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AN ADJUSTABLE-SPEED PFC BRIDGELESS BUCK–BOOST CONVERTER-FED BLDC MOTOR DRIVE WITH THREE SWITCH LEG VSI INVERTER

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Abstract: 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 performance of the proposed drive is evaluated over a wide range of speed control and varying supply voltages (universal ac mains at 90–265 V) with improved power quality at ac mains. The obtained power quality indices are within the acceptable limits of international power quality standards such as the IEC 61000-3-2. The performance of the proposed drive is simulated in MATLAB/Simulink environment, and the obtained results are validated experimentally on a developed prototype of the drive.

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

I. 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 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 problem. 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 IEC 61000-3-2.A BLDC motor when fed by a DBR with a high value of dc link capacitor draws peaky current which can lead to a THD of supply current of the order of 65% and power factor as low as 0.8. Hence, a DBR followed by a PFC converter is utilized for improving the power quality at ac mains. The choice of mode of operation of a PFC converter is a critical issue because it directly affects the cost and rating of the components used in the PFC converter. The continuous conduction mode and discontinuous conduction mode are the two modes of operation in which a PFC converter is designed to operate. IN CCM, the current in the inductor or the voltage across the intermediate capacitor remains continuous, but it requires the sensing of two voltages (dc link voltage and supply voltage) and input side current for PFC operation, which is not cost-effective. On the other hand, DCM requires a single voltage sensor for dc link voltage control, and inherent PFC is achieved at the ac mains, but at the cost of higher stresses on the PFC converter switch; hence, DCM is preferred for low-power applications. The conventional PFC scheme of the BLDC motor drive utilizes a pulse width-modulated voltage source inverter (PWM-VSI) for speed control with a constant dc link voltage. This offers higher switching losses in VSI as the switching losses increase as a square function of switching frequency. As the speed of the BLDC motor is directly proportional to the applied dc link voltage, hence, the speed control is achieved by the variable dc link voltage of VSI. This allows the fundamental frequency switching of VSI (i.e., electronic commutation) and offers reduced switching losses. They have proposed a buck–boost converter feeding a BLDC motor based on the concept of constant dc link voltage and PWM-VSI for speed control which has high switching losses. A SEPICbased BLDC motor drive has been proposed but has higher losses in VSI due to PWM switching and a higher number of current and voltage sensors which restricts its applicability in low-cost application. They have proposed a buck-boost converter-fed BLDC motor drive with the concept of variable dc link voltage. This reduces the switching losses in VSI due to the fundamental switching frequency operation for the electronic commutation of the BLDC motor and to the variation of the speed by controlling the voltage at the dc bus of VSI. 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) have presented BL buck and boost converters, respectively. This paper presents a BL buck–boost converter-fed BLDC motor drive with variable dc link voltage of VSI for improved power quality at ac mains with reduced components.

II. PROPOSED PFC BL BUCK–BOOST CONVERTER-FEDBLDC MOTOR DRIVE

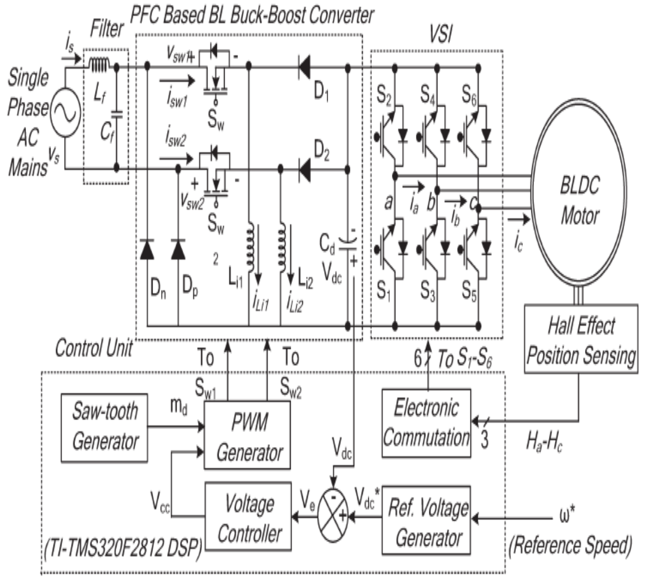


Fig. 1. Proposed BLDC motor drive with front end BL buck–boost converter.

Fig. 1 shows the proposed BL buck–boost converter-based VSI-fed BLDC motor drives. The parameters of the BLbuck–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. 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. 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. The proposed configuration of the BL buck–boost converter has the minimum number of components and least number of conduction devices during each half cycle of supply voltage which governs the choice of the BL buck–boost converter for this application.

III. PRINCIPLES OF OPERATION

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.

A. Operation during Positive and Negative Half Cycles of Supply Voltage

In the proposed scheme of the BL buck–boost converter, switches Sw1 and Sw2 operate for the positive and negative half cycles of the supply voltage, respectively. During the positive half cycle of the supply voltage, switch Sw1, inductor Li1,and diodes D1 and Dpare operated to transfer energy to dclink capacitor Cd as shown in Fig. 2(a)–(c). Similarly, for the negative half cycle of the supply voltage, switch Sw2, inductorLi2, and diodes D2 and Dnconduct as shown in Fig. 3(a)–(c).In the DICM operation of the BL buck–boost converter, the current in inductor Li becomes discontinuous for a certain duration in a switching period. Fig. 2(d) shows the waveforms of different parameters during the positive and negative half cycles of supply voltage.

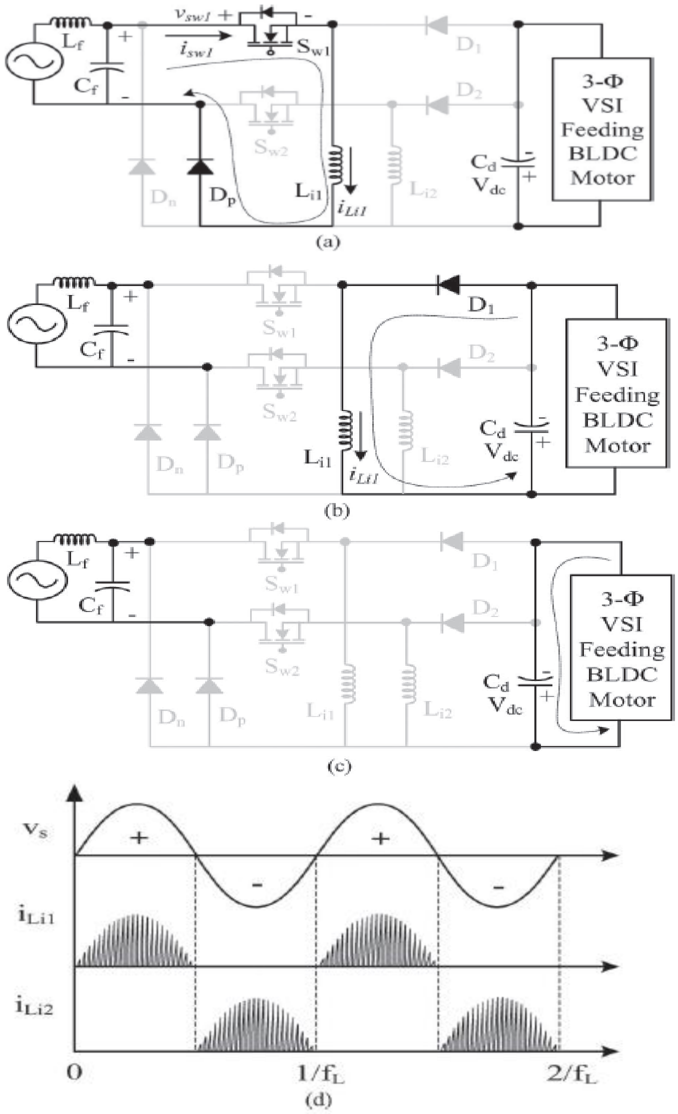


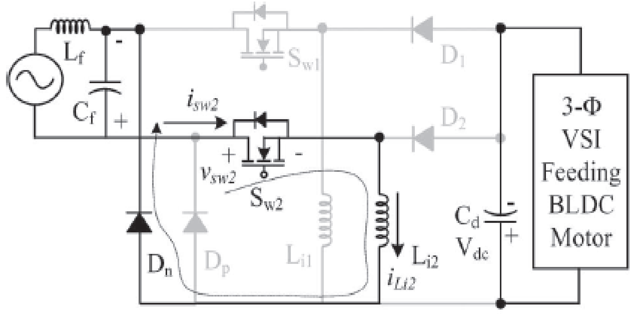
Fig. 2. Operation of the proposed converter in different modes (a)–(c) fora positive half cycle of supply voltage and (d) the associated waveforms.(a) Mode I. (b) Mode II. (c) Mode III. (d)Waveforms for positive and negative half cycles of supply voltage.

B. Operation during Complete Switching Cycle

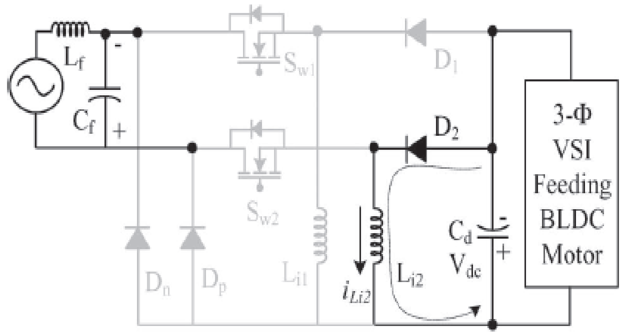
Three modes of operation during a complete switching cycleare discussed for the positive half cycle of supply voltage asshown hereinafter.

Mode I: In this mode, switch Sw1 conducts to charge theinductor Li1; hence, an inductor current iLi1 increases in thismode as shown in Fig. 2(a). Diode Dpcompletes the input sidecircuitry, whereas the dc link capacitor Cd is discharged by theVSI-fed BLDC motor as shown in Fig. 3(d).

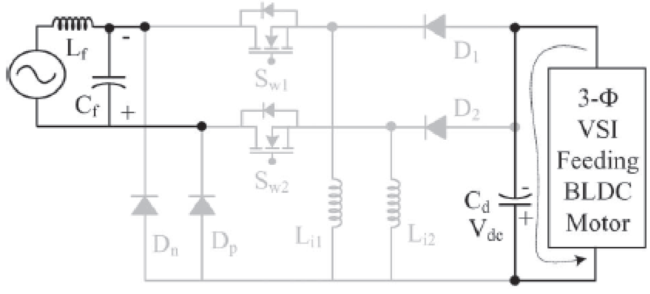
Mode II: As shown in Fig. 2(b), in this mode of operation, switch Sw1 is turned off, and the stored energy in inductorLi1 is transferred to dc link capacitor Cd until the inductor is completely discharged. The current in inductor Li1 reduces and reaches zero as shown in Fig. 3(d). Mode III: In this mode, inductor Li1 enters discontinuous conduction, i.e., no energy is left in the inductor; hence, currentiLi1 becomes zero for the rest of the switching period. As shown in Fig. 2(c), none of the switch or diode is conducting in this mode, and dc link capacitor Cd supplies energy to the load; hence, voltage Vdc across dc link capacitor Cd starts decreasing. The operation is repeated when switch Sw1 is turned on again after a complete switching cycle.



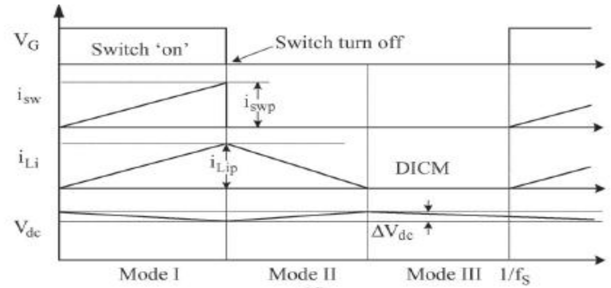
(a)



(b)



(c)



(d)

Fig. 3. Operation of the proposed converter in different modes (a)–(c) fora negative half cycle of supply voltage and (d) the associate waveforms.(a)Mode I. (b)Mode II. (c)Mode III. (d)Waveforms during complete switching cycle.

IV. CONTROL OF BLDC MOTOR: ELECTRONIC COMMUTATION

An electronic commutation of the BLDC motor includes the proper switching of VSI in such a way that a symmetrical current is drawn from the dc link capacitor for 120◦ and placed symmetrically at the center of each phase. A Hall-effect position sensor is used to sense the rotor position on a span of60◦, which is required for the electronic commutation of the BLDC motor. The conduction states of two switches (S1 andS4) are shown in Fig. 4. A line current iab is drawn from thedc link capacitor whose magnitude depends on the applied dclink voltage (Vdc), back electromotive forces (EMFs) (ean andebn), resistances (Ra and Rb), and self-inductance and mutualinductance (La, Lb, and M) of the stator windings. Table Ishows the different switching states of the VSI feeding a BLDCmotor based on the Hall-effect position signals (Ha − Hc).

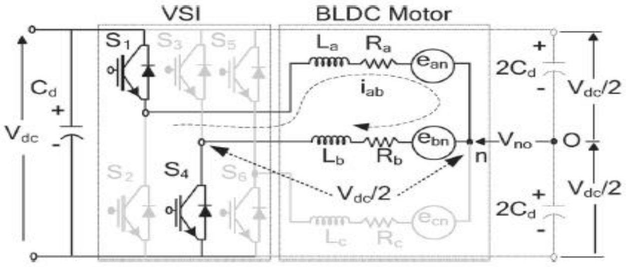


Fig. 4. Operation of a VSI-fed BLDC motor when switches S1 and S4 are conducting.

TABLE I
SWITCHING STATES FOR ACHIEVING ELECTRONIC COMMUTATION OF BLDC MOTOR BASED ON HALL-EFFECT POSITION SIGNALS

θ (°)	Hall Signals			Switching States					
	H_a	H_b	H_c	S_1	S_2	S_3	S_4	S_5	S_6
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

V. 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 BLbuck–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, andit is a recommended solution applicable to low-power BLDC motor drives.

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