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Performance Evaluation of reduced Rule Base Fuzzy Logic Controller for Indirect Vector Controlled Induction Motor Drive

BHAVNESH KUMAR, Y. K. CHAUHAN,VIVEK SHRIVASTAVA

School of Engineering, Gautam Buddha University, Gr. Noida, UP, India-201310

Abstract. This paper investigates the performance of a fuzzy logic speed controller with a reduced rule base for an indirect vector controlled induction motor drive. Generally in the control of complex systems where high performance is required, traditional controllers does not meet the required performance. In this paper a fuzzy logic controller is developed in such a way that it can provide high performance while using lesser rule. The drive is simulated successfully using Simulink/MATLAB. The performance of the drive has been examined under various rigorous working conditions. The Simulation results show that the proposed fuzzy logic controller (FLC) works satisfactorily making the drive more suitable for high performance applications.

Keywords : Induction motor, vector control, fuzzy logic controller

1. Introduction

Although induction motors are among the most widely used motors in the industrial as well as domestic applications as it provides many advantageous features such as low cost, reasonably small size, ruggedness, low maintenance, and operation with an easily available power supply. However, its speed control is quite complex due to the nonlinearity because of coupling and core saturation, which increase the challenge to use them in high performance applications [1]. In recent years vector control scheme (VCS) has made the task easy by separately providing the control over torque and flux by decoupling them. However, this decoupling feature can be adversely affected by the load disturbances, parameter variations and the nonlinearities, so controller design and selection plays a key role in drive performance [2].

Fuzzy logic controller (FLC) is now a day is widely accepted as one of the best alternative to conventional proportional-integral-derivative (PID) controller used in the speed control applications where high performance is required. There are two main strengths of FLC: Firstly is that no mathematical model of the plant is needed, but knowledge of the expert is required to create a rule base. Secondly they have capability to handle various types of nonlinearities. FLC modeling incorporates certain amount of human knowledge into its component such as fuzzy rule bases, membership functions etc. These components must be selected with an utmost care as the selection of these components greatly influences the performance of FLC and decides the strength of FLC [3]-[4]. Lot of work has been reported witnessing the superior performance of drive with FLC in comparison to PI controller [5], [6], [7]. However most of these works are focused just on the speed performance evaluation while using a standard (7x7) rule base.

The objective of this paper is to provide a detailed comparative study and to present a simplified FLC for an induction motor drive to produce a high standard of performance while employing a less complex structure, thus reducing computational burden and allowing for real-time operation at higher motor speeds with lower currents on computers having limited processor and memory resources. The drive is implemented with the help of Simulink/Matlab Software.

2. Vector Control of Induction Motor

Coupling effect between the flux and torque component of current in the induction motor makes its speed control sluggish and complex. Vector control force the AC drive to behave just like a DC drive, by transforming three phase quantities into two phase quantities and discarding the coupling effect. The schematic diagram of proposed indirect vector control induction motor drive is shown in Fig.1[2]. Indirect vector control is just like a direct vector control the only difference is that the unit vectors are computed by calculating the rotor flux angle using the measured speed position. From the d-q equivalent circuit of induction motor the following equations can be derived [7],[8].

The rotor equation of induction motor containing flux linkages as variables in synchronously rotating refernce frame indiacted by suffix '*e*'are given by

$$R_r i_{qr}^e + p\psi_{qr}^e + \omega_{sl}\psi_{dr}^e = 0 \tag{1}$$

$$R_r i_{dr}^e + p\psi_{dr}^e + \omega_{sl}\psi_{qr}^e = 0 \tag{2}$$

Where $R_r, i_{qr}^e, i_{dr}^e, \psi_{qr}^e, \psi_{dr}^e, \omega_{sl}, p$ are the rotor resistance, q- axes rotor current, d-axis rotor current, q-axis rotor flux linkage, d-axis rotor flux linkage slip speed and differential operator respectively.

The rotor q-axis and d-axis flux linkages are given by

$$\psi_{qr}^e = L_m i_{qs}^e + L_r i_{qr}^e \tag{3}$$

$$\psi_{dr}^e = L_m i_{ds}^e + L_r i_{dr}^e \tag{4}$$

Where, L_m, L_r, i_{qs}^e and i_{ds}^e are mutual inductance, rotor inductance, q-axis stator current and d-axis stator current respectively.

Since rotor flux linkage is aligned with d-axis

$$\psi_r = \psi_{dr}^e \tag{5}$$

$$\psi_{qr}^e = 0 \tag{6}$$

$$p\psi_{qr}^e = 0 \tag{7}$$

From the above equations

$$R_r i_{qr}^e + \omega_{sl}\psi_r = 0 \tag{8}$$

$$R_r i_{dr}^e + p\psi_r = 0 \tag{9}$$

Therefore

$$i_{qr}^e = -\frac{L_m}{L_r} i_{qs}^e \tag{10}$$

$$i_{dr}^e = \frac{\psi_r}{L_r} - \frac{L_m}{L_r} i_{qs}^e \tag{11}$$

And the electromagnetic torque obtained from machine flux linkages and currents is given by:

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}(\psi_{dr}^e i_{qs}^e) \tag{12}$$

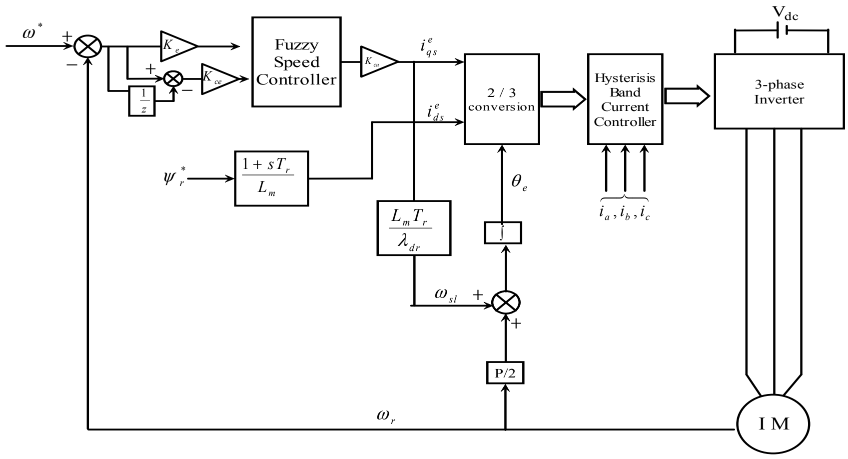

Fig.1 Schematic model of Indirect vector control induction motor drive

3. Fuzzy Logic Controller Designing

In order to design a fuzzy speed controller, speed error $e(k) = \omega^* - \omega_r$ and change in speed error $ce(k) = e(k) - e(k-1)$ are the two inputs for the controller, while after the decision making electromagnetic torque is produced. Basically it is made up of four components: fuzzification, rule base, inference engine, and defuzzification. Before giving to the fuzzy controller Input variables (speed error and change in speed error) are scaled using a scaling factor. Utmost care must be taken in choosing the scaling factor as it affects the stability, oscillations and damping of the system [8]. The values of scaling factors K_e, K_{ce} and K_{cu} calculated using the motor data are 0.006, 20 and 1 respectively.

3.1. Fuzzification

This is a process in which the crisp input variables to the fuzzy controller are transformed into a normalized fuzzy set. A fuzzy set is a set containing the range of input values and an associate membership function describing the degree of confidence of the input belonging to this range. All the linguistic variables of the fuzzy-control system (speed error, speed-error variation) were scaled into a common discourse universe with values between [−1, 1]. As a consequence, it was possible to map all the variables simultaneously with a unique set of membership functions.

3.2.Rule Base

The rule base was designed with (3x3) 9 rules in comparison to 49 rule of standard rule base. The linguistic terms used for input and output variables are described as: “ZE” is “Zero”; “NE” is “Negative”; and “PE” is “Positive”. The universe of discourse for the linguistic variables “speed-error” and “change in speed error” was was therefore normalized to [−1, 1] by scaling them before the fuzzification process. The Rules used for this particular problem are given in Tab.1[2].

Tab.1 Rulebase for FLC

e→ ce↓	NE	ZE	PE
NE	NE	NE	ZE
ZE	NE	ZE	PE
PE	ZE	PE	PE

The rules are in general format of “*if* anticedent1 *and* antecedent2 *then* consiquent”.

3.3.Fuzzy Inference Engine

The Fuzzy inference engine has two basic tasks to perform: (i) determining the degree to which each rule is relevant to the current situation as characterized by the inputs , and (ii) drawing conclusions using the current inputs (speed error and change in speed error) and the information in the rule-base.Mamdani type fuzzy inference engine is used for theis particular work.

3.4.Defuzzification

Converse to the fuzzification process is a defuzzification process in which the combined output fuzzy set produced from the inference engine is translated into a crisp output value of real-world meaning. Among the various defuzzification techniques centre of gravity (COG) is chosen for this work because of its known merits [11]. COG method is based upon the general formulae given as:

$$u = \frac{\sum_{i=1}^{l} x_i \mu(x_i)}{\sum_{i=1}^{l} \mu(x_i)} \tag{13}$$

Where x_i is a running point in a discrete universe, and $\mu(x_i)$ is its membership value in the membership function.

4. Results & Discussion

For the performance evaluation of the proposed fuzzy logic controller based vector control induction motor drive detailed study has been carried out for which drive was simulated several times under different operating conditions such as sudden change in command speed, step change in load. The parameters of the 4KW, 3phase, 415 V squirrel cage induction motor used for this work are given below in Tab.2.

Tab.2 Induction motor parameters

Parameter	Value
Stator Resistance (R_s)	1.405 Ω
Rotor Resistance (R_r)	1.395 Ω
Stator Inductance (L_s)	0.005839 H
Rotor Inductance (L_r)	0.005839 H
Mutual Inductance (L_m)	0.1722 H
Inertia (J)	0.0131 Kg.m2
Pole Pair (P)	2
Friction Factor (F)	0.002985 N.m.s

For comparison, beside the implementation of fuzzy logic controller for vector controlled induction motor drive one other controller i.e. PI controller is implemented in the Simulink environment.

4.1.Reference Speed Tracking

The drive is started up from stand still to trace the speed command of 120 rad/sec. without any load. Fig.2 gives the speed responses of the drive with fuzzy logic controller and PI controller. In Fig.2 it can be easily observed that the speed response of the drive with FLC shows no sign of overshoot as observed with PI controller thus reducing the settling time. Steady state error with both the controllers is almost zero.

For the checking of robustness, the drive was tested by applying step changes in command speed at regular interval of 0.5 sec. The drive is initially started from standstill to trace the speed of 120 rad/sec., 60 rad/sec, 120 rad/sec, -120 rad/sec and 60 rad/sec respectively at a regular interval of 0.5 sec. It can be evident from the reponse graph shown in Fig.3 that FLC gives better performance in comaparison to PI controller.

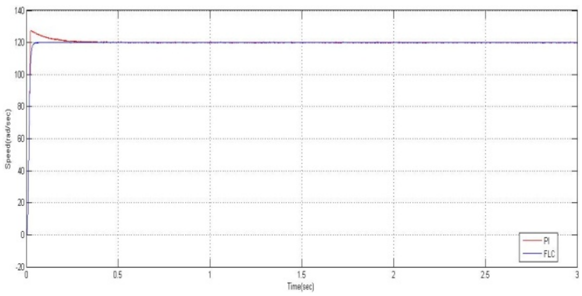

Fig.2 Comparison of speed response during start-up to reference speed tracking

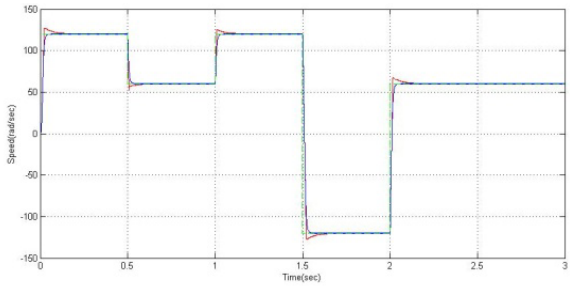

Fig.3.speed response of the drive under step change in command speed

4.2. Load Disturbance Rejection

The drive is started under noload condition to track the command speed of 120 rad/sec. After attaining steady state condition the drive was brought under loaded condition by applying rated load of 26 Nm at time $t = 1\sec$. The drive was then brought to the no-load condition by suddenly removing the applied load at time $t = 2\sec$. From the response shown in Fig.4 it is evident that both controllers rejected the load disturbance but the FLC based drive recovered very quickly under both conditions.

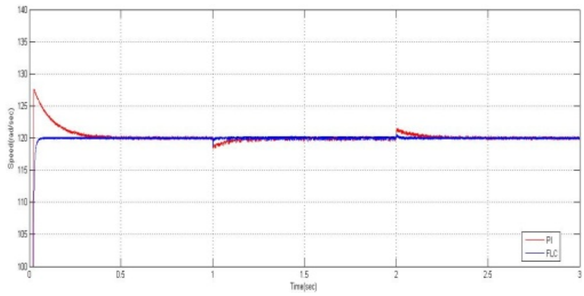

Fig.4 Speed response of drive during application of rated load at $t = 1\sec$ and removal of load at $t = 2\sec$.

5. Conclusion

This work investigates and analyzed the performance of indirect vector controlled induction motor drive with a fuzzy logic controller having minimum sized rulebase with nine rules. The drive has been simulated for different loading conditions such as sudden change in reference speed, step change in load torque, etc. using Simulink/MATLAB. The results have shown that the proposed FLC has worked satisfactorily making the drive more robust for high performance in the industrial applications.

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