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Power Quality Inquiry of Two BL-Converter fed BLDC Motor Drive Configurations

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ABSTRACT: This paper presents a power quality inquiry of Two BL- Converter fed BLDC Configurations. A single Voltage sensor method is used for speed control of motor and PFC at the AC mains. The BL-Buck-Boost and the BL-Luo converters are the two configurations which are designed to operate at DICM. The Variable DC link voltage approach allows a low frequency switching of the VSI for the electronic commutation of the BLDC Motor. The systems also provide high power quality indices as recommended by the IEC 61000-3-2. The two configurations can be suggested for low power applications such as computer applications, DVD/CD drives and electric fans in coaches of Indian railway.

KEYWORDS: Bridge less (BL) Converter, Brushless DC Motor (BLDC), Power factor correction (PFC), Discontinuous Inductor current mode (DICM), Voltage source Inverter (VSI)
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I. INTRODUCTION

Developments in the field of electronic control and material technology have given new momentum to the designs of new types of electric motors. High efficiency, high power density, compact size, high ruggedness, low maintenance and immunity to electro-magnetic interference (EMI) problems have been the much needed necessities in the past decade. BLDC (Brushless Dc Motor) motors came to the front line in the years with all the above said capabilities. BLDC motor is considered to be a high performance motor which is capable of providing large amounts of torque over a wide range of speed. BLDC motors are a derivative of the most commonly used DC motor, and they share the same torque and speed characteristics. BLDC motors do not have brushes (hence the name “brushless DC”) and are electronically commutated based on the rotor position as sensed by Hall effect sensors there by eliminating the problems of sparking, wear and tear of brushes, EMI, noise interference [1].

A conventional BLDC motor drive using a front-end diode bridge rectifier (DBR) and a high value of the dc-link capacitor draws highly distorted peaky current which is rich in harmonics [2]. The scheme of the BLDC motor drive is fed by a pulse width modulation (PWM)-based Voltage Source Inverter for speed control is shown in Fig.1. Very low power factor and high total harmonic distortion are the disadvantages of this design. International power quality standards viz. IEC 61000-3-2 does not accept the said power quality indices [3]. Hence, to improve the power quality at ac mains, improved power quality converters (IPQC) are used which also reduce EMI problems [2], [3]. The use of improved power quality converters for BLDC motors are recommended to meet the requirement of power factor above 0.9 and THD below 19% for class D (under 600W, ≤ 16 A, single phase).

Either Continuous conduction mode or discontinuous conduction mode can be used as the IQPC designs of operation. The advantage of CCM is lower stress on a PFC converter switch but requires two control loops for achieving a dc link voltage control with PFC at ac mains [4]. Three sensors are required for this operation, which is costly, therefore preferred mostly for high power ratings. On the other hand, the converter operating in DCM acts as an inherent power factor corrector and hence requires a single voltage control loop for dc link voltage control. However DCM is preferred for low power applications as a higher stress on the PFC converter switch is obtained in a PFC converter working in a discontinuous conduction mode.

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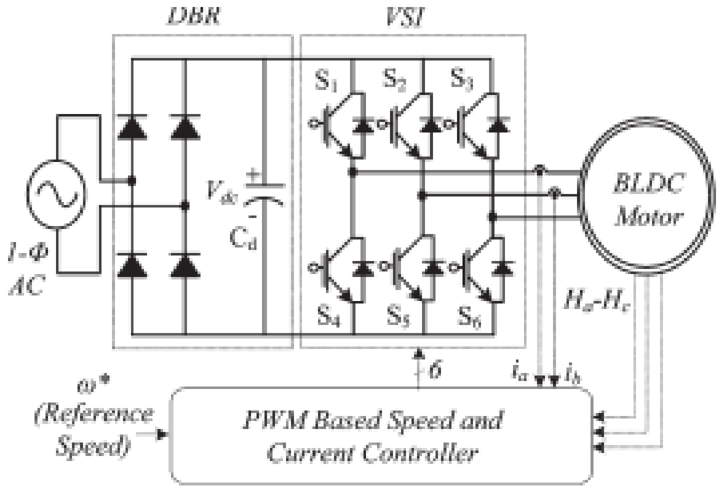

Fig. 1 Conventional PFC based BLDC motor drive [14]

Many configurations of PFC converter feeding a BLDC motor drive have been reported in the literature [5], [6] - [7]. The design of input electromagnetic interference (EMI) filters for power factor correction (PFC) circuits is becoming increasingly important in the light of the new harmonic and EMI reduction standards. The use of standard input filter design procedures developed for dc-dc converters generally results in poor power factor due to large reactive currents [8]. The three main requirements of a PFC circuit input filters are (a) Switching noise attenuation (b) Low input displacement angle between filter input voltage and current, and (c) Over all system stability.
In terms of efficiency, voltage ripple, harmonic content, THD and losses, Luo converter is a better converter compared to other converters such as buck, buck-boost, cuk etc [9]. Converter topology based on a SEPIC converter operating in DCM has been proposed for unipolar excitation of brushless dc motors [10] .The advantages are (a) the converter uses only four controlled switches, all of which are referenced to ground. This considerably simplifies their gate drive circuitry and results in low cost and compact packaging. (b) It is capable of bucking or boosting the available input dc voltage to maximize the current-regulated operation of the drive. (c) The input current naturally follows the input voltage to a certain extent, reducing the amount of low-order harmonics and resulting in a high power factor. (d) Eliminates the possibility of shoot-through faults which could occur in bipolar converters. (e) Lower conduction and switching losses because of the presence of only one switch and diode per phase as opposed to two in the bipolar case. A Cuk dc-dc converter is used as a PFC converter [9]. Bridgeless converter configurations have gained importance in the past decade due their higher efficiency. The front end DBR is eliminated in this configuration, which reduces the conduction losses associated in them. The PF and THD of bridgeless boost converter at full load is more improved one than the bridge type boost converter. Bridgeless PFC boost converter has larger common more noise than conventional PFC boost converter. Suffer from limited voltage conversion ratio [11],[12]. Due to the inherent characteristics of voltage lifting Luo converters are widely used. The use of Luo converter as a PFC has been explored in [13]. Inheriting the advantages of Luo converter and buck boost converter, bridgeless configuration of these converters are explored in this paper for feeding a BLDC motor as a low cost solution for low power applications such as BLDC Fan motor in trains.
In this paper two BL-configurations BL Buck Boost and BL Luo converters were used as the PFC converters for BLDC motors. A single voltage follower method is used for speed control of the BLDC motor. VSI fed BLDC motor drive with small switching frequency is implemented by MATAB/SIMULINK. The simulations have been done for a 400W BLDC motor. The advantages of using BL converters are also discussed.

II. PROPOSED PFC BASED MOTOR DRIVE

The proposed PFC based bridgeless converter fed motor drive is shown in Fig. 2. To feed a voltage source inverter driving a BLDC motor, a single phase supply followed by a filter and a bridgeless converter is used. The bridgeless converters are designed to operate in DICM to act as an inherent power factor pre regulator. By adjusting the dc link voltage of voltage source inverter (VSI), the speed of the BLDC motor can be controlled. This allows the VSI to operate at lower switching frequencies and in turn has low switching losses in it, compared to PWM based VSI fed BLDC motor which has considerably high losses.

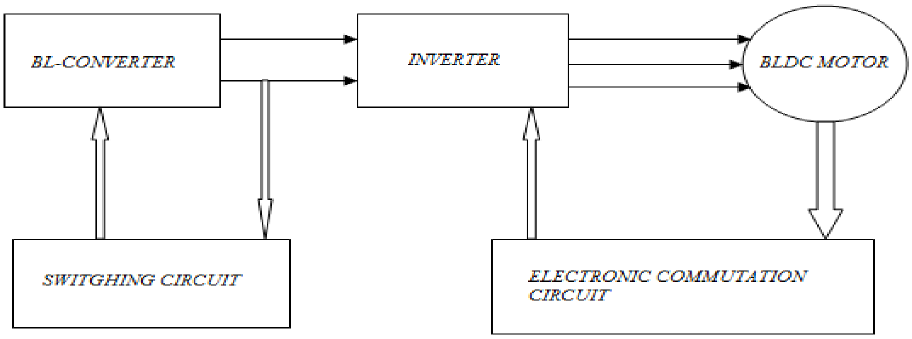

Fig. 2 Proposed PFC bridgeless converter fed BLDC motor drive

A.BL- BUCK BOOST CONVERTER

A buck boost converter is a type of switched mode power supply which combines the principles of both buck and boost converters. The buck boost converter is basically a dc-dc converter and has a negative output voltage with respect to ground. BL-Buck boost converter is the combination of a rectifier and a buck-boost converter. The detailed operating principle of the converter is explained in [14].

B.BL- LUO CONVERTER

LUO converters are a series of new DC-DC step (boost) converters, which were developed from voltage lifting techniques. They possess high output voltage with small ripples. The detailed working principle of the converter is explained in [15]

C.BLDC MOTOR

A BLDC motor is a synchronous electric Motor powered by direct-current (DC) electricity and having an electronic commutation system. BLDC motors are high rpm, low torque motors which are most commonly used in computer applications, DVD/CD drives and electric fans in coaches of Indian railway. They are quiet and have long life with less serviceability related issues unlike the typical AC or DC motors, and have high efficiency. The mathematical modeling of a BLDC motor [1] can be represented from the following equations:

$$V_a = Ri_a + (L-M)\frac{dia}{dt} + e_a$$

$$V_b = Ri_b + (L-M)\frac{dia}{dt} + e_b$$

$$V_c = Ri_c + (L-M)\frac{dia}{dt} + e_c$$

Where e_a,e_b,e_c are the phase back emf V_a,V_b,V_c are the phase voltages and i_a,i_b,i_c are the respective phase currents. L is the phase inductance of each phase. M is the mutual inductance between two phases. The electromagnetic torque can be obtained as:

$$Te = \frac{1}{\omega r}[e_a i_a + e_b i_b + e_c i_c]$$

Wr is the mechanical speed of rotor and Te is the electromagnetic torque. The equation of motion is

$$\frac{d\omega r}{dt} = \frac{1}{J}(Te - Tl - B\omega r)$$

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Where B is the damping constant, J is the moment of inertia T_l is the load torque. The electrical speed is related to mechanical speed by

$$we = \left(\frac{p}{2}\right) wm$$

Where P is the number of poles.

III. CONTROL OF PFC BL CONVERTER- FED BLDC MOTOR DRIVE

The control of the system can be classified into two parts.

D.DC LINK VOLTAGE CONTROL

The dc link voltage control of PFC converter generates the PWM pulses for the converter switches (S_{w1} and S_{w2}).Voltage follower approach (single voltage control loop) is utilized for the PFC BL-converter operating in DICM. The reference dc link voltage is generated from the reference speed of the BLDC motor.

$$V_{dc}^* = k_v w^*$$

k_v and w* are the motor's voltage constant and reference speed. The reference dc link voltage is compared with the measured dc link voltage to generate the voltage error signal V_e which is given as

$$V_e = V_{dc}^* - V_{dc}$$

This error signal is used to generate a controlled voltage V_{cc}.
The output voltage controller is compared with a high frequency saw tooth signal to generate the PWM pulses for the converter switches.

B. Electronic commutation of BLDC Motor
BLDC Motor drives require variable frequency, variable amplitude, excitation which are usually provided by a 3 phase, full bridge inverter as shown in Fig. 3.

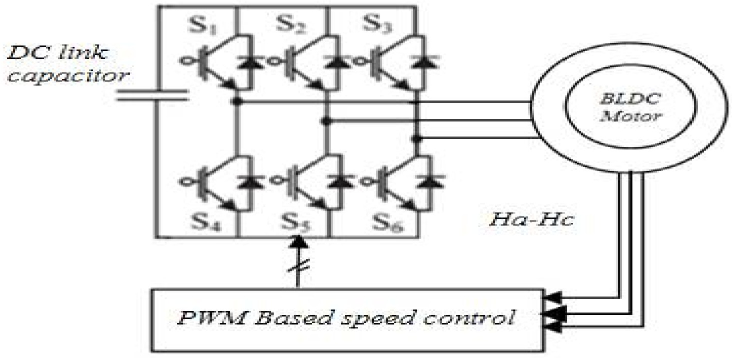

Fig.3 Six step inverter fed BLDC Motor drive

The inverter is usually responsible for electronic commutation. The position information obtained from the position sensors is used to open and close the six inverter switches. There are only two inverter switches – one upper and one lower that conduct at any instant, each for 120° electrical. A rotor position on a span of 60° is required for electronic commutation, which is sensed by the Hall Effect position sensors. The conduction states of two switches are shown in Fig. 4.

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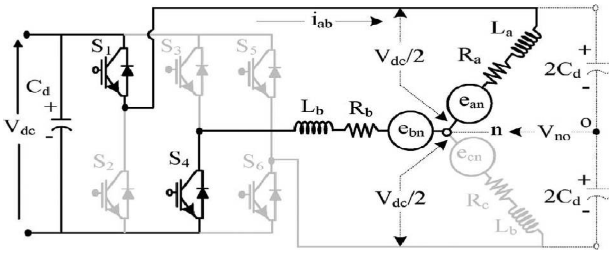

Fig. 4 Conduction states of two switches [16]

A line current I_{ab} is drawn from the dc link capacitor, whose magnitude depends on the applied dc link voltage (V_{dc}), back electro motive forces (e_{an} & e_{bn}), resistance (R_a & R_b), and self and mutual inductances (L_a,L_b & M) of the stator windings. Switching states of VSI based on Hall Effect position signals are shown in Table.1.

Table.1

SWITCHING STATES OF VSI FOR ELECTRONIC COMMUTATION

θ°	Hall signals			Switching States					
	H_a	H_b	H_c	S1	S_2	S_3	S_4	S_5	S_6
0-60	1	0	1	1	0	0	1	0	0
60-120	1	0	0	1	0	0	0	0	1
120-180	1	1	0	0	0	1	0	0	1
180-240	0	1	0	0	1	1	0	0	0
240-300	0	1	1	0	1	0	0	1	0
300-360	0	0	1	0	0	0	1	1	0

IV. SIMULATION AND RESULTS

Here a six-step inverter is used to drive the permanent magnet brushless DC motor. To provide unity power factor in ac mains, the Bridgeless buck-boost converter and Bridgeless Luo converter are designed to operate in discontinuous inductor current mode (DICM). The speed control of BLDC motor is achieved by controlling the dc link voltage of the voltage source inverter feeding BLDC motor using a single voltage sensor. The simulation is carried out using MATLAB /SIMULINK. The following waveforms were obtained. A 314W BLDC motor has been modelled which is fed by a combination of BL converter and VSI. The converters are designed at a power rating of 400W.

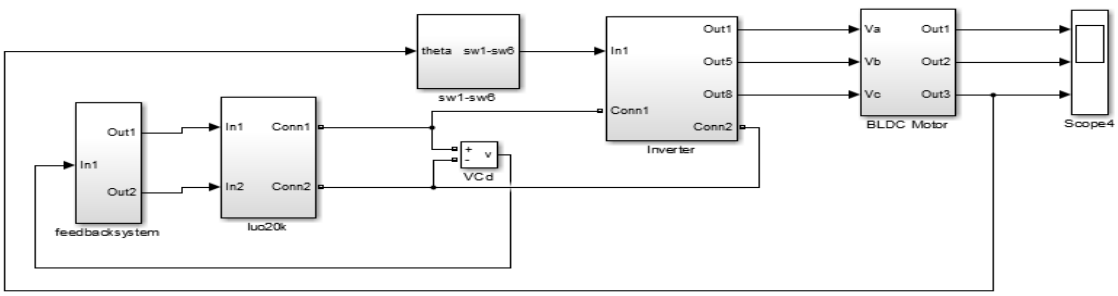

Fig.5 Simulation diagram of BL-LUO converter fed BLDC motor drive

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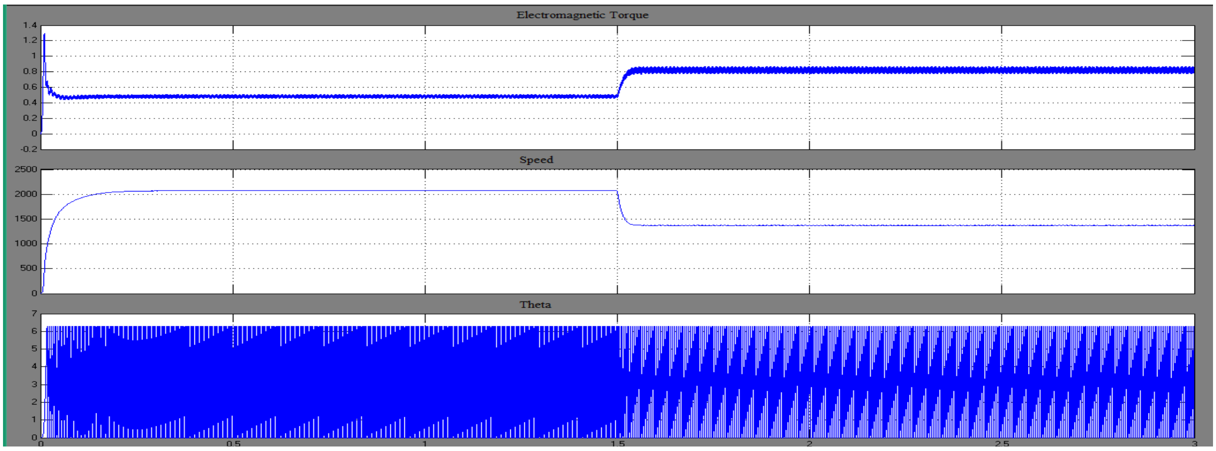

Fig.6 Torque, Speed and Angle waveforms of BL- Luo converter fed BLDC Motor drive (V_{dc}=200V,T_l=.6Nm at 1.5s)

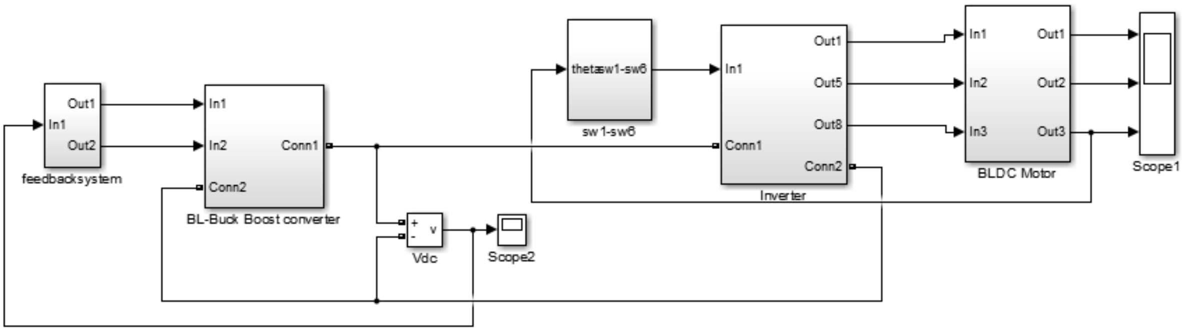

Fig.7 Simulation diagram of BL-Buck Boost converter fed BLDC motor drive

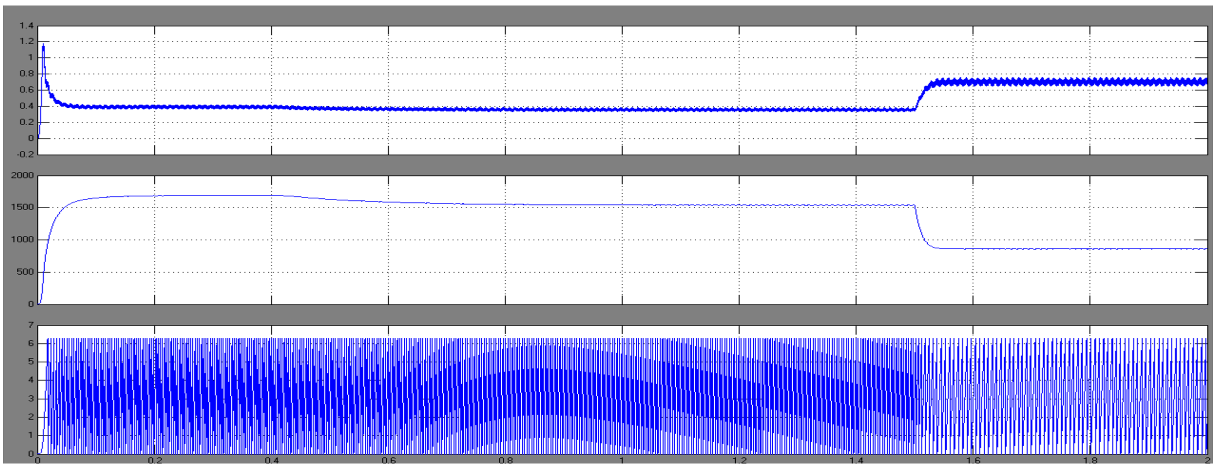

Fig.8 torque, speed and angle waveforms of BL-Buck boost converter fed BLDC Motor drive (V_{dc}=150V,T_l=.6Nm at 1.5s)

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By using FFT analysis, overall THD of the input current is calculated. The Total Harmonic Distortion of the signal is measurement of the harmonic distortion present and it is the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. THD is the measurement of the extent of that distortion. FFT analysis has been done for BL converter - inverter fed BLDC motor drive system for different speeds and is shown in table.2

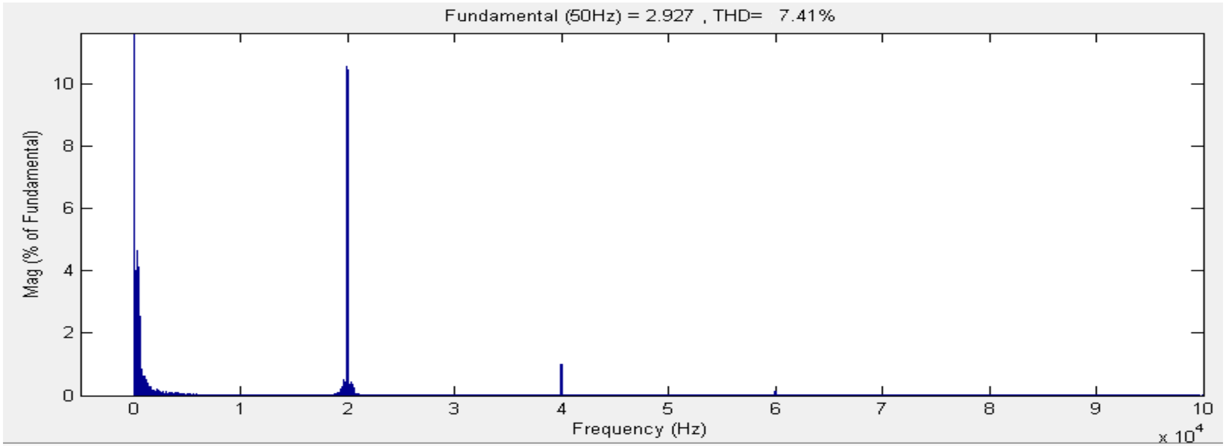

Fig.9 THD analysis of input current of the BL-Luo converter fed BLDC motor drive system (at 400 rpm)

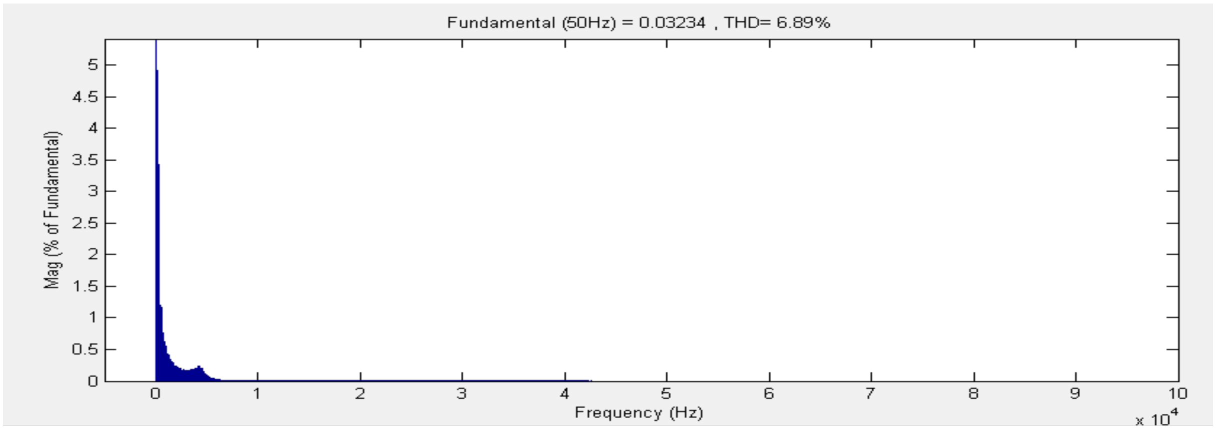

Fig.10 THD analysis of input current of the BL-Buck Boost converter fed BLDC motor drive system (at 380 rpm)

TABLE.2
PERFORMANCE OF BL CONVERTER FED BLDC MOTOR DRIVE

BL LUO CONVERTER				BL BUCK BOOST CONVERTER			
V_{dc} (V)	N (rpm)	THD of I_s (%)	PF	V_{dc} (V)	N (rpm)	THD of I_s (%)	PF
50	380	7.4	.9972	50	400	6.89	.9976
100	900	5	.9987	100	980	4.78	.9988
150	1500	4.6	.9989	150	1510	3.2	.9994
200	1970	3.9	.9992	200	2000	2.69	.9996

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V. CONCLUSION

The PFC BL-converter based VSI fed BLDC motor drive has been proposed for low power applications. Here speed control is achieved by adjusting the dc link voltage at the dc bus and the operating frequency of VSI for electronic commutation is very low which is nearly equal to fundamental frequency. There by reducing the switching losses associate with the system. In both the configurations, the front end diode bridge is eliminated and the converters are designed to operate in DICM. Therefore improved power factor correction at the ac mains occurs. Based on the comparison we can conclude that the BL-Luo converter is some more efficient than the BL Buck Boost converter. A satisfactory performance has been achieved by the two systems and therefore recommended for low power applications.

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