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Fuzzy Logic Based Speed Control of Three Phase Induction Motor

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Abstract – In the industrialized countries, three phase induction motors have wide applications due to robustness, low maintenance, low cost, reliability and simple construction. The speed control of motor is required to obtain maximum torque and improved performance. This paper deals with the theory and simulation of a rule based fuzzy logic controller applied to induction motor model in closed loop to control its speed efficiently in a simple way. The control systems using artificial intelligence technique are the smart and intelligent control systems. Induction motor has non-linear features, so conventional control methods cannot ensure good performance, hence knowledge based fuzzy logic controllers are used which works efficiently and does not require accurate mathematical model. Fuzzy logic is the convenient way to incorporate the knowledge of human experts in to the systems. The fuzzy logic controller depends on a set of simple linguistic if-then rules. The scalar control strategy based on simplified volts/Hertz control scheme with stator frequency regulation is implemented where the slip value is the variable to be regulated to provide the required frequency signal for speed control. This paper presents Mamdani type FLC applied to induction motor control and its simulation results. Various toolboxes in Matlab are used for testing the simulated design to analyze the performance.

Keywords- Induction Motor, MATLAB, Simulink, Fuzzy, Scalar Control.

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I. INTRODUCTION

Three-phase induction motors are the most commonly used machines in the industries. These are simple in construction, with high power to weight ratio. Their maintenance is easy. Some other advantages are their ruggedness, lower rotor inertia, absence of commutator and brushes, besides the lower price and smaller size. In the past conventional methods were used only to control the speed of induction motor. Those controllers like PI controller show simplicity in design and stability in performance. They still require the mathematical model of induction motor (Senthilkumar and Vijayan, 2012).

To overcome these problems, intelligent and smart control systems, based on fuzzy logic, are being widely used for induction motor control. These control systems may be based on both artificial intelligence and conventional control theories.

When intelligent controller with fuzzy logic is used, excellent performance can be achieved even in the presence of parameter variations and non-linearities. In addition, the fuzzy logic has following advantages: (i) The linguistic variables result in control process being same as human thinking. (ii) It relates output to input, without understanding all the variables (iii) A fixed set of rules based on expert's knowledge. (iv) Complete knowledge of the system is not required before starting work. (v) It has increased robustness (vi) Only a few rules can handle greater complexity.

For the motor speed control, two required input variables for FLC are: the speed error of the motor (e) and its derivative, which represents the change of speed error (ce). The controller output is the change in frequency of the voltage supply fed to motor. The output of FLC is given to the 3 phase inverter to produce waveform with variable voltage and frequency. It controls the speed of the induction motor.

Based on the reference point and feedback, FLC produces the control signal to be used by the inverter for control of the speed of the induction motor. The control signal, representing frequency is than given to Volt/Hz block which maintains a constant ratio between voltage and frequency. This keeps the torque constant while the speed varies. The closed loop control system of FLC and three-phase voltage source inverter has been simulated by using Mat lab software. Simulation results show better result of the proposed FLC over the conventional one with PI controller. The FLC has proved highly advantageous in the industries as it has the capability to control the complex nonlinear systems better.

Induction Motor Model

For the Induction Motor dynamic modeling is done through SIMULINK/ MATLAB software by using mathematical equations. Synchronous frame of reference is used with following variables:

$w_0 =$ (base frequency)

$w_m =$ (Rotor Frame) frequency

w_k = (dq Frame) frequency

w_s = (Synchronous Frame) frequency;

(rad/sec)

$\lambda_s =$ 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 = em 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, • = 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 –

Ford 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:

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

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

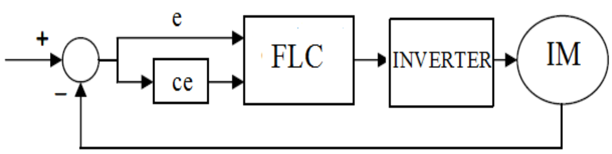
3- Mechanical system equations-

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

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

$$w_{mech} = \frac{2}{P} w_m \qquad (ix)$$ (Asija, 2010).

II. Proposed Control System



Fuzzy Speed Control Method of IM

III. FUZZY LOGIC CONTROLLER

FLC is an efficient technique to create human-like thinking within a control system. It can be designed for utilizing human deductive thinking, i.e., to take decisions from what they know. It has been mainly applied for controlling the process through fuzzy linguistic descriptions (Chitra and Prabhakar, 2006).

FLC has been utilized to design controllers for plants with complex dynamics with highly nonlinear models. In a motor control system, the function of FLC converts linguistic control rules into control strategy on the basis of information using knowledge of experts. This approach is very useful for induction motor speed drives as there is no need for exact mathematical model of the induction motor (Bose, 2002). It has a fixed set of control rules, usually derived from human knowledge. The membership functions (MF) of the input and output linguistic variables is already defined. For the successful design, proper selection of input and output scaling factors (gains) or tuning of the other controller parameters are critical, which in many cases done through trial and error for improved control performance (Bose, 2002, Miloud.)

The structure of FLC is shown in fig.2. The structure shows four functions, each one achieved by block (Badr, et. al.)

(a) **Fuzzification Block-** The fuzzy control converts crisp error and the change of error into fuzzy variables; then mapped into linguistic labels. Membership functions are defined in the normalized range (-1, 1), and associated with each label: NL (Negative Large), NS (Negative Small), ZE (Zero), PS (Positive Small) and PL (Positive Large). Five MFs are chosen for e(pu) and ce(pu) signals and five for output. All the MFs are symmetrical for the positive and negative values of the variables. Thus, maximum 5x5 = 25 rules could be formed as tabulated at Table 1. The surface view and membership functions for the inputs (error and change of error) and output of fuzzy control for scalar control are shown in fig 3.

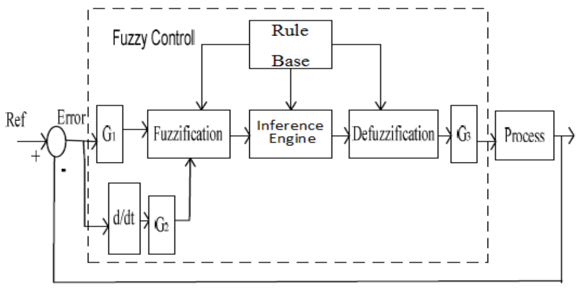


Fig.2. Structure of Fuzzycontrol

(b) **Rule Base-** (a set of If-Then rules), This contains the definition of the fuzzy subsets, their membership functions, their universe of discourse and the whole of the rules based on experts knowledge for achieving good control.

(c) **Fuzzy Inference Mechanism-** ("inference engine") This is heart of a fuzzy control, possess the capability of taking the human decisions and utilizes the expert's decision in interpreting and applying knowledge for better control of the plant.

(d) **Defuzzification Block-** which converts the conclusions of the fuzzy inference into actual inputs for the control process. In this work; Center Of Area (COA) is used as a defuzzification method, which can be presented as:

$$X^{crisp} = \sum^{n}_{i=1} x_i \mu_A(x_i) / \sum^{n}_{i=1} \mu_A(x_i)$$

Where

n: Number of the discrete elements

x_i: The value of the discrete element

$\mu_A(x_i)$: The corresponding MF value at the point x_i.

Gains G1, G2, and G3 are scaling factors to adapt the variables to the normalized scale. However, the inference strategy is the mamdani FIS, so the if-then rules for fuzzy control will be twenty five rules (Badr, et. al.)

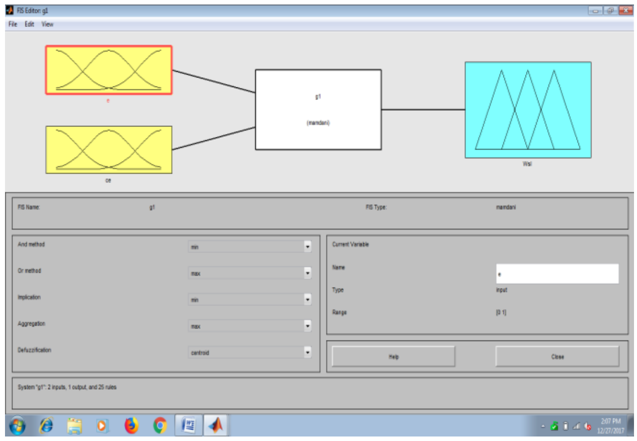


Fig. 3 (a) FIS editor

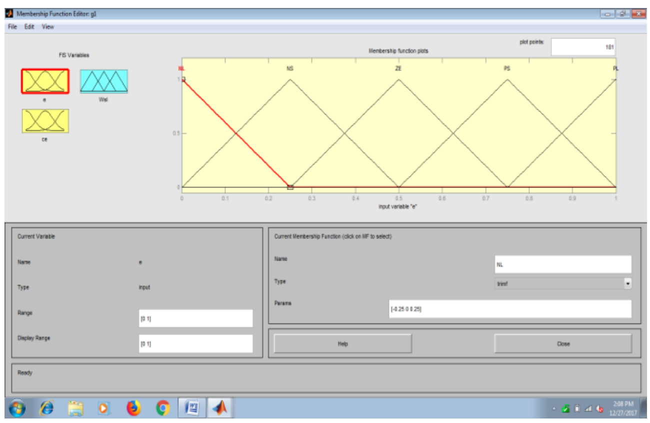


Fig. 3 (b) Inputs membership function

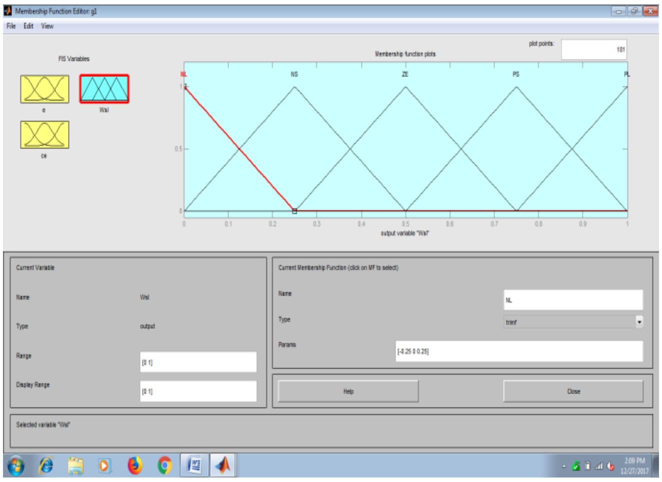


Fig. 3 (c) Output membership function

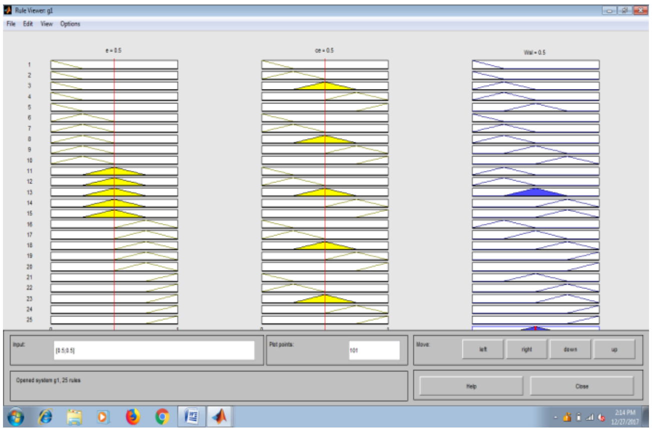


Fig. 3 (d) Rule view

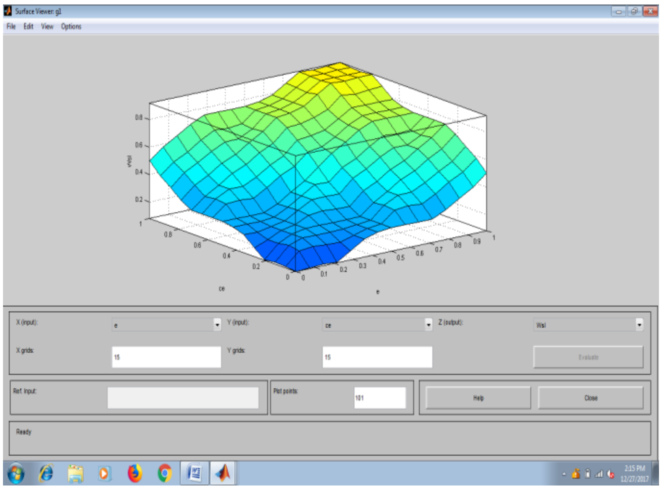


Fig. 3 (e) Surface view

Table 1

Rules for Fuzzy Controller

e \ ce	NL	NS	ZE	PS	PL
NL	NL	NL	NS	NS	ZE
NS	NL	NS	NS	ZE	PS
ZE	NS	NS	ZE	PS	PS
PS	NS	ZE	PS	PL	PL
PL	ZE	PS	PS	PL	PL

Table 2

Induction Motor Parameter

PARAMETERS	VALUE
Stator resistance (p.u)	0.01
Rotor resistance (p.u)	0.02
Stator leakage inductance (p.u)	0.1
Rotor leakage inductance (p.u)	0.1
Magnetizing inductance (p.u)	4.5
Base frequency (rad/sec)	2*pi*50
Poles	2
Inertia constant (s)	0.3
Viscous friction coefficient	$1\ e^{-5}$

The parameters of fuzzy speed controller are:

Kp=0.3; Ki=1

The parameters of PI speed controller are:

Kp=3; Ki=5; saturation limit (p.u)=0.5

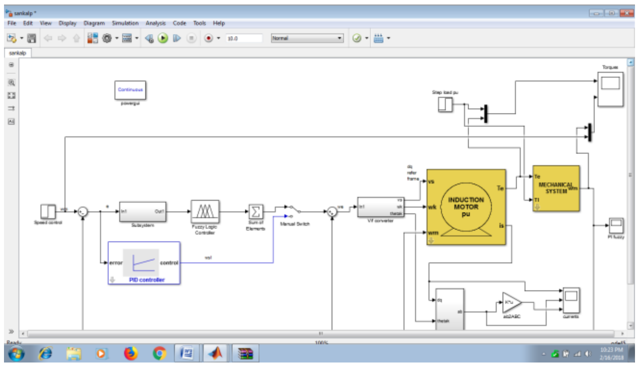


Fig.4.Scalar Control of Induction Motor in Simulink in Matlab (Ramon, et. al.)

IV. SIMULATION RESULTS

Simulation is performed to validate a theoretical development. Simulation model was made in Simulink/Matlab. A simullink model is carried out to realize induction motor equation using parameters in Table 2. Fig 4 shows the implementation of fuzzy controller for scalar control. Fig 5 shows the torque/speed response of the induction motor using fuzzy logic controller.

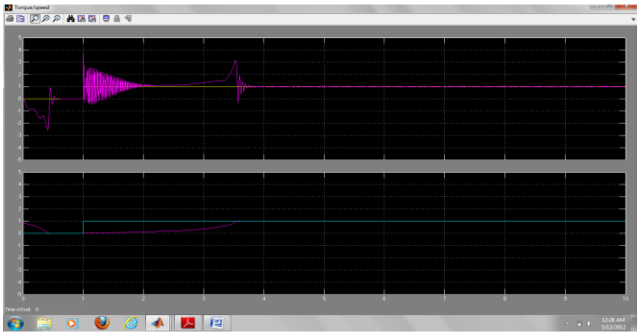


Fig 5

V. CONCLUSION

Fuzzy Logic Controller with the Mamdani FIS is quite convenient to implement. It does not require any cumbersome procedures. The proposed controller shows noticeable fast control response with induction motor. The proposed new FLC gives maximum torque over the entire speed range. Simple linguistic rules here control the speed. This fuzzy speed controller shows fast response, smooth performance and high dynamic response along with dynamic and transient conditions.

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