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COMPARISON OF PI AND FUZZY BASED CONTROLLERS OF VECTOR CONTROLLED INDUCTION MOTOR DRIVE

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Abstract

This paper presents an intelligent speed controller for Indirect vector controlled induction motor drive. Because of the low maintenance and robustness induction motors have many applications in the industries. Vector controlled induction motor drives with variable speed applications are widely used in order to achieve good dynamic performance and wide speed control. The fuzzy logic controller is implemented using the Field Oriented Control technique as it provides better control of motor torque with high dynamic performance. Based on settling time and dynamic response the performance of Fuzzy logic controller is compared with that of conventional PI controller to sudden load changes and the results conclude that the proposed Fuzzy based controller showed increased dynamic performance. Conventional–PI Controller and Fuzzy logic Controller are implemented using MATLAB/Simulink

Keywords ***:*** Induction Motor, Field Oriented Control, Modeling of induction motor, PI Controller, Fuzzy logic controller.

1. INTRODUCTION

AC Induction motors are being applied today to a wider range of applications requiring variable speed. Generally, variable speed drives for Induction Motor (IM) require both wide operating range of speed and fast torque response, regardless of load variations. This leads to more advanced control methods to meet the real demand. The conventional control methods have the following difficulties

1. It depends on the accuracy of the mathematical model of the systems
2. The expected performance is not met due to the load disturbance, motor saturation and thermal variations
3. Classical linear control shows good performance only at one operating speed
4. The coefficients must be chosen properly for acceptable results, whereas choosing the proper coefficient with varying parameters like set point is very difficult

To implement conventional control, the model of the controlled system must be known. The usual method of computation of mathematical model of a system is difficult. When there are system parameter variations or environmental disturbance, the behavior of the system is not satisfactory. Usually classical control is used in electrical motor drives. The classical controller designed for high performance increases the complexity of the design and hence the cost. Advanced control based on artificial intelligence technique is called intelligent control. Intelligent control, act better than conventional adaptive controls. Fuzzy logic is a technique to embody human-like thinking into a control system. A fuzzy controller can be designed to emulate human deductive thinking, that is, the process people use to infer conclusions from what they know. Fuzzy control has been primarily applied to the control of processes through fuzzy linguistic descriptions. Fuzzy control system consists of four blocks as shown in Fig. 1.

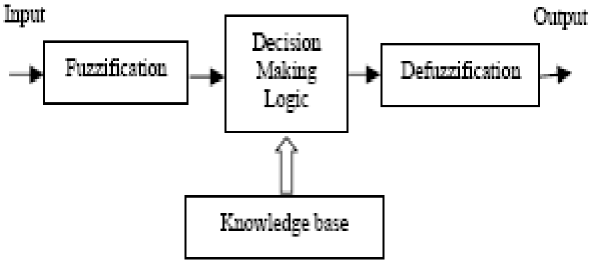


Fig. 1 Fuzzy Control System

In this paper, conventional method, a PI controller is used for processing the speed error between reference speed and speed feedback signals. PI controller is replaced with Fuzzy Logic Controller and the dynamic response of vector controlled induction motor with the proposed controllers is compared. The basic concept of Mathematical Modeling of the induction motor is in Section 2. Field oriented control of induction is in section 3. A brief description of controllers is in Section 4. In section 4, the fuzzy based controller is proposed. Simulation results are shown in Section 5. Finally, the paper is concluded in Section 6.

2. INDUCTION MOTOR MODELING

An Induction Motor of uniform air gap, with sinusoidal distribution of mmf is considered as shown in Fig.2. The saturation effect and parameter changes are neglected. The dynamic model [2] of the induction motor is derived by transforming the three phase quantitiesinto two phase direct and quadrature axes quantities. The equivalence between the three-phase and two-phase machine models [1] is derived from the concept of power invariance: the power must be equal in the three phase machine and its equivalent two-phase model. The d and q axes mmfs are found by resolving the mmfs of the three phases along the d and q axes. The mathematical model of the 3-phase IM could be represented by an equivalent 2-phase, where d^s, q^s, d^r *and* q^r correspond to the stator, rotor, direct and quadrature axes, respectively. The stator voltage equations formulated from stationary reference frame and the rotor voltage equations formulated to the rotating frame fixed to the rotor.

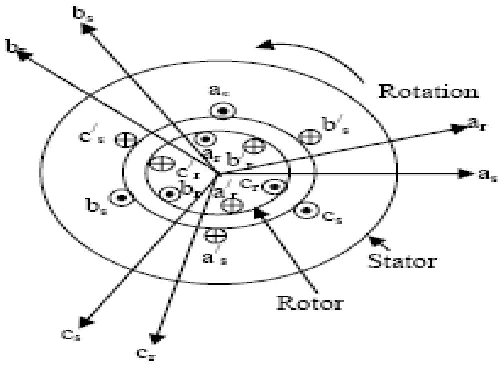


Fig.2. Mmf distribution in Induction Motor

The 3-phase stator and rotor voltage equations written in vector-matrix can be further transformed into 2-phase stator and rotor voltage equations using the well-known Park's transformation. The 3-phase stationary reference frame variables *as-bs-cs* are transformed into 2-phase stationary reference frame variables (d^s–q^s). Furthermore, these 2-phase variables are transformed into synchronously rotating reference frame variables (d^e–q^e) and vice-versa.

The stator circuit equations can be modeled as follows:

$$v^s{}_{qs} = R_s i^s{}_{qs} + \frac{d}{dt}\psi^s{}_{qs}$$

-------- (2.1)

$$v^s{}_{qs} = R_s i^s{}_{ds} + \frac{d}{dt}\psi^s{}_{qs}$$

-------- (2.2)

Equations (2.1) and (2.2) are further converted into d^e– q^e frame. The flux linkage expressions in terms of the currents can be written as

$$\psi_{qs} = L_{ls} i_{qs} + L_m (i_{qs} + i_{qr})$$

-------- (2.3)

$$\psi_{qr} = L_{lr} i_{qr} + L_m (i_{qs} + i_{qr})$$

-------- (2.4)

$$\psi_{qm} = L_m (i_{qs} + i_{qr})$$

-------- (2.5)

$$\psi_{ds} = L_{ls} i_{ds} + L_m (i_{ds} + i_{dr})$$

------- (2.6)

$$\psi_{dr} = L_{lr} i_{dr} + L_m (i_{ds} + i_{dr})$$

-------- (2.7)

$$\psi_{dm} = L_m (i_{ds} + i_{dr})$$

------- (2.8)

Using above equations in voltage equations, the electrical transient model of the IM in terms of *v* and *i* is given in matrix form. The development of torque is also very important in the modeling of IMs. The speed ωr cannot be treated as a constant and is related to the torques as

$$T_e = T_L + j\frac{d}{dt}\omega_m = T_L + \frac{2}{P}J\frac{d\omega_r}{dt}$$

------- (2.9)

where T_L is the load torque, J is the rotor inertia and ωm is the mechanical speed of the IM. Resolving the variables into *de–qe* components, we obtain

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\left(\Psi_{dr} i_{qr} - \Psi_{qr} i_{dr}\right)$$

------- (2.10)

The dynamic machine model in stationary frame can be derived simply by substituting $\omega e = 0$. The corresponding stationary frame equations are given as follows:

$$v^s{}_{qs} R_s i^s{}_{qs} + \frac{d}{dt}\Psi^s{}_{qs}$$

------- (2.11)

$$v^s{}_{ds} R_s i^s{}_{ds} + \frac{d}{dt}\Psi^s{}_{ds}$$

------- (2.12)

$$0 = R_r i^s{}_{qr} + \frac{d}{dt}\Psi^s{}_{qr} - \omega_r \Psi^s{}_{dr}$$

------- (2.13)

$$0 = R_r i^s{}_{dr} + \frac{d}{dt}\Psi^s{}_{dr} - \omega_r \Psi^s{}_{qr}$$

------- (2.14)

The torque Equations can also be written with the corresponding variables in the stationary frame as follows:

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\left(\Psi^s{}_{dr} i^s{}_{qr} - \Psi^s{}_{qr} i^s{}_{dr}\right)$$

------- (2.15)

The equations(1) and (15) form the mathematical model equations of a three phase induction motor.

3. VECTOR CONTROL OR FIELD ORIENTED CONTROL (FOC)

The Vector Control or Field Oriented Control is used to control Induction motor like a dc motor. Using vector control strategy, the torque and flux components can be controlled independently like dc motor. The basic principles of vector control can be explained with the help of dynamic model of induction motor where we need to convert 3Φ quantities into 2-axes system by 3Φ/2Φ transformation called d-q machine model. There are two methods of vector control, Direct Vector Control method & Indirect Vector Control (IFOC) method. In indirect vector control strategy rotor flux vector is estimated using the field oriented control equations requiring a rotor speed measurement. Due its implementation simplicity, Indirect Vector Control method is more popular than Direct Vector Control in industrial applications.

3.1 INDIRECT FIELD ORIENTED CONTROL (IFOC)

In the Indirect Vector Control method, by using summation of rotor speed and slip frequency, the rotor flux angle is calculated. Hence the unit vectors are obtained indirectly. Then the d-q axis currents are obtained from the torque and flux producing components of stator current.

$$\theta_e = \int \omega_e dt = \int (\omega_r + \omega_{st}) dt = \theta_r + \theta_{st} \quad \text{----- (3.1)}$$

The rotor circuit equations

$$\frac{d\psi_{dr}}{dt} + \frac{R_r}{L_r}\psi_{dr} - \frac{L_m}{L_r} R_r i_{ds} - \omega_{sl}\psi_{qr} = 0 \quad \text{----- (3.2)}$$

$$\frac{d\psi_{qr}}{dt} + \frac{R_r}{L_r}\psi_{qr} - \frac{L_m}{L_r} R_r i_{qs} - \omega_{sl}\psi_{dr} = 0 \quad \text{----- (3.3)}$$

For decoupling control Ψqr = 0 ,So the total flux Ψ r directs on the de axis. Now from equations 3.1 and 3.2, we get

$$\frac{L_r}{R_r}\frac{d\psi_{dr}}{dt} + \psi_r = \frac{L_m}{L_r} i_{ds} \quad \text{---- (3.4)}$$

As well , the slip frequency can be calculated as

$$\omega_{sl} = \frac{L_m}{\psi_r}\frac{R_r}{L_r} i_{qs} = \frac{R_r}{L_r}\frac{i_{qs}}{i_{ds}} \quad \text{---- (3.5)}$$

The slip gain is

$$K_s = \frac{\omega^{\bullet}_{sl}}{i^{\bullet}_{qs}} = \frac{L_m R_r}{L_r \psi_r} \quad \text{---- (3.6)}$$

It is found that the ideal decoupling can be achieved if the above slip angular command is used for making field orientation. The constant flux Ψ r and Ψr I= 0can be substituted in equation 3.4 , so that rotor flux sets as

$$\psi_r = L_m i_{ds} \qquad \text{---- (3.7)}$$

The electromechanical torque developed is given by

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\psi_r i_{qs} \qquad \text{---- (3.8)}$$

A block diagram of a basic IFOC scheme is presented in Fig. 3.

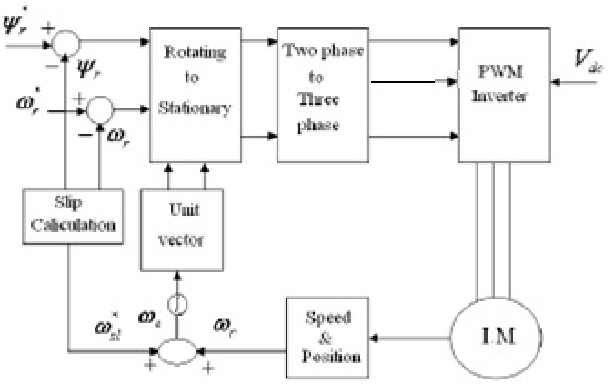


Fig. 3. Indirect Vector Control Method

The principle of indirect vector control can be understood with the help of block diagram. To implement indirect vector control and to estimate rotor flux, the above mentioned equations are used. The outer speed loop generates torque producing component and similarly the flux producing component is obtained. Hysteresis band PWM is used for current control in which actual current continuously follows the command current within a hysteresis limit.

4. CONTROLLERS DESIGN

The Kp and Ki gain values of the controller are tuned by using the common technique of Zeigler-Nicholas tuning method is used. In case of PI controller, if the gains exceeds certain value then the command torque variations increases and destabilizes the system. Because of continuous variation of machine parameters ,fixed gain of PI Controllers varies. And it is Unable to provide desired control performance. Speed controller is necessary to control the speed of the induction motor drive. Design of this speed controller greatly affects the performance of the electric drive. PI controllers are the most commonly used speed controllers before the introduction of fuzzy controller. Design and tuning of the controllers are defined in this section.

4.1 PROPOTIONAL-PLUS-INTEGRAL CONTROLLER

Controllers are used to keep the motor speed at required set-point. PI controller has a property of Zero steady state error as the type 1 transfer function is used. The actual speed and the command speed are compared and the error is reduced by using PI controllers. The basic formula used for this is as in Eq. 11, and the circuit for pi controller is shown in fig 3.1.

$$\frac{Y(t)}{E(t)} = K_p e(t) + K_i \int e(t)dt \qquad (11)$$

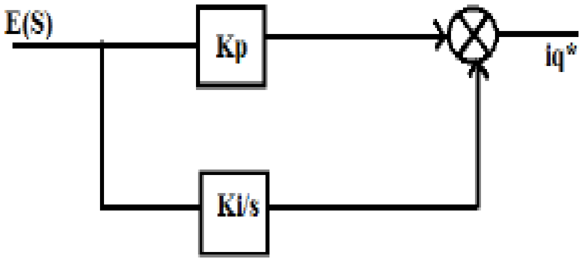


Fig 3.1 PI controller

Mathematical model of the system is mandatory for these works which limits the use of PI controller. The drawback of tuning PI controller which is very complex is then eliminated by the invention of Fuzzy Logic controller.

4.2 FUZZY LOGIC CONTROLLER

Fuzzy Logic implementation requires no exact knowledge of a model. The block diagram of a FLC is shown in Fig. 4.

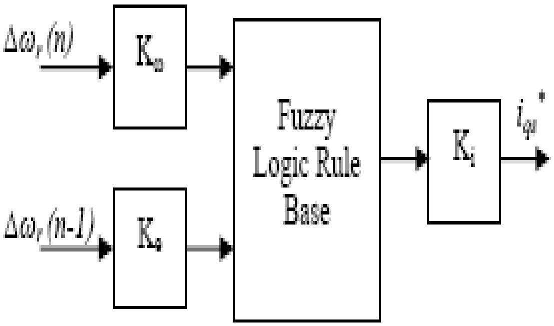


Fig. 4. Fuzzy Logic Based Controller block

It involves the use of the concept of fuzzy subset and rule based modeling. By permitting certain amount of imprecision, complex solutions are modeled with ease.

4.2.1. Concept of Fuzzy Logic

The idea of formulating the control algorithmsby logical rules introduced the implementation of human understanding and human thinking in control algorithms[3]. The lack of analytical description makes the fuzzy control conceptually different from conventional control. One defines a subset with the aid of a characteristic function which describes membership in the subset. Let X be the universe of discourse and let S be a subset of X. The characteristic functionassociated with S is a mapping

$$f S : X \to \{0,1\} \quad (12)$$

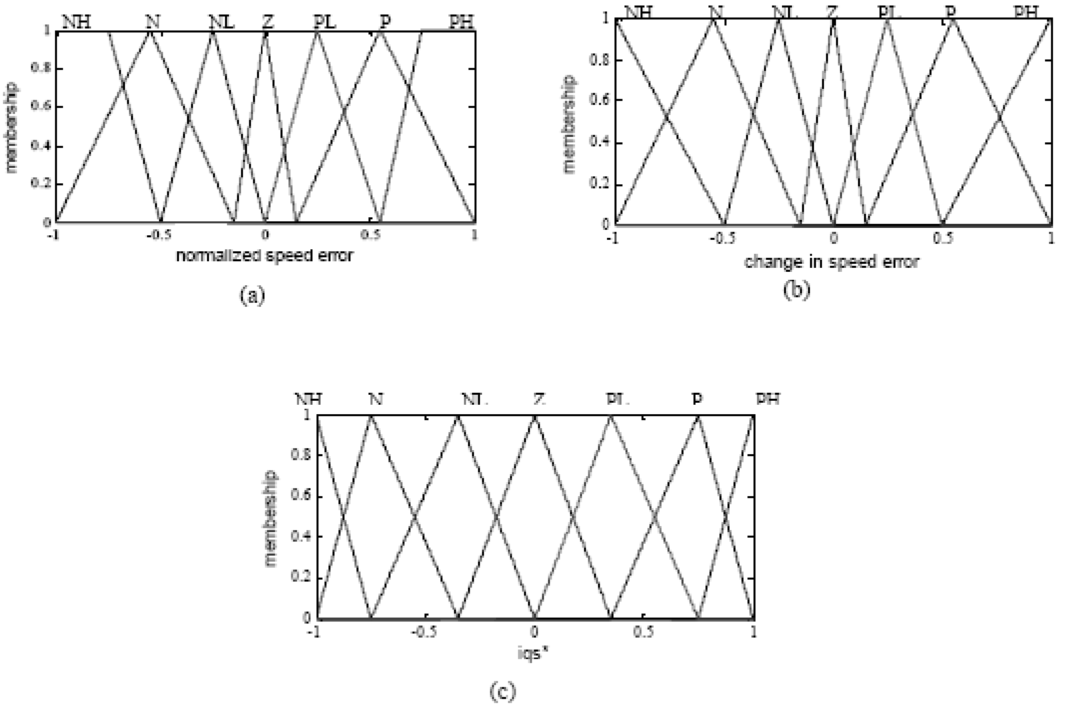
Such that for any element x of the universe, fS(x) =1 if x is a member of S and fS(x) =0 if x is a nonmember of S. This is also called a crisp subset.The fuzzy subset generalizes the idea of a crisp subset by extending the range of the characteristic function from the binary pair {0, 1} to the unit interval [0, 1]. Then the characteristic function associated with a fuzzy subset A of X is given by the mapping

$$f\,S : X \rightarrow [0,1] \quad (13)$$

In the framework of fuzzy set theory the characteristic function is called the membership function associated with the fuzzy subset A. A fuzzy logic controller is described by a knowledgebased system consisting of IF … THEN rules with vague predicates and a fuzzy logic inference mechanism. The present fuzzy logic controller adopted is of the Mamdani Controller type [12]. The speed error and the change in the speed error are given as inputs to the FLC. The torque producing current component is the output. A knowledge rule base which simulates the performance of the system is defined. The rule baseacts upon the inputs to produce the given outputs.

4.2.2 Membership Functions

The Fuzzy Logic Controller initially converts the crisp error and change in error variables into fuzzy variables and then are mapped into linguistic labels. Membership functions are associated with each label as shown in the Fig.4.1 which consists of two inputs and one output.



(a) (b)

(c)

Fig. 4.1 Membership Functions of inputs and output

The linguistic labels are divided into seven groups. They are: NH-negative high, N-Negative,NL-negative low, Z-zero, PL-positive low, Ppositive, PH-positive high. Each of the inputs andthe output contain membership functions with all these seven linguistics. This method of formulation of control algorithms allows implementing heuristic strategies . A straightforward source of deriving the linguistic control strategies are human experience and understanding, which essentially contain the model of the control system in an implicit form.

4.2.3. Knowledge Rule Base

The mapping of the fuzzy inputs into the required output is derived with the help of a rule base as given in Table 1.Each rule of the FLC is characterized with an IF part, called the antecedent, and with a THEN part called the consequent. The antecedent of a rule contains a set of conditions and the consequent contains a conclusion. If the conditions of the antecedents are satisfied, then the conclusions of the consequent apply. Considering the first rule, it can be interpreted as: IF change in speed error is NH and change is speed is NH, THEN the output will be NH.

4.2.4. Defuzzification

Generally the output obtained is fuzzy in nature and has to be converted into a crisp value by using any Defuzzification technique.

TABLE 1 KNOWLEDGE RULE BASE

CE \ E	NH	N	NL	Z	PL	P	PH
NH	NH	NH	NH	NH	N	NL	Z
N	NH	NH	N	N	NL	Z	PL
NL	NH	N	NL	NL	Z	PL	P
Z	NH	N	NL	Z	PL	P	PH
PL	N	NL	Z	PL	PL	P	PH
P	NL	Z	PL	P	P	PH	PH
PH	Z	PL	P	PH	PH	PH	PH

5. SIMULATION RESULTS

The performance of indirect vector control induction motor drive has been simulated in MATLAB environment using simulink.

5.1 Simulation Model of Indirect Vector Control

The model for indirect vector control induction motor drive is shown in the Figure 5.1 below. In this simulation we have taken dc voltage of 780V for the inverter. The hysteresis band is taken of 1Amp. The induction motor output results with PI controller and Fuzzy controller are obtained using simulation and are analyzed in Table.2. The results are shown in below figures5.2 and 5.3

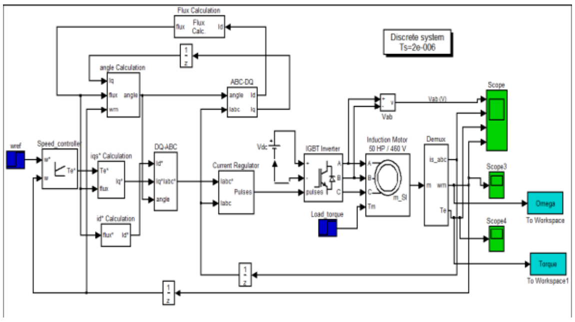


Figure 5. 1. Simulation Model for Indirect Vector Control

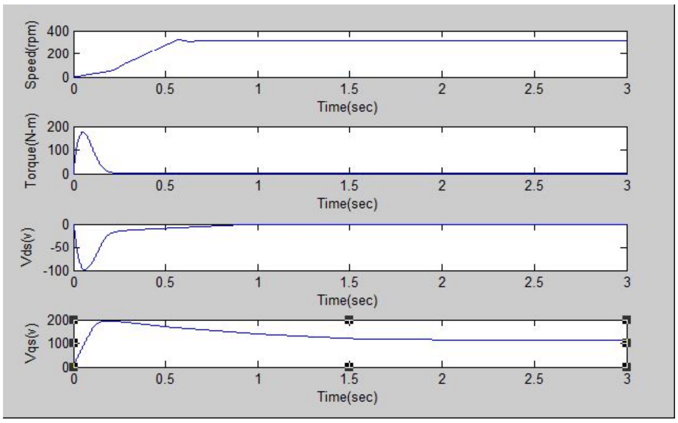


Fig 5.2 Simulation results with PI controller

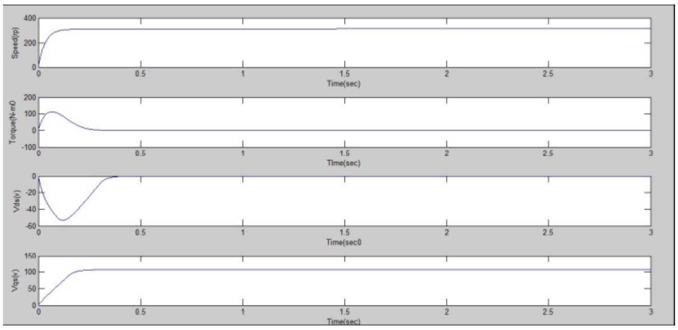


Fig 5.3 Simulation results with Fuzzy controller

Controller	Rise Time (sec)	Settling Time (sec)	Peak overshoot (%)	Steady state error(%)
PI	0.6	0.8	11.89	0.0013
Fuzzy PI	0.1	0.3	5.7	0.0001

Table.2 Summary of Results

CONCLUSION

In this paper, conventional PI controller and Fuzzy logic controller based Indirect vector controlled induction motor drive are compared. Among the conventional PI controller and the Fuzzy Logic controller, FLC proved to be better than PI. Response with PI controller has overshoot and takes more settling time to reach rated value. It is concluded that the proposed intelligent controller has shown superior performance than that of the parameter fixed PI controller. The results obtained from the simulation shows that dynamic response is very fast for vector controlled drive. So, it can be stated that vector controlled induction motor drives have very fast dynamic response and less steady state error and these drives are very suitable for exact speed control over a wide range.

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