

Elimination of Conduction Losses using a bridgeless buck–boost converter for low power application in a cost effective manner.



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ABSTRACT:

In electrical engineering, the power factor of an AC electrical power system is defined as the ratio of the real power flowing to the load to the apparent power in the circuit. Brushless Direct Current (BLDC) motors are one of the motor types rapidly gaining popularity. They do not use brushes for commutation; instead, they are electronically commutated. This paper presents a power factor corrected (PFC) bridgeless (BL) buck–boost converter-fed brushless direct current (BLDC) motor drive as a cost-effective solution for low-power applications. An approach of speed control of the BLDC motor by controlling the dc link voltage of the voltage source inverter (VSI) is used with a single voltage sensor. This facilitates the operation of VSI at fundamental frequency switching by using the electronic commutation of the BLDC motor which offers reduced switching losses. A BL configuration of the buck–boost converter is proposed which offers the elimination of the diode bridge rectifier, thus reducing the conduction losses associated with it. A PFC BL buck–boost converter is designed to operate in discontinuous inductor current mode (DICM) to provide an inherent PFC at ac mains. The proposed PMBLDCM drive is modeled in Mat lab- Simulink environment and evaluated for an air conditioning compressor load. The performance of the proposed PFC drive is evaluated on the basis of various parameters such as total harmonic distortion (THDi) and the crest factor (CF) of the current at input AC

mains, displacement power factor (DPF), power factor (PF) and efficiency of the drive system (η_{drive}) at different speeds of the motor.

Index Terms—Bridgeless (BL) buck–boost converter, brushless direct current (BLDC) motor, discontinuous inductor current mode (DICM), power factor corrected (PFC), power quality.

Introduction:

Efficiency and cost are the major concerns in the development of low-power motor drives targeting household applications such as fans, water pumps, blowers, mixers, etc. The use of the brushless direct current (BLDC) motor in these applications is becoming very common due to features of high efficiency, high flux density per unit volume, low maintenance requirements, and low electromagnetic interference problems.

These BLDC motors are not limited to household applications, but these are suitable for other applications such as medical equipment, transportation, HVAC, motion control, and many industrial tools. A BLDC motor has three phase windings on the stator and permanent magnets on the rotor.

The BLDC motor is also known as an electronically commutated motor because an electronic commutation based on rotor position is used rather than a

mechanical commutation which has disadvantages like sparking and wear and tear of brushes and commutator assembly. Power quality problems have become important issues to be considered due to the recommended limits of harmonics in supply current by various international power quality standards such as the International Electro technical Commission (IEC) 61000-3-2. For class-A equipment (< 600 W, 16 A per phase) which includes household equipment, IEC 61000-3-restricts the harmonic current of different order such that the total harmonic distortion (THD) of the supply current should be below 19%.

The simplest way to control the harmonic current is to use a filter that passes current only at line frequency (50 or 60 Hz). The filter consists of capacitors or inductors, and makes a non-linear device look more like a linear load. An example of passive PFC is a valley-fill circuit. A disadvantage of passive PFC is that it requires larger inductors or capacitors than an equivalent power active PFC circuit. Also, in practice, passive PFC is often less effective at improving the power factor.

Active PFC is the use of power electronics to change the waveform of current drawn by a load to improve the power factor. Some types of the active PFC are buck, boost, buck-boost and synchronous condenser. Active power factor correction can be single-stage or multi-stage.

In the case of a switched-mode power supply, a boost converter is inserted between the bridge rectifier and the main input capacitors. The boost converter attempts to maintain a constant DC bus voltage on its output while drawing a current that is always in phase with and at the same frequency as the line voltage. Another switched-mode converter inside the power supply produces the desired output voltage from the DC bus. This approach requires additional semiconductor switches and control electronics, but permits cheaper and smaller passive components. It is frequently used in practice.

SMPSs with passive PFC can achieve power factor of about 0.7–0.75, SMPSs with active PFC, up to 0.99 power factor, while a SMPSs without any power factor correction have a power factor of only about 0.55–0.65.

Existing System:

The parameters of the BL buck–boost converter are designed such that it operates in discontinuous inductor current mode (DICM) to achieve an inherent power factor correction at ac mains. The speed control of BLDC motor is achieved by the dc link voltage control of VSI using a BL buck–boost converter. This reduces the switching losses in VSI due to the low frequency operation of VSI for the electronic commutation of the BLDC motor.

The performance of the proposed drive is evaluated for a wide range of speed control with improved power quality at ac mains. Moreover, the effect of supply voltage variation at universal ac mains is also studied to demonstrate the performance of the drive in practical supply conditions. Voltage and current stresses on the PFC converter switch are also evaluated for determining the switch rating and heat sink design. Finally, a hardware implementation of the proposed BLDC motor drive is carried out to demonstrate the feasibility of the proposed drive over a wide range of speed control with improved power quality at ac mains.

Proposed System:

The operation of the PFC BL buck boost converter is classified into two parts which include the operation during the positive and negative half cycles of supply voltage and during the complete switching cycle.

Operation During Positive and Negative Half Cycles of Supply Voltage

In the proposed scheme of the BL buck boost converter, switches S_{w1} and S_{w2} operate for the positive and negative half cycles of the supply voltage, respectively. During the positive half cycle of the supply voltage, switch S_{w1} , inductor L_{l1} , and diodes

$D1$ and Dp are operated to transfer energy to dc link capacitor Cd as shown in Fig. 2(a)–(c). Similarly, for the negative half cycle of the supply voltage, switch $Sw2$, inductor $Li2$, and diodes $D2$ and Dn conduct.

Operation During Complete Switching Cycle

Three modes of operation during a complete switching cycle are discussed for the positive half cycle of supply voltage as shown here in after.

Mode I: In this mode, switch $Sw1$ conducts to charge the inductor $Li1$; hence, an inductor current $iLi1$ increases in this mode as shown in Fig. 2(a). Diode Dp completes the input side circuitry, whereas the dc link capacitor Cd is discharged by the VSI-fed BLDC motor.

Design of PFC BL Buck–Boost Converter

A PFC BL buck–boost converter is designed to operate in DICM such that the current in inductors $Li1$ and $Li2$ becomes discontinuous in a switching period. For a BLDC of power rating 251 W (complete specifications of the BLDC motor are given in the Appendix), a power converter of 350 W (Po) is The proposed converter is designed for dc link voltage control from 50 V ($Vdc\ min$) to 200 V ($Vdc\ max$) with a nominal value ($Vdc\ des$) of 100 V; hence, the minimum and the maximum duty ratio ($dmin$ and $dmax$) corresponding to $Vdc\ min$ and $Vdc\ max$ are calculated as 0.2016 and 0.5025, respectively.

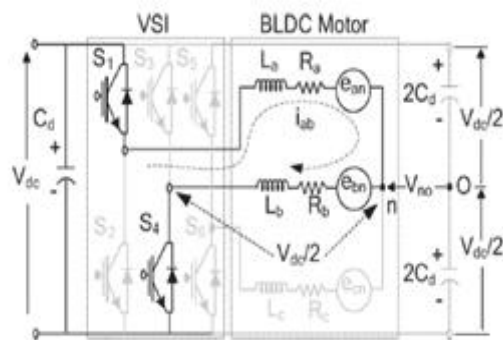


Fig. Operation of a VSI-fed BLDC motor when switches S_1 and S_4 are conducting.

Simulated Performance of Proposed BLDC Motor Drive

The performance of the proposed BLDC motor drive is simulated in MATLAB/Simulink environment using the Sim Power System toolbox. The performance evaluation of the proposed drive is categorized in terms of the performance of the BLDC motor and BL buck–boost converter and the achieved power quality indices obtained at ac mains. The parameters associated with the BLDC motor such as speed (N), electromagnetic torque (Te), and stator current (ia) are analyzed for the proper functioning of the BLDC motor. Parameters such as supply voltage (Vs), supply current (is), dc link voltage (Vdc), inductor's currents ($iLi1$, $iLi2$), switch voltages ($Vsw1$, $Vsw2$), and switch currents ($isw1$, $isw2$) of the PFC BL buck–boost converter are evaluated to demonstrate its proper functioning.

Steady-State Performance

The steady-state behavior of the proposed BLDC motor drive for two cycles of supply voltage at rated condition (rated dc link voltage of 200 V) is shown in Fig. 6. The discontinuous inductor currents ($iLi1$ and $iLi2$) are obtained, confirming the DICM operation of the BL buck boost converter. The performance of the proposed BLDC motor drive at speed control by varying dc link voltage from 50 to 200 V is tabulated in Table III. The harmonic spectra of the supply current at rated and light load conditions, i.e., dc link voltages of 200 and 50 V, are also shown in Fig. 7(a) and (b), respectively, which shows that the THD of supply current obtained is under the acceptable limits of IEC 61000-3-2.

A new speed control strategy of a PMBLDCM drive is validated for a compressor load of an air conditioner which uses the reference speed as an equivalent reference voltage at DC link. The speed control is directly proportional to the voltage control at DC link. The rate limiter introduced in the reference voltage at DC link effectively limits the motor current within the desired value during the transient condition (starting and speed control).

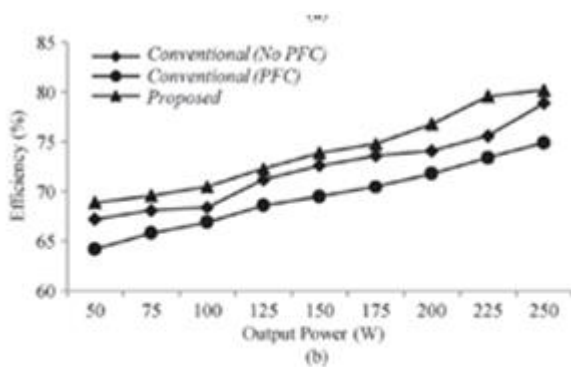


Fig. Comparative analysis of (a) losses and (b) the efficiency of the conventional and the proposed configuration.

Table VII shows a comparative analysis of three different configurations of the BLDC motor drive. The evaluation is based on the control requirement, sensor requirement, and losses in the PFC converter and VSI-fed BLDC motor. The proposed scheme has shown a minimum amount of sensing requirement and cost with the highest efficiency among the three configurations, and hence, it is a recommended solution for low-power applications.

Conclusion

A PFC BL buck–boost converter-based VSI-fed BLDC motor drive has been proposed targeting low-power applications. A new method of speed control has been utilized by controlling the voltage at dc bus and operating the VSI at fundamental frequency for the electronic commutation of the BLDC motor for reducing the switching losses in VSI. The front-end BL buck–boost converter has been operated in DICM for achieving an inherent power factor correction at ac mains. A satisfactory performance has been achieved for speed control and supply voltage variation with power quality indices within the acceptable limits of IEC 61000-3-2. Moreover, voltage and current stresses on the PFC switch have been evaluated for determining the practical application of the proposed scheme. Finally, an experimental prototype of the proposed drive has been developed to validate the performance of the proposed BLDC motor drive under speed control with improved power quality at ac mains. The proposed scheme has shown satisfactory

performance, and it is a recommended solution applicable to low-power BLDC motor drives.

References

- [1] Vashist Bist & Bhim Singh, An Adjustable-Speed PFC Bridgeless Buck–Boost Converter-Fed BLDC Motor Drive, *IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS*, VOL. 61, NO. 6, JUNE 2014.
- [2] J. Moreno, M. E. Ortuzar, and J. W. Dixon, “Energy-management system for a hybrid electric vehicle, using ultracapacitors and neural networks,” *IEEE Trans. Ind. Electron.*, vol. 53, no. 2, pp. 614–623, Apr. 2006.
- [3] Y. Chen, C. Chiu, Y. Jhang, Z. Tang, and R. Liang, “A driver for the singlephase brushless dc fan motor with hybrid winding structure,” *IEEE Trans. Ind. Electron.*, vol. 60, no. 10, pp. 4369–4375, Oct. 2013.
- [4] C. L. Xia, *Permanent Magnet Brushless DC Motor Drives and Controls*. Hoboken, NJ, USA: Wiley, 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] *Limits for Harmonic Current Emissions (Equipment Input Current ≤ 16 A Per Phase)*, Int. Std. IEC 61000-3-2, 2000
- [8] S. Singh and B. Singh, “A voltage-controlled PFC Cuk converter based PMSBLDCM drive for air-conditioners,” *IEEE Trans. Ind. Appl.*, vol. 48, no. 2, pp. 832–838, Mar./Apr. 2012.
- [9] B. Singh, B. N. Singh, A. Chandra, K. Al-Haddad, A. Pandey, and D. P. Kothari, “A review of single-



phase improved power quality acdc converters,” *IEEE Trans. Ind. Electron.*, vol. 50, no. 5, pp. 962–981, Oct. 2003.

[10] 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.

[11] S. Singh and B. Singh, “Power quality improved PMBLDCM drive for adjustable speed application with reduced sensor buck-boost PFC converter,” in *Proc. 4th ICETET*, Nov. 18–20, 2011, pp. 180–184.

[12] 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.

[13] Y. Jang and M. M. Jovanović, “Bridgeless high-power-factor buck converter,” *IEEE Trans. Power Electron.*, vol. 26, no. 2, pp. 602–611, Feb. 2011.

[14] L. Huber, Y. Jang, and M. M. Jovanović, “Performance evaluation of bridgeless PFC boost rectifiers,” *IEEE Trans. Power Electron.*, vol. 23, no. 3, pp. 1381–1390, May 2008.

[15] A. A. Fardoun, E. H. Ismail, M. A. Al-Saffar, and A. J. Sabzali, “New ‘real’ bridgeless high efficiency ac-dc converter,” in *Proc. 27th Annu. IEEE APEC Expo.*, Feb. 5–9, 2012, pp. 317–323.