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Comparison of different controllers for the improvement of Dynamic response of Indirect Vector Controlled Induction Motor Drive

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ABSTRACT

As the technology is fast changing, there is more and more use of machine intelligence in modern motor controllers. These controllers are employed in advanced electric motor drives in particular, the present day Induction motor drives. These systems emulate the human logic. This is particularly useful when the application has poorly defined mathematical model. In this present paper the analysis of fuzzy logic as the artificial intelligence is used. The comparative study of Fuzzy PI, Fuzzy MRAC is made. There is always a compromise of the cost and complexity. So this paper presents a new approach and its dynamic response in comparison to the Fuzzy PI and Fuzzy MRAC. The proposed controller is Fuzzy PI with scaling factors. This approach is validated with the Speed, torque responses of Indirect vector controlled Induction motor (IVCIM) drive.

***Keywords* –** Fuzzy logic, Fuzzy MRAC, Fuzzy PI, Fuzzy PI with scaling factors, IVCIM

I. INTRODUCTION

The concept of field orientation (also called vector control), was proposed by Hasse in 1969 using an indirect method and Blaschke in 1971, using a direct method. This constitutes the most important paradigms in the practice of control of induction motors. The objective was to make the induction motor emulate the dc motor in which the flux and torque are orthogonal. In the ideal dc machine, the torque in vector expression is given as

$$T_M = K_T Ia\ If \qquad (1)$$

Where I_a is armature current. It is related to torque and I_f is the field current and it is related to flux. In the dc motor these two are orthogonal and decoupled. The field oriented control is transforming a dynamic structure of an ac motor into that of a dc motor model. While decoupling, the induction motor is adversely affected by parameter variations. So we use the intelligent controllers. The vector control technique is classified into two big groups: (a) Direct or feedback vector control and (b) indirect or feedforward vector control.[1] The direct vector control relies on direct sensing of the rotor flux using rotor sensors. The second method is essentially the same as the direct vector control, only the unit vector signals are generated in feedforward manner, by using sensors to find out the rotor position and stator currents. There are classical speed controllers like proportional-integral (PI) where the controller variables are static and are not changed. This has an inherent drawback. Controllers based on the principles of machine intelligence (MI) have been employed in advanced high performance drives. In the intelligent controllers, the primary idea is to emulate the way humans think. They are effective in the models characterized by complex mathematical models. They are more robust and adaptive. In this paper, the fuzzy logic is exclusively dealt. And the fuzzy logic is applied in different controllers. They are Fuzzy PI, Fuzzy Model Reference Adaptive Control (MRAC) and Fuzzy PI with scaling factors. The design of the Fuzzy PI is easier and is implemented easily. Fuzzy MRAC is complex with three fuzzy blocks and hence the output is far superior and refined than that of the Fuzzy PI. The settling time of fuzzy MRAC is less than that of Fuzzy PI. It is more parameter insensitive. Hence a compromise is to be made between the complexity and the accuracy. The proposed Fuzzy PI with scaling factors fits into this mode. It is easy to implement and the output is superior to the fuzzy PI. The settling time of Fuzzy PI with scaling factors is less than that of Fuzzy MRAC and it has no overshoots.

II. II. MATHEMATICAL MODEL OF IVCIM

A 3 phase, 50 hp, 460V, 50Hz induction motor is supplied through a current controlled voltage source inverter (CC-VSI). The gating signals are generated by PWM current regulator. The d^s-q^s axes are fixed on the stator, but the d^{r}-q^r axes are fixed on the rotor, moving at a speed ω_r.[2]. Synchronously rotating axes are rotating ahead of the rotor axes by the positive slip angle Θ_{sl} corresponding to slip frequency ω_{sl}. The unit vector signal is as shown below**:**

$$\theta e = \int \omega e \, dt = \int (\omega r + \omega sl)\, dt = \theta r + \theta sl \qquad (2)$$

The rotor position slips with the rotor at a frequency of ω_{sl}. The torque equations are as shown below.

$$\begin{bmatrix} v_{qs}^{e} \\ v_{ds}^{e} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + \rho L_s & \omega_e L_s & \rho L_m & \omega_e L_m \\ -\omega_e L_s & R_s + \rho L_s & -\omega_e L_m & \rho L_m \\ \rho L_m & (\omega_e - \omega_r) L_s & R_r + \rho L_r & (\omega_e - \omega_r) L_r \\ -(\omega_e - \omega_r) L_m & \rho L_m & (\omega_e - \omega_r) L_r & R_r + \rho L_r \end{bmatrix} \begin{bmatrix} i_{qs}^{e} \\ i_{ds}^{e} \\ i_{qr}^{e} \\ i_{dr}^{e} \end{bmatrix} \qquad (3)$$

$$T_e = J_m \frac{dw_r}{dt} + B_m + T_L \qquad (4)$$

$$T_e = \frac{3}{2}\frac{P}{2} L_m (i_{qs}^{e} i_{dr}^{e} - i_{ds}^{e} i_{qr}^{e}) \qquad (5)$$

$$\frac{d\theta_r}{dt} = \omega_r \qquad (6)$$

In the above equations v_{ds}^{e} and v_{qs}^{e} are the d, q-axis stator voltages, i_{ds}^{e} and i_{qs}^{e} are the d, q-axis stator currents, i_{dr}^{e} and i_{qr}^{e} are d, q-axis rotor currents.

R_s and R_r are the stator and rotor resistances per phase.

L_s and L_r are the self inductances of the stator and rotor respectively.

L_m is the mutual or magnetizing inductance.

ω_e is the speed of the rotating magnetic field.

ω_r is the rotor speed.

P is the number of poles.

ρ is the differential operator (*d/dt*).

T_e is the developed electromagnetic torque.

T_L is the load torque.

J_m is the rotor inertia;

B_m is the rotor damping coefficient. and θ_r is the rotor position.

The Simulink model of the indirect vector controlled induction motor drive[3] is presented here. All the sub systems are the basic systems that are available in the MATLAB software. For decoupling control, the rotor flux and the change in rotor flux on the q axis should be zero.[4] Only then the slip speed can be achieved in the desired form. The slip speed thus obtained is as under:

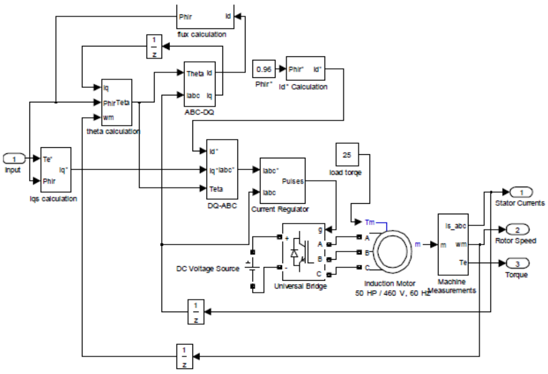

Fig. 1 MATLAB model of IVCIM

III. FUZZY LOGIC, FUZZY MRAC

Fuzzy logic is one of the artificial intelligent techniques that are used in the controllers for the precise control of the models that are mathematically complex models. Fuzzy logic requires no exact knowledge of the system. This is a tremendous control tool for all the control applications. The versatile Fuzzy Logic Toolbox in MATLAB has several features which allow implementing the fuzzy logic effectively. The different tools that are available in the fuzzy logic toolbox are: (1) The Fuzzy Inference System or FIS editor, (2) The membership Function Editor, (3) The rule editor, (4) The rule viewer, (5) The surface viewer. For effective implementation of the fuzzy logic the variables need to be defined and the corresponding membership functions are to be taken. There are many in built membership functions that are available in the fuzzy logic tool box. And based on the design, the membership functions are taken. Raw output signals from the controlled plant are pre-processed and applied to the fuzzyfier. Based on the predefined membership functions, the fuzzyfier assigns one or more of fuzzy values to each crisp variable received. The resulting fuzzy variables along with their membership functions are forwarded to inference engine, which is the part of the fuzzy controller that performs computations. The output of the inference engine is calculated from individual expert rules. The last part of the fuzzy controller is output calculation. This is called the defuzzification. There are several defuzzification methods that have been developed. In this paper, centre of gravity method is adopted.

The MRAC method[5] has two fuzzy controllers. The basic theme of this paper's MRAC control was proposed by Gilberto C.D. Sousa et al.1993 []. Here the fuzzy controller generates a weighing factor combining the reactive power and the stator d- axis voltage. The other controller is used for the fast convergence. It tunes the slip gain based on the combined detuning error and its slope. The block diagram of the MRAC[6] is shown here:

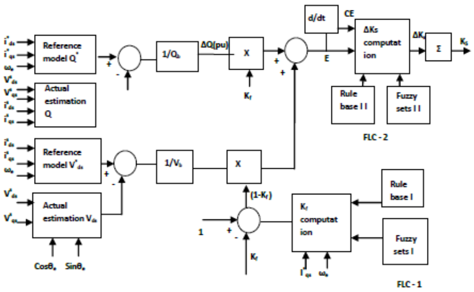

Fig. 2 MRAC with slip gain tuning

IV. FUZZY PI WITH SCALING FACTORS

The normal Fuzzy PI controller is slower in terms of the settling time when compared to Fuzzy MRAC. The complexity of the Fuzzy MRAC makes it difficult to implement when the systems grow in order and the number of variables increase too. Hence there is a need for the compromise in terms of the complexity and the output. Since the requirement of the best output forces the usage of MRAC, not all requirements demand the same parameter sensitivity. For those applications the proposed model fits in as the perfect controller. The fuzzy PI with scaling factors [7] is easy to implement and the complexity is not at all an issue. The inputs to the ordinary fuzzy pi controller are scaled by a factor. And then it is given to the controller. Thus there is just an addition of one extra step in the process. That too the multiplication when compared to the ordinary Fuzzy PI. This is shown below:

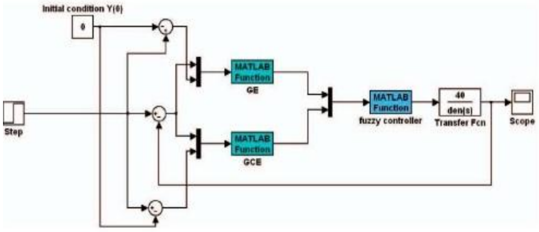

Fig. 3 MATLAB implementation of Fuzzy PI with scaling factors

The input variables to the Fuzzy PI controller would be E (Error) and CE (Change of Error). But in this, scaling factors are multiplied to these variables and the corresponding variables are given to the controller. The scaling factors are given below:

GE(K) = (1+dGE(K))/h (7)

GCE(K)= (1+dGCE(K))/h*10 (8)

h=SP-YO ;*SP* = set point, *YO*= Initial condition.

V. RESULTS AND DISCUSSION

The following simulation results show that the Fuzzy PI with scaling factors has the better settling time compared to the Fuzzy PI, and the Fuzzy MRAC is insensitive to the change in resistance from 1 p.u. to 0.75 p.u. Whereas, the Fuzzy PI and Fuzzy PI with scaling factors lags behind in that parameter insensitivity. But for the requirements where the faster settling time is required, then the Fuzzy PI with scaling factors is a better choice compared to conventional Fuzzy PI.

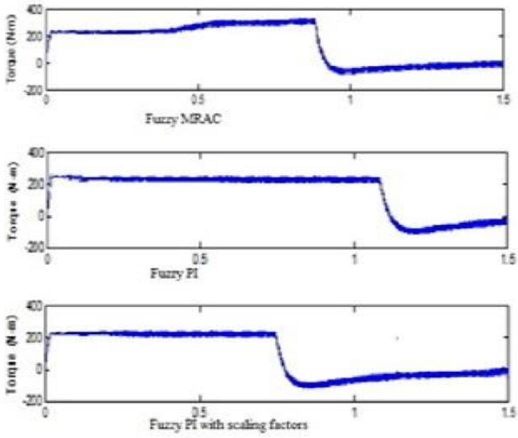

Fig.4 Torque comparison of the controllers

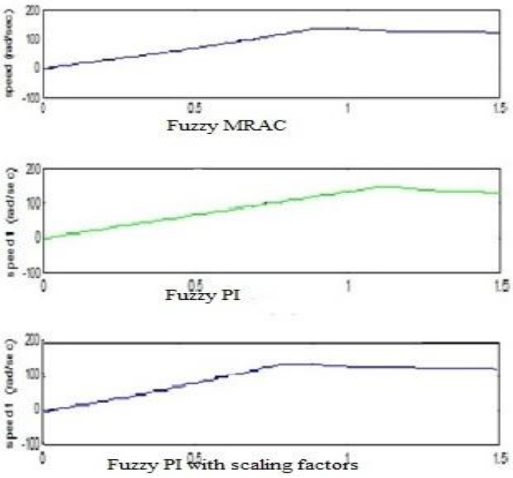

Fig. 5 Speed comparison of the controllers

Table 1 Settling times of various controllers

CONTROLLER	SETTLING TIME IN SECONDS
FUZZY MRAC	0.9
FUZZY PI	1.1
FUZZY PI WITH SCALING FACTORS	0.75

VI. CONCLUSION

This paper analyses the speed and torque responses of the Fuzzy PI, Fuzzy MRAC and Fuzzy PI with scaling factors. As the complexity of the Fuzzy MRAC is high, the need for the alternate method is inevitable and Fuzzy PI lags apart in the settling time as well as parameter insensitivity. Fuzzy PI with scaling factors leads the way in settling time. The settling time of Fuzzy PI with scaling factors is less than that of Fuzzy MRAC and it has no overshoots.

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