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Slip Gain Tuning of Induction Motor Induction using Model Reference Adaptive Control

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***Abstract:*-- The aim of this paper is to regulate the speed of an indirect vector controlled induction motor (IVCIM) drive using Fuzzy logic controller based Model Reference Adaptive Control (MRAC). The design and configuration of a fuzzy logic controller (FLC) based MRAC for induction motor drive is presented. The MATLAB/SIMULINK software is used to implement the PI and fuzzy logic controller based MRAC. Finally the performance of PI and FLC-MRAC based induction motor drive is compared at dynamic load conditions to verify the robustness of the FLC-MRAC.**

***Keywords:*— Indirect vector control, induction motor, fuzzy logic controller, PI controller, speed control.**

I. INTRODUCTION

Electric motors used in industrial and commercial premises consume high electricity. Previously DC motors were used in applications for instance industrial robots and numerically controlled machinery where speed and position control is required. This is because it is easy to control flux and torque. But the main drawback of DC motor is, it uses a commutator because of which the motor size and maintenance cost is increased and motor life is reduced. The induction motor control has become a cost-effective solution due to the improvements in power electronics and digital technology. Thus, induction motors replaced the DC motors in various industrial plants.

There are many scalar control techniques that operate variable speed of three phase electric motors. In recent times, it has been exposed that speed calculation can be done from the current and voltage across the AC motor thus the need of speed sensors is eliminated. There are problems in controlling speed sensorless induction motor which are addressed by many proposals. Field oriented control helps in providing smooth motion at low speeds and active operation at high speeds[1]. But the performance of the field orientation is largely dependent on exact knowledge of the machine parameters. The above problems can be overcome by the induction motor control based on the research done. Fuzzy logic controller based model reference adaptive control is used in providing the dynamic smooth performance of induction motor[2]. Fuzzy controller based MRAC along with the PWM controlled inverter gives accurate controlled speed through controlling voltage level and it simplifies complex task into manageable subtasks.

The induction motor is fed by the voltage source inverter with predictive current controller using fuzzy logic controller based MRAC. The technique helps induction motor in achieving similar torque and speed control performance of dc machine hence replacing the dc machine with induction machine in many high-performance applications. The performance of FLC-MRAC has been successfully compared with conventional PI controller.

II. INDIRECT VECTOR CONTROL OF INDUCTION MOTOR DRIVE

The induction motor can be transformed to a dc motor with field oriented control. In induction motor the armature winding is on the rotor and currents generatefield in the stator winding as in dc machine. The rotor conduction motion with respect to stator field and armature current induces EMF in the winding, this derives the rotor current. In other words, the source for the magnetic field and the armature current is stator current. In the squirrel cage motor which is the most commonly used, only the stator current can be controlled as the rotor winding cannot be accessed. There is no rigid physical disposition between stator and rotor fields and non linear torque equation results in non inherent optimal torque production condition.Therefore the field and torque control is not as easy as in dc motor. The block diagram of an indirect vector control of induction motor drive is shown in fig. 1. The following dynamic equations are taken into consideration to implement indirect vector control strategy [3].

$$\theta_e = \int \omega_e dt = \int(\omega_r + \omega_{sl}) = \theta_r + \theta_{sl} \qquad (1)$$

The rotor circuit equation

$$\frac{d\Psi_{dr}}{dt} + \frac{R_r}{L_r}\Psi_{dr} - \frac{L_m}{L_r}R_r i_{ds} - \omega_{sl}\Psi_{qr} = 0 \qquad (2)$$

$$\frac{d\Psi_{qr}}{dt} + \frac{R_r}{L_r}\Psi_{qr} - \frac{L_m}{L_r}R_r i_{qs} + \omega_{sl}\Psi_{dr} = 0 \qquad (3)$$

For decoupling control $\Psi_{qr} = 0$, the total flux $\widehat{\Psi_r}$ directs on the d^e axis.

Now from equations (1) and (2) we get

$$\frac{L_r}{R_r}\frac{d\widehat{\Psi_r}}{dt} + \widehat{\Psi_r} = L_m i_{ds} \qquad (4)$$

Slip frequency can be calculated as

$$\omega_{sl} = \frac{L_m R_r}{\widehat{\Psi L_r}} i_{qs} \qquad (5)$$

For constant rotor flux Ψ_r and $d\Psi_r/dt$=0, substituting in equation (4) yields the rotor flux set as

$$\widehat{\Psi_r} = L_m i_{ds} \qquad (6)$$

The electromechanical torque developed is given by

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\widehat{\Psi_r} i_{qs} \qquad (7)$$

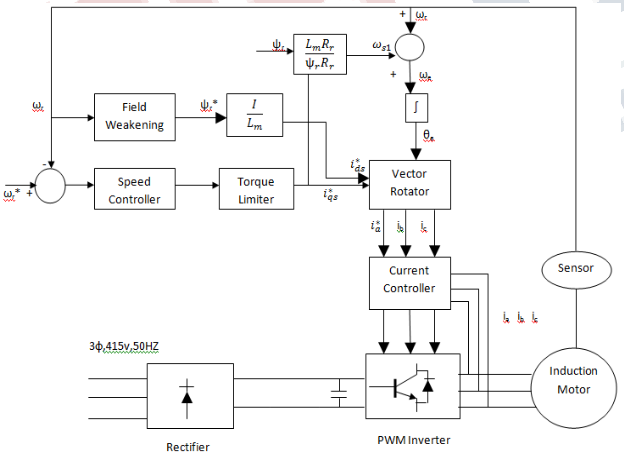

Figure 1: Indirect vector controlled Induction Motor Dive

III. DESIGN OF FUZZY LOGIC CONTROLLER BASED MRAC FOR INDUCTION MOTOR DRIVE FUZZY LOGIC CONTROLLER:

Fig. 2 shows the functional block diagram of fuzzy logic controller (FLC)[4].Here the first input is the speed error 'e' and second is thechange in speed error 'ce' at sampling time 'ts'. The two inputvariables e(ts) and ce(ts) are calculated at every sampling timeas

$$e(t_s) = \omega_r^*(t_s) - \omega_r(t_s) \qquad ce(t_s) = e(t_s) - e(t_s - 1) \qquad (8)$$

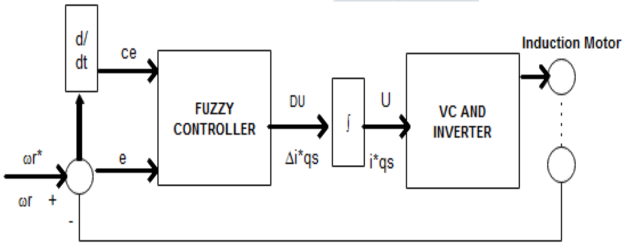

Fig.2 Functional block diagram of Fuzzy Logic Control

where 'ce' denotes the change of error 'e', $\omega_r^*(t_s)$ is the reference rotor speed, $\omega_r(t_s)$ is the actual speed, $e(t_s - 1)$is the value of error at previous sampling time.

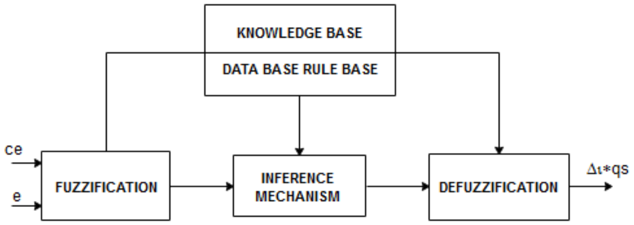

Fig.3 Fuzzy Logic Controller Internal structure

The output variableis the change in torque ΔT which is integrated to get thereference torque as shown in the equation

$$T^*(t_s) = T^*(t_s - 1) + \Delta T \qquad (9)$$

As shown in Fig. 2, the fuzzy logic controller consists of fourblocks, Fuzzification, inference mechanism, knowledge baseand Defuzzification.

A. Fuzzification:

The variables of input error e(t_s) and change in error ce(t_s) are modified intro fuzzy variables in this stage. It maps the *e* and *ce* to linguistic labels of fuzzy sets. Each label is associated with membership function consisting two inputs and an output. All the inputs and output have membership function with the following linguistic labels: NB, NM, NS, ZE, PS, PM, PB.

B. Knowledge base and Inference mechanism:

Knowledge base defines the rules termed as IF-THEN rules which govern the input and output relationship in terms of membership function. The input variables e(ts)and ce(ts) executes 7*7 rules and are processed by inference mechanism using Mamdani's algorithm. For example if we consider the first rule, IF change in speed and change in speed error is NB, THEN the output is NB.

C. Defuzzification:

Defuzzification uses various methods in producing fuzzy set value of fuzzy variable ΔT. Here the centre of gravity or centroids method is used in calculating the final fuzzy value $\Delta T(t_s)$.COA method used in defuzzification generates $\Delta T^*(t_s)$ output with the help of centre of gravity in which ΔT(ts) is considered as geometric centre of $\mu_{out}(\Delta T)$area, the $\mu_{out}(\Delta T)$ is formed byuniting all the contributions of rules satisfying the condition to be greater than zero. The COAexpression can bewritten as

$$\Delta T = \frac{\sum_{i=1}^{n} \Delta T_i . \mu_{out}\,(T_i)}{\sum_{i=1}^{n} \mu_{out}\,(\Delta T_i)} \qquad (10)$$

The Te* obtained by integration is used to calculatei*qs.

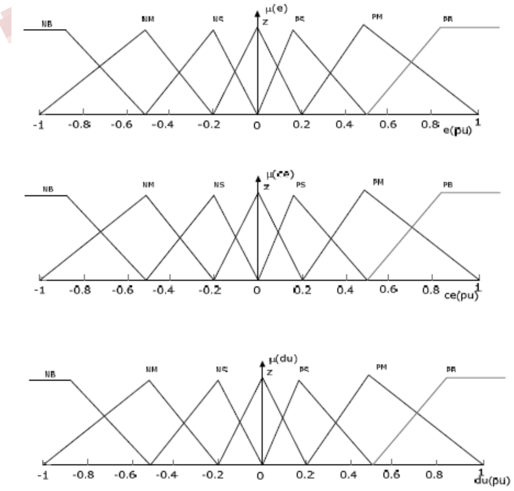

Fig.4. Membership Function of Fuzzy Variables μe, μce and μ(du)

e(pu) / ce(pu)	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
ZE	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

Table: 1 Fuzzy Controller Rule Base

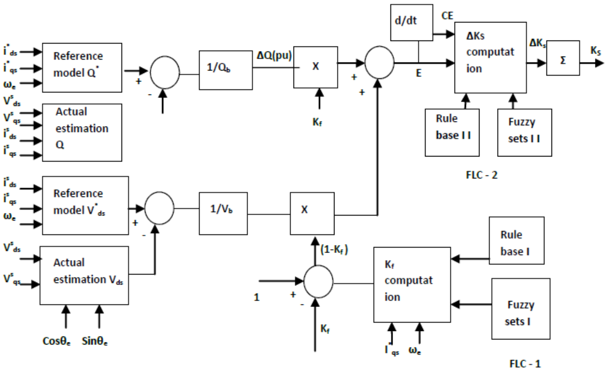

Fig.5Model Reference Adaptive Control with Slip Gain Tuner

IV. FUZZY LOGIC BASED MODEL REFERENCE ADAPTIVE CONTROL WITH SLIP GAIN TUNER FOR IVCIM DRIVE:

The MRAC method basedon reactive power and stator d-axis voltage arecombined together with a weighting factor which isgenerated by a fuzzy controller. The weighting factorensures the dominant use of reactive power method inlow speed high torque region whereas the d – axisvoltage method is dominant in high speed low torqueregion (Gilberto C.D. Sousa et al.1993). A secondfuzzy controller tunes the slip gain based on combineddetuning error and its slope so as to ensure fast convergence at any operating point on torque-speedplane. Ablock diagram of fuzzy logic based on model referenceadaptive control (MRAC) of slip gain tuner is shown inFig.5. Here the reference model output signals X* thatsatisfied the tuned vector control is usually a functionof command current ids*, iqs*, machine inductance, andoperating frequency. The adaptive model X is usuallyestimated by machine feedback voltage and current.The reference model output is compared with that ofadaptive model and the resulting error generates theestimated slip gain through a fuzzy P-I controller.The slip tuning occurs when X matches with X*.The objective is to provide an adaptive feedback control forfast convergence at any operating point ,irrespective ofthe strength of error signal E and its derivative signalCE.

V. SIMULATION RESULTS AND DISCUSSION

The machine will be at stand still initially without any load. The reference speed increases linearly from zero and its rated value is 314 rpm with FLC-MRAC and PI controller.The simulation wasdone on both PI controller and fuzzy logic controller based MRAC on the indirect-vector controlled induction motor. The simulink block diagram of indirect vector controlled induction motor drive is demonstrated in Fig. 6. Fig.7 and Fig.10 shows the stator currents using PI controller and fuzzy logic controller based MRAC respectively. It is shown that the disturbance in the stator currents using PI controller as in Fig.7 has been reduced when fuzzy logic controller based MRAC was used as in Fig.10.

Load torque and electromagnetic torque using PI controller and fuzzy logic controller based MRAC are depicted in Fig.8 and Fig.11 respectivelyHere the PI controller was affected when there is a change in load whereas there is no affect on FLC-MRAC. Fig. 11 shows that the proposed FLC-MRAC is more robust to load disturbance compared to PI controller. Finally Fig.9 and Fig.12 depicts the reference speed and actual speed response using PI controller and FLC-MRACrespectivelyand it is clear that FLC-MRACoffers faster response compared to PI. Hence FLC-MRACbased drive system is superior to PI based drive system in all respect rise time, settling time and overshoot.

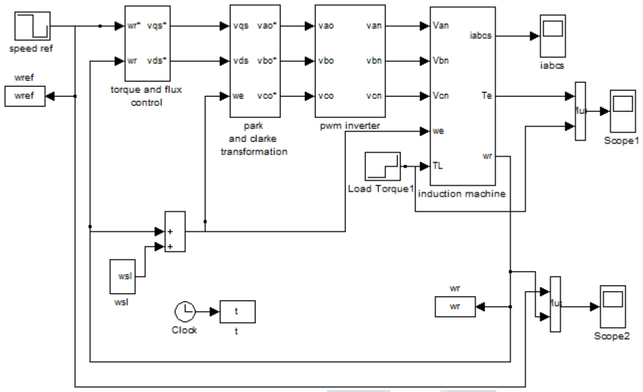

Fig 6. Simulink block diagram of indirect vector controlled induction motor drive

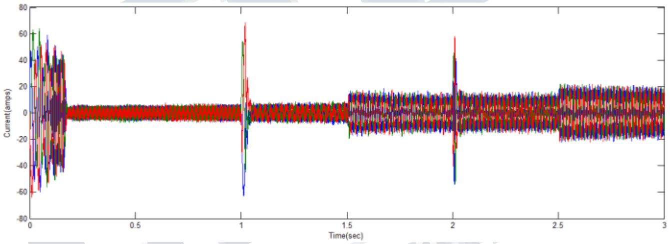

Fig 7. Stator currents using PI controller

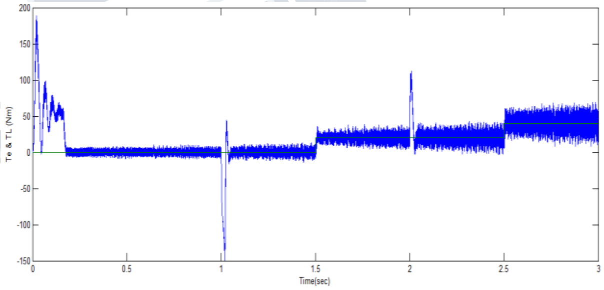

Fig 8. Load torque and electromagnetic torque using PI controller

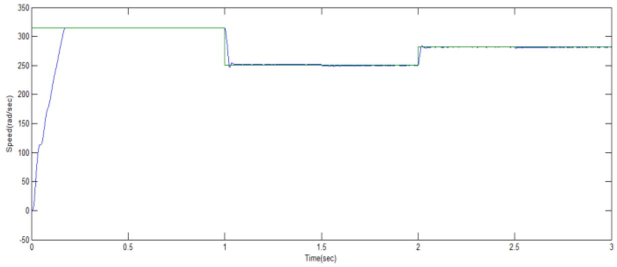

Fig 9. Reference speed and actual speed using PI controller

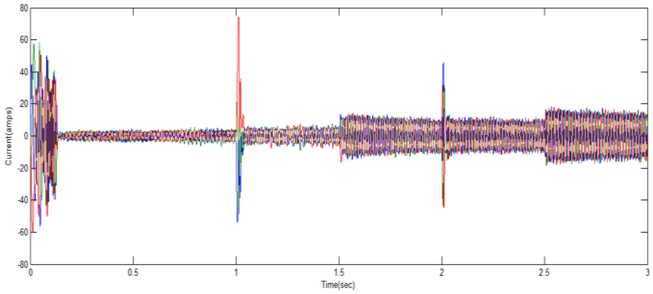

Fig 10. Stator currents using fuzzy logic controller based MRAC

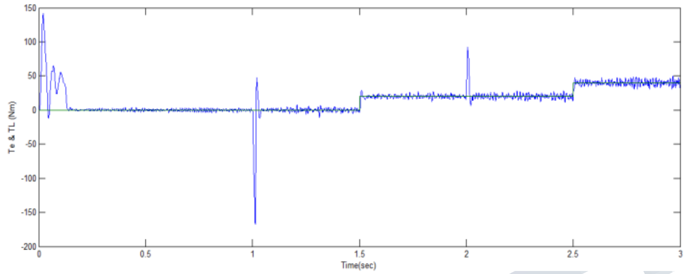

Fig 11. Load torque and electromagnetic torque using fuzzy logic controller based MRAC

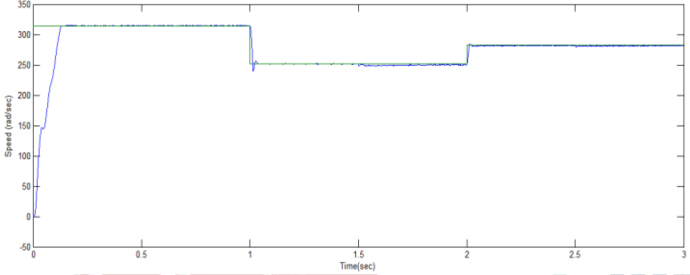

Fig 12. Reference speed and actual speed using fuzzy logic controller based MRAC

VI. CONCLUSION

In this paper fuzzy logic controller based model reference adaptive control (MRAC) was proposed for speed regulation of an indirect vector controlled induction motor drive. The performance of the FLC-MRACbased indirect vector controlled induction motor drive was compared with that of conventional PI controller at dynamic load conditions. The simulation results show that the designed FLC-MRACbased indirect vector control induction motor driveperforms better than PI controllerat different dynamic operating conditions such as sudden change in reference speed, step change in load, etc.

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