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Direct Vector Control of Induction Motor Based on Sinusoidal PWM Inverter with Fuzzy Logic Controller

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ABSTRACT
This paper presents the speed control scheme of direct vector control of Induction Motor drive (IM drive). The Fuzzy logic controller is (FLC) used as the controller part here for the direct vector control of Induction Motor using Sinusoidal PWM Inverter (SPWM). Fuzzy logic controller has become a very popular controlling scheme in the field of Industrial application. The entire module of this IM is divided into several parts such as IM body module, Inverter module, coordinate transformation module and Sinusoidal pulse width modulation (SPWM) production module and so on. With the help of this module we can analyze a variety of different simulation waveforms, which provide an effective means for the analysis and design of the IM control system using FLC technique.
***Keywords* –** IM drive system, Mathematical model of IM drive, Vector control, Fuzzy Logic speed Controller

I. INTRODUCTION

Among all types of ac machine, the Induction machine (IM), particularly the cage type, is most commonly used in industry. These machines are very economical, rugged and reliable and available in the ranges of fractional horse power (FHP) to multi-megawatt capacity. Low-power FHP machines are available in single-phase, but poly-phase (three-phase) machines are used most often in variable-speed drives. In vector control the IM can be controlled like a separately excited dc motor, brought a renaissance in the high-performance control of ac drives. . In vector control the Magnetic field can be decoupled to get a good control performance, hence the torque and flux can be controlled independently [5]. Based on the nature of fuzzy human thinking, Lofti Zadeh, a computer scientist at the University of California, originated the “fuzzy logic,” or fuzzy set theory, in 1965. In the last decade many closed loop speed control techniques have been developed to provide good performance. However, the desired drive specification still cannot be perfectly satisfied and/or their algorithms are too complex. After the invention of the fuzzy logic approach, it found application in many domains of control problem. [2] The main advantage of fuzzy logic control method as compared to conventional control techniques reside in fact that no mathematical modeling is required for controller design [1] and also it does not suffer from the stability problem. It requires skill to create the rules in a particular FL controller. In motion control, fuzzy logic can be considered as an alternative approach to conventional feedback control. Fuzzy logic is a non-linear control and it allows the design of optimized non linear controllers to improve the dynamic performance of the conventional regulators. By using FLC in this paper the output waveforms of different variables has better response compare to the conventional control techniques. Here, paper FLC is used for speed control loop. Here we used three triangular and two trapezoidal membership functions with overlap for speed error and similarly five for change in speed error. Therefore 25 rules are used to design the FUZZY logic controller.

II. IM DRIVE SYSTEM

Here we present the general block diagram model of the vector control of IM drive using fuzzy logic controller shown in the Fig 1. The block diagram consist of Fuzzy logic controller part, Inverse Park transformation, SPWM Generator block, Inverter block, IM motor block. The reference speed (Wr*) is compared with the Induction motor rotor speed (Wr) and then the error is passed through the fuzzy logic controller block. The output of this speed controller generates the q axis current Iq*, which is the torque producing component. The Id* current is flux producing component. This two current is converted to the Iabc * current by Inverse PARK transformation. Then this current is compared with the actual Iabc current of the motor to generate the pulse for the SPWM Inverter, which gives the supply for the IM drive. Thus we obtained the speed response for the IM drive.

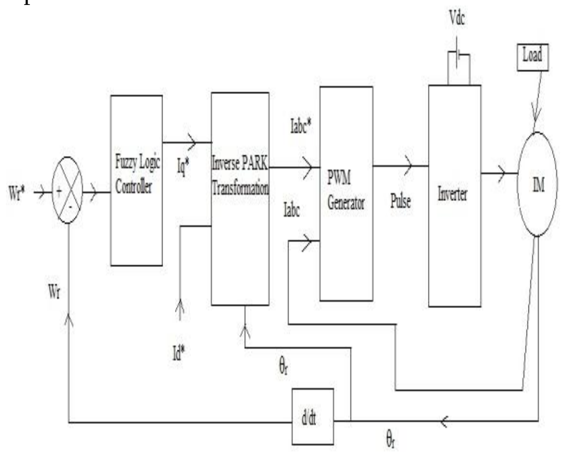

Fig 1: Vector Control IM using Fuzzy Logic Technique

III. MATHEMATICAL MODELING OF INDUCTION MOTOR

The mathematical model of an IM [6] in terms of phase voltages for stator and rotor can be written as:

For stator:

$$v_{abcs} = r_s i_{abcs} + p\lambda_{abcs} \quad (1)$$

For rotor:

$$v_{abcr} = r_r i_{abcr} + p\lambda_{abcr} \quad (2)$$

The flux linkage can be written as in matrix from:

$$\begin{bmatrix} \lambda_{abcs} \\ \lambda_{abcr} \end{bmatrix} = \begin{bmatrix} L_{ss} & L_{sr} \\ L_{rs} & L_{rr} \end{bmatrix} \begin{bmatrix} i_{abcs} \\ i_{abcr} \end{bmatrix} \quad (3)$$

The flux linkage equations are:

$$\lambda_{abcs} = L_{ss} i_{abcs} + L_{sr} i_{abcr} \quad (4)$$

$$\lambda_{abcr} = L_{rs} i_{abcs} + L_{rr} i_{abcr} \quad (5)$$

Where,

$$L_{ss} = \begin{bmatrix} l_{ls} + l_{ms} & -½l_{ms} & -½l_{ms} \\ -½l_{ms} & l_{ls} + l_{ms} & -½l_{ms} \\ -½l_{ms} & -½l_{ms} & l_{ls} + l_{ms} \end{bmatrix} \quad (6)$$

L_{sr} =

$$L_{sr} \begin{bmatrix} \cos\theta_r & \cos(\theta_r + 120°) & \cos(\theta_r - 120°) \\ \cos(\theta_r - 120°) & \cos\theta_r & \cos(\theta_r + 120°) \\ \cos(\theta_r + 120°) & \cos(\theta_r - 120°) & \cos\theta_r \end{bmatrix}$$

(7)

L_{rs} =

$$L_{rs} \begin{bmatrix} \cos\theta_r & \cos(\theta_r - 120°) & \cos(\theta_r + 120°) \\ \cos(\theta_r + 120°) & \cos\theta_r & \cos(\theta_r - 120°) \\ \cos(\theta_r - 120°) & \cos(\theta_r + 120°) & \cos\theta_r \end{bmatrix}$$

(8)

$$L_{rr} = \begin{bmatrix} l_{lr} + l_{mr} & -½l_{mr} & -½l_{mr} \\ -½l_{mr} & l_{lr} + l_{mr} & -½l_{mr} \\ -½l_{mr} & -½l_{mr} & l_{lr} + l_{mr} \end{bmatrix} \quad (9)$$

Now applying the transformations (1) and (5) to voltages, flux linkages and currents in the equations (6), (7), (9) and (10) we get a set of simple transformed equations as:

The voltage equation in q-d reference frame:

$$v_{qs} = r_s i_{qs} + p\lambda_{qs} + \omega\lambda_{ds} \quad (10)$$

$$v_{ds} = r_s i_{ds} + p\lambda_{ds} - \omega\lambda_{qs} \quad (11)$$

$$v_{qr} = r_r i_{qr} + p\lambda_{qr} + (\omega - \omega_r)\lambda_{dr} \quad (12)$$

$$v_{dr} = r_r i_{dr} + p\lambda_{dr} - (\omega - \omega_r)\lambda_{qr} \quad (13)$$

The flux linkage equation in q-d reference frame:

$$\lambda_{qs} = (l_{ls} + L_M)i_{qs} + L_M i_{qr} \quad (14)$$

$$\lambda_{ds} = (l_{ls} + L_M)i_{ds} + L_M i_{dr} \quad (15)$$

$$\lambda_{qr} = L_M i_{qs} + (l_{lr} + L_M)i_{qr} \quad (16)$$

$$\lambda_{dr} = L_M i_{ds} + (l_{lr} + L_M)i_{dr} \quad (17)$$

Here, l_{ls} and L_M are leakage and mutual inductance respectively. ω is the synchronous speed and ω_r is the speed of the rotor.

The electromagnetic torque (T_e) for rotor current can be written as:

$$T_e = (3/2)(P/2)(\lambda_{dm} i_{qr} - \lambda_{dm} i_{dr}) \quad (18)$$

The electromagnetic torque (T_e) for stator current can be written as:

$$T_e = (3/2)(P/2)(\lambda_{dm} i_{qs} - \lambda_{dm} i_{ds}) \quad (19)$$

The equation for motor dynamics is:

$$T_e = Jp\omega_r + B\omega_r + T_l \quad (20)$$

IV. VECTOR CONTROL

Vector control is also known as decoupling or field orientated control. Vector control decouples three -phase stator current into two phase d-q axis current, one producing flux and other producing torque [9]. This allows direct control of flux and torque. In case of vector control of an IM drives operates similarly like a separately excited dc motor drive. In a dc machine, neglecting the armature reaction effect and field saturation, the developed torque is given by

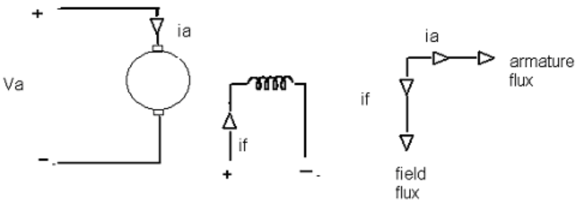

Fig.2. Dc motor model

$$T_e = K_t I_a I_f \quad (21)$$

Where I_a = armature current and I_f = field current. The construction of a dc machine is such that the field flux φ_f produced by the current I_f is perpendicular to the armature flux φ_a , which is produced by the armature current I_a [6]. These space vectors, which are stationary in space, are orthogonal or decoupled in nature. So in case of an IM the phase currents are decoupled in q-d reference frame for vector controlling. The dc motor model is shown in the Fig.2. [8].

When three-phase voltages are applied to the machine, they produced three-phase fluxes both in the stator and the rotor. The three-phase fluxes can be represented in a two-phase stationary $(\alpha - \beta)$ frame. If these two phase fluxes along $(\alpha - \beta)$ axes are represented by a single-vector then all the machine flux will be aligned along that vector. This vector is commonly specified as d-axis which makes an angle with the stationary frame α-axis, as shown in the fig. 3. The q-axis is set perpendicular to the d-axis. The flux along the q-axis in case will obviously zero. The phasor diagram Fig.3 presents these axes. When the machine input current change sinusoidally in time, the angle keeps changing. Thus the problem is to know the angle accurately, so that the d-axis of d-q frame is locked with the flux vector.

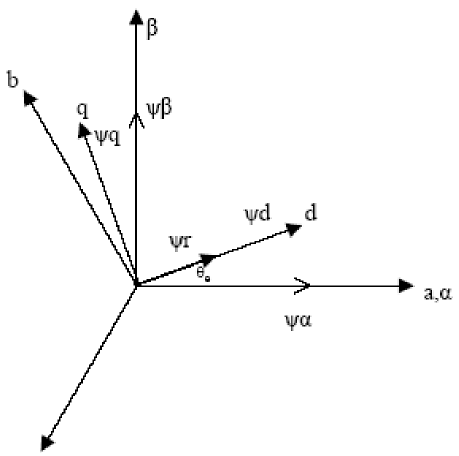

Fig.3. Phasor diagram of a field orientated system

The controller part of the vector control of IM is inverse transformed from q-d reference frame to α-β reference frame and then to the stationary phase voltage frame which is then given through a inverter to the machine model part.

V. FUZZY LOGIC CONTROLLER

Here the Fuzzy Logic Controller is used to control the speed of the IM drive. In FLC the input-output variables plays a very important role in controlling. In FLC we use two input variables one is speed error and another is change of speed error, shown in Fig .4 [7]. The speed error is the difference between the reference speed and IM rotor actual speed, the change of speed error is its time derivative. The output of the FLC controller is used to change the command of the q-axis current component Iq*, which is the torque producing component. The speed error and change of speed error can be written as:

$$e(k) = \omega_r * (k) - \omega_r(k) \quad (22)$$
$$ce(k) = e(k) - e(k-1) \quad (23)$$

Where, “e” denotes the speed error and “ce” denotes the change of speed error. $\omega_r * (k)$ Is the reference speed and $\omega_r(k)$ is the actual rotor speed of the IM drive. $e(k-1)$ is the value of error at a previous sampling time. The actual value of FLC output is given by:

$$i_q{*}(k) = i_q * (k-1) + \Delta i_q * (k) \quad (24)$$

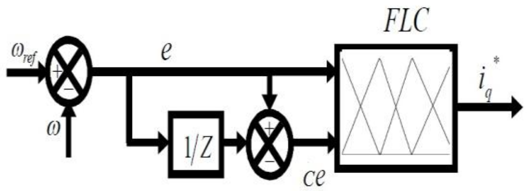

Fig.4. Schematic model of FUZZY logic controller

The standard structure of FUZZY logic controller is shown in the Fig.5. Fuzzy logic controller has three blocks:

1. Fuzzification, 2. FUZZY Inference system, 3. Defuzzification

Fuzzification is the control process of converting the crisp (real number) [4] variables of the inputs $e(k)$ and $ce(k)$ are converted into fuzzy variables that can be identified by the level of membership in the fuzzy set.

In **FUZZY Inference system,** consists three main component i.e. rule base, data base, reasoning mechanism. It is a knowledge base involves defining the rules represented as IF-THEN [3] rules statements governing the relationship between inputs and output variables in terms of membership functions. In this stage the input variables $e(k)$ and $ce(k)$ are processed by the inference engine that executes 5*5= 25 rules for designing the inference system. Inference stage includes also application of fuzzy operator (AND, OR), implication and aggregation.

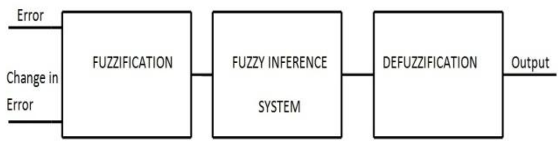

Fig.5. Block Diagram model of Fuzzy Logic Controller

The linguistic variables are defined as {NB, NS, ZE, PS, PB} meaning negative big, negative small, zero, positive small and positive big. The FUZZY rules are summarized in Table I. The type of FUZZY interface engine is MAMDANI.

Table I

ce \ e	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NS	ZE
NS	NB	NB	NS	ZE	PS
ZE	NB	NS	ZE	PS	PB
PS	NS	ZE	PS	PB	PB
PB	ZE	PS	PB	PB	PB

In **Defuzzification** stage introduces different [3] inference methods that can be used to transform the fuzzy set variables (Fuzzy Number) to the crisp output (real number).

VI. SIMULATION RESULT

Here for the simulation of the proposed vector control of IM drive using FLC technique for the speed control of the IM rotor speed different kinds of machine parameters are used. The list of these machine parameters is given below in the Table II.

Table II

Name	Symbol	Value
Stator Resistance	Rs	6.03 Ω
Rotor Resistance	Rr	6.085 Ω
Stator Inductance	Ls	489.3e-3 H
Rotor Inductance	Lr	489.3e-3 H
Mutual Inductance	Lm	450.3e-3 H
Poles	P	4
Inertia	J	0.00488 kg- m^2
Base Speed	Wr	200 rpm
Magnetic flux density	Bm	0.004Wb/m^2
Flux Linkage	Pm	0.1 wb
Inverter Voltage	Vdc	440 volt DC

Now the different waveforms of this proposed model is given below:

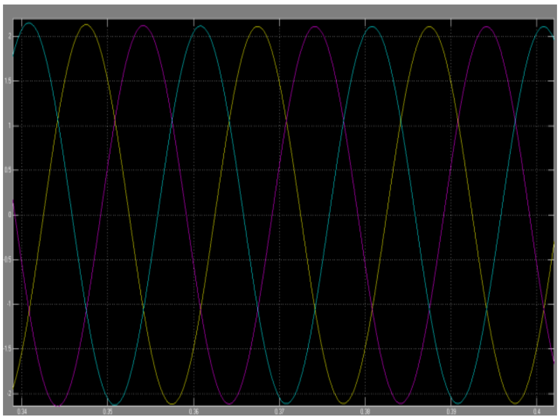

Fig.6. Iabc current waveform response

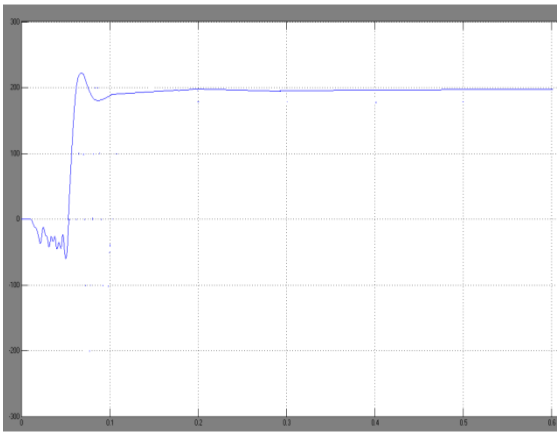

Fig.7. Speed waveform response

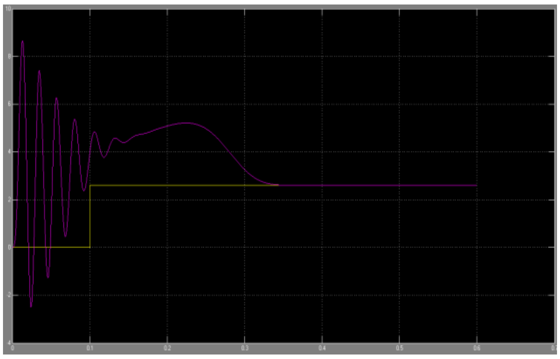

Fig.8. Electromagnetic torque response

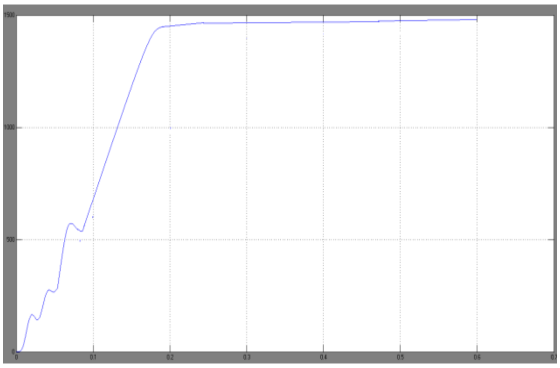

Fig.9. Synchronous speed waveform response

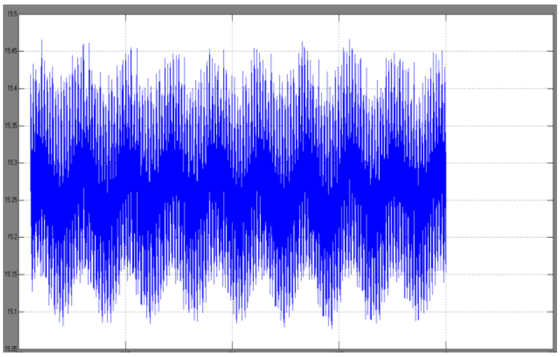

Fig.10. Iqs current waveform

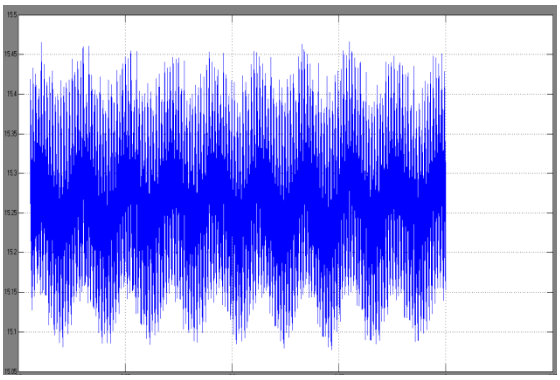

Fig.11. Ids current waveform

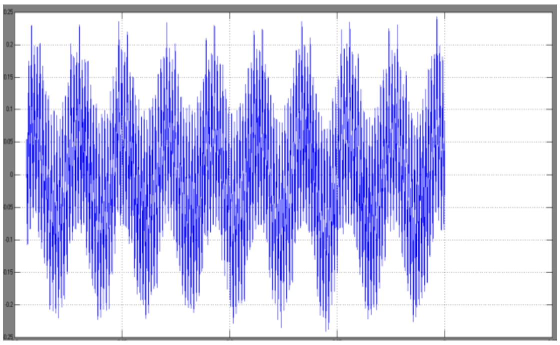

Fig.12. Iqr current waveform

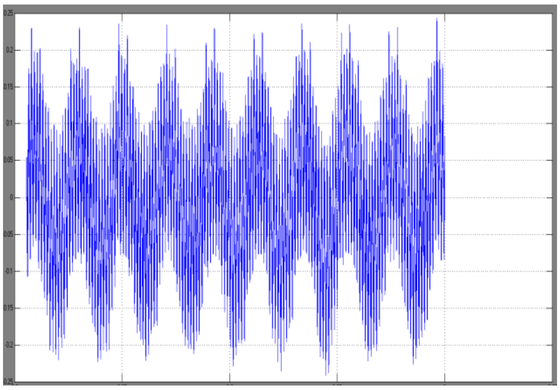

Fig.13. Idr current waveform

VII. CONCLUSION

Here we present the direct vector control of IM drive using Fuzzy logic controller and from the discussion throughout this paper about the controller we see that the FLC is much faster and smoother compare to the other conventional controller. From the simulation result we see that the waveform of the different machine parameters is quite satisfactory. The speed response gives the desired value which we set as the reference value. Also the response of the different curve becomes faster and accurate. Here we set the simulation time-0.6s and the step time for the step load as-0.1s.

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