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THD Improved Bridgeless Buck Boost Converter Fed-BLDC Motor Drive

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Abstract—*This paper presents a bridgeless buck boost converter fed brushless DC motor drive with total harmonic distortion improvement for low power application. A conventional diode bridge rectifier suffers from high conduction losses at the ac mains which can lead the total harmonic distortion of the order of 65%. To solve this problem a bridgeless buck boost converter has been designed with improved total harmonic distortion. A single DC link capacitor with PI controller has been used for the speed control of Brushless motor drive. The use of DC link capacitor allows us to use the voltage source inverter at fundamental frequency which further reduces conduction and switching loss. The performance of the Motor Drive is evaluated at variable speed with increase power quality at the ac mains. The obtained power quality are found within the permissible limit of international power quality standards such as IEC 61000-3-2.A simulink model has been proposed in Matlab/Simulink to verify the results.*

1. INTRODUCTION

The use of Brushless DC motor drives has been increased widely in the past decade due to advantages such as high efficiency[1], low maintenance required[2], their immunity to electromagnetic inference (EMI),compact size, ruggedness, noiseless operation and higher speed range. Due to these advantages BLDC motors find applications in chemical industry, medical sector ,HVAC etc. A Brushless DC motor is an ac synchronous motor with three phase winding on the stator and permanent magnets on the rotor. As compared to conventional DC motor Brushless DC Motor does not require any segment of commutator and brushes for the commutation purpose rather this motor uses electronic commutation based on rotor position as sensed by Hall effect position sensors[3]. The presence of Hall sensors eliminates sparking ,wear and tear of brushes and electromagnetic inference as caused in conventional DC motors.

A conventional diode bridge rectifier (DBR) with high value of DC link capacitor draws a peaky current from the supply mains which leads to a high total harmonic distortion (THD) of the order of 65-68 %[4].This also causes a high value of conduction and switching losses. In order to minimize these losses and to improve the THD, a bridgeless buck –boost converter has been used in this work. Such type of power quality are within the permissible limits of international power quality standards such as IEC 61000-3-2.Hence improved power quality are obtained at the ac mains[5].

An improved power quality bridgeless converter can be designed in either continuous conduction mode (CCM)orin discontinuous conduction mode(DCM).But continuous conduction mode requires the study of two control loops (Voltage and current loop) which is not a cost effective solution and may also cause imbalance in the reading dur to different sensitivities of the sensors[6]. On the other hand, Discontinuous mode of conduction requires only a single voltage loop for the speed control purpose. This eliminates the problem of current sensitivity and reduces the cost of the system also. But DCM of conduction lead a high voltage stress at the switches so this mode of conduction is preferred mainly for low power household applications such as fan load[7], mixers[8], driers[9] etc.

A conventional PI controller is the most useful technology for control applications of motor drives as PI controller can handle non-linearity, load disturbances and parametric variations[10]. Due to these reasons the for the speed control of BLDC motor a variable voltage DC link capacitor with PI controller is used[11].THD is evaluated at variable speed and supply voltages [12]. A matlab/simulink model has been used to verify the performance of this bridgeless converter fed BLDC motor drive.

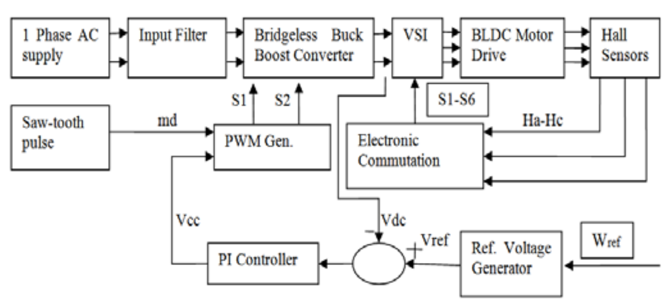

Fig. 1: Block diagram of Bridgeless Buck Boost Converter Fed BLDC Motor Drive

This paper is arranged as follows: The preceding Section 1 consists of literature survey of BLDC motor drive, Bridgeless Buck Boost Converter and PI controller, in next Section 2: the detailed operation of Bridgeless Buck Boost Converter is given

Section 3:consists of a brief overview of BLDC motor derive, Section 4 comprises of Simulation and results are shown in Section 5 and Finally, Section 6 concludes the paper.

2. BRIDGELESS BUCK BOOST CONVERTER

Fig. 1 shows the complete block diagram of Bridgeless Buck Boost Converter Fed BLDC Motor Drive. In this a single Phase supply is used which is given directly to input filter circuit to remove higher order harmonics. The output of Filter circuit is fed to the converter circuit which produces a controlled DC output. This DC voltage is applied to the Voltage Source Inverter and output of inverter circuit is fed to the BLDC Motor.

Fig. 2 shows the circuit diagram of the Bridgeless Buck Boost Converter which consists oftwo switches (S!-S2), two main fast diode (D1-D2) ,two slow diode (Dp-Dn),two inductors (L1-L2) and a DC link capacitor.

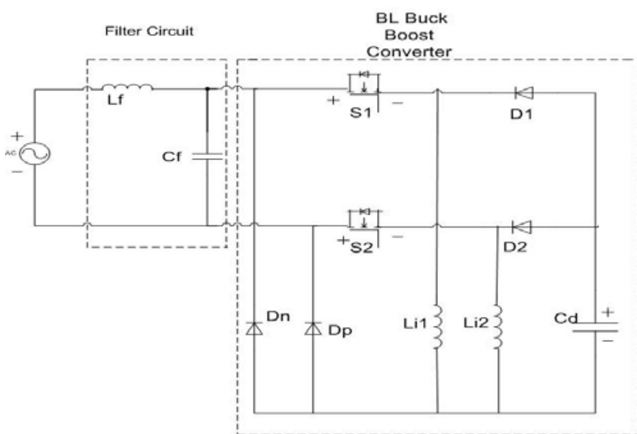

Fig. 2: Bridgeless Buck Boost Converter

Now, complete operation of Bridgeless Buck Boost Converter can be explained in 2 steps which contains the operation between positive and negative half cycle.

2.1 Operation in Positive half cycle

Mode 1 : As shown in Fig. 3(a) in mode 1 switch S1 conducts when gate pulse is applied to it. Magnetizing current flow from S1 -L1-Dp-source. Due to this current inductor L1 charges and initial charge stored by the DC link capacitor gets discharges by the BLDC Motor Drive.

Mode 2 : In this mode switch S1 is turned off and ttal energy stored in the inductor is transferred to the DC link capacitor. Now inductor energy reduces to zero and Cd charges completely. This is shown in Fig. 3(b)

Mode 3 : Now in this mode as shown in Fig. 3(c) inductor falls into discontinuous mode of conduction. Energy across the inductor is zero so there is no more charging of DC link capacitor. Now DC link capacitor start discharging by the VSI fed BLDC Motor Drive. Now Cd starts decreasing and this process repeats itself when switch S1 is triggered again.

2.2 Operation in Negative half cycle

Similarly in negative half cycle switch S2-D2-L2 and Dn completes the path. At first when switch S2 is triggered then magnetizing current flows from S1-L1-Dn-source. This magnetizing current leads to store an energy in the inductor L2 and initial charge stored by the DC link capacitor gets discharges by the BLDC Motor Drive. Now when switch S2 is turned off , total energy stored in the inductor (L2) is transferred to the DC link capacitor. Now inductor energy reduces to zero and Cd charges completely. Now inductor falls into discontinuous mode of conduction. Energy across the inductor is zero so there is no more charging of DC link capacitor. Now DC link capacitor start discharging by the VSI fed BLDC Motor Drive. Now Cd starts decreasing and this process repeats itself when switch S2 is triggered again.

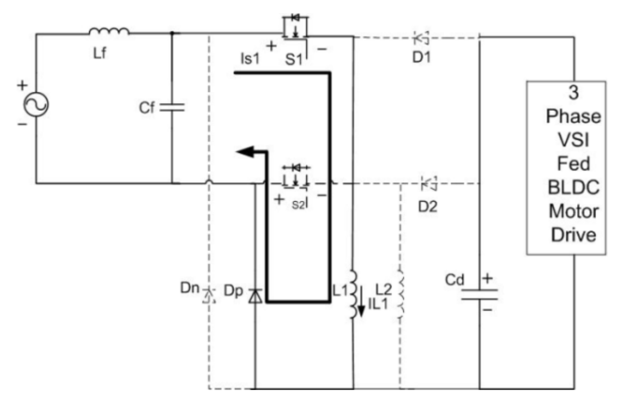

Fig. 3(a)

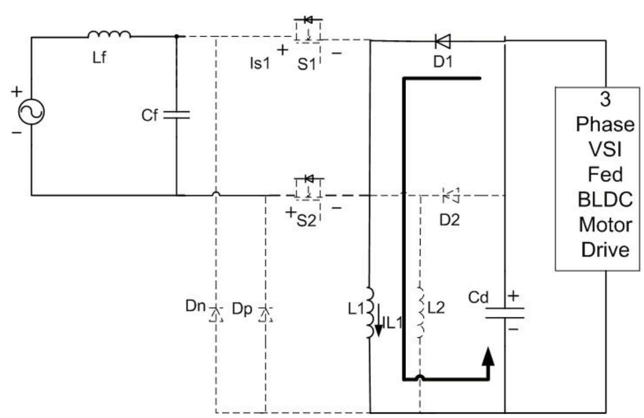

Fig. 3(b)

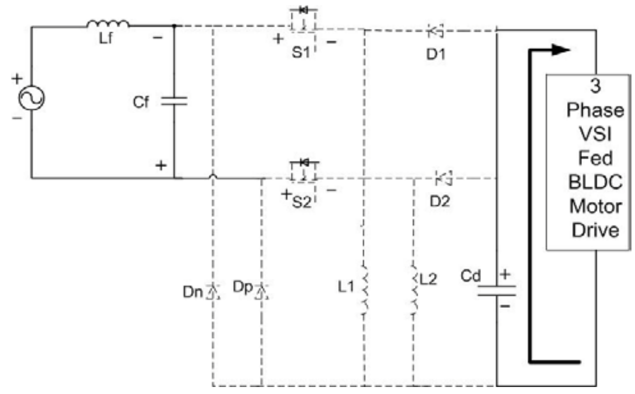

Fig. 3(c)

2.3 Operation during complete cycle

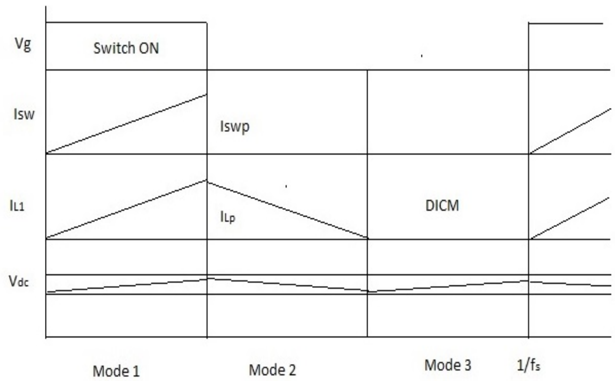

Fig. 3(d)

Fig. 3(d) shows the complete operation of bridgeless Buck Boost Conv0erter in DCM mode. Till the time S1 is 'ON' ,inductor current increases proportionally and in mode 2 current decreases which leads to decrease in the capacitor voltage across DC link capacitor. No inductor goes into DCM mode where it has no stored energy and DC link capacitor discharges to VSI fed BLDC Motor Drive.

2.4 Design of converter parameters

In order to ensure discontinuous mode of conduction bridgeless converter parameters has been designed such as input filter inductance(Lf)[13], input filter capacitance(Cf) [14], input inductors (L1,L2)[15-16]and DC link capacitor (Cd) [17].

For an input voltage of 220 V rms, average voltage at the supply mains is given by

$$Vin = \frac{2\sqrt{2}Vs}{\Pi} \tag{1}$$

So Vin =198 V (approx.).The duty pulse for the Buck Boost Converter is given by

$$d = \frac{Vdc}{Vdc + Vin} \tag{2}$$

On calculation we get d= 0.2015(min.)-0.5023(max.).

For a BLDC motor of power rating 251W, designed value of other parameters has been given in Table 1 as given below.

Table 1: Table Designed parameters

Parameter	Designed Value
DC Link Capacitor (Cd)	1512.9 µF
Input Inductors (L1,L2)	375.97 µH
Input Filter Inductance (Lf)	2.449 mH
Input Filter Capacitance (Cf)	546.99 nF
Duty Ratio for BL converter (d)	0.202 – 0.503

2.5 Control of DC link voltage

For controlling the DC link voltage a voltage follower approach is used. A single voltage loop is used for this purpose. Reference voltage is generated as below

$$Vdc^* = Kv.\ w^* \tag{3}$$

Where w* is the reference speed.Now this generated ref voltage is compared with DC link voltage and an error signal Ve(k) is generated. This error signal is fed to PI controller to generate a controlled votage signal (Vcc).

$$Ve(k) = Vdc^*(k) - Vdc(k) \tag{4}$$

$$Vcc(k) = Vcc(k-1) + Kp\{Ve(k) - Ve(k-1)\} + KiVe(k) \tag{5}$$

Where Kp and Ki are the proportinal and integral gain of PI controller.

Now the Vcc is compared with the high frequency saw-tooth signal(md) to generate PWM for the Bridgeless converter as follows

For Vs >0 { if md < Vcc ,S1='ON'}
{ if md ≥ Vcc ,S1='OFF'}
For Vs <0 { if md < Vcc ,S2='ON'}
{ if md ≥ Vcc ,S2='OFF'} (6)

3. MODELING OF BLDC MOTOR

3.1 Electronic commutation

An electronic commutation in BLDC motor leads to draw a symmetrical DC current from DC link capacitor placed at an space difference of 120 degree [18]. A hall effect position sensor is used to sense the position at an span of 60 degree [19]. Table 2 shows the different switching states of VSI fed BLDC drive with hall sensor states.

Table 2: Switching signals of BLDC motor by Hall effect position sensor

Θ®	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

3.2 Mathmatical Modeling of BLDC Motor

In this paper, The BLDC is modeled as a function of rotor position f(Θ) so that rotor position can be actively calculated according to the variation in speed. Back emf can be expressed as a function of rotor positions.[20]

$$\begin{bmatrix} ea \\ eb \\ ec \end{bmatrix} = Ke.w^* \begin{bmatrix} fa(\Theta) \\ fb(\Theta) \\ fc(\Theta) \end{bmatrix} \quad (7)$$

Where w* is the rotor speed in mech. rad/s ,fa(Θ),fb(Θ)and fc(Θ) are the unit function generator corresponding to emfs of the BLDC motor drive as a function of rotor position.

$$\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} = R \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} + \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} z \begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} + \begin{bmatrix} ea \\ eb \\ ec \end{bmatrix} \quad (8)$$

Where Va, Vb, Vc are the phase voltages, Ia, Ib, Ic are the phase current, R is the resistance, L inductance, M mutual inductance ,z is the time differential operator and ea, eb, ec are the trapezoidal back emfs.

For a3 phase star connected BLDC motor, sum of stator currents is zero i.e.

$$Ia+Ib+Ic=0 \quad (9)$$

Now electromagnetic torque can be expressed as

$$Te=\frac{eaIa+ebIb+ecIc}{wr} \quad (10)$$

4. RESULTS AND SIMULATION

To evaluate the performance of the proposed system a simulink model has been established using Matlab/Simulink. The performance of the drive wih PI controller is studied. The parameters of BLDC motor are tabulated in Table 3.

Table 3. BLDC Motor Parameters

Parameter	Value
Rs	0.36Ω
Ls	0.6 mH
J	48 g-cm2
Kv	78 V/Kr/min
Kp	0.4
Ki	0.3

Fig. 4 shows the input voltage supply (220 V) rms.

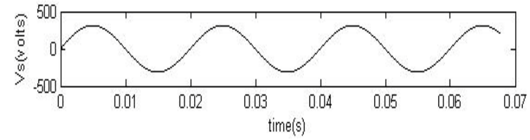

Fig. 4: Supply Voltage

Fig. 5 shows the voltage across the DC link capacitor(Vdc).

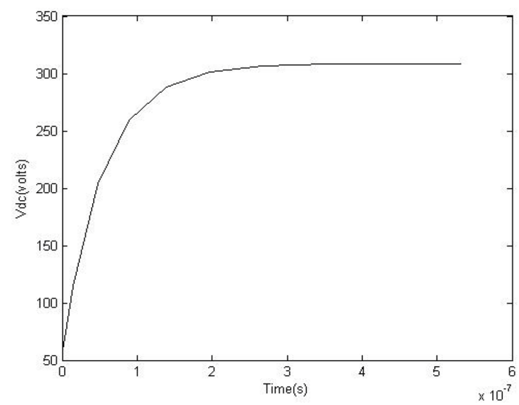

Fig. 5: DC link voltage

Fig. 7 and Fig. 8 shows the rotor speed (in rpm) and electromagnetic torque(Nm) respectively.

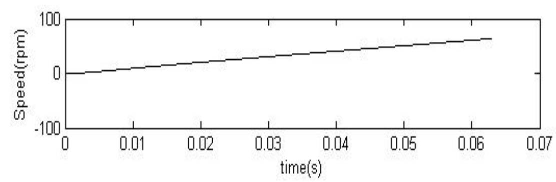

Fig. 7 : Rotor speed (rpm)

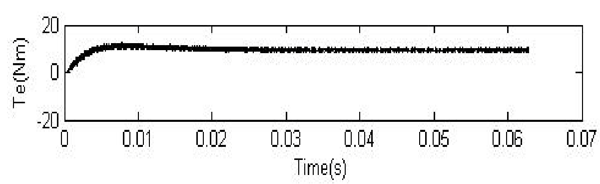

Fig. 8: Electromagnetic Torque(Te)

Fig. 9 shows the THD analysis of supply current at supply frequency of 50 Hz.

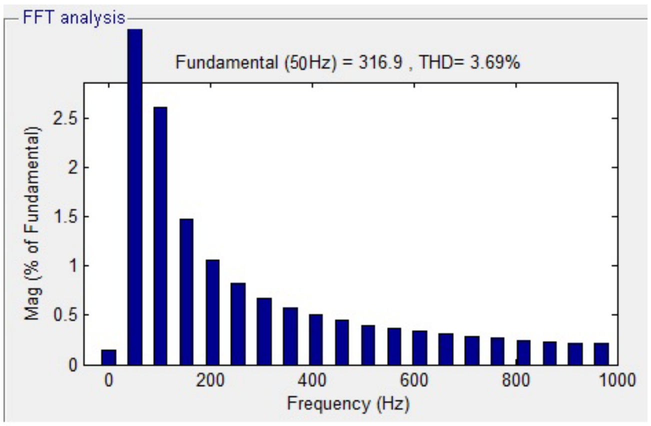

Fig. 9: THD of supply current

5. CONCLUSION

A THD improved Bridgeless Buck Boost converter has been used for low power household applications. DC link capacitor allows the switching of VSI at fundamental frequency leading to less switching and conduction losses. The. Bridgeless Converter has been operated in discontinuous conduction mode which is cost effective also. The obtained power quality are found within the permissible limit of international power quality standards such as IEC 61000-3-2.A PI controller has been established for the speed control of BLDC motor. Finally a simulink model is developed in Matlab/Simulink which has shown satisfactory performance.

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