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Fuzzy Logic based Speed Control of an Induction Motor Using Indirect Vector Control Method

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Abstract

Efficiency optimization of motor drives is very important not only from the viewpoints of energy loss and hence cost saving, but also from the perspective of environmental pollution. Several efficiency optimization methods for induction motor (IM) drives have been introduced nowadays by researchers. Distinctively, artificial intelligence (AI)-based techniques, in particular Fuzzy Logic (FL) one, have been emerged as a powerful alternative to conventional methods. Design objectives that are mathematically hard to express can be incorporated into a Fuzzy Logic Controller (FLC) using simple linguistic terms. The merit of FLC relies on its ability to express the amount of ambiguity in human reasoning. When the mathematical model of a process does not exist or exists with uncertainties, FLC has proven to be one of the best alternatives to move with unknown process.

In this paper, an implementation of intelligent controller for speed control of an induction motor (IM) using indirect vector control method has been developed and analyzed in detail. The project is complete mathematical model of field orientation control (FOC) of induction motor and simulated in MATLAB for studies of a 50 HP, squirrel cage type induction motor has been considered. The comparative performance of Fuzzy Logic control technique has been presented and analyzed in this work. The present approach avoids the use of flux and speed sensor which increase the installation cost and mechanical robustness. The fuzzy logic controller is found to be a very useful technique to obtain a high performance speed control. The indirect vector controlled induction motor drive involves decoupling of the stator current in to torque and flux producing components.

Keywords: *Induction motor(IM) drive, Indirect Vector Control of Induction Motor(IVCIM), Fuzzy Logic Controller(FLC),Field Oriented Control(FOC), Matlab, Fuzzy Inference System(FIS), Simulink model*

1. Introduction

Induction motors play a vital role in the industrial sector especially in the field of electric drives & control. The induction motor is considered since its discovery as actuator privileged in the applications of constant speed, and it has many advantages, such as low cost, high efficiency, good self starting, and its simplicity of design, virtually maintenance free electrical drives and a small inertia [1-3]. However, induction motor has disadvantages, such as complex, nonlinear, and multivariable mathematical model of induction motor and the induction motor is not inherently capable of providing variable speed operation.

These limitations can be solved through the use of smart motor controllers and adjustable speed controllers, such as scalar and vector control drive [4-6]. Field Oriented Control (FOC) or vector control was invented in the late 1960 [4]. When the induction motors are controlled using scalar control methods like the volt hertz control, the magnitude and frequency of the stator voltages are determined from steady-state properties of the motor, which leads to poor dynamic performance. In FOC the magnitude, frequency and instantaneous position of voltage, current and flux linkage vector are controlled and valid for steady state as well as transient conditions.

FOC is a technique that provides a method of decoupling the two components d and q of stator current: one producing the air gap flux and the other producing the torque respectively. Therefore, it provides independent control of torque and flux, which is similar to a separately excited DC machine. The FOC schemes are classified into two groups: the direct method of field orientation [8] proposed by Blaschke and the indirect method of field orientation [9] proposed by Hasse. The direct method requires flux acquisition, which is mostly obtained by computation techniques using machine terminal quantities, where as indirect method avoids the requirement of flux acquisition by using known motor parameters to compute the appropriate motor slip speed ωsl to obtain the desired flux position. The scheme of indirect is simpler to implement than the direct method of FOC hence, indirect method has become more popular.

Conventional control of an induction motor is difficult due to strong nonlinear magnetic saturation effects and temperature dependency of the motor's electrical parameters. As the conventional control approaches require a complex mathematical model of the motor to develop controllers for quantities such as speed, torque, and position. Recently, to avoid the inherent undesirable characteristics of conventional control approaches, Fuzzy Logic Controller (FLC) is being developed. FLC offers a linguistic approach to develop control algorithms for any system. It maps the input-output relationship based on human expertise and hence, does not require an accurate mathematical model of the system and can handle the nonlinearities that are generally difficult to model. This consequently makes the FLC tolerant to parameter variation and more accurate and robust [10-12].

2. Over View of Scalar and Vector Control Schemes for Speed Control of Three Phase Induction Motor

2.1 Scalar Control:

Scalar control as the name indicates, is due to magnitude variation of the control variable only, and disregards the coupling effect in machine. For example, the voltage of machine can be controlled to control the flux, and frequency or slip can be controlled to control the torque. However flux and torque are also function of voltage and frequency respectively. A scalar controlled drive gives somewhat inferior performance. Scalar control is easy to implement. Scalar controlled drives have been widely used in industry, but the inherent coupling effect (both torque and flux are function of voltage or current and frequency) gives sluggish response and system is easily prone to instability because of higher order (fifth order) system effect. To make it clearer, if torque is increased by incrementing the slip (the frequency), the flux tends to decrease .it has been noted that the flux variation is also sluggish. Decreases in flux then compensated by the sluggish flux control loop feeding an additional voltage.

This temporary dipping of flux reduces the torque sensitivity with slip and lengthens the response time. However, their importance has diminished recently because of the superior performance of vector or Field orientated control (FOC) drives. To improve speed control performance of the scalar control method, an encoder or speed tachometer is required to feedback the rotor angle or rotor speed signal and compensate the slip frequency. However, it is expensive and destroys the mechanical robustness of the induction motor. So these are the limitation of scalar control which is overcome by Field orientated control (FOC) for induction motor drive [5-7].

2.2 Field Orientated Control (FOC):

Blaschke in 1972 has introduced the principle of field orientation to realize dc motor characteristics in an induction motor derive. For the same, he has used decoupled control of torque and flux in the motor and gives its name transvector control. In DC machine the field flux is perpendicular to the armature flux. Being orthogonal, these two fluxes produce no net interaction on one another.

Adjusting the field current can therefore control the DC machine flux, and the torque can be controlled independently of flux by adjusting the armature current [4-5]. An AC machine is not so simple because of the interactions between the stator and the rotor fields, whose orientations are not held at 90 degrees but vary with the operating conditions. We can obtain DC machine-like performance in holding a fixed and orthogonal orientation between the field and armature fields in an AC machine by orienting the stator current with respect to the rotor flux so as to attain independently controlled flux and torque. Such a control scheme is called flux-oriented control or vector control. Vector control is applicable to both induction and synchronous motors.

The cage induction motor drive with vector or field oriented control offers a high level of dynamics performance and the closed-loop control associated with this derive provides the long term stability of the system .Induction Motor drives are used in a multitude of industrial and process control applications requiring high performances. In high performance drive systems, the motor speed should closely follow a specified reference trajectory regardless of any load disturbances, parameter variations, and model uncertainties. In order to achieve high performance, field-oriented control of induction motor (IM) drive is employed. However, the controller design of such a system plays a crucial role in system performance. The decoupling characteristics of vector-controlled IM are adversely affected by the parameter changes in the motor. So the vector control is also known as an independent or decoupled control.

3. Fuzzy Logic Control(FLC):

Due to continuously developing automation systems and more demanding small Control performance requirements, conventional control methods are not always adequate. On the other hand, practical control problems are usually imprecise. The input output relations of the system may be uncertain and they can be changed by unknown external disturbances. New schemes are needed to solve such problems. One such an approach is to utilize fuzzy control. Since the introduction of the theory of fuzzy sets by L. A. Zadeh in 1965[10], and the industrial application of the first fuzzy controller by E.H. Mamdani in 1974, fuzzy systems have obtained a major role in engineering systems and consumer's products in 1980s and 1990s. New applications are presented continuously. A reason for this significant role is that fuzzy computing provides a flexible and powerful alternative to contract controllers, supervisory blocks, computing units and compensation systems in different application areas [10-12]. With fuzzy sets nonlinear control actions can be performed easily. The transparency of fuzzy rules and the locality of parameters are helpful in the design and maintenances of the systems. Therefore, preliminary results can be obtained within a short development period. Fuzzy control is based on fuzzy logic, which provides an efficient method to handle in exact information as basis reasoning. With fuzzy logic it is possible to convert knowledge, which is expressed in an uncertain form, to an exact algorithm. In fuzzy control, the controller can be represented with linguistic if-then rules [10, 12].

4. Matlab Model of Indirect Vector Control IM Drive(IVCIM) using FLC

4.1 Hysteresis Current Regulator:

The current regulator, which consists of three hysteresis controllers, is used to compare the actual motor currents and reference current. The motor actual currents are provided by the measurement output of the Asynchronous Machine block.

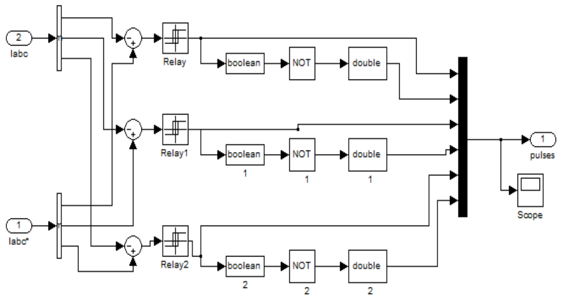


Figure 1: Hysteresis Current Regulator

4.2 Universal Bridge:

The Universal Bridge block implements a universal three-phase power converter that consists of up to six power switches connected in a bridge configuration. The type of power switch and converter configuration is selectable from the dialog box. Power Electronic device and Port configuration options are selected as IGBT/Diode and ABC as output terminals respectively. The DC link input voltage is represented by a 780 V DC voltage source .Set the Snubber capacitance Cs to inf to get a resistive snubber.

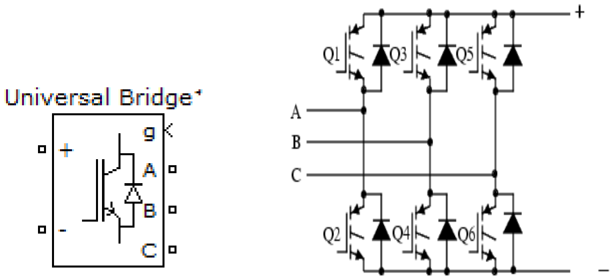


Figure 2: Universal Bridge block

4.3 abc to d-q Transformation Blocks:

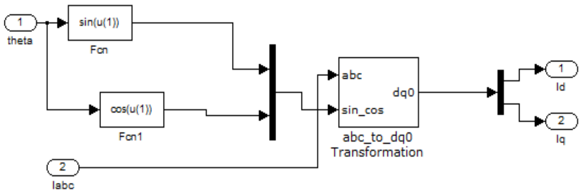


Figure 3: abc to d-q Transformation Blocks

4.4 d-q to abc Transformation Blocks:

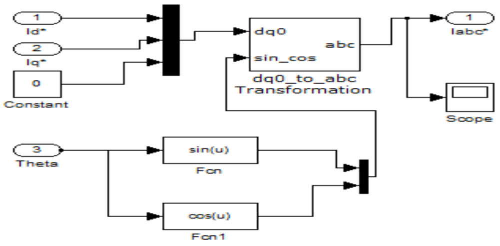
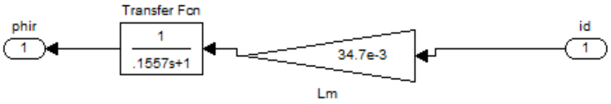


Figure 4: d-q to abc transformation blocks

4.5 Flux Calculation Block:



Lm = 34.7 mH

Tr = Lr / Rr = 0.1557 sec

Rr = 0.228 Ω

Flux (Phir) = Lm *Id / (1 +Tr .s)

Figure 5: Flux Calculation Block

4.6 Theta Calculation Block:

The rotor flux position (θe) is calculated by the Theta Calculation Block.

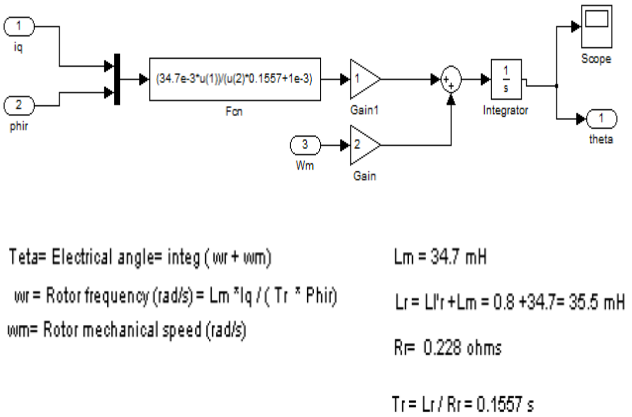


Figure 6: Theta Calculation block

4.7 The stator quadrature-axis current reference iqs* calculation block:

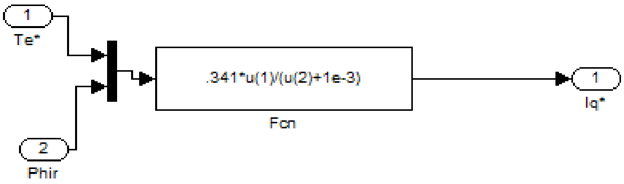


Figure 7: iqs* calculation block

iqs* is calculated from torque reference Te* as

$$i_{qs}^* = \frac{2}{3}\cdot\frac{2}{p}\cdot\frac{L_r}{L_m}\cdot\frac{T_e^*}{|\psi_r|_{est}}$$

|ψr|est=Phir=calculated rotor flux linkage

P is the number of poles.

4.8 Fuzzy Logic Controller in IVCIM:

The motor speed ω is compared to the reference ω* and the error is processed by the Fuzzy based speed controller to produce a torque command Te* by following block

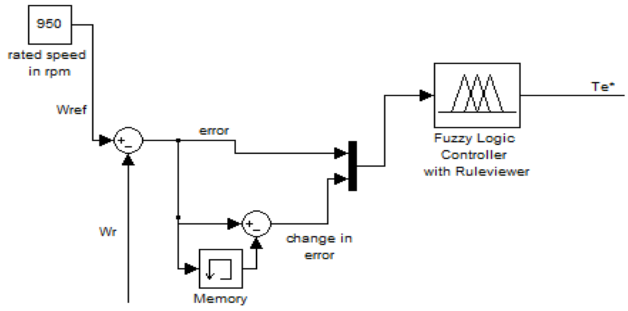


Figure 8: torque command produced by the FLC

4.9 Matlab Simulation of IVCIM Using Fuzzy Logic Controller:

Overall simulating block diagram is as shown below

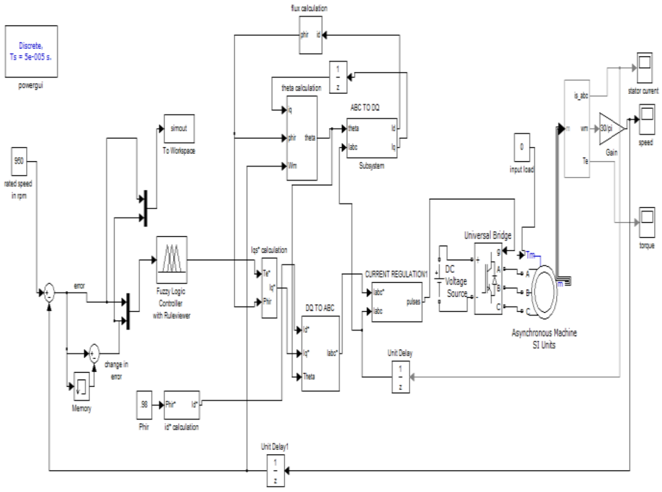


Figure 9: Matlab Simulink Block diagram of indirect vector control using Fuzzy Logic controller

5. Fuzzy Logic Controller Design

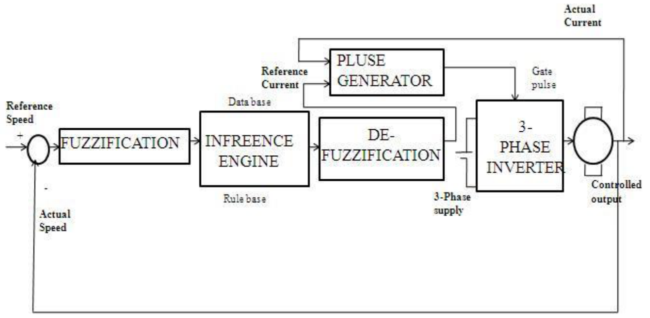


Figure 10: Block diagram for Fuzzy controlled Induction motor

The block diagram point out that the controlled output from the fuzzy controller is converted to equivalent three phase current and which is the provided to one of the input of the pulse generator. Another input is provided with the actual current from the motor. Based on the reference current and actual current the pulse generator will generate a pulse, which is provided as gate pulse to the inverter. When the gate pulse changes automatically the output voltage from the inverter changes which is provided as the input voltage to the motor [15] .As Voltage and speed are directly proportional, when the voltage to the motor controlled the speed also get controlled.

The inputs to the FIS controller, i.e., the error & the change in error are modelled using the following two Eq.

$$e(k) = \omega_{ref} - \omega_r \text{---------} (1)$$

$$\Delta e(k) = e(k) - e(k-1) \text{------} (2)$$

Where, ω_{ref} is the reference speed, ω_r is the actual rotor speed, e (k) is the error and delta e (k) is the change in error.

The fuzzification unit converts the crisp data into linguistic variables, which is given as inputs to the rule based block. The set of 49 rules are written on the basis of previous knowledge / experiences in the rule based block. The rule base for selection of proper rules is written as shown in the table 1.

E ΔE	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Table1: Rule base for controlling the speed.

As there are 2 input variables & 7 fuzzified variables, the controller has a set of 49 rules for the FIS controller. The developed fuzzy rules (7×7) = 49 are designed in the MAMDANI FIS editor which are given as follows

```
1. If (ERROR is NB) and (CHANGE_IN_ERROR is NB) then (CHANGE_IN_CONTROL is NB) (1)
2. If (ERROR is NB) and (CHANGE_IN_ERROR is NM) then (CHANGE_IN_CONTROL is NB) (1)
3. If (ERROR is NB) and (CHANGE_IN_ERROR is NS) then (CHANGE_IN_CONTROL is NB) (1)
4. If (ERROR is NB) and (CHANGE_IN_ERROR is ZE) then (CHANGE_IN_CONTROL is NB) (1)
5. If (ERROR is NB) and (CHANGE_IN_ERROR is PS) then (CHANGE_IN_CONTROL is NM) (1)
6. If (ERROR is NB) and (CHANGE_IN_ERROR is PM) then (CHANGE_IN_CONTROL is NS) (1)
7. If (ERROR is NB) and (CHANGE_IN_ERROR is PB) then (CHANGE_IN_CONTROL is ZE) (1)
8. If (ERROR is NM) and (CHANGE_IN_ERROR is NB) then (CHANGE_IN_CONTROL is NB) (1)
9. If (ERROR is NM) and (CHANGE_IN_ERROR is NM) then (CHANGE_IN_CONTROL is NB) (1)
10. If (ERROR is NM) and (CHANGE_IN_ERROR is NS) then (CHANGE_IN_CONTROL is NM) (1)
11. If (ERROR is NM) and (CHANGE_IN_ERROR is ZE) then (CHANGE_IN_CONTROL is NM) (1)
12. If (ERROR is NM) and (CHANGE_IN_ERROR is PS) then (CHANGE_IN_CONTROL is NS) (1)
13. If (ERROR is NM) and (CHANGE_IN_ERROR is PM) then (CHANGE_IN_CONTROL is ZE) (1)
14. If (ERROR is NM) and (CHANGE_IN_ERROR is PB) then (CHANGE_IN_CONTROL is PS) (1)
15. If (ERROR is NS) and (CHANGE_IN_ERROR is NB) then (CHANGE_IN_CONTROL is NB) (1)
16. If (ERROR is NS) and (CHANGE_IN_ERROR is NM) then (CHANGE_IN_CONTROL is NM) (1)
17. If (ERROR is NS) and (CHANGE_IN_ERROR is NS) then (CHANGE_IN_CONTROL is NS) (1)
18. If (ERROR is NS) and (CHANGE_IN_ERROR is ZE) then (CHANGE_IN_CONTROL is NS) (1)
19. If (ERROR is NS) and (CHANGE_IN_ERROR is PS) then (CHANGE_IN_CONTROL is ZE) (1)
20. If (ERROR is NS) and (CHANGE_IN_ERROR is PM) then (CHANGE_IN_CONTROL is PS) (1)
21. If (ERROR is NS) and (CHANGE_IN_ERROR is PB) then (CHANGE_IN_CONTROL is PM) (1)
22. If (ERROR is ZE) and (CHANGE_IN_ERROR is NB) then (CHANGE_IN_CONTROL is NB) (1)
23. If (ERROR is ZE) and (CHANGE_IN_ERROR is NM) then (CHANGE_IN_CONTROL is NM) (1)
24. If (ERROR is ZE) and (CHANGE_IN_ERROR is NS) then (CHANGE_IN_CONTROL is NS) (1)
25. If (ERROR is ZE) and (CHANGE_IN_ERROR is ZE) then (CHANGE_IN_CONTROL is ZE) (1)
26. If (ERROR is ZE) and (CHANGE_IN_ERROR is PS) then (CHANGE_IN_CONTROL is PS) (1)
27. If (ERROR is ZE) and (CHANGE_IN_ERROR is PM) then (CHANGE_IN_CONTROL is PM) (1)
28. If (ERROR is ZE) and (CHANGE_IN_ERROR is PB) then (CHANGE_IN_CONTROL is PB) (1)
29. If (ERROR is PS) and (CHANGE_IN_ERROR is NB) then (CHANGE_IN_CONTROL is NM) (1)
30. If (ERROR is PS) and (CHANGE_IN_ERROR is NM) then (CHANGE_IN_CONTROL is NS) (1)
31. If (ERROR is PS) and (CHANGE_IN_ERROR is NS) then (CHANGE_IN_CONTROL is ZE) (1)
32. If (ERROR is PS) and (CHANGE_IN_ERROR is ZE) then (CHANGE_IN_CONTROL is PS) (1)
33. If (ERROR is PS) and (CHANGE_IN_ERROR is PS) then (CHANGE_IN_CONTROL is PS) (1)
34. If (ERROR is PS) and (CHANGE_IN_ERROR is PM) then (CHANGE_IN_CONTROL is PM) (1)
35. If (ERROR is PS) and (CHANGE_IN_ERROR is PB) then (CHANGE_IN_CONTROL is PB) (1)
36. If (ERROR is PM) and (CHANGE_IN_ERROR is NB) then (CHANGE_IN_CONTROL is NS) (1)
37. If (ERROR is PM) and (CHANGE_IN_ERROR is NM) then (CHANGE_IN_CONTROL is ZE) (1)
38. If (ERROR is PM) and (CHANGE_IN_ERROR is NS) then (CHANGE_IN_CONTROL is PS) (1)
39. If (ERROR is PM) and (CHANGE_IN_ERROR is ZE) then (CHANGE_IN_CONTROL is PM) (1)
40. If (ERROR is PM) and (CHANGE_IN_ERROR is PS) then (CHANGE_IN_CONTROL is PM) (1)
41. If (ERROR is PM) and (CHANGE_IN_ERROR is PM) then (CHANGE_IN_CONTROL is PB) (1)
42. If (ERROR is PM) and (CHANGE_IN_ERROR is PB) then (CHANGE_IN_CONTROL is PB) (1)
43. If (ERROR is PB) and (CHANGE_IN_ERROR is NB) then (CHANGE_IN_CONTROL is ZE) (1)
44. If (ERROR is PB) and (CHANGE_IN_ERROR is NM) then (CHANGE_IN_CONTROL is PS) (1)
45. If (ERROR is PB) and (CHANGE_IN_ERROR is NS) then (CHANGE_IN_CONTROL is PM) (1)
46. If (ERROR is PB) and (CHANGE_IN_ERROR is ZE) then (CHANGE_IN_CONTROL is PB) (1)
47. If (ERROR is PB) and (CHANGE_IN_ERROR is PS) then (CHANGE_IN_CONTROL is PB) (1)
48. If (ERROR is PB) and (CHANGE_IN_ERROR is PM) then (CHANGE_IN_CONTROL is PB) (1)
49. If (ERROR is PB) and (CHANGE_IN_ERROR is PB) then (CHANGE_IN_CONTROL is PB) (1)
```

6. Simulation Results & Discussions

Performance of Indirect Vector Control IM Using Fuzzy Control:

Figure10 shows the performance characteristic of a 50 hp, 460 V, 60 Hz IM, operating at no load with a fuzzy logic speed controller. The reference speed is 950 rpm. It is observed that motor picks up the speed 950 rpm at t = 0.31 sec with a very smooth increase in speed curve. Also the motor draws low starting current and the torque quickly drops to a stable value as compared to other conventional speed controller.

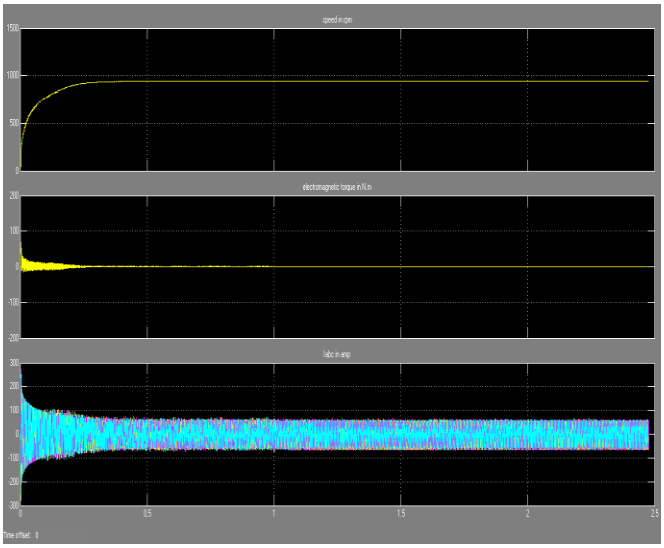


Figure 10: Performance of IVCIM using Fuzzy logic control at no load with reference speed of 950 rpm

Fuzzy control results:
From figure10, we get
Case 1: Results at initial starting for no load with reference speed 950 rpm

Motor current (Iabc) = 275 amps
Torque (Te) = 68 N-m

Case 2: Results at no load for speed reach 120 rpm at time t=0.31 sec

Motor current (Iabc) = 64 amps
Torque (Te) = (0.1 -2) N-m

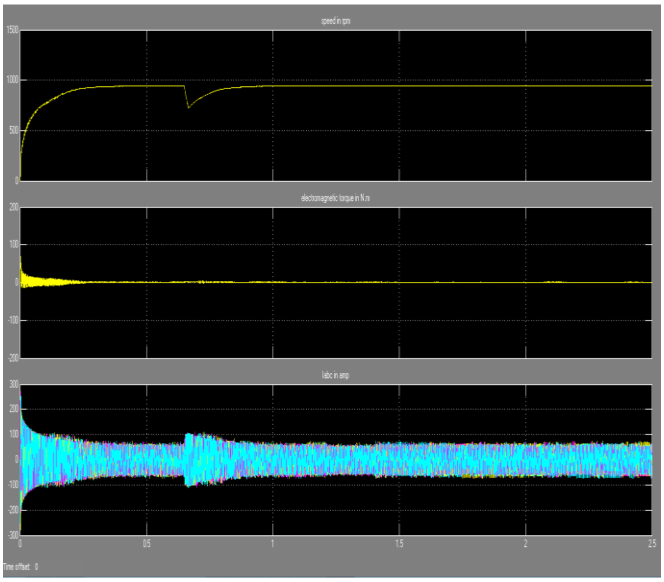


Figure 11: Response of IVCIM with fuzzy logic control at load torque =15n-m, at time t=.64 sec

Case 3: From figure 11, we get

Results after applying 15 n-m load torque at time t=.64 sec.

Motor current (Iabc) = 105 amps
Torque (Te) = 10 N-m

7. Conclusions

In this paper fuzzy logic controller for the control of an Indirect vector-controlled induction motor was described. The drive system was simulated with fuzzy logic controller its performance was compared. Here simulation results shows that the designed fuzzy logic controller realises a good dynamic behaviour of the motor with a rapid settling time, no overshoot and has better performance than other conventional controller. Fuzzy logic control has more robust during change in load condition.

8. Future Directions

- A Self-Tuned NeuroFuzzy-Based IM Drive based on Adaptive Neuro Fuzzy Inference System (ANFIS) system can be developed.
- There is a provision to optimize the performance of sensor less induction motor drive at very low speed and zero speed using a MRAS (Model Reference Adaptive System) speed observer based on the ANFIS system.
- Genetic algorithms combined with fuzzy and neural networks can be considered a future entity.

Acknowledgment

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