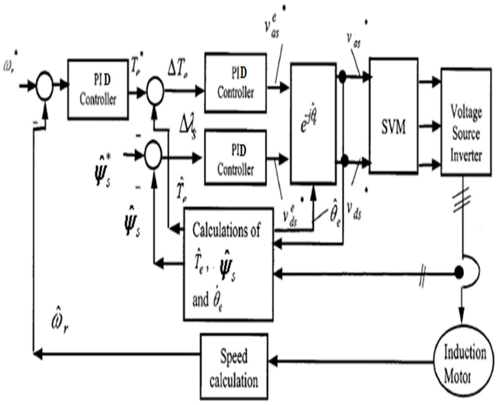

Fig .1: Proposed SVM-DTC induction motor.

Therefore the main theme of direct torque control is to regulate the torque and magnitude of flux directly without invoking any concept of field orientation. Following this essential concept, SVM based induction motor drives has two PID type controllers to regulate the flux amplitude and torque, respectively. Therefore, both the torque and the magnitude of flux are under control, there by generating the voltage command for inverter control. Noting that no decoupling mechanism is required since the flux magnitude and torque can be regulated by the PID controllers.

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The electromagnetic torque developed by induction motor is

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)(\psi_{ds}^s i_{qs}^s - \psi_{qs}^s i_{ds}^s) \qquad (1)$$

The stator flux and torque close loop control is achieved by the DTC-SVM unit. In order to reduce the torque and flux pulsations and, implicitly, the current harmonics content, in contrast to the standard DTC, we do use decoupled PID flux and torque controllers and space vector modulation. Equations (2)-(3) are the inputs of SVM unit and it gives the control signal to inverter.

$$E_d^* = (K_{P\psi} + K_{I\psi} + K_{D\psi}/S)(\psi_s^* - \psi_s) \qquad (2)$$

$$E_q^* = (K_{PT} + K_{IT} + K_{DT}/S)(T_e^* - T_e) + \psi_s\omega_{\psi s} \qquad (3)$$

$$E_d = Ri_d + S\psi_s \qquad (4)$$

$$E_q = Ri_q + \psi_s\omega_{\psi s} \qquad (5)$$

$$T_e = 1.5 p\psi_s i_q \qquad (6)$$

$K_{p\psi}, K_{I\psi}, K_{D\psi}$: Proportional, integration and derivative constant of stator flux.

K_{PT}, K_{IT}, K_{DT}: Proportional, integration and derivative constant of torque.

The inverter control signals are produced by the SVM unit. It receives the reference voltages (2) and (3) in a stator flux reference frame. The SVM principle is based on the switching between two adjacent active vectors and a zero vector during one switching period. The reference voltage vector defined by its length $|V_{ref}|$ (7) and angle α (8) in a stator reference can be produced by adding two adjacent active vectors &, if necessary, a zero vector V_0 or V_7..

$$\left|V_{ref}\right| = \sqrt{E_d^{*2} + E_q^{*2}} \qquad (7)$$

$$\alpha = \tan^{-1}\left(\frac{E_q{}^{*}}{E_d{}^{*}}\right) + \theta_{\psi s} \qquad (8)$$

3. PROPOSED FUZZY PID CONTROLLER

In the original DTC scheme the stator flux and the electric torque errors are reduced selecting an appropriate stator voltage vector over seven possible inverter vectors. Depending on the sign of the errors and on the stator flux angle a switching selection table selects the vector that keeps the magnitude of the errors inside a band around the references. Since there are only seven vectors available the flux and torque responses have a high level of ripple. If pulse width modulation (PWM) is used, the number of available vectors can be arbitrarily increased depending on the PWM resolution. This fact allows a better performance of the control scheme with lower levels of ripple than in the DTC_SVM. The switching selection table is replaced by a fuzzy inference system (FIS) based SVM. Fig.2 shows the proposed control scheme.

3.1 Fuzzy PID parameters:

Two separate Fuzzy interface system algorithm are employed in speed and torque loops. Each of them has two inputs error (e) and differential of error (eu). The outputs are Kp, Kd, Ki. Fuzzy controller inference is Mamdani type of two-inputs and three-outputs. The input error fuzzy set are {negative big (NB), negative middle (NM), negative small (NS), zero (Z), positive small (PS), positive middle (PM), positive big (PB)} and the differential set are {NB, NM, NS, Z, PS, PM, PB} all the degree of membership function of input and output variance are triangular membership function (trimf), see Fig. 3.The relations between input variables and output variables are expressed by a table of rules For example for a given stator flux vector the following "IF-THEN" rule can be applied: " IF (e is NB) and (eu is NM) then (Kp is PB) (Ki is NB) (Kd is NS)". Another example is: " IF (e is NB) and (eu is NS) then (Kp is PM) (Ki is NM) (Kd is NB) ".

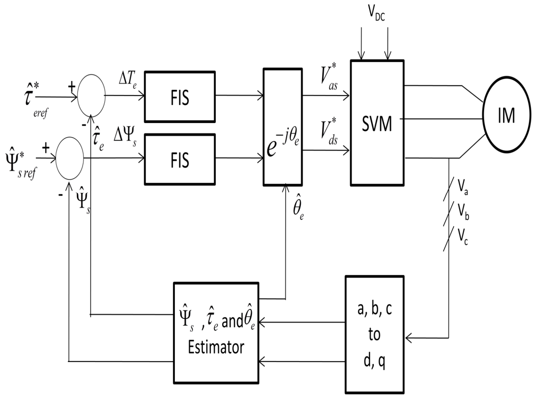

Fig. 2: Proposed control scheme of SVM-DTC with fuzzy interface system

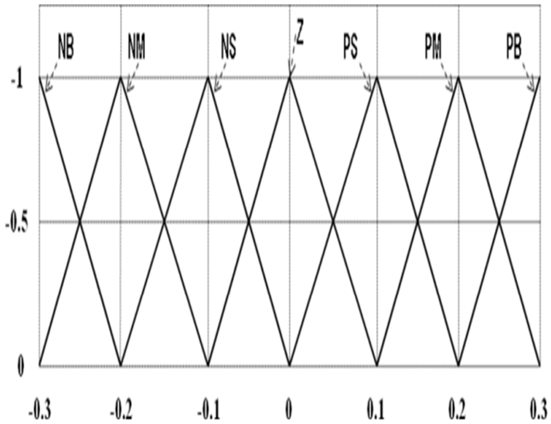

Fig. 3: Degree of membership functions of e, eu, Kp, Ki, Kd.

The other rules can be determined in a similar manner and the corresponding matrices are shown in Table 1, Table 2 and Table 3.The method used for defuzzification is centroid. It creates a distant output values based on the relative membership of the entire active rule that applies. The other rules can be determined in a similar manner and the corresponding matrices are shown in Table 1, Table 2 and Table 3.

Flux error fuzzy membership function

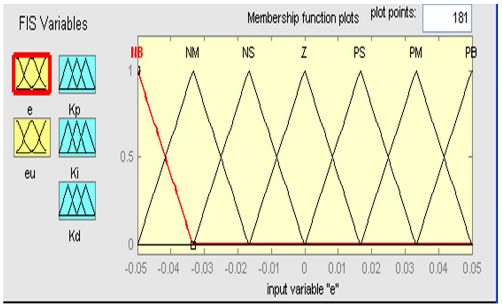

Fig. 4: Fuzzy membership function for input variable “e”

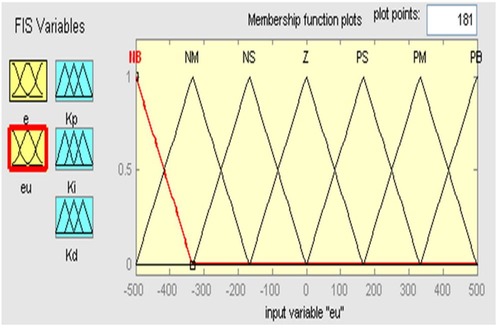

Fig.5: Fuzzy membership function for input variable “eu”

Torque error membership function

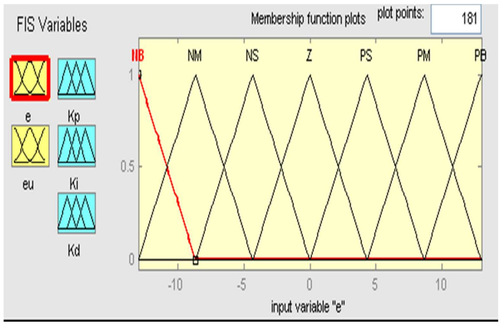

Fig.6: Fuzzy membership function for input variable “e”

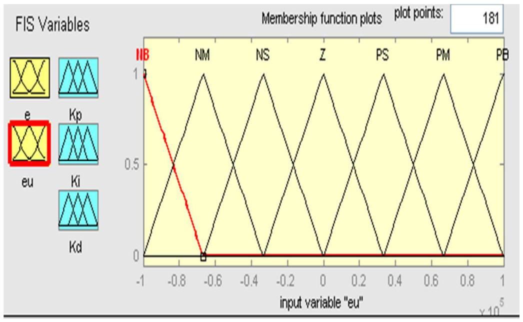

Fig.7: Fuzzy membership function for input variable “eu”

Table 1 fuzzy regulation table of Kp

kp		eu						
		NB	NM	NS	Z	PS	PM	PB
e	NB	PB	PB	PM	PM	PS	Z	Z
	NM	PB	PB	PM	PM	PS	Z	NS
	NS	PM	PM	PM	PS	Z	NS	NS
	Z	PM	PM	PS	Z	NS	NM	NM
	PS	PS	PS	Z	NS	NS	NM	NM
	PM	PS	Z	NS	NM	NM	NM	NB
	PL	Z	Z	NM	NM	NM	NB	NB

Table 2 fuzzy regulation table of Ki

ki		eu						
		NB	NM	NS	Z	PS	PM	PB
e	NB	NB	NB	NM	NM	NS	Z	Z
	NM	NB	NB	NM	NS	NS	Z	Z
	NS	NB	NM	NS	NS	Z	PS	PS
	Z	NM	NM	NS	Z	PS	PM	PM
	PS	NM	NB	Z	PS	PS	PM	PB
	PM	Z	Z	PS	PS	PM	PB	PB
	PL	Z	Z	PS	PM	PM	PB	PB

Table 3 fuzzy regulation table of Kd

kd		eu						
		NB	NM	NS	Z	PS	PM	PB
e	NB	PS	NS	NB	NB	NB	Z	Z
	NM	PS	NS	NB	NM	NM	Z	Z
	NS	Z	NS	NM	NM	NS	PS	PS
	Z	Z	NS	NS	NS	NS	PM	PM
	PS	Z	Z	Z	Z	Z	Z	Z
	PM	PB	PS	PS	PS	PS	PS	PB
	PL	PB	PM	PM	PM	PS	PS	PB

4. SIMULATION AND RESULTS

A series of simulation tests are conducted on a 1.1KW, 4 poles inverter-fed IM to evaluate the performance of proposed DTC method.

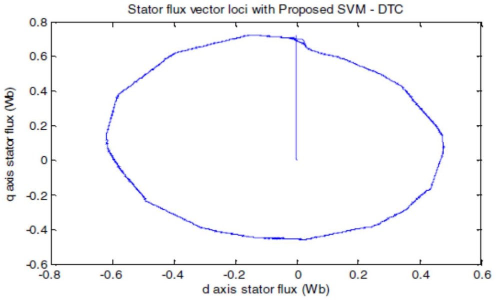

Fig.8: Simulation results for Stator flux loci for SVM- DTC.

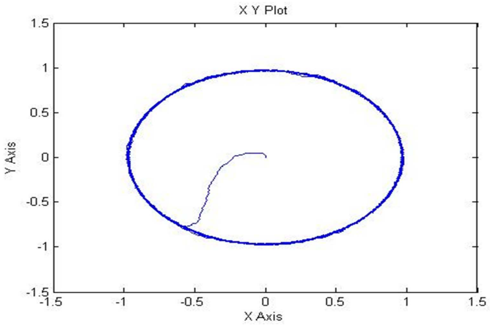

Fig.9: Stator flux loci for proposed Fuzzy PID controller.

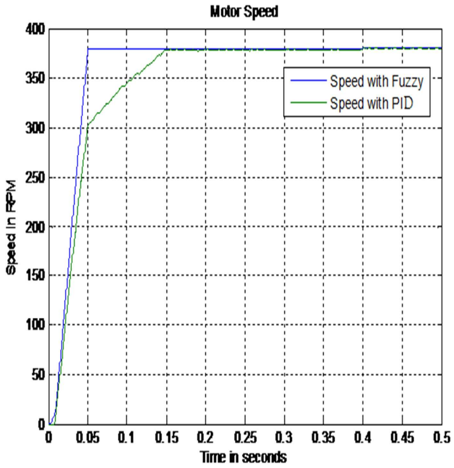

Fig.10: Simulation results for speed response with fuzzy and SVM_DTC

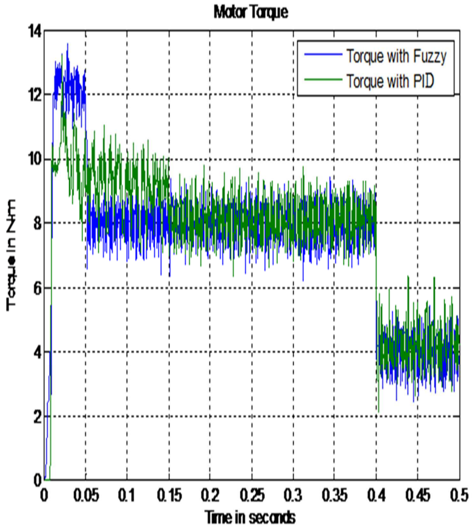

Fig.11: Simulation results for Torque response with fuzzy and SVM_DTC**.**

Figure-8 and 9 shows stator flux trajectory for classical PID and proposed DTC respectively.

Figure 11 the Torque command shows reduction in torque ripple using FLC controller. Figure 10 initially speed command shows 0.05seconds setting time for fuzzy controller as against 0.15seconds setting for PID controller it also shows oscillations in PID controller.

Figure 12 shows speed and torque response at zero speed and full load torque condition for SVM_DTC and proposed SVM_DTC with fuzzy interface system.

Figure 13 shows speed and torque response when rotor resistance decreases to 50 percentage of its initial value (7.55 ohms) for SVM _DTC and proposed SVM_DTC with fuzzy interface system.

Figure 16 shows speed and torque response when inertia increases to twice of its initial value (J =0.013Kg-$\mathbf{m^2}$) for SVM _DTC and proposed SVM_DTC with fuzzy interface system.

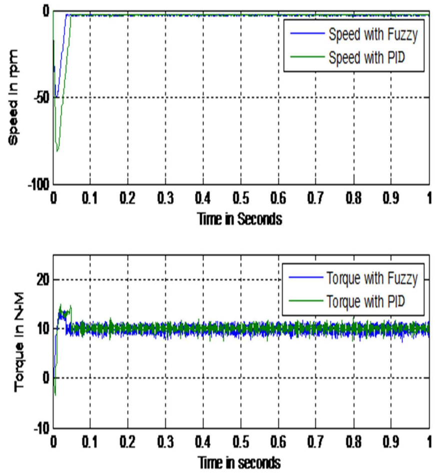

Fig.12: Simulation results for speed and torque response at zero speed and full load torque condition

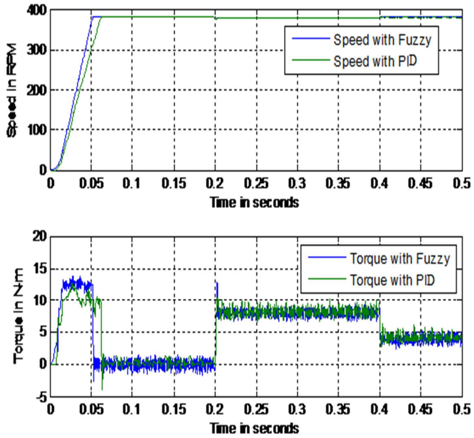

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Fig.13: Speed and Torque response when rotor resistance decreased to 50**%.**

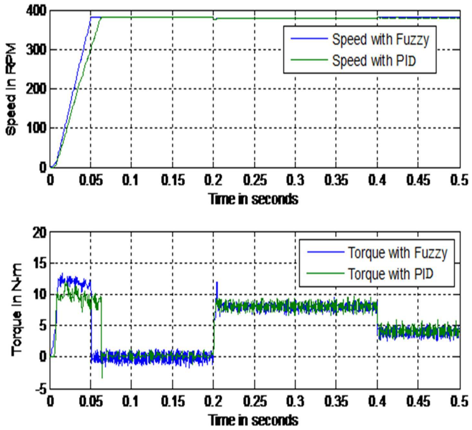

Fig.14: Speed and Torque response when rotor resistance increased to 50**%**

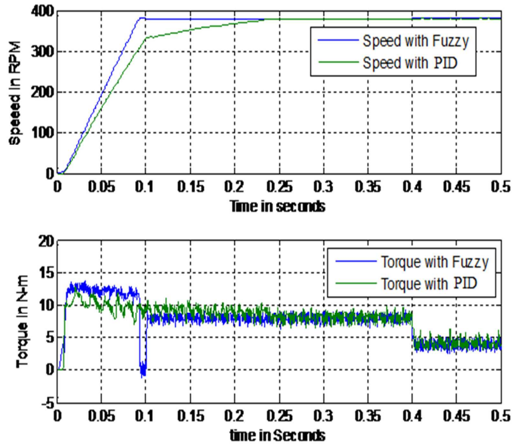

Fig.15: Simulation results for speed and torque response when inertia is increased to 0.026Kg-**m²**.

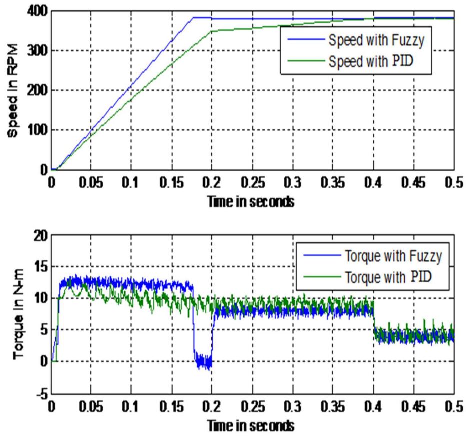

Fig.16: Simulation results for speed and torque response when inertia is increased to 0.052Kg-**m²**.

The results are:

- step speed command was given to the switching table Fuzzy PID controller had a response time 50ms as against SVM based PID, which is 150ms [It shows in figure 10].
- Torque and Current ripples are less with fuzzy PID [shows in Figure 11].
- Fuzzy based PID can handle parameter variations for change in rotor resistance satisfactorily [Figure 13-14].
- It also has better transient response with increased in inertia (2 times and 4 times

the nominal value) [Figure 15-16].

- Fuzzy PID and DTC_SVM PID results were also compared with respect to non linearity in the load. Fuzzy based PID produces ripple free torque irrespective of the nonlinearity like friction etc. in the load. So it becomes more practical as all loads are nonlinear. [Figure17-18].

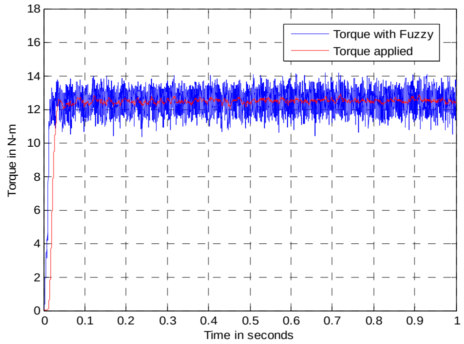

Fig. 17. Torque responses with non linear load in Fuzzy controller.

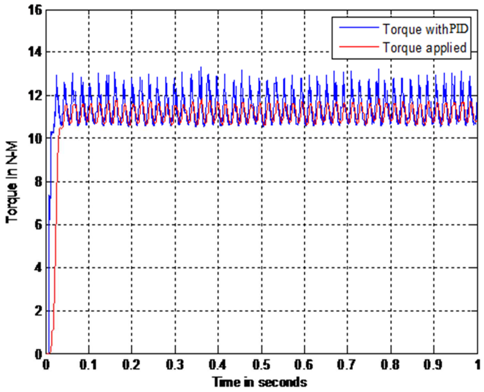

Fig.18: Torque response with non linear load in PID.

5.CONCLUSIONS

Direct Torque Control is supposed to be one of the best controllers for driving any induction motor. In this paper, the Fuzzy Space Vector Modulation for DTC is studied thoroughly and implemented on MATLAB SIMULINK platform. Initially, the model of an induction machine is analyzed with its complete theoretical details and the required equations. This is the required foundation to understand the DTC schemes in detail. The results of SVM_DTC were compared with the proposed fuzzy logic DTC. Extensive simulations were carried out. Proposed DTC strategy realizes almost ripple-free operation for the entire speed range. Consequently, the flux, torque, and speed estimation is improved. It gives better dynamic response and preserves the robustness. Simulation results show the validity of the FLDTC method not only achieving a considerable reduction in torque ripple, but also reducing the energy consumption taken from the mains supply.

APPENDIX

3-Phase Induction Motor Parameters
Rotor type: Squirrel cage, Reference frame: Stationary
R_s=7.83 ohms, R_r=7.55 ohms ,L_s=0.4751 H ,L_r=0.4751 H , M=0.4535H,P=4,J=0.013 ,V_{dc}=2*155 ,P=1.1kw.

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