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PERFORMANCE OF INDUCTION MOTOR DRIVE BY INDIRECT VECTOR CONTROLLED METHOD USING PI AND FUZZY CONTROLLERS

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Abstract: The most commonly used controller for the speed control of Induction motor is Proportional plus Integral (PI) controller. However, the PI controller has some disadvantages such as: the high starting overshoot, sensitivity to controller gains and sluggish response due to sudden disturbance. So, the relatively a new intelligent controller based on Fuzzy set theory is proposed in this work to overcome the disadvantages of the PI controller. So, this paper presents a study the speed control of Indirect Vector Controlled Induction motor drive. The performance of the intelligent controller has been investigated through Matlab/Simulink environment, for different operating conditions. Finally, the results are compared with PI controller and intelligent Fuzzy controller. It is observed that fuzzy logic based controllers give better responses than the traditional PI controller for the speed control of Indirect Vector Controlled Induction motor drives.

Keywords: Indirect Vector control, Fuzzy Logic Intelligent controller, PI controller, Induction motor drives, Speed control.

I. Introduction

The electromagnetic forces or torques developed in the driving motor tend to propagate motion of the drive system. This motion may be uniform if the linear velocity or the angular velocity is constant. Therefore the electrical drives good dynamic performance is mandatory so as to respond the changes in command speed and torques. The most commonly used controller for the speed control of Induction motor is Proportional plus Integral (PI) controller [1]. However, the PI controller has some demerits such as: the high starting overshoot, sensitivity to controller gains and sluggish response due to sudden disturbance. To overcome these problems, replacement of PI controller by an intelligent controller based on Fuzzy set theory is proposed in this work. The fuzzy logic has certain advantages compared to the classical controllers such as simplicity of control, low cost, and the possibility to design without knowing the exact mathematical model. The vector control methods are

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classified into two types, such as direct vector control and indirect vector control methods. In this paper the Indirect Vector Control method is used [2-3]. Since, it is a fast dynamic response and speed response without cogging or torque pulsations at low speed, smooth speed reversal under any torque conditions.

In this paper application of Fuzzy logic to the intelligent speed control of Indirect Vector Controlled Induction Motor Derive is investigated. The analysis design and simulation of the controller is carried out based on the fuzzy set theory [4-5]. This can be accomplished by vector control of induction machines, which emulate the performance of dc motor and brushless dc motor servo drives. Compared to dc and brushless dc motors, induction motors have a lower cost and a more rugged construction. Operation of the drive with constant full torque below base speed and above base speed with reduced flux. Torque is the fundamental variable of an induction machine, to get the accurate control of speed and position by controlling the torque of induction machines.

A new control of a drive system is formulated and it is often convenient to study the system performance by using Matlab/Simulink package, when compared to other packages like PSPICE and EMTP etc. The Matlab Simulator has an ease in modeling, the transients of electrical machines and drives and to include controls in the simulation. The superior control performance of the proposed controllers is demonstrated at Simulink platform using the Fuzzy logic tool box for different operating conditions.

II. Methodology

This paper is organized as follows: at first step, describes the Indirect Vector Control System; Section III discussed the design and description of PI controller and intelligent based fuzzy controller. The case study of this paper is presented in section IV, Section V and conclusions of the work.

A. Indirect Vector Control System

Fig.1 shows an Indirect Vector Control Method. It consists of a slip frequency calculation, Inverter, Voltage and Current sensing Elements, integrator of error speed signal Speed sensor element and the corresponding Phase diagram is shown in Fig.2.

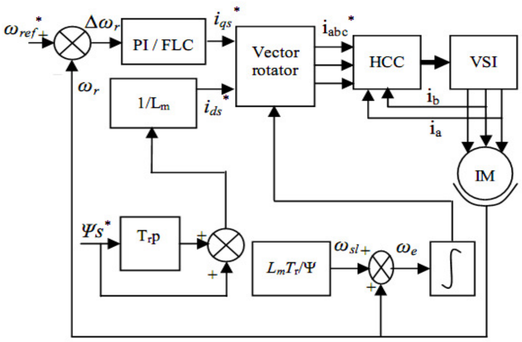


Fig.1 Indirect Vector Control method of induction Motor.

The Vector control techniques have made possible the application of induction motors for high-performance applications, where traditionally only DC drives were applied. The vector control scheme enables the control of the induction motor in the same way as separately excitation DC motors. As in the DC motor, torque control of induction motor is achieved by controlling the torque current component and flux current component independently. In the indirect vector control method, the rotor field angle and thus the unit vectors are indirectly obtained by summation of the rotor speed and slip frequency [6-7]
The machine parameters are given in APPENDIX.

For high performance drive the indirect method of vector control is preferred. The indirect vector control method is essentially same as the direct vector control except that the rotor angle θ_e is generated in an indirect manner using the measured speed ω_r and the slip speed ω_{sl}. To implement the indirect vector control strategy, it necessary to take the following dynamic equations into consideration. With respect to phasor diagram of Indirect Vector Control method of induction motor, which is shown in Fig.2.

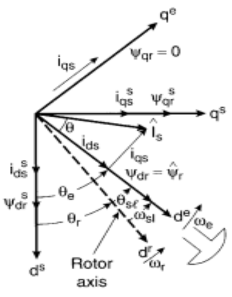


Fig.2 Phasor diagram indirect vector control method of Induction motor.

$$\theta_e = \int \omega_e \, dt = \int (\omega_r + \omega_{sl}) \, dt = \theta_r + \theta_{sl} \qquad \dots (1)$$

The rotor circuit equations

$$\frac{d\psi_{dr}}{dt}+\frac{R_r}{L_r}\psi_{dr}-\frac{L_m}{L_r}R_r i_{ds}-\omega_{sl}\psi_{qr}=0 \quad \ldots (2)$$

$$\frac{d\psi_{qr}}{dt}+\frac{R_r}{L_r}\psi_{qr}-\frac{L_m}{L_r}R_r i_{qs}+\omega_{sl}\psi_{dr}=0 \quad \ldots (3)$$

For decoupling control $\psi_{qr}=0$, So the total flux ψ_r directs on the d^e axis

Now from equations (1) and (2) we get

$$\frac{L_r}{R_r}\frac{d\psi_r}{dt}+\psi_r=L_m i_{ds} \quad \ldots (4)$$

As well, the slip frequency can be calculated as:

$$\omega_{sl}=\frac{L_m}{\psi_r}\frac{R_r}{L_r}i_{qs}=\frac{R_r}{L_r}\frac{i_{qs}}{i_{ds}} \quad \ldots (5)$$

The slip gain is

$$K_s=\frac{\omega_{sl}^*}{i_{qs}^*}=\frac{L_m R_r}{L_r\psi_r} \quad \ldots (6)$$

It is found that the ideal decoupling can be achieved if the above slip angular speed command is used for making field orientation. The constant rotor flux ψ_r and $\frac{d\psi_r}{dt}$=0 can be substituted in equation (4), so that the rotor flux sets as

$$\psi_r=L_m i_{ds} \quad \ldots (7)$$

The electromechanical torque developed is given by

$$T_e=\frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\psi_r i_{qs} \quad \ldots (8)$$

B. Generalized Design Analysis of PI Controller

Historically, the first tuning rule (formula) for setting up controller parameters was defined in 1934 for the design of a Proportional Plus Derivative (PD) controller for a process exactly modeled by an Integrator Plus Delay (IPD) model. Subsequently, tuning rules were defined for PI, PD and PID controllers out of which the PI and PID controllers have been at the heart of control engineering practice. However in this paper PI controller is considered, in which the controller parameters are adapted to the controller structure, and structurally optimized controllers, in which the controller structure and parameters are adapted optimally to the structure and parameters of the process model.

The proportional controller is a device that produces an output signal which is proportional to the input signal. It improves the steady state tracking accuracy, disturbance signal rejection and relative stability. It also decreases the sensitivity of the system to parameter variations. The PI controller produces an output signal consisting of two terms- one proportional to input signal and the other proportional to the integral of input signal. The concerns of PI controller in the system is to reduce the steady state error and increased the order and type of the system by one[8] which is shown in Fig.3.

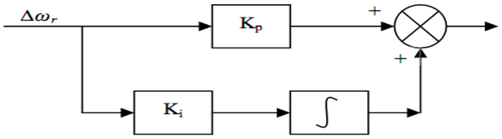


Fig.3 Block Diagram of PI controller

The transfer function of the PI controller is:

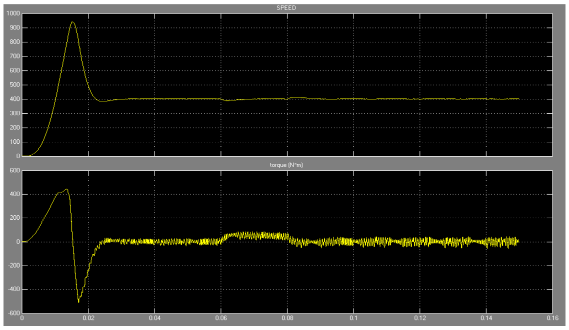
$$\frac{K_P S + K_I}{S} = K_P + \frac{K_I}{S}$$

Transfer function (PI) = $K_p + K_I / S$ … (9)

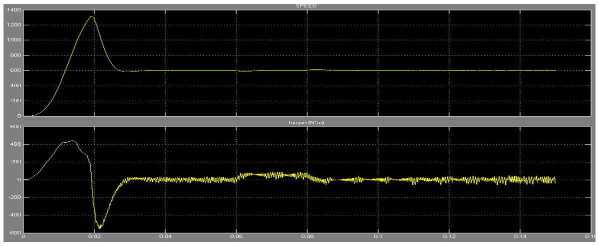
$i_{qs}^{*} = K_p \Delta\omega_r + K_i \int \Delta\omega_r dt$ … (10)

From equations (1)-(10), the variable ($\Delta\omega_r$) represents the tracking error, the difference between the desired input value (ω_r^{*}) and the actual output (ω_r). This error signal ($\Delta\omega_r$) will be sent to the PI controller, which is shown in Fig.1, and the controller computes the integral of this error signal. The signal (i_{qs}^{*}) just past the controller is now equal to the proportional gain (K_P) times the magnitude of the error plus the integral gain (K_I) times error**.** The output signal of the controller will be sent to the Vector rotator, and finally control the Induction motor drive. So, the use of the PI controller is ubiquitous in industry. It has been stated, for example, that in process control applications, and more than 95% of the controller is PI type.

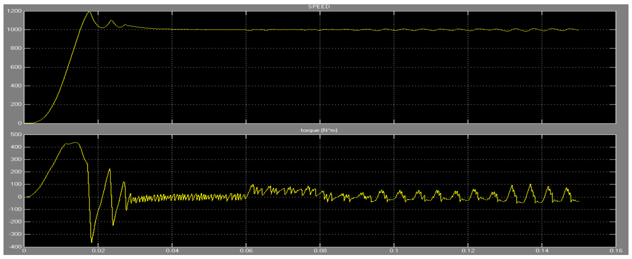
A. SIMULATION RESULTS



(a) Speed and Torque response at 400 rpm (at load disturbance torque is 50-Nm)



(b) Speed and Torque response at 600 rpm (at load disturbance torque is 50-Nm)



(c) Speed and Torque response at 1000 rpm (at load disturbance torque is 50-Nm)

Fig.4 PI controller of Load Torque Disturbance

Fig. 4.is carried out to examine the disturbance rejection of a controller, when the machine is operated at 400 rpm, 600rpm and 1000rpm when load disturbance torque (50-Nm) is suddenly applied, first, at 0.05sec and then at 0.08sec. The PI controller takes much longer to return to speed command and presents an overshoot i.e the speed with a maximum drop of 11.5rpm for 400 rpm,12.5rpm for 600 rpm and 8.5rpm for 1000 rpm respectively. The PI controller's disturbance rejection performance can be improved by readjusting the gains at the expense of speed tracking performance. For larger integral gains can be used to reduce the errors, but will cause serious speed overshoots and long Settling times which is shown in Fig's 4(a), (b) and (c). This problem can be overcome by introducing intelligent Fuzzy logic controller (FLC). This can be described in the following section.

III. Design and Description of Intelligent Fuzzy Logic Controller

The implementation of offline tuning of PI controller is difficult in dealing with continuous parametric variation in the induction motor as well as the nonlinearity present in the entire system.

However, the fuzzy logic bases intelligent controller is used instead of the PI controller, excellent control performance can be achieved even in the presence of parameter variation and drive nonlinearity. In addition, the fuzzy logic possesses the following advantages: (1) the linguistic, not numerical, variables make the process similar to the human think process.

(2) It relates output to input, without understanding all the variables, permitting the design of system more accurate and stable than the conventional control system. (3) Simplicity allows the solution of previously unsolved problems. (4) Rapid prototyping is possible because, a system designer doesn't have to know everything about the system before starting work. (5) It has increased robustness. (6) A few rules encompass great complexity.

The work presented in uses a Fuzzy Logic Controller to set the torque component of reference current based on speed error and change of speed error. The inverter is then switched to follow the reference current within hysteresis band. However, the constant hysteresis band of the current regulated Voltage Source Inverter of the Fuzzy logic based indirect vector control system possesses problem in achieving superior dynamic performance, even the drive control system includes the efficient Fuzzy logic controller. This paper discusses the fuzzy logic speed control for VSI fed indirect vector controlled induction motor drives.

Fig. 6 shows the block diagram of Fuzzy logic based speed control system. Such a Fuzzy logic controller consists of four basic blocks viz., Fuzzification, Fuzzy Inference Engine, Knowledge base and defuzzification.

The overall model for fuzzy logic based speed control system for indirect vector controlled induction motor drive is shown in Fig. 5. The parameters of the motor are given in **Appendix.**

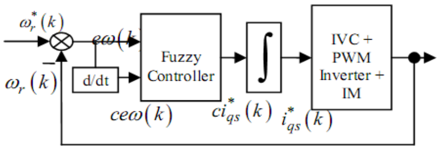


Fig. 5 Block diagram of Fuzzy logic speed control system for Indirect Vector Controlled Induction Motor Drive

A. Input/ Output variables

The design of the fuzzy logic controller starts with assigning the input and output variables. The most significant variables entering the fuzzy logic speed controller has been selected as the speed error and its time variation. Two input variables $e\omega(k)$ and $ce\omega(k)$ are calculated at every sampling instant as:

$e\omega\ (k)=\omega_r^*(k)-\ \omega_r\ (k)$ … (11)

$ce\omega\ (k)=e\omega(k)-e\omega(k-1)$ … (12)

Where $\omega_r^*(k)$ is the reference speed, ω_r (k) is the actual rotor speed and eω(k-1) is the value of error at previous sampling time.

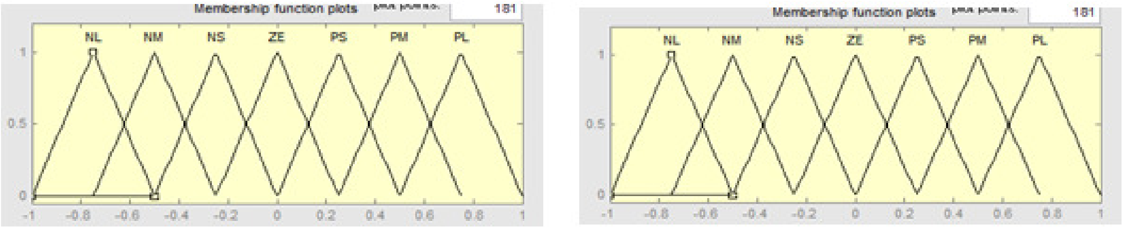
The output variable of the fuzzy logic speed controller is the variation of command current, $ci_{qs}^*(k)$ which is integrated to get the reference command current, $i_{qs}^*(k)$ as shown in the following equation.

$$i_{qs}^*(k) = i_{qs}^*(k-1) + ci_{qs}^*(k) \qquad \dots (13)$$

B. Fuzzification

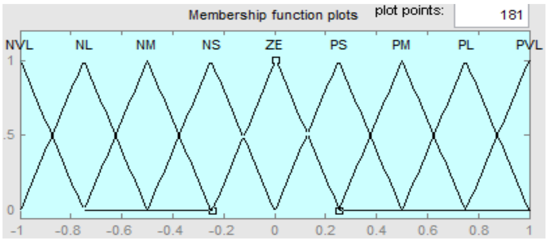
In this stage, the crisp variables eω(k) and ceω(k) are converted in to fuzzy variables and respectively. The membership functions associated to the control variables [9] have been chosen with triangular shapes as shown in Fig. 6.

The universe of discourse of all the input and output variables are established as (-1,1). The suitable scaling factors are chosen to bring the input variables to this universe of discourse. The universe of discourse is divided into seven overlapping fuzzy sets: NL (Negative Large), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (positive Medium), and PL (Positive Large) and the output variables to this universe of discourse is divided into nine overlapping fuzzy sets with an addition of NVL (Negative Very Large) and PVL (Positive Very Large) to the input variables. Each fuzzy variable is a member of the subsets with a degree of membership varying between 0 (nonmember) and 1 (full member).



(a) Speed error

(b) Change of Speed error



(c) Change of Command current

Fig.6 Membership function for fuzzy speed control

C. Knowledge base and Inference Stage

Knowledge base involves defining the rules represented as IF-THEN statements governing the relationship between input and output variables in terms of membership functions. In this stage, the variables eω and ceω are processed by an inference engine that executes 49 rules which is shown in Table.1. These rules are established using the knowledge of the system behavior and the experience of the control engineers. For illustration purpose the each rule is expressed in th followingway: IF (eω) is Negative Large AND (ceω) is Positive Large) THEN (ci_{qs}^*) is zero (ZE). Different inference engines can be used to produce the fuzzy set values for the output fuzzy variableci_{qs}^*. In this paper, the Maxproduct inference method is used [4-5].

Table 1 Rule Matrix for Fuzzy Speed Control

eω ceω	NL	NM	NS	ZE	PS	PM	PL
NL	NVL	NVL	NVL	NL	NM	NS	ZE
NM	NVL	NVL	NL	NM	NS	ZE	PS
NS	NVL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PVL
PM	NS	ZE	PS	PM	PL	PVL	PVL
PL	ZE	PS	PM	PL	PVL	PVL	PVL

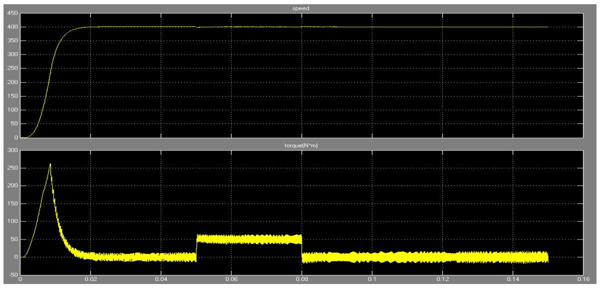
D. Defuzzification

In this stage a crisp value of the output variable $ci_{qs}^*(k)$ is obtained by using height defuzzufication method, in which the centroid of each output membership function for each rule is first evaluated. The final output is then calculated as the average of the individual centroid, weighted by their heights (degree of membership) as follows:

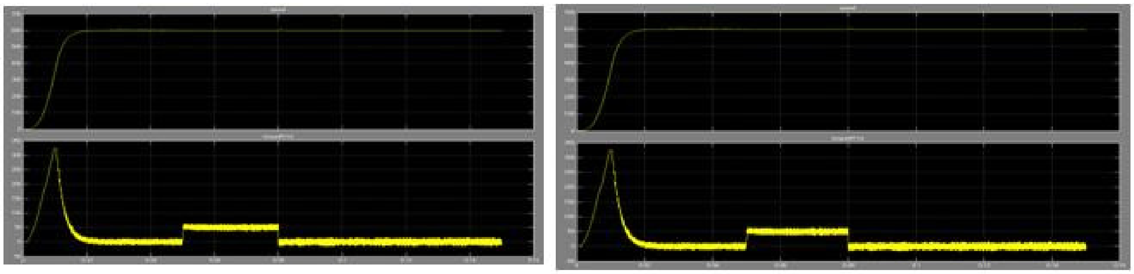
$$ci_{qs}^*(k) = \frac{\sum_{i=0}^{n} \mu[(ci_{qs}^*)_i](ci_{qs}^*)_i}{\sum_{i=1}^{n} \mu[(ci_{qs}^*)_i} \qquad \ldots (14)$$

The reference value of command current $i_{qs}^*(k)$ that is applied to vector control system is computed by the equation (14).

E. SIMULATION RESULTS



(a) Speed and Torque response at 400 rpm (at load disturbance torque is 50-Nm)



(b) Speed and Torque response at 600 rpm (at load disturbance torque is 50-Nm)

(c) Speed and Torque response at 1000 rpm (at load disturbance torque is 50-Nm)

Fig.7 FLC controller: Load Torque Disturbance

Fig. 7 is carried out to examine the disturbance rejection of a controller, when the machine is operated at 400rpm, 600rpm and 1000rpm and same load disturbance torque (50-Nm) is suddenly applied, at 0.05 s and then at 0.08s. It returns the speed to the command speed within 0.002 s with a maximum drop of 2rpm for 400rpm, 1rpm for 600rpm and 4rpm for 1000 rpm respectively. So, the proposed method of Fuzzy logic controller rejects the load disturbance very quickly with no overshoot and with a negligible Steady state error which is shown in Fig's.9 (a), (b) and (c). So, this proves the robustness of the FLC controller.

V. CONCLUSION

The performance of Fuzzy logic based intelligent controller for the speed control of Indirect Vector Controller, Voltage Source Inverter Fed Induction Motor Drive has been verified and compared with that of conventional PI controller performance. The simulation results were obtained and it will confirm that, it is very good dynamic performance and robustness of the Fuzzy Logic Controller during the transient period and during the sudden loads. It is concluded that the proposed intelligent Fuzzy logic controller has shown superior performance than that of the parameter fixed PI controller of conventional method

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APPENDIX

Motor Rating	
Rated Power	1.5KW
Poles	4
Voltage	220/380 V
Current	6.4/3.7 A
Phase	3
Frequency	50Hz
Motor Speed	1420 rpm
Stator resistance(R_s)	4.85Ω
Rotor resistance(R_r)	3.805 Ω
Stator Inductance(L_{ls})	27.4mH
Rotor Inductance(L_{lr})	27.4mH
Mutual Inductance(L_m)	25.8mH
Inertial mass(J)	0.031 Kg.m^2
Coefficient of dashpot(B)	0.00114Kg.m^2/s

Notations:

d^e-q^e	Synchronously rotating reference frame (or rotating frame) direct and quadrature axes
d^s-q^s	Stationary reference frame direct and quadrature axes (also known as α-β axes
i_{dr}^s	d^s-axis rotor current (Ampere)
i_{ds}^s	d^s -axis stator current
i_{qr}	q^e-axis rotor current
i_{qs}	q^e -axis stator current
J	Moment of inertia (Kg-m^2)
θ_e	Angle of synchronously rotating frame ()
θ_r	Rotor angle
θ_{sl}	Slip angle

L_m	Magnetizing inductance
L_r	Rotor inductance
L_{lr}	Rotor leakage inductance
L_{ls}	Stator leakage inductance
P	Number of poles (also active power)
R_r	Rotor resistance (Ohm)
R_s	Stator resistance
T_e	Developed torque (Nm)
ψ_r	Rotor flux linkage
ψ_{dr}^{s}	d^s -axis rotor flux linkage
ψ_{ds}^{s}	d^s -axis stator flux linkage
ψ_{qr}	q^e -axis rotor flux linkage
ψ_{qs}	q^e -axis stator flux linkage
ω_r	Rotor electrical speed
ω_{sl}	Slip frequency
K_P	Proportional gain
K_I	Integral gain
$\Delta\omega_r$	Change in Rotor electrical speed