

The Art of Intelligent Control of Induction Motor Drive Using Fuzzy Logic Controller

Devangi J Jain¹, Jigar J Jain²

¹Lecturer, Electrical Engineering Dept, BBIT

²Asst. Prof, Electrical Engineering Dept, DJMIT

Abstract- In this paper Induction motors are the most important workhorse in industries and they are manufactured in large numbers. The induction motors have mainly developed in constant speed motor drives for general purpose application. The motor drive system comprises a voltage source inverter-fed induction motor (VSIM): namely a three-phase voltage source inverter and the induction motor. The squirrel-cage induction motor voltage equations are based on an orthogonal d-q reference rotating frame where the coordinates rotate with the controlled source frequency. The paper presents a novel fuzzy logic controller for closed loop Volts/Hz induction motor drive system. Fuzzy logic is a part of artificial intelligence(AI), which is an important branch of computer science or computer engineering. The inputs to the fuzzy logic controller are the linguistic variables of speed error and change of speed error, while the output is change in switching control frequency of the voltage source inverter. In this paper a comparison between fuzzy logic controller and traditional PI controllers are presented. The results validate the robustness and effectiveness of the proposed fuzzy logic controller for high performance of induction motor drive. Simulink software that comes along with MATLAB was used to simulate the proposed model.

Index terms- Artificial Intelligence, Induction motor, PI controller, fuzzy logic controller, speed control

I. INTRODUCTION

Today three phase induction motor drives are employed in different industrial fields with a wide power range. All this drives are working without speed sensors. Simulink induction machine models are available in the literature [1-2], but they appear to be black boxes with no internal details. Some of them in [1-2] recommend using S functions, which are software source codes for Simulink blocks. This technique does not fully utilize the power and ease of

Simulink because S-function programming knowledge is required to access the model variables. Another approach is using the Simulink Power System Block set [3] that can be purchased with Simulink. This block set also makes use of S-functions and is not as easy to work with as rest of the Simulink blocks. Reference [4] refers to an implementation approach similar to the one in this paper but fails to give any details. In this paper, a modular, easy to understand Simulink induction motor model is described. With the modular system, each block solves one of the model equations. Though induction motors have few advantageous characteristics, they also possess nonlinear and time-varying dynamic interactions [5 6], Using conventional PI controller, it is very difficult and complex to design a high performance induction motor drive system. The fuzzy logic control (FLC) is attractive approach, which can accommodate motor parametric variations and difficulty in obtaining an accurate mathematical model of induction motor due to rotor parametric and load time constant variations. The FLC is a knowledge-based control that uses fuzzy set theory and fuzzy logic for knowledge representation [7]. This paper presents a fuzzy logic controller suitable for speed control of induction motor drives.

II. INDUCTION MOTOR MODEL

One of the most popular induction motor models derived from this equivalent circuit is Krause's model [6]. An induction machine model can be represented with four differential equations. To solve these equations, they have to be rearranged in the state-space form, $\dot{X}=Ax+b$ Where $X=[Fqs FdsFdr Fdr w r]$ T is the state vector.

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$$\frac{dFqs}{dt} = \omega b \left[vqs - \frac{\omega e}{\omega b} Fds + \frac{Rs}{Xls} (Fmq + Fqs) \right] \dots (1)$$

$$\frac{dFds}{dt} = \omega b \left[vds + \frac{\omega e}{\omega b} Fqs + \frac{Rs}{Xls} (Fmd + Fds) \right] \dots (2)$$

$$\frac{dFqr}{dt} = \omega b \left[vqr - \frac{(\omega e - \omega r)}{\omega b} Fdr + \frac{Rr}{Xlr} (Fmq - Fqr) \right] \dots (3)$$

$$\frac{dFdr}{dt} = \omega b \left[vdr + \frac{(\omega e - \omega r)}{\omega b} Fqr + \frac{Rr}{Xlr} (Fmd - Fdr) \right] \dots (4)$$

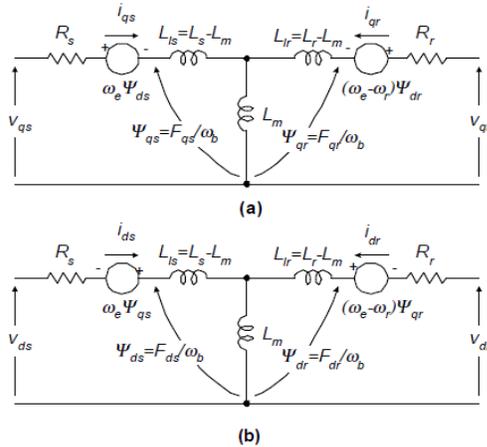


Fig 1 Dynamic or d-q equivalent circuit of an induction Machine

- Where d: direct axis,
- q: quadrature axis,
- s: stator variable,
- r: rotor variable,
- vqs, vds : q & d axis stator voltages,
- vqr, vdr : q&d axis rotor voltages,
- Fmq, Fmd : q& d axis magnetizing flux linkages
- Rr: rotor resistance,
- Rs: stator resistance,
- Xls: stator leakage reactance (we Lls),
- Xlr: rotor leakage reactance (we Llr)

III SIMULINK IMPLEMENTATION

The inputs of a squirrel cage induction machine are the three-phase voltages, their fundamental frequency, and the load torque. The outputs, on the other hand, are the three phase currents, the electrical torque, and the rotor speed.

The d-q model requires that all the three-phase variables be transformed to the two-phase synchronously rotating frame. Consequently, the induction machine model will have blocks

transforming the three-phase voltages to the d-q frame and the d-q currents back to three-phase

The induction machine model implemented in this paper is shown in Fig. 2. It consists of five major blocks: the o-n conversion, abc-syn conversion, syn-abc conversion, unit vector calculation, and induction machine d-q model blocks.

The following subsections will explain each block

A. O-N Conversion Block:

This block is required for an isolated neutral system, otherwise it can be bypassed. The transformation done by this block can be represented as follows:

$$\begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} = \begin{bmatrix} +\frac{2}{3} & -\frac{1}{3} & -\frac{1}{3} \\ -\frac{1}{3} & +\frac{2}{3} & -\frac{1}{3} \\ -\frac{1}{3} & -\frac{1}{3} & +\frac{2}{3} \end{bmatrix} \begin{bmatrix} v_{ao} \\ v_{bo} \\ v_{co} \end{bmatrix} \dots (5)$$

B. Unit Vector Block Calculation

Unit vectors $\cos \theta_e$ and $\sin \theta_e$ are used in vector rotation blocks, "abc-syn conversion block" and "syn-abc conversion block". The angle θ_e is calculated directly by integrating the frequency of the input three-phase voltages, ωe .

$$\theta_e = \int \omega e dt \dots (6)$$

The unit vectors are obtained simply by taking the sine and cosine of θ_e . This block is also where the initial rotor position can be inserted, if needed, by adding an initial condition to the Simulink "Integrator" block. Note that the result of the integration in (6) is reset to zero each time it reaches $2n$ radians so that the angle always varies between 0 and $2n$.

C. abc-syn conversion block:

To convert three-phase voltages to voltages in the two phase synchronously rotating frame, they are first converted to two-phase stationary frame using (7) and then from the stationary frame to the synchronously rotating frame using

$$\begin{bmatrix} v_{qs}^s \\ v_{ds}^s \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -\frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \end{bmatrix} \begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} \dots (7)$$

$$\begin{cases} v_{qs} = v_{qs}^s \cos \theta_e - v_{ds}^s \sin \theta_e \\ v_{ds} = v_{qs}^s \sin \theta_e + v_{ds}^s \cos \theta_e \end{cases}$$

where the superscript "s" refers to stationary frame

D. syn-abc conversion block:

This block does the opposite of the abc-syn conversion block for the current variables using (5) and (6) following the same implementation techniques as before.

$$\begin{cases} i_{qs} = v_{qs} \cos \theta_e + v_{ds} \sin \theta_e \\ i_{ds} = -v_{qs} \sin \theta_e + v_{ds} \cos \theta_e \end{cases} \quad (9)$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \end{bmatrix} \quad (10)$$

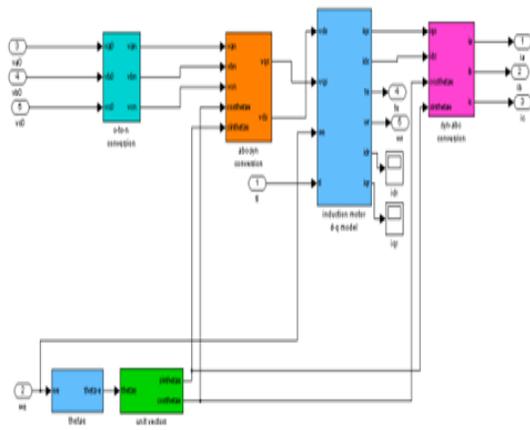


Fig.2 Induction machine model implementation in SIMULINK

E. Induction machine d-q model block

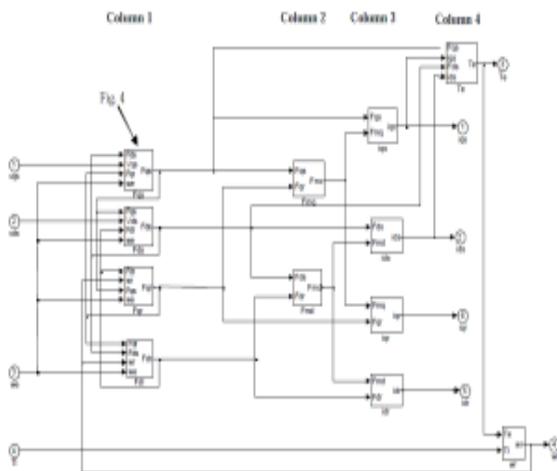


Fig.3 Induction machine dynamic model implementation

The resulting model is modular and easy to follow. Any variable can be easily traced using the Simulink

'Scope' blocks. The blocks in the first two columns calculate the flux linkages, which can be used in vector control systems in a flux loop. The blocks in Column 3 calculate all the current variables, which can be used in the current loops of any current control system and to calculate the three-phase currents. The two blocks of Column 4, on the other hand, calculate the torque and the speed of the induction machine, which again can be used in torque control or speed control loops, These two variables can also be used to calculate the output power of the machine.

IV. OPEN-LOOP CONSTANT V/Hz OPERATION

Fig. 4 shows the implementation of open-loop constant V/Hz control of an induction machine. This figure has two new blocks: command voltage generator and 3-phase PWM inverter blocks. The first one generates the three-phase voltage commands, and it is nothing more than a "syn-abc" block explained earlier.

The latter first compares the reference voltage, Vref to the command voltages to generate PWM signals for each phase, then uses these signals to drive three Simulink "Switch" blocks switching between +Vd/2 and -Vd/2 (Vd: dc link voltage). The open-loop constant V/Hz operation is simulated for 1.2s ramping up and down the speed command and applying step load torques.

V. CLOSED LOOP CONSTANT V/Hz OPERATION

The closed loop circuit has the fuzzy logic controller as the new component. The inputs to the fuzzy logic controller are the speed error and rate of change of speed error. The output is fed to the power converter-pwm inverter, which is used to adjust the inverter switching control frequency. The output of FLC controls the firing angle of the inverter, thereby varying the output voltages. The reference speed of the pwm inverter is modified each time when there is a different output of the fuzzy controller. These outputs are found from the truth table (rule table). The pwm inverter output is then fed to the induction machine where a constant V/Hz operation is carried out.

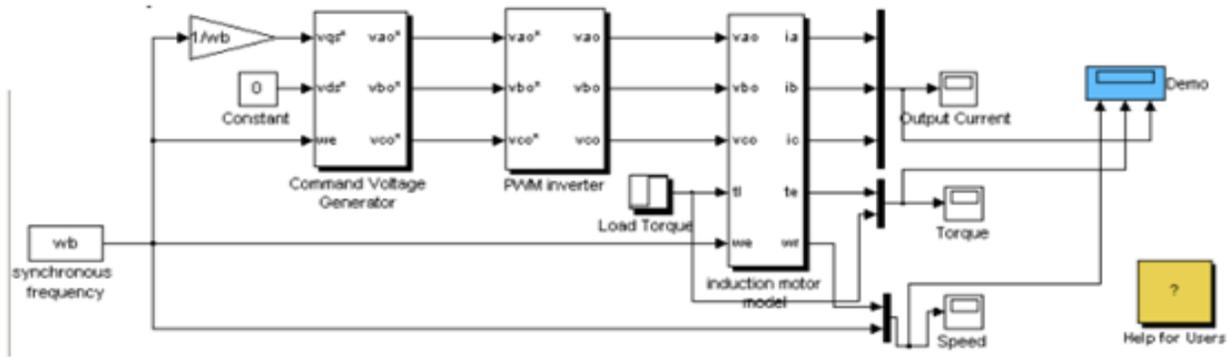


Fig.4.Open loop V/Hz Operation

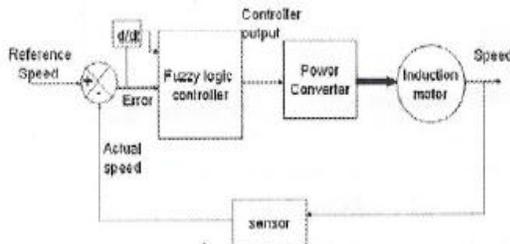
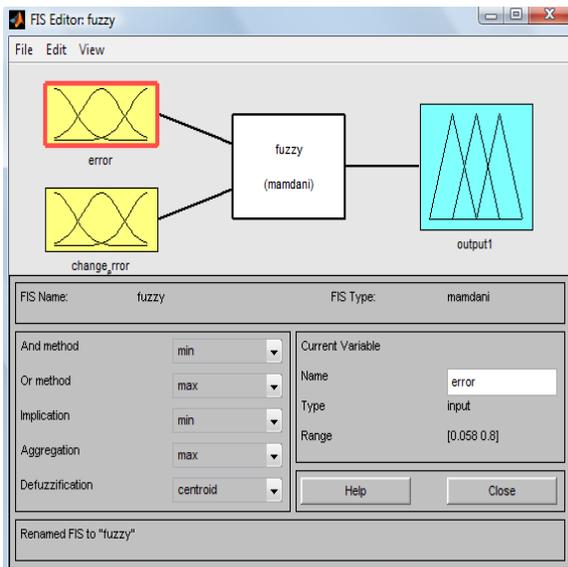


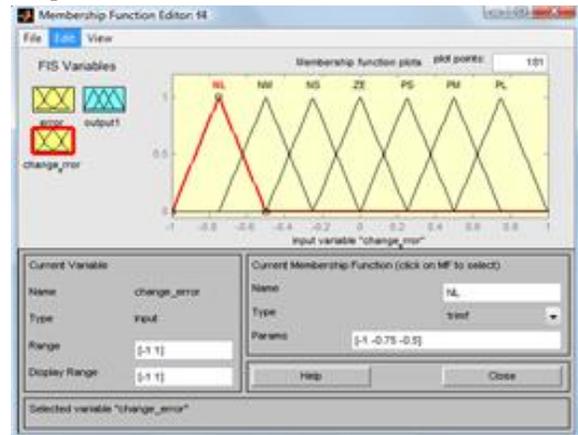
Figure 5. Block Diagram of Closed Loop Using Fuzzy Logic Controller

VI. FUZZY LOGIC CONTROLLER DESIGN

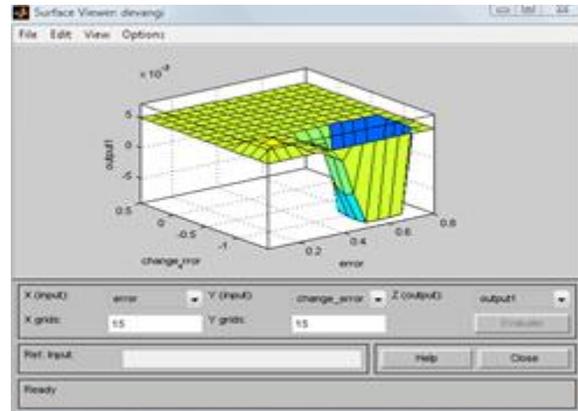
The fuzzy logic controller has been designed using the fuzzy logic GUI provided in Matlab. As shown above, we have three FIS variables: Error, change in error, and the output. For each of the following, we define the ranges from the data obtained, and then we use the triangular membership function and have such member functions for each FIS.



MEMBERSHIP FUNCTION



SURFACE VIEWER



FUZZY LOGIC CONTROL ALGORITHM

A fuzzy algorithm consists of situation and action pairs. Conditional rules expressed in IF and THEN statements are generally used. For example, the control rule might be:

if the output is lower than the requirement and the output is dropping moderately then the input to the system shall be increased greatly. Such a rule has to be converted into a more generally statement for application to fuzzy algorithms. To achieve this the

following terms are defined: error equals the set point minus the process output, error change equals the error from the process output minus the error from last output: and control input applied to the process. In addition, it is necessary to quantize the qualitative statements and the following linguistic sets are assigned

The membership function are:

- NG= Negative biG
- NP= Negative small
- Z= Zero
- PP= Negative
- PG= Negative big

TRUTH TABLE

| e→ Δe↓ | NG | NP | Z | PP | PG |
|-----------|----|----|----|----|----|
| NG | NG | NG | NP | NP | Z |
| NP | NG | NP | NP | Z | PP |
| Z | NP | NP | Z | PP | PP |
| PP | NP | Z | PP | PP | PG |
| PG | Z | PP | PP | PG | PG |

RESULT

The output of the fuzzy logic controller (FLC) is used to adjust the inverter switching control frequency and the dc voltage at the inverter using a constant (VF) ratio the induction motor drive system using FLC. Results were obtained using a three phase squirrel cage induction motor with 208 volt phase to phase, 60 Hz rated frequency, 1750 rpm rated speed and ¼ Hp rated power.

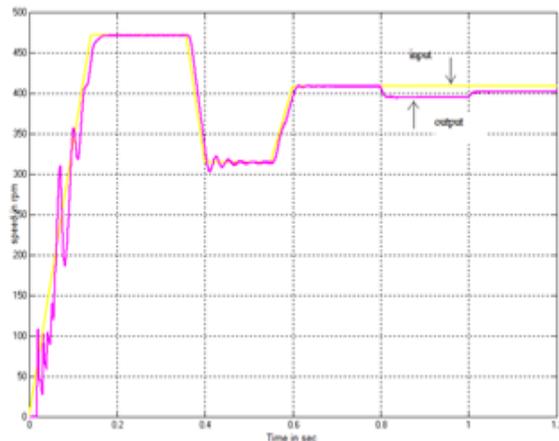


Fig. Speed v/s Time for Closed Loop constant V/Hz with fuzzy logic controller

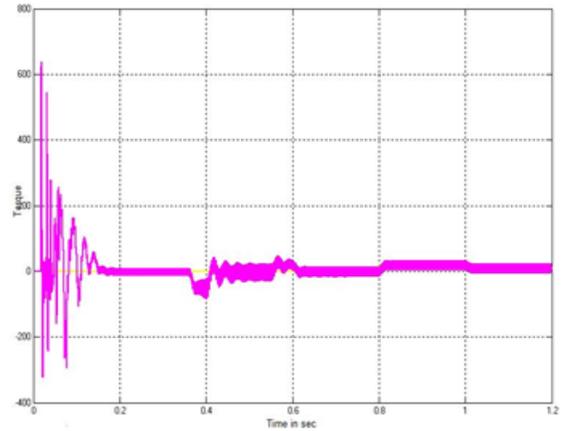


Fig. Torque v/s time for closed loop V/Hz using Fuzzy logic controller

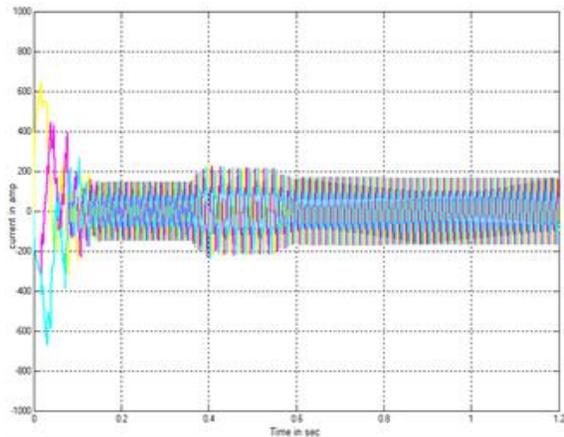


Fig. Current v/s Time for Closed Loop constant V/Hz control with fuzzy controller

VII. CONCLUSION

This paper presents a simple, novel and robust fuzzy logic speed controller for high performance induction motor drives. The FLC does not need exact knowledge of induction motor and tolerate range load excursions and parametric variations. The control assignment rules are obtained using heuristic trial and error and human expertise. The simulation test results validate the FLC robustness for different speed trajectories.

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