IJERST

International Journal of Engineering Research and Science & Technology

ISSN : 2319-5991
Vol. 4, No. 4
November 2015

www.ijerst.com

Email: editorijerst@gmail.com or editor@ijerst.com

International Journal of Engineering Research and Science & Technology

ISSN 2319-5991 www.ijerst.com
Vol. 4, No. 4, November 2015

Research Paper

POWER QUALITY IMPROVEMENT USING BRIDGELESS BUCK-BOOST CONVERTER FED BLDC MOTOR DRIVE

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BLDC motors are widely using in many of the industrial applications. Various converter topologies are used for feeding these Brushless Direct Current (BLDC) motor drives. In this paper, a Power Factor Corrected (PFC) bridgeless (BL) buck-boost converter topology is proposed in order to fed a BLDC motor drive for low-power applications. A bridgeless buck-boost converter which avoids the need of the diode bridge rectifier, reducing the conduction losses which incurred because of it. Filters are usually provided along with these converters for the correction of power quality and thereby reducing the total harmonic distortion level. Finally, in Matlab/Simulink environment, performances of the proposed drive are simulated, which improves the power quality at ac mains.

Keywords: Power factor correction, BLDC motor, Bridgeless buck-boost converter, Total harmonic distortion

INTRODUCTION

Brushless DC (BLDC) motors have become increasingly popular in the past decade due to the advantages such as high efficiency, high power density, compact size, high ruggedness, low maintenance requirements and their immunity to Electro-Magnetic Interference (EMI) problems (Xia, 2012; Kenjo, 1985; and Krishnan, 2001). A BLDC motor is a three phase synchronous motor having torque-speed characteristics of a DC motor (Xia, 2012; Kenjo, 1985; and Krishnan, 2001). It has three phase windings on the stator which are excited by a Voltage Source Inverter (VSI) and permanent magnets on the rotor. It does not require any brushes and commutator assembly; rather an electronic commutation based on the rotor position as sensed by Hall Effect position sensors is used (Sokira, 1989; Toliyat, 2004). Hence the problems such as sparking, wear and tear of brushes, EMI and noise interference are eliminated in the BLDC motor.

There is a requirement of an improved Power Quality (PQ) as per the international PQ standard IEC 61000-3-2 which recommends a high Power Factor (PF) and low Total Harmonic Distortion (THD) of ac mains current for Class-A

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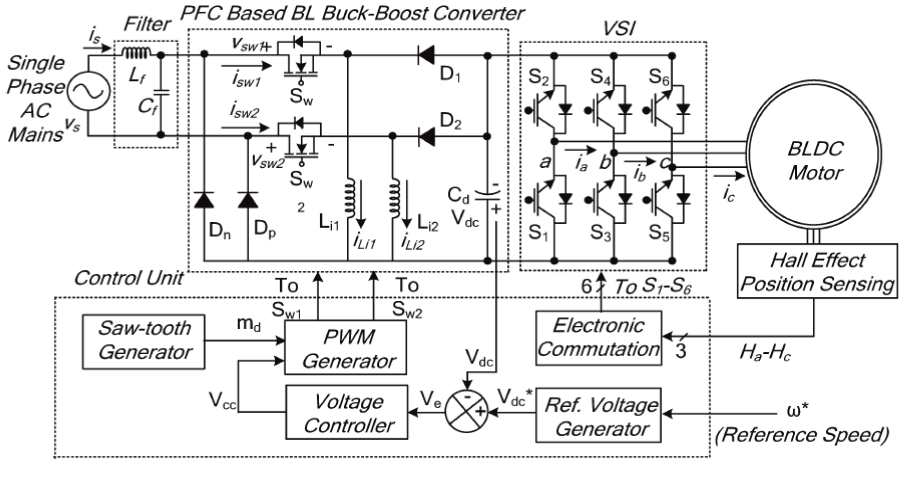
applications. A conventional BLDC motor drive using a front-end Diode Bridge Rectifier (DBR) and a high value of DC link capacitor draws highly distorted peaky current which is rich in harmonics. It leads to a very low power factor of the order of 0.72 and high Total Harmonic Distortion (THD) of supply current at AC mains. Improved Power Quality Converters (IPQC) are used for improving the power quality at AC mains which also reduce EMI problems. Many configurations of PFC converter feeding a BLDC motor drive have been reported in the literature (Singh and Singh, 2012; Chang, 2012; Shikha, 2015; Gopalarathnam, 2003). Gopalarathnam *et. al.* (2003) have used this concept and have proposed a SEPIC (Single Ended Primary Inductance Converter) for feeding a BLDC motor drive. It uses a bifilar winding which uses a PWM based control of VSI and have high switching losses .Singh *et al*. (2012), have proposed a PFC Cuk converter fed BLDC motor drive using the control of variable DC link voltage. This utilizes a Cuk converter operating in CCM; hence requires three sensors and is preferred for higher power rating. Gopalarathnam *et al.* (2003) have used this concept and have proposed a SEPIC (Single Ended Primary Inductance Converter) for feeding a BLDC motor drive. It uses a bifilar winding which uses a PWM based control of VSI and have high switching losses. Bridgeless converter configurations have gained importance in the past decade due to their high efficiency. The front end DBR is eliminated in these configurations which reduce the conduction losses associated in them

Filters are usually provided along with these converters for the correction of power quality and thereby reducing the total harmonic distortion level. The mode of operation of PFC converters are selected with great importance since it determines the cost and component ratings. Converters can be operated in both Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM). DCM is mostly selecting in low power applications. This is because, for employing CCM it requires two sensors, one for sensing the inductor current and other for sensing the capacitor voltage. In DCM there requires only one sensor to detect the DC link voltage only. DC link voltage control cannot be selected in high power applications since it creates high stress on the switches.

Figure 1: BLDC Motor Drive Fed By A Pfc Buck Boost Converter



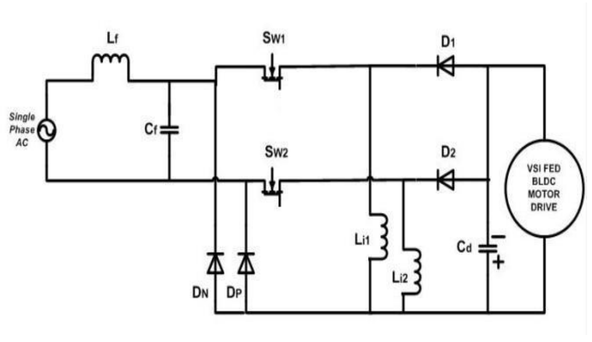
The Proposed buck-boost converter feeding a BLDC motor based on the concept of constant dc link voltage and PWM-VSI for speed control which has a high switching losses. A buck-boost converter configuration is best suited among various BL converter topologies for applications requiring a wide range of dc link voltage control (i.e., bucking and boosting mode). The proposed converter reduces the conduction losses.

PROPOSED BRIDGELESS BUCK-BOOST CONVERTER FEEDING BLDC MOTOR DRIVE

The proposed converter is operating in discontinuous inductor current mode for reducing the switching stress. An L filter is used at the input to improve the power quality. A dual buck boost converter is used in which one operating during positive half cycle and the other operating during the negative half cycle. In each of the half cycles, the DC link capacitor is continuously feeding the drive through three different modes. A voltage source inverter is used to provide alternating stator current to the motor drive. Electronic commutation is employed for controlling the switches of inverter so that the speed control of the BLDC drive can be made possible. Power factor correction is done by the voltage feedback control of the converter along with the filter operation.

The circuit is operating in three modes in each of the half cycles. Lf and Cf are the filter inductance and capacitance at the input stage. SW1 and Sw2 are the switches, L1 and L2 are the inductors, D1 and D2 are the diodes in the dual buck boost converter. The inverter switches are numbered through S1 to S6 and the BLDC motor drive employed with hall Effect position (Ha-Hc) sensors are also shown in the circuit.

Figure 2 : Proposed Converter



OPERATION OF BL BUCK BOOST CONVERTER

The converter is a dual buck boost converter operating in both positive and negative half cycles of input supply voltage. It is performed in three different modes in each of the half cycles which is given below.

Operation During the Positive Half Cycle

During this half cycle of operation the switch Sw1 , inductor L1 and the diodes Dp, D1 are operated to transfer energy from input to the load.

Mode 1: The switch Sw1 is conducting and as result of this the inductor charges and the inductor current iL1 increases. The diode Dp completes the circuit. The previously stored charge in DC link capacitor will be transferred to the motor. It is shown in Figure 3(a).

Mode 2: During this mode of operation, the switch Sw1 turns off and the energy stored in inductor will be transferred to the DC link capacitor and the current iL1 will be decreased. It is shown in Figure 3(b).

Mode 3: In this mode none of the switch and the diode are conducting. The inductor enters into the discontinuous mode since the inductor current become zero. The energy stored in the DC link capacitor C d will be transferred to the load. The Switch Sw1 conducts again after the complete switching cycle. This improves the power quality at the AC mains. It is shown in Figure 3(c).

Operation During the Negative Half Cycle

It is shown in Figure 3(c), during the positive half cycle of operation the switch Sw1, inductor L1 and the diodes Dp, D1 are operated to transfer energy from input to the load.

Mode 1: The switch Sw2 is conducting and as result of this the inductor charges and the inductor current iL2 increases. The diode Dn completes the circuit. The previously stored charge in DC link capacitor will be transferred to the motor. It is shown in Figure 4(a).

Mode 2: During this mode of operation, the switch Sw2 turns off and the energy stored in inductor will be transferred to the DC link capacitor and the current iL2 will be decreased. It is shown in Figure 4(b).

Mode 3: In this mode none of the switch and the diode are conducting. The inductor enters into the DCM since the inductor current become zero. The energy stored in the DC link capacitor Cd

Figure 3(a): Mode 1 Fig 3(b):Mode 2 Fig 3(c): Mode 3 operation of converter during positive half cycle

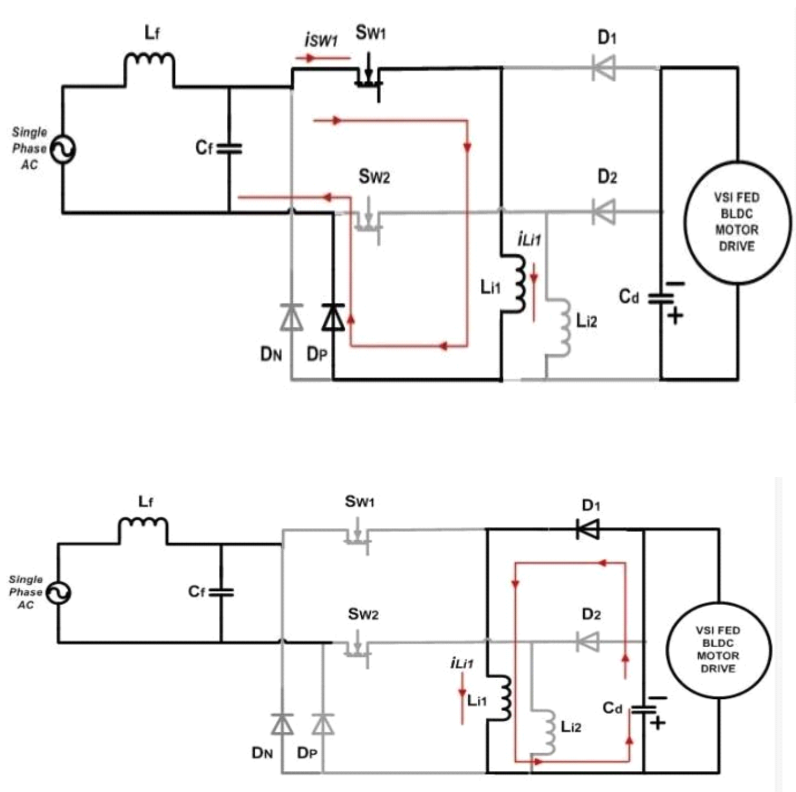


Figure 4(a) : Mode 1 Fig 4(b):Mode 2 Fig 4(c): Mode 3 operation of converter during negative half cycle

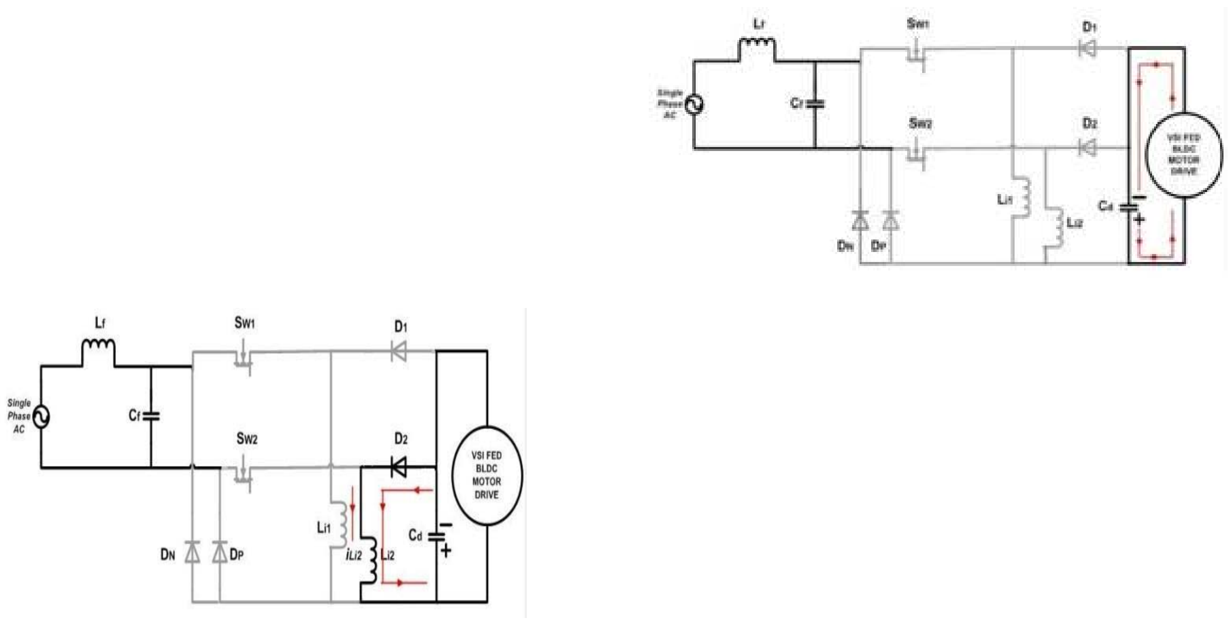
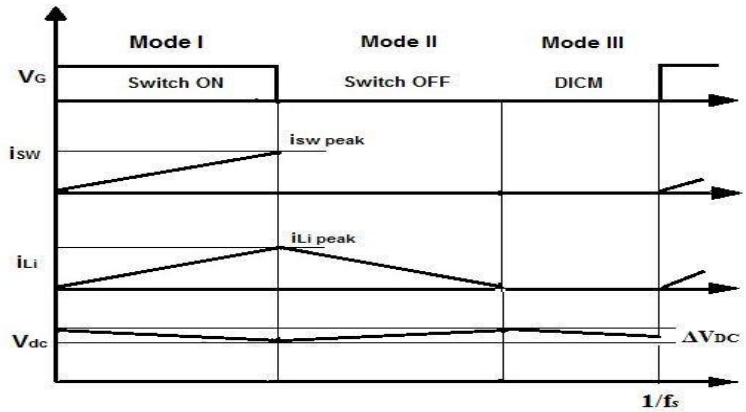


Figure 5 : Waveform representing mode of operation in each half cycle



will be transferred to the load. The Switch Sw2 conducts again after the complete switching cycle. It is shown in Figure 4(c).

During this half cycle of operation the switch Sw 2 , inductor L2 and the diodes Dn, D2 are operated to transfer energy from input to the load.

CONTROL OF POWER FACTOR CORRECTED BRIDGELESS BUCK BOOST CONVERTER

A. Control of PFC Converter

The converter is operating in DICM mode and it is being controlled by voltage follower approach.

The PWM signals to the switches Sw1 and Sw2 are generated by comparing the DC link voltage with a reference signal. The reference signal is generated such that

$Vdc^{*} = kv\ w^{*}$

Where kv is the motors voltage constant and w^{*} is the reference speed. The error signal is generated by comparing this DC link voltage level with the reference DC link voltage.

$Ve = Vdc^{*} - Vdc$

This error signal is given to the PI controller to produce the control output voltage. This output control voltage is compared with a saw tooth wave of high frequency (md) to generate the PWM pulses.

If Vs> 0,

If md<Vcc , then Sw1 ON If mde"Vcc then Sw1 OFF

If Vs< 0,

If md<Vcc , then Sw2 ON If md e" Vcc , then Sw2 OFF

Sw1 and Sw2 are the switching signals.

B. Electronic Commutation

Electronic commutation is performed with proper switching of the VSI switches such that symmetrical current is taken from the DC link capacitor for 120^{0} and placed symmetrically at each phase. Hall effect position sensor is required to determine the rotor position. Depending upon this, the gating signals to the inverter switches are produced by means of a decoder and corresponding switches from the upper and lower leg are activated to complete the current flow and thereby actuating the stator windings. Figure 6 shows the case of line current iab drawn from the DC link capacitor whose values depending on the VDC voltage along with the emfs ean,ebn, resistance Ra, Rb and the inductances La, Lb and M. Table shows the switching sequence of VSI along with the status of hall effect position sensors.

Figure 6: Operation of BLDC motor when switch S1 and S4 are conducting

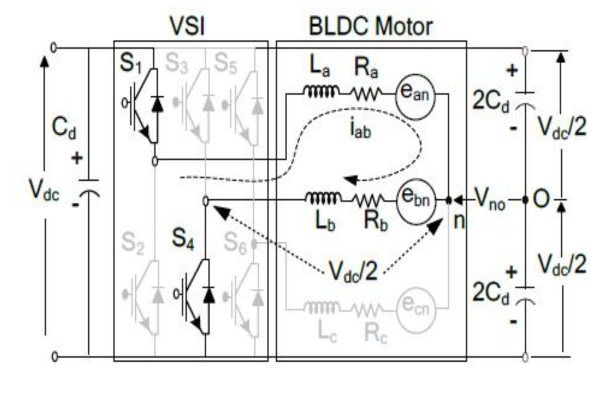


Table 1: Switching States for Achieving Electronic Commutation Based on Hall Sensor Output Signal Levels

Hall Signals			Switching Sequence					
Ha	Hb	Hc	S1	S2	S3	S4	S5	S6
0	0	0	0	0	0	0	0	0
0	0	1	1	0	0	0	0	1
0	1	0	0	1	1	0	0	0
0	1	1	0	0	1	0	0	1
1	0	0	0	0	0	1	1	0
1	0	1	1	0	0	1	0	0
1	1	0	0	1	0	0	1	0
1	1	1	0	0	0	0	0	0

The frequency of the hall sensors is not same. Their variation in active states is decoded for making the following switching sequence. The upper leg switches should provided with a bootstrap oriented gate control since the switch is connected in the higher voltage side.

SIMULATION RESULTS

The performance of 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 performance of BLDC motor, BL buck boost converter and the achieved power quality indices obtained at AC mains. The parameters associated with BLDC motor such as speed, electromagnetic torque and the stator current are analysed for proper functioning of BLDC motor. Parameters such as supply voltage, supply current, DC link voltage, inductor currents, switch voltages and switches currents of PFC BL buck boost converter are evaluated to demonstrate its proper functioning. Moreover, power quality indices such as PF (Power Factor), and THD (Total Harmonics Distortion) of supply current are analyzed for determining power quality at AC mains. The simulation results are shown below.

Figure 7: Power Factor After Power Quality ControlFigure 10: Stator Current

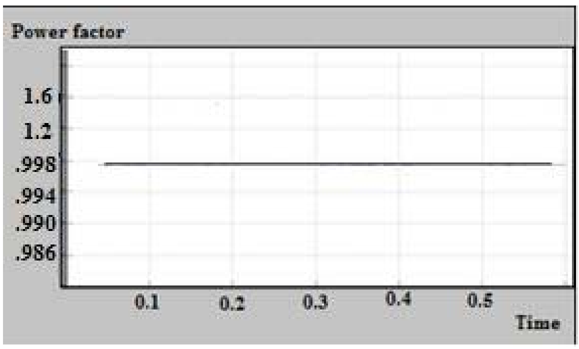


Figure 8: Rotor Speed

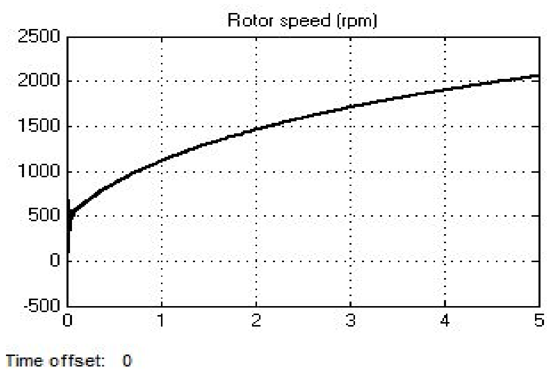


Figure 9: Stator Back EMF

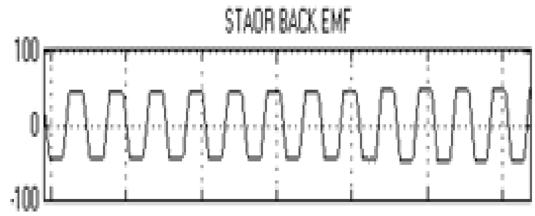


Figure 10: Stator Current

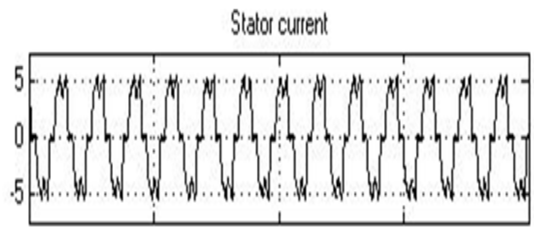


Table 2: Speed performance and PFC of Existing System (CUK converter fed BLDC drive)

Vdc	40	60	80	100	120	140
Speed	380	580	790	990	1210	1410
Power Factor	0.998	0.998	0.998	0.998	0.998	0.998

Table 3: Speed performance and PFC of proposed System (BL BUCK-BOOST Converter fed BLDC drive)

Vdc	40	60	80	100	120	140
Speed	380	580	790	990	1210	1410
Power factor	0.99	0.99	0.99	0.99	0.99	0.99

COMPARATIVE ANALYSIS OF PROPOSED AND EXISTING SYSTEM

Thus the proposed system shown a satisfactory performance and validity is proved.

CONCLUSION

This paper presents the simulation of bridgeless buck boost converter feeding a BLDC motor drive in low power applications. With this proposed converter the power quality can be improved at the AC mains. The power factor can be improved up to 0.99 with this arrangement. The speed control of the BLDC motor can be carried out by varying the DC bus voltage level. Electronic commutation will leads to the reduction of switching stress in the inverter. Speed can be controlled by the variation in DC link voltage. Future scope includes the introduction of any isolation network to control the undesired flow of electric current and a dynamic load change analyzer can be used for detecting rapid load changes**.**

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ISSN 2319-5991