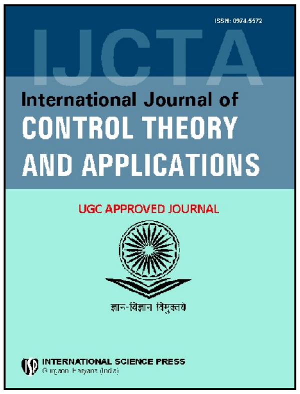

International Journal of Control Theory and Applications

ISSN : 0974-5572

© International Science Press

Volume 10 • Number 34 • 2017

Control Advancement on Direct Torque Control of Induction Motor Using Adaptive Neuro-Fuzzy Inference System

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Abstract: The Direct Torque Control (DTC) System is a robust control method induction drive control system. The several controllers were used in DTC scheme to meet desired torque, flux and speed using PI/PID/fuzzy logic controller. This paper presents DTC of induction motor using Adaptive Neuro-fuzzy Inference System (ANFIS) with PID for space vector modulation. The present control is deriving an upper and lower frequency limits in bandwidth control circuit for desired bandwidth frequency. The proposed scheme of sector selection is used to control an angle of thyristor which is based on flux and torque variation. The present ANFIS approach is greatly reduces ripple across Electromagnetic torque, flux and stator current by appropriate auto-tune, desired estimation and also provide fast transient response of rotor speed. The classical control scheme is suffered from auto tune on ripple minimization even it has good decoupling and control capability of flux and torque. This paper presents the performance and described importance ANFIS in DTC control on induction motor by latterly compared with PI/PI-Fuzzy logic controller using MATLAB/Simulink. The simulations results are due to ripple minimize of torque and also show that proposed control has unique and robust of performance.

Index terms: DTC, PI, PID, Fuzzy, ANFIS, SVM, Induction Motor, Flux Estimation, Torque control.

1. INTRODUCTION

During the last decades, induction motor is preferred mostly to the environment because it has simple mechanical construction in nature, reliable, ruggedness, less maintenance required and extensively used in industrial application [1]. The several control approach is developed using direct torque control for induction motor [2-5]. The indirect field oriented control approach is applied generally in variable speed drive Application in induction drive [6]. Even it has decoupling capacity, separate control of torque and flux control, direct torque control is required for fast dynamic performance, minimal torque response time than conventional methods [7], [8]. The modified form of direct torque control is based on high load, minimum speed region and improving the start up of motor, reducing parameters of machine and sensitive to parameters variation [9]. The predictive control of torque on induction motor is implemented for accurate estimation of parameters and torque control region [10]. The prediction methods are limited in lack of control, high maintenance cost, less reliability in operation.

DTC (Direct torque control) technique is implemented in variable frequency or fixed switching frequency operation. The variable frequency operation of DTC methods applied for simple construction so less maintenance required for control law and structure [11]. The limitation of excessive band of frequency is obtained when flux and torque reference are constant in variable frequency method. It results an unresolved harmonics is generated with large value of spectrum of frequency. Fixed frequency of direct torque control method is introduced for induction motor torque control to overcome the above limitation. SVM (Space vector modulation) based DTC applied to induction motor using fuzzy logic scheme for induction motor is introduces with fixed frequency concept [12].

This method is used to reduce line current harmonics and steady state response of rotor speed for wide range of operation. But it is required additional filters and integrated algorithm is required for accurate estimation of flux and torque parameters. So this is required high maintenance and additional loops. The simple fuzzy logic controller approach is not enough to obtain performance in chance of changes in error by means of predefined SF's(scaling factors) and MF's (Membership functions). To overcome this problem self tuned fuzzy with PI controller is implemented for accurate performance by changing error control of fuzzy logic. This control structure provided a better performance even at parameters variation and non-linearity [13]. In order to improve the quick and transient response of system, neural network is introduced in DTC scheme using space vector method [14].

This paper is presented a direct torque control of induction motor using PID based ANFIS (Adaptive neuro-fuzzy inference System) for space vector modulation technique. ANFIS is represented by suguno-fuzzy logic scheme and it is a hybrid learning algorithm which is ability of fuzzy logic and neural network. Fuzzy logic is an ability of reasoning and neural network is an ability of learning [15], [16]. The accurate automated band width control of PID+ANFIS is introduced for stator current variation in proposed direct torque control scheme. This control loop is used to control the torque and flux without additive loop requirement. An appropriate switching selection is applied for induction motor in present space vector PWM generation. The proposed approach is greatly reduces the ripple around torque, flux and reduces line current harmonics. The MATLAB/Simulink result was achieved for this approach. The proposed performance is proved better in quick transient response, reliable operation, less number of loops and accurate control of torque and flux by comparing with conventional PI and fuzzy-PI controller scheme.

2. DIRECT TORQUE CONTROL (DTC) SCHEME

In nature of DTC is described and control of torque and flux control by appropriate switching vector selection to Voltage Source Inverter is beneficial to keep constant of flux and Torque in desired limits. This method is obtained by variable frequency of PWM control or hysteresis band control [17]. The aim of this technique is to obtain a decoupled control of Torque and Flux by sensing of stator current and actual speed. This method is described from switching table in the input and output variables and elements. The input variables are torque and flux error, stator flux angle. The output elements which are described in inverter setting function. The direct torque control of proposed enhancement topology does not require any complex transformation which is shown in Fig. 1. This control structure of automated bandwidth control circuit is used to obtain an accurate bandwidth of control and reduces complexity on space vector and speed control loop.

The feedback signal of flux and Torque estimation is used for controller and switching state is described by estimated value of flux and torque signals in loop. The torque generation in induction drive is expressed by

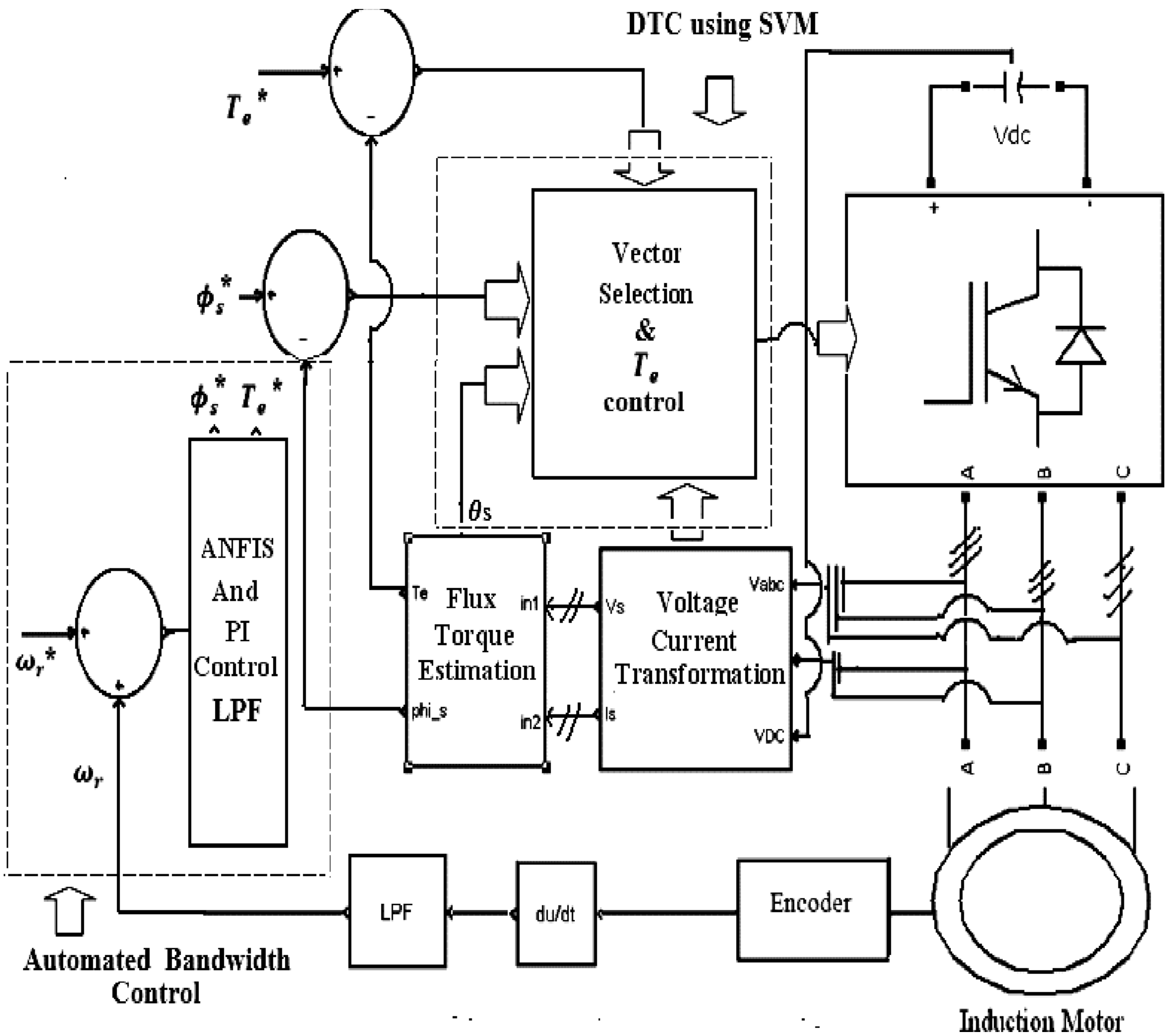


Figure 1: Block diagram of direct torque control for induction motor using ANFIS with PID control

$$T_e = \frac{3}{2}\left(\frac{p}{2}\right)\overline{\psi}_s \times \overline{I}_s \tag{1}$$

The developed torque is explained from equation (1) is in the form of flux and torque is defined by

$$T_e = \frac{3}{2}\left(\frac{p}{2}\right)\frac{L_m}{L_r L_s}|\psi_s||\psi_r|\sin\gamma \tag{2}$$

Here,

$$\overline{\psi}_s = L_s\overline{I}_s + L_m\overline{I}_r \tag{3}$$

$$\overline{\psi}_r = L_r\overline{I}_r + L_m\overline{I}_s \tag{4}$$

$$L_s' = L_r L_r - L_s^2 \tag{5}$$

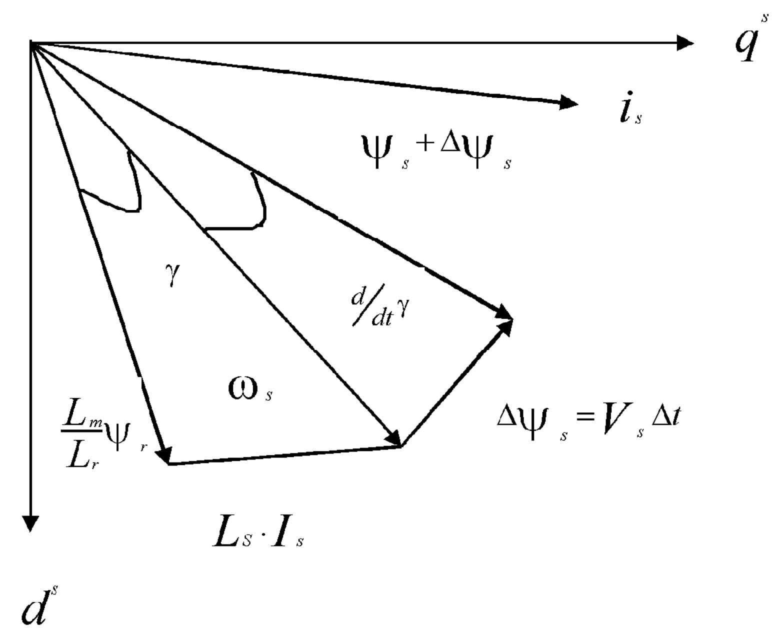


Figure 2: Phasor diagram for space vector modulation

The above equation is explained about stator flux magnitude, rotor flux magnitude and phase angle (γ) between vector of stator flux and rotor flux is shown in fig. 2. The asynchronous motor equation is described by

$$\bar{V}_s = \frac{d\bar{\psi}_s}{dt} \tag{6}$$

Or

$$\Delta\bar{\psi}_s = \bar{V}_s \Delta t \tag{7}$$

The above expression is implies in voltage vector and changes in Stator flux is shown in Fig 3 and 3. The changes made on torque generation in motor by increasing phase angle between stator flux and rotor flux.

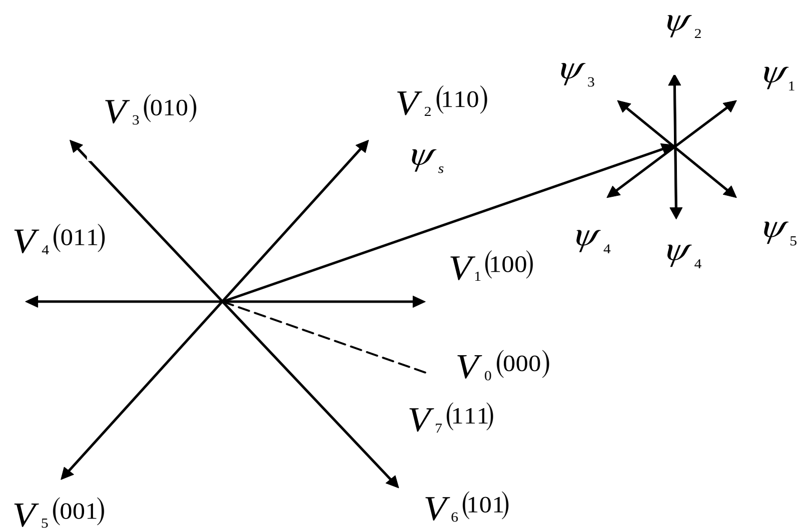


Figure 3: Voltage vector for voltage source inverter with respect to derivative of flux (Ψ) and variation of current

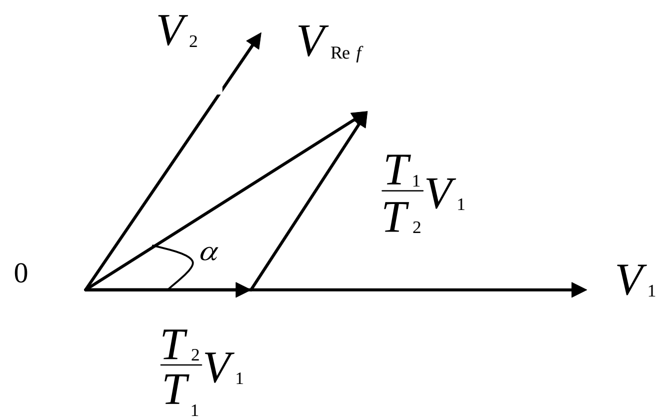


Figure 4: Formation of V_{ref} vector

The two components of acting and radial components of stator flux linkage vector on its locus are directly proportional to equal voltage of space vector. The present space vector modulation scheme is considered the given alternative signal as vector signal which is in constant amplitude and frequency rate. The vector shown in Fig. 3 denotes that Reference Voltage(V_{Ref}) is generated by combination of eight vector sequence ($V_0 - V_7$) belongs to two adjacent vectors and two Non-zero vectors and angle between each of six sector is 60^0. The figure shown in 4 is proved that time interval of V_{Ref} and T_z is same. The uniform of symmetrical pulse pattern is design by vectors ($V_0 - V_7$) at T_0, T_1, T_2 shown in Fig. 5.

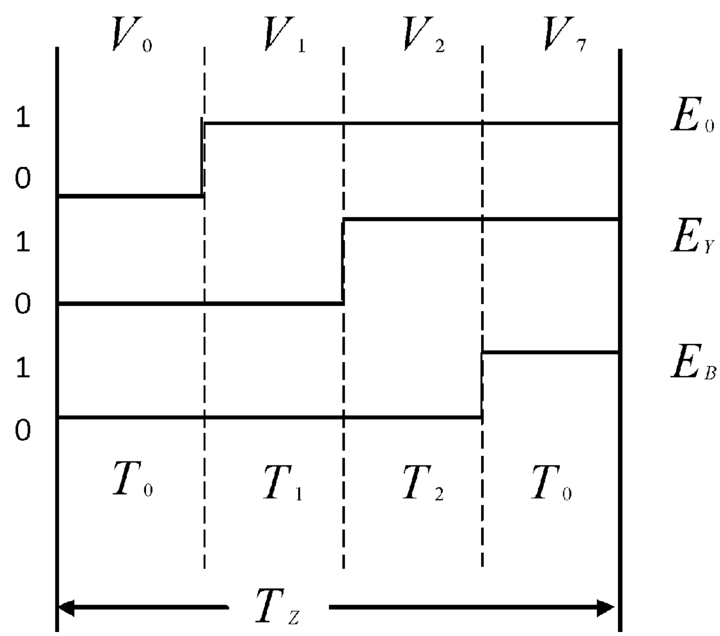


Figure 5: Uniform of pulse patter using space vector pulse width modulation

The mathematical function of T_0, T_1, T_2 is given by

$$T_1 = \frac{\sqrt{3}\, T_z\, |V_{ref}|}{V_{dc}} \left(\sin \frac{n}{3} \pi - \alpha \right) \tag{8}$$

$$T_1 = \frac{\sqrt{3}T_z\left|V_{ref}\right|}{V_{dc}}\left(\sin\left(\alpha - \frac{n-1}{3}\pi\right)\right) \tag{9}$$

Where $n = 1$ through 6 sectors $0 \le \alpha \le 60°$

The automated control technique is introduced for stability and accuracy of bandwidth operation depends on variation in stator current signal. This control loops is adapted to bandwidth control by PID with adaptive inference topology is obtained by

$$G(s) = \frac{a}{s+b} = \left(\frac{a}{b}\right)\frac{1}{1+\frac{s}{b}} \tag{10}$$

Here, $s = jb = \frac{b}{2\pi}$; $b =$ Band width $\left({}^{rad}\!/_{\sec}\right)$, Pass band gain $= \frac{a}{b}$. The Estimated flux is derived or changed with respect to stator current (I_S) and actual speed (ω_r). The desired rotor flux and rotor torque reference estimation is needed to obtain by effective control law. So proposed controller can easily derive Rotor flux as

$$\overline{\psi} = \frac{L_r}{L_m}\left(\overline{\psi}_s - \sigma L_s \overline{I}_s\right) \tag{11}$$

$$\sigma = \frac{L_s}{(L_s + L_m)(L_r + L_m)} \tag{12}$$

The resultant value of filter is obtained a torque equation in desired frequency rate is given by

$$\omega_r = \frac{d}{dt}\left(w_s - \Gamma_r \frac{T_e}{\psi_r^2}\right) \tag{13}$$

Frequency and stator current is measured with flux generation which is in (8) and this measured signal is applied to **PI/PI-fuzzy/PID+ANFIS** controller for estimation of torque, flux references and performance are analyses.

3. MAGNETIC FLUX AND TORQUE ESTIMATION

This estimation loop contains torque and flux reference signal estimation to obtain a required range of torque, flux and speed performance. This circuit was implemented using conventional PI and PI-Fuzzy controller and it is compared with proposed configuration of Adaptive fuzzy inference system. The control circuit, estimation procedure and details described in bellow section.

(A) PI Control

The control tuning is applied in PI controller with respect to stability boundary by Ziegler-Nichols method [23]. The response based tuning is implemented and saturation is neglected by its integral nature [23]. The control block is used for estimating flux and torque references which is shown in Fig. 6

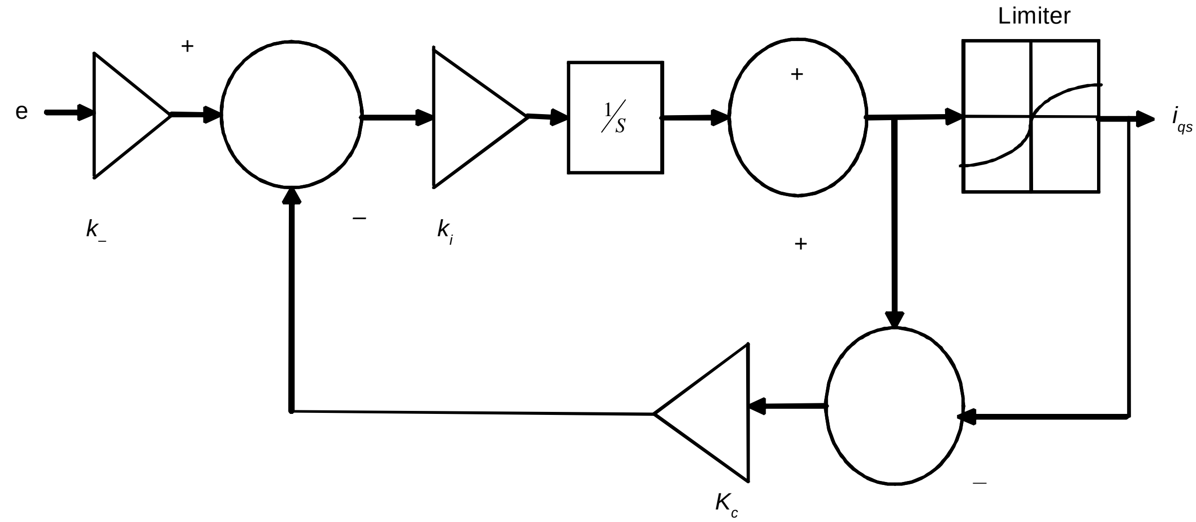


Figure 6: Block of PI Controller

(B) Fuzzy-PI Controller

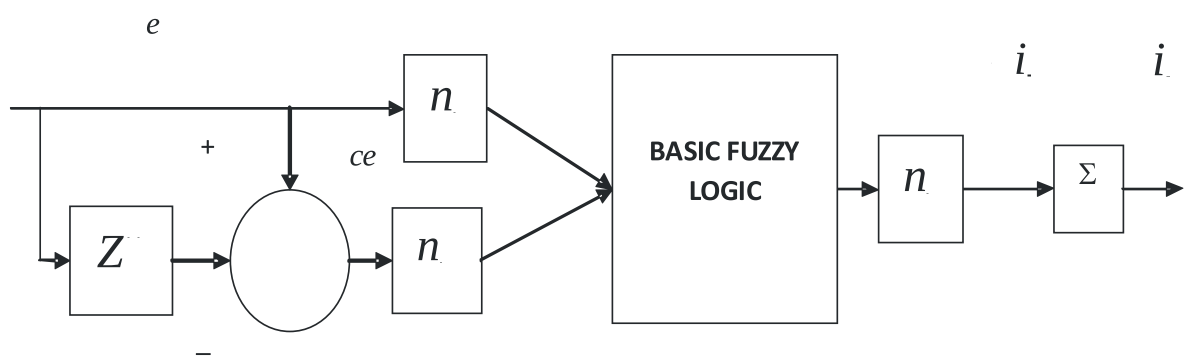


Figure 7: Block of fuzzy logic control

The control and deriving of output scaling factors is designed by fuzzy-PI controller which is shown in fig.7. The given fuzzy logic scheme is developed under mamdani scheme and its two input function are error signal (e) and rate of change of error signals n_e, n_{ce} and n_u. The fuzzy logic circuit is a collection of interfacing of fuzzification, mechanism with respect to fuzzy rules and interfacing of defuzzification. The fuzzification of input and output membership function (*Mfn*) is developed by five symmetrical membership function *S*(*mfn*) and triangular membership function *T*(*mfn*) and both *S*(*mfn*) and *T*(*mfn*) is regularized in the range between -1 to +1.

The basic membership functions are NB-Negative Big, NM-Negative Medium, and ZE-Zero, PB-Positive Big and PM-Positive medium. The summation of membership function is unity at entire run time while adjacent value of membership function is complementary. This fuzzy rules scheme of 2-D phase plan is reduces the burden of speed control structure and output variables is varied by tuning of fuzzy logic gain. So the fuzzy logic scheme of rules is generally developed by dynamic form of resultant speed error signal (W_r^*) and symmetrical form of matrix. The fuzzy-PI controller has major merits such as reducing complexity and burden of control structure, accuracy and smooth transient performance over PI controller.

(C) Adaptive Neuro-fuzzy Inference System

The inference system is a non-linear system which is able to estimate Real system empirical data, least-squares combination and back propagation of gradient descent methods are used for training FIS membership function parameters to model a given set of input/output data. The fuzzy logic rules having the limitation while executing the human knowledge based on non-linearity and data among the limitation and complexity. Adaptive neuro fuzzy system having decoupling merits of fuzzy logic and artificial neural network such as complicated system, learning reading of instruction [18], [19].

Neural networks performance in two methods reading and processing output, transferring information among in between the nodes. This operation of feed forward neural networks is performed in present adaptive inference system with sugeno-fuzzy logic controller. The encoding of speed is applied and compared with reference speed and finally given proposed adaptive fuzzy inference system and its architecture is shown in fig. 8.

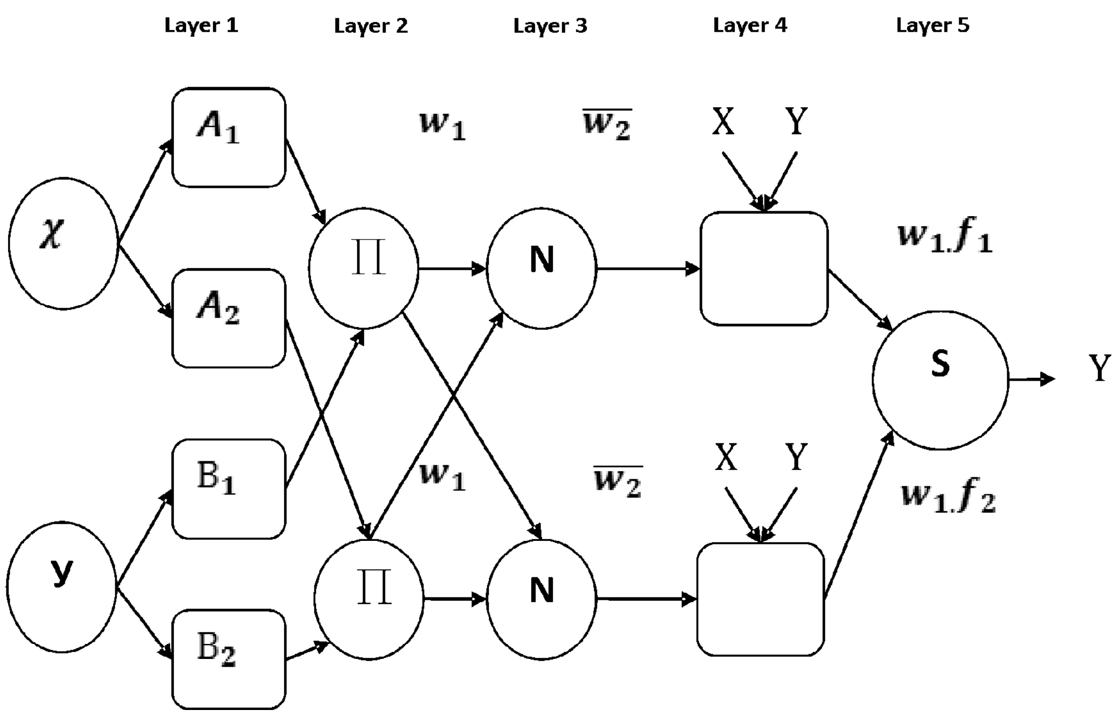


Figure 8: ANFIS architecture

This control loop is easily obtained an automated bandwidth change for torque control by controlling the phase current. The proposed automated bandwidth control loop is combination of **ANFIS control and filter with** respect to both input and output scaling factors which is like self tuning methods [20]-[22]. The torque and flux estimation signal is applied to conventional PI, PI-fuzzy and proposed ANFIS controller which is implemented using space vector based DTC scheme. This controller is obtaining which is adequate and desired limits of torque and flux reference signal. The combined performance of low pass and high pass filter performance is achieved using proposed ANFIS control law with five layers and its structure.

The present control loops performed as good scaling factors and noise suppression across signals and provided accurate torque references in desired frequency range and it's provided better performance while it enrolled in proposed space vector approach and reducing complexity of space vector based switching selection and its loops. Adaptive neuro-fuzzy inference system is described in bellow which three set of rules for each three input selection i.e the totally a nine set of rules is described using Sugeno method in proposed ANFIS topology.

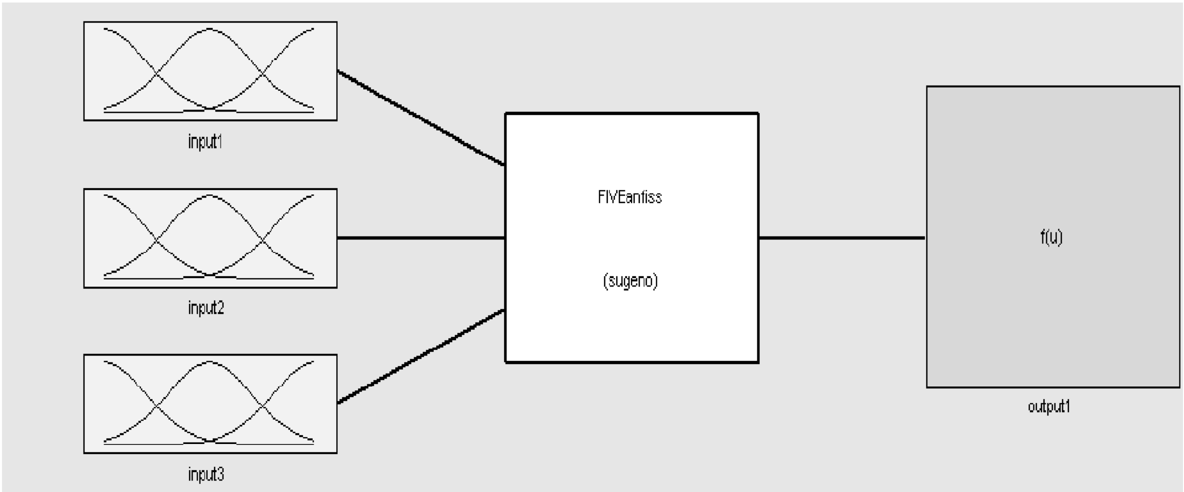


Figure 9: Enhancement of ANFIS structure

The simulation implementation of nine set of if-then rules is implemented as

1) If (input1 is input1mfn1) and (input2 is input2mfn1) and (input3 is input3mf1) then (output1mfn1 is p1input1+q1input2+h1input3.
2) If (input1 is input1mfn2) and (input2 is input2mfn2) and (input3 is input3mfn2) then (output1mfn2 is p2input1+q2input2+h2input3.
3) If (input1 is input1mfn3) and (input2 is input2mfn3) and (input3 is input3mfn3) then (output1mfn3 is p3input1+q3input2+h3input3.

The present proposal of ANFIS system is given bellow with respect to layers is shown in fig.8 and this implemented is shown in Fig.9.

Layer 1

The adaptive node of this layer is used to creating a languishing label of membership function and given input variables is performed by membership function of Gaussian (*mfn*):

$$O_{2,j} = w_j = \mu_1^{i_1} \mu_1^{i_2} \mu_1^{i_3} \mu_1^{i_4} \mu_1^{i_5} \tag{14}$$

$$(j = 1, ..., c_i), (i_1 = 1, ..., c_1), ..., (i_5 = 1, ..., c_5)$$

Here $C_1 = ... = C_2 = 3$. **Layer 2** performed as it is performance details given in Layer 2

Layer 3

This layer gives regularized results of firing strength from input of this layer and this layer (J^{th}) node is calculating the ratio between firing strength across the node to total firing strength of entire node.

$$O_{3,j} = \overline{w_j} = wb_j = \frac{w_j}{\Sigma_i w_i}, (i = 1, ..., 3) \tag{15}$$

Layer 4

The node value of this layer is square node and its correlation between inputs to output function of this layer is expressed by

$$O_{4j} = \overline{w_j} f_i = \overline{w_j}\left(p_j t_{ox} + q_j t_{si} + h_j T + g_j V_{gs} + k_j V_{ds} + r_j\right), \quad (16)$$

j = 1,.. 3. Here, $\overline{w_j}$ Is the third layer output and parameter set $\{p, q, h, g, k, r\}$. The resultant parameters is calculated from previous layer

Layer 5

The particular node of this layer output is calculating the summation of all incoming signals

$$O_s = \Sigma_j \overline{w_j} f_i = \frac{\Sigma_j w_j f_i}{\Sigma_i w_j} \quad (17)$$

Here , O_s, is denoted as output layer for layer 5.

4. TUNING OF PROPOSED CONTROLLER

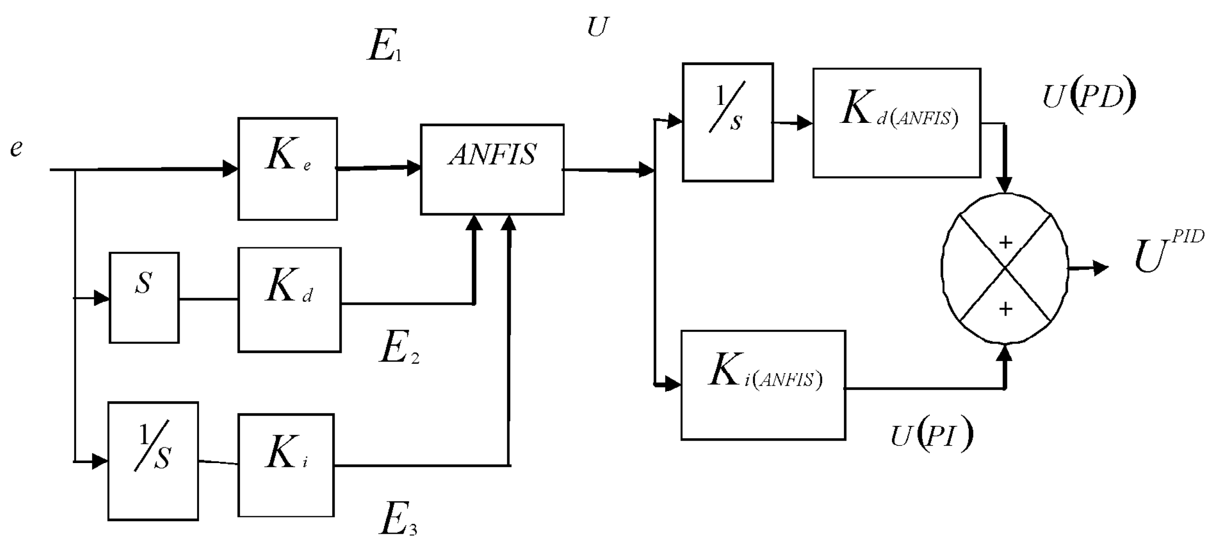


Figure 10: Proposed ANFIS tuning structure

The proposed Adaptive fuzzy inference system is designed is based on characteristic of asynchronous drive, fuzzy logic scheme and neural network of self tuning. The many more control structures and tuning methods presented [24], [25].but present controller is the combination of self tuning of PID and ANFIS tuning which is shown in Fig. 10. The parameters (K_p, K_i and K_d) changes are made with respect three-input variable of fuzzy inference system such as actual form of speed error (e), derivative $\left({de}/{dt}\right)$ form of speed error and integral ($\int e(t)dt$) form of speed error. The optimized function of adaptive fuzzy inference system signal (17) is applied to tuning of torque is shown bellow.

$$T_e^* = K_{p(ANFIS)}.e(t) + K_{i(ANFIS)}.\int e(t)dt + K_{d(ANFIS)}.{de(t)}/{dt} \quad (18)$$

Where

$$K_{p(ANFIS)} = \left(K_p + K_{p(FI)}\right) * O_s \quad (19)$$

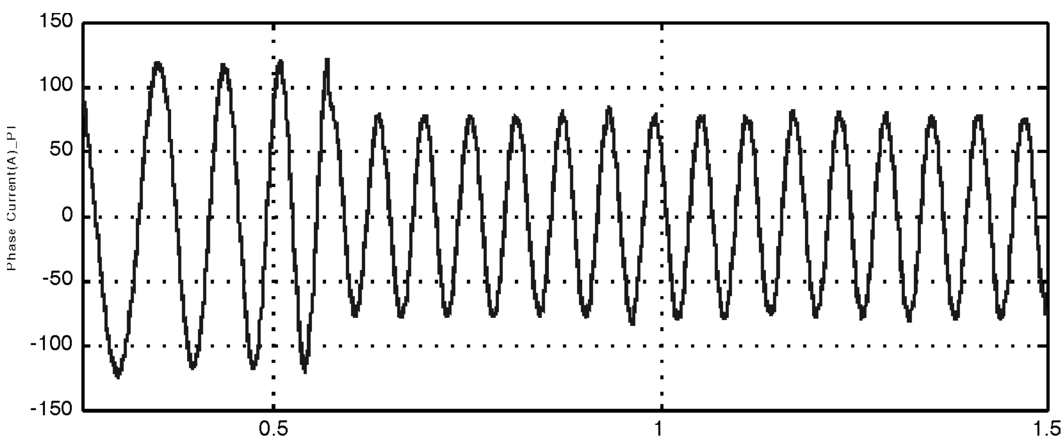
$$K_{i(ANFIS)} = \left(K_i + K_{i(FI)}\right) * O_S \quad (20)$$

$$K_{d(ANFIS)} = \left(K_d + K_{d(FI)}\right) * O_S \quad (21)$$

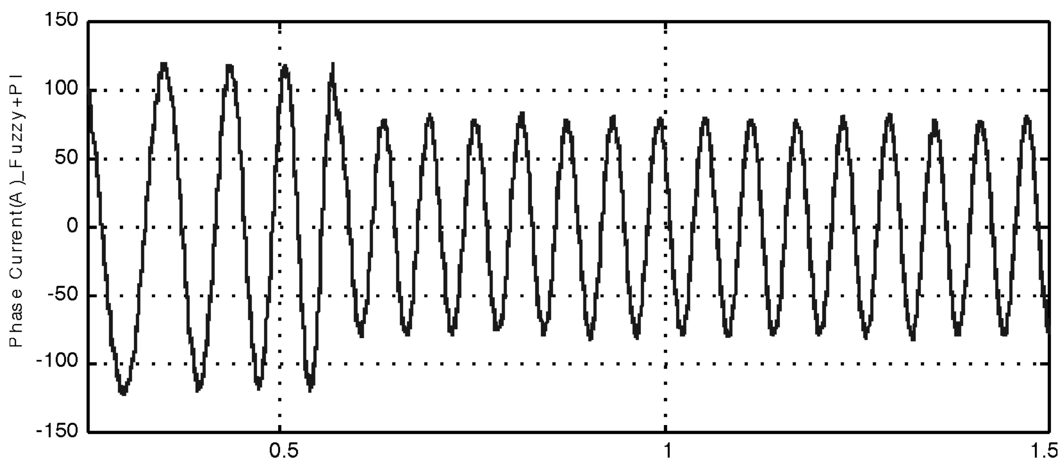
O_S, is the scaling factor for obtained gain factors of $K_{p(FI)}$, $K_{i(FI)}$ and $K_{d(FI)}$ in present adaptive fuzzy inference topology. The gain factors are derived by applying adaptive fuzzy inference system from equation (14) to (17).

5. SIMULATION RESULT AND DISCUSSION

The present control configuration of adaptive neuro fuzzy inference system (ANFIS) with PID is compared with conventional structure of PI/PI with fuzzy controller is analyses over here with simulation result. Torque ripples are greatly reduces by proposed configuration results over conventional control methods are shown in fig 13. And also proposed configuration is achieved fast and quick response of speed by corresponding torque variation is shown in fig. 14. The enlarged view of flux performance is shows clearly about importance and controller capability of proposed controller in fig. 12. Stator current performance is obtained minimum and ripple free performance is achieved using proposed configuration results while comparing with existing topology.



(a)



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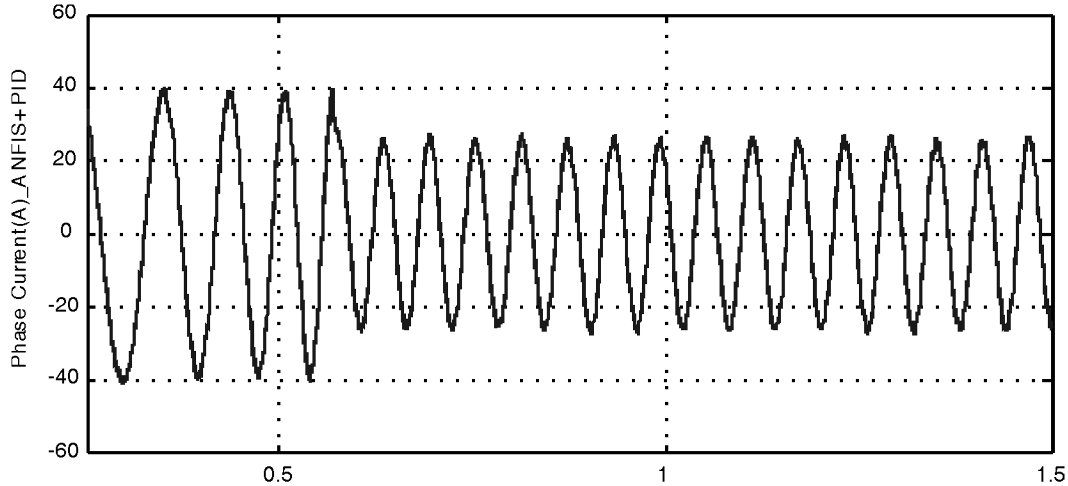
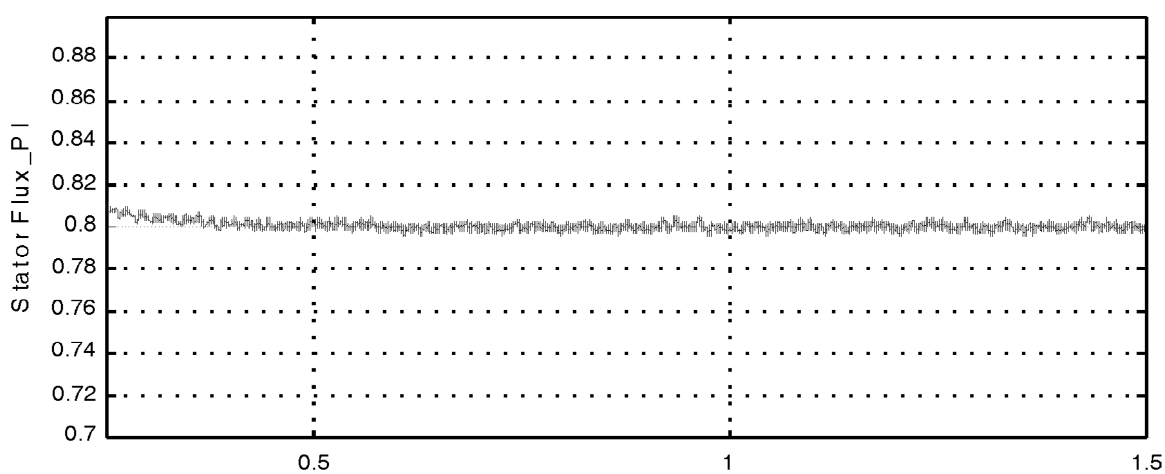
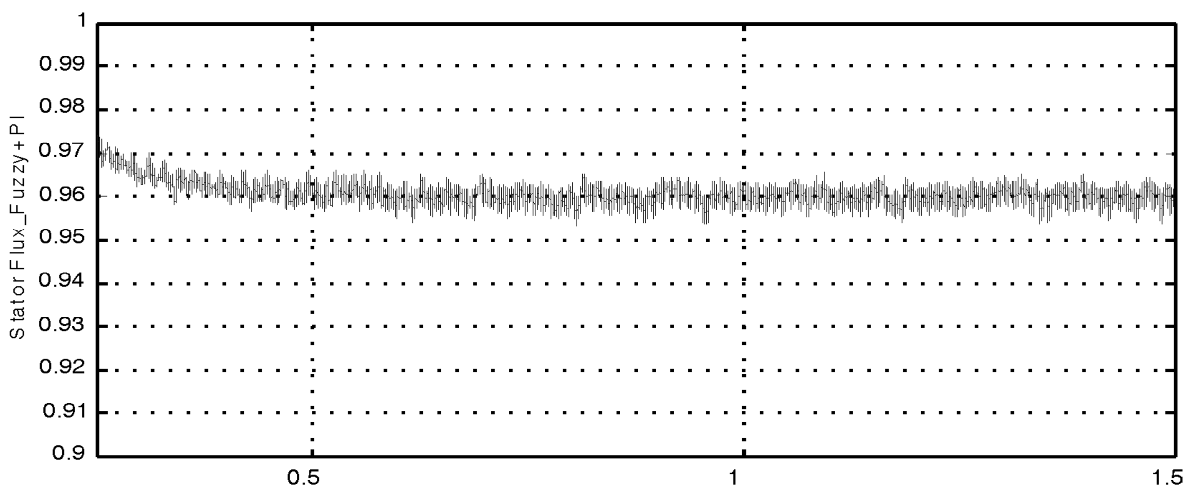


(c)

Figure 11: Stator Current Performance: (a) Using PI Controller. (b) Using Fuzzy+ PI Controller. (c) Proposed ANFIS+PID Controller



(a)



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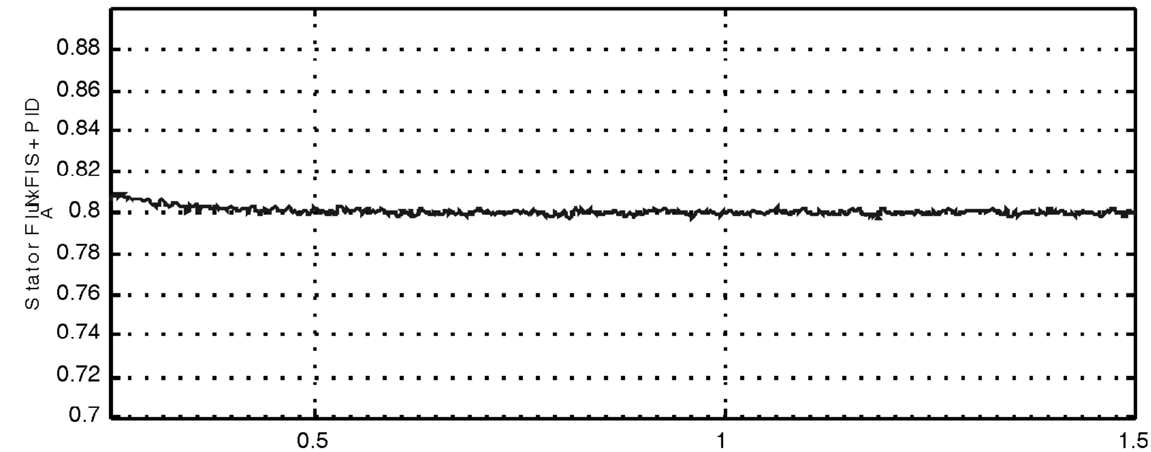
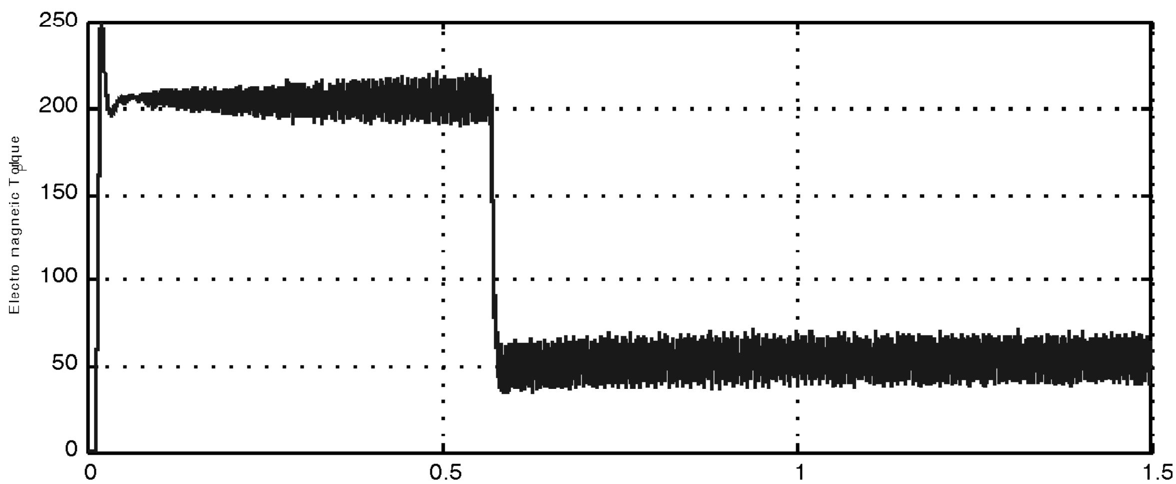
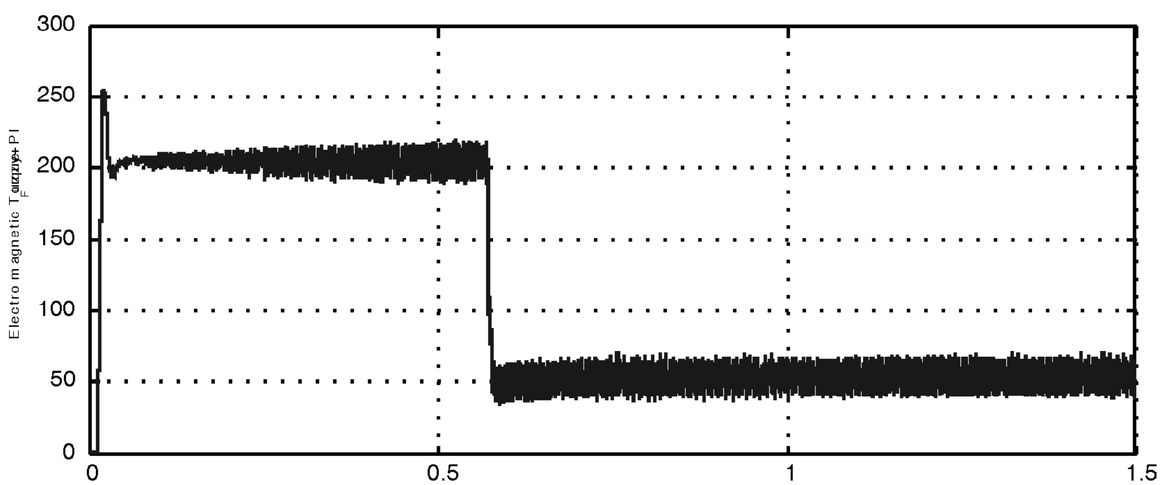


(c)

Figure 12: Enlarged version of flux performance: (a) Using PI controller. (b) Using Fuzzy+PI controller. (c) Proposed ANFIS+PID controller



(a)



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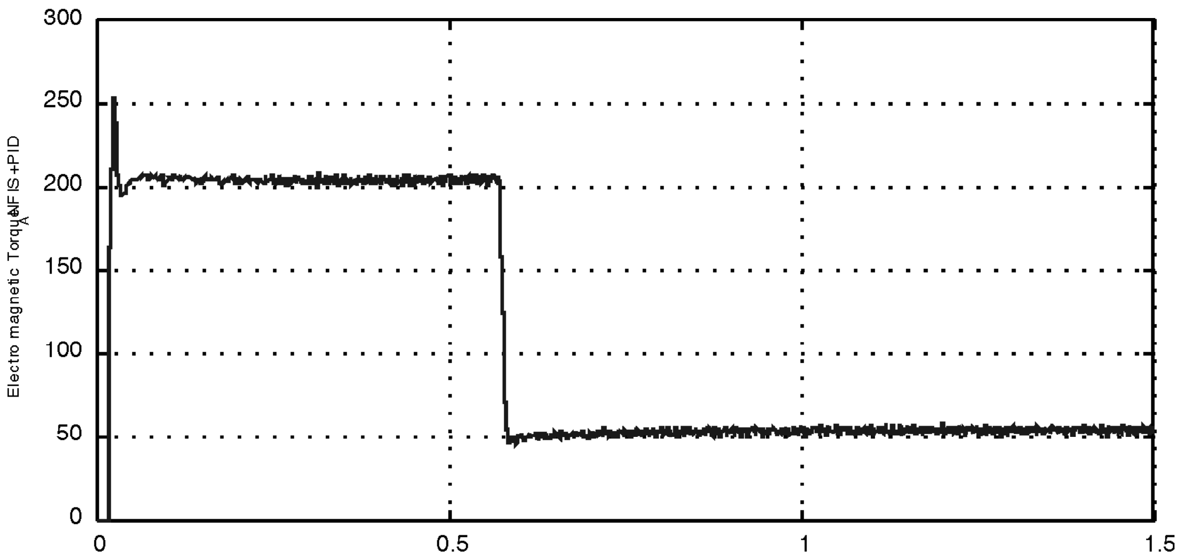

(c)

Figure 13: Electromagnetic Torque performance: (a) Using PI controller. (b) Using Fuzzy+PI controller. (c) Proposed ANFIS+PID controller

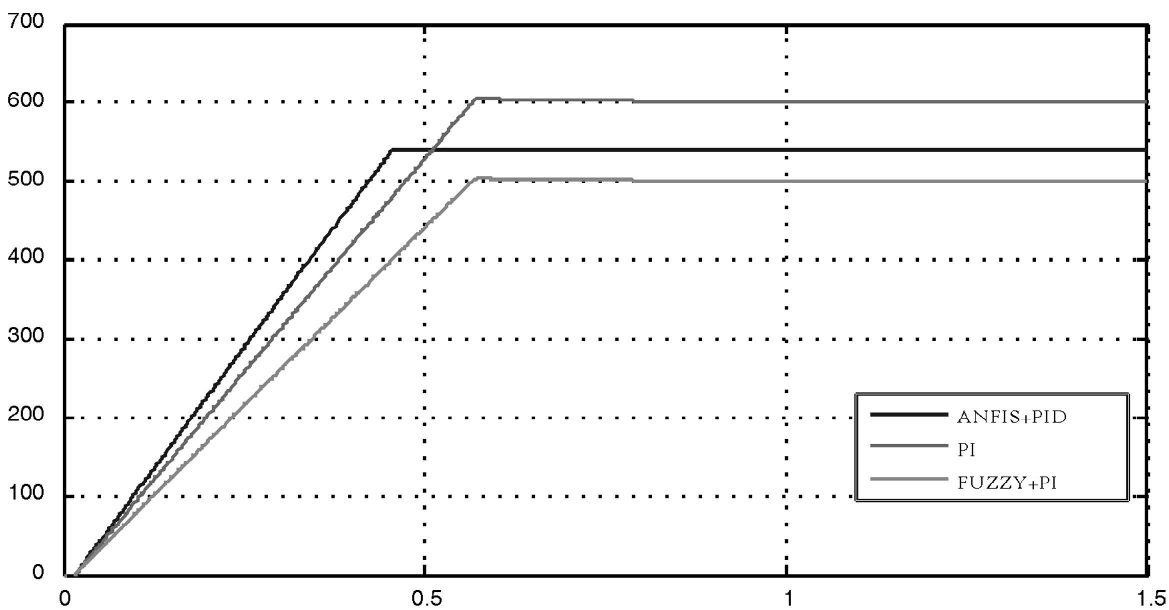

Figure 14: Speed Performance comparison using Conventional and Proposed Topology

6. CONCLUSION

This paper presents a direct torque control of induction motor using adaptive neuro-fuzzy inference system with PID control. This control technique involves in flux and torque estimation circuit to obtain a desired range and it is applied to proposed space vector selection. ANFIS is reduces the complexity of direct torque control by a capable of auto-bandwidth control, torque ripple minimization and fast speed response. The conventional control circuit of PI and fuzzy with PI controller is implemented in simulation and compared with proposed adaptive

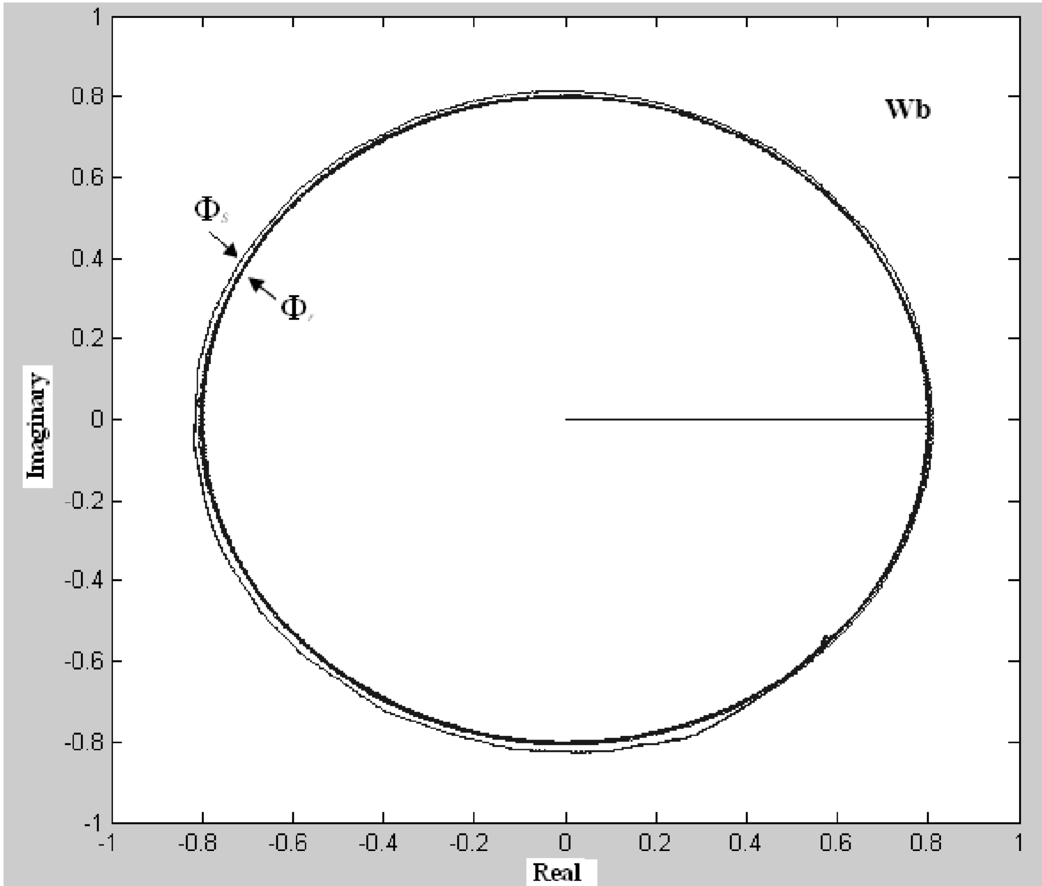

Figure 15: Flux Vector Trajectories for proposed scheme

fuzzy inference system. The obtained simulation results are shows that performance of conventional controller and complexity of torque/flux control and auto tuning of bandwidth control. The Present scheme is proved as better choice for direct torque control scheme by comparing of simulation results with and performance.

REFERENCES

[1] G.S. Buja and M.P. Kazmierkowski, "Direct torque control of PWM inverter-fed AC motors - a survey," *IEEE Transactions on Industrial Electronics,* 51 (4), 744-757, 2004.

[2] H.F. Rashag, S.P. Koh, A.N. Abdalla, N.M.L. Tan and K.H. Chong. "Modified direct torque control using algorithm control of stator flux estimation and space vector modulation based on fuzzy logic control for achieving high performance from induction motors," *Journal of Power Electronics,* 13 (3), 369-380, 2013.

[3] P. Ponce, A. Molina and A. Tellez, "Neural network and fuzzy logic in a speed close loop for DTC induction motors," *International Caribbean Conference on Devices, Circuits and Systems (ICCDCS),* 2 (4), pp. 1-7, April 2014.

[4] A.K. Rathore, "Improved performance of fuzzy logic based direct field oriented controlled induction motor," *9th IEEE International* in *Power Electronics Congress, CIEP 2004*, 17 (22), pp. 152-157, Oct. 2004.

[5] M.N. Uddin and M. Hafeez, "FLC-based DTC scheme to Improve the Dynamic Performance of an IM Drive," *IEEE Transactions on Industry Applications,* 48 (2), 823-831, 2012.

[6] M. Masiala, B. Vafakhah, J. Salmon and A.M. Knight, "Fuzzy self-tuning speed control of an indirect field-oriented control induction motor drive," *IEEE Transactions on Industry Applications,* 44 (6), 1732-1740, 2008.

[7] H.A.F. Mohamed and W.P. Hew, "A fuzzy logic vector control of induction motor,"*Proceedings* in *TENCON*, vol.3, pp.324-328, 2000.

[8] M.N. Uddin and M. Hafeez, "FLC based DTC scheme to improve the dynamic performance of an IM drive," *2010 IEEE* on *Industry Applications Society Annual Meeting (IAS),* pp. 1-7, 2010.

[9] T.G. Habetler and D.M. Divan, "Control strategies for direct torque control using discrete pulse modulation," *IEEE Transactions on Industry Applications,* 27 (5), 893-901, 1991.

[10] K. Drobnic, M Nemec, D. Nedeljkovic and V. Ambrozic, "Predictive direct control Applied to AC Drives and Active Power Filter," *IEEE Transactions on Industrial Electronics,* vol.56, no.6, pp.1884-1893, June 2009.

[11] I. Takahashi and T. Noguchi, "A new quick-response and high-efficiency control strategy of an induction motor," *IEEE Transactions on Industry Applications,* 22 (5), 820-827, 1986.

[12] K. Chikh, M. Khafallah, A. Saad, D. Yousfi and H. Chaikhy, "A novel fixed-switching-frequency DTC for PMSM drive with low torque and flux ripple based on sinusoidal pulse with modulation and predictive controller," *International Conference on Multimedia Computing and Systems (ICMCS),* 10 (12), 1069-1075, May 2012.

[13] K.N. Sujatha and K. Vaisakh, "Self-tuning fuzzy PI scheme for DTC induction motor drive," *2010 IEEE* on *Power and Energy Society General Meeting,* 25 (29), 1-6, July 2010.

[14] P. Ponce, A. Molina and A. Tellez, "Neural network and fuzzy logic in a speed close loop for DTC induction motors," *2014 International Caribbean Conference on Devices, Circuits and Systems (ICCDCS),* 2 (4), pp.1-7, April 2014.

[15] R. Simon and A. Geetha, "Comparison on the performance of induction motor control using fuzzy and ANFIS controllers," 2013 International Conference on Emerging Trends in Computing, Communication and Nanotechnology (ICE-CCN), 25 (26), pp. 491-495, March 2013.

[16] F.J. Lin and P.H. Shen, "Adaptive fuzzy-neural-network control for a DSP-based permanent magnet linear synchronous motor servo drive," IEEE Transactions on Fuzzy Systems, 14 (4), 481-495, 2006.

[17] F.J. Lin and P.H. Shen, "A DSP-based permanent magnet linear motor servo drive using adaptive fuzzy-neural-network control," *IEEE Conference on Robotics, Automation and Mechatronics,* 1 (3), 601-606, Dec. 2004.

[18] H. Daneshmand, T. Tavousi, M. Khosravi and S. Tavakoli, "Modeling minimum temperature using adaptive neuro-fuzzy inference system based on spectral analysis of climate indices: A case study in Iran," *Journal of the Saudi Society of Agricultural Sciences,* 14 (1), 33-40, 2015.

[19] J. Rostamimonfared, A. Talebbaigy, T. Esmaeili, M. Fazeli, and A. Kazemzadeh, "Cylindrical silicon nanowire transistor modeling based on adaptive neuro-fuzzy inference system (ANFIS)." *Journal of Electrical Engineering & Technology,* 8 (5), 1163-1168, 2013.

[20] M.Yoshida, Y. Tsutsumi, and T. Ishida, "Gain tuning method for design of fuzzy control systems," In *Proceedings of International Conference on Fuzzy Logic & Neural Networks IIZUKA 90,* vol. 1, 405-408. 1990.

[21] S. Mir and M.E. Elbuluk, "Precision torque control in inverter-fed induction machines using fuzzy logic," *PESC '95 Record, 26th Annual IEEE* on *Power Electronics Specialists Conference,* 18 (22), 396-401, June 1995.

[22] T. Iwasaki and A. Morita. "Auto-tuning controller with fuzzy identification." In *Proceedings of International Conference on Fuzzy Logic & Neural Networks IIZUKA 90,* Vol. 1, 401-404, 1990.

[23] G.F. Franklin, D. Powell, and A. Emami-Naeini, *Feedback Control of Dynamics Systems*, Addison-Wesley, Reading, MA, 1994.

[24] H.X. Li, L. Zhang, K.Y. Cai, and G. Chen. "An improved robust fuzzy-PID controller with optimal fuzzy reasoning." *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics,* 35 (6), 1283-1294, 2005.

[25] V. Kumar and R.R. Joshi, "Hybrid controller based intelligent speed control of induction motor", Journal of Theoretical and Applied Information Technology, 3 (1), 71-75, 2007.

[26] Z. Boussada, M.B. Hamed and L. Sbita, "Adaptive neuro-fuzzy inference system into inductor motor estimation" IEEE 2014 International Conference on Electrical Sciences and Technologies in Maghreb (CISTEM), pp. 1-5, 2014.