Adaptive Fuzzy PID Regulator for the Speed Control of Brushless Dc Motor

Dr. Anitha P[1]

'Professor, Department of Electrical & Electronics Engg, NSS College of Engg'

Abstract*: This paper presents an intelligent speed control system based on self tuning fuzzy PID controller for a brushless DC motor.PWM based motor current control is implemented with the help of three hall sensors placed around the motor shaft and a three phase inverter model is implemented for motor commutation .Dynamic performance of electromagnetic torque developed are analysed   for this model. Traditional speed control system of BLDCM introduces conventional PI regulator in outer speed loop which debases the performance of whole system. To overcome this problem, replacement of PI controller by an intelligent controller based on fuzzy set theory is proposed. The performance of the intelligent controller has been investigated through Matlab Simulink package for different operating conditions such as sudden changes in load torque. The simulation results   demonstrate that the performance of the proposed controller is better than that of conventional PI controller.*
Keywords: *Fuzzy Logic Controllersr, BLDC,PID Controller*

I.   Introduction

With the rapid developments in power semiconductor technologies and manufacturing technology for high quality magnetic materials, the BLDC motors have been widely used for various industrial and servo applications. BLDC motors are reliable, easy to control and inexpensive. Due to their favourable electrical and mechanical properties ,BLDC motors are widely used in applications such as automotive,aerospace ,medical ,instrumentation, actuation ,robotics and industrial automation equipments.BLDC motors has many advantages over conventional dc servo motors such as high dynamic response,long operating life ,high efficiency,long operating characteristics and high torque-weight ratio.The stator of BLDC motors have three phase windings ,whereas rotor has pole magnets.The hall sensors embedded in the motor detects rotor position and decoder decodes the position of rotor and produces gate pulses to trigger the six pulse inverter to produce ac voltages that energizes the stator windings.BLDC motors have electronic commutators instead of brushes ,thus they have higher efficiency, noiseless operation and long operating life. Fuzzy control provides a formal methodology for representing, manipulating and implementing a human heuristic knowledge about how to control the performance of a real dynamic system .Some simulation models based on state space equations,analysis of torque ripple due to phase commutation have been proposed for the analysis of BLDC motor drives[1],[2].Furthermore fuzzy logic controllers are used to analyse BLDC motor drives in literature[3],[4]. The FLC technique is a model-free techinique and inherently robust to load disturbances with the ease of implementation[5]. In this paper, a self tuning PID Fuzzy Logic Controller is proposed for the speed control of BLDC motor.

II.   Modelling Of Permanent Magnet Brushless Dc Motor

The complete BLDC motor drive system consists of a permanent magnet motor fed by a three phase PWM inverter ,hysteresis current controller,rotor position sensor and speed controllerThe phase variables are used to   model the BLDC motor due to its nonsinusoidal back emf and phase current.The controlled power to motor is supplied by the inverter. The magnitude and frequency of the inverter output voltage depends on the switching signals generated by the hysteresis controller. The state of these switching signals at any instant is determined by the rotor position, speed variation and winding currents. The controller facilitates the variable speed operation of the drive and also synchronizes winding currents with the rotor position. It maintains the motor speed reference value even during load and supply variations. The Fig.1 shows the configuration of Permanent Magnet Brushless DC Motor drive system
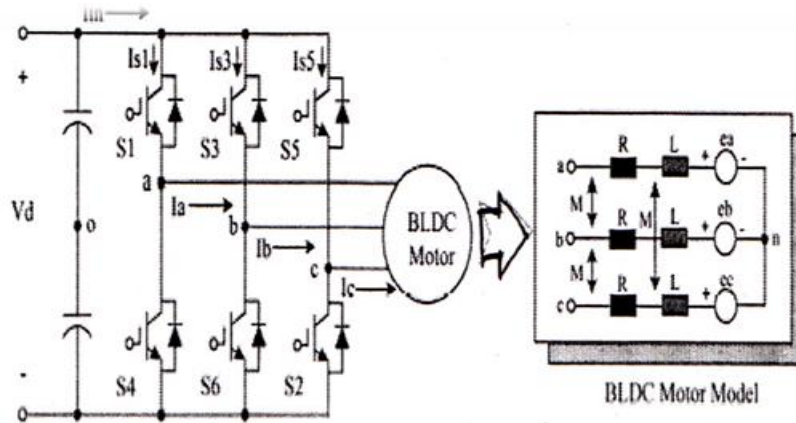
Fig.1 Brushless DC Motor Drive system

The mathematical model of the motor is developed based on the assumption in [4]. The terminal voltage equation of BLDC motor can be written as

$$v_a = Ri_a + L_a \frac{di}{dt} + e_a$$

$$v_b = Ri_b + L_b \frac{dib}{dt} + e_b$$

$$vc = Ri_c + L_c \frac{di_c}{dt} + e_c \qquad (1)$$

Where Va,Vb andVc are the phase voltages,ia,ib,ic are the phase currents,e_a,e_b and e_c are phase back emf voltages, R is the phase resistance ,L=La=Lb=Lc is the synchronous inductance per phase and includes both leakages and armature reaction inductances.
The electmro magnetic torque is given by

$$Ta = e_a i_a + e_b i_b + e_c i_c / w_m \qquad (2)$$

Where 'w_m' is the mechanical speed of motor.

III. Design Of Adaptive Fuzzy Pid Controller

The membership functions for controller input error and change in error are defined on the common interval [-1 1]. The membership function for gain updating factor is defined on [0 1]. The triangular membership function is selected with fifty percent overlap except at the two membership functions at the extreme end. The membership functions for error and change in error are shown in Fig. 2 and Fig.3 respectively. Their control output is shown in Fig. 4. The membership function for gain updating factor α is obtained by translating Fig. 4 along the horizontal axis by an amount +1 and mapping it on [0 1] using the relation y = 0.5(x+1) and it is shown in Fig. 5. The values of actual inputs e and Δe are mapped on to [-1 1] by the input scaling factors. The fuzzy logic controller output is mapped to actual output by output scaling factor .The actual output of adaptive FLC is obtained by using effective scaling factor αGU.

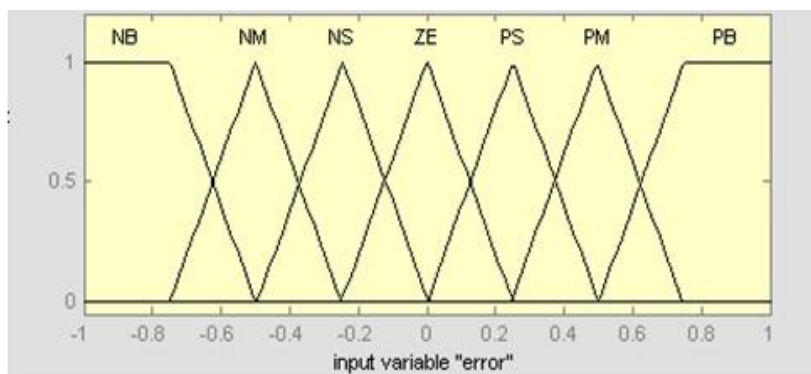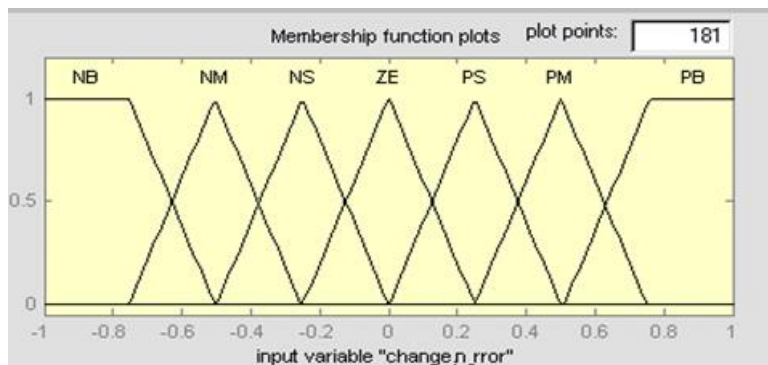**Fig. 2 Membership function plot for Error**

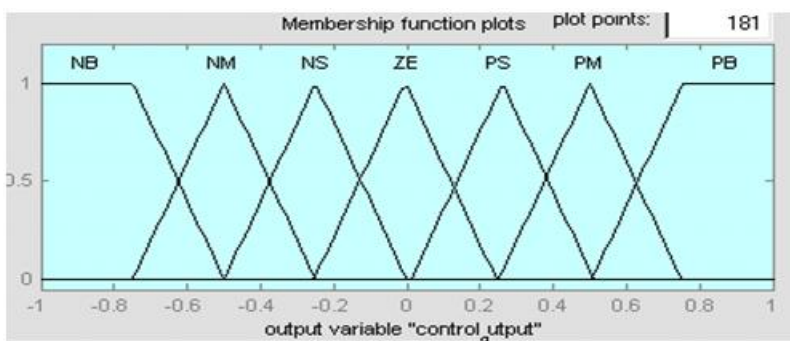**Fig.3 Membership function plot for change in Error**

Fig.4 Membership function of control output

The relationship between scaling factors and input and output variables of adaptive FLC are given by Eqns. (3),(4) and (5).

$$E=GE*e \qquad\qquad (3)$$
$$CE=GCE*\Delta e \qquad\qquad (4)$$
$$U=(\alpha GU)\,u \qquad\qquad (5)$$

where GE, GCE and GU are scaling factors at the input and output of FLC . The term 'u' represents the fuzzy controller output and 'U' denotes scaled output of fuzzy logic controller. The fuzzy PD controller uses rules of the form:

R_{PID}: If e is PB(Positive Big) and Δe is PS (Positive Small) then u is PB (Positive Big).

The gain updating factor (α) are calculated using fuzzy rules of the form:

R_{α} : If e is NB (Negative Big) and Δe is NB (Negative Big)then α is VB(Very Big).

Some of the important considerations that have been taken into account for the rule formation is to minimize the effects of delayed control action due to process dead time or measuring lag. The rules have been realized of the form : If e is PS and Δe is PB then α is VB.(The process output is not only far away from the set point but also is moving farther away from it). 2) Using the rule 'If e is ZE and Δe is PM then α is B' overshoot can be reduced. 3) When the processes are subjected to load disturbances in order to improve the control performance, the gain should be sufficiently large during the steady state condition.
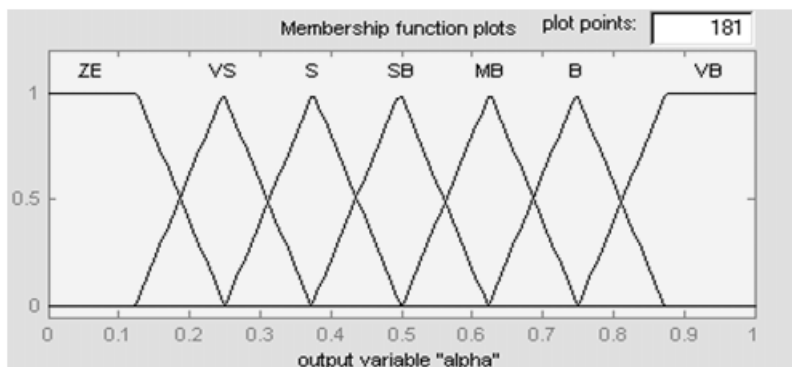

Fig. 5 Membership function for tuning factor' alpha'

The fuzzy rules for computation of control input 'u' are shown in Table 1 and the fuzzy rules for computation of α are shown in Table 2.

Table1 Fuzzy rules for computation of control input'u'

E/ΔE	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NM	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PS
ZE	NM	NM	NS	ZE	PS	PM	PM
PS	NS	NS	ZE	PS	PS	PM	PS
PM	NS	ZE	PS	PM	PM	PM	PS
PB	ZE	PS	PM	PS	PS	PS	PS

Table 2 Fuzzy rules for computation of α

E/Δe	NB	NM	NS	ZE	PS	PM	PB
NB	VB	VB	VB	S	VS	VS	ZE
NM	VB	VB	MB	SB	S	S	S
NS	VB	B	B	MB	VS	MB	SB
ZE	B	B	VB	ZE	VB	B	B
PS	SB	MB	VS	MB	B	B	VB
PM	S	S	S	SB	MB	VB	VB
PB	ZE	VS	VS	S	VB	VB	VB

To make controller produce lower overshoot and settling time the controller gain is set at a small value when error is big. If e is NB and Δe is PS then α is VS . In order to prevent excessive oscillation, the rule for α is selected as 'if e is PS and Δe is NS then α is 'S'. This type of gain variation will also result in the convergence rate of process to the set point. To improve control performance under load disturbance gain should be sufficiently large around steady state condition. Immediately after a large load disturbance, e may be small but Δe will be sufficiently large and in this case α is needed to be large to increase the gain. Fig.6 shows the simulation diagram of BLDC motor control system and Fig.7 demonstrates the fuzzy PIDregulator simulation .
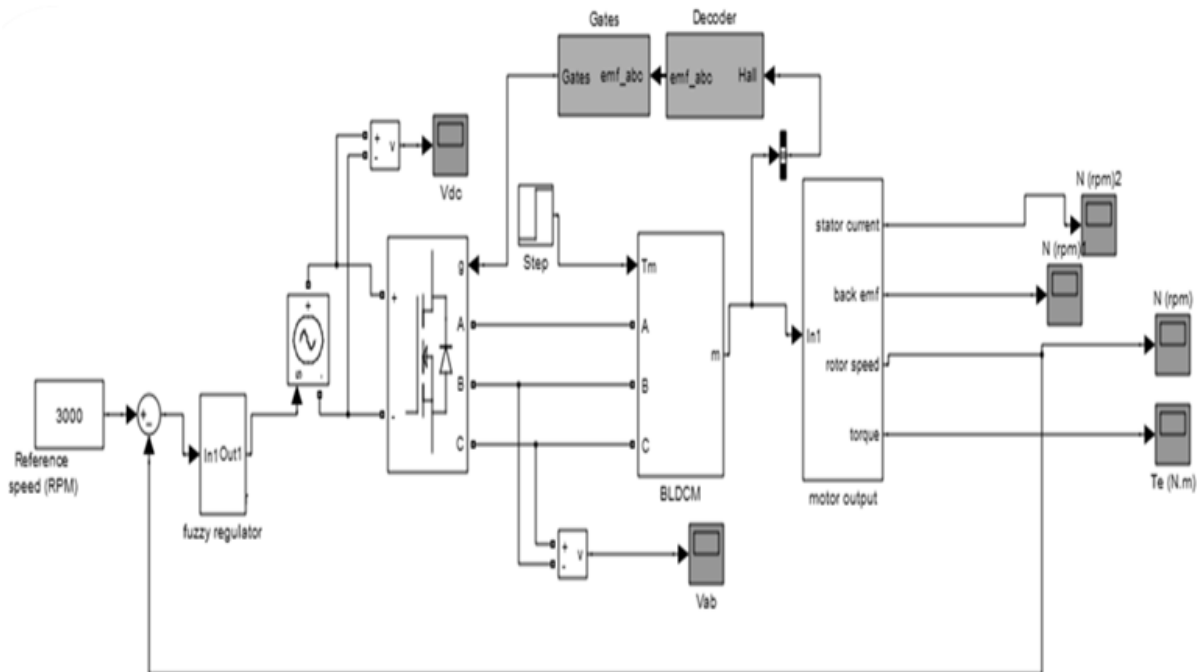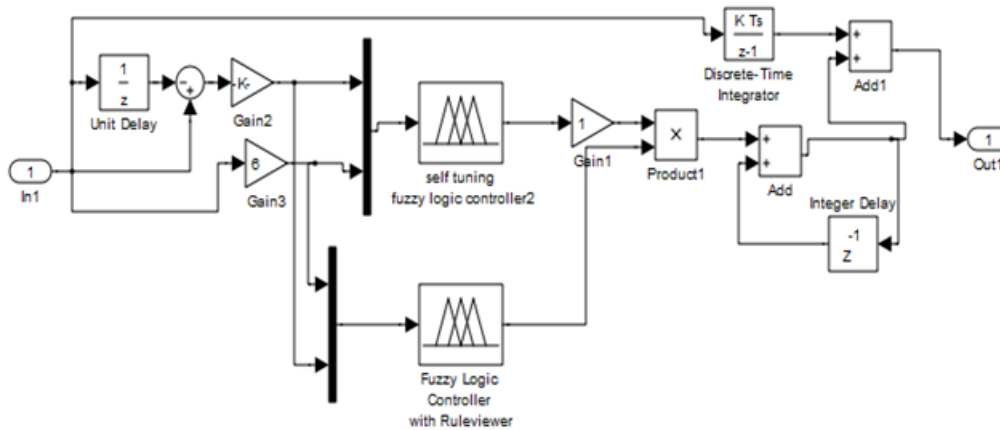

Fig.6 Simulation diagram of BLDC motor system

Fig.7 Simulation diagram of Fuzzy regulator

IV.   Simulation Results

Simulation resuls includes variations of different parameters of BLDC motor like electromagnetic torque,rotor speed,line-line motor terminal voltages w.r.t time.   Fig.8(a) and Fig.8(b) shows dynamic responses of the rotor speed   using conventional PID Controller and Adaptive fuzzy PID Controller. and Fig.9(a) and Fig.9(b) shows dynamic responses of the electromanetic torque developed using fuzzzy PID controller and conventional PID controller.From the torque response curve it can be observed that for the system with fuzzy PID Controller torque ripple is minimized under variable load conditione.
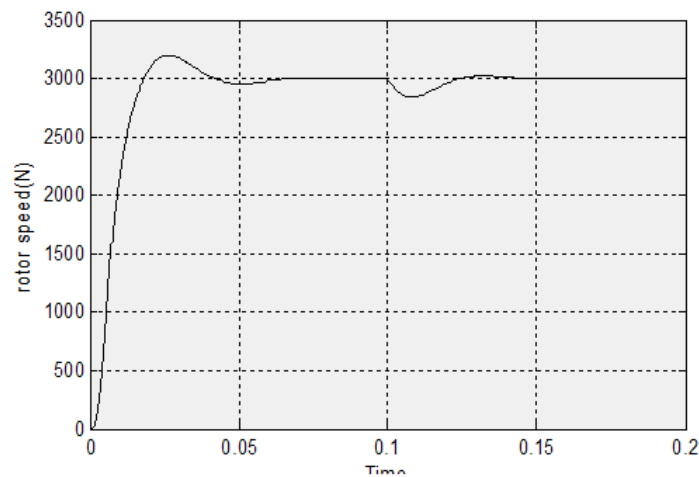

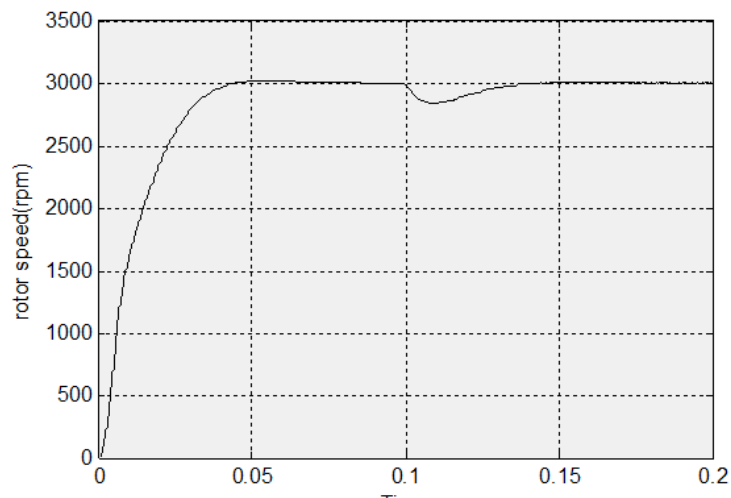**Fig.8** (a) Rotor speed response using conventionalPID Controller.

Fig.8 (b) Rotor speed response using adaptive fuzzy controller

With adaptive fuzzy PID controller percentage overshoot is found to be zero compared to the response of conventional PID Controller.The produced line-to-line voltage Vab,Vbc and Vca according to the conduction modes is demonstrated in Fig.10, 11and 12 respectively.
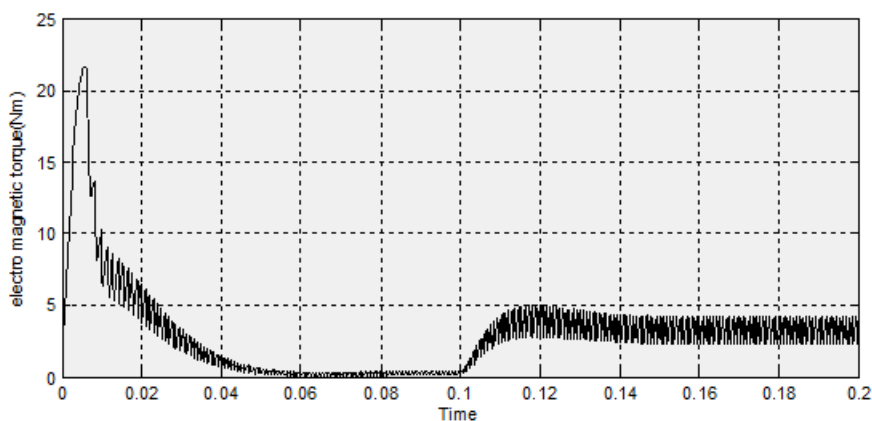

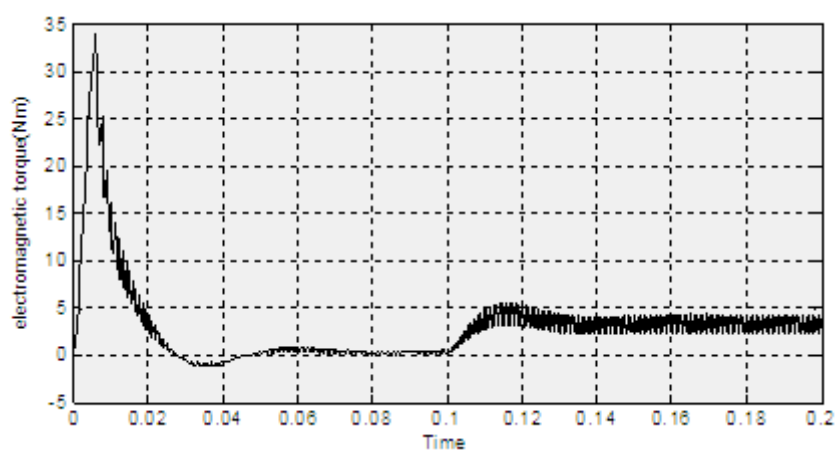**Fig.9 (a) Torque response curve with fuzzy PID Controller**

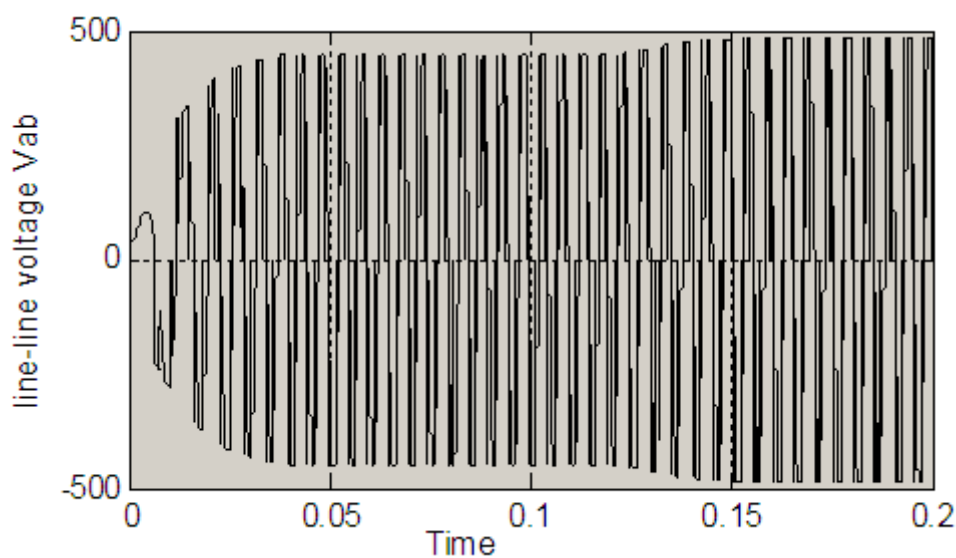**Fig,9(b)Torque response curve with conventional PID Controller**
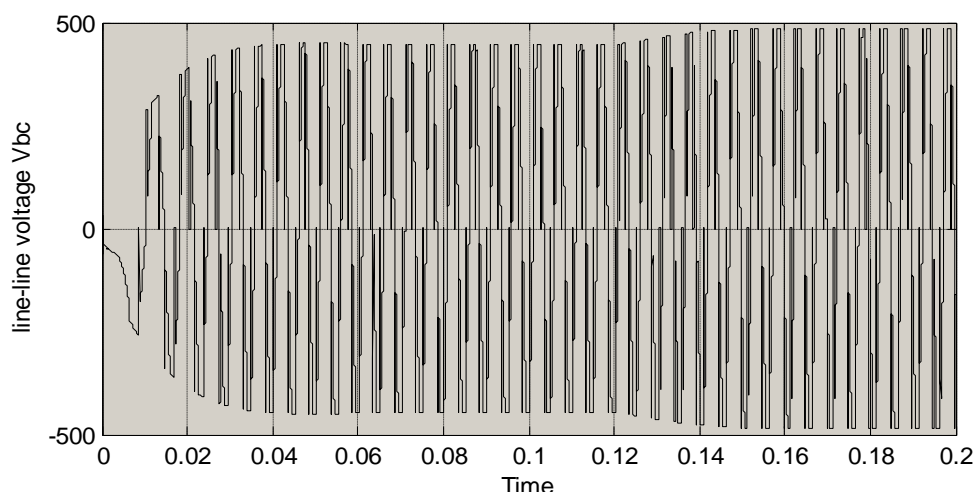

Fig.10 line-line voltage Vab
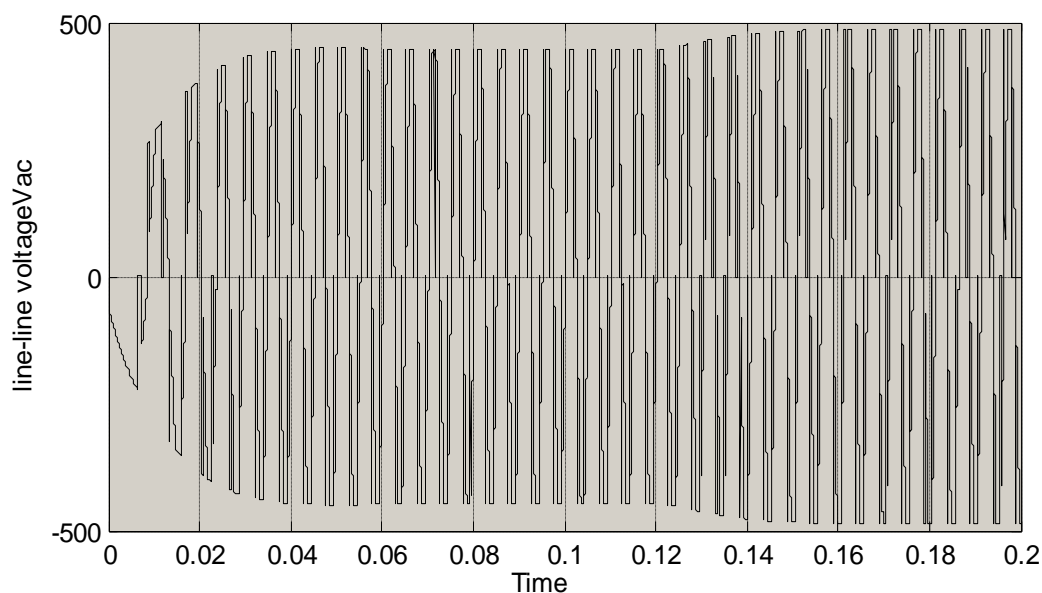
Fig.11 line-line voltage Vbc

Fig.12 line-line voltage VAC

V.   Conclusions

A performance comparison of PID Controller and Adaptive fuzzy Logic controller has been carried out by several simulations. The results have shown that Adaptive fuzzy logic regulator is better than conventional PID controller under variable operating conditions such as sudden variation in load conditions. The performance of AFLC is excellent for reducing torque ripples. The conclusion is that Adaptive fuzzy regulator is found to be more robust, stable flexible and insensitive to parameter variations as compared with conventional PID Controllers.

References

[1].   P Pillay and R Krishnan,Modelling Simulation and Analysis of Prrmanent Magnet drives Inverters:The brushless DC motor drive,IEEE Trans. On Industry applications 25,274-279,1989

[2].   P.D Evans and D.Brown,Simulation of Brushless DC Drives,Proc. Of the IEE 137,299-308,1990

[3].   R.Carlson,M.Lajoie-Muzene,and   C.D.S Fagundes,Analysis of Torque ripple due to phase commutation in brushless DC machines,IEEE Trans. On Industry applications 28,632-638,1992

[4].   B.K.Lee and M.A Ehsani,Simplified functional model for 3-phase voltage source inverter using switching function concept,IEEE Trans.on Industrial Electronics48,309-321,2001

[5].   Yen-Shin Lai,Fu-San Shyaand YUNG-Hsinchang,'Novel loss Reductio n PWM Tecchnique for BLDCM drives fed by MOSTET inverter',IEEE Trans.on Power electronics,Vol.19,N0.6,Nov 2009

[6].   AntonioMorcuo ,'A General PWM Strategy for four-switch three phase Inverters,'IEEE Transactions on Power Electronics,Vol. 2006

[7]. Mauricio Beltrao 21,No.6,Novem de Rossiter,Cursino Brcondao Jacobin,Edison Roberto Cabral da saliva and Yuanguan Wu,Zhiquan Deng,Xiaolin Wang,Xingling and Xincao,'Positin sensorlessControl based on Co-ordinate transformation for Brushless DC Motor Drives',IEEE Transactions on power electronics,vol.25,No.9,Sep 2010

[8]. Hamid A.Taliyat ,Stevan Campbell ,'DSP based Electromechanical motion control',2004CRC .Press,LLC

[9]. Zhen-Yu Zhao,MasayoshiTomizuka and Satoru Isaka,1993'Fuzzy Gain scheduling of PID Controllers',IEEE Transactions on Systems,man and Cybernetics,23No.5

[10]. George K I Mann,Bao-GangHu and Raymond G.Goshi1999,'Analysis of Direct action fuzzy PID Controller structures',IEEE transactions on Sstems,man and cybernetic-partbcybernetics 29(3)