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A Bridgeless Resonant Pseudo boost Converter Fed BLDC Motor Drive

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ABSTRACT: In this paper A Bridgeless Resonant Pseudo boost PFC rectifier Fed Brushless DC motor Drive is presented. It is suitable for small capacity brushless dc motors. Here absence of input diode bridge rectifier is an advantage over other topologies used for BLDC motor drives. The control circuitry is simple since same pulses can be given to both switches. The number of components in the converter circuit is less. In the converter part resonant mode of operation gives zero current switching. Since this topology operates in discontinuous conduction mode it is suitable only for low power applications. BLDC Motors found applications in air conditioners etc. Here the BLDC motor speed control is achieved by DC link control. So the stress on the switches used in electronic commutation part of BLDC motor gets reduced. As the output voltage is free from lower order harmonics, BLDC motor torque is free from ripples. The input side power factor of this converter is also good compared with other topologies.

KEYWORDS: Pseudo boost converter, resonant switching, BLDC motor drive, Electronic commutation

I.INTRODUCTION

The use of permanent magnet brushless dc motor (PMBLDCM) in low power drives of home appliances like fans, water pumps, blowers, mixers etc. is increasing day by day. The increasing acceptability of PMBLDC motor is due to its high efficiency, wide speed range, low maintenance, lower electromagnetic interference(EMI) problems…etc[7].The PMBLDC motor also found to have wide applications in industrial tools, heating ventilation and air conditioning systems, low power medical equipment drives, etc. One of the applications of PMBLDC motor is the compressors in air conditioners. Higher efficiency can be achieved if the compressor's working speed is controllable as per the room temperature requirement with constant shaft torque. For this PMBLDC motor drive is preferred over the single phase induction motor –based air conditioning system. In single phase induction motor drive smooth speed control can't be achieved. A permanent magnet brushless DC motor has rotor with permanent magnets. Its stator consists of three phase winding and is excited from 3phase voltages of 120 degree displacement .These voltages can be obtained from a voltage source inverter and can be controlled by some electronic commutation module[2].Thus a constant current in stator windings of a PMBLDC motor with variable voltage across the terminals can maintain a constant torque under variable speed operations.

In household appliances and air conditioners, dc supply is required to give to the VSI which is to be derived from the available single phase ac mains. For this different converter topologies were used and discussed in [2][3][4][7]..etc. In [2] a bridgeless buck-boost converter was used for driving a BLDC motor. There the two controlled switches, works in different half cycles. During each switching interval the inductor charges and discharges the output dc link capacitor. Buck converter, boost converter cuk converter etc are used for driving BLDC motor. In [3] a SEPIC converter is explained which can also be used for BLDC motor drive. A diode bridge rectifier fed BLDC drive has lower efficiency. In this paper a bridgeless pseudo boost converter fed PMBLDC motor is introduced. This requires lesser no. of components. Since the same control signal can be fed to both switches, its control circuitry is simple. Principle of operation, design equations, MATLAB simulation block diagram and waveforms were presented in this paper.

II.PRINCIPLE OF OPERATION

The pseudo boost converter in fig.1 is designed to work in discontinuous conduction mode during the switch turn on interval and in resonant mode during the switch turn off interval i.e, during the switch turn on time inductor charges to a peak value. When switch turns off, the inductor forms a resonant tank circuit with capacitor C_1. The pseudo boost

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converter for positive and negative polarities was discussed in [1]. This converter can operate in both steady state and in dynamic conditions satisfactorily. So it is suitable for a PMBLDC motor drive. The four different stages of a single switching interval of the converter can be explained using the fig2.

Stage 1: This stage starts when the controllable switch Q_1 is turned on. Body diode of Q_1 is reverse biased while the body diode of Q_2 is forward biased. Both the diodes D_1 and D_2 will be reverse biased due to the voltages across C_1 and C_0. In this stage inductor L_1 charges through switches Q_1 and Q_2. At this stage capacitor C_0 will provide energy to BLDC motor.Fig.2(a)

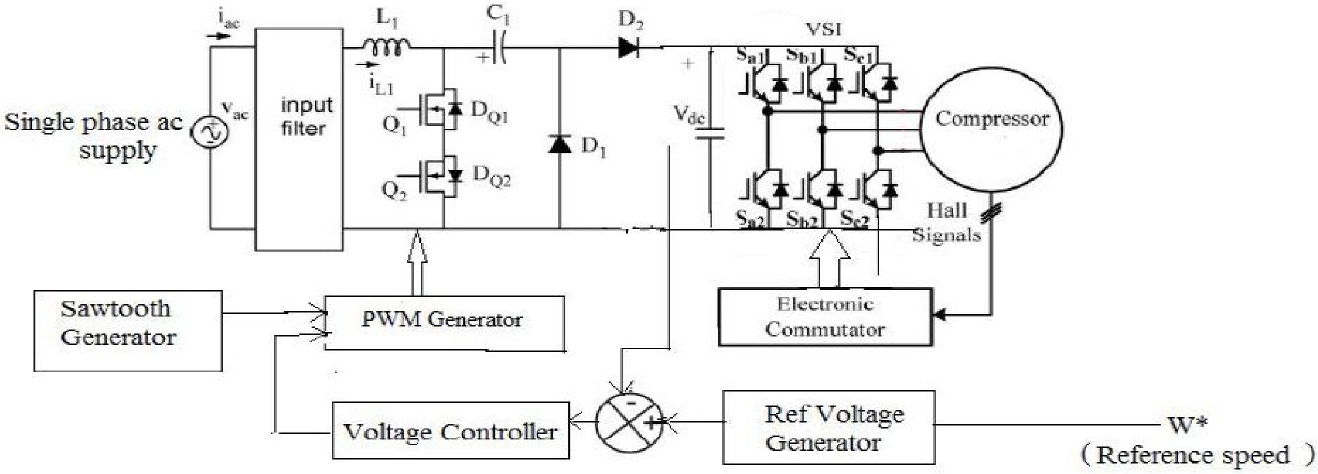

Fig. 1 Proposed BLDCM Drive using Pseudo boost Converter

Stage 2: This stage begins when the switch Q_1 is turned off. Now the diode D_2 is forward biased and the inductor reverses its voltage polarity. Inductor energy is now gradually transferred to capacitor. When capacitor voltage V_{C1} becomes equals to the supply voltage, Diode D_1 is reverse biased. During this stage output dc link capacitor C_0 is charged by the supply as well as the capacitor (C_1) voltage. Fig.2(b)

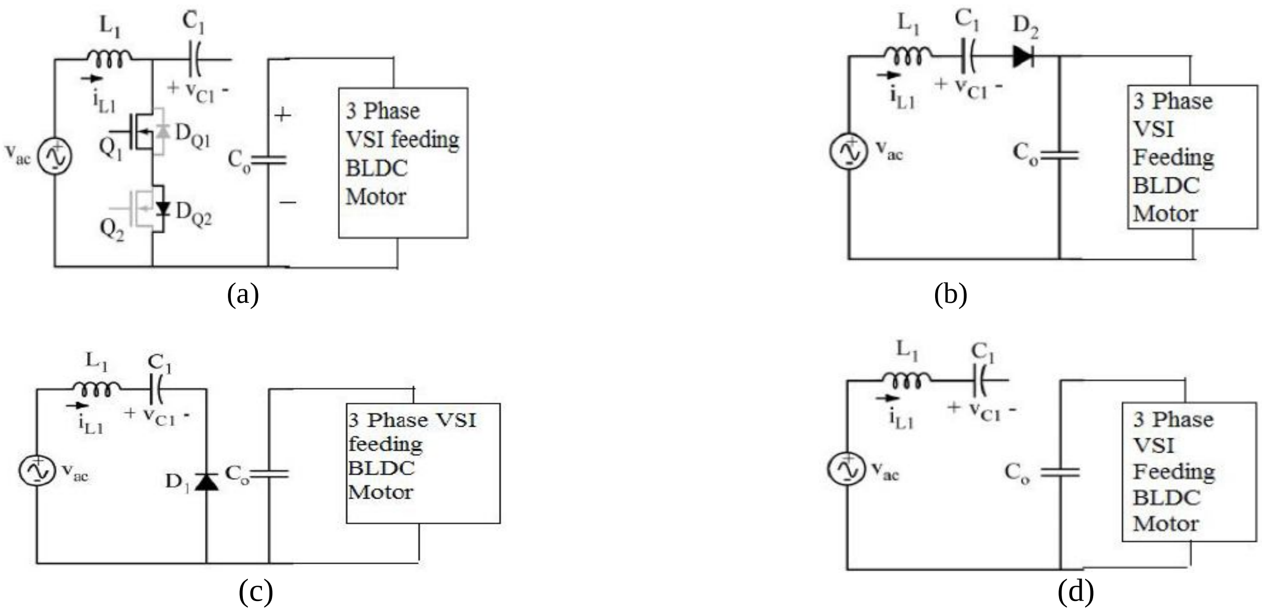

Fig. 2 Topological stages of the BLDCM drive

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Stage 3: In this stage diode D_1 is forward biased due to the negative polarity at the right plate of capacitor C_1, and now inductor current reverses its direction. Here diode D_1 is turned on and off at zero inductor current conditions. If assuming a constant input ac voltage during T_s, the capacitor C_1 will discharge the voltage V_F to voltage V_x.Fig.2(c)
Stage 4: In this stage all switches are in off state. Inductor current will be zero and constant capacitor voltage. DC link capacitor will provide supply to BLDC motor. The duration of this stage must be greater than or equal to zero.Fig.2 (d).

The relevant waveforms for both positive and negative half cycles are shown in fig.3.Inductor charging current in the time interval d1Ts, Diode current (i_{D2}) during the interval d2Ts, Diode current (i_{D1}) during the interval d3Ts and freewheeling interval d4Ts were shown in Fig.3.

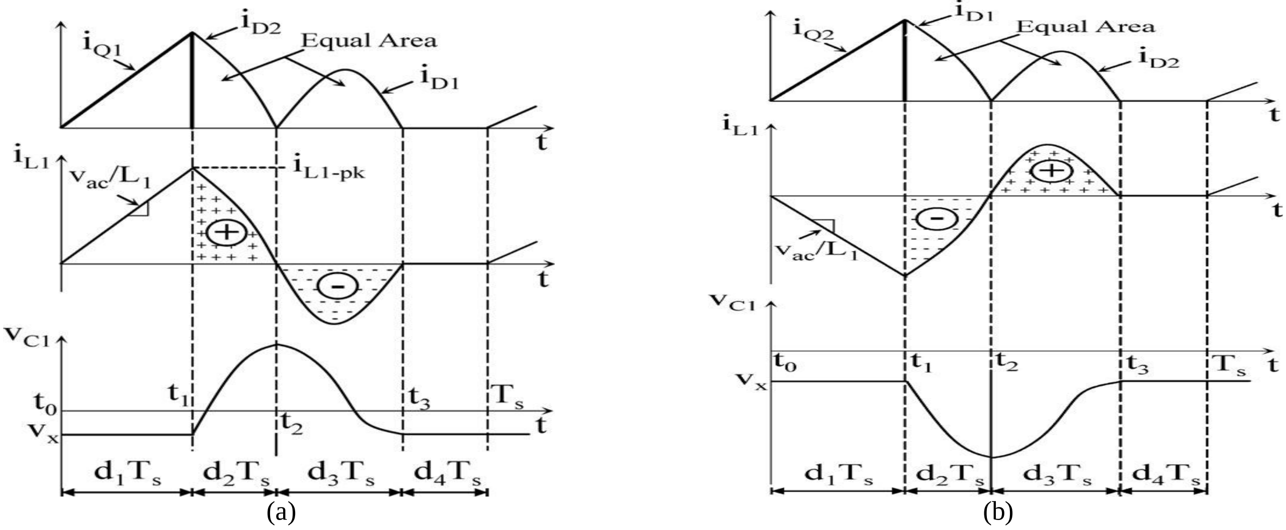

Fig. 3 Topological theoretical waveforms for the converter of BLDC Motor Drive (a) For Positive Half Cycle (b) For Negative half cycle

III.CONTROL OF BLDC MOTOR: ELECTRONIC COMMUTATION

A PMBLDC motor is fed with a voltage source inverter [VSI]. The six switches in VSI are controlled by an electronic commutation module. This module receives Hall Effect position sensor output signals from the BLDC motor. The received signals being processed and angle of rotation is sensed. Corresponding switches in VSI will be turned on to get 3 phase voltages of 120 degree displacement. Switching states for electronic commutation is shown in Table I.[2]

Θ(deg)	Hall Signals			Switching states					
	Ha	Hb	Hc	S1	S2	S3	S4	S5	S6
NA	0	0	0	0	0	0	0	0	0
0-60	0	0	1	1	0	0	0	0	1
60-120	0	1	0	0	1	1	0	0	0
120-180	0	1	1	0	0	1	0	0	1
180-240	1	0	0	0	0	0	1	1	0
240-300	1	0	1	1	0	0	1	0	0
300-360	1	1	0	0	1	0	0	1	0
NA	1	1	1	0	0	0	0	0	0

Table I Switching states of VSI fed BLDCM using Hall Effect sensor signals

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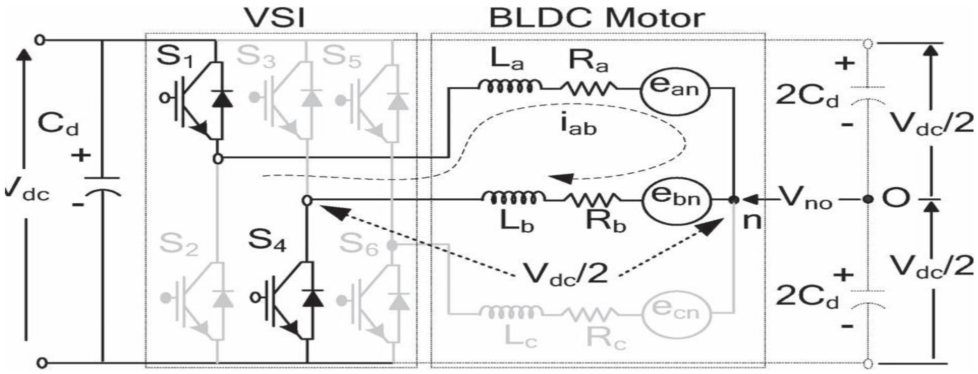

Fig. 4 Operation of a VSI fed BLDC motor when switches S1 and S4 conducting [2]

IV.DESIGN EQUATION

Design of pseudo boost converter is done by assuming $V_{acrms} = 220V_{rms}$, $V_o = 320\ V$, $P_o = 130\ W$, switching frequency $f_s = 50kHz$.[1]

1) Voltage Conversion Ratio (m)

$$M = \frac{V_o}{V_m} = \frac{V_o}{\sqrt{2}V_{acrms}}$$

To ensure discontinuous conduction mode of operation F (Ratio of switching frequency (f_s) to resonant frequency (f_r)) is taken as 0.8 [1]

2) $L_{cri} \leq \frac{R_L T_S}{4}\left(\frac{F}{\pi}\right)^2$ $L_1 \leq L_{cri}$

3) Resonant Capacitance (C_1)

$$C_1 = \frac{1}{L_1(2\pi f_r)^2}$$

4) Duty ratio of switch $Q_1(d_1)$

$$d_1 = M\sqrt{2k} \quad \text{Where } k = \frac{2L_1}{R_L T_S}$$

Peak current through switch $Q_1(I_{PK})$

$$I_{pk} = \frac{w_r d_1 T_S}{M}$$

5) $w_r d_1 T_S + \sin^{-1}\left(\frac{4i_{pk}}{4+i_{pk}^2}\right) + \pi \leq \left(\frac{2\pi}{F}\right)$

V.RESULT AND DISCUSSION

The BLDC motor speed is controlled by dc link voltage control. The dc link voltage is controlled by controlling the duty ratio of switch Q_1. The reference speed is converted to a reference voltage and it is compared with the actual dc link voltage. The corresponding PWM switching signals will be generated.

1) **Steady state response under a fixed reference speed:** The proposed drive gives a dc link voltage with minimum fluctuations and correspondingly the speed of the motor will stay on the reference speed itself. This can be viewed in fig.5. Here the reference speed is 7000 rpm and the motor achieves this speed with minimum fluctuations. Similarly the stator current i_a and back emf e_a of phase "a" follows a trapezoidal shape.

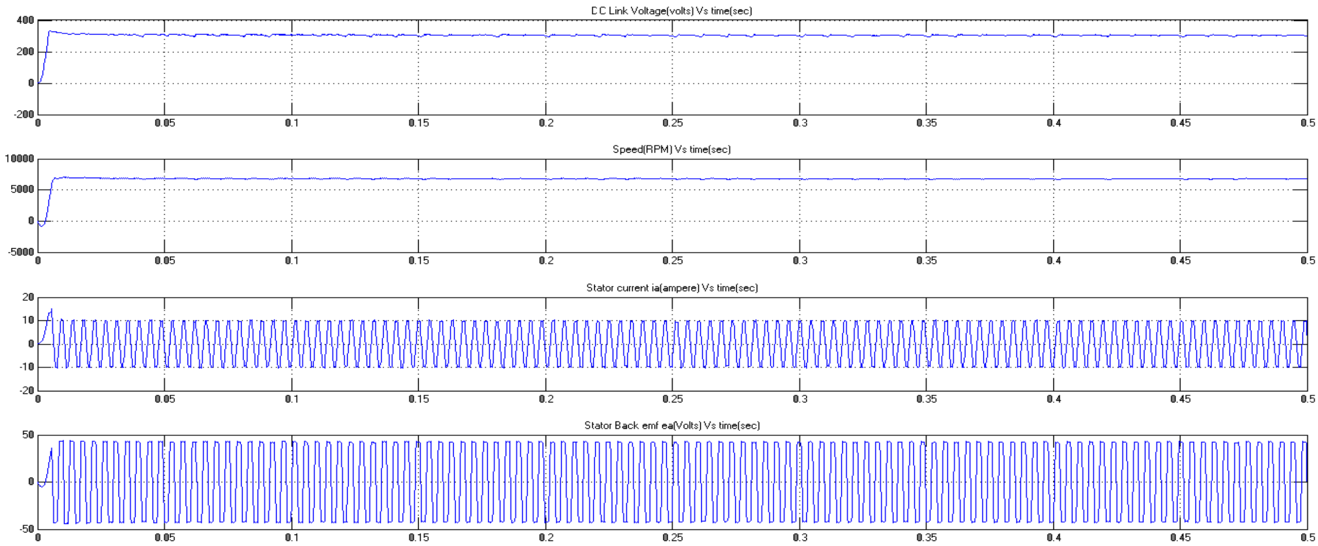

Fig. 5 Steady state response under a fixed reference speed

2) **Transient response at starting:** At the time of starting, drive tries to attain reference speed from the input supply voltage and is achieved within 5msec i.e, within ¼ th cycle of supply voltage, Transient response of the drive at starting can also be analyzed from fig.5.

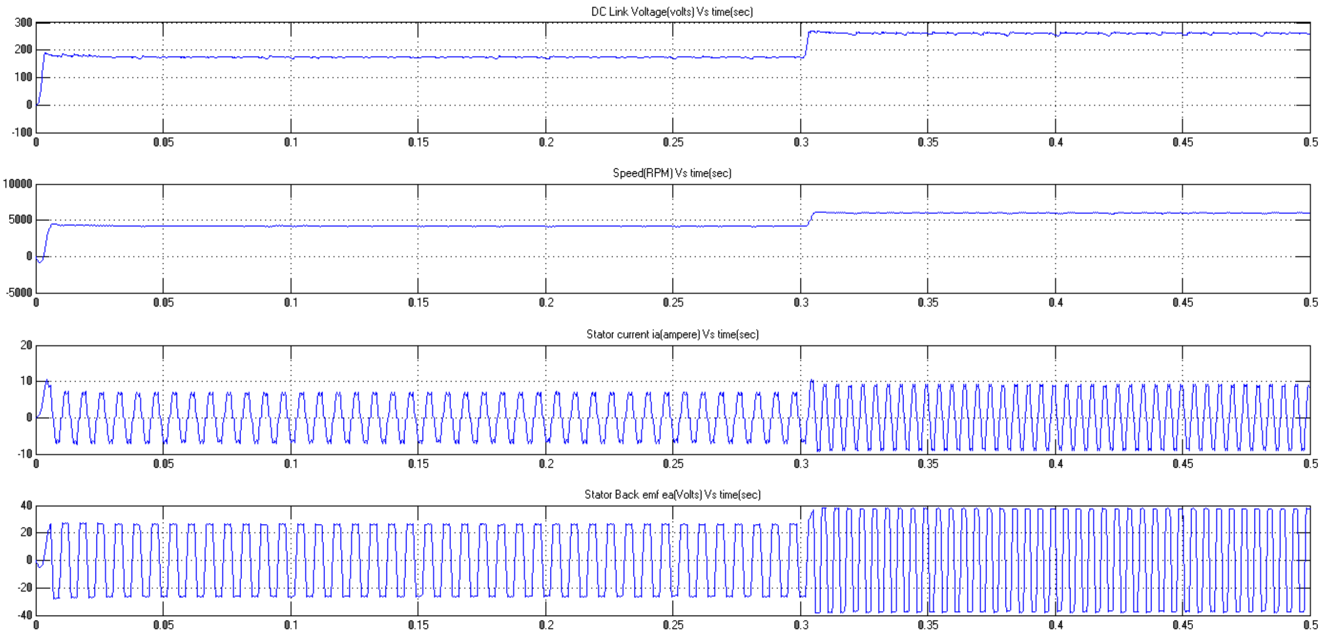

Fig. 6 Simulated Waveforms of DC Link Voltage Vs time, Speed Vs time, Stator current Vs time and Stator Back emf Vs time for a step change in reference speed.

3) Transient response under a change in reference speed: In this case a step change in reference speed is simulated. The drive follows the reference speed change from 4000 rpm to 6000 rpm. The dc link voltage changes from

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165V to 250V instantly without much overshoot and oscillations. Similarly stator current and stator back emf follows the changes, in a transient free manner as shown in fig.6.

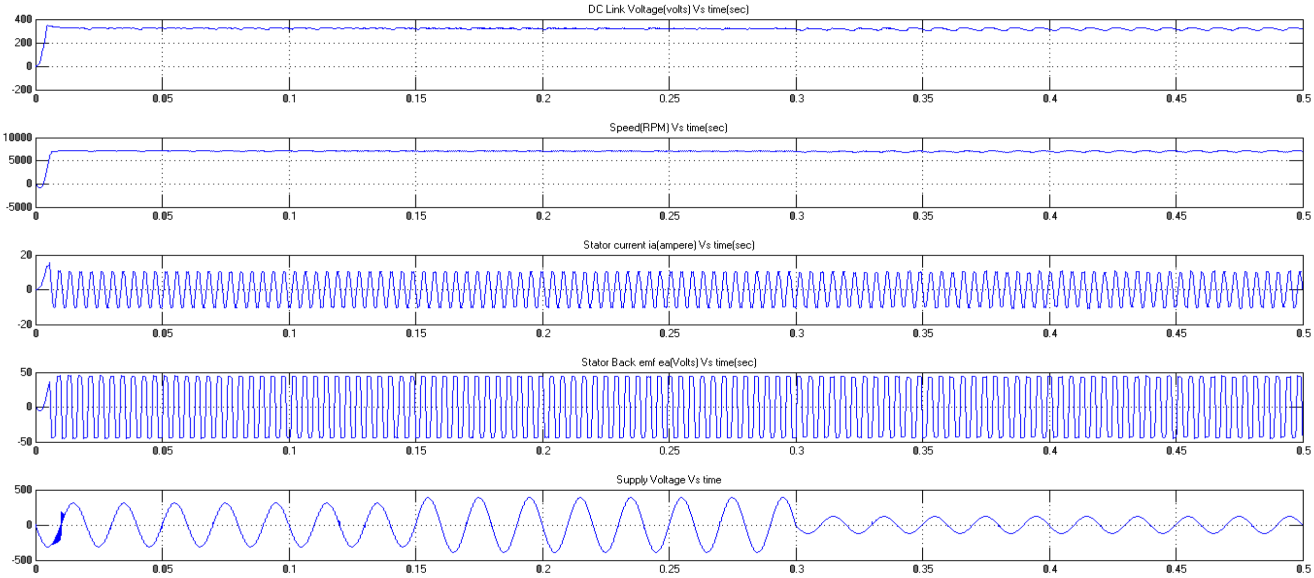

Fig. 7 Transient response of the drive under supply voltage variations

4) **Transient response under supply voltage variations:** In this case the results are verified for a dc link voltage of 320V and load torque=0.25Nm. The supply voltage is varied over +/- 25% .DC link voltage is noted down and listed in Table II. Transient response during a change in supply voltage from 220 V_{rms} to 275 V_{rms} & from 275Vrms to 85Vrms is shown in fig.7. The change in supply voltage is not reflected in output dc link voltage.

Supply Voltage Vs (Volt)	DC Link Voltage Vdc(Volt)	Motor speed N(RPM)
85	331	7000
120	330	7170
150	328	7150
180	329	6825
220	320	7100
260	331	7150
275	335	7225

Table II: Change in DC link voltage for a change in supply voltage.

Thus the proposed drive can perform steady state operation satisfactorily. Therefore the speed can be varied by varying the dc link voltage over a wide range. The converter can perform better during a step like change in speed requirement. This drive can perform better also under the supply voltage variation.

VI.CONCLUSION

A new speed control strategy for a PMBLDC motor using a reference speed equivalent dc voltage at dc link has been simulated in MATLAB using a pseudo boost converter. The PMBLDC motor block in MATLAB is used and speed control is achieved by the use of ac-dc pseudo boost converter. The reference speed entered is successfully converted to

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a reference voltage and a dc link voltage is obtained. This drive is more suitable for low power applications like fans, blowers, and mixers, medical equipments etc.

APPENDIX: BLDC motor rating: two poles, Manufacturer: National Instruments, Prated (rated power):130W, V rated (rated dc link voltage):320V, Trated (Rated Torque):0.31Nm, Wrated (rated speed) =8000 r/min., Kb (back emf constant) =12.5V/Krpm. Moment of inertia (J) =$3.1x10^{-6}$ kgm^2 Controller Gain: Kp=0.4 ; Ki= 3.

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