Speed Control of Impedance Source Inverter fed Electronically Commutated Motor drive Using Fuzzy and ANFIS Controllers

Dr.B.V.Arun Kumar[1], Dr.M. Nayeemuddin[2], Dr. G. Venkata Subba Reddy[3], Dr.V.Anantha Lakshmi[4], B.Rajeswari [5]

[1, 5] Assistant Professor, Department of E.E.E. Dept., G.Pulla Reddy Engineering College(A), Kurnool, A.P.
[2,3&4] Associate Professor, Department of E.E.E. Dept., G.Pulla Reddy Engineering College(A), Kurnool, A.P.

ABSTRACT

The functioning of the Z-source inverter fed Brushless Direct Current Motor drive using an impedance source inverter is discussed in this study using a novel technique. Variable speed drives (VSD) have been replaced by impedance source inverters (ISI)[7], which feature boost capabilities that enable inverters to function in the shoot through condition. This suggested strategy takes into account utilising fuzzy and ANFIS controllers for brushless direct current motor[11] driving speed control. When compared to an ANFIS Controller, speed control via a fuzzy logic controller does not produce better results. The MATLAB simulation confirms the speed control improvisation using the ANFIS controller, and the results are obtained and described in this work.

Key words: Z source inverter, Brushless Direct Current Motor, Fuzzy logic and ANFIS controllers.

1. INTRODUCTION

There are many business and residential applications for brushless direct current motors. The advantages of Brushless DC motors have led to better control strategies to anticipate the motor's presentation. In a conventional brushed direct current motor, the brushes mechanically create a series of electrical contacts on the rotor known as the commutator. This establishes an electrical circuit that joins the DC power source and the armature coil windings. As the armature rotates, the stationary brushes come into contact with various areas of the commutator. A spinning commutator and brush system is employed to allow electrical current to flow through the armature coils close to the field, which could be an electromagnet or a permanent magnet [1]. When a brushless direct current motor is used, permanent magnets rotate in place of the armature coils. As a result, the difficulty of providing current to a moving armature is removed because the armature doesn't move. A brushless direct current motor's commutator is swapped out with an electronic controller with coil switching capabilities [2]. Brushless DC motors' key advantages are improved performance, extended usable life, decreased noise, and adjustable high speed ranges.

Every industry on the market uses brushless direct current motors, including appliances, industrial control, automation, aircraft, etc. The three most significant categories of brushless direct current motor operation control are positioning applications, variable loads, and constant loads. In Fig. 1, the BLDC circuit architecture is shown.

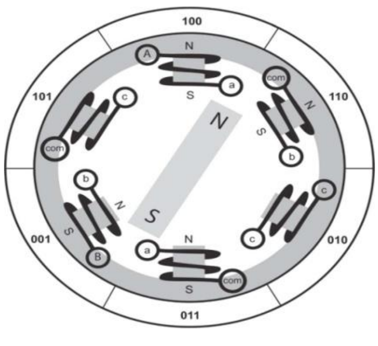

Fig (1): BLDC Motor construction

2. Brushless Direct Current (BLDC) Motor Drive System Modeling:

A. Modeling of BLDC Motor

The d-q axis and abc phase changing models are mathematically used in BLDC motors. The fact that the back emf of a BLDC motor is trapezoidal suggests that the mutual inductance of the rotor and stator windings prior to being updated for d-q axis representation is not sinusoidal. Because this method does not have an exquisite benefit, we employ the adc phase variable approach. We assume that the BLDC motor is properly linked in this instance via an isolated neutral. In BLDC motor modeling, the following presumptions are not fully embraced [2]

i.Self and mutual commitments were made.

ii. The stator resistance of all the windings in a BLDC motor is constant.

iii. Semiconductor technology is perfect by design.

The brushless direct current servomotor driving scheme's balanced circuit is shown. The matrix version of the line-to-line voltage equations is as follows:

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = \begin{bmatrix} R & -R & 0 \\ 0 & R & -R \\ -R & 0 & -R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & M-L & 0 \\ 0 & L-M & M-L \\ M-L & 0 & L-M \end{bmatrix} \times \frac{di}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a - e_b \\ e_b - e_c \\ e_c - e_a \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Mutual inductance (M) is neglected as compared to the self-inductance (L); as a result matrix equation can be rewritten as

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} \begin{bmatrix} R & -R & 0 \\ 0 & R & -R \\ -R & 0 & -R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L & -L & 0 \\ 0 & L & -L \\ -L & 0 & L \end{bmatrix} \times \frac{di}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a - e_b \\ e_b - e_c \\ e_c - e_a \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where

L=Self-inductance.

M= per phase Mutual inductance;

R=per phase stator winding Resistance;

e_a, e_b and e_c= phases a, b, and c Back EMFs;

$i_a, i_b,\ i_c$= phase streams of phases a, b, and c, individually.

In BLDC motor, torque generated by means of the BLDC motor can be expressed as

$T_e=(e_a i_a + e_b i_b + e_c i_c) / \omega = K_t I$ ……. (3)

Where $i_a = i_b = i_c$= I, ω is the speed in r/s, and $K_t$is the torque invariable. Since this torque generated by means of the BLDC motor is used to conquer the differing torques of inertia and load, it can also be written as

$T_e = T_L + J_M d_\omega /dt + B_M \omega$ ………… (4)

Where T_L = load torque

J_M = inertia, and B_M= friction Brushless direct current servomotor's constant.The requirements of the load inertia JL and friction BL mechanism may be used to articulate the load torque as follows:

$$T_L = J_L \frac{d\omega}{dt} + B_L \omega \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The power output developed by BLDC motor is

$P = T_e \omega$ ……………………….(6)

$E = e_a = e_b = e_c = K_b \omega$ …………..(7)

where Kb has returned E, the electromotive force, is back. EMF is the electromotive force per phase, and r/s is the speed [5].

3. Introduction to Impedance Source Inverter

Mathematically, the d-q axis and abc phase shifting models are used in BLDC motors. Because of the trapezoidal back emf of BLDC motors, it is likely that the mutual inductance of the rotor and stator windings is not sinusoidal prior to being updated for d-q axis representation. We employ the adc phase variable strategy since the exactness of the former is not a benefit of the latter. We assume that in this instance, the BLDC motor is star linked via an isolated neutral. The BLDC motor modeling does not include the following presumptions[2].

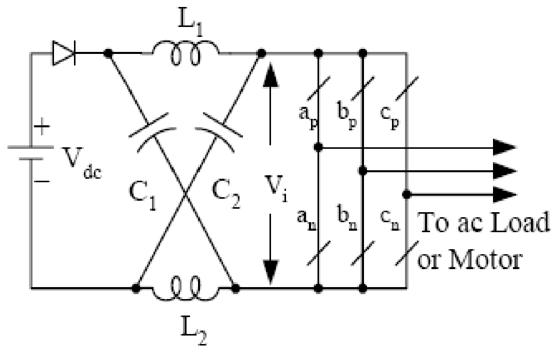

Fig 2 General structure of Z-source inverter

The typical impedance source inverter construction is seen in Fig. 2 [3]. In order to provide distinguishing qualities that cannot be seen in the traditional V and I - source inverters, which utilise a capacitor and an inductor, respectively, it uses a special impedance network (or circuit) to connect the converter main circuit to the power source, load, or another converter. The Z-source inverter offers a unique power conversion idea that circumvents the theoretical and conceptual restrictions of the traditional V-source converter and I-source converter stated above [4].

3.1 Design OF Z-SOURCE INVERTER:

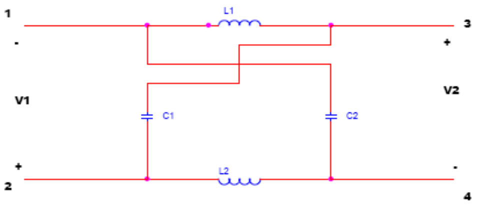

Fig .3 Impedance network

Figure 3 illustrates the architecture of the impedance network, where C1 and C2 are parallel capacitors and L1 and L2 are series arm inductors.

Redrawing the network is as

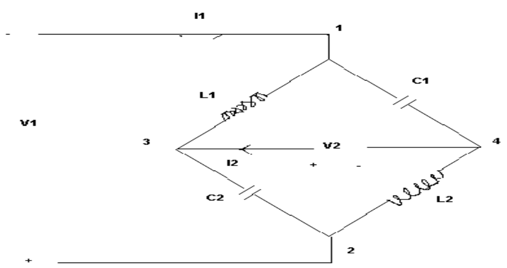

Fig .4 Impedance network diagram

From above Network diagram shown in Fig. 4, Now assume I_2=0, the current I_1 enters thee bridge at point 1 and divides equally between two arms of the bridge.

Using Kirchhoff's law

$I_1 L/2+V_2={}^{I_1}/_{2c}$……………………..(8)

$V_2={}^{I_1}/_{2c}-\frac{L}{2}I_1$……………………..(9)

Assume c=5.5mf

$440=5/2\left[{}^{1}/_{5.5}*10^{-3}-L\right]$

L=5.8H

V_{dc}=B.V_o=${}^{2B}/_{B+1}$*V_c……………(10)

4. Fuzzy Logic Controller System:

By removing the PI controller, the fuzzy logic controller was applied to the speed controller. Fig. 5 displays the block diagram for the fuzzy logic-controlled Brushless Direct Current Motor drive system.

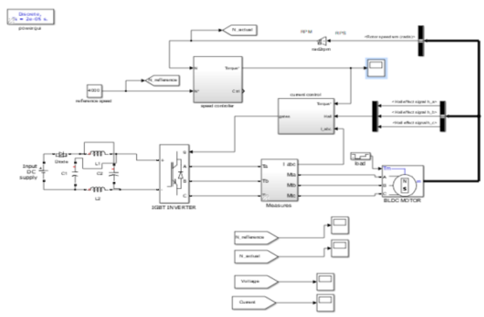

Fig 5 : simulink digram for fuzzy logic controller

Input variables like speed error (E) and change in speed error (CE) are calculated by the controller.The position or reference current (Iref) output variable, a component of torque, is calculated using the variation in position current at the controller's output. The controller and corresponding output DU observe the error signal's pattern in order to compare the true speed to the reference speed. The FLC has the two input signals,first one is the error $E=\omega_{ref}-\omega_m$ and second one is the change in error CE, which is connected to the derivative $\frac{dE}{dt}=\frac{\Delta E}{\Delta t}=\frac{CE}{T_s}$,

where ΔE in the sampling time T_s ,CE is preportional to $\frac{dE}{dt}$. The output of the controller DE in brushles direct current motor drive is Δi_{qs}^{*} current .The signal is incorporated to generate the real control signal U or current i_{qs}^{*} . We can write

$$\int DU = \int K_1 E dt + \int K_2 \; CE \, dt \qquad (11)$$
$$U = K_1 \int E dt + K_2 E \qquad (12)$$

where $K_1$and K_2 are gain factors together with the summation process.

By extending the same approach and the adaptive gains with nonlinear characteristics, we may create an FLC algorithm for P and P-I-D.The following criteria are used to choose the fuzzy membership functions for the input and output variables: Positive Large: PL Negative Large: NLPositive Medium: PM Negative Medium: NM Positive Small: PS Negative Small: NS And zero: ZO

The range of the speed error (E) and change in error (CE)

$$-1 \leq \omega_e \leq +1 \qquad (13)$$
$$\text{And } -1 \leq \omega_{ce} \leq +1 \qquad (14)$$

and the output variable reference current change Δi_{qs} is define in the range of

$$-1 \leq \Delta i_{qs} \leq +1 \qquad (15)$$

The member ship functios are taken as traingular shpae due that resulting most excellent control performance and effortlessness.

5. Adaptive Neuro-Fuzzy Inference System (ANFIS) controller:

A fuzzy inference system with a back propagation approach. For a conventional fuzzy inference, the membership function parameters are frequently selected through trial and error or experience. The adaptive neuro-fuzzy inference system, however, can get around this problem by learning to adapt the membership functions to the input/output data in order to account for these kinds of variations in the data values rather than arbitrarily choosing parameters associated with a given membership function. This learning approach also functions in a manner similar to that of neural networks.A fuzzy Sugeno model called the Adaptive Neural Fuzzy Inference System (ANFIS) was included into the framework to facilitate learning and adaptation. Fuzzy logic becomes more systematic and relies less on specialised knowledge thanks to such a network. The goal of ANFIS is to modify a fuzzy system's parameters by implementing a learning process utilising input-output training data. ANFIS's fundamental design contains a single output f and two inputs, x and y.

The fundamental distinction between a fuzzy controller and an adaptive neurofuzzy controller in Matlab is that the former uses Mamdani fuzzy controllers, while the latter uses Sugeno fuzzy controllers.

The Mamdani type of fuzzy controller in Matlab requires input and output to be provided using certain assumptions, but the Sugeno type only needs inputs, with outputs being taught automatically. This is the key distinction between the two fuzzy controllers.

As a result, in Matlab, Sugeno type fuzzy controller is utilised as an adaptive neural fuzzy controller while Mamdani type fuzzy controller is used as an ordinary fuzzy controller.

a fuzzy inference system and a back spread computation. For a typical fuzzy conclusion, the parameters in the contribution capabilities are frequently controlled by experience or the experimental approach. The adaptive neuro-fuzzy induction system can overcome this difficulty by learning how to tailor the participation capacities to the input/output information in order to represent these types of variations in the information values, as opposed to arbitrarily selecting parameters associated with a given enrollment work. This learning strategy operates similarly to how brain systems do.

A fuzzy Sugeno display called the Adaptive Neural Fuzzy Inference System (ANFIS) is integrated into the structure to provide learning and adjustment strategies. Such a technique helps fuzzy foundation become more organised and less reliant on master data. ANFIS aims to modify a fuzzy system's parameters by using a learning approach that makes use of input-output prepared data. The fundamental structure of ANFIS contains one output f and two information sources (x and y).

The main distinction between a fuzzy controller and an adaptive neural fuzzy controller in Matlab is that there are two different types of fuzzy controllers: Mamdani and Sugeno.

Sugeno sort differs from Mamdani in that we only offer inputs, from which they generate outputs. Mamdani is a typical fuzzy controller in which we provide input and output while taking various possibilities into account. These two fuzzy controllers in Matlab differ significantly from one another on a basic level. The structural layout of the ANFIS controller is shown in Figure 6.

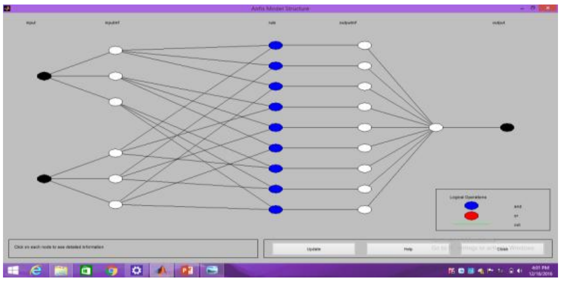

Fig. 6: ANFIS structure

- Layer 1: Input variables (membership functions) make up layer 1.
- As it receives the input values from the first layer and computes the membership values that identify the degree to which the input value belongs to the fuzzy set
- Layer 2 ensures the weights of each membership function and also serves as the input to Layer 3.
- The fuzzy rules' requirement matching is carried out by Layer 3, i.e., they determine each rule's commencement level, with the number of layers being equal to the number of fuzzy rules.
- Layer 4 offers the output values produced by the rules, conducts normalisation, and produces what are known as normalised firing strengths as a consequence**.**

Layer 5 is called the output layer which sum up all the inputs coming from layer 4 and changes the results into a crisp (binar**y).**

The simulink diagram of ANFIS controller is shown in Fig.7

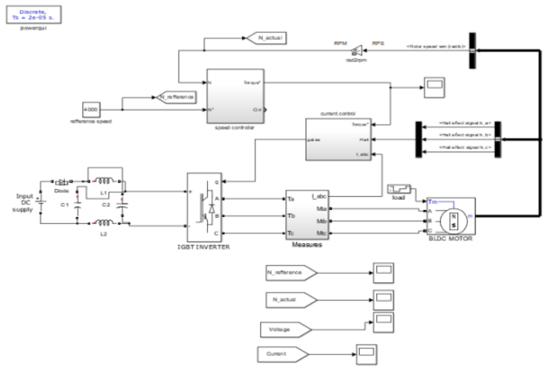

Fig 7: simulink diagram for ANFIS controller

6. Results and Discussion:

A. Fuzzy logic controller:

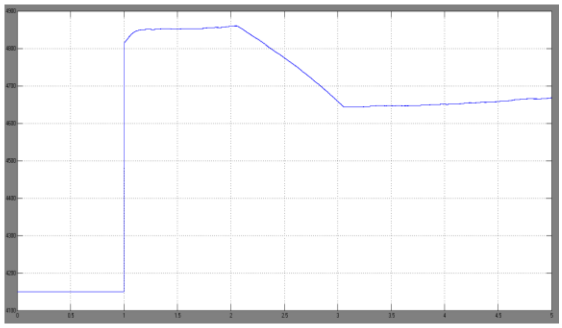

Fig .8: speed vs time charecteristics for for fuzzy logic controller

Fig.8 represents the speed control of motor using fuzzy logic controller. Here the speed wave form takes 3.75 sec to reach steady state value. The peak overshoot is also very high.

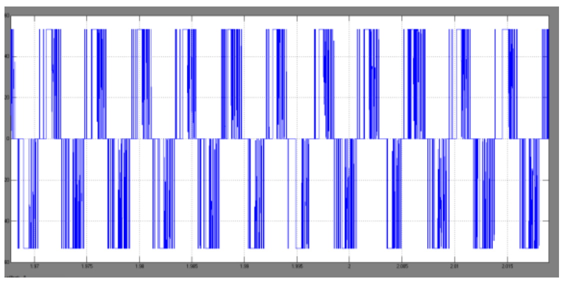

Fig. 9: output voltage with fuzzy logic controller

Compared to a voltage source inverter, the inverter increases the voltage by a ratio of 1.93. The comparison between the VSI and ZSI is shown in Table I below.

Table I. Comparison of VSI and ZSI

S.No	Input voltage 200 V DC	VSI	ZSI
1.	Output voltage (rms)	38 V	73.5 V

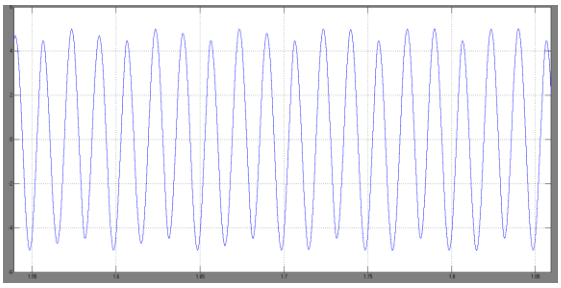

Fig 10: current waveform for fuzzylogic controller

Fig. 10 will display the waveform of the output current. The current in this instance uses a fuzzy logic controller and has some harmonics. Therefore, using the suggested ANFIS controller, harmonics will be avoided.

B. ANFIS controller:

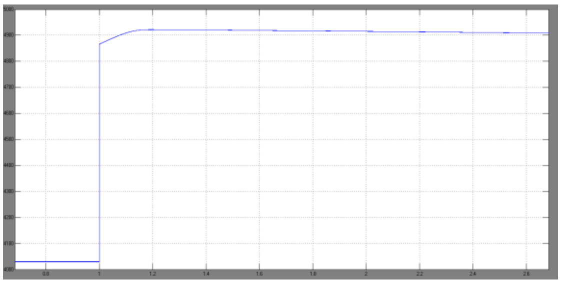

Fig 11: speed vs time charecteristics for for anfis controller

Figure 11 represents the speed control of BLDC motor Drive using ANFIS controller. Here the speed wave form takes 1.30 sec to reach steady state value. The peak overshoot is also very low compared with fuzzy logic controller. Comparison of fuzzy and ANFIS controllers in table III.

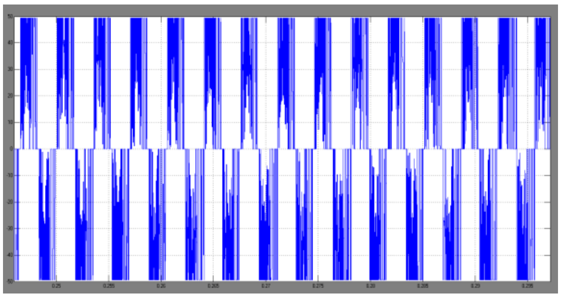

Fig 12: output voltage with ANFIS controller

Fig. 10 will display the output current waveform. Using a fuzzy logic controller, the current in this case has some harmonics. Therefore, harmonics will be prevented by using the suggested ANFIS controller.

Table .II
Comparison of VSI and ZSI.

S.No	Input voltage 200 V DC	VSI	ZSI
1.	Output voltage (rms)	39.5 V	76 V

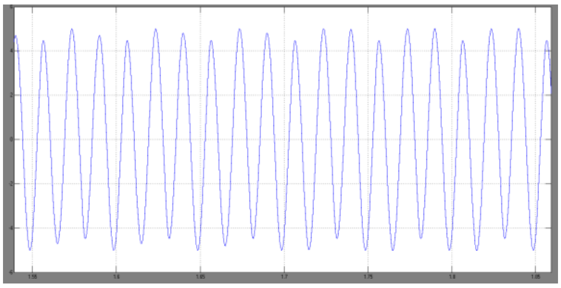

Fig 13: current waveform for ANFIS controller

Figure 13 will display the waveform of the current output current. Here, the proposed ANFIS controller will be used to some extent to reduce the current harmonics. The speed control variation in Fuzzy and ANFIS controllers is shown in Table III below. When compared to a fuzzy logic controller, the proposed ANFIS controller has less overshoot and settling time.

Table III

Time (in sec)	Fuzzy controller (time in sec)	Anfis controller (time in sec)
Peak time	2	1.17
Settling time	3.75	1.30
Overshoot	0.045	0.012

Motor and ZSI specifications are shown in Table IV.

Table IV

Motor and ZSI specifications**:**

s.no	Parameter	Value
1.	Dc voltage(v)	230
2.	Rated speed(rpm)	4000
3.	No of poles	4
4.	no of phases	3
5.	Rated torque(N-m)	0.5
6.	Inertia (kg-m^2)	23*e^{-6}
7.	R/phase (ohm)	0.57
8.	L/phase(H)	0.0015
9.	Impedance source inductance (L1&L2)	0.12mH
10.	Impedance source capacitance(C1&C2)	1.5µF

7. Conclusion:

Recently, Z-Source inverters have been presented as an alternative to adjustable speed drives (ASD) with boost capabilities since they let inverters work in the shoot through mode. The use of an impedance source inverter to increase output voltage by 1.9 times. The speed management of brushless direct current motor drive employing fuzzy and ANFIS controllers is taken into account in this suggested technique. When compared to an ANFIS Controller, speed control via a fuzzy logic controller does not produce better results. The MATLAB simulation confirms the speed control innovation using the ANFIS controller.

REFERENCES:

[1] Fardoun AA, Ismail EH, Al-Saffar MA, Sabzali AJ. New 'real' bridgeless high efficiency ac-dc converter. Proc. 27th Annu. IEEE APEC Expo, Feb. 5–9, 2012; 317–323

[2] Peng, F.Z.; Xiaoming Yuan; Xupeng Fang; Zhaoming Qian; "Z-source inverter for adjustable speed drives" IEEE Power Electronics Letters, Vol. 1, Issue: 2, pp.33 – 35, June 2003

[3] Je.w park,s eon.Hwan Hwang, "Sensorless control of brushless DC motor with torque constant estimation for home appliances", IEEETrans.ind.appl.,vol.48,no.2,pp.677-684, mar/apr.2012.

[4] D.K Kim, K.w lee and B.I.Kwon, "commutation torque ripple reduction in a position sensorless brushless DC motor drive", IEEE trans.power electron.,vol.21,no.6.pp.1762-1768,nov.2006.

[5] W.Lee,ju Hyung Kim,Wooyoung Choi,Bulent sarlioglu,"Torque ripple minimization via PWM control technique with GaN-based Motor Drive for High speed single Phase Brushless DC Motor',IEEE,2015.

[6]H.S.Chuang,Yu.Lung.ke,Y,C.Chuang,"Analysis of commutation torque ripple using different PWM modes in BLDC motors",IEEE ICPS,in proc.2009.

[7] Karthikeyan, V., V.J. Vijayalakshmi, and P. Jeyakumar. "Selective Harmonic Elimination (SHE) for 3-Phase Voltage Source Inverter (VSI)." American Journal of Electrical and Electronic Engineering 2.1 (2014):17-20.

[8] F. Z. Peng, "Z-source inverter" IEEE Transactions on Industrial Applications, vol. 39, no.2,pp. 504–510, Mar./Apr. 2003

[9] Yong.Liu,Z.Q.Zhu,"Direct torque control of brushless DC drives with reduced torque ripples",IEEE trans.ind.appl., vol.41, no.2, pp.599608,mar/april-2005.

[10]Y.Liu,Z.Q.Zhu,"commutation-torque-ripple minimization in Direct-torquecontrolled PM Brushless DC Drives" IEEE trans.ind.appl.,vol.43,no.4,july/aug 2007.

[11] T.M.Jahns and W.L.Soong,"Pulsating torque minimization techniques for permenant AC motor drives-a review",IEEE Trans.on industrial Electronics,vol.43pp.321-330,1996.

[12] c. Zhang,D.Bian,"A PWM control algorithm for eliminating torque ripple caused by stator magnetic field jump of brushless DC motors",IEEE,june 25-27,2008.

[13] Sakthival G, Anandhi TS, Natarjan SP. Real time implementation of DSP based Fuzzy logic controller for Speed control of BLDC

motor. International Journal of Computer Applications 2010; 10(8).

[14] Naga Sujatha K, Vaisakh K, Anand G. Artificial Intelligence based speed control of brushless DC motor. IEEE 2010.

[15] AN885 - Brushless DC (BLDC) Motor Fundamentals. Microchip Technology Inc. 2003.

[16] Huber L, Jang Y, Jovanovic MM. Performance evaluation of bridgeless PFC boost rectifiers. IEEE Trans. Power Electron 2008; 23(3): 1381-1390.