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Comparative Analysis of PID and FUZZY Control Techniques for Speed Control of DC and Induction Motors

Mohammed Jamaluddin Khan Junaid
M.Tech (CS),
LORDS Institute of Engineering and Technology,
Hyderabad, Telangana, India.

M.Rama Krishna
Associate Professor & HOD,
Department of EEE,
LORDS Institute of Engineering and Technology,
Hyderabad, Telangana, India.

ABSTRACT:

This paper presents a speed-sensor less control system for a separately excited DC motor. In particular, an adaptive observer is developed to estimate the actual speed of the motor. In addition, instead of using a traditional linear PI controller like previous researches, a Fuzzy Logic Controller (FLC) has been proposed to significantly improve the performance of the motor. A fuzzy controller used for speed control of motor drive has asymmetric membership functions which need much more manual adjusting by trial and error if optimized performance is wanted. The main task of the tuning method is to adjust the parameters of the membership functions and weights in order to minimize the square of the speed error between actual and reference values.

Index Terms:

DC motor, speed sensor less control, PID, fuzzy logic, induction motor.

I.INTRODUCTION:

Most of DC motor drives are designed to control the speed and the position with the use of sensors such as pulse encoders ortachchogenerators. In order to reduce the cost, several researches [1-4] have proposed the control algorithms for speed sensor less DC motor control systems. In general, these control algorithms are quite complicated or require a lot of computational steps. Fuzzy logic controllers (FLCs) developed from the theory of fuzzy sets has been applied to many nonlinear control systems in electric drives and power electronics [6-9].

Obviously, fuzzy logic should be intensively used for DC motor drives to improve the performance of these systems.In particular, a FLC has been proposed to improve the performance of a speed-sensorless separately-excited DC motor control system. The paper is organized as follows. Section II mentions the dynamic model of a separately-exited DC motor. Induction motors (IMs) have been widely used as workhorse in the industry over the years due to its low cost, and simple and robust construction. However, the control of IM is complex due to its nonlinear nature, and the parameters change with operating conditions. Traditionally, the conventional fixed-gain proportional–integral (PI) and PI–derivative (PID) controllers and their adaptive versions have been widely used for motor drives.A fuzzy controller (FC) is considered because of the limitations of fuzzy logic control (FLC).

A fuzzy controller used for speed control of motor drive has asymmetric membership functions which need much more manual adjusting by trial and error if optimized performance is wanted. On the other hand, it is extremely tough to create a serial of training data for ANN that can handle all the operating modes. Despite many advantages of intelligent controllers, the industry has been still reluctant to apply these controllers for commercial drives due to high computational burden imposed by large number of membership functions, weights, and rules, particularly on self-tuning condition. High computational burden leads to low sampling frequency, which is not sufficient for real-time implementation. Only weights were tuned online, but the membership functions were fixed to keep the computational burden at reasonable level. The membership functions were adjusted in simulation by trial-and-error procedure. Moreover, a high-torque ripple was observed due to the low sample rate for the conventional two-input NFC.

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A fast processor may be used to implement such high computational intelligent algorithms, but the high cost of the fast processor is another concern for the industry.

II.MODEL OF DC MOTOR:

DC motors are most suitable for wide range speed control and are therefore used in many adjustable speed drives. Fig 1 shows a separately excited DC Motor. Ra is the armature resistance and La is the armature inductance of separately excited dc motor. Rf is the field resistance and Lf is the inductance of the field winding.

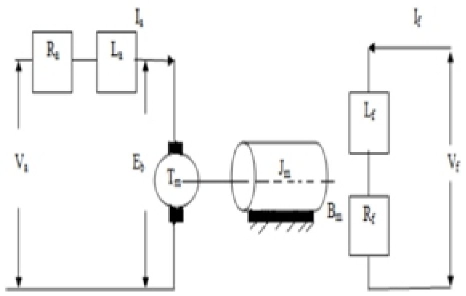

Fig. 1 Separately Excited DC Motor Model

A linear model of a simple DC motor consists of an electrical equation and mechanical equation as determined in the following equations

Va = Eb + IaRa + La (dIa/dt)
Tm = Jmdωdt + Bm ω + TL

For a specific separately-excited DC motor, the power supply of the excitation circuit is separated from the power supply of the armature circuit. The dynamics of the separately-excited DC motor includes the following equations:

$$u_a(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + e_b(t)$$
$$e_b(t) = k\omega(t)$$
$$T_m(t) = k i_a(t)$$
$$\frac{d\omega(t)}{dt} = \frac{T_m(t) - T_L(t)}{J}$$

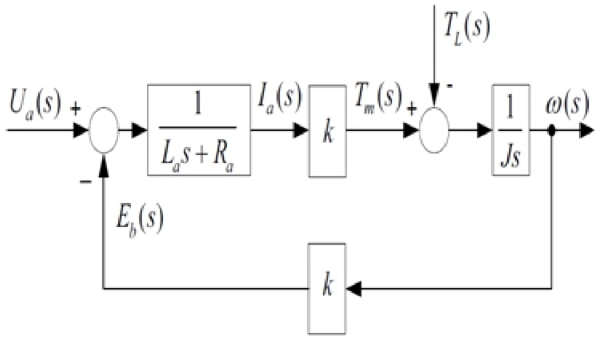

Fig 2: Block diagram of separately-excited DC motor model

III.INDUCTION MOTOR DYNAMICS:

The mathematical model for a three-phase Y-connected squirrel-cage IM in a de − qe synchronously rotating reference frame is described in (1)-(4).

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

$$T_e = J_m \frac{d\omega_r}{dt} + B_m \omega_r + T_L$$
$$T_e = \frac{3}{2}\frac{P}{2} L_m (i_{qs}^e i_{dr}^e - i_{ds}^e i_{qr}^e)$$
$$\frac{d\theta_r}{dt} = \omega_r$$

where VeqsVeds are d,q axis stator voltages, Ieqs, Ieds are d,q axis stator currents, Ieqr, Iedr are d,q axis rotor currents, Rs , Rr are the stator and rotor resistances per phase, Ls ,Lr are the self-inductances of the stator and rotor, respectively; Lm is the mutual or magnetizing inductance; ωeis the speed of the rotating magnetic field; ωr is the rotor speed; P is the number of poles; p is the differential operator (d/dt); Te is the developed electromagnetic torque; Tl is the load torque; Jm is the rotor inertia; Bm is the rotor damping coefficient; and θr is the rotor position. The motor parameters are given in the appendix. The two-axis stator voltages and currents are related to the three-phase representations by equation

$$\begin{bmatrix} X_{qs}^e \\ X_{ds}^e \end{bmatrix} = \begin{bmatrix} -\sin\omega_e t & \cos\omega_e t \\ \cos\omega_e t & \sin\omega_e t \end{bmatrix} \begin{bmatrix} \frac{2}{3} & -\frac{1}{3} & -\frac{1}{3} \\ 0 & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \end{bmatrix} \begin{bmatrix} X_{as} \\ X_{bs} \\ X_{cs} \end{bmatrix}$$

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Where x may represent the current or voltage

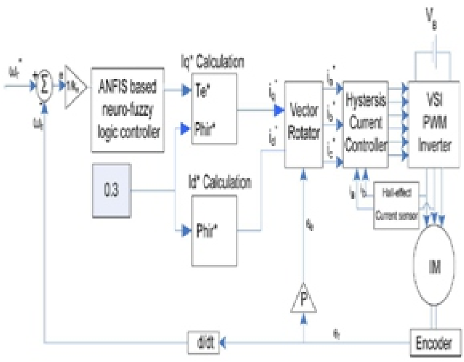

Fig 3: Block diagram of the proposed NFC based IM drive.

IV.CONTROL STRUCTURE:

The key feature of the field-oriented control is to keep the magnetizing current at a constant rated value by setting iedr = 0. Thus the torque-producing current component ieqr can be adjusted according to the torque demand. With this assumption, the mathematical formulations can be rewritten as:

$$\omega_{sl} = \frac{R_r}{L_r}\frac{i^e_{qs}}{i^e_{ds}}$$

$$i^e_{qs} = -\frac{L_m}{L_r} i^e_{qr}$$

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\lambda^e_{dr} i^e_{qs}$$

Where ωsl is the slip speed and λedr is the d-axis rotor flux linkage. Equations are used to simulate the whole drive system. The schematic diagram of the proposed NFC-based indirect field oriented control of induction motor is shown in Fig.1. The basic configuration of the drive system consists of an induction motor fed by a current controlled voltage source inverter. The normalized speed error Δω% is processed by the neuro-fuzzy controller to generate the reference torque Te*(n). The command current i*e(n)is calculated from above equation as following:

$$i^*_q(n) = T^*_e(n)\frac{2}{3}\frac{2}{P}\frac{L_r}{L_m}\frac{1}{\lambda^*_{dr}}$$

Currents i*q and i*d are transformed into i*a, i*b and i*c. The phase command currents i*a, i*b and i*c are then compared with the corresponding actual currents, ia, ib and ic to generate PWM logic signals, which are used to fire the power semiconductor switches of the 3-phase inverter. Thus the inverter produces the actual voltages to run the induction motor.

V.SPEED CONTROL BY FUZZY LOGIC:

As shown in Figure 3, a linear PI controller is used for controlling the motor speed. However, in order to obtain the best performance of the whole system, a fuzzy logic based speed controller should be used and it will be replaced for the traditional PI controller. The structure of a typical FLC is shown in Figure 4.
The inputs of the FLC includes
The error e = C1 [w*- w^]
The change of the error ce = C2 (ek –ek-1) with ek and ek-1 are the values of e at the sampling time k and k −1, respectively,
The FLC has a single output variable u accompanying C3. C1, C2 and C3 are specified after several trials. Figure 5 is the forms of membership functions for the input and output variables. Table I is called 'The rule table'.

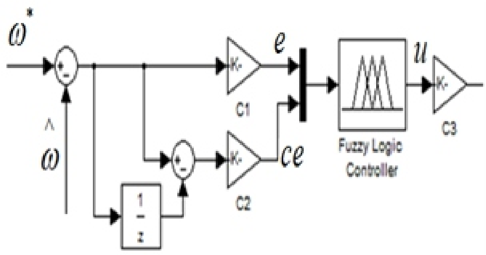

Fig 4: Structure of a typical fuzzy logic controller

At a specific moment, according to Table.I, we can express some fuzzy rules as follows:
• IF e is PB AND ce is NB THEN u is ZZ
• IF e is PS AND ce is NB THEN u is NS
• IF e is ZZ AND ce is NB THEN u is NS
• IF e is NS AND ce is NB THEN u is NB
• IF e is NB AND ce is NB THEN u is NB
Finally, the output fuzzy set will be defuzzified using the method of Centre of Area (COA) as follows:

$$x_{COA} = \frac{\sum_i \mu(x(i)) \times x(i)}{\sum_i \mu(x(i))}$$

where
• x(i) is the i -th value of the change of the membership function of the variable u ,
• μ(x(i))is the value of the membership function of the variable u corresponding to x(i)
• COA x is the value of the variable u after defuzzification.

VI.SIMULATION RESULTS:

By PI controller

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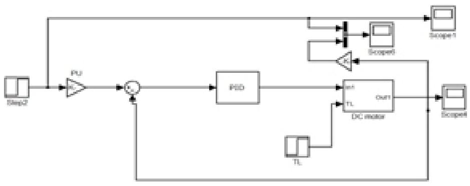

Fig 5: simulation circuit of PI controlled DC motor

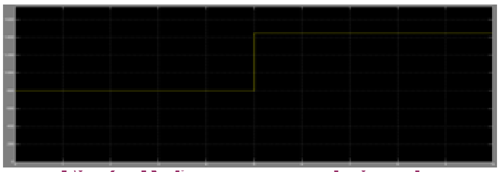

Fig 6: Reference speed signal

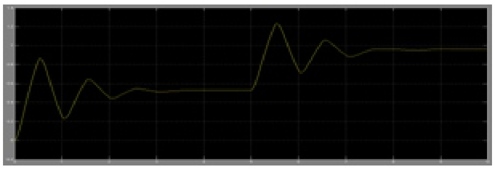

Fig 7: DC motor Output signal

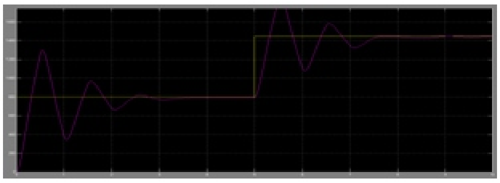

Fig 8: comparative wave form of reference and output signal Speed control by Fuzzy controller

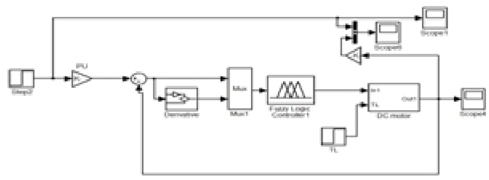

Fig 9: Simulation circuit of DC motor fuzzy controller

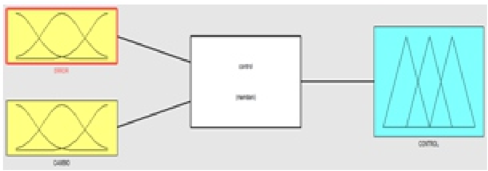

Fig 10: fuzzy controller membership functions

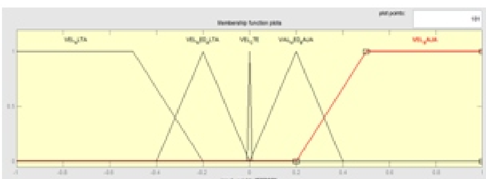

Fig 11: Membership function of input variable "ERROR"

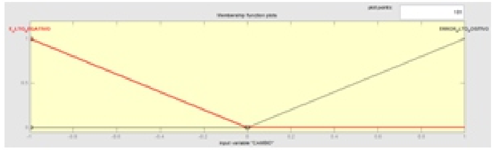

Fig 12: Membership functions of input variable "CAMBIO"

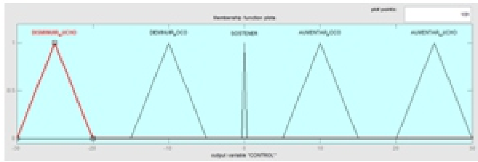

Fig 13: Membership function of output variable "CONTROL"

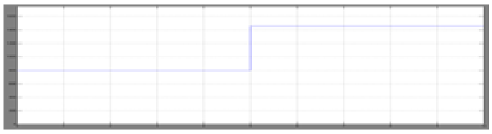

Fig 14: Reference speed signal

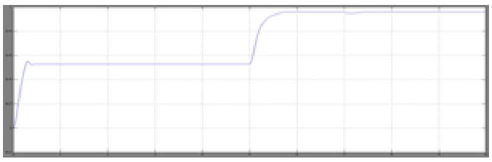

Fig 15: Output speed signal with fuzzy controller

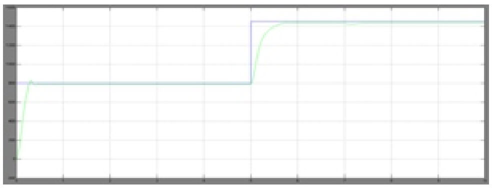

Fig 16: comparative wave form of reference and output signal with fuzzy controller

A fuzzy controller (FC) is considered because of the limitations of fuzzy logic control (FLC). A fuzzy controller used for speed control of motor drive has asymmetric membership functions which need much more manual adjusting by trial and error if optimized performance is wanted. On the other hand, it is extremely tough to create a serial of training data for ANN that can handle all the operating modes. Despite many advantages of intelligent controllers, the industry has been still reluctant to apply these controllers for commercial drives due to high computational burden imposed by large number of membership functions, weights, and rules, particularly on self-tuning condition.

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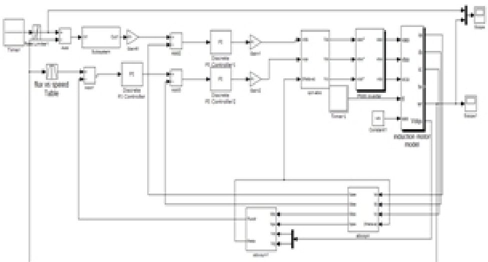

Fig 16: simulation circuit for induction motor with control strategy

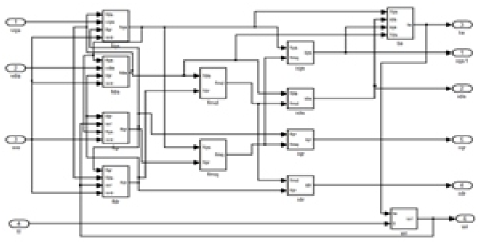

Fig 17: dynamic modeling of induction motor in simulink

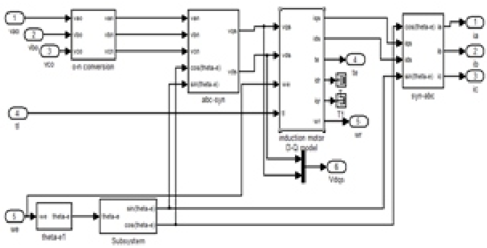

Fig 18: synchronous frame representation of induction motor

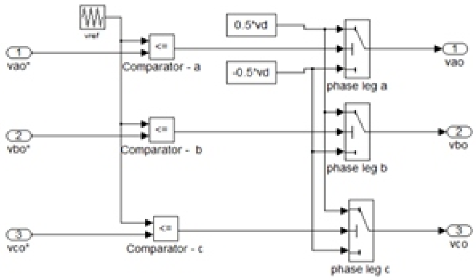

Fig 19: PWM inverter

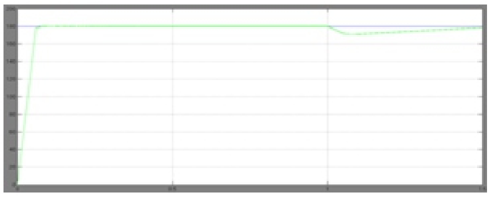

Fig 20: reference rotor speed and actual speed under PI controller

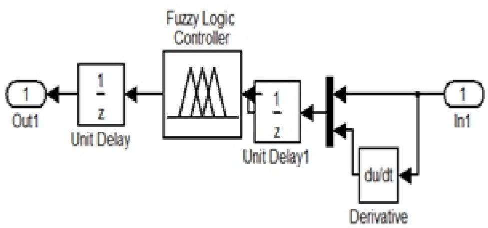

Fig 21: fuzzy logic controller

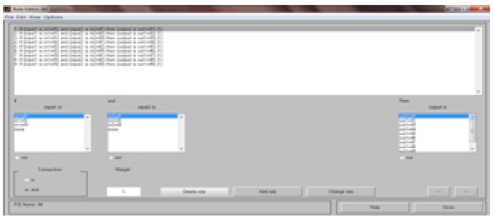

Fig 22: fuzzy rules

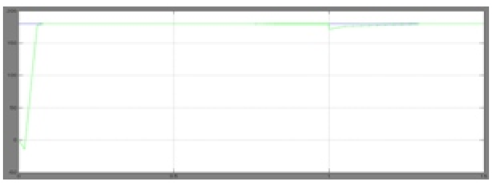

Fig 23: reference rotor speed and actual speed under double input

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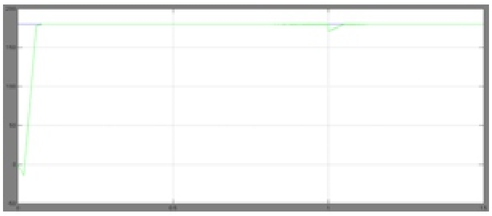

Fig 24: reference rotor speed and actual speed under proposed NFC

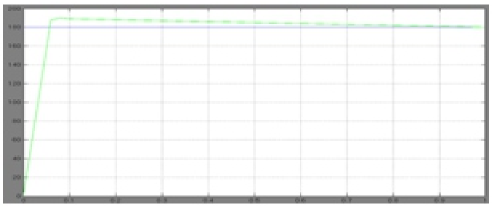

Fig 24: Simulated speed responses of the IM drive with doubled rotor resistance PI controller

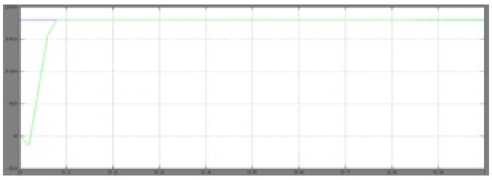

Fig 25: Simulated speed responses of the IM drive with doubled rotor resistance Conventional two-input NFC

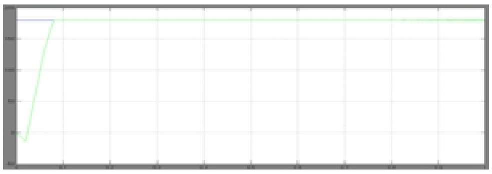

Fig 26: Simulated speed responses of the IM drive with doubled rotor resistance Proposed NFC

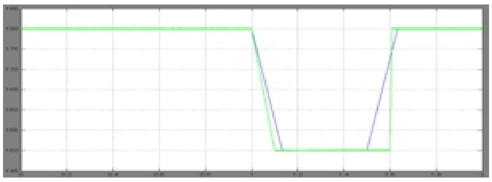

Fig 27: Simulated speed responses of the IM drive at a step change of speed reference PI controller

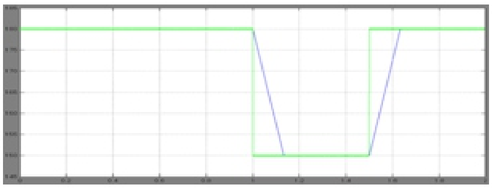

Fig 28: Simulated speed responses of the IM drive at a step change of speed reference Conventional two-input NFC.

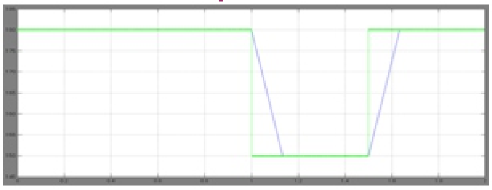

Fig 29: Speed responses of the IM drive at a step change of speed reference Proposed NFC.

VII.CONCLUSION:

The performance of the system is significantly improved by introducing a FLC for the speed control with the change of the reference speed or the change of the load torque. In addition, this method will be effective if the motor parameters of the DC motor such as Ra, La can be exactly identified. A novel and simplified on-line self-tuning FC-based speed control of IM drive has been simulated. In the proposed FC, both weights and membership functions are on-line tuned based on operating conditions. The proposed controller can also be applied to other types of motors of different sizes only by adjusting the tuning rates.

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