International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 8, August - 2014

Modeling and Simulation of Indirect Field Oriented Control of Three Phase Induction Motor using Fuzzy Logic Controller

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***Abstract*—Indirect field oriented induction motor drives are rapidly increasing in the industrial sector, but the performance of the drive decreases by the change in the motor parameters. This paper presents the modelling and simulation of indirect field oriented control of induction motor drives. This scheme is explained using field orientation control principle of induction motor drive fed through inverter. The fuzzy logic controller for speed control is used in the outer loop of the induction motor drive so that the machine will follow a reference model. To verify the design of the proposed controller, the simulation is carried out in the Matlab/Simulink platform. The simulation results are presented to demonstrate the effectiveness of the proposed fuzzy logic controller.**

***Keywords-Induction motor; Fuzzy logic control; indirect vector control*.**

I. INTRODUCTION

Over the years electric drives have emerged, and so their techniques to control their speed, torque and efficiency. It is advantageous to use AC motors as compared to DC motors as AC motors are cheaper and have simple mechanical structure. With the number of growing techniques such as vector control or field oriented control, the complicated control issues of the adjustable speed drive applications of the induction motor are solved. The controller design of the system plays a very important role in the performance of the system. However, it is difficult to develop a mathematical model for unknown load variations and parameter variations due to variations in temperature, saturation effects and the disturbances in the system

The vector control technique is used for high performance control of speed and torque. The performance of this method is the same as the performance is obtained from the separately excited dc motor. The vector control technique provides a decoupling control of the rotor flux and the torque producing component with a fast torque response.

In order to overcome the problem discussed above, a fuzzy logic controller is used for the control purpose. With a comparison with PI, PID and other adaptive control systems, the FLC has various advantages as (1) there is no need of the exact system mathematical model (2) it handles the nonlinearity and the complexity of the system (3) it is based on the linguistic rules with an IF-THEN general structure, which uses the human experience and logic. However the fuzzy logic has some disadvantages also as it includes high computations, so there is a high computation burden

II. PRINCIPLE OF VECTOR CONTROL OR FIELD ORIENTED CONTROL

A renaissance in the high performance of induction motors has been brought by the demonstration that the induction motor can be controlled as a separately excited DC motor. The field oriented control has become very popular, as it guarantees high dynamic and static performance. FOC is based on the idea of decoupling torque and flux via nonlinear coordinate transformation and controlling these variables by acting on the direct and quadrature current vector components by means of unit vector ($\sin\theta_e$ and $\cos\theta_e$). FOC has two methods: (a) direct or feedback vector control and (b) indirect or feed-forward vector control. In direct FOC, unit vectors are generated by stator voltages and currents (Voltage model estimator) or by stator currents and rotor speed (Current model estimator). The drawbacks of this method are: (a) dependency on the rotor resistance value and (b) computation requirements and time delay due to the use of current control loops and axes transformation. As Field Orientated Control is simply based on projections the control structure handles instantaneous electrical quantities. This makes the control accurate in every working operation.

This paper presents a relatively simple fuzzy logic controller that is efficient in the speed tracking, rejecting the disturbances and the variation in the parameters without any need of the complex control technique which require mathematical models. This is achieved by carefully designing the linguistic rule base.

III. AXES TRANSFORMATION

The three coordinated are transformed in the in FOC system using the Clarke transformation, park transformation and inverse park transformation.

Clarke transformation is that transforms from a three-phase stationary coordinate system (a,b,c) to a two-phase stationary coordinate system (α-β). Assuming that the axis a and axis α are aligned in same direction. Clarke transformation equations are shown in equation (1). Park transformation is that transforms from a two-phase stationary coordinate system (α-β) to a two-phase rotating coordinate system (d-q). The relationship of the two-coordinate system is shown in Fig. 2 on the basis of the consideration that that the d-axis is aligned with the rotor flux. The equation for park transformation is given in equation (2).

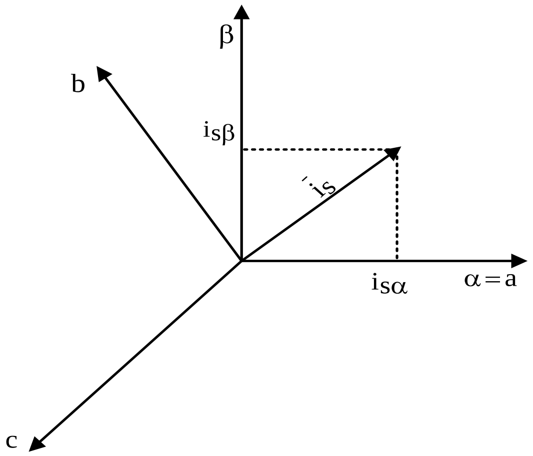


Fig. 1. Stator currents space vectors and its components in (α-β).

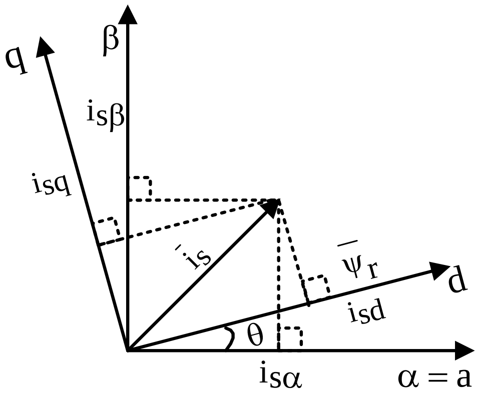


Fig. 2. Stator currents space vectors and its components in dq coordinate system.

Inverse park transformation is that which transforms a two-phase rotating coordinate system (d-q) into a two-phase stationary coordinate system (α-β). The equation for inverse park transformation is given in equation (3).

$$\begin{pmatrix} i_\alpha \\ i_\beta \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} \qquad (1)$$

$$\begin{pmatrix} i_d \\ i_q \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} i_\alpha \\ i_\beta \end{pmatrix} \qquad (2)$$

$$\begin{pmatrix} i_\alpha \\ i_\beta \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} i_d \\ i_q \end{pmatrix} \qquad (3)$$

IV. INDIRECT VECTOR CONTROL OF INDUCTION MOTOR

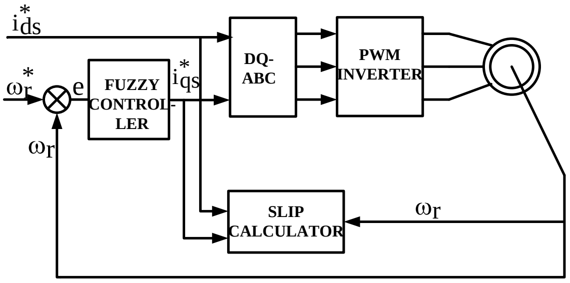


Fig 3. Block diagram of indirect vector control of induction motor drive

The indirect vector control of induction motor is the same as the direct vector control method but with a difference that the unit vectors are generated in an indirect fashion using the measured speed ω_r and the slip speed ω_{sl}. The equations for the indirect vector control are as

$$\theta_e = \int \omega_e dt = \int (\omega_r + \omega_{sl}) dt = \theta_r + \theta_{sl} \qquad (4)$$

The rotor current equations are

$$\frac{d\psi_{dr}}{dt} + \frac{R_r}{L_r}\psi_{dr} - \frac{L_m}{L_r} R_r i_{ds} - \omega_{sl}\psi_{qr} = 0 \qquad (5)$$

$$\frac{d\psi_{qr}}{dt} + \frac{R_r}{L_r}\psi_{qr} - \frac{L_m}{L_r} R_r i_{qs} - \omega_{sl}\psi_{dr} = 0 \qquad (6)$$

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

Substituting this condition in equations (5) and (6), we get

$$\frac{L_r}{R_r}\frac{d\psi_r}{dt} + \psi_r = L_m i_{ds} \qquad (7)$$

the slip frequency can be calculated as

$$\omega_{sl} = \frac{L_m R_r}{\psi_r L_r} i_{qs} \qquad (8)$$

For constant rotor flux ψ_r and $\frac{d\psi_{qr}}{dt} = 0$, substituting in equation (7) yields

$$\psi_r = L_m i_{ds} \qquad (9)$$

The electromechanical torque equation is given by

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\frac{L_m}{L_r}\psi_r i_{qs} \qquad (10)$$

The block diagram of the indirect vector control scheme is shown in Fig. 3.

V. FUZZY LOGIC CONTROLLER DESIGN FOR INDUCTION MOTOR

From the knowledge generated over the fuzzy logic controllers, we have come to know that the fuzzy logic is the efficient way. In designing the controller, non linearities with the individual's with the individual's experience and expert knowledge about the process to be controlled. This approach enhances the performance, reliability and robustness of the system more than the conventional linear controllers.

The block diagram of fuzzy logic controller is shown in the Fig. 4. There are two inputs to the controller. The first input is the error 'e' and the second input is the change in error 'Δe'. The calculation of error and change in error is shown as

$$e(t_s) = \omega_r^*(t_s) - \omega_r(t_s) \qquad (11)$$

$$\Delta e(t_s) = e(t_s) - e(t_s - 1) \qquad (12)$$

where, $\omega_r^*(t_s)$ is the reference speed of the rotor and $e(t_s - 1)$ is the value of the error at one sample before. The output of the fuzzy controller is the change in torque (ΔT) which is then integrated to get the reference torque value, the equation is as

$$T^*(t_s) = T^*(t_s - 1) + \Delta T \qquad (13)$$

The fuzzy controller mainly consists of four blocks as fuzzification, inference mechanism, knowledge base and defuzzification.

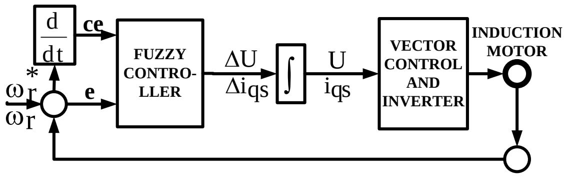


Fig. 4. Functional block diagram of Fuzzy Logic Controller

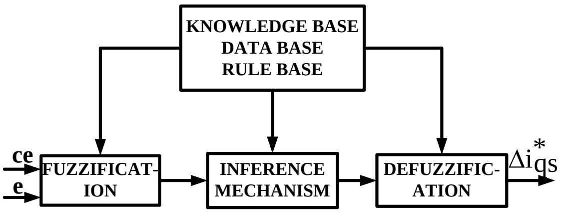
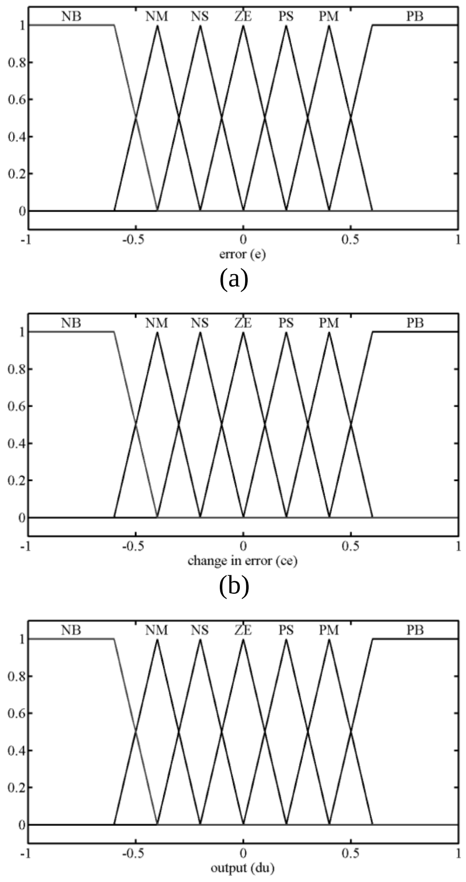


Fig. 5. Internal structure Fuzzy Logic Controller



(a)

(b)

(c)

Fig. 6. Membership Functions; (a) for error; (b) for change in error; (c) output

A. *Fuzzification*

In the process of fuzzification the crisp input variables $e(t_s)$ and $\Delta e(t_s)$ are converted into fuzzy variables with a degree of certainty given by the membership functions associated. The membership functions are of triangular shape, and have two inputs and one output. The linguistic labels of the proposed controller are NB, NM, NS, ZE, PS, PM, PB. All the inputs and output membership functions contains all these seven linguistics.

B. *Knowledge base and inference mechanism*

Knowledge base includes defining the rules represented by IF-THEN general structures which governs the relationship between the input and output variables. The inference engine, which is based upon the input fuzzy sets, uses the IF-THEN rules in the knowledge base to make the decisions. tn this the mamdani's algorithm is used for inference engine.

C. *Defuzzification*

The output of the inference engine produces the output for the fuzzy set. This stage includes various methods that are used for producing the fuzzy set value for the output fuzzy variable ΔT.

The method of defuzzification used in this is the centroid or centre of gravity to calculate the final fuzzy value. In this the crisp output variable ΔT is taken to be the geometric centre for the output fuzzy variable. The discretised universe of discourse is given by

$$\Delta T = \frac{\sum_{i=1}^{n} \Delta T_i \cdot \mu_{out}(T_i)}{\sum_{i=1}^{n} \mu_{out}(\Delta T_i)} \qquad (14)$$

TABLE I. RULE BASE FOR FLC BASED INDUCTION MOTOR DRIVE.

e	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
ce							
NB	NB	NM	NM	NS	NS	NS	ZE
NM	NM	NM	NS	NS	NS	ZE	PS
NS	NM	NM	NS	NS	ZE	PS	PM
ZE	NS	NM	NS	ZE	PS	PM	PM
PS	NS	NS	ZE	PS	PS	PM	PM
PM	NS	ZE	PS	PS	PS	PM	PM
PB	ZE	PS	PS	PM	PM	PB	PB

The reference electromagnetic torque T_e^* can be obtained by integrating the above equation and is further used to calculate i_{qs}^*. The membership functions which are defined for the input and output variables are shown in Fig. 6. The rule base of the control technique is given in Table 1.

VI. SIMULATION RESULTS

The simulation results are shown for the fuzzy logic controller based induction motor drive. The waveforms shown for the indirect vector control method based induction motor drive are the rotor speed, N_r and reference rotor speed, N_r^*. Stator currents I_{abc}, stator line voltage V_{ab}, electromagnetic torque T_e and load torque T_l. The reference speed is taken out to be 70 rad/sec. The rotor speed of the proposed fuzzy logic control based indirect vector control comes out to be almost smooth and no overshoot. The waveforms are shown on load and the reference speed is achieved in a very less time period with a very less steady state error.

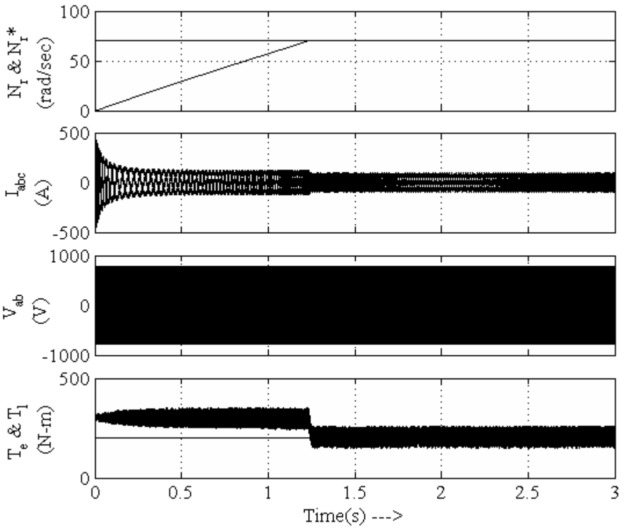


Fig. 7. Waveforms for the indirect vector control of induction motor using fuzzy logic controller

VII. CONCLUSION

Based on the study of indirect field oriented control of three phase induction motor a simulation model using Matlab/Simulink software package has been established. The simulation results show that the simulink model smoothly works over the fuzzy logic controller and has proper static and dynamic characteristics under normal working condition. The fuzzy logic controller proves to be more robust as compared with other conventional control techniques. The experimental results have shown the correctness and feasibility of control of the induction motors using fuzzy logic controller.

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