Fuzzy Speed Control Method in Three Phase Induction Motor

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Abstract – This paper presents the theory, design and simulation of a controller based on fuzzy logic artificial intelligence techniques used for the speed control of three-phase induction motor. The motor model is designed and membership functions are chosen according to the parameters of the motor model. This technique adjusts the speed of the motor by controlling the frequency and amplitude of the stator voltage, keeping the ratio V/f constant. The simulations have been done by Simulink Toolbox in Matlab and the results are interesting considering the presence of non-linearity in the IM model. Torque-speed response of the proposed control system is investigated. The simulation results demonstrate that the performance of the FLC is better than that of the conventional one. When fuzzy logic based intelligent controller is used instead of the PI controller, excellent performance can be achieved even in the presence of parameter variations and non-linearity. The proposed FLC requiring less circuitry can control speed with fast response and good stability. Fuzzy logic technique is a replacement of the conventional method in the machine control applications for efficient control. The fuzzy logic has advantages compared to conventional methods such as simplicity of control, low cost, and the possibility to control without knowing the exact mathematical model of plant The main advantage of using fuzzy logic controller is that, without having deep knowledge of the induction motor, it is easier to design a well-performing speed control system.

Keywords- Induction motor, Scalar, FLC, Matlab, Simulink.

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I. INTRODUCTION

In the industries, approximately 60% of the total electricity is consumed by A.C motors, mostly induction motors. Three-phase induction motors are the most common and frequently employed machines in industry because these have simple design, high power to weight ratio, easy maintenance, high robustness, reliability, lower cost, high efficiency and good self-starting capability. However, induction motor has disadvantages, such as nonlinear characteristics and having complex mathematical model (Senthilkumar and Vijayan, 2012).

The induction motor was considered as actuator privileged in the applications of nearly constant speed and it is not inherently capable of providing variable speed operation. These limitations have been solved through the use of motor controllers and adjustable speed controllers (Basem et. al., 2010).

The conventional approaches need a complex mathematical model of the motor to develop controllers for quantities such as speed, torque, and position. Hence, to avoid the inherent undesirable characteristics of conventional methods, Fuzzy Logic Controller (FLC) is being developed. FLC offers a simple linguistic approach to develop control system. It maps the input-output relationship based on the knowledge of experts and hence, does not require an accurate mathematical model of the system and can handle the nonlinearities that are difficult to model (Basem et. al., 2010).

II. MODEL OF INDUCTION MOTOR

The dynamic modeling of Induction Motor is done through SIMULINK/ MATLAB software by using its mathematical equations. Synchronous frame of reference is used where:

w_0 = base frequency

w_m = rotor frame frequency

w_k = dq frame frequency

w_s = synchronous frame frequency;

(rad/sec)

λ_s = stator flux

λr = rotor flux

R_s, R_r =stator and rotor resistance

v_s , v_r = stator and rotor voltage

i_s , i_r = stator and rotor current

L_s , L_r = stator and rotor inductance

L_m = magnetizing inductance

L_{sl} = stator leakage inductance

L_{rl} = rotor leakage inductance

T_e = electromagnetic torque

T_L = load torque

B_m = viscous friction coefficient;

(pu)

d,q = direct, quadrature axis

p = number of poles

H = inertia constant(s)

Operators: $\otimes$ = cross product, $\bullet$ = dot product

1. Electrical system equations :

$$v_s = R_s i_s + \frac{1}{w_0}\frac{d\lambda_s}{dt} + w_k M_{\frac{\pi}{2}} \lambda_s \qquad (i)$$

$$v_r = R_r i_r + \frac{1}{w_0}\frac{d\lambda_r}{dt} + (w_k - w_m) M_{\frac{\pi}{2}} \lambda_r \qquad (ii)$$

where

$$\lambda = \begin{bmatrix} \lambda_d \\ \lambda_q \end{bmatrix}$$

$$i = \begin{bmatrix} i_d \\ i_q \end{bmatrix}$$

$$M\left(\frac{\pi}{2}\right) = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$$

2. Flux linkage current relations –

For d axis :

$$\lambda_{sd} = L_s i_{sd} + L_m i_{rd} \qquad (iii)$$

$$\lambda_{rd} = L_m i_{sd} + L_r i_{rd} \qquad (iv)$$

For q axis:

$$\lambda_{sq} = L_s i_{sq} + L_m i_{rq} \qquad (v)$$

$$\lambda_{rq} = L_s i_{sq} + L_m i_{rq} \qquad (vi)$$

3- Mechanical system equations-

$$T_e = 2H \frac{dw_{mech}}{dx} + B_m w_{mech} + T_L \qquad (vii)$$

$$T_e = \lambda_s \otimes i_s = M_{\frac{\pi}{2}} \lambda_s \bullet i_s \qquad (viii)$$

$$w_{mech} = \frac{2}{P} w_m \qquad (ix)$$

III. FUZZY LOGIC CONTROLLER

Fuzzy logic controller works on control system based on fuzzy logic. Just as fuzzy logic can be described simply as "computing with words rather than numbers", fuzzy logic control can be described as "controlling with sentences rather than (mathematical) equations". The function of a fuzzy logic controller is to convert linguistic control rules based on expert's knowledge into control strategy. Fuzzy logic is useful when systems are too complex (Fuzzy Logic Toolbox)

These control systems are based on artificial intelligence theory as well as conventional control theory.

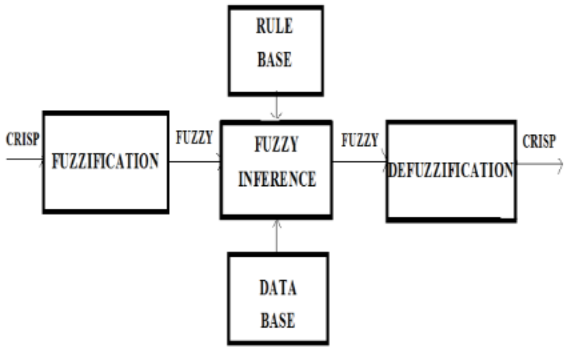

Fig. No.1 Fuzzy control system

Fuzzification converts a crisp input signals into fuzzy signals that can be identified by its level of membership into the fuzzy sets. The inference mechanism uses the linguistic control rules to convert the input conditions into the fuzzy output. Finally, the defuzzification converts the fuzzy outputs into crisp signals, which is the change in frequency for driving the induction motor (Mao-Fu et. al., 2002).

The flowchart representing fuzzy logic control algorithm is-

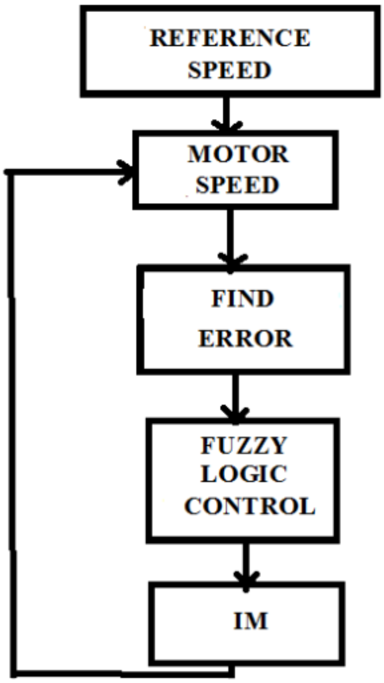

Fig. No.2 Flowchart (Mao-Fu et. al., 2002).

IV. SCALAR CONTROL OR V/F CONTROL OF IM

Variable frequency control is normally associated with change in voltage in order to make the flux constant. This method of speed control is called V/f control. With constant supply voltage, if frequency is increased then the synchronous speed and hence the motor speed increases, but flux and torque gets reduced. Hence along with frequency, voltage must be changed so as to make V/f ratio constant. This maintains constant air gap flux giving speed control without affecting the performance of the motor (Bose, 2002).

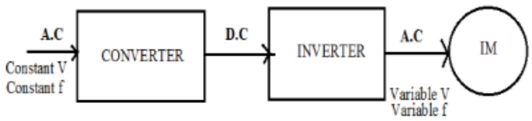

Fig. No.3 Scheme for V/f Control

The speed control of the induction motor was carried out by keeping constant the voltage- frequency ratio in order to maintain the air-gap flux constant. If the supply voltage is varied without adjusting frequency, the induction motor can operate in the flux saturation region or with a weakened field (Senthilkumar and Vijayan, 2012).

The scalar control method based on the constant volt per hertz (V/f) method employs the highly efficient fuzzy controller to reduce the speed error.

5. FUZZY CONTROLLER USING MAMDANI FIS IN MATLAB

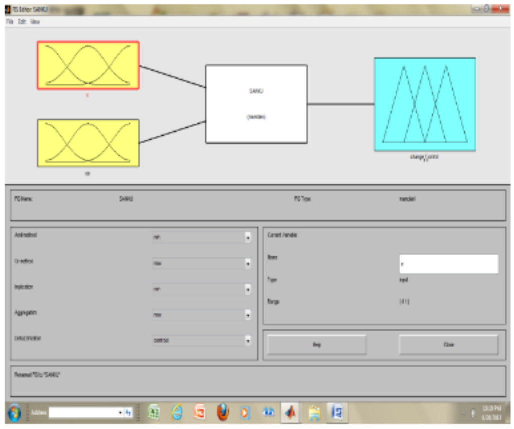

Fig. No. 4(a) FIS Editor

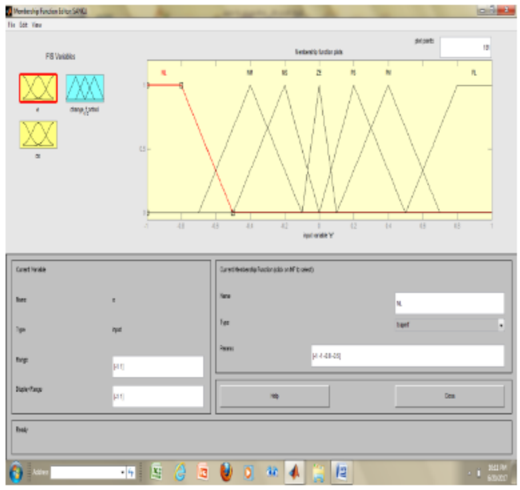

Fig. No.4(b) Membership functions for inputs – error and change in error.

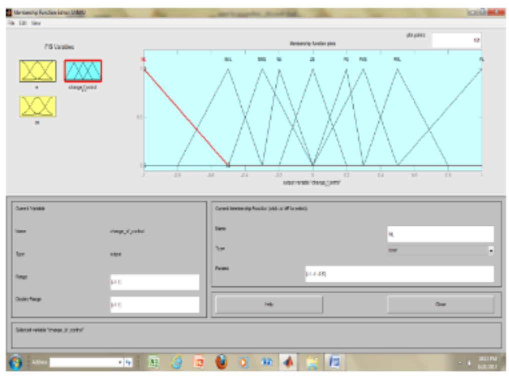

Fig No.4(c) Membership functions for output- control of slip.

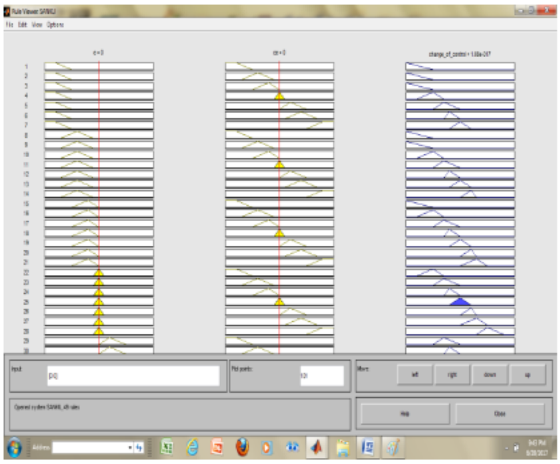

Fig No.4(d) Rule view of fuzzy logic controller

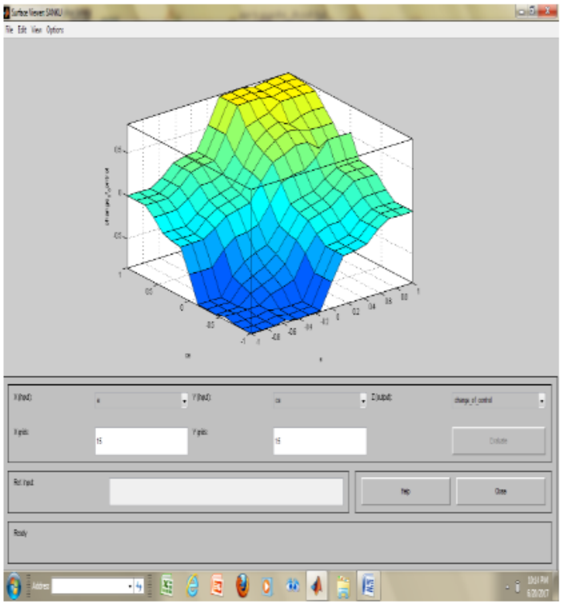

Fig No.4(e) Surface view of fuzzy logic controller

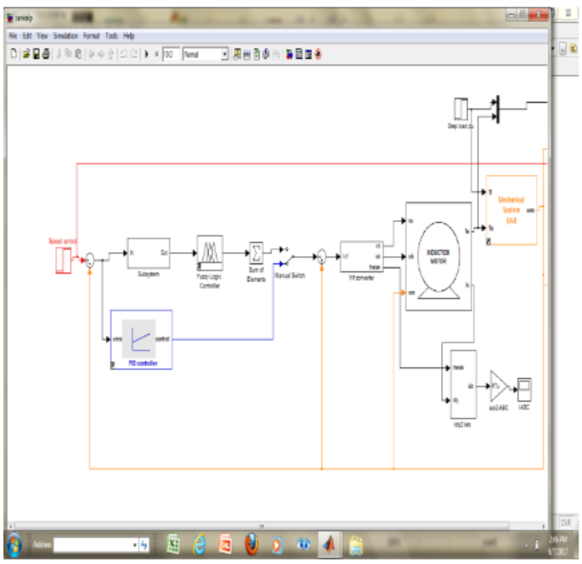

Fig No.5 Simulink Model of Scalar speed control of three phase IM using FLC.

6. SIMULATION RESULTS

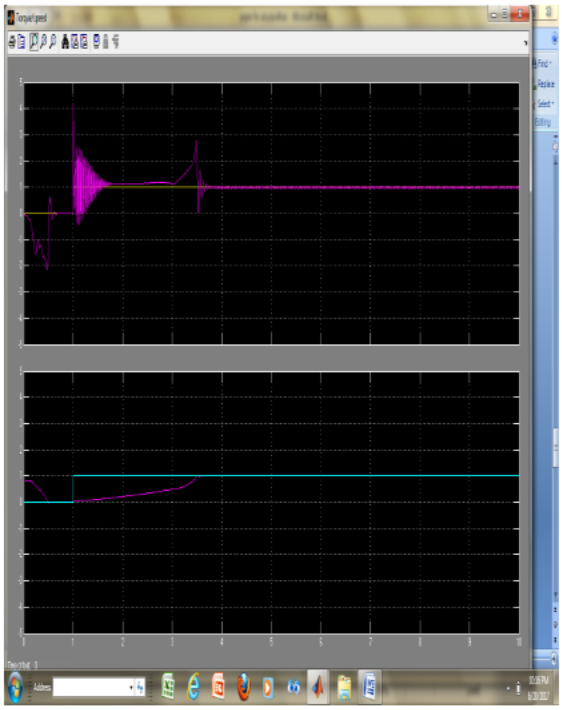

Fig No. 6 Torque / speed response of FLC

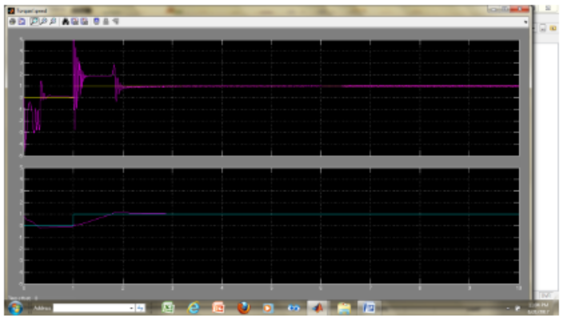

Fig No.7 Torque/speed response of PI controller

7. CONCLUSION

The proposed controller demonstrates that the performance of scalar IM speed drives can be improved by using fuzzy logic. This FLC gives maximum torque over the entire speed range. This technique uses the linguistic if-then rules based on expert's knowledge for adjusting the speed. PI Fuzzy Logic controller can be implemented instead of traditional PI controller.

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