Fuzzy Logic Based Position-Sensorless Speed Control of Multi Level Inverter Fed PMBLDC Drive

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***Abstract*—This paper presents multi level inverter fed Permanent Magnet Brushless DC Motor (PMBLDCM) with a simplified voltage control technique. It is based on the "indirect position sensing," which was justified by the observation that position sensing came indirectly from voltage and current waveforms. The switching angle for the pulse is selected in such way to reduce the harmonic distortion. This drive system has advantages like reduced total harmonic distortion and higher torques. PI, Fuzzy and Hybrid (Fuzzy and PI) controllers are discussed. Closed loop simulation response is obtained for PI, Fuzzy and Hybrid controller with a disturbance in the input source. The conventional circuit is improved by introducing Hybrid Controller. In Industrial application the physical integration of Hybrid controller in the motor body itself is able to make them most suitable for low power (0.5hp) blowers and low power (50W) tube axial fans for cooling the electronic equipment. The performance of the PMBLDCM system is simulated and implemented. Simulation results of these systems are presented and the performance measures are compared. The simulation results with Hybrid controller indicate improved performance. The experimental results are compared with simulation results.**

***Index Terms* : Three level inverter, FLC, PI, Hybrid, trapezoidal back emf, PWM, , Sim Power systems.**

I. Introduction

With the rapid development of microelectronics and power switches, most adjustable-speed drives are now realized with ac machines. Permanent Magnet Synchronous Motor (PMSM) with sinusoidal shape back-EMF and brushless DC (BLDC) motor with trapezoidal shape back-EMF drives have been extensively used in many applications, ranging from servo to traction drives due to several distinct advantages such as high power density, high efficiency, large torque to inertia ratio, and better controllability. Brushless DC motor (BLDC) fed by two-phase conduction scheme has higher power/weight, torque/current ratios and it is less expensive due to the concentrated windings which shorten the end windings compared to three-phase permanent magnet synchronous motor (PMSM) [1]- [6]. There are two methods of controlling PMBLDC motor namely sensor control and sensorless control. The latter has advantages like cost reduction, reliability, elimination of difficulty in maintaining the sensor etc. Sensorless control is highly advantageous when the motor is operated in dusty or oily environment, where cleaning and maintaining of Hall Sensors is required for proper sensing of rotor position. Sensorless method is preferred when the motor is in less accessible location. Accommodation of position sensor in motor used in compact unit such as computer hard disk may not be possible. Novel direct back emf detection for sensorless BLDC motor is given in [7]. Analysis of BLDC motor is given in [8]. Modeling of BLDC motor is given in [9]. Feed forward speed control of Brushless DC motor with input shaping is given in [10]. A PSO-based optimization of PID controller for a Linear BLDC Motor is given in [11]. Speed Control of BLDC based on CMAC & PID controller is given in [12]. A sensorless drive system for BLDC using a Digital Phase-Locked Loop is given in [13]. Classical control methods can be implemented in well- defined systems to achieve good performance of the systems. To control a system, an accurate mathematical model of the complete system is required. Systems with non linear behavior cannot be exactly modeled. The fuzzy Logic control has adaptive characteristics that can achieve robust response to a system with uncertainty, parameter variations and load disturbance. Fuzzy Logic and Fuzzy set theory was presented by Zadeh [14]. Fuzzy Logic Controllers have been broadly used for ill-defined, non-linear and complex systems [15], [16]. In the area of electrical drives, fuzzy logic controllers have been applied to switched reluctance motors [17], [18], induction motors [19] and PMBLDC motors [20] successfully. The above literature does not deal with voltage control method to control the speed using sensorless approach. This paper demonstrates a sensorless technique to drive a three phase brushless DC motor with a multi level voltage Inverter system using voltage control method with Hybrid Fuzzy logic control. PMBLDC motors drives are used in a wide range of commercial and residential applications such as domestic appliances, heating, ventilating and air-conditioning

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equipment due to their highest possible efficiencies. The speed control ability using Hybrid fuzzy controller is able to provide operation at their high efficiency.

In *Section* I Voltage control based PMBLDC motor is described. In Section II three level inverter is presented with some basics of mode of conduction. In Section III three level inverter fed PMBLDC motor with PI controller is presented. In Section IV three level inverter fed PMBLDC motor with Fuzzy Logic controller is presented. Hardware circuit is fabricated and tested.

A. VOLTAGE CONTROL BASED PMBLDC MOTOR

The measurement of armature current in the three phases is not required because there is no neutral connection, and hence the third phase current can be obtained from the other two. The quasi square-wave armatures current are mainly characterized through their maximum amplitude value, which directly controls the machine torque. The inverter performance is very much reliable because there is natural dead time for each transistor. Hence, allows designing a circuit for controlling only a DC component, which represents the maximum amplitude value of the trapezoidal currents, I_{MAX} .and reduces the complex circuitry required by other machines, allowing the self-synchronization process for the operation of the machine. The most popular way to control BLDCM for traction applications is through voltage-source current-controlled inverters. The inverter must supply a quasi-square current waveform whose magnitude, I_{MAX} , is proportional to the machine shaft torque. Then, by controlling the phase-currents, torque and speed can be adjusted. The response of phase voltage , phase currents, speed, and feedback current with disturbance at the source are obtained.

The waveforms of the armature currents are quasi-square. These currents are sensed through current sensors. These signals are then rectified , and a DC component, with the value of the ceiling of the currents, I_{max} , is obtained. It is filtered and DC voltage is obtained across resistor. The voltage Vmax is compared with Vref and from this comparison, an error signal "e(t)' is obtained. This error signal is then processed using PI controller. The output of PI controller is used to vary the input voltage of three level inverter. The strategy becomes simple, because the control only needs to be in command of DC current instead of three alternating waveforms. The control strategy also allows regenerative braking, which is very important in applications, like electric vehicles, where energy can be returned to the battery pack.

II. THREE LEVEL INVERTER

In three level inverter modeling,120 degree conduction mode is employed. The gating signals given to the MOSFET are sequenced to every 60 degree interval. Each MOSFET conducts for a duration of 120 degrees. The MOSFET is used as a switch since it can operate high switching frequency. This feature is helpful in driving the motor with high current and low voltage conditions. The three level inverter circuit is shown in Fig 1.

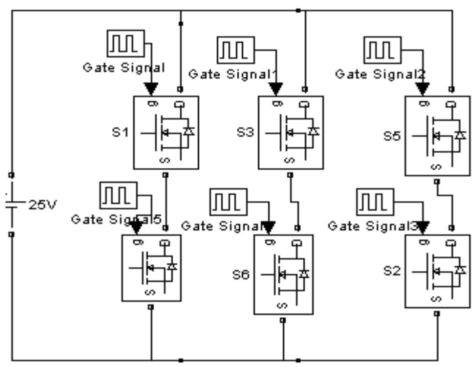

Fig 1. Three level Inverter Circuit

A. THREE LEVEL INVERTER FED PMBLDC MOTOR

Fig. 2 shows the schematic diagram of the Closed loop Sensorless Speed Control of PMBLDC motor using PI Controller. The MOSFETs are used as switching devices. For speed control of motor, the output frequency of the inverter is varied. The applied voltage to the motor is varied in linear proportion to the supply frequency to maintain the flux constant. The MATLAB simulation is carried out and the simulation results are presented in this section. The Fig.3 shows the driving pulses applied to the MOSFETs.

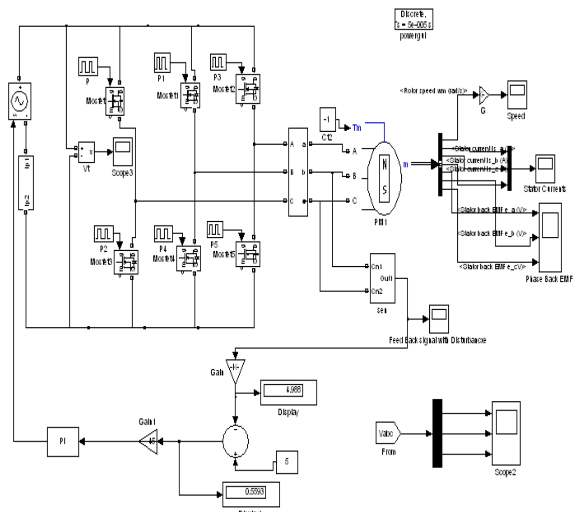

Fig 2.Closed loop Sensorless Speed Control of PMBLDC motor

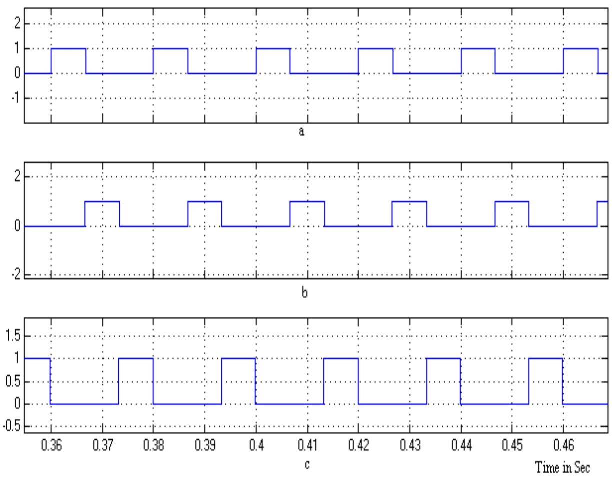

Fig3 a,b,c.Driving Pulses to the MOSFETs

B.THREE LEVEL INVERTER FED PMBLDC MOTOR WITH FUZZY LOGIC CONTROLLER

Fuzzy Logic Controller

The block diagram showing the implementation of the Fuzzy speed controller is illustrated in Figure 4. It includes four major blocks: knowledge base, fuzzification, inference mechanism, and defuzzification. The knowledge base is composed of a data and a rule base. The data base, consisting of input and output membership functions. The rule base is made of a set of linguistic rules relating the fuzzy input variables into the desired fuzzy control actions.

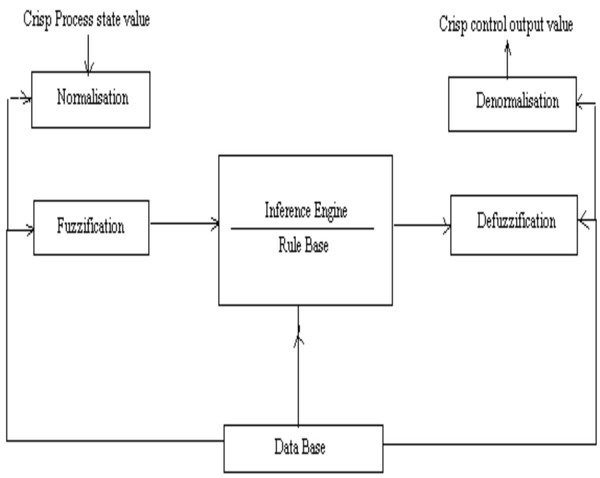

Fig 4 . Block Diagram of Fuzzy Logic Controller

Initial rule base that can be used in drive systems for a fuzzy logic controller consist of 49 linguistic rules, as shown in Table I, and gives the change of the output of fuzzy logic controller in terms of two inputs: the error (e) and change of error (de). The membership functions of these variables are given in Fig.5.In Table I, the following fuzzy sets are used: NB negative Big , NM negative medium, NS negative small, ZR zero, PS positive small, PM positive medium and PB positive Big. For example, it follows from Table I that the first rule is:

IF **e** is NB and **de** is NB then **du** is NB

The linguistic rules are in the form of IF-THEN rules and take form:

IF (e is X and de is Y) then (du is Z),

Where X, Y, Z are fuzzy subsets for the universe of discourse of the error, change of error and change of the output .For example, X can denote the subset NEGATIVE BIG of the error etc. On every of these universes is placed seven triangular membership functions. It was chosen to set these universes to normalized type for all of inputs and output. The range of universe is set to -1 to 1.

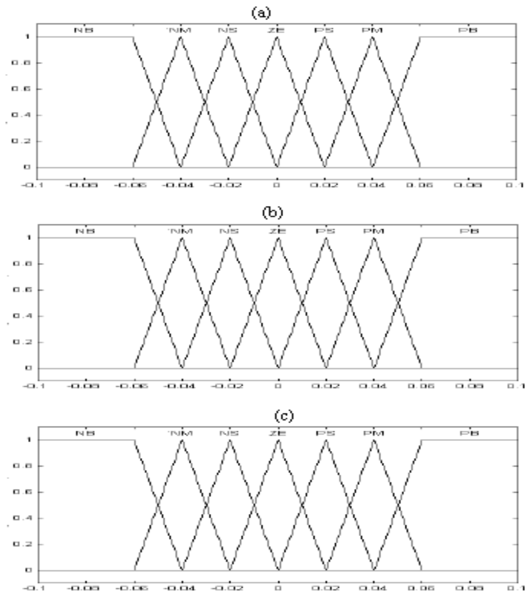

Fig 5. Membership function for error, derror, controller output

D. THREE LEVEL INVERTER FED PMBLDC MOTOR WITH HYBRID CONTROLLER

The fuzzy PI controller is shown in Fig 6. The fuzzy controller is basically an input/output static nonlinear mapping, hence the controller action is in the form

$$K_1E+K_2CE=DU \quad (1)$$

Where K_1 and K_2 are nonlinear coefficients or gain factors.

$$\int DU=\int K_1Edt+\int K_2CEdt \quad (2)$$

$$U=K_1\int Edt+K_2E \quad (3)$$

Equation (3) is a fuzzy P-I controller with nonlinear gain factors.

TABLE I : FAM TABLE FOR HYBRID CONTROLLER

	NB	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NM	NS	NS	ZE
NM	NB	NM	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PM	PB
PB	ZE	PS	PS	PM	PB	PB	PB

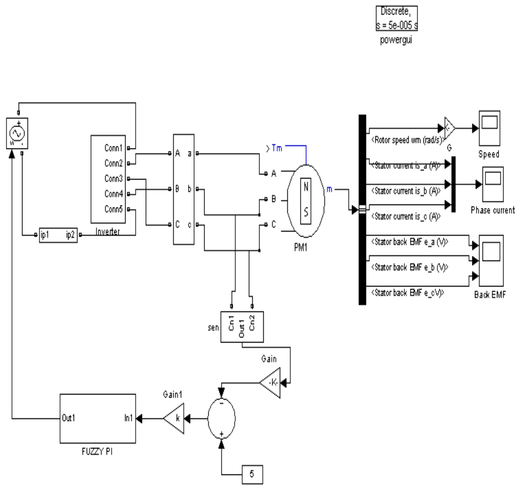

Fig. 6 Closed loop Sensorless Speed Control of PMBLDC motor using Hybrid Controller

III. SIMULATION RESULTS

A. RESPONSE OF HYBRID CONTROLLER

With the help of designed circuit parameters the MATLAB simulation of the above circuit is performed and the results are presented here.

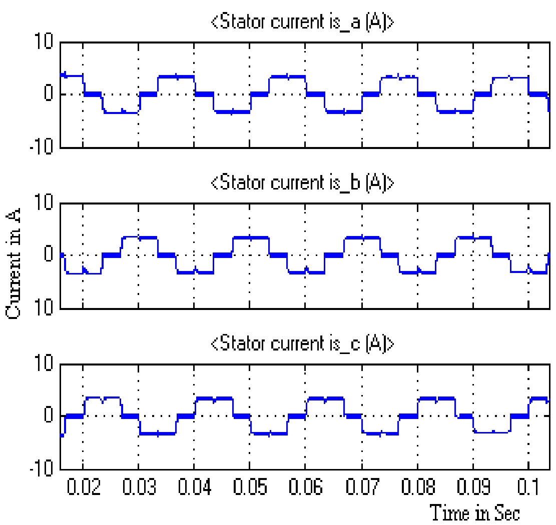

Fig 7. Three Phase Inverter Stator Current

The simulation results of stator current are shown in Fig 7. The currents are quasi square wave with a displacement of 120°.

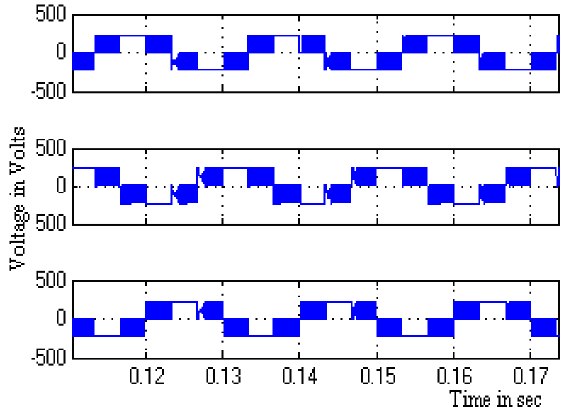

Fig 8.Three level Inverter Output Voltage

The stator voltages are shown in Fig 8. They are also displaced by 120° .

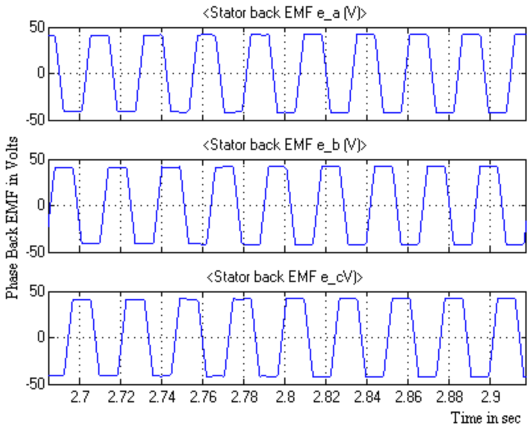

Fig 9. Trapezoidal shape Phase Back EMF

The stator phase back emf is shown in Fig 9. The phasor back emf is trapezoidal as shown.

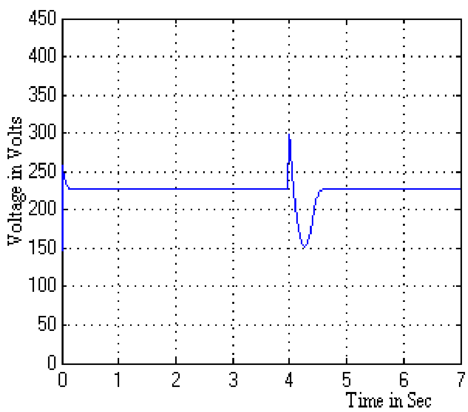

Fig.10 DC Input Voltage to Inverter with Disturbance at t=4 sec

Fig 10 shows the DC input voltage to the 3-level inverter with a disturbance at t=4 Sec. The closed loop system brings the voltage to the normal value by adjusting the input voltage of the inverter.

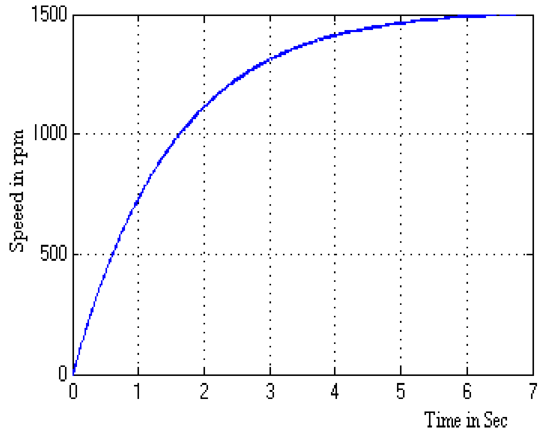

Fig. 11 Rotor Speed in rpm

The rotor speed characteristic of 3-level inverter fed PMBLDC motor using Hybrid controller is shown in Fig 11. The rotor reaches the rated speed in 5.5 Sec.

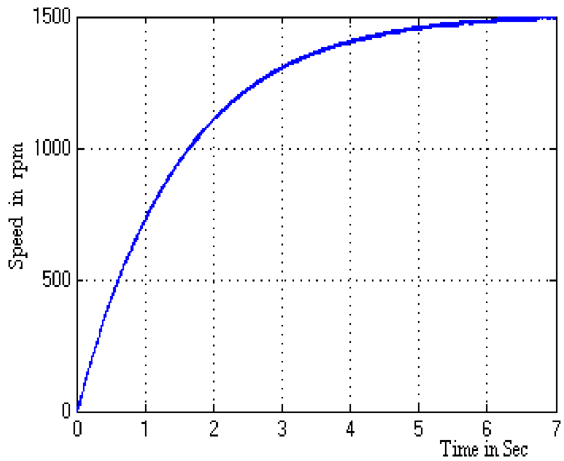

Fig 12. Rotor Speed in rpm

The rotor speed characteristic of 3-level inverter fed PMBLDC motor with PI controller is shown in Fig 12. The rotor reaches rated speed in 6.1 Sec. The time taken to settle at rated speed is comparatively more in conventional controller.

TABLE II PERFORMANCE ANALYSIS

Controller	THD	IAE	ISE	tss
PI Controller	0.5747	42.79	334	6.1
Fuzzy Controller	0.4173	28.39	107	6.00
Hybrid Controller	0.3825	10.49	29.35	5.5

IV. Experimental Results

After the simulation studies, a Hybrid Fuzzy logic based Three level inverter fed PMBLDC motor is fabricated and tested. The top view of the hardware is depicted in Fig 13. The hardware consists of power circuit, control circuit and PMBLDC motor.

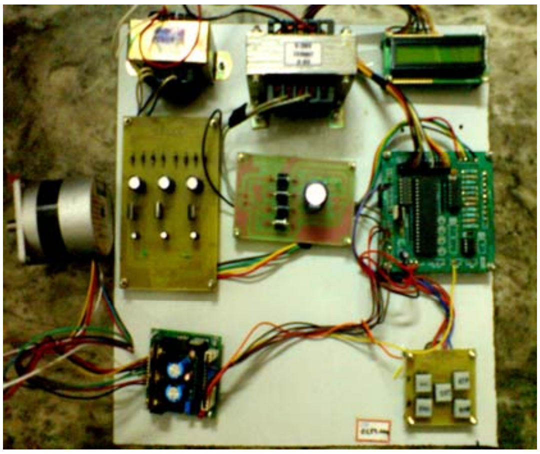

Fig 13 Top View of Hardware circuit

The regulators 7812 and 7805 in the control circuit give the DC supply required by the driver and microcontroller chips respectively. The driver chip amplifies 5V pulse to 10V level. DC output from the rectifier is ripple free due to the filter. The Atmel microcontroller 89C2051 is used to generate the pulses. Port 1 of the microcontroller is used for generating the gate pulses. Timer 0 is used for producing the delay required for the duration T_{ON} and T_{OFF}. The microcontroller operates at a clock frequency of 12 MHz.

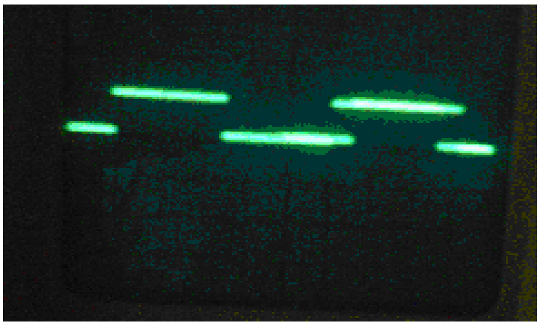

Fig 14 Pulse Signal waveform

The pulses produced by the microcontroller are amplified using the driver IC IR 2110. Three driver ICs are used to amplify the gate pulses. The oscillogram of pulse signal is given in Fig 14.

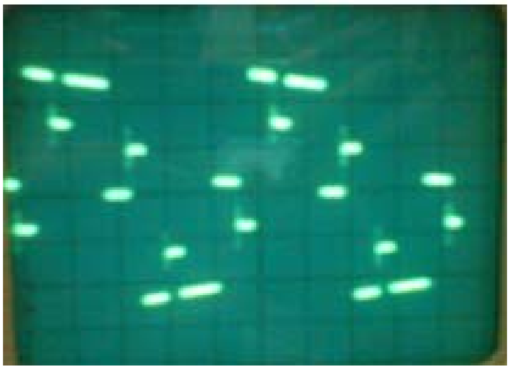

Fig 15 Three level inverter voltage

The oscillogram of three phase inverter output voltage is depicted in Fig 15. The Back EMF waveform of Three Phase PMBLDC is depicted in Fig 16. The Back emf waveforms are trapezoidal as shown.

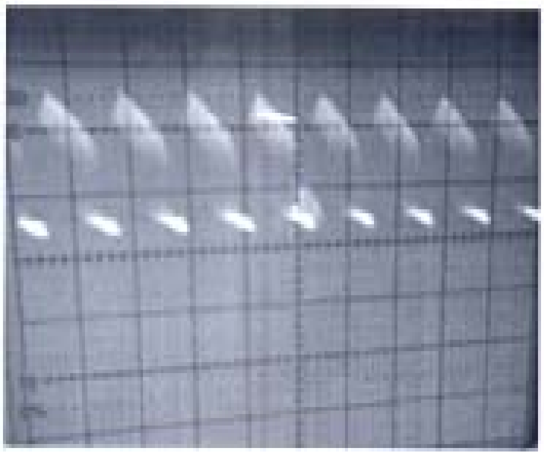

Fig16. Back EMF waveform

PMBLDC motors drives are used in a wide range of commercial and residential applications due to their highest possible efficiencies. The speed control ability of compressors and blowers is able to provide operation at their high efficiency. The physical integration of controller in the motor body itself is able to make them most suitable for low power (0.5hp) blowers and low power (50W) tube axial fans for cooling the electronic equipment.

V. CONCLUSION

The closed loop controlled sensorless PMBLDC drive is modeled and simulated using the blocks of simulink. The simulation results of closed loop system are presented. The closed loop system is able to maintain constant speed by maintaining constant voltage. The simulation results agree with the analytical predictions. The PMBLDCM drive system is successfully fabricated and tested. The hardware system used in the present work has obvious advantage of using single phase supply. This drive can be used for variable speed applications like Electrical vehicles, Robotics etc., The experimental results coincide with the simulation results.

This Paper also presents a comparative study of fuzzy controllers with conventional controller of sensorless speed control of Permanent magnet Brushless DC Motor. The simulation results show that the Hybrid controller is the best performance in all aspects. It can be noticed that the hybrid controller exhibits fast rise time, no overshoot, and lesser settling time with lesser THD, IAE and ISE.

REFERENCE

[1] B.K. Bose, Power Electronics and AC Drives, Prentice Hall, Englewood Cliffs, NJ: 1986.
[2] L. Hao, H. A. Toliyat, "BLDC motor full-speed operation using hybrid sliding mode observer," in *Proc. IEEE-APEC Annu. Meeting*, Miami, FL, Feb. 9-13, 2003, vol. 1, pp. 286-293.
[3].P.Pillay and R. Krishnan, ''Application characteristics of permanent magnet synchronous and brushless dc motors for servo drives,'' *IEEE Trans.on Ind. Appl.*, vol. 27, no. 5, pp. 986--996, Sep./Oct. 1991.
[4].T.J.E. Miller, " Brushless Permanent-Magnet and Reluctance Motor Drives," Oxford, 1989.
[5].R Krishnan, "Electric motor drives- modeling, analysis and control ", Prentice Hall of India Private Limited, 2002.
[6].K.Uzuka, H.Uzuhashi, et al., "Microcomputer Control for Sensorless Brushless Motor ," IEEE Trans. on Industry Application ,Vol.IA-21, May-June, 1985
[7].J.Shao, D.Nolan, and T.Hopkins, "A Novel Direct Back EMF Detection for Sensorless Brushless DC(BLDC) Motor Drives," Applied Power Electronic Conference (APEC 2002), pp33-38.
[8] N.Mastui, " Sensorless PM Brushless DC Motor Drives," IEEE Trans. on Industrial Electronics, Vol. 43, April 1996.
[9].R Krishnan, "Electric motor drives- modeling, analysis and control ", Prentice Hall of India Private Limited, 2002.
[10].Rene Zwahlen,Timothy Chang, " Feed forward speed control of Brushless DC motor with input shaping," The 33rd Annual Conference of the IEEE Industrial Electronics Society (IECON), Nov 5-8,2007.
[11].Mehdi Nasri, Hossein Nezamabadi-Pour, Malihemaghfoori, "A PSO-Based optimization of PID controller for a Linear BLDC Motor" Proc. Of World academy of Science Engg & Tech,Vol.20,April 2007.
[12].Zhiqiang Li & Changliangxia, " Speed Control of BLDC based on CMAC & PID controller" Proc. Of 6th World congress on Intelligent Control & Automation. China, June 21-23,2006.
[13].Yoko Amano, Toshio Tsuji, Atsushi Takahashi, Shigaoonchi, "A Sensorless Drive system for BLDC using a Digital phase-Locked Loop," Wiley periodicals Inc. vol.142 No.1pp1155-1162, 2003.
[14].L.A.Zadeh, " Fuzzy sets," in Information and Control. New York: Academic, 1965, vol.8,pp. 338-353.
[15]."Outline of a new approach to the analysis of complex systems and decision processes," IEEE Trans. Syst.,Man,Cybern.,vol.3, Jan.1973.

[16].C.Lee," Fuzzy logic in control systems, fuzzy logic controller, PartsI and II," IEEE Trans. Syst.,Man,Cybern., vol.20,pp.404-435,1990.
[17].C.Elmas and O.F.Bay, " Modeling and operation of a nonlinear switched reluctance motor drive based on fuzzy logic," in Proc. Eur. Power Electronics Applications Conf., Sevilla, Spain, Sep.18-21, 1995, pp.3.592-3.597.
[18].O.F.Bay, C.Elmas, and M.Alci," Fuzzy Logic based control of a switched reluctance drive," in Int. Aegean Conf. Electrical Machines Power Electronics, Kusadasi, Turkey, June 5-7, 1995, pp.333-337.
[19].O.F.Bay, "Fuzzy control of a field orientation controlled induction motor," J.Polytechnic, vol.2, no.2, pp.1-9, 1999.
[20].C.Elmas and M.A.Akcayol, "Fuzzy logic controller based speed control of brushless DC motor," J.Polytechnic, vol.3, no.3, pp.7-14, 2000.

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