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FUZZY OPTIMIZATION FOR SPEED CONTROLLER OF AN INDIRECT VECTOR CONTROLLED INDUCTION MOTOR DRIVE USING MATLAB SIMULINK

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ABSTRACT

The aim of this paper is to investigate the performance of a Fuzzy-Logic-Controller (FLC) which is applied on three-phase induction motor drive system for high-performance industrial applications. In this paper, the FLC is used as a speed controller to replace the conventional PI speed controller. The FLC will determine the time of switching on the Space Vector Pulse Width Modulation (SVPWM) inverter that supplies power to drive the induction motor considering variable direct and quadrature axis inductances. The performance of the suggested technique has been simulated and developed using MATLAB/ SIMULINK for dynamic operating condition, such as certain change in command speed, and step change in load. The simulation result shows the feasibility of the proposed technique in order to improve the speed response and low torque ripple on three phase induction motor drive.

Keywords: *Field Oriented Control, Fuzzy Logic Controller, Space Vector PWM, Induction motor*

1. INTRODUCTION

Among various ac motors, induction motor (IM) occupies almost 90% of the industrial drives due to its simple and robust construction; however, the control of IM is complex due to its nonlinear nature and the parameters change with operating conditions. 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 logic controller (FLC), 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 conventional PI controller.

2. INDUCTION MOTOR MODEL

The dynamic space vector model of IM in an arbitrary frame is expressed as

$$u_s = R_s\, i_s + p\,\psi_s + j\omega_k\,\psi_s \quad (1)$$

$$0 = R_r\, i_r + p\,\psi_r + j(\omega_k - \omega_r)\,\psi_r \quad (2)$$

$$\psi_s = L_s\, i_r + L_m\, i_r \quad (3)$$

$$\psi_r = L_m\, i_r + L_r\, i_r \quad (4)$$

$$T_e = \frac{3}{2} N_p \frac{L_m}{L_r}\,\psi_r \otimes i_s = T_L + \frac{J}{N_p}\frac{d\omega_r}{dt} \quad (5)$$

Where u_s, i_s, i_r, ψ_s and ψ_r are the stator voltage, stator current, rotor current, stator flux linkage and rotor flux linkage, respectively; T_e and T_L are electromagnetic torque and load torque; R_s, R_r, L_s, L_r, L_m and N_p are stator resistance, rotor resistance, stator inductance, rotor inductance, mutual inductance and number of pairs of motor; ω_r is the rotor speed and subscript $\boldsymbol{k}$ denotes the rotating coordinate.

Suppose ω_k is equal to the rotating speed of rotor flux, and the d-axis is aligned to the orientation of rotor flux, thus Rotor Field Oriented Control (RFOC) is obtained, and the model of IM is simplified and expressed as

$$u_{sd} = R_s i_{sd} + \sigma L_s\, p\, i_{sd} + \frac{L_m}{L_r} p\,\psi_r - \sigma Ls\,\omega_k\, i_{sq} \quad (6)$$

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$$u_{sq} = R_s i_{sq} + \sigma L_s\, p\, i_{sq} + \omega_0 i_{sq}\,(\sigma L_s i_{sq} + \frac{L_m}{L_r}\psi_r) \quad (7)$$

$$\psi_r = \frac{L_m}{T_r\, p+1}\, i_{sd} \quad (8)$$

$$\omega_{sl} = \omega_k - \omega_r = \frac{L_m\, i_{sd}}{T_r\, \psi_r} \quad (9)$$

$$T_e = \frac{3}{2} N_p \frac{L_m}{L_r}\, \psi_r\, i_{sq} \quad (10)$$

Where rotor flux is only decided by the d-axis current, and if rotor flux is constant, the electromagnetic torque is proportional to the q-axis current, thus rotor flux and electromagnetic torque is decoupled, which provides convenience for control.

In conventional RFOC, PI is used to regulate the d-axis and q-axis current in synchronous frame and the control law is

$$i_{sd}^* = (K_p + K_I/s)(\psi_r^* - \psi_r) \quad (11)$$

$$i_{sq}^* = (K_p + K_I/s)(\omega_r^* - \omega_r) \quad (12)$$

3. PRINCIPLE OF FLC

The mathematical tool for the FLC is the Fuzzy set theory introduced by Zadeh [11], which incorporates human experience in the controller. A typical FLC block diagram is illustrated in Fig. 1.

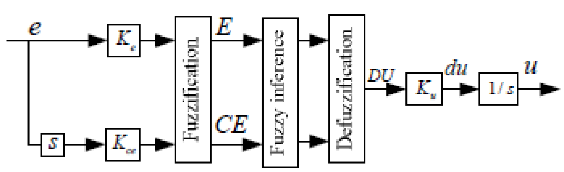

Fig. 1. Block of FLC

The range of input and output variables after scaling is between -5 and +5. Fig.2 and Fig. 3 show the fuzzy sets and corresponding triangular membership function description of each signal. The fuzzy sets are defined from big to small as follows: PVB, PB, PM, PS, Z, NS, NM, NB, NVB.

The membership function of input and output are shown in Fig. 2 and Fig. 3 respectively. Tab. I shows the inference rule used in this paper, which is the key part of FLC. By well designing the inference rule, excellent performance can be achieved. The mapping relationship between input variables and output variable is illustrated in Fig. 4.

TABLE I
RULE MATRIX OF FLC

Output		Input 1(E)						
		NB	NM	NS	Z	PS	PM	PB
Input 2(CE)	NB	NVB	NVB	NVB	NB	NM	NS	Z
	NM	NVB	NVB	NB	NM	NS	Z	PS
	NS	NVB	NB	NM	NS	Z	PS	PM
	Z	NB	NM	NS	Z	PS	PM	PB
	PS	NM	NS	Z	PS	PM	PB	PVB
	PM	NS	Z	PS	PM	PB	PVB	PVB
	PB	Z	PS	PM	PB	PVB	PVB	PVB

To obtain fast response for dynamic performance and high accuracy for steady state, asymmetric triangular is selected as the membership function, which can be seen in Fig. 2 and Fig. 3 and is different from conventional design.

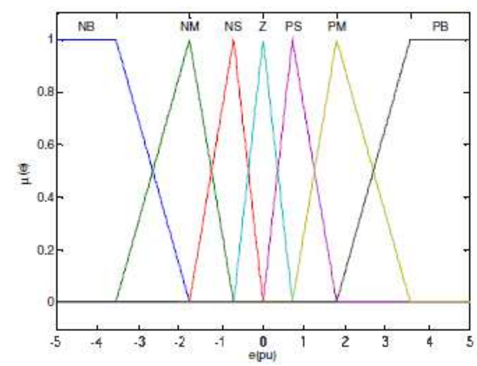

Fig. 2. Input membership functions

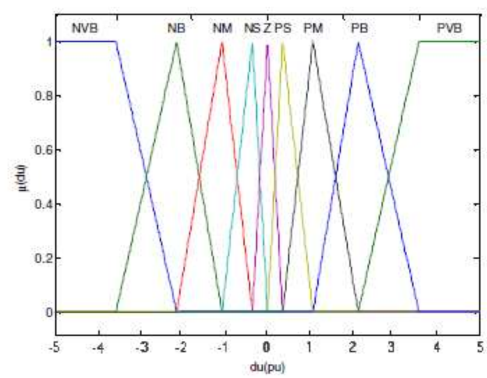

Fig. 3. Output membership function

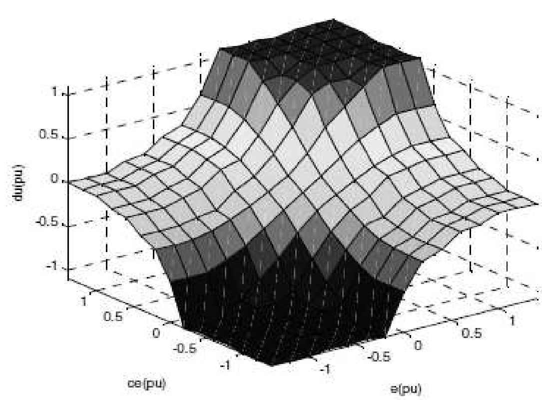

Fig. 4. Control surface of FLC

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The input of FLC for speed control is the error between commanding speed value and real speed value, and its output is q-axis torque current. The input of FLC for flux control is the error between commanding flux value and real flux value, and its output is d-axis magnetizing current.

4. DESIGN SYSTEM CONTROL

Theoritically, the field oriented control for the Induction motor drive can be manly categorized into two types; indirect and direct schemes. The field to be oriented could be rotor, stator, or air gap flux linkage. In the indirect filed oriented control, the slip estimation with measured or estimated rotor speed is required in order to compute the synchronous speed. There is no flux estimation appearing in the system. For the direct scheme, the synchronous speed is computed basing on the flux-angle which is available from flux estimator or flux sensor (e.g., Hall effect).

In this implementing system, the indirect flux oriented control system with measured speed based on capture is chosen. The overal block diagram can be depicted in figure 5.

The fundamental of field oriented control (or flux vector control) for the AC motors, such as induction or synchronous motors, is to align the total flux into the synchronously rotating d-axis.

With the important result of this alignment, the electromagnetic torque and flux produced by motor can be independently controlled by the d-axis and q-axis stator current in the synchronously rotating reference frame, respectively. Figure 6 shows the stator current and rotor flux vectors in rotor field oriented control.

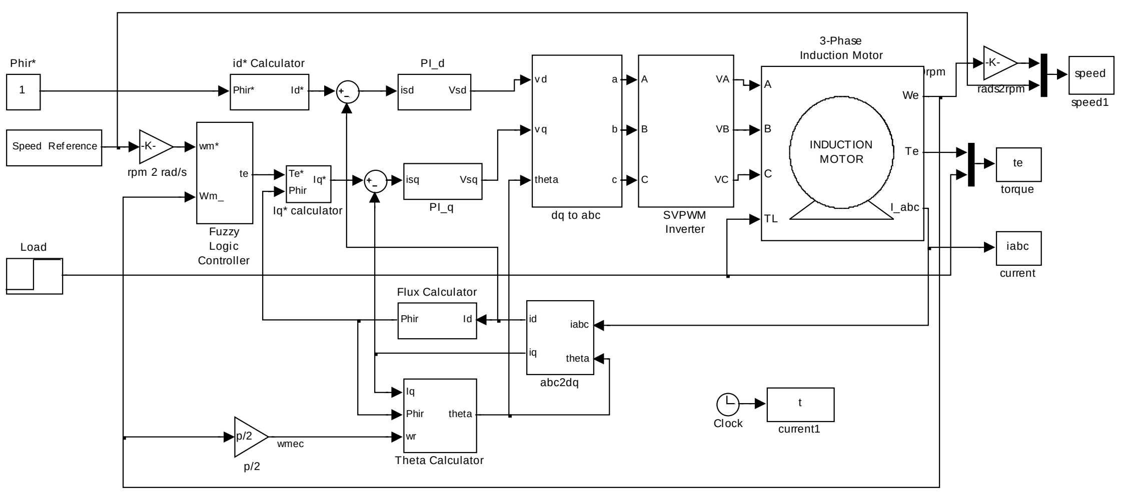

Fig. 5. Blok diagram of Indirect Field Oriented Control.

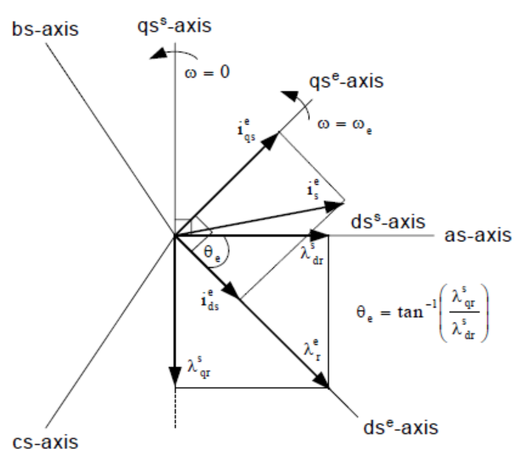

Fig. 6. Stator current and rotor flux vectors in rotor field oriented control.

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5. SIMULATION RESULT

Fig. 7 shows the simulated speed response of rotor using conventional technique PI. The green line color shows the speed reference at starting 1300 rpm, then after 1 second command speed was given to reduce the speed at 1000 rpm while the blue line color shows the speed actual motor.

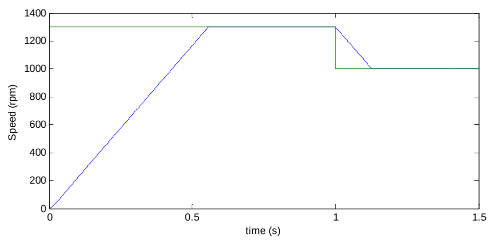

Figure 7. Simulated speed response of PI

Next, Fig. 8 shows torque response of motor in conventional technique PI, then Fig.9 show stator currents transient response.

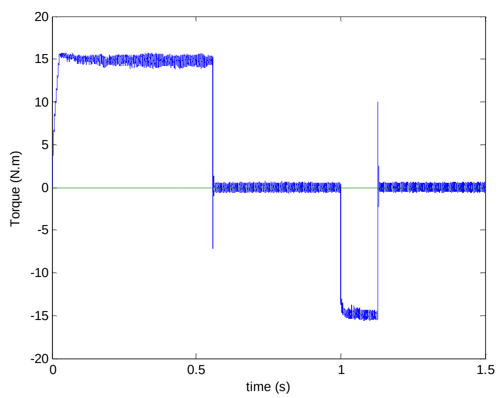

Figure 8. Simulated torque response of motor in conventional technique PI

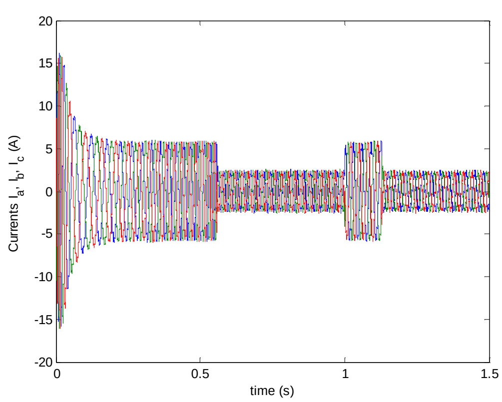

Figure 9. Simulated stator currents transient response of motor in conventional technique PI

In Fig. 10 shows simulated speed response of rotor in FLC technique and below are respectively torque response in FLC, Fig .11. Then Fig. 12 shows stator currents transient in FLC.

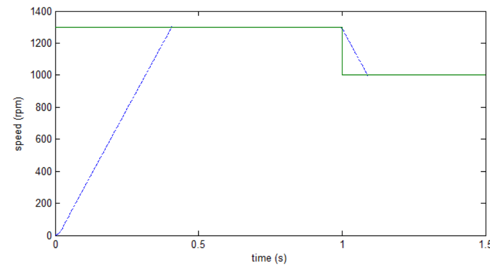

Figure 10. Simulated speed response using FLC technique

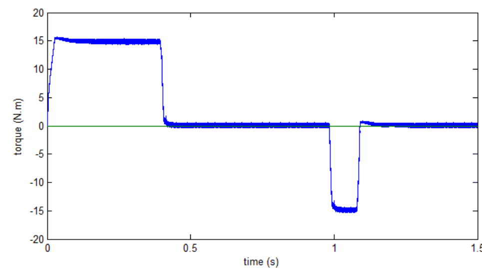

Figure 8. Simulated torque response of motor using FLC technique

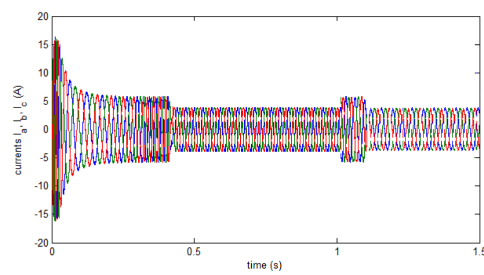

Figure 9. Simulated stators current transient response of motor using FLC technique

6. CONCLUSION

In this work, a Fuzzy logic based algorithm of speed controller has been applied for the speed control of a three-phase induction motor. The variable of *d*- and *q*-axis inductances based on Indirect Field Oriented Control system with Space Vector PWM technique is applied in inverter-fed IM drive. This simulation results show the performance of the proposed technique compared with the conventional PI controller. The FLC can eliminate the overshoot and steady state error which is produced by PI controller. for speed

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The ripple torque is also can be reduced through this method. In the future work the prototype will be developed in order to verify simulation and experimental results. The suggested algorithm will be implemented in experimental to drive three phase induction motor using DSP control board TMS320F2812.

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