MODELING AND DIRECT TORQUE CONTROL OF INDUCTION MOTOR BY USING FUZZY LOGIC CONTROL TECHNIQUE

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Abstract

In this paper fuzzy rule based field oriented speed controlling of induction motor is proposed. The proposed speed controller estimate the suitable inputs in terms of logic variables to control the system. The speed of the motor is controlled by controlling the electromagnetic torque. To control the electromagnetic torque, the actual torque and change in torque is processed through fuzzy logic controller (FLC) which will produce the controlled electromagnetic torque in proportional to the speed of the motor. The proposed direct torque controller (DTC) improves the transient performance of induction motor with potential features. The entire proposed system is designed and tested under MATLAB/SIMULINK environment and simulation results also presented. And also the proposed fuzzy logic controller (FLC) performance is compared with the conventional Proportional-Integral (PI) controller performance to demonstrate the attractive performance of the proposed fuzzy logic controller.

Key words: *Induction motor, DTC, fuzzy logic controller.*

1. INTRODUCTION

Induction Machine is an important class of electric machines which finds wide applicability as a motor in industry. Generally, variable-speed drives for induction motors require both wide operating range of speed and fast torque response, regardless of load variations [17]. To improve the motor efficiency, the flux must be reduced by obtaining a balance between copper and iron losses [19]. The variations of electrical parameters, the inaccuracy of estimated fluxes will degrade the speed control performance [7]. The control of IM is complex due to its nonlinear nature, and the parameters change with operating conditions [4]. Speed estimation is an issue of particular interest with induction motor drives, where the mechanical speed of the rotor is generally different from the speed of the revolving magnetic field [18].

Direct Torque Control (DTC) technique controls the torque and speed of the motor, which is directly based on the electromagnetic state of the motor [1]. The name direct torque control is derived from the fact that on the basis of the errors between the reference and the estimated values of torque and flux, it is possible to directly control the inverter states in order to reduce the torque and flux errors within the permissible limits [8]. The main advantages of DTC are robust and fast torque response, no requirements for coordinate transformation, requirements for PWM pulse generation and current regulators [20]. The DTC method is a simple and give fast transient response against the speed variations of the motor, hence most of the industrial drives are equipped with DTC [15]. The different induction motor control were in development currently. The present paper concerns with the implementation of Fuzzy rule based technique to improve the speed/torque characteristics of the induction motor. Techniques such as DTC with space vector modulation (SVPWM) technique, artificial intelligence techniques etc. [5] [9]

2. MATHEMATICAL MODEL OF DTC OF INDUCTION MOTOR

The mathematical model of the induction machine is used for analyzing the dynamic behavior of the motor. The change in the dynamic behavior of the motor affects the motor parameters such as speed, torque, resistance, flux etc. So, the dynamic model is required for analyzing the performance of the induction motor. The dynamic model of the induction motor is derived by transforming the three phase quantities into two phase direct and quadrature axes quantities. The mathematical equation of DTC of the induction motor is given below.

2.1 Voltage equations:

$$V_{s\alpha} = r_s i_{s\alpha} + P\psi_{s\alpha} \quad (1)$$

$$V_{s\beta} = r_s i_{s\beta} + P\psi_{s\beta} \quad (2)$$

$$V_{r\alpha} = r_r i_{r\alpha} + P\psi_{r\alpha} + \psi_{r\beta}\omega_r \quad (3)$$

$$V_{r\beta} = r_r i_{r\beta} + P\psi_{r\beta} - \psi_{r\alpha}\omega_r \quad (4)$$

Where, $\psi_{s\alpha} = \psi_{r\alpha} = i_{r\alpha}L_r + i_{s\alpha}L_s$ and (4.a)

$\psi_{s\beta} = \psi_{r\beta} = i_{r\beta}L_r + i_{s\beta}L_s$. (4.b)

These stator flux equations are rewritten as follows,

2.2 Stator Flux:

$$\psi_{s\alpha} = \int (V_{s\alpha} - r_s i_{s\alpha})dt \quad (5)$$

$$\psi_{s\beta} = \int (V_{s\beta} - r_s i_{s\beta})dt \quad (6)$$

The magnitude of the stator flux (ψ_s) is the combination of $\alpha - axis$ and $\beta - axis$ flux which is expressed as follow,

$$|\psi_s| = \sqrt{\psi_{s\alpha}^2 + \psi_{s\beta}^2} \quad (7)$$

The magnetic track phase angle (θ)is expressed as follow,

$$\theta = arctan\left({}^{\psi_{s\alpha}}/_{\psi_{s\beta}}\right) \quad (8)$$

Where,$V_{s\alpha}$, $V_{s\beta}$, $V_{r\alpha}$ and $V_{r\beta}$ are the $\alpha - axis\ and\ \beta - axis$ voltages of stator and rotor respectively. Then, $i_{s\alpha}$, $i_{s\beta}$, $i_{r\alpha}$ and $i_{r\beta}$ are the $\alpha - axis\ and\ \beta - axis$ currents of stator and rotor respectively. The resistance and inductance of the stator and rotor winding are denoted as r_s, r_r, $L_s$and L_r respectively. The stator and the rotor flux of the motor are described as$\psi_{s\alpha}$,$\psi_{r\alpha}$, $\psi_{s\beta}$ and $\psi_{r\beta}$ respectively.

The electromagnetic torque of the motor is obtained from the inductance and the $\alpha - \beta\ axis$ current. The $\alpha - \beta\ axis$ current of the motor is obtained from the flux linkages that occurred in the stator and rotor of the motor. The expression of the electromagnetic torque that is produced by the motor is given as follows.

2.3 Electromagnetic Torque:

$$T_e = {}^3/_2 \cdot {}^P/_2 \left(\psi_{s\alpha} i_{s\beta} - \psi_{s\beta} i_{s\alpha}\right) \quad (9)$$

The actual torque developed by the motor in terms of rotor speed is illustrated as follow.

$$T = T_e - T_L = {}^P/_2 \left(J\frac{d\omega_r}{dt} + B\omega_r\right) \quad (10)$$

Where, P is the number of poles,

J is the moment of inertia of rotor,

B is the damping coefficient,

ω_r is the rotor speed,

T_L is the load torque,

T_e is the electromagnetic torque.

2.4 *Vector Diagram:*

Considering the vector diagram shown in fig.1. The three phase currents $i_a, i_b\ and\ i_c$ are converted to a two-phase orthogonal system with axes $\alpha\ and\ \beta$ by means of a technique called the Clarke Transformation. For simplicity, axis α can be made equal to axis a. The two orthogonal currents i_α and $i_\beta$are then transformed to a time-invariant, rotating orthogonal system represented by the field and torque components d and q of the equivalent rotor currents i_d and i_q. The α/β coordinate frame is rotated counterclockwise to line up with the rotor flux axis ψ_r. The angle of rotation (θ) is determined with the help of the motor model. The vector diagram of flux linkages in the stator and rotor winding is illustrated as following.

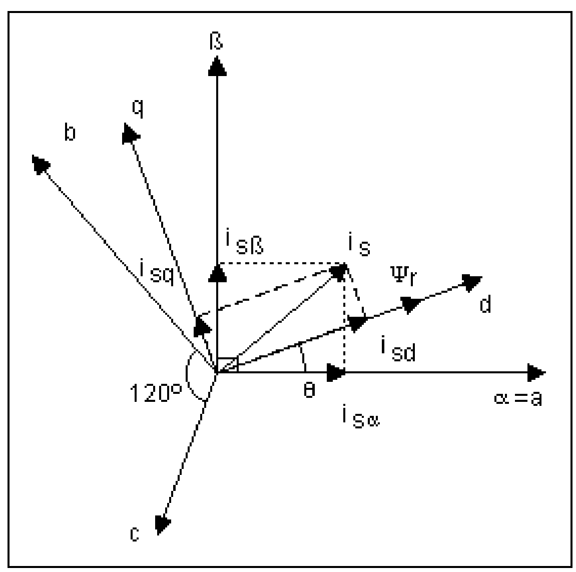

Fig. 1: Vector Diagram of DTC of Induction Motor

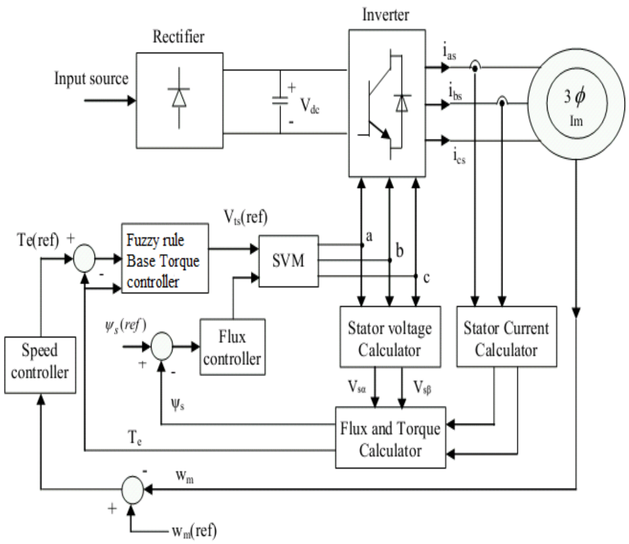

Fig. 2: Proposed fuzzy rule Based DTC System

In Figure 2, the control structure of proposed FLC is easily described. In the proposed model, the actual torque (T_e^*) and change of torque (ΔT_e^*) are determined. The reference values of the torque are varied by the variation of load variation so, it's necessary to optimize reference torque. Then, the change of torque is determined from the torque deviated from the reference torque of the system. These actual torque and change torque is applied to FLC and the controlled output is determined. Based on the controlled output, the PWM control signal is generated for controlling the inverter gate. Here, the space vector PWM modulation technique is used for determining the gate control signal. The SVM based switching table is referred from [29] switching output, the IGBT gate is controlled. Then, the detailed description of fuzzy logic controller will be discussed in the preceding section.

3. FUZZY LOGIC CONTROLLERS

The conventional PI controllers are fixed-gain controllers i.e., the proportional and integral gains are constant. So, this type of controllers will not compensate properly, if the parameter changes and it does not adjust with changes in environment. The response of the PI-controller is too slow due to its sluggish response to relatively prompt variations in the state which will result more settling time. In addition to finding the gain constants related to system is very difficult. Therefore the fuzzy control algorithm is capable of improving the system performance as compared with the classical methods. The two FLC input variables are the electromagnetic torque (T) and change of electromagnetic torque (ΔT). The operation of a fuzzy logic controller depends on the shape of membership functions for rule base.

In this paper a fuzzy logic control scheme (Figure 2) is proposed for speed control of an induction motor. The fuzzy logic controller have advantages to be robust and relatively simple to design. The irrespective of system exact model we can able to design fuzzy logic controller. The fuzzy rule based approach is done through three stages. They are Fuzzification, inference engine and defuzzification.

3.1. Fuzzification

The fuzzy membership function values are assigned to the linguistic variables using five fuzzy subsets. In this paper the electromagnetic torque (T) and change in electromagnetic torque (ΔT) are selected as input variables of the system. In this paper the fuzzy logic controller is designed in Sugeno model. The input membership functions are shown in fig.3 the gbellmf type of membership functions are selected to control the system. . The range of each membership function is taking by taking torque and change in torque as the reference.

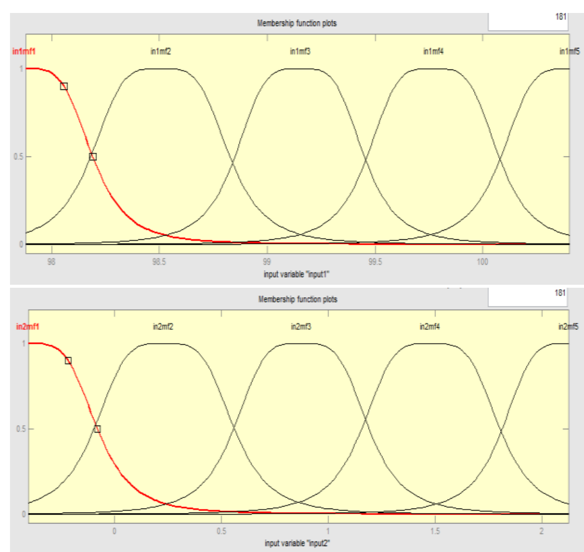

Fig.3 input membership functions.

3.2. Inference engine

This stage mainly consist of fuzzy rule base. In this rule base evaluation is done. In this stage first the inputs are fuzzified and this fuzzified inputs are fed through inference engine and rule base is applied. Then fuzzy output sets are identified.

3.3. Defuzzification

After identification of fuzzy output sets the defuzzification is needed because to obtain the controlled torque. The centroid defuzzification method is used defuzzification in the proposed technique. The output membership functions params values and the fuzzy rules are given in appendix-A. The controlled torque which is the output of the fuzzy logic controller is converted in to stator voltage. This is poses through the SVM, this will generates the firing pulses to the inverter to control he speed of the induction motor which closely related to the reference speed.

4. Simulation

The proposed fuzzy rule based DTC technique was implemented in MATLAB/SIMULINK platform. Then, the speed control performance of proposed control technique was tested with induction motor of rating 2.2Kw/400V. The speed control performance of proposed control technique was compared with PI controller. From the proposed model, the speed, torque, current, flux and d-q axis voltage were analyzed. The Simulink model of proposed speed control system is illustrated in Fig.5. and the conventional PI controller model is shown in fig.4. The implementation parameters of proposed model is depicted in appendix-A.

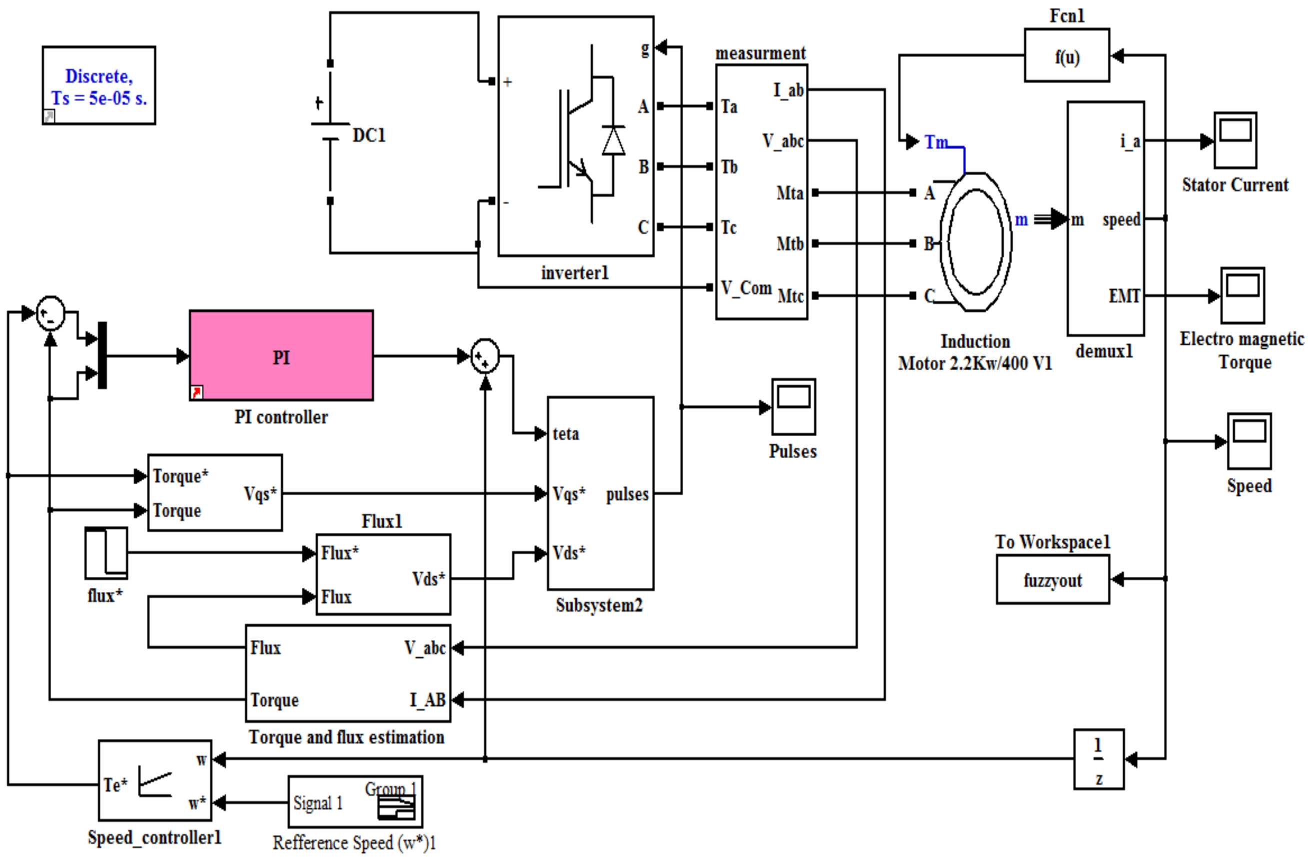

Fig. 4: Simulink Model of PI Speed control System.

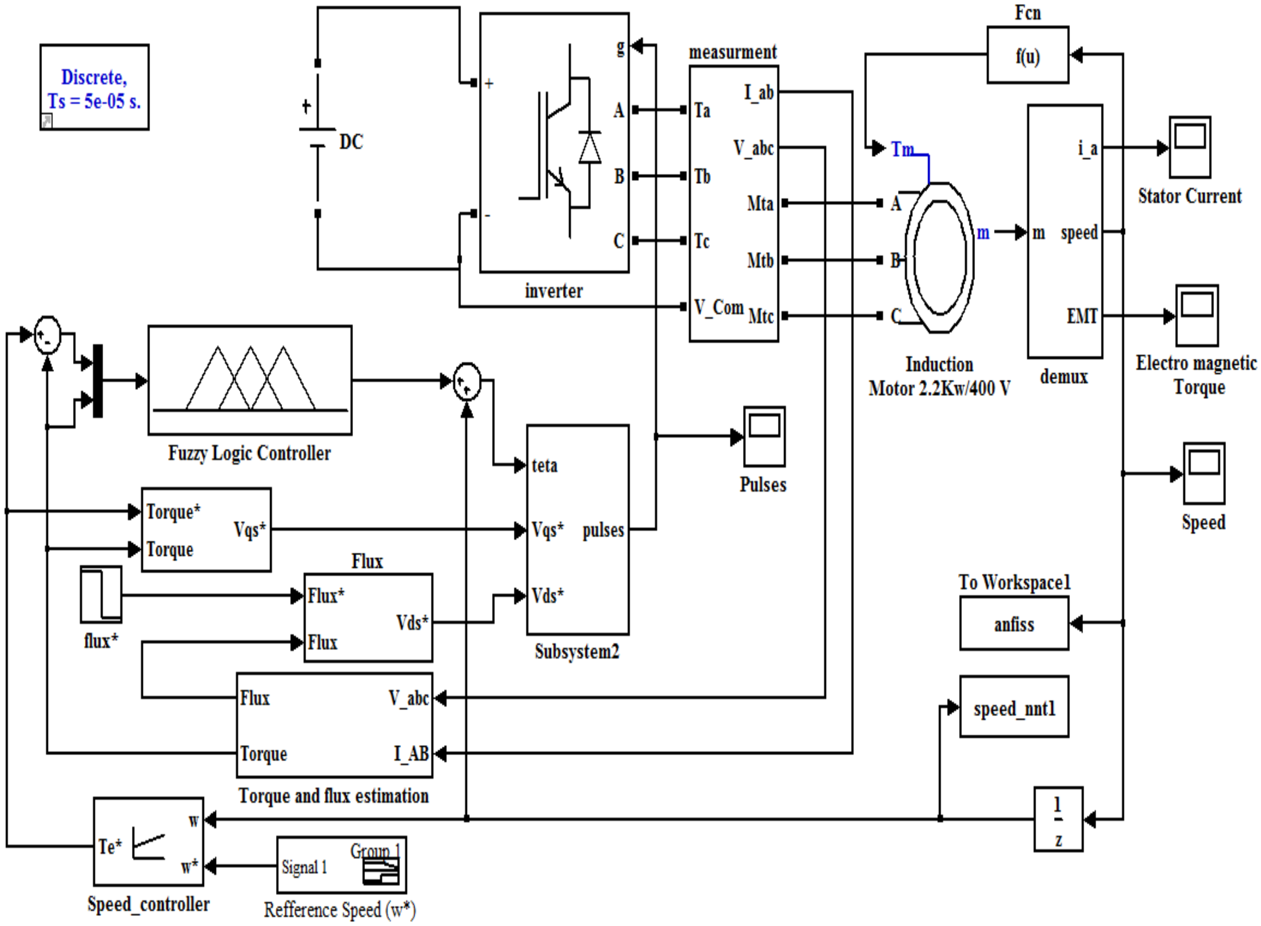

Fig. 5: Simulink Model of Fuzzy Logic Speed control System.

5. Results and Discussion

From the above simulation results, the set point is described by the dynamic response of the IM when the speed set point is 80 rad/sec from rest at the duration of 0.5 sec. Then the speed set point is varied from 80 rad/sec to 60 rad/sec at duration of 0.5 sec. After that the speed set point is varied from 60 rad/sec to 100 rad/sec at duration of 1sec. The performance of current, voltage, flux, torque, speed and comparison of torque and speed are depicted from Fig. 6 to Fig. 17.

Figures (6), (7) and (8) shows the stator current, stator voltage and stator flux with PI controller respectively which are independent of set point.

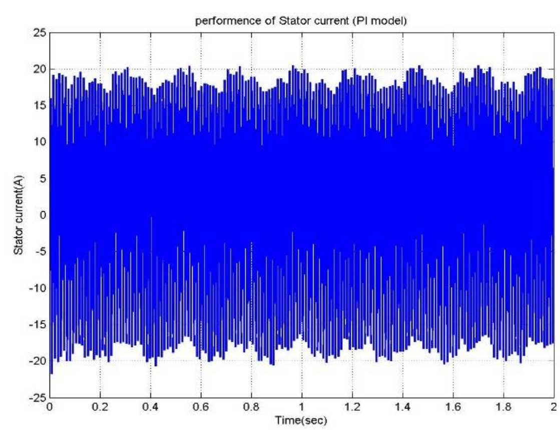

Fig. 6: Dynamics of Stator Current.

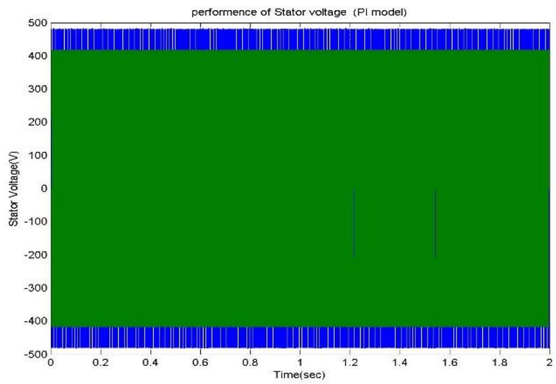

Fig. 7: Transformed d-q axis of Stator Voltage.

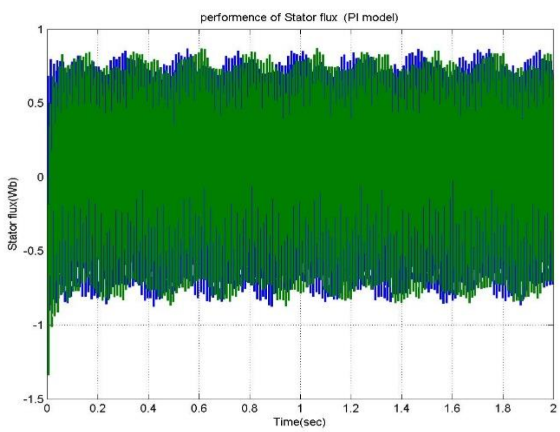

Fig. 8: Dynamics of d-q axis Stator Flux

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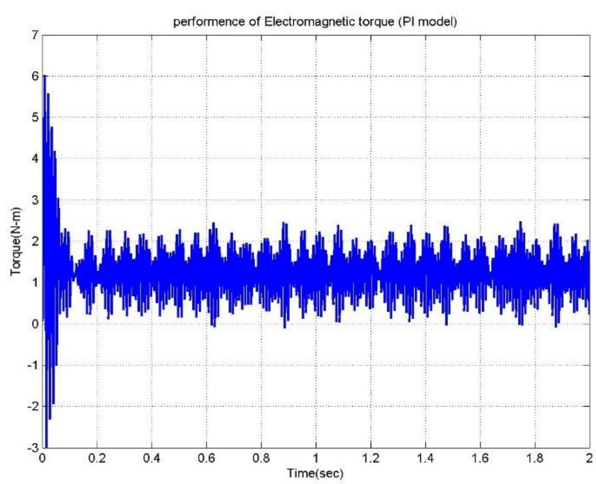

Fig. 9: Variations of Electromagnetic Torque.

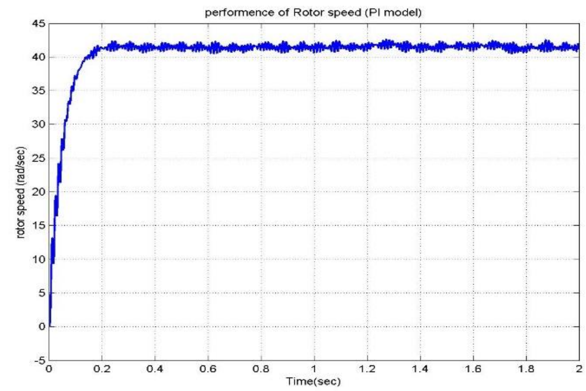

Fig. 10: Performance of Speed.

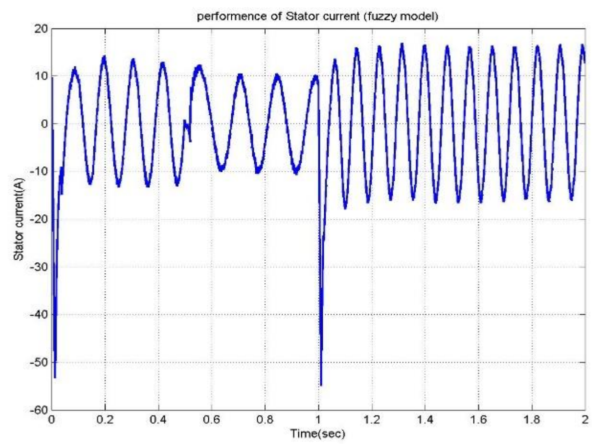

Fig. 11: Dynamics of Stator Current.

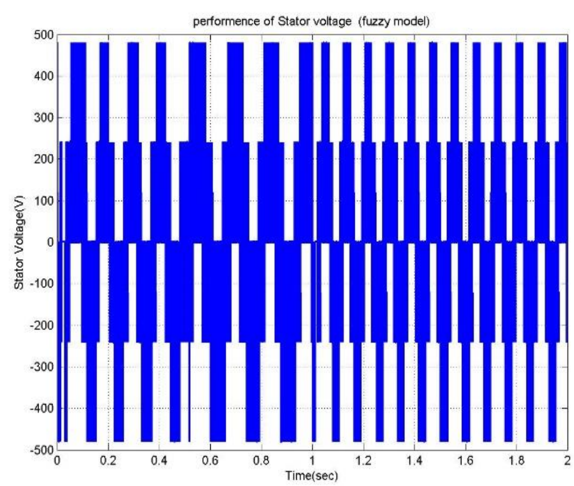

Fig. 12: Transformed d-q axis of Stator Voltage.

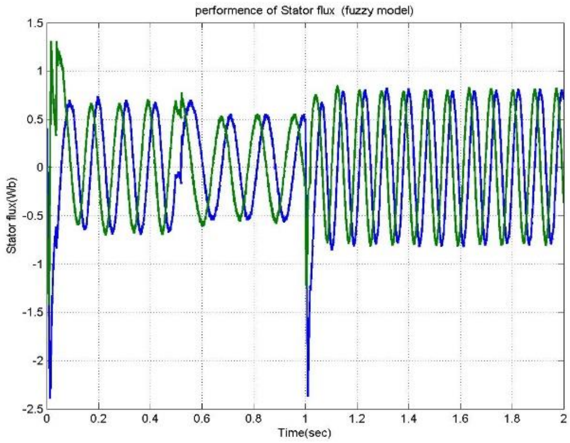

Fig. 13: Dynamics of d-q axis Stator Flux.

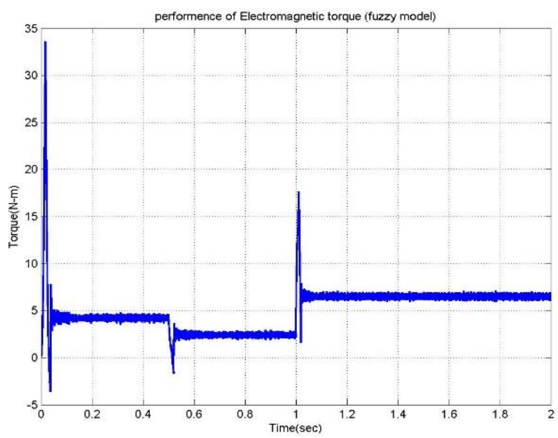

Fig. 14: Variations of Electromagnetic Torque

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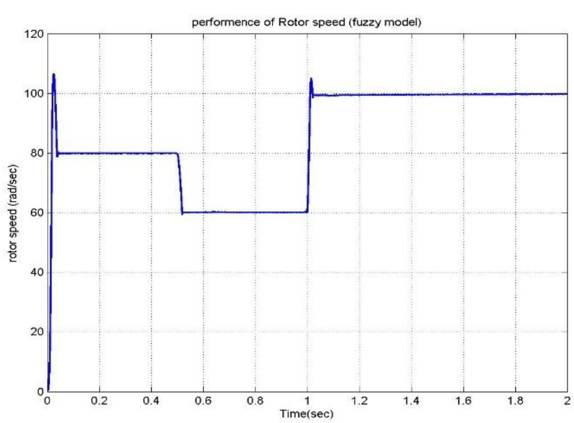

Fig.15: Performance of Speed.

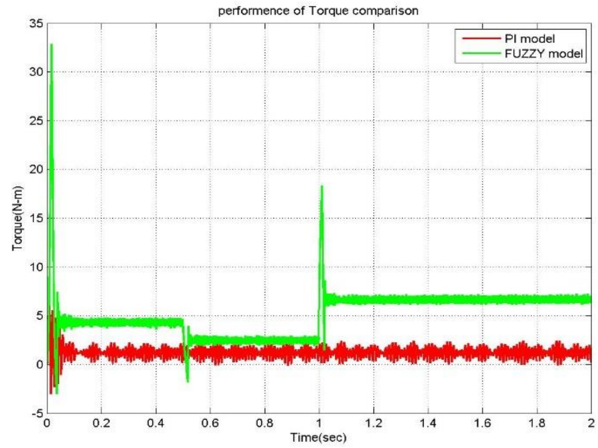

Fig. 16: Comparison Performance of Electromagnetic Torque

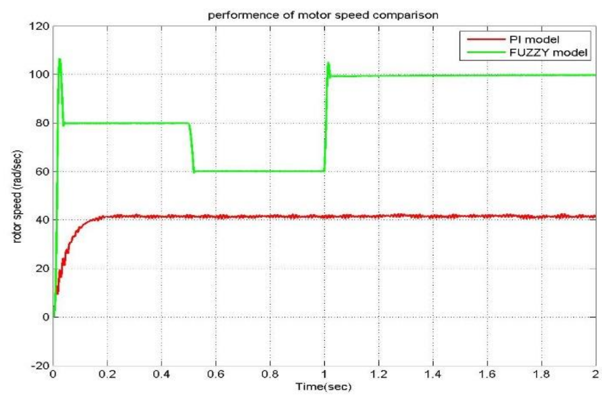

Fig. 17: Comparison Performance of Rotor Speed.

In figure 17, the comparison performance of the proposed Fuzzy speed controller and PI speed controller are described. From the comparative analysis, the proposed Fuzzy speed controller provides smooth speed control performance with less settling time, oscillations and steady state error when compared with the PI controller. The PI controller does not reach the steady state set point. Hence, the proposed FUZZY speed controller is better than PI speed controller.

6. CONCLUSIONS

In this paper fuzzy rule based field oriented speed controlling of induction motor is proposed. To evaluate the performance of the proposed technique was tested on 2.2Kw/400V induction motor. The mathematical model of the induction motor was analyzed in terms of stator voltage and torque equation. The actual torque and the error in torque was possess through a Fuzzy logic controller this estimates the controlled electromagnetic torque, finally this signal is applied to SVM by converting it into the stator voltage. The SVM generates the control signal to control the speed of the motor which is closely related to the reference speed. The performance speed and torque of the motor are analyzed and this performance characteristics are compared with PI controller. From the comparative analysis it is concluded that the proposed fuzzy logic control technique is better than PI control technique.

APPENDIX-A

Table I: Implementation parameters.

Parameters	Values
Nominal power	2200 watts
Line to line voltage	400 volts
Frequency	50 Hz
Stator resistance	3.67 ohm
Stator inductance	0.0269 H
Rotor resistance	2.1 ohm
Rotor inductance	0.0269 H
Mutual inductance	0.0324 H
Inertia	0.0155 kg.m^2
Friction	0.0025 N.m.s
Number of poles	2

REFERENCES

1. R.Rajendran and N.Devarajan, "FPGA Based Implementation of Space Vector Modulated Direct Torque Control for Induction Motor Drive", International Journal of Computer and Electrical Engineering, Vol.2, No.3, pp.589-594, June, 2010
2. Cosmas .U. Ogbuka and Marcel. U. Agu, "A Modified Approach to Induction Motor Stator Voltage and Frequency Control", Proceedings of the World Congress on Engineering, Vol.2, 2011
3. Nalin Kant Mohanty and Ranganath Muthu, "Implementation of Proportional Integral (PI) Controlled DSP Based Cost Effective Inverter Fed Speed Control of Induction Motor Drive with VisSim/ Embedded Controls and Developer (ECD)", International Journal of the Physical Sciences Vol. 6 ,No.20, pp. 4790-4797, 23 September, 2011
4. Anggun Anugrah, Rosli Omar, Marizan Sulaiman,Azhar Ahmad, "Fuzzy Optimization for Speed Controller of An Indirect Vector Controlled Induction Motor Drive Using Matlab Simulink", Journal of Theoretical and Applied Information Technology, Vol.28, No.2, 2005
5. Ehsan Hassankhan and Davood A. Khaburi, "DTC-SVM Scheme for Induction Motors Fed with a Three-level Inverter", World Academy of Science, Engineering and Technology, Vol.44, pp.168-172, 2008
6. Walid Emar, Hussein Sarhan, Rateb Al-Issa,Issam TTrad,Mahmoud Awad, "V/F Control of Squirrel Cage Induction Motor Drives Without Flux or Torque Measurement Dependency", International Journal of Robotics and Automation (IJRA), Vol. 2,No. 2,2011
7. Yeong-Hwa Chang, Chun-I Wu, Hung-Wei Lin and Nien-Der Kuo,"Robust Performance Control Of Vector-Controlled Induction Motors With Gain-Scheduled Estimation And Input-Output Linearization," International Journal of Innovative Computing, Information and ControlVol.7, No.1, January 2011
8. Isao Takahashi and Toshihika Noguchi, "A New Quick-Response and High Efficiency Control Strategy for an Induction Motor", IEEE Transaction on Industry Application, Vol.22, No.5, pp.820-827, 1986
9. T. G. Habetler, F. Profumo, M.Pastorelli, L. Tolbert "Direct torque control of induction machines using space vector modulation," IEEE Transaction on Industry Applications, Vol.28, No.5, pp.1045-1053, October 1992
10. A. K. Sharma, et,al., "Performance Of Ann Based Indirect Vector Control Induction Motor Drive", Journal of Theoretical and Applied Information Technology, Vol.3, No.3, pp.50-57, 2007
11. K. Srivastava, S. M. Tripathi, "Current Source Inverter fed Induction Motor Drives: A Survey", International Journal of Electrical Systems (IJES), Vol.1, No.1, pp. 14~27, June 2011
12. Thanga Raj,S. P. Srivastava, and Pramod Agarwal, "Energy Efficient Control of Three-Phase Induction Motor - A Review", International Journal

of Computer and Electrical Engineering, Vol.1, No.1, pp.1793-8198, April 2009

13. M. Siva Satyanarayana, D. Subba Rayudu, T. Brahmananda Reddy and V. Sowmya Sree, "Comparison Of Vector Control Of Induction Motor Drive Using Conventional Method and Look –Up Tables With 6- And 24- Sectors", International Journal of Engineering Science and Technology (IJEST),Vol. 3, No. 7, July 2011
14. Vinod Kumar, R.R.Joshi, "Hybrid Controller based Intelligent Speed Control of Induction Motor", Journal of Theoretical and Applied Information Technology, 2005
15. Badre Bossoufi, Mohammed Karim, Silviu Ionita and Ahmed Lagrioui, "DTC Control Based Artificial Neural Network For High Performance PMSM Drive", Journal of Theoretical and Applied Information Technology, Vol33, No.2, pp.165-176, 2011
16. K.Ranjith Kumar,D.Sakthibala,S.Palaniswami, "Efficiency Optimization of Induction Motor Drive using Soft Computing Techniques", International Journal of Computer Applications Vol. 3, No.1, pp.0975 – 8887, June 2010
17. Pundaleek. B. H.,Manish G. Rathi,Vijay Kumar M. G., "Speed Control of Induction Motor: Fuzzy Logic Controller v/s PI Controller", IJCSNS International Journal of Computer Science and Network Security, Vol.10, No.10, October 2010
18. Karim Negadi, Abdellah Mansouri, Belkheir Khtemi, "Real Time Implementation of Adaptive Sliding Mode Observer Based Speed Sensorless Vector Control of Induction Motor",Serbian Journal Of Electrical Engineering, Vol. 7, No. 2, pp.167-184, 2010
19. E. Siavashi, A. Pahlavanhoseini, R. Pejmanfar, A. Khanjanzadeh, "Using Clonal Selection Algorithm to optimize the Induction Motor Performance", Canadian Journal on Electrical and Electronics Engineering, Vol. 2, No. 9, September 2011
20. Fatiha Zidani and Rachid Nait Said, "Direct Torque Control of Induction Motor with Fuzzy Minimization Torque Ripple", Journal of Electrical Engineering, Vol.56, No.7-8, pp.183-188, 2005
21. Ameur Fethi Aimer, et.al, "Application of Fuzzy Logic for a Ripple Reduction Strategy in DTC Scheme of a PWM Inverter fed Induction Motor Drives", Journal of electrical systems, No.1, pp.13-17, November 2009
22. S.M. Gadoue, D. Giaouris, and J.W. Finch, "Artificial intelligence-based speed control of DTC induction motor drives—A comparative study", Electric Power Systems Research, Vol.79, pp.210–219, 2009
23. Shu-Xi Liu, Ming-Yu Wang, Yu-Guang Chen and Shan Li, "A Novel Fuzzy Direct Torque Control System for Three-level Inverter-fed Induction Machine", International Journal of Automation and Computing, Vol.7, No.1, pp.78-85, February 2010
24. Zhifeng Zhang, Renyuan Tang, Baodong Bai and Dexin Xie, "Novel Direct Torque Control Based on Space Vector Modulation With Adaptive Stator Flux Observer for Induction Motors", IEEE Transactions on Magnetics, Vol.46, No.8, pp.3133-3136, August 2010
25. V. Talaeizadeh, R. Kianinezhad, S.G. Seyfossadat, and H.A. Shayanfar, "Direct torque control of six-phase induction motors using three-phase matrix converter", Energy Conversion and Management, Vol.51, pp.2482–2491, 2010
26. Tobias Geyer, "Computationally Efficient Model Predictive Direct Torque Control", IEEE Transactions on Power Electronics, Vol.26, No.10, pp.2804-2816, October 2011
27. Brahim Metidji, Ahmed Azib, Farid Tazerart, Nabil Taib and Toufik Rekioua, "Fuzzy Direct Torque Control with Torque Ripple Reduction for Induction Motor Drives fed by Matrix converters", International Journal of Research and Reviews in Computing Engineering, Vol.1, No.1, pp.23-28, March 2011
28. Allirani S., and Jagannathan, "Direct Torque Control Technique for Voltage Source Inverter Fed Induction Motor Drive",International Journal of Electrical Engineering, Vol.5, No.5, pp.629-640, 2012
29. Zhifeng Gao, Peng Shi, and Yufei Xu , "Adaptive Fault-Tolerant Tracking Control of Near-Space Vehicle Using Takagi–Sugeno Fuzzy Models", IEEE Transactions on Fuzzy Systems, Vol.18, No.5, pp.1000-1007, 2010.

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