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"Intelligent Nonlinear Control of IPMSM using Belbic"

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ABSTRACT

In this paper speed control of Interior Permanent Synchronous Motor is investigated. Performance of the IPMSM depends on several factors such as load torque, variation of motor parameters and different working situations. Load torque, reference speed, and stator currents are taken as input variables and output torque, rotor mechanical speed and flux are taken as output variables. Due to high capabilities of artificial intelligence methods, the main focus of this thesis is use of these methods for speed control of PMSM.

Two different methods are used for controlling the PMSM speed. The first method is the classical PI method and the second method is the brain emotional learning based intelligent control. The performances of the applied methods are compared. The results show that the brain emotional learning based intelligent control has a higher performance to the classical method.

Keywords: *Emotional Controller, Emotional Learning, IPMSM*

1. INTRODUCTION

Interior Permanent Magnet Synchronous Motors (IPMSM) fed by PWM inverters are widely used for industrial applications, especially servo drive applications [12],[22] in which constant torque operation is desired. With advances in new magnetic material (Nd-Fe-B), in 1980, the popularity of PM motors with high power increased especially where systems with long life, high efficiency and power density are needed. In these uses, PMSM is a wise choice. Among ac motors, permanent magnet synchronous motor drive featuring high torque-to-current and power-to-weight ratios, high efficiency, high power factor, lack of commutator and as a result elimination of mechanical losses caused by commutator, has got a unique place, in recent years, in many military and industrial uses as robotics and submarines, among the researchers [17].

The IPMSM drive system has been controlled using a PI controller due to its simplicity. However, it cannot provide good performance in both transient and load disturbance conditions. Several researchers have investigated the speed controller design of adjustable-speed IPMSM systems to improve their transient responses, load disturbance rejection capability, tracking ability, and robustness (Rebeiro R.S *et al.*,2012) have analyzed the performance of IPMSM using Fuzzy logic controllers for torque and speed. It improves system performance (Uddin M.N *et al.*, 2004)by reducing ripples in torque but it increases processing time. M. Fazlur Rahman, Md. Enamul Haque Lixin Tang, and Limin Zhong, have studied the problem associated with DTC of IPMSM (Fazlur Rahman 2004). DTC has some smart features such as lesser parameter dependence, no requirement for mechanical rotor position sensor for the inner torque control loop and fast dynamic response. Even though it is difficult [14] to control torque and flux at very low speed, relatively high noise level at low speed and lack of direct current control.

Considering the current conditions, controller must be flexible enough to deal with different situations. Intelligent control is a branch of control engineering in which the control algorithm is based on intelligent biologic systems.

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BELBIC was introduced [15] as a controller based on the computational model of the limbic system of the mammalian brain. In the past few years this controller has been utilized in control devices [16] and drives [24] for several industrial applications. So Artificial Intelligence based BELBIC is proposed to limit the overshoot and to reduce the settling time.

2. MODEL OF PMSM IN DQ FRAME

The mathematical model of IPMSM is similar to that of wound rotor synchronous motor [20]. The following assumptions are considered in the model [18], [21]

1. The magnetic permeability of iron is considered to be infinite
2. The operation is far from magnetic saturation.
3. Higher harmonics are neglected.
4. The magnetic motive force and the flux profiles are considered sinusoidally distributed.

With these assumptions, the stator d, q axis equations of the IPMSM in the rotor reference frame are [3], [7].

$$U_q = R_s i_q + L_q pi_q + \omega_r L_d i_d + \omega_r \Psi_f \tag{1}$$

$$U_d = R_s i_d + L_d pi_d - \omega_r L_d i_q \tag{2}$$

Also flux linkage equation can be written as [7].

$$\Psi_d = L_d i_d + \Psi_f \tag{3}$$

$$\Psi_q = L_q i_q \tag{4}$$

where,

U_d and U_q are the d, q axis voltages, i_d, i_q are the d, q axis stator currents, L_d, L_q are defined as *dq*-axis inductances,

Ψ_d and Ψ_q are the d, q axis stator flux linkages,

R_s : stator resistance

ω_r is rotor electrical speed .

The electromagnetic torque generated by

$$T_e = (3/2)(P/2)[\Psi_f i_q - (L_d - L_q) i_d i_q] \tag{5}$$

Where P is the number of poles, T_L is the load torque, B is the damping co-efficient, ω_m is the rotor mechanical speed, J is the moment of inertia and p is the differential operator [1].

$$\omega_r = (P/2)\omega_m \tag{6}$$

Where θ_m is the position angle of the rotor.

In order to achieve maximum torque per ampere and maximum efficiency, direct axis current component i_d is forced to be zero [4].

$$T_e = (3/2)(P/2)\Psi_f i_q \tag{7}$$

The d, q variables in dq frame are acquired from park transform [10].

$$U_q = 2/3[Ua \cos\theta + U_b \cos(\theta - 2\Pi/3) + U_c \cos(\theta + 2\Pi/3)] \tag{8}$$

$$U_d = 2/3[U_a \sin\theta + U_b \sin(\theta 2\Pi/3) + U_c \sin(\theta + 2\Pi/3)] \tag{9}$$

The a, b, c variables in abc frame are acquired from inverse of park transform [5],

$$U_a = U_q \cos\theta + U_d \sin\theta \tag{10}$$

$$U_b = U_q \cos(\theta - 2\Pi/3) + U_d \sin(\theta - 2\Pi/3) \tag{11}$$

$$U_c = U_q \cos(\theta + 2\Pi/3) + U_d \sin(\theta + 2\Pi/3) \tag{12}$$

3. SIMULATION SETUP FOR IPMSM

The IPMSM drive system consists of speed loop, current loop, park transformation, PWM inverter and IPMSM motor. Block diagram of IPMSM drive is shown in figure 1.

Speed loop has three inputs such as reference speed, measured speed and i_q. Its output is reference current of i_q.

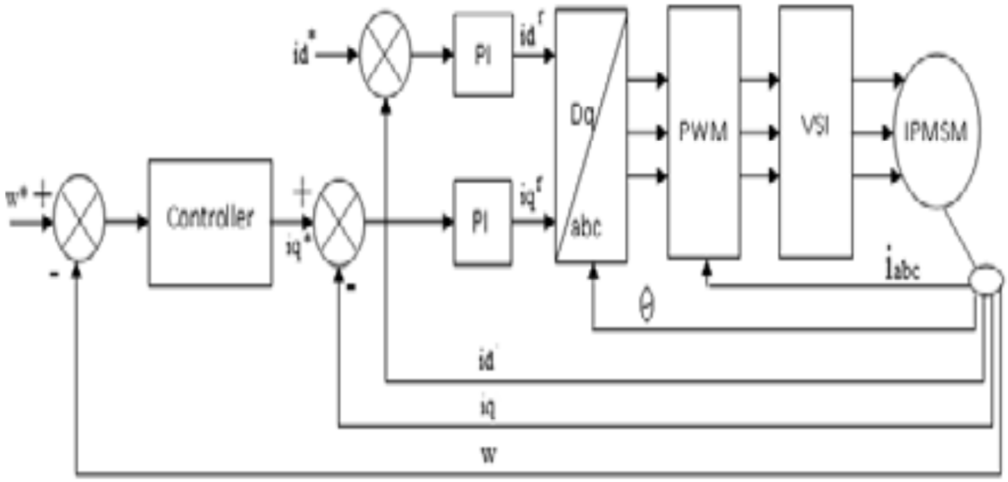

Figure 1: Simulation setup for IPMSM

Difference between desired speed and actual speed as a error signal is given to PI controller. Output of speed controller is compared with the measured i_q. By passing the error signal through PI controller it produces i_q reference. Current loop has i_d* and i_d as inputs. Its output is reference current i_d. Error of i_d* and i_d is given to the PI controller to produce reference current of i_d. Inverse Park transformation receives the two reference current signals from speed loop and current loop. It converts that current i_d and i_q into i_a, i_b & i_c. The reference current for PWM is obtained from the I_{abc} current produced by inverse park transformation.

4. DESIGN OF SPEED CONTROL LOOP

Set speed of the machine is achieved by optimum tuning of controller in a speed control loop. Performance of IPMSM drive using various controllers are analyzed in this paper. Fuzzy PI and Brain emotional learning based intelligent controller are proposed and compared with the conventional PI controller.

4.1. PI Conctroller

The conventional PI controller is the simplest method of feedback control and widely used in industries. (P + I) Controller enlarges the speed of response. Output of this block is a very low steady state error.

Figure 2 shows the setup for PI controller. We use the error signal e(t) as the PI input and the output of controller is taken in to the systemThe equation of PI controller can be written as follow:

$$u\,(t) = k_p\, e\,(t) + k_i + \int e(t) \tag{13}$$

$$e(t) = SP\text{-}PV \tag{14}$$

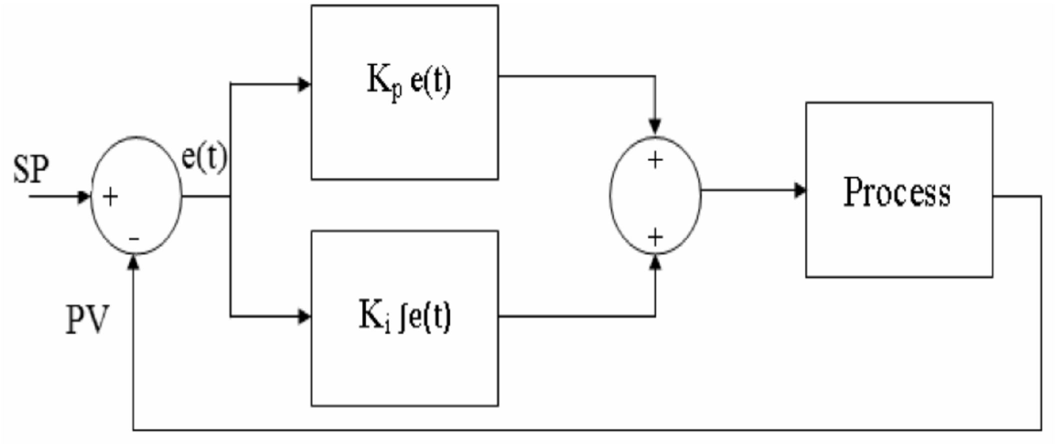

Figure 2: Setup for (P+I) Controller

e (t) is the error of actual measured value (***PV***) from the set-point (***SP***). k_p is proportional gain, k_i is the integral gain and u(t) is the controller output.

In this paper Ziegler Nichols' method of tuning is implemented to find the optimum value of K_p & K_i values. In an IPMSM drive PI controller is used in both loops such as speed loop and current loop.

4.2. Fuzzy PI Controller

The fixed value of Kp and K_i in a PI controller produces the high overshoot, settling time and speed drop during a change in load. By Online tuning of K_p and K_i in a PI controller it can overcome this problem. In a Fuzzy PI controller Fuzzy logic is considered as an auto tuning part for parameters in PI controller. The Fuzzy PI controller is considered the major contribution of this research [9] ,[11],[21]. The fuzzy inference of fuzzy PI controller is based on the fuzzy associative matrices. The calculation of the speed of the controller is very quick, which can satisfy the rapid need of the controlled object. The setup for control system is shown in Figure 3.

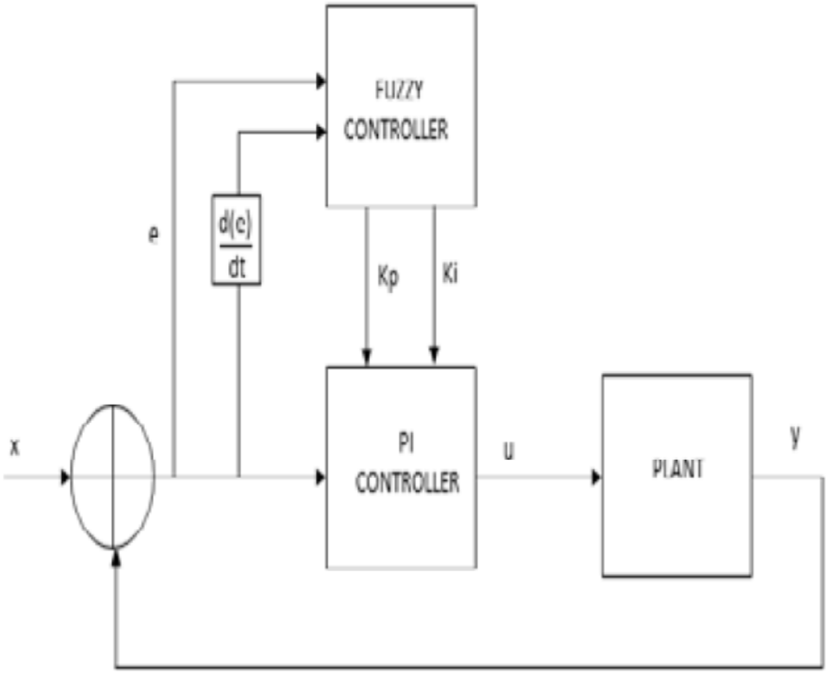

Figure 3: Setup for Fuzzy PI Controller

The control law of usual PI controller can be written as:

$$u(k) = k_p e(k) + k_i \int e(k)$$

Where, k_p is the proportional gain, k_i is the integral gain and e (k) is the speed error.

The design algorithm of Fuzzy PI controller in this paper is to adjust the kp and ki parameters online through fuzzy inference based on the current speed error e and error change rate ec to make the control object attain the good dynamic and static performances.

Fuzzy block inputs are speed (e) and speed change (ec) and outputs are k_p and k_i. The degree of truth of E and EC are configured as 5 degrees, all defined as {NB, NS, ZO, PS, PB}, where NB, NS, ZO, PS and PB represent negative big, negative small, zero, positive small and positive big respectively.

The degree of truth of KP and KI configured as 4 degrees, are defined as {Z, S, M, B}, where Z, S, M and B represent zero, small, medium and big. The membership functions of E, EC, KP and KI are triangular distribution functions. The membership functions for each variable are shown in Figure 4, Figure 5 and Figure 6 respectively.

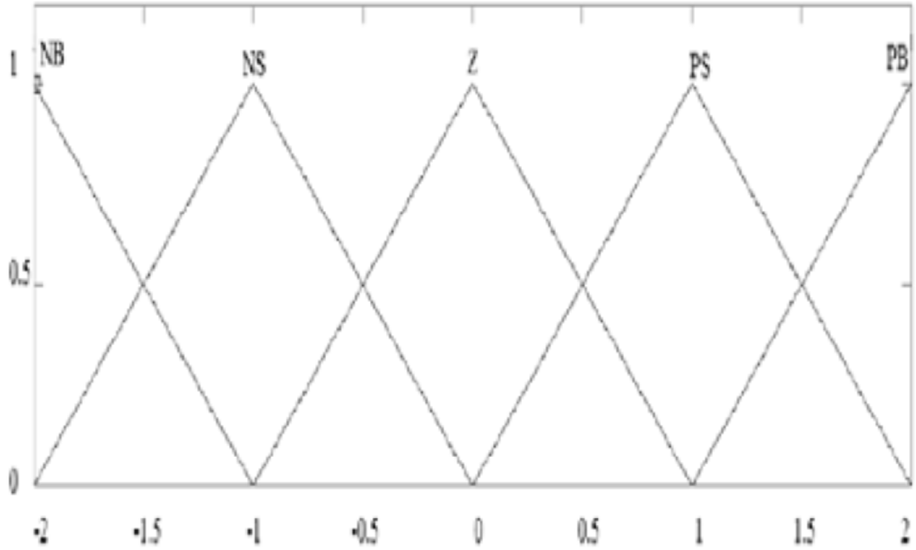

Figure 4: Fuzzy Membership Functions of E and EC

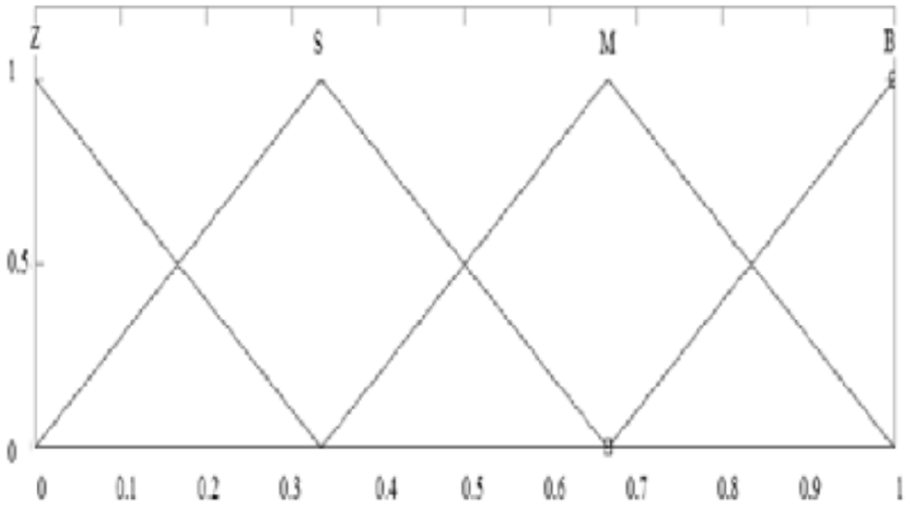

Figure 5: Fuzzy Membership Functions of KP

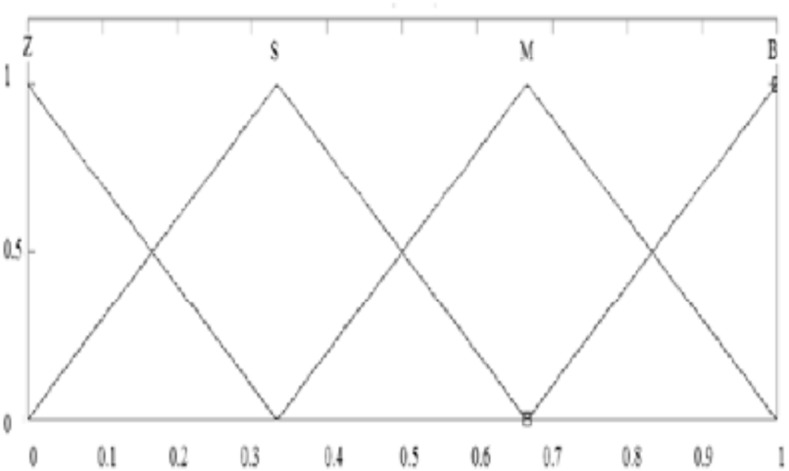

Figure 6: Fuzzy Membership Functions of KI

The principle of designing fuzzy rules is that the output of the controller can make the system output response dynamic and static performances optimal. The fuzzy rules are generalized as table I and table II according to the expert experiment in the PMSM servo system and simulation analysis of the system. The Mamdani inference method is used as the fuzzy inference mode. The inference can be written as

"IF E is NS AND EC is PS THEN KP is S, KI is M". KP and KI are written the same as 25 fuzzy condition statements. The MIN - MAX method of fuzzification is applied. The weighted average method is used for defuzzification.

Table 1
Rules for KP

e	*NB*	*NS*	*ZO*	*PS*	*PB*
NB	Z	Z	Z	Z	Z
NS	M	M	M	M	M
ZO	B	B	Z	B	B
PS	S	M	M	M	M
PB	Z	S	B	B	B

Table 2
Rules for k_p K_i

e	*NB*	*NS*	*ZO*	*PS*	*PB*
NB	B	B	B	B	M
NS	M	B	S	S	S
ZO	M	B	Z	S	B
PS	S	S	S	S	S
PB	M	B	B	M	B

The fuzzy PI controller reduces the overshoot, settling time and drop in speed during load change. Even though it produces some overshoot which should be reduced to improve the performance of drive, it necessitates the simple and effective artificial intelligent controller.

4.3. Belbic Controller

To enhance the speed performance a controller with less processing time, easy and effective control BELBIC is proposed in this paper. It is proposed to reduce the overshoot, settling time and drop in speed during change. It can be achieved by proposing BELBIC because it is a dual feedback controller. PI and Fuzzy PI are single feedback controllers.

BELBIC receives speed error of machine as one of the feedbacks and the BLEBIC output as another feedback. It results in accurate tuning of controller based on the present state.

BELBIC is based on the architecture of the "Limbic System" of the human brain. The limbic system is responsible for the emotional learning in human beings. Figure 7 shows the block diagram of BELBIC controller [27].

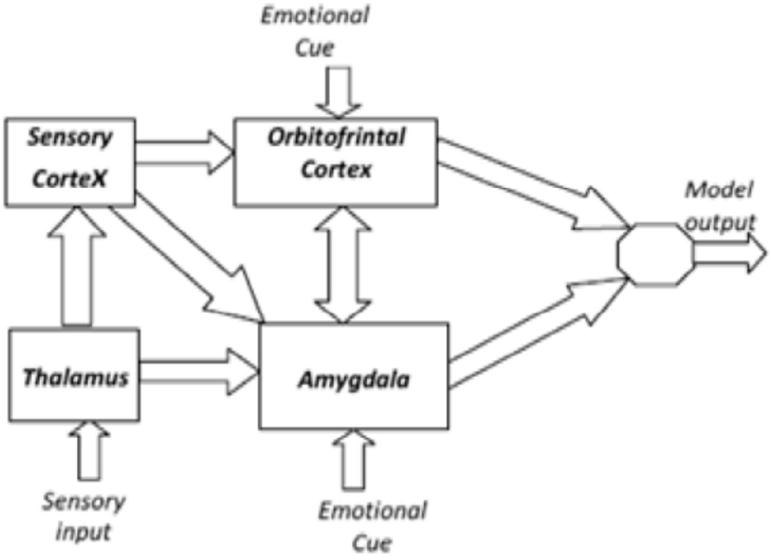

Figure 7: Block Diagram of BELBIC

BELBIC is a simple composition of the Amygdala and Orbitofrontal cortex in the brain. A simple limbic system of the brain is shown in Figure 8.

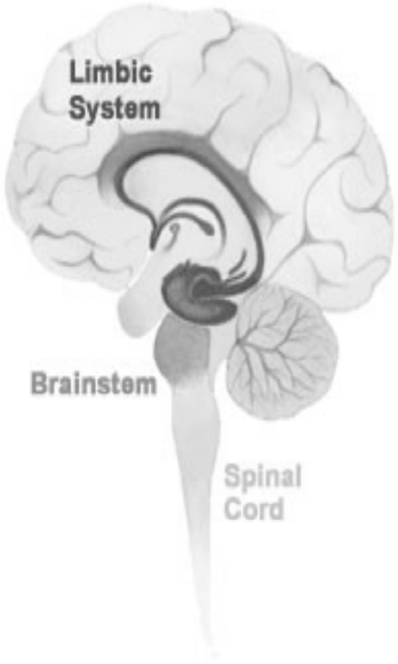

Figure 8: Limbic System of Brain

Pre-processing on sensory input signals such as noise reduction or filtering can be done in Thalamus. The emotional evaluation of stimulus signal is carrying out through the Amygdala, which is a small part in the medial temporal lobe in the brain. As a result, this emotional mechanism is utilized as a basis of emotional states and reactions.

At first, Sensory Input signals are going into Thalamus for pre-processing on them. In this paper speed error is considered as Sensory input. Then Amygdala and Sensory Cortex will receive their processed form and their outputs will be computed by Amygdala and Orbitofrontal based on the Emotional Signal received from the environment. Final output is the subtraction of the Amygdala and Orbitofrontal Cortex. One of the Amygdala's inputs is called Thalamic connection and calculated as the maximum overall Sensory Input S as in equation (15). This specific input is not projected into the Orbitofrontal part and cannot by itself be inhibited and therefore it differs from other Amygdala's inputs.

$$A_{th} = i_{max}\, S_i \tag{15}$$

Every input is multiplied by a soft weight V in each A node in Amygdala to give the output of the node. The O nodes behaviors produce their output signal by applying a weight W to the input signals as well as A nodes. To adjust the Vi difference between the reinforcement signal rew and the activation of the A nodes is been made use. For tuning the learning rate the parameter is used and it is set to a constant value. As shown in equation (16) Amygdala learning rule is an example of simple associative learning system, although this weight adjusting rule is almost monotonic. For instance, Vi can just be increased.

$$\Delta_1 vi = \alpha(s_1 i.\max(0, rew - \Sigma\, A_1 j) \tag{16}$$

α Is the learning step in the Amygdala. The reason of this adjusting limitation is that after training of emotional reaction, the result of this training should be permanent, and it is handled through the Orbitofrontal part when it is inappropriate [6]. Subtraction of reinforcing signal from previous output E makes the signal of reinforcement for O nodes. To put it in another way, comparison of desired and actual reinforcement signals in nodes O inhibits the model output. The learning equation of the Orbitofrontal Cortex is drawn in Eq. (17).

$$Si = \Sigma(Oj - rew) \tag{17}$$

The amygdala and Orbit frontal learning rules are much alike, but the Orbitofrontal weight W can be changed in both ways to increase and decrease as needed to track the proper inhibition. And rule of β in this formula is similar to the α ones. Simulation model of BELBIC is shown in figure 9.

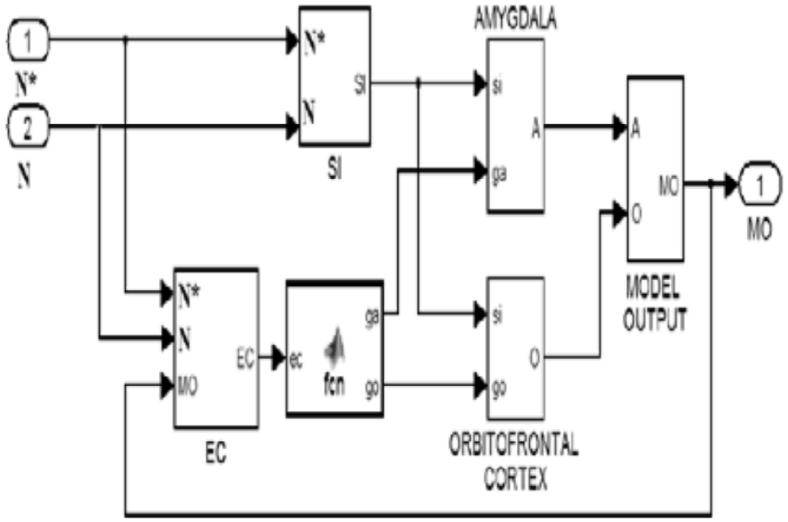

Figure 9: Simulation Model of BELBIC

Mathematics the Linear Model of BEL Controller is represented by Following Simplified Equations

$$A = G_A \,.\, SI \tag{18}$$

$$O = G_{OC} \,.\, SI \tag{19}$$

$$(dG_1A) / dt) = \alpha SI(ES - A) \tag{20}$$

$$(dG_{oc}/dt) = \beta SI\ (A - OC - ES) \tag{21}$$

$$MO = A - OC \tag{22}$$

where MO is Model Output, SI is Sensory Input, E is Emotional Sensor, A is Amygdala Output, O is Orbitofrontal Cortex, α is Learning rate of Amygdala, P is Learning rate of Orbitofrontal cortex, G_A is Gain for Amygdala, G_{OC} is Gain for Orbitofrontal Cortex. Based on the above equations mathematical model of BELBIC is formed. Since BELBIC is purely formed by the arithmetic equations it is easy to implement and consumes less processing time.

5. SIMULATION RESULTS AND DISCUSSIONS

IPMSM dive is simulated using MATLAB/Simulink. IPMSM dive is analyzed using conventional PI controller. Then the same system is analyzed with Fuzzy PI controller and BELBIC. For the analysis load changes during run time. Reference speed and load are same for all PI, Fuzzy PI controller and BELBIC.

The simulation model of IPMSM drive is shown in figure 10.

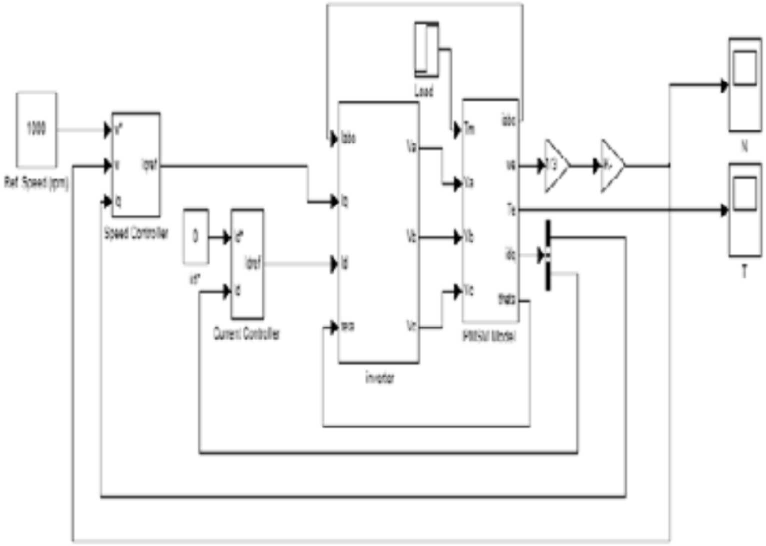

Figure 10: Simulation Setup for IPMSM

The parameters of IPMSM used in this simulation model are given in table 3.

Table 3
Motor Parameters

Parameters		*Value*
Stator Resistance	Rs	1.4 Ω
Direct axis inductance	Ld	6.6 mH
Quadrature axis inductance Lq	0.0116H	
Moment of Inertia	J	20.00176 Kg.m
Rotor flux linkage	φ f	0.1546 Wb
Number of poles	P	6

The results of IPMSM drive system using a conventional PI controller for speed is shown in figure 11 and figure 12.

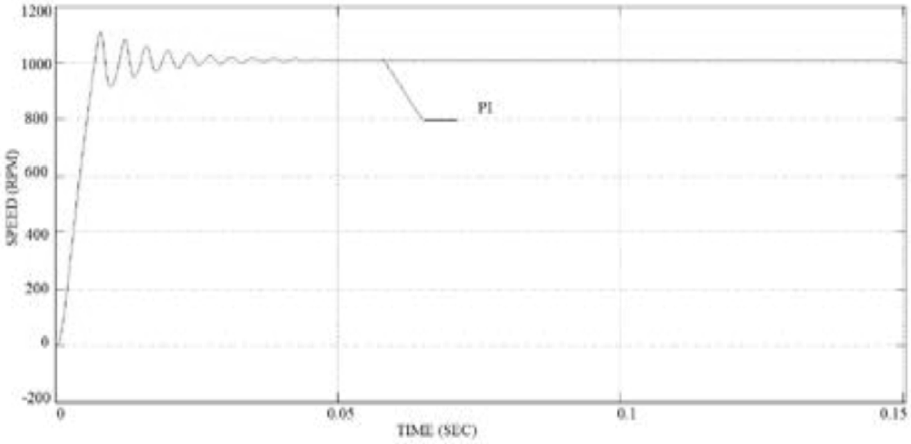

Figure 11: Speed Response of IPMSM Drive Using PI Controller

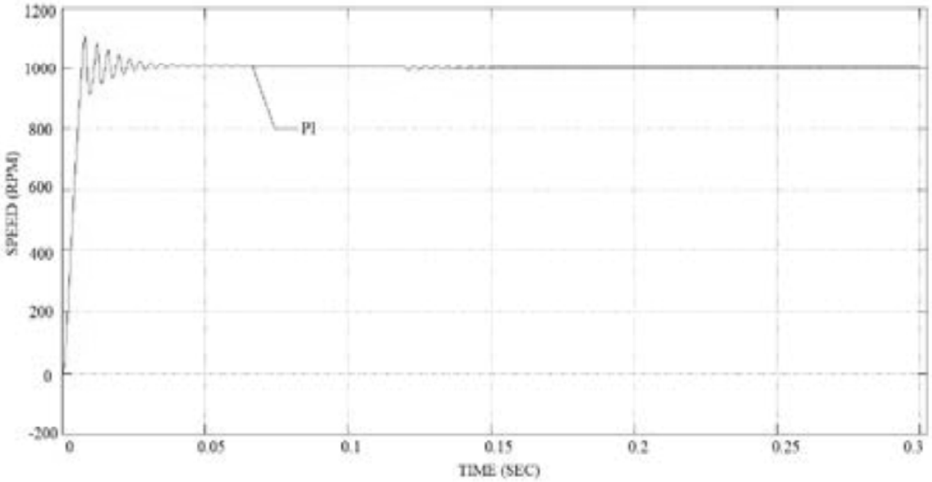

Figure 12: Speed Response of IPMSM Drive Using A PI Controller With Change In Load

The results of IPMSM drive system using proposed Fuzzy PI controller for speed is shown in figure 13 and figure 14.

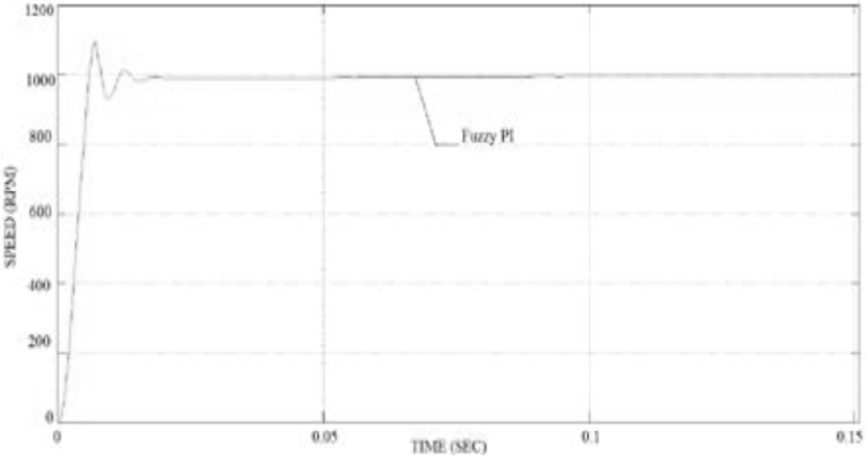

Figure 13: Speed Response of PMSM with Fuzzy PI Controller

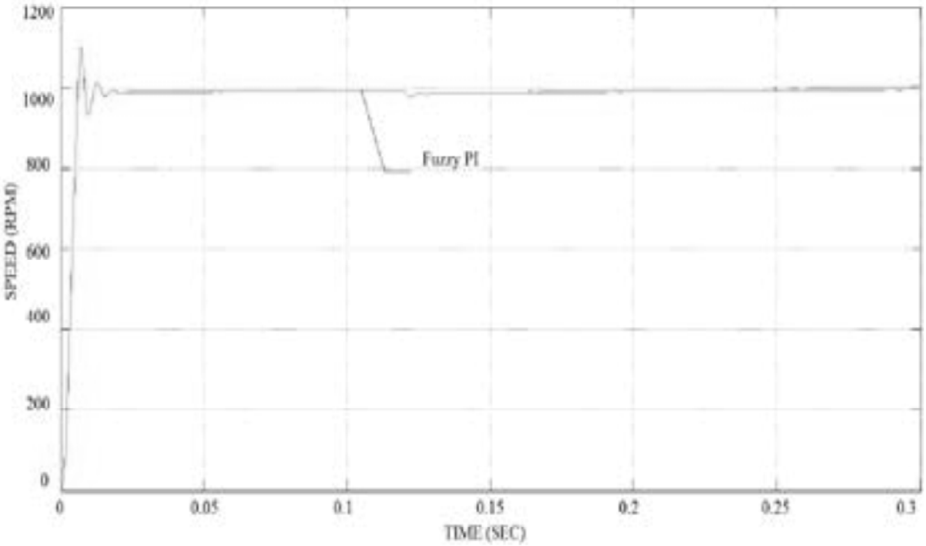

Figure 14: Speed Response of IPMSM Drive Using A Fuzzy PI Controller With Change In Load.

The results of IPMSM drive system using the proposed Emotional controller for speed is shown in figure 15 and figure 16.

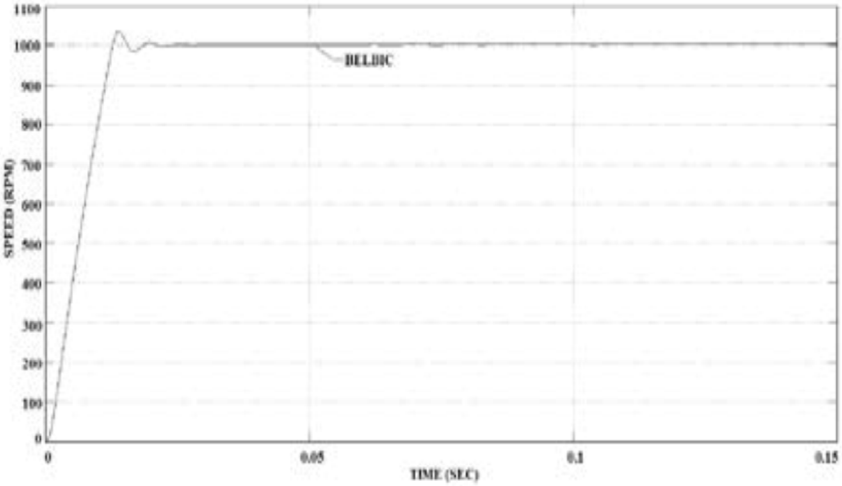

Figure 15: Speed Response of IPMSM Using BLEBIC

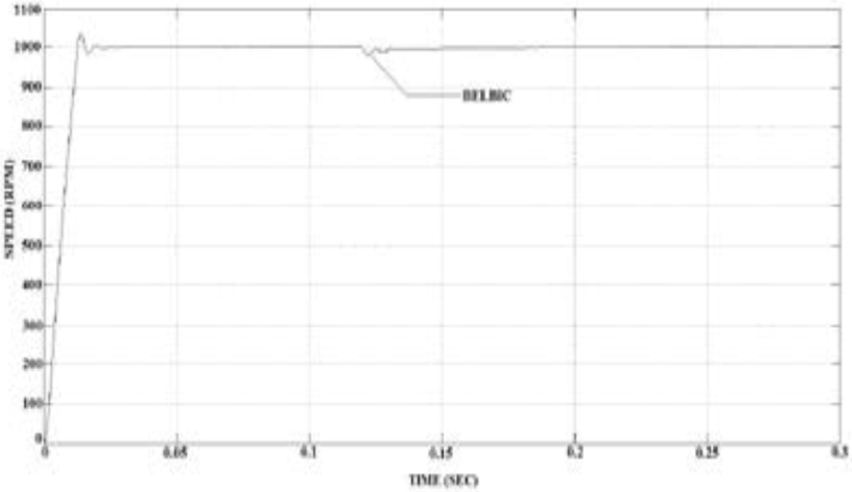

Figure 16: Speed Response of IPMSM Using BLEBIC With Load Variation

Comparison of speed response of IPMSM drive using PI, Fuzzy PI and BLEBIC controller is shown in figure 17.

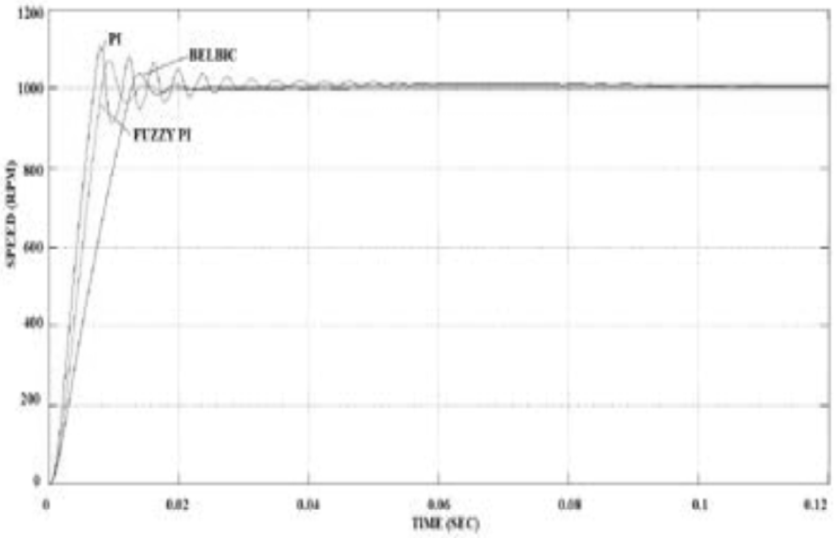

Figure 17: Comparison of Speed Response of IPMSM Drive Using PI, Fuzzy PI and BLEBIC Controller

Speed response of IPMSM drive using BLEBIC at various speed references such as rated speed, above rated speed and below rated speed is shown in figure 18.

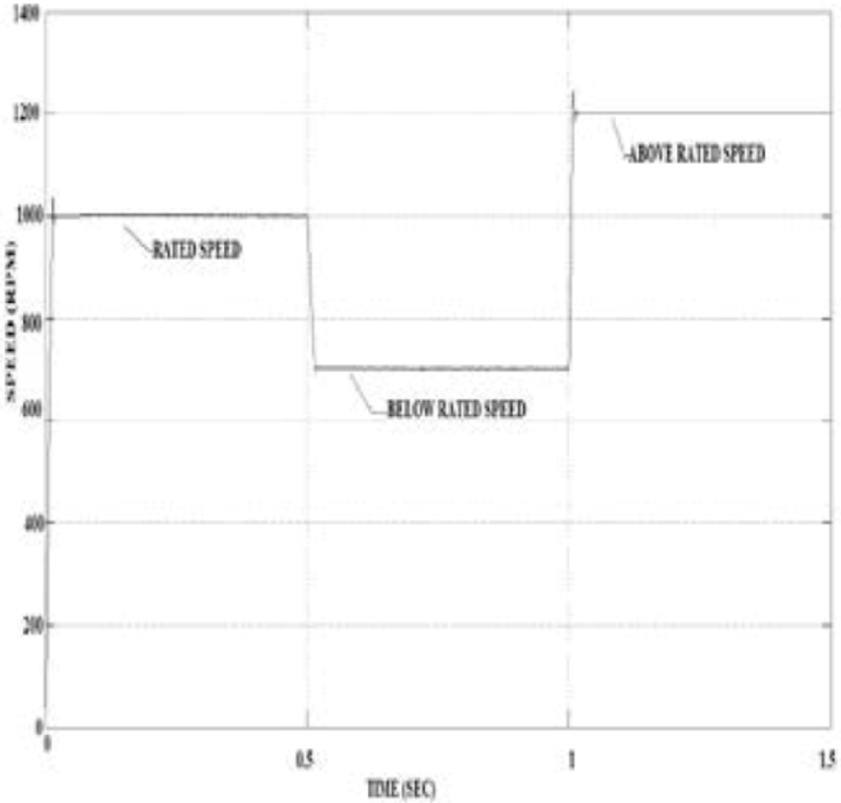

Figure 18: Speed Response of IPMSM Using BLEBIC with Various Speed Reference

The comparison of controller performance for speed ω_m = 1000 RPM using PI, Fuzzy PI and BLEBIC controller are tabulated in Table 4.

Table 4
Comparison of Controller Performance

Controller	*Peak overshoot%*	*Steady state error %*	*Speeddrop during load %*	*Settlingtime after load Sec*
PI	11	0.6	0.4	0.04
Fuzzy PI	7	0.3	0.2	0.02
BLEBIC	3.5	0.1	0.18	0.018

6. CONCLUSION

The essential characteristics of traction motor are accurate speed and stability during load change. In this paper three types of controllers PI, Fuzzy PI and BLEBIC are used as speed controllers in the IPMSM control and simulated in Matlab / Simulink. The performance of the system is analyzed with all three controllers and compared. From the simulation results it is clear that system performance is improved by Fuzzy PI and BLEBIC controller. The Fuzzy PI controller improves speed response compared to conventional PI controller in terms of overshoot, steady state error, drooping speed during load change and settling time after load change.

BLEBIC controller is better than PI and Fuzzy PI controller in terms of stability. It quickly settles in speed after load change compared to other two controllers. Meantime BLEBIC controller produces the same response for rated speed, above rated speed and below rated speed of the machine. Simulation results show the excellent robust performance of BELBIC in disturbance rejection and load variations. The BLEBIC controller based IPMSM drive is suitable to operate in a wide speed range and wide load changing condition.

REFERENCES

[1] Ambrish Pati Tripathi, Vikram Singh, Ankush Patidar, "Permanent Magnet Synchronous Motor Voltage Vector Control by Simulation", *International Journal of Scientific & Engineering Research.*, Vol. 3, No. 12, December 2012.

[2] Azizur Rahman M, Mahinda Vilathgamuwa D, Nasir Uddin M," Nonlinear Control of Interior Permanent-Magnet Synchronous Motor", *IEEE Transactions on Industry Applications.*, Vol. 39, No. 2, March 2003.

[3] Bimbra P S, "*Generalized Theory of Electrical Machines*", Khanna Publishers, 2002.

[4] Bhim Singh., B. P. Singh., Sanjeet Dwivedi., "DSP Based Implementation of Hybrid Speed Controller for Vector Controlled Permanent Magnet Synchronous Motor Drive", *IEEE ISIE.*, July 2006, pp. 2235-2241.

[5] Davendra Yadav, Sunil Bansal, Munendra Kumar, "Design, Development & Simulation of Fuzzy Logic Controller to Control the Speed of Permanent Magnet Synchronous Motor Drive System", *International Journal of Scientific Research Engineering & Technology.*,Vol. 1, No. 5, August 2012, pp. 101-106.

[6] Dishore S V, Devdas G, "Simulation of PMSM Vector Control system Based on Propeller Load characteristic", *International Journal of Engineering Research & Technology.*, Vol.2, No. 1,January 2013.

[7] Faiz J., Manoochehri M., Shahgholia Gh., "Performance Improvement of a Linear Permanent Magnet Synchronous Drive using Fuzzy Logic Controller", *Proceedings of the IEEE International Conference on Power System Technology.*, 2010, pp. 1-5.

[8] Fazlur Rahman. M, Md. Enamul Haque Lixin Tang, and Limin Zhong, "*Problems Associated With the Direct Torque Control of an Interior Permanent-Magnet Synchronous Motor Drive and Their Remedies*", IEEE Transactions on Industrial Electronics., Vol. 51, No. 4, August 2004, pp. 789-809.

[9] Han Ho Choy and Jin-Woo Jung, "Discrete- Time Fuzzy Speed Regulator Design for PM Synchronous Motor", *IEEE Transactions on Industrial Electronics.*, Vol. 60, No. 2, Feb. 2013, pp. 600-607.

[10] Hyoung-Seok Kang, Cheon-Kyu Kim and Young-Seok Kim , "Position Control for Interior Permanent Magnet Synchronous Motors using an Adaptive Integral Binary Observer", *Journal of Electrical Engineering & Technology.*, Vol. 4, No. 2, 2009, Page 240-248.

[11] Kiran Boby, Ananthamoorthy N.P, "Simulation of PMSM Vector Control System with Fuzzy Self-adjusting PID Controller Using MATLAB", *International Journal of Scientific and Research Publications*, Vol. 3, No. 3, March 2013.

[12] Krishnan R., “Selection criteria for servo motor drives”, *IEEE Transactions on Industrial Applications.*, Vol. IA 23, No.2, March 1987, pp. 270-275.

[13] Krishnan R, “A Textbook of Electric Motor Drives Modeling Analysis and control”, *New york (Pearson Education Publisher Company*, 2003.

[14] Lixin Tang, Limin Zhong,Rahman, M.F. and Yuwen Hu, “A novel direct torque controlled interior permanent magnet synchronous machine drive with low ripple in flux and torque and fixed switching frequency”, *IEEE Transactions on Power Electronics,*Vol. 19, No. 2, March 2004, pp. 346–354.

[15] Lucas C., Shahmirzadi D, Sheikholeslami N “Introducing Belbic : Brain Emotional Learning Based Intelligent Controller”, *Intelligent Automation and Soft Computing*, Vol. 10, No. 1, 2004, pp. 11-22.

[16] Lucas, Caro, Milasi, Rasoul M. and Araabi, Babak N,Intelligent Modeling and Control of Washing Machine Using Locally Linear Neuro-Fuzzy (Llnf) Modeling and Modified Brain Emotional Learning Based Intelligent Controller, *Asian Journal of Control.*,Vol. 8, No. 4, Oct 2006, pp. 393-400.

[17] Mini Sreejeth, Madhusudan Singh, Parmod Kumar; Prakhar Varshney, and Priyanka Sachdeva, “Implementation of supervisory control system for PMSM drive*”, IEEE 5th India International Conference on Power Electronics (IICPE)*, 2012, pp. 1-6.

[18] Naruttam Kumar Roy, Abdur Rafiq, Rajib Kundu and B.C. Ghosh, “Intelligent Control of Interior Permanent Magnet Synchronous Motor Drive”, *Journal of Electrical & Electronics Engineering.*,Vol. 9, No. 1, January 2009, pp. 781-789.

[19] Pillay P., Krishnan R., “Modelling Simulation and Analysis of Permanent Magnet Synchronous Motor Drives Part I: The Permanent Magnet Synchronous Motor Drive, *IEEE Transactions on Industry Applications*, Vol. 25, No. 2, April 1989, pp. 265-273.

[20] Pillay P., Krishnan R., “Modelling of Permanent Magnet Motor Drives”, *IEEE Transactions on Industrial Electronics*. Vol. 35, No. 4, November 1988, pp. 537-541.

[21] A. ShakilaBanu, Dr. RSD. Wahidabanu. “Comparative performance analysis of ipmsm Drive using anti windup pi and fuzzy piController”, *Archives Des Sciences*, Vol. 66, No. 3; Mar 2013, pp. 412-423.

[22] Rajat Varshney, Gunjan Gupta, “ Neuro- Fuzzy Based Speed Controller For Permanent Magnet Synchronous Motor”, *International Journal of Advanced Research in Computer Science and SoftwareEngineering.*, Vol. 2, No. 11, 2012, pp. 313-317.

[23] Ramana P, Santhosh Kumar B,Alice Mary K, Surya Kalavathi M, “Comparison of various PWM techniques for field oriented control VSI fed PMSM drive, Vol. 2, No. 7, July 2013, pp. 2928-2936.

[24] Rebeiro. R. S. and Uddin, M. N., “Performance Analysis of an FLC-Based Online Adaptation of Both Hysteresis and PI Controllers for IPMSM Drive”, *IEEE Transactions on Industry Applications.*, Vol. 48, No. 1, January 2012, pp. 12–19.

[25] Rouhani, Hossein, Emotional learning based intelligent speed and position control applied to neuro fuzzy model of switched reluctance motor, *Control and Cybernetics*., Vol. 36, No. 1, 2007.

[26] Uddin, M.N. and Rahman, M.A., “Development and Implementation of a Hybrid Intelligent Controller for Interior Permanent-Magnet Synchronous Motor Drives”, *IEEE Transactions on Industry Applications.*,Vol. 40, No. 1, January 2004, pp. 68-76.

[27] Guoyong Huang, Ziyang Zhen and Daobo Wang, “Brain Emotional Learning Based Intelligent Controllerfor Nonlinear system”, *IEEE conference proceedings on Intelligent Information Technology Application, 2008. IITA ‘08. Second International Symposium Intelligent Information Technology Application on*, 20-22 Dec. 2008 Vol. 2, pp. 660-6.