International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 4, Issue 4, April 2015

Speed Control and Power factor Correction using Bridgeless Buck Boost Converter for BLDC Motor Drive

R.shanthini[1] Dr.K.Boopathy[2]

[1]Mtech, EEE, B.S.Abdur Rahman University,Chennai

[2]Associate professor, EEE, B.S. Abdur Rahman University,Chennai

***Abstract* – This paper presents less number of components with high power factor correcting bridgeless buck boost converter as a cost effective solution for the speed control of BLDC motor drive. The performance analysis of the bridgeless (BL) buck boost converter and the conventional converter are comparatively analyzed and validated. The speed of the BLDC motor is controlled by the variable dc link voltage of the voltage source inverter which operates at the fundamental switching frequency due to electronic commutation which reduces the switching losses. The BL configuration eliminates the diode bridge rectifier thus reducing the conduction losses. The PFC bridgeless buck boost converter is designed to operate in discontinuous mode of operation to obtain the improved PFC in the mains. The overall performance of the drive is simulated in the MATLAB / Simulink environment and the results are analyzed with various factors.**

***Index* – Brushless direct current (BLDC), Power factor corrected (PFC), Bridgeless (BL) Buck boost converter, Voltage source inverter (VSI).**

I. INTRODUCTION

Nowadays, BLDC motors are widely used for its high efficiency and low maintenance which is an essential criteria for the dc motor applications. BLDC motor has a wide range of advantages over the other motors due to its high flux density/volume, low electromagnetic interference problem, high torque and maximum power [1]. Electronic commutation based on the rotor position sensor is used where the elimination of brushes has no problem of sparkling and wear and tear problems [5],[6]. The diode bridge rectifier followed by dc link capacitor draws a high peaky current which leads the supply current to a total harmonic distortion of 65% and a power factor of 0.8. Hence, a diode bridge rectifier with the power factor converter is used with minimum number of components. The converter is made to operate in a discontinuous mode of operation to reduce the number of components where only a single voltage sensor is used to sense the dc link voltage whereas in continuous mode of operation, the current and voltage remains continuous and requires two voltage sensors for the supply voltage, dc link voltage and current sensor the input current [7],[8]. The conventional methods utilizes pulse width modulated voltage source inverter with constant dc link voltage for the speed control which offers higher switching losses in the inverter as it increases as a square function of switching frequency .

Here the speed control is achieved by variable dc link voltage of VSI which allows fundamental frequency switching (electronic commutation), thus reducing switching losses. The buck boost converter feeding a BLDC motor with constant dc link voltage and PWM-VSI for speed control resulted in higher switching losses [2]. The SEPIC based BLDC motor drive has [3] has higher switching losses due to PWM switching and requires higher number of components.

All Rights Reserved © 2015 IJSETR

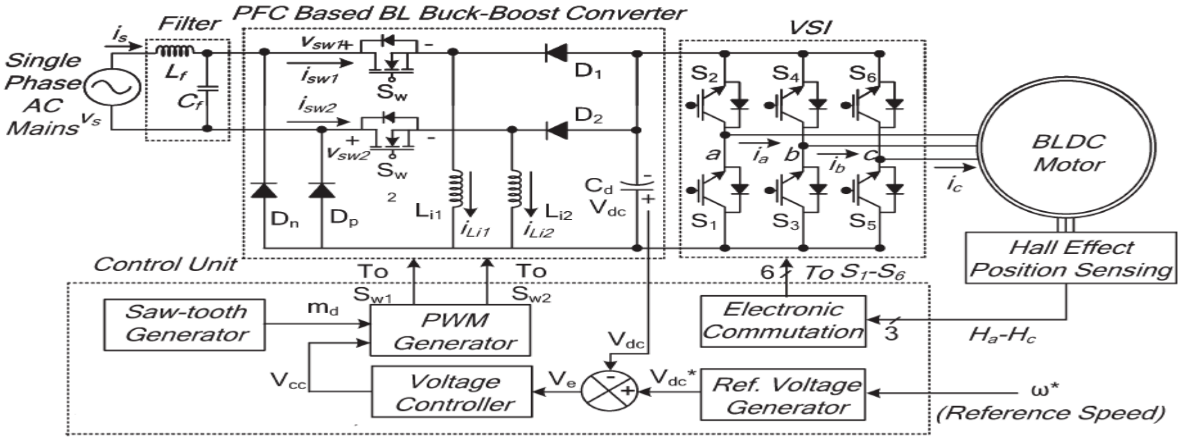

Fig 1.Proposed BL Buck boost converter fed BLDC motor drive

The Cuk converter fed BLDC motor drive [4] with variable dc link voltage and electronic commutation reduces switching losses but requires three sensors for continuous current conduction mode of the converter. This paper presents the BL buck boost converter fed BLDC motor drive with variable dc link voltage of VSI by electronic commutation, with reduced number of components as a cost effective solution.

II.PROPOSED PFC BL BUCK BOOST CONVERTER

Fig 1.shows the proposed PFC BL buck boost converter fed BLDC motor drive. The converter is designed such that it operates in discontinuous mode of conduction and the speed control is achieved by variable dc link voltage where electronic commutation is achieved thereby reducing the switching losses. The proposed configuration of BL buck boost converter has minimal number of components and least number of conduction devices for every half cycle of the supply voltage.

III.OPERATING MODES OF PFC BL BUCK BOOST CONVERTER

The operation is classified as positive and negative switching cycles of the supply voltage. There are three modes of operation in which both the cycles operate.

MODE I: In this mode I switch S_{w1} conducts to charge the inductor L_{i1} hence the inductor current i_{L1} increases in this mode and the diode D_p completes the input side circuitry where the capacitor C_d is discharged by the VSI fed BLDC motor drive as shown in the fig 2.1.

MODE II: In this mode II switch S_{w1} is turned off and the stored energy in the inductor L_{i1} is transferred to dc link capacitor C_d until the inductor current is discharged and reaches zero as shown in fig 2.2.

MODE III: In this mode III the inductor L_{i1} reaches discontinuous conduction, no energy is left in the inductor and the current i_{L1} becomes zero for the rest of the switching period. No switch or diode is conducting in this mode and the dc link capacitor C_d supplies energy to the load. The voltage V_{dc} starts decreasing in the capacitor C_d. The operation is repeated when the S_{w1} is turned on again after complete switching fig 2.3.

Similarly for the negative half cycle of the supply voltage switch S_{w2}, inductor L_{i2} and diodes D_n, D_2 operate for the voltage control and PFC operation.

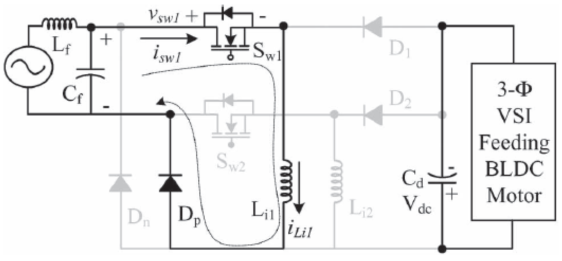

Fig 2.1 MODE I

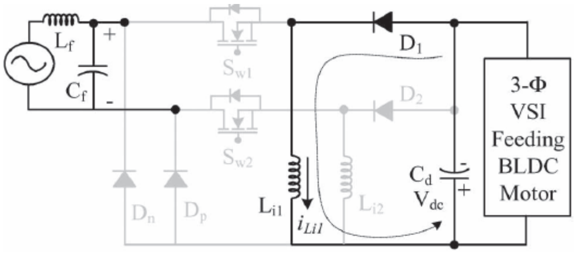

Fig 2.2 MODE II

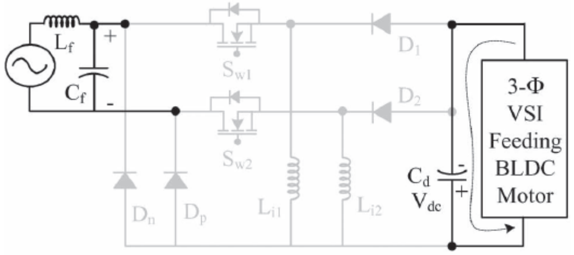

Fig 2.3 MODE III

IV.DESIGN OF PFC BL BUCK BOOST CONVERTER

For the BLDC motor of power rating 250W, a power converter of 350 W (appendix), for the supply voltage of rms value 220 V, the average voltage [10]appearing in the input side

$$V_{in} = \frac{2\sqrt{2}(v_s)}{\pi} = \frac{2\sqrt{2}(220)}{\pi} = 198 \text{ V} \quad (1)$$

The voltage conversion ratio for buck boost converter is given by

$$d = \frac{v_{dc}}{v_{dc} + v_{in}} \quad (2)$$

The proposed converter is designed for dc link voltage from 50 v to 200 v. hence the minimum and maximum duty ratio corresponding to $V_{dc\ min}$ and $V_{dc\ max}$ are 0.2016 and 0.5025.

A.DESIGN OF INPUT INDUCTORS:

The critical value of the input inductance is designed in critical conductance mode[9] for the buck boost converter is given by

$$L_{ic1} = \frac{R(1-d)^2}{2f_s} \quad (3)$$

Where R is the load resistance, d is the duty ratio and f_s is the switching frequency. The inductance value of L_{c1} is calculated for the worst duty ratio to operate it in the discontinuous conduction mode. For the BLDC motor operating at the minimum voltage of 50 V, the p_{min} is given as 90W

$$L_{ic\ 1min} = \frac{v_{dc\ min}^2}{p_{min}} \frac{(1-d_{min})^2}{2f_s} = \frac{(50)^2}{90} \frac{(1-0.2010)^2}{2(20000)}$$

$$= 443.33\mu H \quad (4)$$

The value of inductances L_{ic1} and L_{ic2} are taken less than 1/10th value of the critical inductance so that it operates in discontinuous mode of conduction. The supply current at higher values of inductances get distorted and makes the converter unable to operate in discontinuous conduction mode. The value of inductor is selected one by tenth of critical inductance as 40μH.

B.DESIGN OF DC LINK CAPACITOR

The design of dc link capacitor is designed by the amount of second order current flowing in the capacitor. For a power factor corrected operation supply current (i_s) must be in phase with the supply voltage (v_s)[11] the input power p_{in} is given by

$$P_{in} = \sqrt{2}\, V_s I_s \sin \omega t * \sqrt{2}\, V_s I_s \sin\omega t \quad (5)$$

$$= 2 V_s I_s (1-\cos 2\omega t)$$

Where the second term corresponds to the second order harmonics in the dc link capacitor as,

$$i_c(t) = -\frac{V_s I_s}{v_{dc}} \cos 2\omega t \quad (6)$$

The dc link voltage ripple to this capacitor current is given by,

$$\Delta v_{dc} = \frac{1}{c_d} \int i_c (t) dt = -\frac{I_d}{2\omega c_d} \sin 2\omega t \quad (7)$$

For the maximum value of voltage ripple, $\sin \omega t$ is taken as 1, and the equation (7) becomes

$$c_d = \frac{I_d}{2\omega \Delta v_{dc}} \quad (8)$$

The value of dc link capacitor is calculated for the designed value of the V_{dc} and the ripple permitted with voltage ΔV_{dc} as 0.02

$$c_d = \frac{I_d}{2\omega \Delta v_{dc}} = \frac{p_0 / v_{dc}}{2\omega \Delta v_{dc}} = \frac{350/140}{2(314)(0.02)(100)} \quad (9)$$

$$= 1990.4\mu F$$

Hence the nearest possible value of C_d is taken as $2000\mu F$.

V.CONTROL OF PFC CONVERTER

The control of front end PFC converter includes the generation of the PWM pulses for the switches S_{w1} and S_{w2} for the dc link voltage control and PFC operation in the AC mains. A voltage control loop is followed to control the converter operation. A reference dc link voltage is generated as

$$V_{dc}^{*} = k_v \, \omega^{*} \tag{10}$$

Where k_v is the motor constant and ω^* is the reference speed. The voltage error signal is generated by comparing the reference dc voltage (V_{dc}^*) and the sensed dc voltage (V_{dc}) , the error voltage is given by,

$$V_e(k) = V_{dc}^{*}(k) - V_{dc}(k) \tag{11}$$

Where k is the sampling instant.

The error voltage is given to the proportional integral controller to give out the controlled output voltage (V_{cc}) as

$$Vcc(k) = Vcc(k-1) + kp\,\{Ve(k) - Ve(k-1)\} \quad (12)$$
$$+ ki\,Ve(k)$$

Where k_p and k_i are proportional and integral gains of voltage PI controller. The final output of the voltage controller is compared with the high frequency saw tooth signal which generates the PWM pulses as

$$\text{For } V_S > 0, \quad \left\{\begin{matrix} \text{if } m_d < v_{cc} \text{ then } s_{w1} = ON \\ \text{if } m_d \geq v_{cc} \text{ then } s_{w1} = OFF \end{matrix}\right\} \quad (14)$$

$$\text{For } V_S < 0, \quad \left\{\begin{matrix} \text{if } m_d < v_{cc} \text{ then } s_{w2} = ON \\ \text{if } m_d \geq v_{cc} \text{ then } s_{w2} = OFF \end{matrix}\right\} \quad (15)$$

Where S_{w1} and S_{w2} are the switching signals to the switches of the PFC converter.

VI.ELECTRONIC COMMUTATION OF BLDC MOTOR

Hall effect sensor is used to sense the rotor position for every 60^0. The electronic commutation is the proper switching of the voltage source inverter and to draw a symmetric dc current from the dc link capacitor. The magnitude of the line current drawn from dc link capacitor depends on applied dc link voltage (v_{dc}), resistances (R_a, R_b), back electro motive forces (emf), self and mutual inductances (L_a, L_b, M) of the motor. The Table1 shows the different switching states of the VSI feeding a BLDC based on the hall effect position sensing (H_a – H_c).

TABLE 1 SWITCHING STATES FOR ELECTRONIC COMMUTATION OF BLDC MOTOR DRIVE BASED ON HALL EFFECT POSTION SIGNALS

θ^0	Hall signals			Switching states					
	H_a	H_b	H_c	S_{w1}	S_{w1}	S_{w1}	S_{w1}	S_{w1}	S_{w1}
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

VII. RESULT ANALYSIS

The performance of the BLDC motor drive had been simulated in the MATLAB/ simulink software. The performance of the BLDC motor drive and the PFC BL buck boost converter had been analyzed individually.

A.BL BUCK BOOST CONVERTER PERFORMANCE

The discontinuous inductor currents (*i*Li1 and *i*Li2) and capacitor voltage are obtained in open loop, confirming the DICM operation of the BL buck–boost converter. The performance of the proposed BL buck boost is comparatively analyzed in open loop with the conventional buck boost converter.

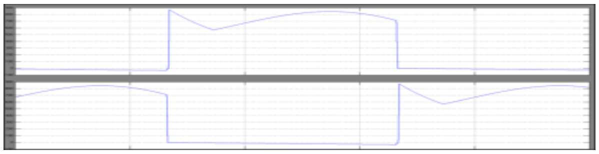

Fig 7(a) Inductor currents

The inductor current of 0.58A, Fig 7(a) shows that the inductor operates in the discontinuous mode of operation for every half cycle. The current operates in continuous mode for a time period of 0.005S.

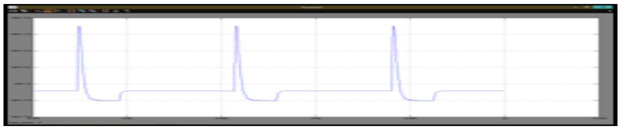

Fig 7(b) Capacitor voltage

ISSN: 2278 – 7798

All Rights Reserved © 2015 IJSETR

From the fig 7(b) during the conducting mode of inductors the capacitor charges to a voltage of 50V and discharges during the discontinuous mode of operation . The capacitor charges for a time period of 0.001S.

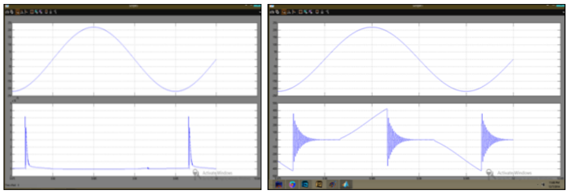

Fig 7(c) comparative analysis of conventional and proposed buck boost converter

The comparative analysis for the conventional and the proposed converter is performed in open loop for different duty ratio of the varying dc link voltage ($V_{dc)}$ and it is found that the power factor is better in the proposed converter as shown in Table 2 which is analyzed using the phase angle displacement of source voltage and source current.

Duty ratio	Proposed converter Power factor	Conventional converter Power factor
0.25	0.875	0.825
0.35	0.877	0.865
0.5	0.863	0.850

Table 2 power factor variation analysis of conventional and BL buck boost converter

B. BLDC MOTOR PERFORMANCE

The BLDC is operated for a supply voltage of 90-270V. The parameters associated with the BLDC motor such as speed (N), electromagnetic torque (T_e), and stator current (I_a) are analyzed for the better functioning of the BLDC motor.

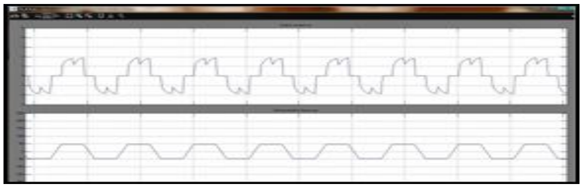

Fig 8(a) Stator current, EMF voltage

Stator current- 2 A, electromotive force-50V . From the fig 8(a) shows the obtained stator current and the electromotive force voltage during the speed control operation of BLDC motor at 1200 rpm.

Fig 8(b) Torque

Electromagnetic torque=2.2 N-m. From the fig 8(b), it is found that the maximum torque obtained is T_{max}=2.2N-m, T_{min}=1.2N-m,T_{avg}=1.7N-m and the torque ripple is found as 58%.

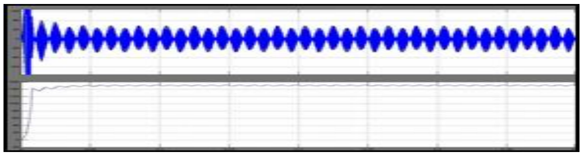

Fig 8(c) Source current, variable dc voltage

Variable dc voltage=140V, source current=0.55A. The fig 8(c) shows the obtained values of source current and the variable dc voltage during the speed control operation of BLDC motor at 1200 rpm.

Fig 8(d) Rotor speed

Rotor speed =1200 rpm. From the fig 8(d), the required speed of 1200 rpm is obtained as the speed output within 0.01S,thereby ensuring the better speed control.

VIII. CONCLUSION

Thus the speed of the BLDC motor had been controlled by the variable dc link voltage of the voltage source inverter which had been operated at the fundamental switching frequency (electronic commutation) reducing the switching losses. The BL configuration had eliminated the diode bridge rectifier thus reducing the conduction losses. Thus the PFC bridgeless buck boost converter designed and operated in discontinuous mode of operation, had obtained the improved PFC in the mains from 0.85 to 0.877 and the required speed of 1200 rpm had been obtained as the speed output within 0.01S,thereby ensuring the better speed control. Thus the proposed scheme had shown satisfactory performance.

APPENDIX

BLDC Motor Rating: four poles, Prated (rated power) =251.32 W, V_{rated} (rated dc link voltage) = 200 V, T_{rated} (rated torque) = 1.2 N · m, ω_{rated} (rated speed) = 2000 r/min, Kb(back EMF constant) = 78 V/kr/min, Kt (torque constant) = 0.74 N -m/A, R_{ph} (phase resistance) = 14.56 Ω, L_{ph} (phase inductance) = 25.71 mH, and J (moment of inertia)=1.3 × 10−4 N-m/A2. Controller Gains: $k_p = 0.4$, $k_i = 3$

REFERENCES

[1] C. L. Xia, Permanent Magnet Brushless DC Motor Drives and Controls. Hoboken,. NJ, USA: Wiley, 2012

[2] S. Singh and B. Singh, “A voltage-controlled PFC Cuk converter based PMBLDCM drive for air-conditioners,” IEEE Trans. Ind. Appl., vol. 48, no. 2, pp. 832–838, Mar./Apr. 2012.

[3] T. Gopalarathnam and H. A. Toliyat, “A new topology for unipolar brushless dc motor drive with high power factor,” IEEE Trans. Power Electron., vol. 18, no. 6, pp. 1397–1404, Nov. 2003.

[4] S. Singh and B. Singh, “A voltage-controlled PFC Cuk converter based PMBLDCM drive for air-conditioners,” IEEE Trans. 2012.

[5] H. A. Toliyat and S. Campbell, DSP-Based Electromechanical Motion Control. Boca Raton, FL, USA: CRC Press, 2004.

[6] P. Pillay and R. Krishnan, “Modeling of permanent magnet motor drives,”IEEE Trans. Ind. Electron., vol. 35, no. 4, pp. 537–541, Nov. 1988.

[7] B. Singh, B. N. Singh, A. Chandra, K. AlHaddad, A. Pandey, and D. P. Kothari, “A review of single-phase improved power quality ac dc converters,” IEEE Trans. Ind. Electron., vol. 50, no. 5, pp. 962–981,Oct. 2003.

[8] B. Singh, S. Singh, A. Chandra, and K. Al-Haddad, “Comprehensive study of single-phase ac-dc power factor corrected converters with high frequency isolation,” IEEE Trans. Ind. Informat., vol. 7, no. 4,pp. 540–556, Nov. 2011.

[9] A. Emadi, A. Khaligh, Z. Nie, and Y. J.Lee, Integrated Power Electronic Converters and Digital Control. Boca Raton, FL, USA: CRC Press,2009.

[10] D. S. L. Simonetti, J. Sebastian, F. S. dos Reis, and J. Uceda, “Design criteria for SEPIC and Cuk converters as power factor pre-regulators in discontinuous conduction mode,” in Proc. Int. Electron. Motion ControlConf., 1992, vol. 1, pp. 283–288.

[11] N. Mohan, T. M. Undeland, and W. P. Robbins, Power Electronics: Converters,Applications and Design. Hoboken, NJ, USA: Wiley, 2003.

R. Shanthini received her B.E degree in Electrical and Electronics Engineering from Krishnasamy college of engineering & technology, cuddalore, affiliated to Anna university, Chennai, Tamilnadu in 2013 and she is currently pursuing her M.Tech degree in Power Electronics and Drives in B.S.Abdur Rahman University, Chennai. Her fields of interest includes Power electronics and electric drives & control.

Dr. K. Boopathy received his B.E degree in electrical and electronics engineering from Madras University in 1999, M.E in Electronics Engineering from Anna University (MIT campus) in 2003 and Ph.D in power electronics from Anna University, Chennai in 2012. Currently he is working as a Associate Professor in Dept. of EEE in B. S. Abdur Rahman University, Chennai. He has published several National and International Journals and Conferences. His area of interest includes Power Electronics and Drives, soft computing technique application to power electronics and electrical machines.