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Comparison between an Interleaved Boost Converter and CUK Converter Fed BLDC motor

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ABSTRACT

There is a great concern of torque ripple and power quality of three phase voltage source converter fed Permanent Magnet Brushless DC Motor (PMBLDCM). In this paper, two control strategies for BLDC motor drive has been investigated. One of the control strategies is based on PFC - CUK converter fed PMBLDCM drive and another one is PFC- interleaved boost converter fed BLDC motor drive. Comparison has been made between the two control stragies in terms of Torque ripple, Total harmonic distortion (THD) and power factor for different operating speeds. The proposed work as been implemented under MATLAB/simulink environment. Simulation results are presented to validate proposed work. From the results, it is observed that PFC interleaved Boost converter fed BLDC motor drive is more effective compared to CUK converter fed BLDC motor drive.

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1. INTRODUCTION

Brushless Direct Current (BLDC) motors are widely used for various applications. They are advantageous compared to other contemporary drives due to more efficiency, higher flux density, less maintenance cost, lower interference (EMI), rugged and wide- range of speed control, A typical BLDC motor consists of stator which has three phase concentrated windings and rotor consisting of permanent magnets [1]-[2]. Hence this motor is called electronically Commutated (EC) motor due to electronic commutation based on Hall Effect sensors sensing the position of rotor [3]-[4]. It is different from conventional DC motor due to absence of mechanical brushes and commutated assembly [5]-[6]. The conventional control scheme of BLDC motor draws current from ac mains which contain harmonics.In order to achieve higher power factor, power factor correction converter are used.PFC converters fed BLDC motor control the motor speed based on variation of duty ratio of pulse width modulation (PWM) signals [7].

The switching losses are propostional on square of switching frequency [8]. Conventional PFC converters include buck-boost, CUK, Zeta converter. The disadvantages of boost PFC converter based direct torque controlled (DTC) BLDC motor are complexity in control and switching losses Finally these configurations efficiently reduces losses in the front end [10] .But the cost increases due to more requirement of number of components.The single phase AC supply through diode bridge rectifier followed by DC link capacitor is used to drive the BLDC motor [11]. The capacitor draws high pulsed current with a peak greater than fundamental input AC mains current due to the uncontrolled charging of capacitor [12]. This results in poor power factor, higher THD and high crest factor [13]. So power factor correction converter is required for BLDC motor drive .In this case CUK DC-DC converter is used for power factor correction.The relative advantages of CUK converter include continuous input and output voltage and small size.

In this paper, two control strategies for BLDC motor based on CUK converter and interleaved boost converter has been developed and comparison is made between this two control strategies for different operating speeds. The performance of the BLDC motor with interleaved boost converter is found to be quite good due to improved power quality, less torque ripple, torque and smooth control of speed of BLDC motor.

2. PROPOSED CONTROL SCHEMES FOR PMBLDC MOTOR

2.1 CUK-Converter Based VSI FED PMBLDC Motor

The Figure 1 shows the block diagram of CUK converter fed BLDC motor .The AC supply is given to the diode bridge rectifier. The variable DC output of bridge rectifier is fed to CUK converter. The output of CUK converter goes to three leg inverter which drives BLDC motor. The power factor correction control scheme is based on the principle of current multiplier approach. This Involves in the presence of current loop inside speed control loop in case of continuous conduction of the converter. The control loop starts with processing of speed error obtained by comparing the actual. Speed with the desired reference speed. The error is fed to the PI controller to obtain the reference torque and compared with actual torque of BLDC motor. The resultant torque error is multiplied with suitable constant amplified is order to provide input to reference current block. The reference current is compared with phase currents, fed to BLDC motor which is again fed to hysteresis current control. The hysteresis current controller generates pluses for operation of three leg inverter.For current control of BLDC motor drive a rate limiter is introduced, which limits the current within specified limits.

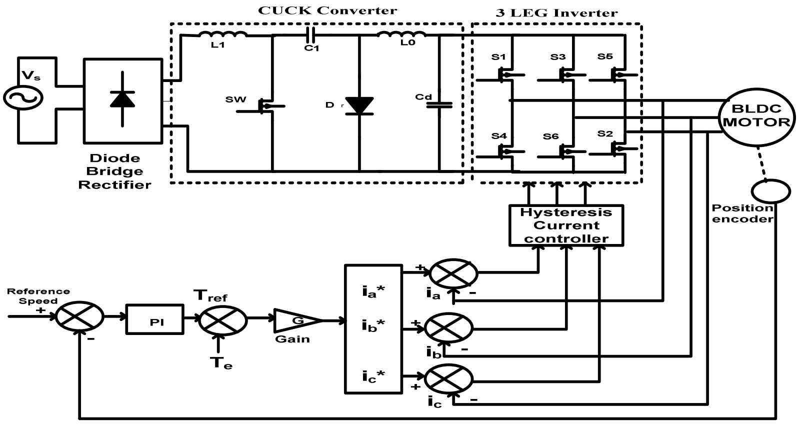

Figure 1. Block diagram of PFC- CUK converter fed BLDC motor

2.2 Design of PFC CUK Converter

The design of the power factor correction based CUK converter fed BLDC motor is described in the following section.
The dc link voltage of the CUK converter is given by

$$\mathrm{v_{dc}} = \frac{\mathrm{DV_{in}}}{(1-\mathrm{D})} \tag{1}$$

Where Vin is the average output of the diode bridge rectifier for a given ac input voltage (Vs)

$$V_{in} = \frac{2\sqrt{2}V_s}{\Pi} \tag{2}$$

The CUK converter uses a boost inductor (Li) and a capacitor (C1) for energy transfer. Their values are given as,

$$\mathrm{L_i} = \frac{\mathrm{DV_{in}}}{\{\mathrm{F_s}(\Delta \mathrm{I_{Li}})\}} \tag{3}$$

$$C_i = \frac{DI_{dc}}{\{F_s(\Delta V_{Ci})\}} \tag{4}$$

Here ΔI_{Li} = Specified ripple content in inductor current
ΔV_{C1} = Specified ripple content in intermediate Capacitor (C_1)
I_{dc} = DC link voltage

A filter is designed to obtained voltage free from ripple at the dc link .The filter consists of inductance (Lo) which limits the ripple content ($\Delta I_{LD)}$ within a specified value for particular switching frequency (Fs).The capacitor in ripple filter is calculated based on allowed ripple content in the DC link voltage (ΔV_{Cd})
The design of L_0 and C_d of the ripple filter is given by

$$L_o = \frac{(1-D)V_{dc}}{\{F_s(\Delta I_{Lo})} \tag{5}$$

$$C_d = \frac{I_{dc}}{(2\omega\Delta V_{cd})} \tag{6}$$

3. INTERLEAVED BOOST CONVERTER BASED VSI FED PMBLDC MOTOR

The Figure 2 shows the interleaved boost converter fed BLDC motor drive system. The control scheme employs hysteresis current control. For three phase of 3-hystersis current controllers and 3- current sensors are required. The AC supply is given to the diode bridge rectifier. The variable DC output of bridge rectifier is fed to interleaved boost converter which is again fed to converter. The output of interleaved boost converter is given to three leg inverter which drives BLDC motor. The power factor correction control scheme works on the principle of current multiplier approach.Which Involves in the presence of current loop inside speed control loop in case of continuous conduction of the converter. The control loop starts with processing of speed error obtained by comparing the actual. Speed with the desired reference speed. The error is fed to the PI controller to obtain the reference torque and compared with actual torque of BLDC motor. The resultant torque error is multiplied with suitable constant and amplified order to provide input to reference current block. The reference current is compared with phase currents fed to BLDC motor which is fed to hysteresis current control. The hysteresis current controller generates pluses for operation of three leg inverter; a rate limiter is introduced, which limits the current within specified limits.

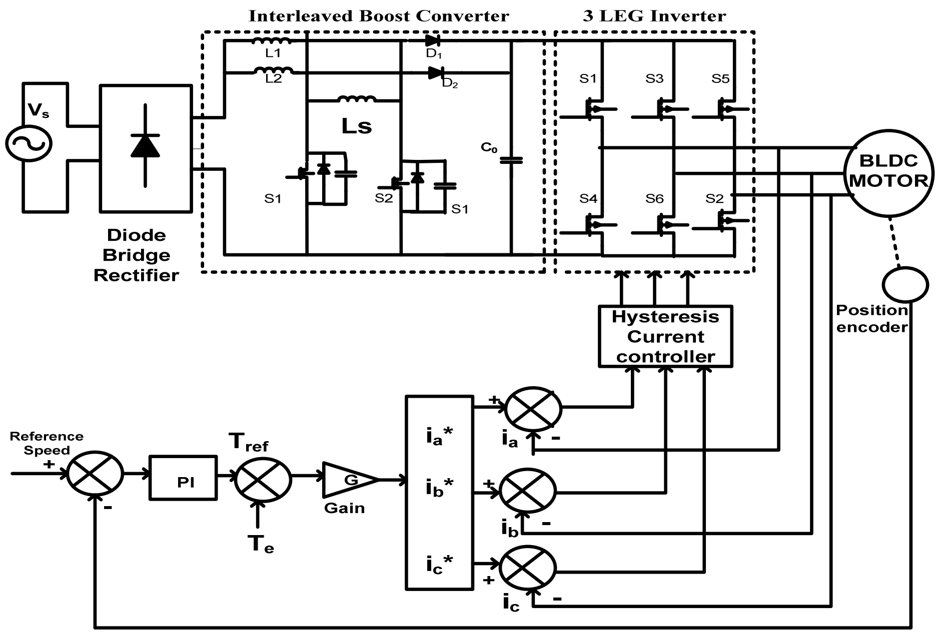

Figure 2. Block diagram of PFC-Interleaved boost converter fed BLDC motor

3.1 Design of PFC Interleaved Boost Converter

The inductors of interleaved boost converter are operating continuous conduction mode. The peak of inductor current is higher due to lower conduction losses of the boost inductor and is related to ripple specification of the current passing through them.
The output of the interleaved converter is given by

$$V_o = \frac{1}{1 - D_{eff}} V_{in} \tag{7}$$

The Ls of the interleaved boost converter

$$\frac{V_O}{L_S} = \frac{2I_L}{(1 - D_{eff)}T_S} = \frac{I_{in}}{(1 - D_{eff})T_s} \tag{8}$$

Here
Ts = switching period
I_{in} = Input current
The load current express is:

$$I_0 = \eta\left(1 - D_{eff}\right)I_{in} \tag{9}$$

The value of Ls can be obtained by

$$L_S = \frac{\eta V_0 T_S (1 - D_{eff})2}{I_0} \tag{10}$$

For normal operation the output voltage Vo is expected to be constant. In order to obtain constant output Voltage is respective of variation in load current of input V_0 items and Vin is written as

$$V_0 = \frac{\eta T_S}{I_{0L_S}} V_{in}^2 = \sqrt{\frac{\eta R T_s}{L_S}} V_{in} \tag{11}$$

The input current I_{in} in terms of output current I_0 is given by

$$I_{in} = \frac{1}{\eta}\sqrt{\frac{V_0 I_0 T_S}{L_S}} \tag{12}$$

Output power Po is given by

$$P_0 = \frac{T_S}{L_S} V_{in}^2 = \eta^2 \frac{L_s}{T_s} = I_{in}^2 \tag{13}$$

The ripples in current of the inductor of boost converter ΔI_L is given by

$$\Delta I_L = \frac{D_{eff}\, T_S}{L} V_{in} \tag{14}$$

Due to the interleaved operation, the input current is the summation of two boost inductor currents.
The ripple in the input current is given by

$$\Delta \mathrm{I_{in}} = \frac{(2 - \mathrm{Deff} - 1)\mathrm{T_s}}{\mathrm{L}} \mathrm{V_{in}} \tag{15}$$

Under certain input current ripple requirement, inductances of inductor L_1 and L_2 can are obtained.The frequency of the ripple content in the output becomes high and a the load receives summation of current from D_1 and D_2
The output ripple voltage ΔV_0 given by

$$\Delta V_c = \frac{I_0 D_{eff}^2 T_s}{2C_0} = \frac{V_0 D_{eff}^2 T_s}{2RC_0} \tag{16}$$

$$\Delta V_{ESR} = I_{in} \times ESR \tag{17}$$

$$\Delta V_O \cong \sqrt{\Delta V_C^2} + \Delta V_{ESR}^2 \tag{18}$$

4. RESULTS AND DISCUSSION

4.1. CUK –Converter and Interleaved Boost Converter Based Six Switch VSI fed PMBLDCM Drive

Figure 3 shows CUK converter (3.a) and interleaved boost converter (3.b). Figure 4(a) shows the stator current waveform of BLDC motor with CUK converter. The stator current reaches to a 22.5 Amps at t=0.01sec. The stator current attains a final steady state value of 4.8Amps and maintains this value there on. Figure 4(b) shows the stator current waveform of BLDC motor with interleaved boost converter. The stator current reaches to a 22.5 Amps at t=0.01sec. The stator current attains a final steady state value of 4.8Amps and maintains this value there on.

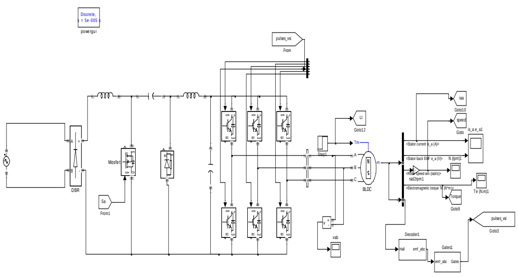

Figure 3(a). CUK converter

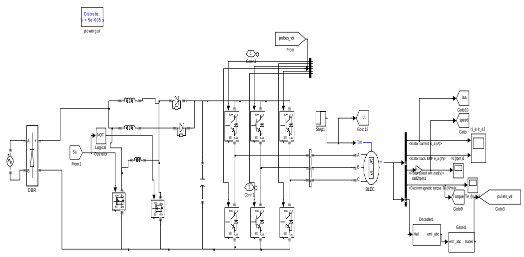

Figure 3(b). Interleaved Boost converter

Figure 3. Simulation diagram of CUK –Converter Six Switch VSI fed PMBLDCM Drive

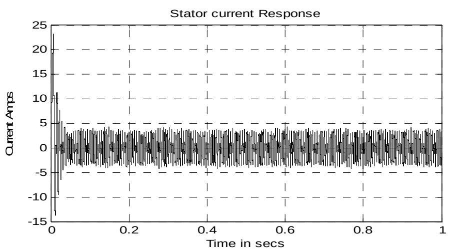

Figure 4(a). CUK- converter

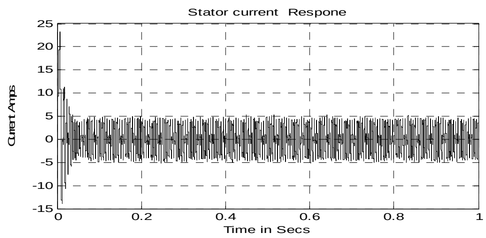

Figure 4(b). Interleaved Boost converter

Figure 4. Stator Current wave form one of the phase of BLDC motor

Figure 5(a) shows the Back EMF waveform of BLDC motor with CUK converter. The back EMF wave form of the BLDC motor is trapezoidal in nature. At t=0.01sec the back EMF wave form is maintained a steady value of the 55V. And gradually increases there on. At t=0.03sec back EMF reaches to110V there after maintains constant value Figure 5(b) shows the Back EMF waveform of BLDC motor with interleaved boost converter.The back EMF wave form is trapezoidal in nature. At t=0.01sec the back EMF is maintained a steady value of the 55V and gradually increases there on t=0.03sec at back EMF reaches to 110V there after maintains constant value.

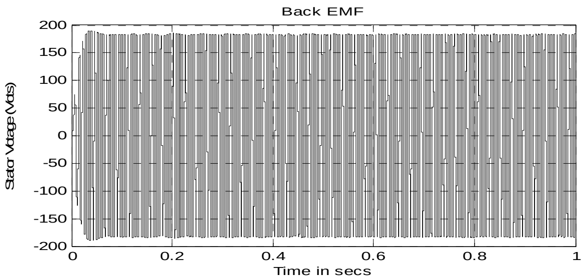

Figure 5(a). CUK-Converter

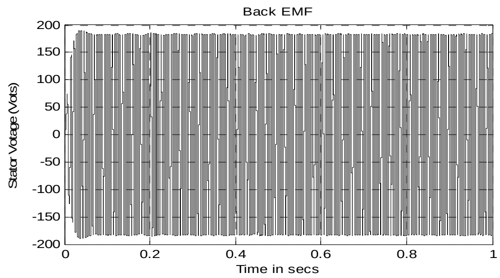

Figure 5(b). Interleaved Boost convereter

Figure 5. Back EMF wave form one of the phase of BLDC motor

Figure 6(a) shows the toque output waveform at speed corresponding to 1500 rpm with CUK converter.The torque rises to 17.5N-m at t=0.01 sec and later fluctuated between 5.5 N-m Figure 6(b) shows the toque output waveform at speed corresponding to 1500 rpm with interleaved boost converter.The torque rises to 19N-m at t=0.01 sec and later fluctuated around 5.2 N-m

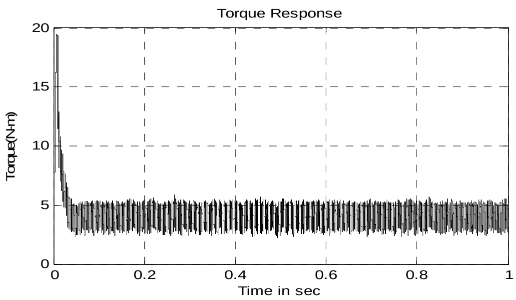

Figure 6(a). CUK-Converter

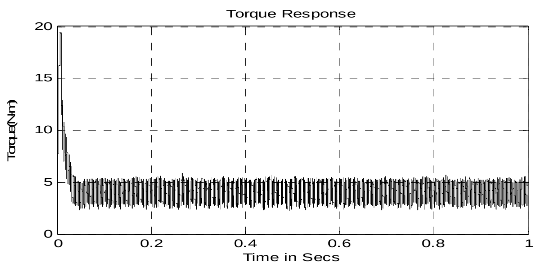

Figure 6(b). Interleaved Boost converter

Figure 6. Torque output wave form at speed corresponding to 1500 rpm

Figure 7(a) shows the torque output waveform at another speed value of 2500 rpm of BLDC motorwith CUK converter.It is observed that the toque rises initially at t=0.01 sec from 0N-m to 32N-m and later it fluctuates between 5N-m there on word. Figure 7(b) shows the toque output waveform at another speed value of 2500 rpm of BLDC motor with interleaved boost converter. It is observed that the torque rises initially at t=0.01 sec from 0N-m to 31N-m and later it fluctuates between 5N-m there on words.

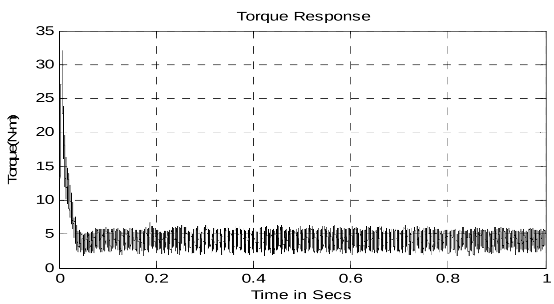

Figure 7(a). CUK-Converter

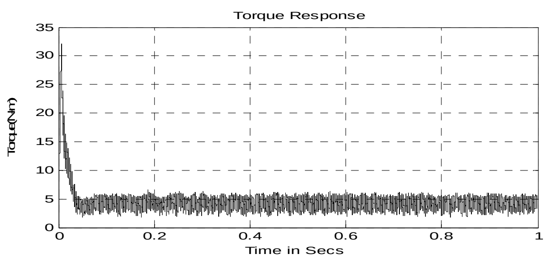

Figure 7(b). Interleaved Boost converter

Figure 7. Torque output wave form at speed corresponding to 2500 rpm

Figure 8(a) shows the speed waves form of BLDC motor with CUK converter. The speed gradually reaches to a value of 1500 rpm and contains constant value for the initially operating range of BLDC motor. Figure 8(b) shows the speed waves form of BLDC motor with interleaved boost converter. The speed gradually reaches to a value of 1500 rpm and contains constant value for the initially operating range of BLDC motor.

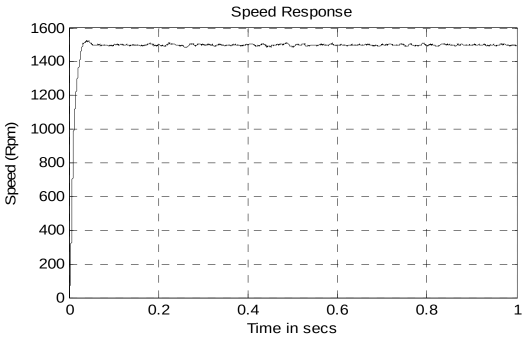

Figure 8(a). CUK –Converter

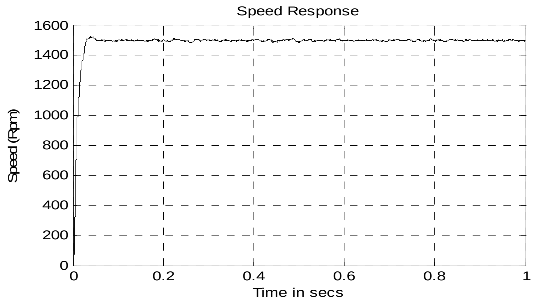

Figure 8(b). Interleaved Boost Converter

Figure 8. Speed output wave form of the drive at constant load torque variable1500 rpm

Figure 9(a) shows harmonic analysis of supply current for CUK converter fed PMBLDCM drive running at 1500rpm It is observed that fundamental component has highest value and dominating followed by lower magnitude 2th, 3th, 4th order again 5th order harmonic content is present and remaining higher order harmonics content is negligible. The total harmonic distortion (THD) value of supply current for CUK converter fed BLDC motor drive system operating at 1500 rpm is 1.97%. Figure 9(b) shows Harmonic analysis of supply current for Interleaved Boost converter fed PMBLDCM drive running at 1500rpm It is observed that fundamental component has highest value and dominating followed by lower magnitude of 2th, 3th, 4th order again 5th order harmonic content is present and remaining higher order harmonics content is negligible. The total harmonic distortion (THD) value of supply current for interleaved boost converter fed BLDC motor drive system operating at 1500 rpm is 2.00%

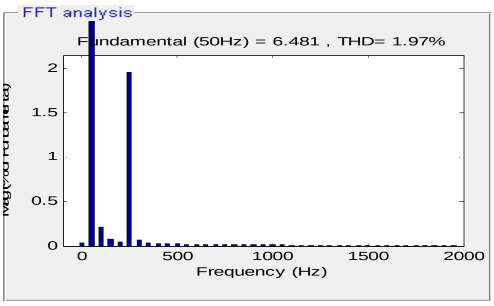

Figure 9(a). CUK –Converter

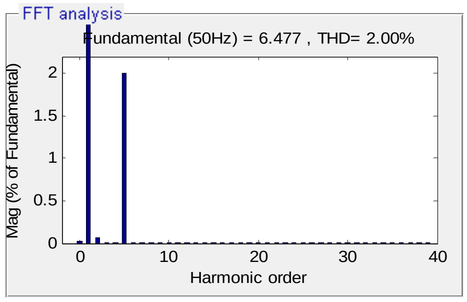

Figure 9(b). Interleaved Boost Converter

Figrue 9. Harmonic analysis of supply current for CUK converter and Interleaved Boost Converter fed PMBLDCM drive running at 1500rpm

Figure 10(a) shows harmonic analysis of supply current for CUK converter fed PMBLDCM drive running at 2500rpm It is observed that fundamental component has highest value and dominating followed by less magnitude 2th, 3th, 4th order and again 5th order harmonic content is present and remaining higher order harmonics content is negligible. The total harmonic distortion (THD) value of supply current for CUK converter fed BLDC motor drive system operating at 2500 rpm is 1.27%. Figure 10(b) shows harmonic analysis of supply current for Interleaved Boost converter fed PMBLDCM drive running at 2500rpm It is observed that fundamental component has highest value and dominating followed by less magnitude of 2th, 3th, 4th order and again 5th order harmonic content is present and remaining higher order harmonics content is negligible. The total harmonic distortion (THD) value of supply current for interleaved boost converter fed BLDC motor drive system with interleaved boost converter operating at 2500 rpm is 1.17%.

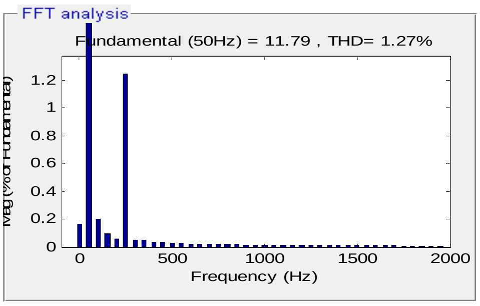

Figure 10(a). CUK –Converter

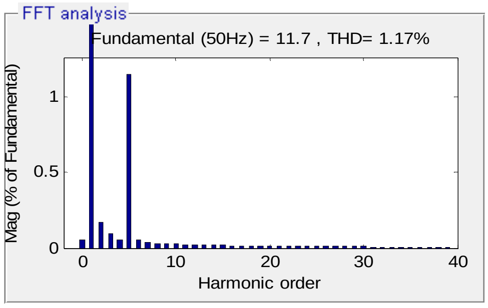

Figure 10(b). Interleaved Boost Converter

Figure 10. Harmonic analysis of supply current for CUK converter and Interleaved Boost Converter fed PMBLDCM drive running running at 2500rpm

5. CONCLUSIONS

This paper presents PFC CUK converter and PFC interleaved boost converter based control strategies for BLDC motor drive.Comparision has been made between two control strategies but PFC interleaved boost converter gives near unity power factor wide range of speed control and variation of input voltage. The Interleaved boost converter fed drive results in torque ripple with smooth speed control compared to CUK converter fed drive.

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