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Modeling and Simulation of BLDC Motor Using Fuzzy Controller and ANN Methods

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ABSTRACT: This paper deals about a novel approach in optimizing the motion of Brushless Direct current (BLDC) motor using Fuzzy Logic System (FLS) and Artificial Neural Network (ANN). To track the variations of speed when the motor is controlled with the above mentioned controllers output speed during load variations. The BLDC has some advantages compare to the others type of motors, however the nonlinearity of the BLDC motor dive characteristics, cause it is difficult to handle by using conventional proportional-integral-differential (PI) controller. In order to overcome this main problem, a fuzzy logic controller and neural network controller with learning technique based on back propagation algorithm is developed. The effectiveness of the proposed method is verified by developed simulation model in the MATLAB - Simulink program. The results have been recorded under various operating conditions. The simulation results showed that the Neural Network Controller made much better performance than the traditional PI controller and fuzzy controller in the speed, torque responses and system performance.
KEYWORDS: BLDC, PI, FLC, ANN Controller, Simulink.

I. INTRODUCTION:

EFFICIENCY and cost are the major concerns in the development of low-power motor drives targeting household applications such as fans, water pumps, blowers, mixers, etc. [1], [2]. The use of the brushless direct current (BLDC) motor in these applications is becoming very common due to features of high efficiency, high flux density per unit volume, low maintenance requirements, and low electromagnetic-interference problems [1]. These BLDC motors are not limited to household applications, but these are suitable for other applications such as medical equipment, transportation, HVAC, motion control, and many industrial tools [2]–[4]. A BLDC motor has three phase windings on the stator and permanent magnets on the rotor [5], [6]. The BLDC motor is also known as an electronically commutated motor because an electronic commutation based on rotor position is used rather than a mechanical commutation which has disadvantages like sparking and wear and tear of brushes and commentator assembly [5]. Power quality problems have become important issues to be considered due to the recommended limits of harmonics in supply current by various international power quality standards such as the International Electro technical Commission (IEC) 61000-3-2 [7]. For class-A equipment (< 600 W, 16 A per phase) which includes household equipment, IEC 61000-3-2 restricts the harmonic current of different order such that the total harmonic distortion (THD) of the supply current should be below 19% [7]. A BLDC motor when fed by a diode bridge rectifier (DBR) with a high value of dc link capacitor draws peaky current which can lead to a THD of supply current of the order of 65% and power factor as low as 0.8 [8]. Hence, a DBR followed by a power factor corrected (PFC) converter is utilized for improving the power quality at ac mains. Many topologies of the single-stage PFC converter are reported in the literature which has gained importance because of high efficiency as compared to two-stage PFC converters due to low component count and a single switch for dc link voltage control and PFCOperation [9], [10].The choice of mode of operation of a PFC converter is a critical issue because it directly affects the cost and rating of the components used in the PFC converter. The continuous conduction mode (CCM) and discontinuous conduction mode (DCM) are the two modes of operation in which a PFC converter is designed to operate [9], [10]. In CCM, the current in the inductor or the voltage across the intermediate capacitor remains continuous, which is not cost-effective. On the other hand, DCM requires a single voltage sensor for dc link voltage control, and inherent PFC is achieved at the ac mains, but at the cost of higher stresses on the PFC converter switch; hence, DCM is preferred for low-power applications [9], [10]. The conventional PFC scheme of the BLDC motor drive utilizes a pulse width-modulated voltage source inverter (PWM-VSI) for speed control with a constant dc link voltage. This offers higher switching losses in VSI as the switching losses increase as a square function of switching frequency. As the speed of the BLDC motor is directly proportional to the applied dc link voltage, hence, the speed control is achieved by the variable dc link voltage of VSI. This allows the fundamental frequency switching of VSI (i.e., electronic commutation) and offers reduced switching losses. Singh and Singh [11] have proposed a buck–boost converter feeding a BLDC motor based on the concept of constant dc link voltage and PWM-VSI for speed control which has high switching losses.

This paper presents a Fuzzy based PFC - BL buck–boost converter-fed BLDC motor drive with variable dc link voltage of VSI for improved power quality at ac mains with reduced components.

II. MATHEMATICAL MODEL OF BLDC MOTOR

The BLDC motor has three stator windings and a permanent magnet rotor on the rotor. Rotor induced currents can be neglected due to the high resistivity of both magnets and stainless steel. No damper winding are modelled, then the circuit equation of the three windings in phase variables are obtained as shown below

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = R_s \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_{an} \\ i_{bn} \\ i_{cn} \end{bmatrix} + \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} p \begin{bmatrix} i_{an} \\ i_{bn} \\ i_{cn} \end{bmatrix} + \begin{bmatrix} e_{an} \\ e_{bn} \\ e_{cn} \end{bmatrix}$$

---(1)

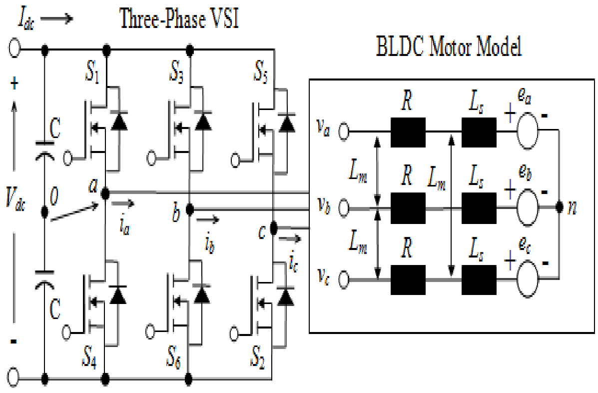


Figure 2.1: VSI-fed PMBLDCM model.

The permanent magnet BLDC motor drive consists of an electronic commutator, a VSI, and a PMBLDCM. Here the electronic commutator uses signals from Hall-effect position sensors to generate the switching sequence for the VSI. The output of VSI to be fed to phase "a" of the PMBLDC motor is calculated from the equivalent circuit of a VSI-fed PMBLDCM

$V_{ao} = V_{dc}/2$ For $S_1=1$

$V_{ao} = -V_{dc}/2$ For $S_4=1$

$V_{ao} = 0$ For $S_1=0$ & $S_4=0$

where V_{ao}, V_{bo}, V_{co} and V_{no} are the voltages the three phases (a, b, and c) and neutral point (n) with respect to the virtual midpoint of the dc link voltage shown as "o" in Fig.2.1.The voltages V_{an}, V_{bn} and V_{cn} are the voltages of the three phases with respect to the neutral terminal of the motor (n), and V_{dc} is the dc link voltage. The values 1 and 0 for Switch represents the "on" and "off" conditions of respective IGBTs of the VSI. The voltages for the other two phases of the VSI feeding the PMBLDC motor, i.e., V_{bo}, V_{bn}, V_{co} and V_{cn} the switching pattern of the other IGBTs of the VSI are generated in a similar way.

2.1 PMBLDC Motor:

The PMBLDCM is modelled in the form of a set of differential equations given as

$V_{an} = R_{ia} + P\lambda_a + C_{an}$ ---(2)

$V_{bn} = Ri_b + P\lambda_b + e_{bn}$ ---(3)

$V_{cn} = Ri_c + P\lambda_c + e_{cn}$ ---(4)

In these equations, P represents the differential operator (d/dt), i_a, i_b and i_c are currents, λ_a λ_b and λ_c are flux linkages, and e_{an}, e_{bn} and e_{cn} are phase-to-neutral back EMFs of PMBLDCM, in respective phases; R is the resistance of motor windings/phase. Moreover, the flux linkages can be represented as

$$\lambda_a = L_s i_a - M(i_b + i_c) \quad \text{---(5)}$$

$$\lambda_b = L_s i_b - M(i_a + i_c) \quad \text{---(6)}$$

$$\lambda_c = L_s i_c - M(i_b + i_a) \quad \text{---(7)}$$

Where Ls is the self-inductance/phase and M is the mutual inductance of PMBLDCM winding/phase. The developed torque Te in the PMBLDCM is given as

$$T_e = \frac{(e_{an}i_a + e_{bn}i_b + e_{cn}i_c)}{w_r}$$

Where w_r is the motor speed in radians per second.
Since PMBLDCM has no neutral connection

$$i_a + i_b + i_c = 0$$

From (15)–(21) and (23), the voltage (V_{no}) between the neutral point (n) and midpoint of the dc link (o) is given as

$$V_{no} = \{V_{ao} + V_{bo} + V_{co} - (e_{an} + e_{bn} + e_{cn})\}/3$$

From (19)–(21) and (23), the flux linkages are given as

$$\lambda_a = (L_s + M)i_a$$

$$\lambda_b = (L_s + M)i_b$$

$$\lambda_c = (L_s + M)i_c$$

From (16)–(18) and (25), the current derivatives in generalized state-space form are given as

$$\mathrm{Pi_x} = \frac{(\mathrm{Vxn\text{-}i_x R\text{-}C_{xn}})}{(\mathrm{L_s + M})}$$

where x represents phase a, b, or c. The back EMF is a function of rotor position (θ) as

$$\mathrm{e_{xn}} = k_b f_x(\theta) w_r$$

Where x can be phase a, b, or c and accordingly $f_x(\theta)$ represents a function of rotor position with a maximum value ±1, identical to trapezoidal induced EMF, given as

$$f_a(\theta) = 1 \text{ for } 0 < \theta < \frac{2\pi}{3}$$

$$f_a(\theta) = 1\left\{(\frac{6}{\pi})(\pi - \theta)\right\} - 1 \text{ for } \frac{2\pi}{3} < \theta < \pi$$

$$f_a(\theta) = -1 \text{ for } \pi < \theta < \frac{5\pi}{3}$$

$$f_a(\theta) = \left\{(\frac{6}{\pi})(\pi - \theta)\right\} + 1 \text{ for } \frac{5\pi}{3} < \theta < 2\pi$$

The functions $f_b(\theta)$ and $f_c(\theta)$ are similar to $f_a(\theta)$ with phase differences of 120◦ and 240◦, respectively. Therefore, the electromagnetic torque expressed as

$$T_e = K_b \{ f_a(\theta) i_a + f_b + f_c(\theta) i_c \}$$

The mechanical equation of motion in speed derivative form is given as

$$pw_r = (P/2)(T_e - T_i - Bw_r)/J$$

Where w_r the derivative of rotor position θ, P is is the number of poles, T_i is the load torque in Newton meters, J is the moment of inertia in kilogram square meters, and B is the friction coefficient in Newton meter seconds per radian.

The derivative of rotor position is given as

$$p\theta = w_r$$

Equations (16)–(34) represent the dynamic model of the PMBLDC motor.

III. SPEED CONTROLLER

3.1 PI Controller:

The Combined effect of proportional and integral terms is important to enhance the speed response and also to eliminate significant steady state error.

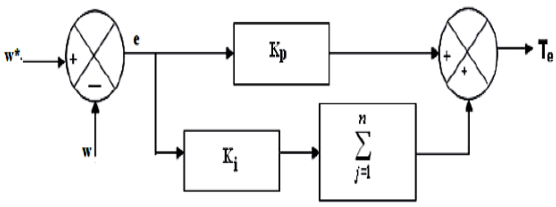


Fig 3.1: Block Diagram of PI Controller.

Command Torque is the output signal of controller where Kp is the proportional gain and Ki is the integral gain.

T_e= Kp $_e$ + Ki $\int_e$dt

3.2. Fuzzy Logic Controller:

In drive operation, the speed can be controlled indirectly by controlling the torque which, for the normal operating region, is directly proportional to the voltage to frequency. The speed is controlled by fuzzy logic controller whose output is the reference current of the inner dc current controller. Fuzzy Logic control (FLC) has proven effective for complex, non-linear and imprecisely defined processes for which standard model based control techniques are impractical or impossible. Fuzzy Logic, unlike Boolean or crisp logic, deals with problems that have vagueness, uncertainty and use membership functions with values varying between 0 and 1.In fuzzy logic a particular object has a degree of membership in a given set, which is in the range of 0 to 1. The essence of fuzzy control algorithms is a conditional statement between a fuzzy input variable A and fuzzy output variable B.

In general a fuzzy variable is expressed through a fuzzy set, which in turn is defined by a membership function. The torque is controlled by varying the dc current. The complete block diagram of the fuzzy logic controller is shown in figure 3.3.

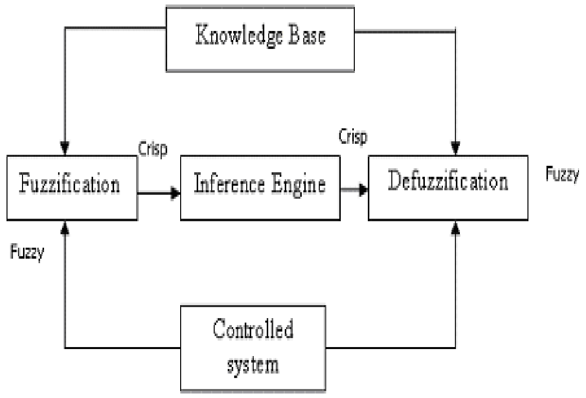


Fig 3.2 : Internal Structure of the Fuzzy Logic Controller

The FLC controller has seven sets for inputs namely e (n) and δe (n). Also for the output nine fuzzy sets are used for V (n). Mamdani model has been considered with triangular membership functions and centroid method of defuzzification is used for the proposed controller. The fuzzy rules were designed based on the dynamic behaviour of the error signal.
The Fuzzy Logic Controller Surface is the output plotted against the two inputs.

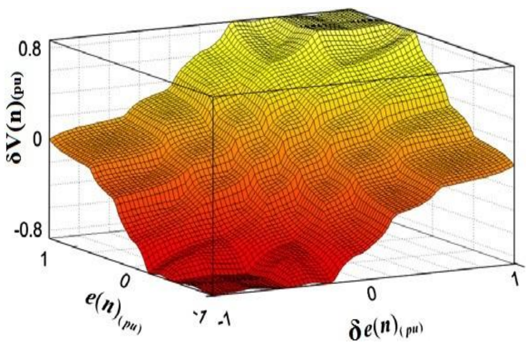


Fig 3.3: Fuzzy Logic Controller Surface

3.4ARTIFICIAl NEURAL NETWORK (ANN)

This project presents an ANN-based controller for the BLDC motor drive which requires minimal offline training yet precisely and accurately follows command speed with insensitivity to load and parameter variations. The system is simplified to a single artificial neuron (SAN) to minimize complexity and computational burden requirements. By using sensor less speed measuring system we can find out the Speed error and conditionally used at each iteration to adaptively modify the SAN parameters to produce the precise command torque to minimize speed error. BLDC is widely used because of its high mechanical power density, simplicity and cost effectiveness. A mathematical model of the drive system is developed to analyse the performance of the proposed drive. ANNs are mathematical systems consisting of many weighted interconnected operation elements (neurons). A processing element is an equation, which is often termed a transfer function. This processing element receives signals from other neurons; combines and converts them; and produces a numerical result. In general, processing elements roughly correspond to real neurons, they are interconnected via a network and this structure constitutes neural networks.
The structure of ANNs contains three main elements neurons, the connection providing input and output route, and connection weights indicating the strength of these connections.

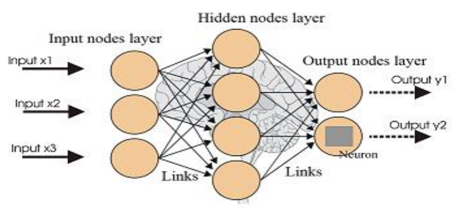


Figure.3.4.1: Architecture of ANN

The ANNs unravel a relationship between the input variables and estimated variables by determining the weights using previous examples. In other words, ANNs are trained". Once these relationships are determined (in other words, once the network is trained), an ANN can be operated with new data and estimations can be produced. The performance of a network is measured by the aimed signal and error criterion. The error margin is obtained by the comparison of the output of the network and the aimed output. A back-propagation algorithm is used to adjust the weights in such a way to reduce the error margin.

IV. SIMULATION RESULTS AND DISCUSSION

4.1 FUZZY BASED MODEL

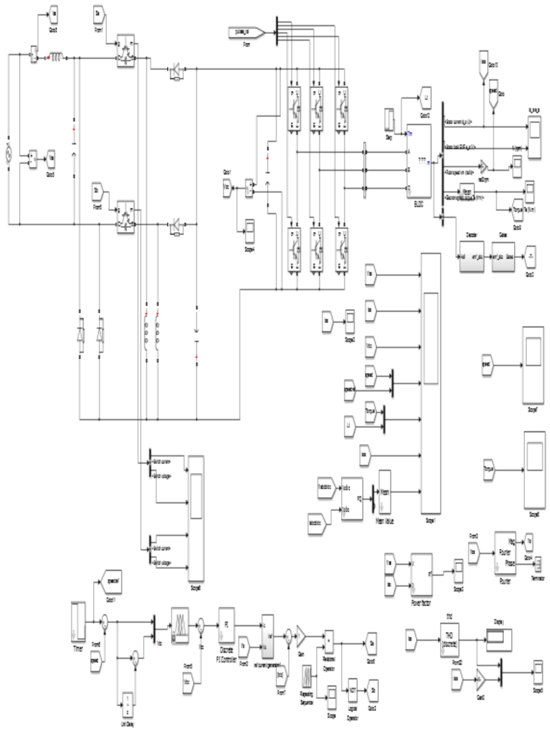


Figure 4.1: Simulink model of the BLDC Motor with Fuzzy Logic Controller (FLC)

4.2 ANN Based Model:

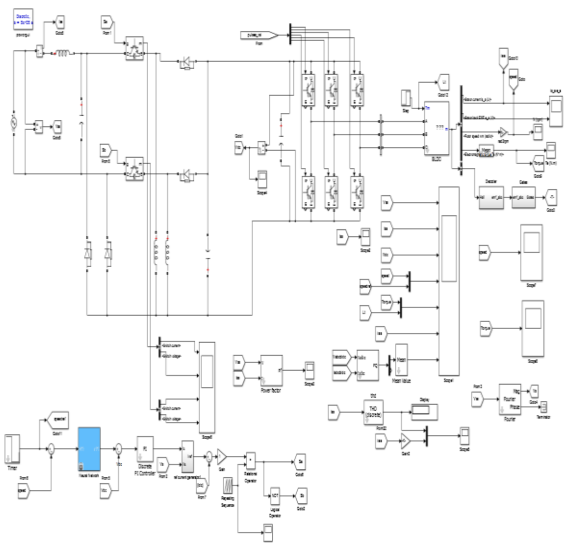
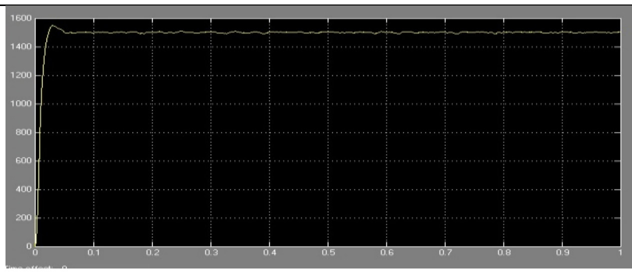
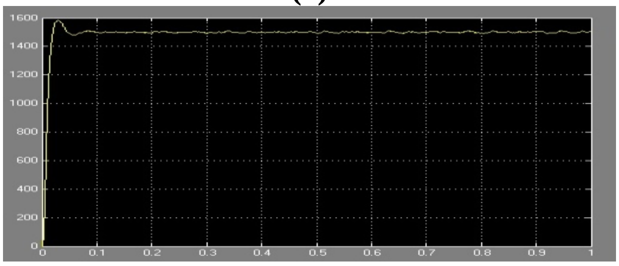


Figure 4.2.1: Simulink model of the BLDC with Proposed (ANN) Controller.



(a)



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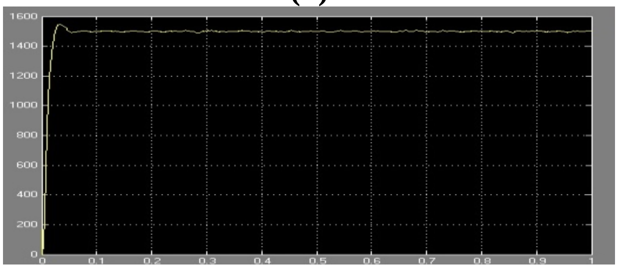
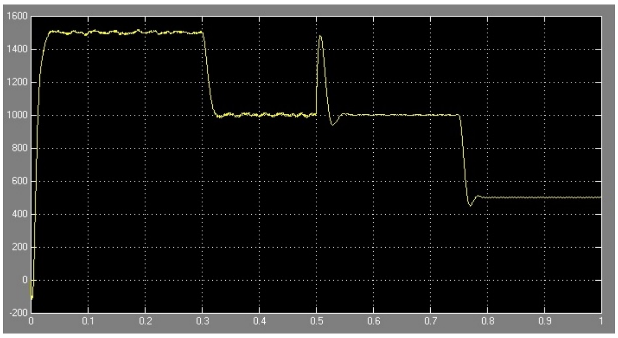
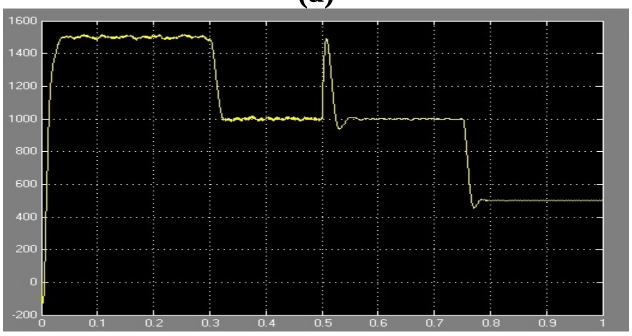


(c)

Figure 4.2.2: Speed characteristics of BLDC motor under NO load with speed of 1500 rpm by using (a) PI controller, (b) FLC, (c) ANN Controller.



(a)



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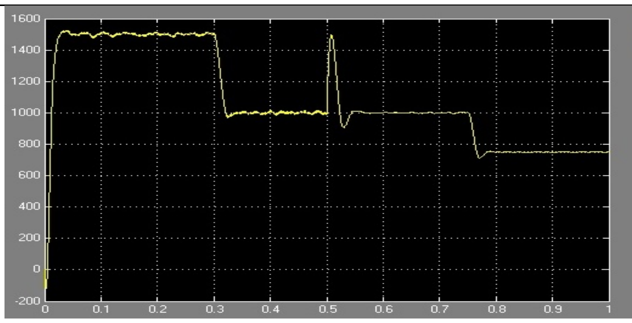
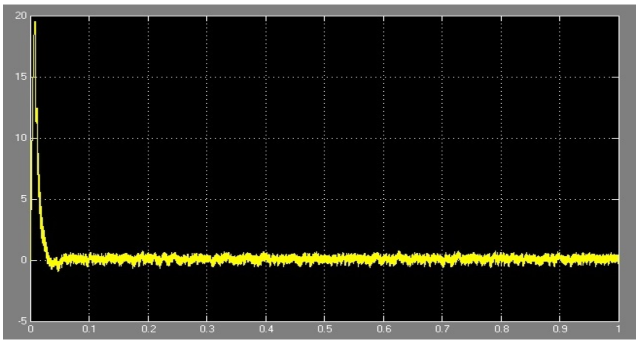


(c)

Figure 4.2.3: Speed characteristics of BLDC motor under load of 10 nm with different speed of 1500, 1000 and 700 rpm at time 0,0.3 and 0.75 sec by using (a) PI controller, (b) FLC , (c) ANN Controller.



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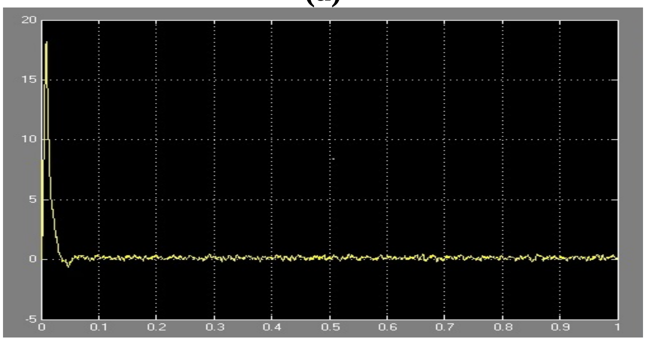

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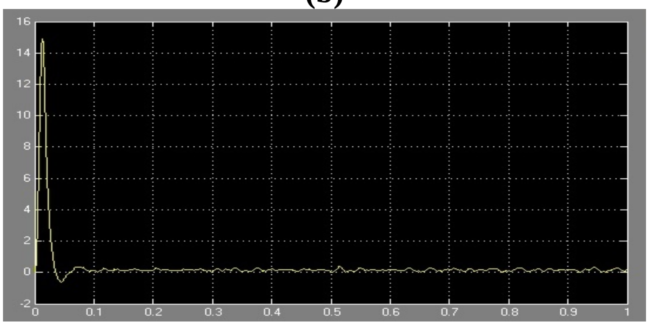
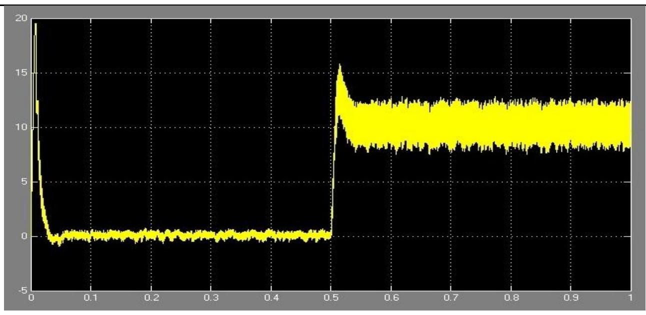


(c)

Figure 4.2.3: Torque characteristics of BLDC motor under NO load with constant speed of 1500 rpm by using (a) PI controller, (b) FLC, (c) ANN Controller.



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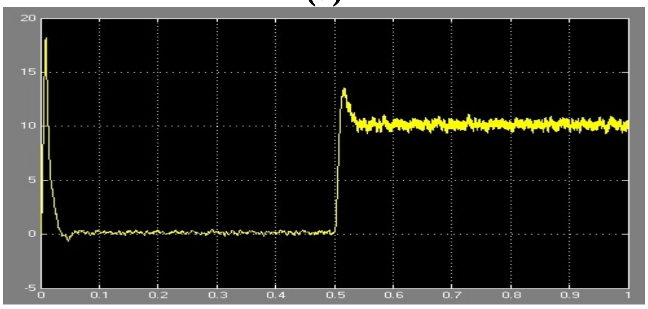

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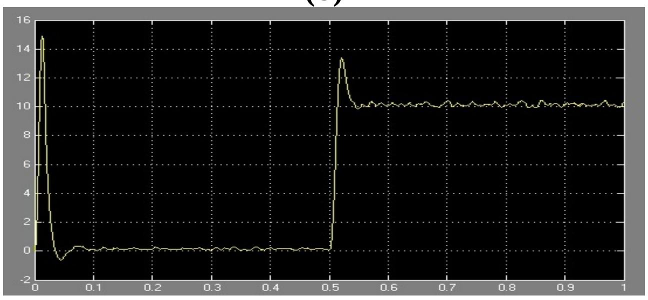
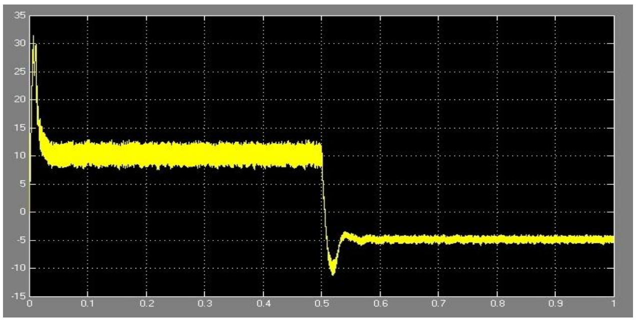


(c)

Figure 4.2.4: Torque characteristics of BLDC motor under load of10 nm at 0.5 sec with constant speed of 1500 rpm by using (a) PI controller, (b) FLC , (c) ANN Controller.



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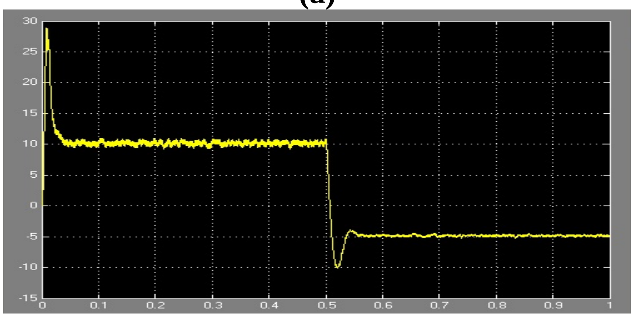

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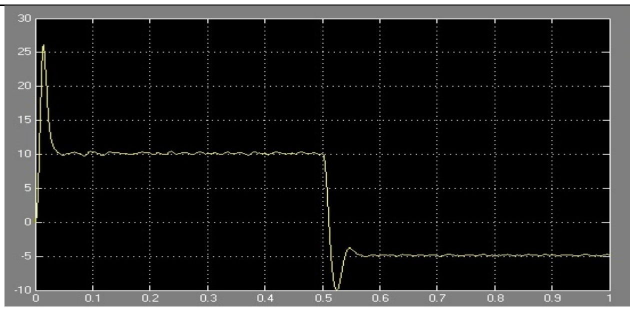
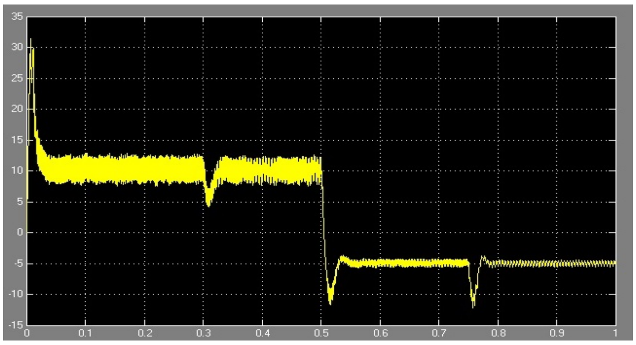


(c)

Figure 4.2.5: Torque characteristics of BLDC motor under load of 10 nm at 0 sec and -5 nm at 0.5 sec with constant speed of 1500 rpm by using (a) PI controller, (b) FLC , (c) ANN Controller



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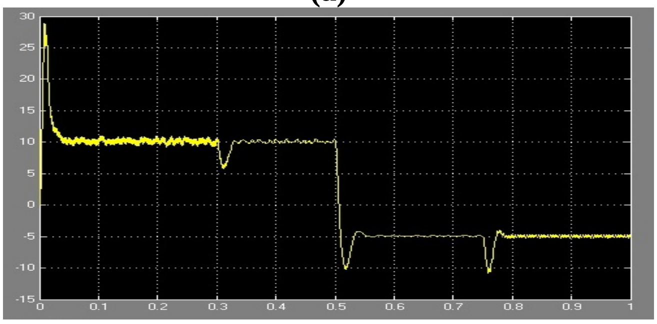

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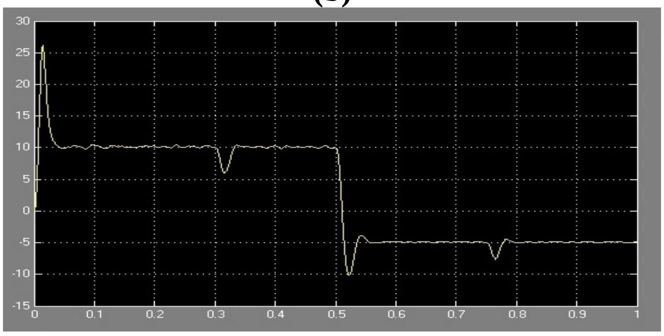

(C)

Figure 4.2.6: Torque characteristics of BLDC motor under load of 10 nm at 0 sec and -5 nm at 0.5 sec with different speed of 1500, 1000 and 700 rpm at time 0, 0.3 and 0.75 sec by using (a) PI controller, (b) FLC , (c) ANN Controller

V. CONCLUSION

A fuzzy logic controller (FLC) and ANN Controller have been employed for the speed control of PMBLDC motor drive This paper presents the new approach for the controlling of BLDC motor. The MATLAB results for proposed controller and conventional PI controller are compared. It can be seen from the simulation results that the ANN controlling is giving better and accurate results than PI and Fuzzy controlling.

The simulation results for various operating conditions are illustrated and investigated. for all operating conditions ANN control will achieves the command signal quickly , this is the major advantage of using the ANN control in servo system applications. And also the proposed control will be stable and operates at desired values for any load changes within the ranges. The controller will tracks the reference speed variations and stabilizes the output during load variation.

VI. SCOPE

As a future scope the fuzzy and ANN controller used in this system can be upgraded to an adaptive neuro fuzzy controller that has the combined advantages of both the neural networks and fuzzy logic along with FPGA. Also Genetic Algorithm can be used for the control design for better response.

VII. REFERENCES

Books:

[1]. C. L. Xia, Permanent Magnet Brushless DC Motor Drives and Controls. Hoboken, NJ, USA: Wiley, 2012.

[2]. H. A. Toliyat and S. Campbell, DSP-Based Electromechanical Motion Control. Boca Raton, FL, USA: CRC Press, 2004.

[3]. B. Singh, S. Singh, A. Chandra, and K. Al-Haddad, ―Comprehensive study of single-phase ac-dc power

Proceedings Papers:

[4]. J. Moreno, M. E. Ortuzar, and J. W. Dixon, ―Energy-*management system for a hybrid electric vehicle, using ultracapacitors and neural networks*, IEEE Trans. Ind. Electron., vol. 53, no. 2, pp. 614–623, Apr. 2006.

[5]. Y. Chen, C. Chiu, Y. Jhang, Z. Tang, and R. Liang, ―*A driver for the singlephase brushless dc fan motor with hybrid winding structure*,IEEE Trans. Ind. Electron., vol. 60, no. 10, pp. 4369–4375, Oct. 2013.

[6]. X. Huang, A. Goodman, C. Gerada, Y. Fang, and Q. Lu, ―*A single sided matrix converter drive for a brushless dc motor in aerospace applications*, IEEE Trans. Ind. Electron., vol. 59, no. 9, pp. 3542–3552, Sep. 2012.

[7]. P. Pillay and R. Krishnan, ―*Modeling of permanent magnet motor drives*, IEEE Trans. Ind. Electron., vol. 35, no. 4, pp. 537–541, Nov. 1988.

[8]. S. Singh and B. Singh, ―A *voltage-controlled PFC Cuk converter based PMBLDCM drive for air conditioners*,IEEE Trans. Ind. Appl., vol. 48, no. 2, pp. 832–838, Mar./Apr. 2012.

[9]. B. Singh, B. N. Singh, A. Chandra, K. Al-Haddad, A. Pandey, and D. P. Kothari, ―*A review of singlephase improved power quality acdc converters*, IEEE Trans. Ind. Electron., vol. 50, no. 5, pp. 962–981, Oct. 2003.

[10]. *Factor corrected converters with high -frequency isolation*,□ IEEE Trans. Ind. Informat., vol. 7, no. 4,pp. 540–556, Nov. 2011.

[11]. S. Singh and B. Singh, ―*Power quality improved PMBLDCM drive for adjustable speed application with reduced sensor buck-boost PFC converter*,in Proc. 4th ICETET, Nov. 18–20, 2011, pp. 180–184.