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DIGITAL IMPLEMENTATION OF PFC HALF BRIDGE CONVERTER FED PMBLDC MOTOR USING MICROCONTROLLER

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ABSTRACT

Digital Simulation and implementation of a Power Factor Correction (PFC) half bridge converter based adjustable speed voltage controlled VSI fed PMBLDC motor is presented in this paper. A single-phase AC-DC converter topology based on the half bridge converter is employed for PFC which ensures near unity power factor over wide speed range. The proposed speed control scheme has the concept of DC link voltage control proportional to the desired speed of the PMBLDC motor. The PFC converter based PMBLDCM drive is designed, modeled and simulated using MATLAB-SimuLink environment. This drive ensures high accuracy and robust operation from near zero to high speed. Simulation and experimental results of these systems are presented and the performance measures are compared. The simulation and experimental results with bridgeless boost converter show that there is an improvement in power factor.

Keywords: Permanent Magnet Brushless DC motor, PFC, boost rectifier, conduction losses, Hall position sensors, PI controller.

1. INTRODUCTION

Permanent Magnet Brushless DC motors are preferred for a wide range of applications due to its features like high efficiency, low maintenance requirements and wide speed range. Due to the presence of high energy permanent magnet materials, these motors exhibits high efficiency with compact structure, high torque to current ratio and high power density. A PMBLDCM which is a kind of three-phase synchronous motor with permanent magnets (PMs) on the rotor and trapezoidal back EMF waveform operates on electronic commutation accomplished by solid state switches. It is powered through a three-phase voltage source inverter (VSI) which is fed from single-phase AC supply using a diode bridge rectifier (DBR) followed by smoothening DC link capacitor. Since, the back-emf of the PMBLDCM is proportional to the motor speed and the developed torque is proportional to its phase current a constant torque is maintained by a constant current in the stator winding of the PMBLDCM whereas the speed can be controlled by varying the terminal voltage of the motor. Based on this logic, a speed control scheme is proposed in this paper which uses a reference voltage at DC link proportional to the desired speed of the PMBLDC motor. The control of VSI is only for electronic commutation which is based on the rotor position signals of the PMBLDC motor. The PMBLDCM drive, fed from a single-phase AC mains through a diode bridge rectifier (DBR) followed by a DC link capacitor, suffers from power quality disturbances such as poor power factor, increased total harmonic distortion (THD) of current at input AC mains and its high crest factor (CF). It is mainly due to uncontrolled charging of the DC link capacitor which results in a pulsed current waveform having a peak value higher than the amplitude of the fundamental input current at AC mains. Moreover, the power quality standards for low power equipments such as IEC 61000-3-2 [1] emphasize on low harmonic contents and near unity power factor current to be drawn from AC mains by these motors. Therefore, use of a power factor correction (PFC) topology amongst various available topologies [2-6] is almost inevitable for a PMBLDCM drive.

A new generation of microcontrollers and advanced electronics has overcome the challenge of implementing required control functions, making the BLDC motor more practical for a wide range of uses [7-9].

2. POWER FACTOR CORRECTION CONVERTERS

Research on PFC circuits for high power applications has increased. PFC using half bridge converters is the recent trend. In these rectifiers only half of the output voltage is applied across the switches thus reducing the stress on them to a greater extent. For the proposed voltage controlled drive, a half-bridge DC-DC converter is selected because of its high power handling capacity. Moreover, it has less switching losses comparable to the single switch converters as only one switch is in operation at any instant of time. It can be operated as a single-stage power factor correction (PFC) converter when connected between the VSI and the diode bridge rectifier fed from single-phase AC mains, besides controlling the voltage at DC link for the desired speed. The conventional active PFC converter has to employ uncontrolled rectifier and costly boost inductor, and these power components result in power loss, low efficiency and high cost. Nevertheless, the bridgeless PFC is characteristic of small number of power switches, making room for low power loss [9]. Additionally, in the conventional active PFC the power switches are in on and off state in a whole mains period, enduring high voltage and current stresses, producing a lot of switching loss and conduction loss and limiting the efficiency. Voltage or current converters results in distorted voltages and current waveforms produce additional power losses, and high frequency noise that can affect not only the power load but also the associated controllers. All these unwanted

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operating characteristics associated with PWM converters could be overcome with improved bridgeless PFC boost converters.

A detailed modeling, design and performance evaluation of the proposed drive are presented for a PMBLDC motor of 500W, 3500 rpm rating.

3. MATHEMATICAL MODEL OF THE PMBLDC MOTOR

Modeling and simulation play an important role in the design of power electronics system. The classic design approach begins with an overall performance investigation of the system, under various circumstances through mathematical modeling [10].

The voltage equations of the BLDC motor are as follows:

$$V_a = R_a i_a + \frac{d}{dt}(L_{aa} i_a + L_{ab} i_b + L_{ac} i_c) + \frac{d\lambda_{ar}(\theta)}{dt}$$

$$V_b = R_b i_b + \frac{d}{dt}(L_{ba} i_a + L_{bb} i_b + L_{bc} i_c) + \frac{d\lambda_{br}(\theta)}{dt}$$

$$V_c = R_c i_c + \frac{d}{dt}(L_{ca} i_a + L_{cb} i_b + L_{cc} i_c) + \frac{d\lambda_{cr}(\theta)}{dt}$$

In balanced system the voltage equation becomes,

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L_a & L_{ba} & L_{ca} \\ L_{ba} & L_b & {}_{cb}L \\ L_{ca} & L_{cb} & L_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \text{------}(1)$$

Considering a PMBLDC motor with symmetric three-phase stator windings and trapezoidal air-gap flux distribution the circuit equations of the three windings in phase variables, when it is driven by an inverter, is expressed as:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \text{———}(2)$$

Where

V_a, V_b, V_c are stator phase voltages
i_a, i_b, i_c are stator currents
R and L are stator winding resistance and inductance
e_a, e_b, e_c are back emfs
The typical waveforms are shown in Figure-1.

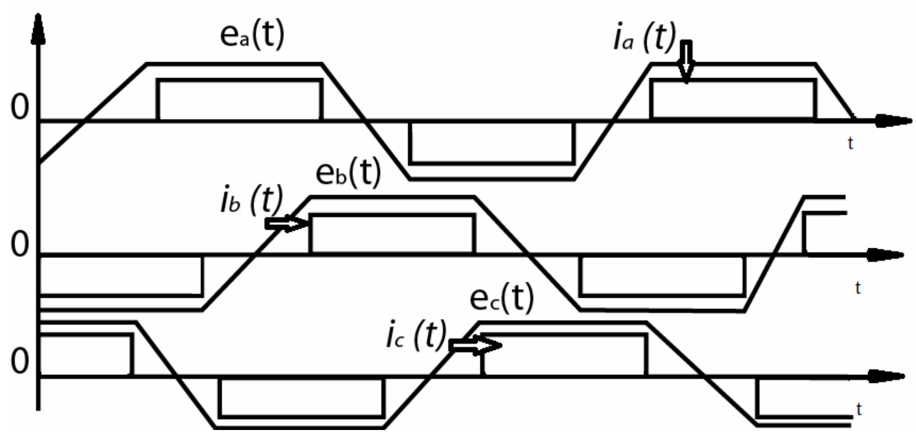

Figure-1. Typical waveforms of the back emfs and the corresponding stator currents of a PMBLDC motor.

4. SPEED CONTROL OF BLDC MOTOR

Block diagram of drive system is shown in Figure-2. In servo applications position feedback is used in the position feedback loop. The rotor position is measured using Hall sensors. By varying the voltage across the motor, we can control the speed of the motor. When using PWM outputs to control the six switches of the three-phase bridge, variation of the motor voltage can be obtained by varying the duty cycle of the PWM signal.

Various sensorless methods for BLDC motors are analyzed in [11-16]. [11] Proposes a speed control of brushless drive employing PWM technique using digital signal processor. A PSO based optimization of PID controller for a linear BLDC motor is given in [12], Direct torque control and indirect flux control of BLDC motor with non sinusoidal back emf method controls the torque directly and stator flux amplitude indirectly using d-axis current to achieve a low-frequency torque ripple-free control with maximum efficiency[13]. [14] Proposes a novel architecture using a FPGA-based system. Fixed gain PI speed controller has the limitations of being suitable for a limited operating range around the operating point and having overshoot. A new module structure of PLL speed controller is proposed by [15].A fixed structure controller (PI or PID) using time constrained output feedback is given in [16]. The above literatures does not deal with PFC in closed loop controlled PMBLDC. This work proposes PFC at the input of PMBLDC drive.

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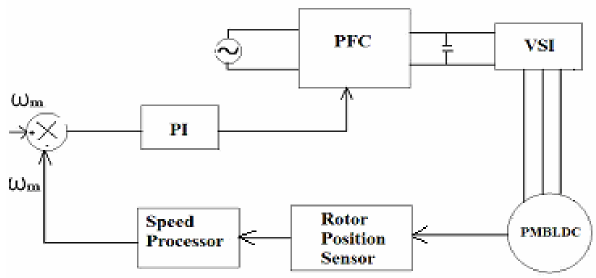

Figure-2. Block diagram of drive system.

5. PMBLDC MOTOR FED FROM A VOLTAGE SOURCE INVERTER WITH PFC FULL BRIDGE CONVERTER

Schematic diagram of a three level voltage source inverter fed PMBLDC motor with PFC full bridge converter is shown in Figure-3. This is a closed loop control circuit using 3 Hall Sensors. MOSFETs are used as switching devices here. To control the speed of the motor the output frequency of the inverter is varied. The MATLAB simulation is carried out and the results are presented.

For very slow, medium, fast and accurate speed response, quick recovery of the set speed is important keeping insensitiveness to the parameter variations. In order to achieve high performance, many conventional control schemes are employed. At present, the conventional PI controller handles these control issues. Moreover conventional PI controller is very sensitive to step change of command speed, parameter variation and load disturbances.

With high frequency switching, the PMBLDC motor rotates at a higher speed. But without the strong magnetic field at stator, the rotor fails to catch up the switching frequency because of weak pull force. Speed of BLDC motor is indirectly determined by the applied voltage magnitude. Current in the winding is increased by increasing the voltage. This produces stronger magnetic pull to align the rotor's magnetic field faster with the induced stator magnetic field. The rotational speed or the alignment is proportional to the voltage applied to the terminals. The torque pulsation is very high as the step size is reduced.

When using PWM outputs to control the six switches of the three-phase bridge, variation of the motor voltage can be achieved easily by changing the duty cycle of the PWM signal. In this method the speed is controlled in a closed loop by measuring the actual speed of the motor. The error in the set speed and actual speed is calculated. A Proportional plus Integral (P.I) controller is used to amplify the speed error and dynamically adjust the PWM duty cycle.

6. SIMULATION RESULTS

The technical specifications of the drive system are as follows C = 2200 microfarad. T_{ON} = 5.88 μsecs., T_{OFF} = 5.88μsecs., T = 11.76 μsecs. Stator Resistance is 2.875 ohms, Stator Inductance is 8.5e-3mH and inertia of the motor is 0.8e-3J. With the help of the designed circuit parameters, the MATLAB simulation is done and results are presented here. Speed is set at 1800 rpm and the load torque is changed at time t = 0.6 sec. The speed response is obtained. The waveforms of input voltage and current are shown in Figure-4. It can be seen from this figure that the power factor is 0.98. The waveforms of the phase voltage and currents are shown in Figures 5 and 6, respectively. They are quasi sinusoidal in shape and are displaced by 120°. The waveforms of back EMF are shown in Figure-7.

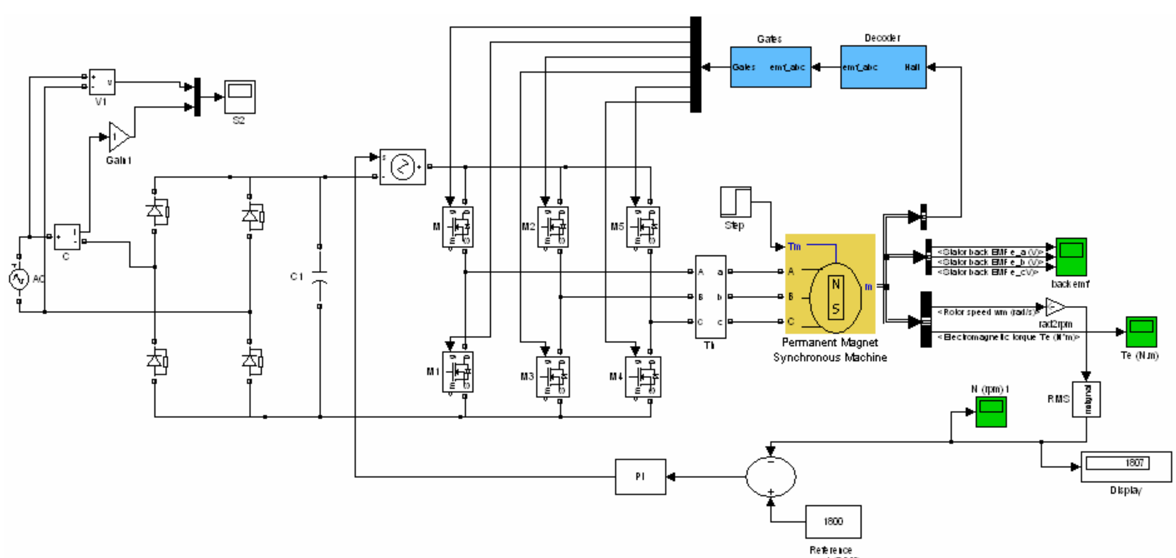

Figure-3. Closed loop model of PMBLDC motor.

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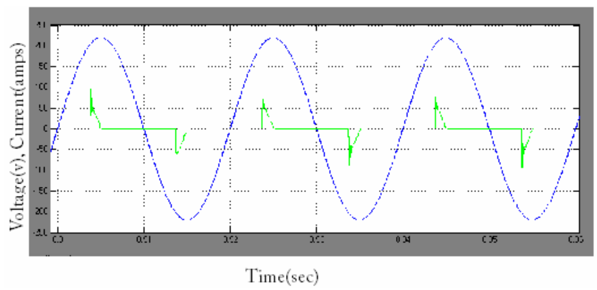

Figure-4. Input voltage and current (PF=0.98)

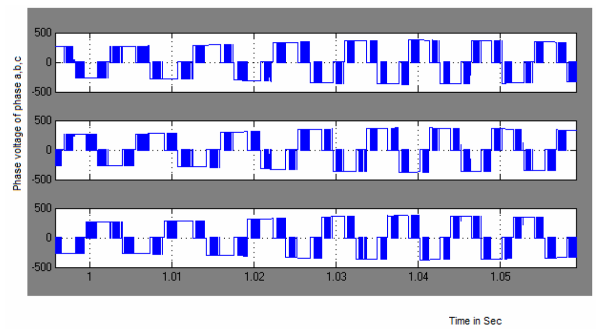

Figure-5. Phase voltage supplied to the stator windings.

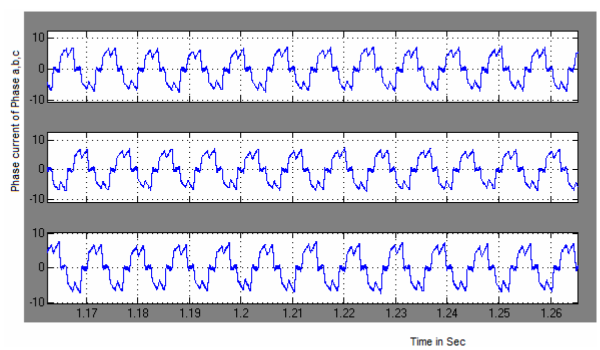

Figure-6. Three phase inverter stator current.

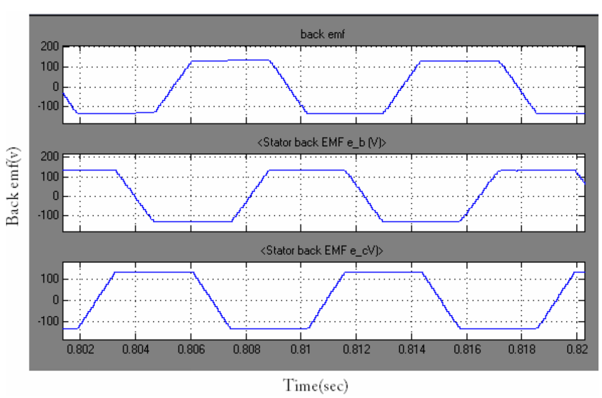

Figure-7. Back emf

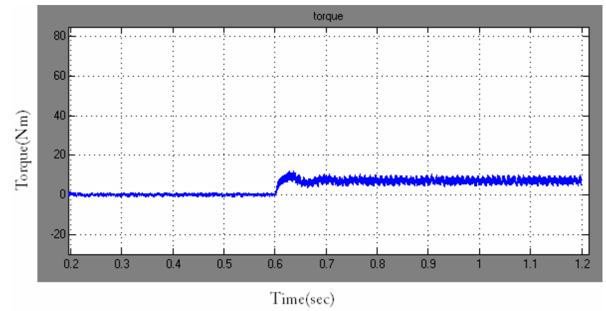

Figure-8. Load Torque disturbance applied at t = 0.6 sec

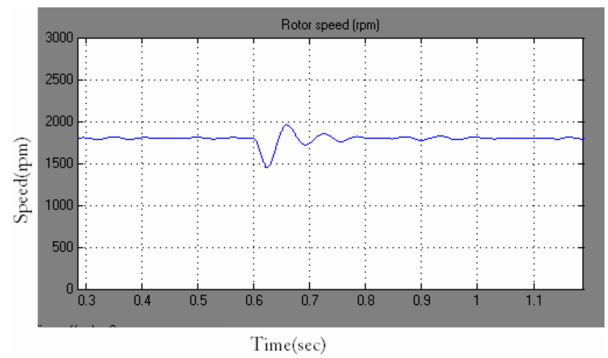

Figure-9. Rotor speed in rpm.

Figure-8 show the step change in load torque at time t = 0.6 sec for a set speed of 1800 rpm. From Figure-9 it can be seen that the closed loop system brings the speed to the normal value.

7. CLOSED LOOP CONTROLLED PMBLDC MOTOR FED FROM A VOLTAGE SOURCE INVERTER

Simulink model of closed loop controlled PMBLDC motor with PFC half bridge converter and a PI controller is shown in Figure-10. A boost converter is used at the input to improve the power factor. AC input voltage and current waveforms are shown in Figure-11. It can be seen that the power factor is improved by using half bridge PFC converter. The waveforms of back emf are shown in Figure-12.

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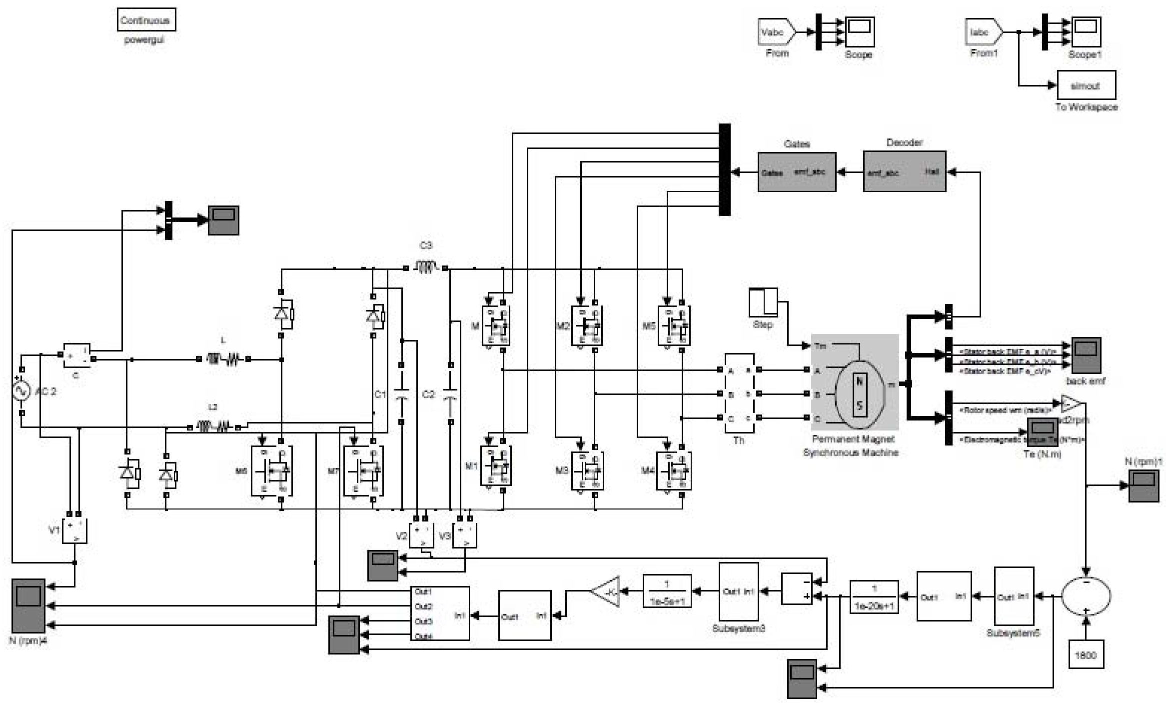

Figure-10. Closed loop speed control of PMBLDC motor with PFC half bridge converter.

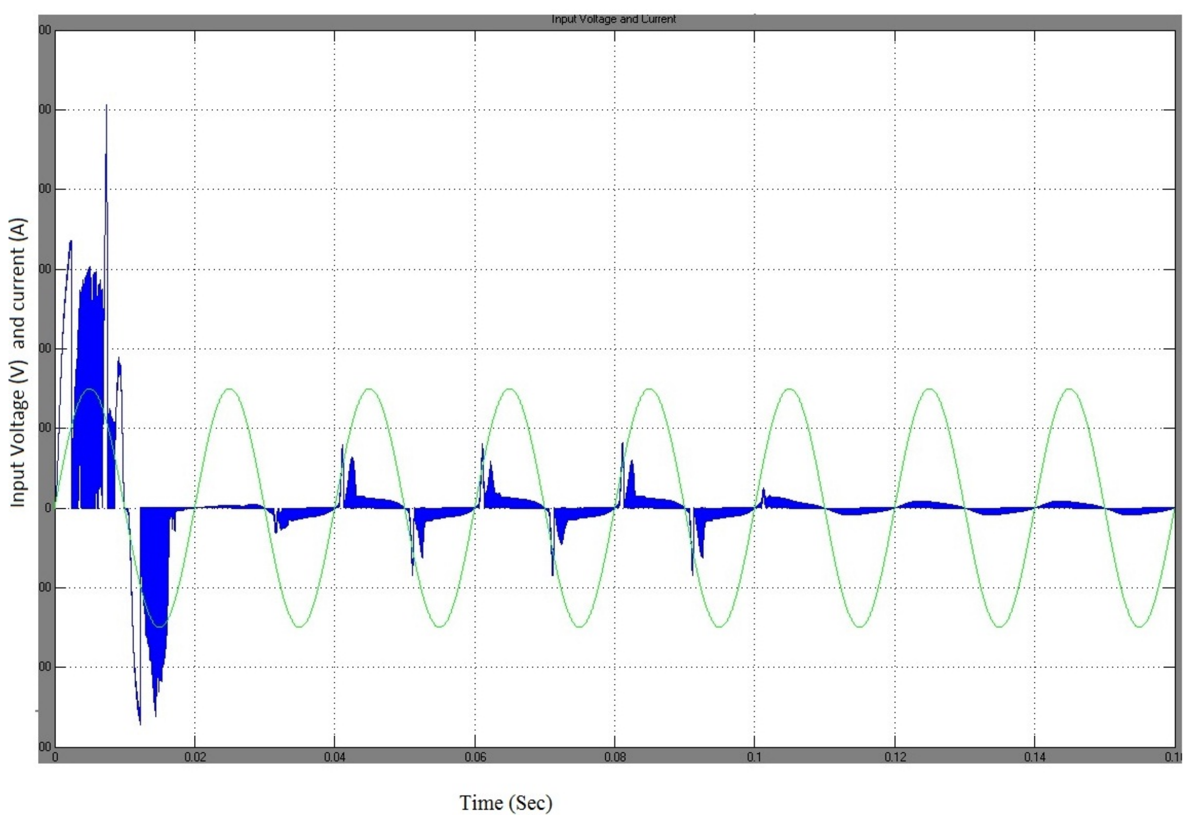

Figure-11. Input voltage and current.

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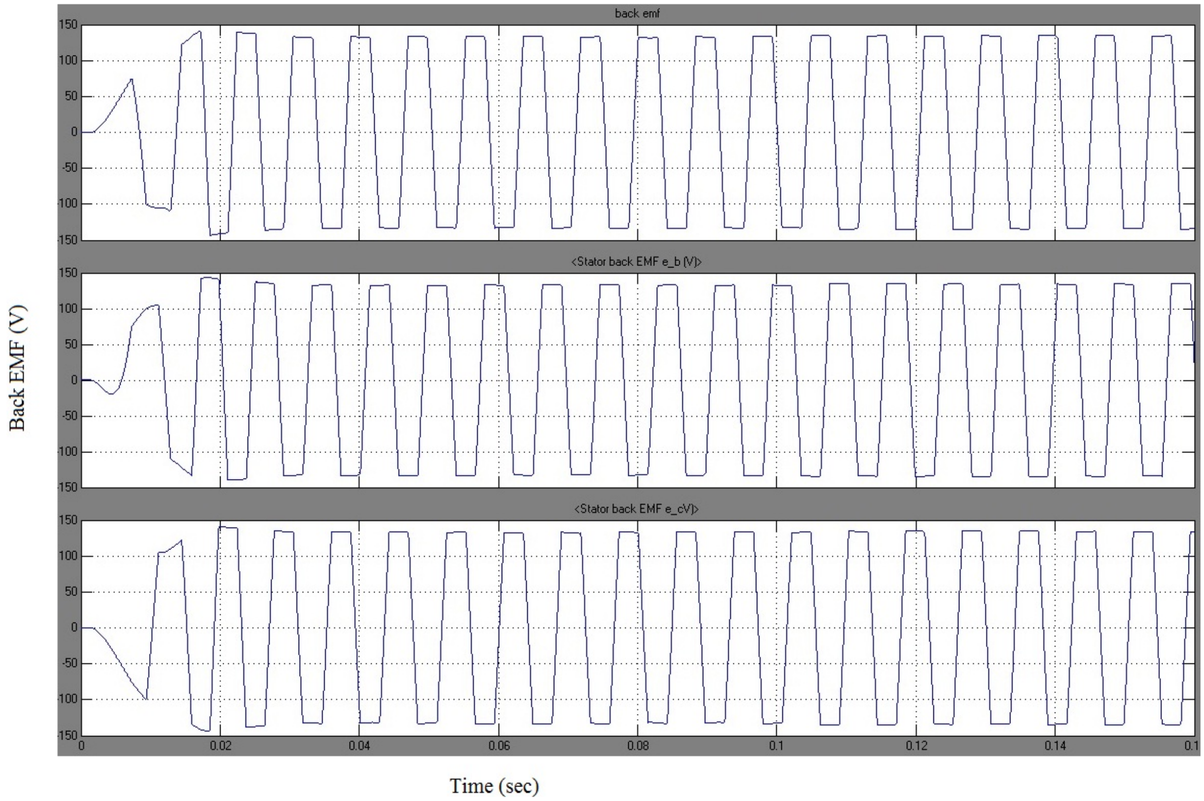

Figure-12. Back EMF.

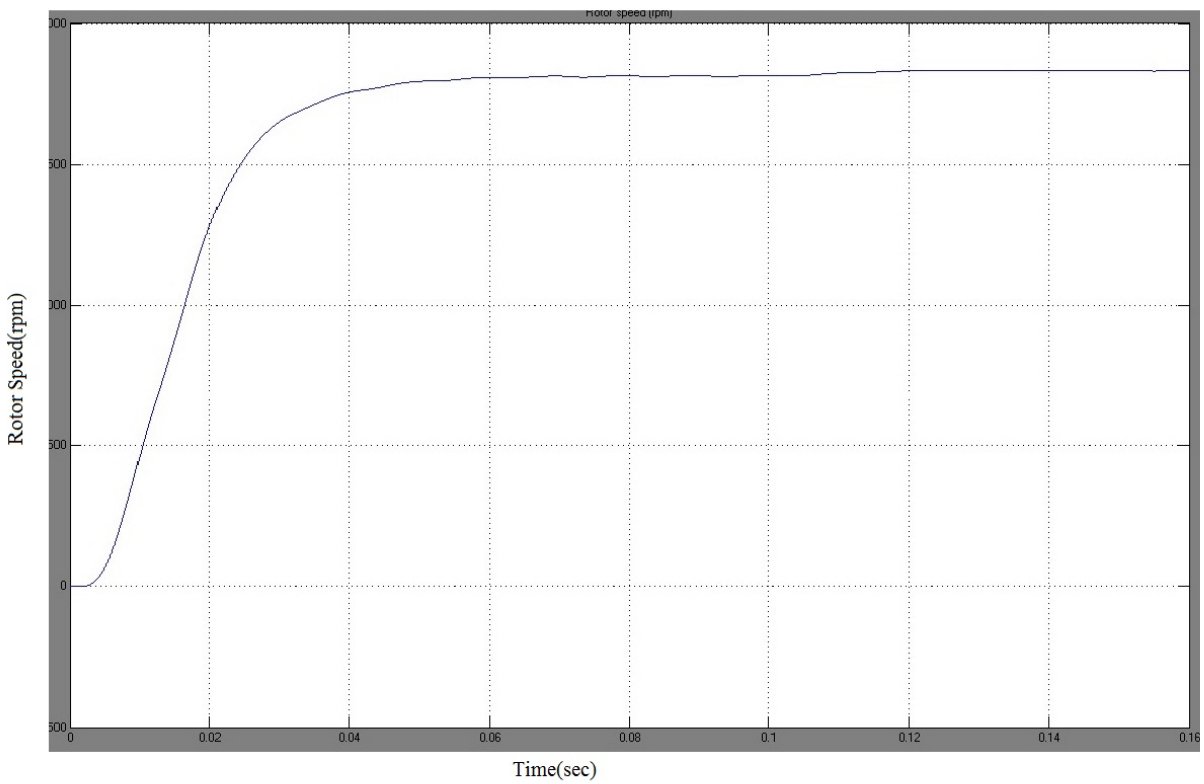

Figure-13. Rotor speed in rpm.

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From Figure-13, it can be seen that the closed loop system brings the speed to the normal value and is maintained constant with the disturbance in the load torque.

8. EXPERIMENTAL RESULTS

After the simulation studies, a closed loop controlled bridgeless boost converter fed BLDC motor with capacitor filter is fabricated and tested. The top view of the hardware is depicted in Figure-14(a). The hardware consists of power circuit, control circuit and PMBLDC motor. The experimental setup is shown in Figure-14(b). Gate pulses are shown in Figure-14(c). Terminal voltage of motor is shown in Figures-14(d). Input voltage and current waveforms are shown in Figure-14(e). It can be seen that the power factor is improved as found in the simulation results. Harmonic Spectrum of source voltage is shown in Figure-14(f) and Harmonic Spectrum of source current is shown in Figure-14(g).

The technical specifications of the drive system are as follows C_{in} = 2200 microfarad. Input voltage is 48V, Bridgeless boost converter output is 58V. Diode IN4007, Microcontroller AT89C2051, MOSFET IRF840, Driver IR2110, Voltage (0-500V) and Current is 8A.

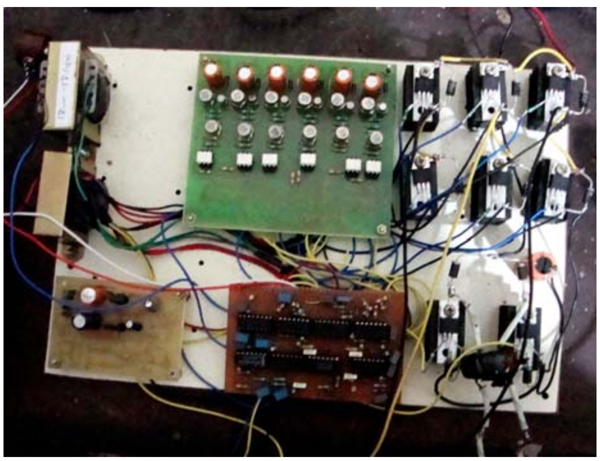

Figure-14(a). Top View of the hardware.

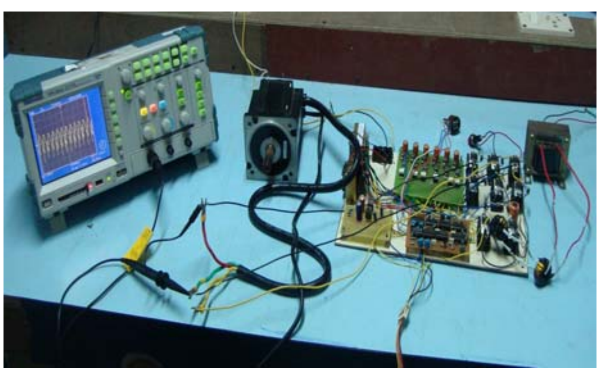

Figure-14(b). Experimental setup.

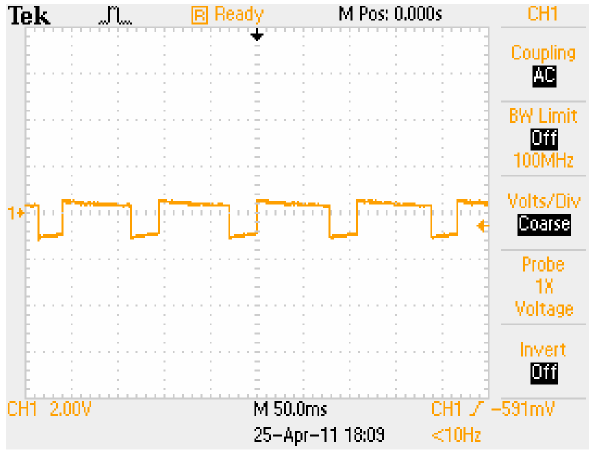

Figure-14(c). Gate pulse.

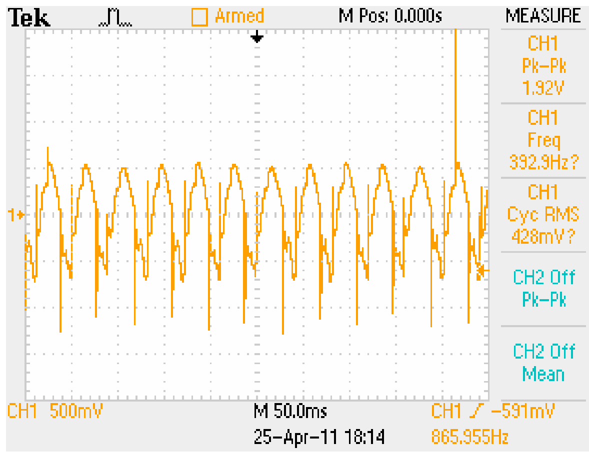

Figure-14(d-i). Terminal voltages of motor.

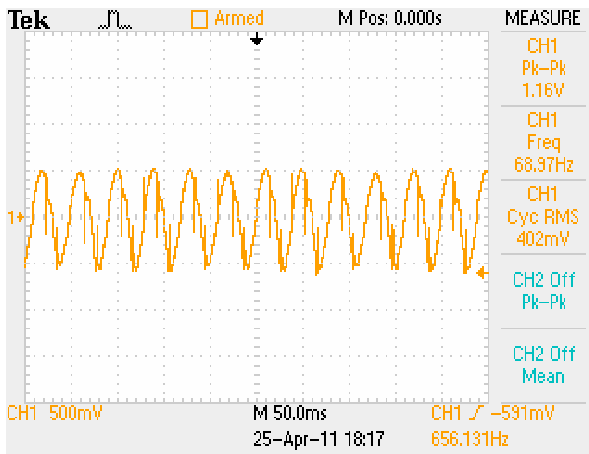

Figure-14(d-ii). Terminal voltages of motor.

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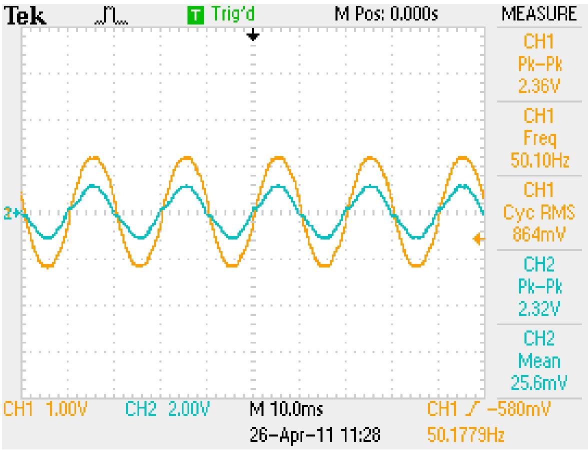

Figure-14(e). Source voltage and current.

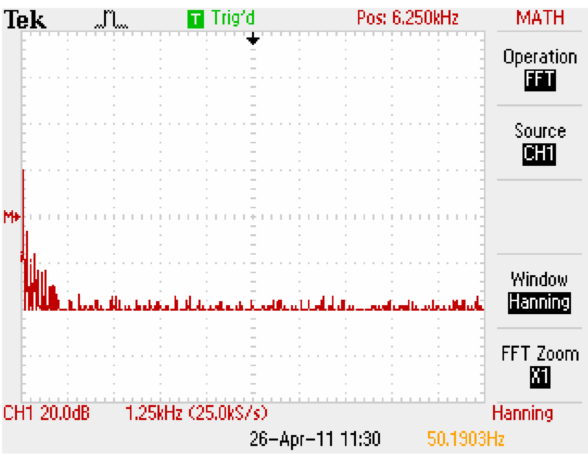

Figure-14(f). Harmonic spectrum of motor voltage.

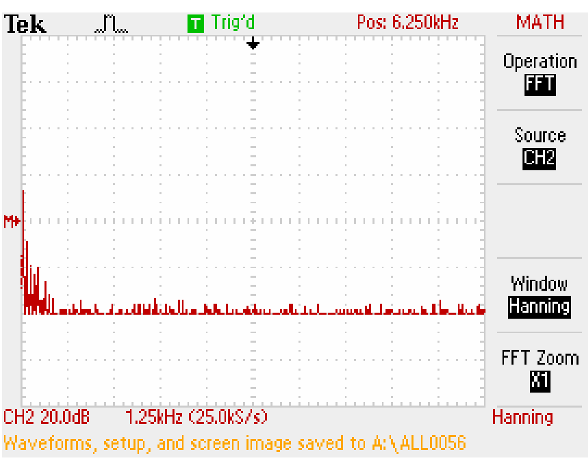

Figure-14(g). Harmonic spectrum of motor current.

8. CONCLUSIONS

Closed loop controlled VSI fed PMBLDC motor with PFC full bridge and half bridge converters are modeled and simulated. Feedback signals from the PMBLDC motor representing speed and position are utilized to get the driving signals for the inverter switches through a PI controller. The power factor is corrected by using PFC converter. PFC converter fed PMBLDC drive is a viable alternative since it has improved power factor. The hardware is fabricated and tested. The experimental results are in line with the simulation results.

REFERENCES

[1] 2000. Limits for Harmonic Current Emissions (Equipment input current _16 A per phase), International Standard IEC 61000-3-2.

[2] Singh B. N. Singh A. Chandra K. Al-Haddad A. Pandey and D. P. Kothari. 2003. A review of single-phase improved power quality AC-DC converters. IEEE Trans. Industrial Electron. 50(5): 962-981, Oct.

[3] J.Y. Lee, G.W. Moon and M.J. Youn. 1999. Design of a power-factor correction converter based on half-bridge topology. IEEE Trans. Ind. Electron. 46(4): 710-723, Aug.

[4] A. Fernandez, J. Sebastian, M.M. Hernando and P. Villegas. 2002. Small signal modelling of a half bridge converter with an active input current shaper. In Proc. IEEE PESC. 1: 159-164.

[5] S.K. Han, H.K. Yoon, G.W. Moon, M.J. Youn, Y.H. Kim and K.H. Lee. 2005. A new active clamping zero-voltage switching PWM current-fed half-bridge converter. IEEE Trans. Power Electron. 20(6): 1271-1279, Nov.

[6] Woo-Young Choi, Jung-Min Kon, Eung-Ho Kim, Jong-Jae Lee and Bong-Hwan Kwon. 2007. Bridgeless Boost Rectifier with Low Conduction Losses and Reduced Diode Reverse-Recovery Problems. IEEE Transactions on Industrial Electronics. 54(2): 769-780, April.

[7] J. C. Salmon. Circuit topologies for PWM boost rectifiers operated from 1-phase and 3-phase AC supplies and using either single or split dc rail voltage outputs. In Proc. IEEE Applied Power Electronics Conf.

[8] Laszlo Huber, Yungtaek Jang and Milan M. Jovanovic. 2008. Performance Evaluation of bridgeless PFC Boost Rectifiers. IEEE Trans, Power Electronics. 23(3), May.

[9] B. Lu, R. Brown and M. Soldano. 1995. Bridgeless PFC implementation using one cycle control

technique. IEEE Applied Power Electronics (APEC) Conf. Proc. pp. 812-817, Mar. 2005 Mar. pp. 473-479.

[10] R. Krishnan. 2001. Electric Motor Drives Modeling, Analysis, and Control, Prentice-Hall International Inc., New Jersey, USA.

[11] G. Madhusudhanrao, B.V. SankerRam, B. Sampath Kumar and K. Vijay Kumar. 2010. Speed Control of BLDC Motor using DSP. International Journal of Engineering Science and Technology. 2(3).

[12] Yingfa Wang, Changliang Xia, Zhiqiang Li, Peng Song.2010. Sensorless Control for BLDC motor using support vector machine based on PSO. IJCIIS .Vol. 1 No. 7

[13] Salih Baris Ozturk, William C. Alexander and Hamid A. Toliyat. 2010. Direct Torque Control of four-switch brushless DC motor with non-sinusoidal back emf. IEEE transactions on power electronics. 25(2), Feb.

[14] Kuang-Yao Cheng. Novel Architecture of a mixed-mode sensor less control IC for BLDC motors with wide speed ranges. 978-1-422-2812-0/09 ©2009 IEEE.

[15] Ting-Yu-Chang, Ching-Tsai-Pan and Emily Fang. A novel high performance variable speed PMBLDC motor drive system. 978-1-4244-4813-5/10 ©2010 IEEE.

[16] Shinn-Ming Sue and Kun-Lin Wu. A voltage controlled brushless DC motor over extended speed range. 978-i-4244-1709-3/08 ©2008 IEEE.