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Power Factor Correction in Two Leg Inverter Fed BLDC Drive Using Cuk Dc-Dc Converter

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ABSTRACT

Earlier for variable speed application conventional motors were used, but these motors have poor characteristics. These drawbacks were overcome by brushless Dc motor drive. Now days in most of the applications such as industrial, domestic, aerospace, defense, medical and traction etc, brushless DC motor (BLDCM) is popular for its high efficiency, high torque to weight ratio, small size, and high reliability, ease of control and low maintenance etc. BLDC motor is a electronic commutator driven drive i.e. it uses a three-phase voltage source inverter for its operation, electronic devices means there is a problem of poor power quality, more torque ripple and speed fluctuations. This paper deals with the CUK converter two leg inverter fed BLDCM drive in closed loop operation. The proposed control strategy on CUK converter two leg inverter fed BLDCM drive with split DC source is modeled and implemented using MATLAB/Simulink. The proposed method improves the efficiency of the drive system with Power factor correction feature in wide range of the speed control, less torque ripple and smooth speed control.

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1. INTRODUCTION

Conventional motor like induction motor and DC motors are most popular electric drives in 20th century. Recently development in power electronics technology and control technology, it application to electrical drive system has increased. The main advantages of induction motor are simple construction, simple maintenance, no slip rings and moderate reliability. The drawbacks are small air gap cracking of rotor bars due to hot spots and lower efficiency and power factor.

The use of permanent magnets in construction of electric machine has following benefits there is no excitation losses, high torque to weight ratio, better dynamic performance, simple construction and less maintenance therefore permanent magnet motors has becomes an attractive option. The development in power electronics technology and control technology and drooping of cost in power electronics devices make possible of operating the motor over a wide speed range and maintaining good efficiency. A 3% increase in motor efficiency can save 2% of energy used [1]

In PMBLDC motor only two phase winding conduct the current and this current in the shape of square or trapezoidal which produce a rotating magnetic field due to this loss are reduced. Another advantage of brushless motor is that power loss occur in stator only, because of this heat transfer condition is good. Considerable improvement in the dynamics is achieved because the air gap flux density high, rotor has low inertia, thus the volume of the motor is reduced by more than 40% [2]. Now days due to the simplicity in

their control, Permanent-magnet brushless dc motors are more widely used in high-performance applications and, the production of ripple-free torque is of primary concern in these applications.

BLDC motor is a electronic commutator driven drive i.e. it uses a three-phase voltage source inverter for its operation, electronic devices means there is a problem of poor power quality, more torque ripple and speed fluctuations. For driving the BLDC motor we use single phase ac supply which is convert to DC with diode bridge rectifier and it output is given to capacitor i.e. DC link capacitor. Due to this DC link capacitor charging and discharging; on AC supply side current is in pulsating form, this cause the power quality problem. Due to many advantages over conventional drives its popularity and its usage is increased and on utility side it cause more severe PQ problem. Research Work is going on to develop an electrical drive system with inherent power factor correction converter (PFC). PFC will force the drive system to draw sinusoidal current from AC supply mains and maintain nearly unity power factor. A PFC converter means an extra cost and complexity which is not acceptable. There are so many PFC converter topologies are available in which DC-DC converter topology is more popular due to low cost and less complexity. Buck, boost, buck boost, SEPIC are the examples for DC-DC converters topology. In air-conditioners applications, a BLDCM with boost PFC converter [3] and PMSM with improved power quality converter [4] have been reported for power quality improvement, results in improvement in performance such as improved efficiency, reduction of harmonics on AC supply side, noise reduction etc .

This paper deals with the application of cuk converter as PFC to feed two leg inverter fed BLDCM with split DC supply, results in improvement in performance such as improved efficiency, reduction of harmonics on AC supply side, noise reduction, nearly unity power factor at ac supply side, less torque ripple and smooth sped control.

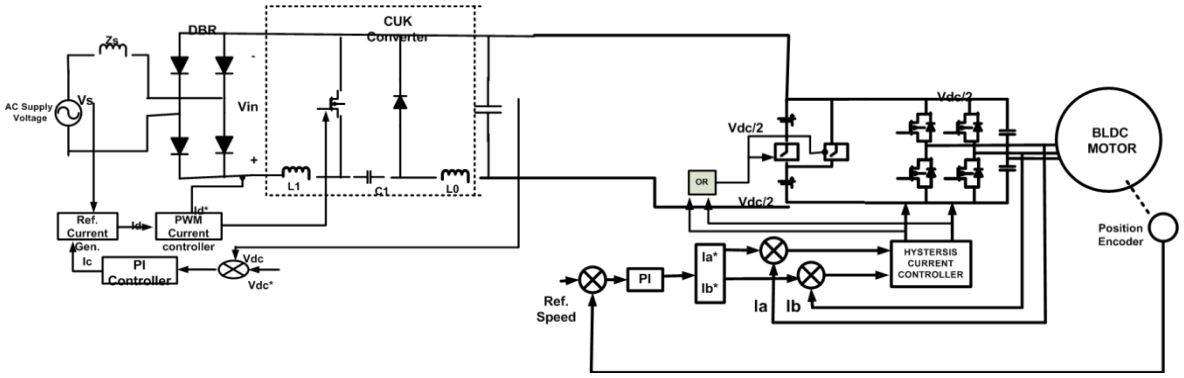


Figure 1. Schematic Diagram of Proposed CUK PFC two leg inverter fed BLDCM with split DC supply

2. OPERATION OF CUK PFC TWO LEG INVERTER FED BLDCM DRIVE

Figure 1 shows the schematic diagram of proposed CUK PFC two inverter fed BLDCM with split DC supply for speed control as well as PFC in vide range of input AC voltage. It consist of two schemes one is Power factor correction control scheme which uses a current multiplier approach concept with a current control loop inside and second one is the speed control loop for continuous-conduction-mode operation of the converter. First reference DC link voltage is compared with the actual DC link voltage which generates the DC link voltage error signal (Vdc_error), which is processed through a PI controller to generate control signal (Ic). This control signal multiplied with a unit template of input ac voltage to get reference DC link current (Idc_ref). This reference DC link current (Idc_ref) is compared with dc link current (IDC) which is sensed after diode bridge rectifier. The resultant DC current error (IDC_err) is amplified and compared with a saw tooth carrier wave of fixed frequency (Fs) to generate the pulse width modulation (PWM) pulse for the Cuk convertor. Its duty ratio (D) at a switching frequency (Fs) controls the dc link voltage at the desired value. For speed control reference speed is compared with actual speed of the motor which gives speed error (Nerr) which is processed through PI controller, which give reference current signal (Iref), this reference current signal is multiply with hall sensor current position information, which generate the reference stator current signal (Ia_ref). This reference stator current signal (Ia_ref) processed with hysteresis controller to generate the firing pulse for voltage source inverter.

3. DESIGN OF PFC CUK CONVERTER

Figure 2 shows the schematic of CUK converter used for PFC and speed control for proposed CUK PFC two inverter fed BLDCM drive. This converter is obtained by using the duality principle of buck boost converter. CUK converter gives negative polarity regulated output voltage w.r.t. the common terminal of input DC voltage. The capacitor C_1 acts as energy storing and energy transferring element from input to output.

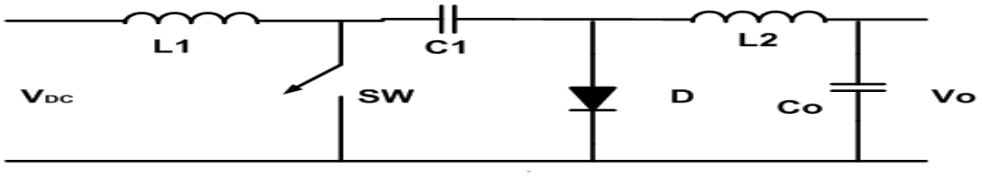


Figure 2. Schematic of CUK converter

The average inductor voltage V_{L1} and V_{L2} is zero at steady state, therefore $V_{C1}=V_{dc}+V_o$ (1)

V_{C1} is large than both V_{dc} and V_O.

When the switch (SW) is off, inductor currents $I_{L1}$and I_{L2} flows through diode, the circuit is as shown in Figure 3. Capacitor C_1 charged through the diode by energy from both the input and L_1. Current I_{L1} decreases, because V_{C1} is greater than V_{dc}. Energy stored in L_2 feeds the output, therefore I_{L2} also decreases.

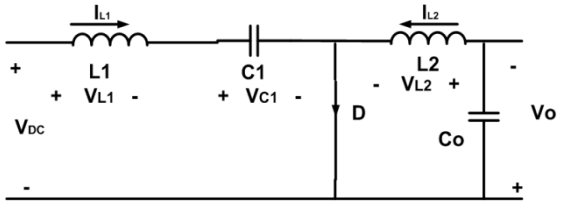


Figure 3. CUK Converter waveform when switch (SW) is off

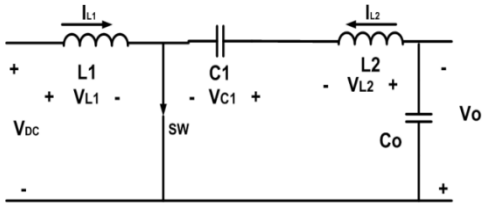


Figure 4. CUK Converter waveform when switch (SW) is on

When the switch (SW) is on, V_{C1} reverse bias the diode, the inductor currents $I_{L1}$and I_{L2} flows through switch (SW), the circuit as shown in Figure 4. Since V_{C1} is greater than V_O, capacitor C_1 discharged through the switch (SW), and transferring the energy to the output and L_2. Therefore Current I_{L1} increases. The input feed energy to L_1 causing I_{L1} to increase.

The inductor currents IL1and IL2 are assumed to be continuous and we assume the capacitor voltage VC1 to be constant, then equating the integral of the voltage across L1 and L2 over one time period to zero gives

At L_1, $V_{dc}DT_s+(V_{dc}-V_{C1})(1-D)T_s=0$ therefore $V_{C1}=\frac{1}{(1-D)}V_{dc}$ (2)

At L_2, $(V_{C1}-V_o)DT_s+(-V_o)(1-D)T_s=0$ therefore $V_{C1}=\frac{1}{D}V_o$ (3)

The dc link voltage of the PFC converter is given as, $v_o=\frac{DV_{dc}}{(1-D)}$ (4)

Where $V_{dc}$the average output of the DBR for a given ac input voltage V_s ,$V_{dc}=\frac{2\sqrt{2}V_s}{\Pi}$ (5)

The Cuk converter uses a boost inductor $L_1$and a capacitor C_1 for energy transfer. Their values are given as,

$$L_1=\frac{DV_{dc}}{\{F_s(\Delta I_{L1})\}} \quad (6)$$

$$C_1 = \frac{DI_{dc}}{\{F_s(\Delta V_{C1})\}} \quad (7)$$

Where ΔI_{L1} is a specified inductor current ripple, ΔV_{C1} is a specified voltage ripple in the intermediate capacitor (C_1), and I_{dc} is the current drawn by the BLDCM from the dc link. A ripple filter is designed for ripple-free voltage at the dc link of the Cuk converter. The inductance (L2) of the ripple filter restricts the inductor peak-to-peak ripple current (ΔI_{L2}) within a specified value for the given switching frequency (Fs), whereas the capacitance (Co) is calculator for the allowed ripple in the dc link voltage (ΔV_{Cd}). The values of the ripple filter inductor and capacitor are given as,

$$L_2 = \frac{(1-D)V_o}{\{F_s(\Delta I_{L2})} \quad (8)$$

$$C_o = \frac{I_{dc}}{(2\omega\Delta V_{cd})} \quad (9)$$

The advantage of CUK converter circuit is that both the input current and the current feeding the output are reasonable ripple free, therefore it is possible to simultaneously eliminate the ripple in both the inductor currents completely, leading to lower external filtering requirements and the disadvantage is the requirement of a capacitor C1 with large ripple current carrying capability.

4. MODELING OF PROPOSED PFC CONVERTER BASED PMBLDCM DRIVE

The PFC cuk two leg inverter fed BLDCM drive with two DC source are the main parts of the proposed drive system, which are modeled by mathematical equations and a combination of these equations represents the complete model of the proposed drive system. The PFC converters consist of DBR, cuk converter and ripple filter. Voltage controller, reference current generator, PWM controller, speed controller, a reference current generator, a PWM current controller and a PMBLDC motor are used for complete representation of cuk fed BLDCM drive system.

PFC Converter

The PFC converter block consists of voltage controller, PWM controller and a reference current generator.

Voltage Controller

The proportional integral (PI) controller is used to control the DC link voltage.
DC voltage error Vdc_e(k) at kth is calculated as $V_{dc\_e}(k) = V^*_{dc}(k) - V_{dc}(k)$
$V^*_{dc}(k)$ is reference DC link voltage and $V_{dc}(k)$ is sensed DC link voltage at kth instant
This DC voltage error is processed through the Proportional integral voltage controller to get desired control signal Iref_dc(k) at kth instant is given as,

$$Iref\_dc(k) = I(k-1) + Kpvc[Ve(k) - Ve(k-1)] + KivcVe(k) \quad (10)$$

Where Kpvc and Kicv are the proportional and integral gains of the voltage controller

Reference Current Generator

The reference inductor current, I^*_{dc} , of the Cuk converter is given as,

$$I^*_{dc} = I(k)u_{vi} \quad (11)$$

Where uvi is the unit template of the input AC mains voltage calculated as,

$$u_{vi} = \frac{V_d}{V_{in}} \quad ;V_d = |V_i| \text{ ; } Vi = Vin \sin \omega t \quad (12)$$

where ω is frequency in rad/s at input AC mains.

PWM Controller

The reference Cuk converter current is compared with its sensed current to generate the current error $\Delta i_{dc} = I^*_{dc} - I_{dc}$. This current error is amplified by gain Pdc and compared with carrier waveform Qd(t). The switching signals for the IGBT of the PFC converter are generated by comparing this amplified current error with saw-tooth carrier waveform of 2 kHz.

If Pdc Δidc > Qd (t) then Scuk = 1 (13)

If Pdc Δidc ≤ Qd (t) then Scuk = 0 (14)

where Scuk is the switching function of the switch used in Cuk converter representing, "on" position with Scuk = 1 and its "off" position with Scuk = 0.

PMBLDCM Drive

The modelling of a speed controller is quite important as the performance of the system depends on this controller. If at kth instant of time, $\omega^*_r(k)$ is reference speed, ωr(k) is rotor speed then the speed error ωe(k) can be calculated as,

$$\omega_e(k) = \omega^*_r(k) - \omega_r(k) \quad (15)$$

This speed error is processed through a speed controller to get desired control signal.

Speed Controller

The output of the PI controller at kth instant T (k) is given as,

$$T(k) = T(k-1) + Kps[\omega e(k) - \omega e(k-1)] + Kis\, \omega e(k) \quad (16)$$

Where Kps and Kis are the proportional and integral gains of the speed controller.

Reference Winding Currents

The amplitude of stator winding current is as,

$$I^* = \frac{T(k)}{2K_{b\_emf}} \quad (17)$$

Where Kb_emf is the back emf constant of the BLDCM.

The reference phase currents of the motor winding are denoted by for phases i^*_a, i^*_b for phases a, b respectively. For duration of 0-60º the reference currents can be given as $i^*_a = 1,$ and $i^*_b = -1,$ Similarly, the reference winding currents during other 60º duration are generated in rectangular 120º block form in phase with trapezoidal voltage of respective phases. These reference currents are compared with sensed phase currents to generate the current errors $\Delta i_a = (i^*_a - i_a)$, $\Delta i_b = (i^*_b - i_b)$, for three phases of the motor.

5. RESULTS AND ANALYSIS

Simulation model was developed using MATLAB/ SIMULINK software to test and validate the performance of PFC cuk two leg inverter fed BLDCM drive using split DC supply. Figure 5 Shows the Simulink block diagram of PFC cuk two leg inverter fed PMBLDC drive using split DC supply. The performance of the PFC cuk two leg inverter fed BLDCM drive using split DC supply is analyzed on the basis of various factor such as mechanical parameters, electrical parameters of the BLDC motor and the front end CUK converter i.e. the speed, stator current and electromagnetic torque, DC link voltage, the cuk inductor current, the voltage across the bulk capacitor, which shows satisfactory performance of the CUK converter fed BLDCM drive. Parameters such as the power factor, the Total Harmonic Distortion, supply current and supply voltage determine the performance of the drive in terms of power quality. The performance of the drive is simulated for constant rated torque (2 Nm) at rated speed of 1000 rpm, with an input AC voltage of 220V, 50 Hz supply.

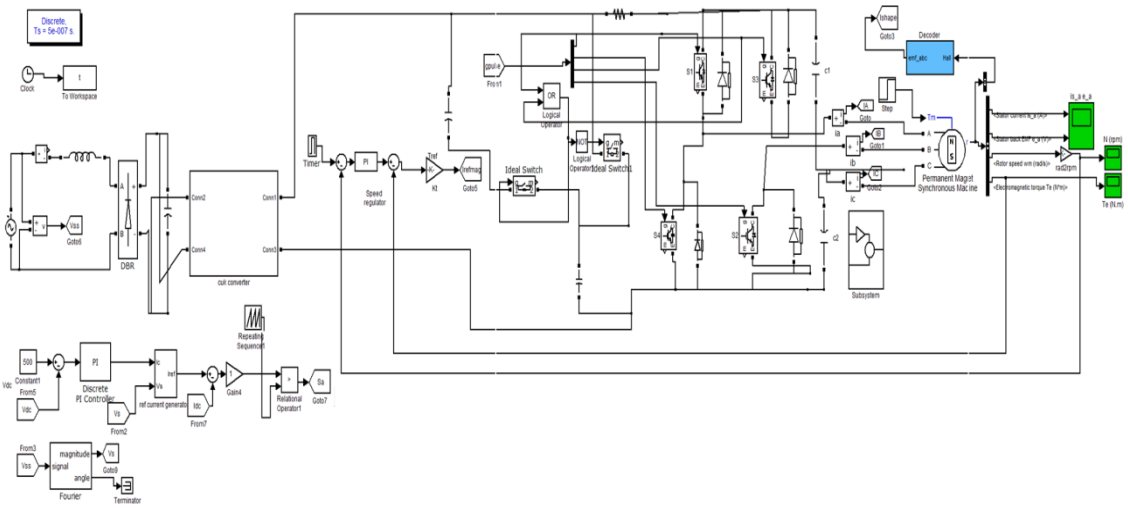
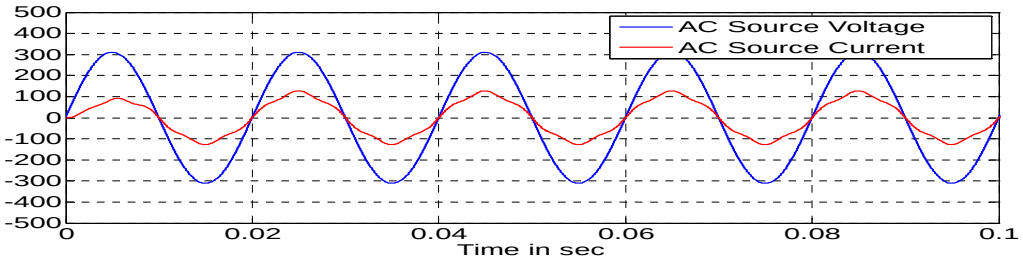


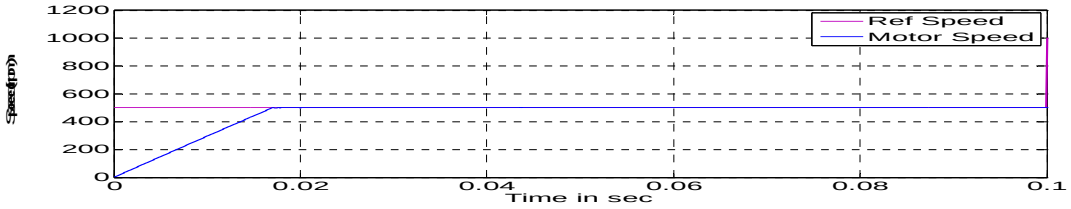
Figure 5. Simulink model of PFC cuk two leg inverter fed PMBLDC drive using two DC supply

a. Performance of CUK Converter Fed PMBLDCM Drive During Starting

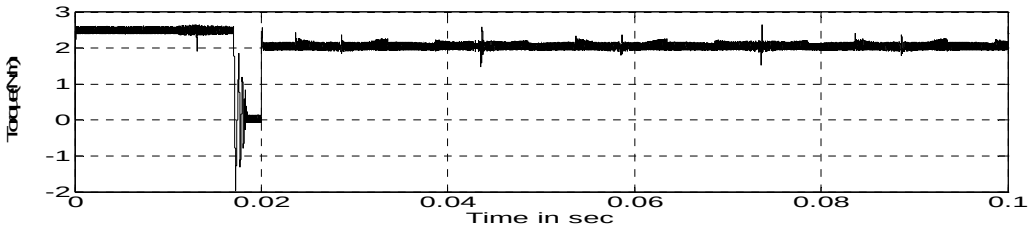
The performance of the CUK converter fed BLDCM drive is evaluated at starting, while the motor is feed from 220 V, 50 Hz AC supply at rated torque of 2 Nm with a reference speed of 500rpm. Figure 6 performance of BLDCM drive during starting in terms of input AC voltage, Ac source current, DC link voltage, speed of the drive, torque developed by motor and phase a stator current. Motor reached to a set speed of 500rpm with a load torque of 2Nm at t=0.015 sec. at the time of starting motor is taking a current of 3amp peaks, Ac voltage waveform and source current are in phase means nearly unity current and voltage are in phase maintains unity power factor from starting.



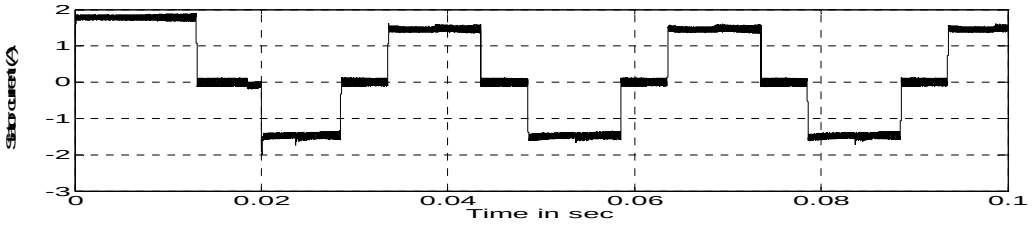
(a). AC source voltage and source current response



(b). Speed response during starting



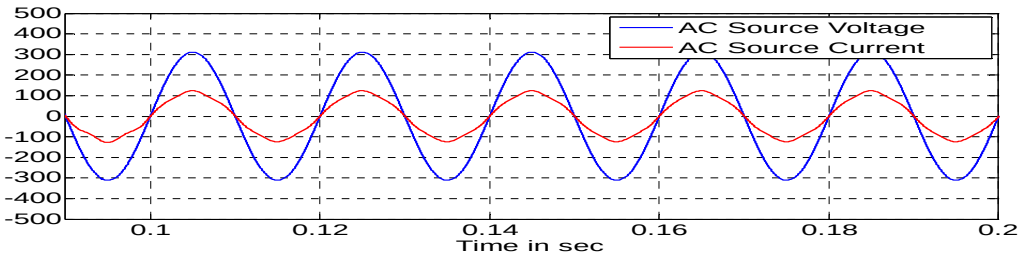
(c). Torque response during starting



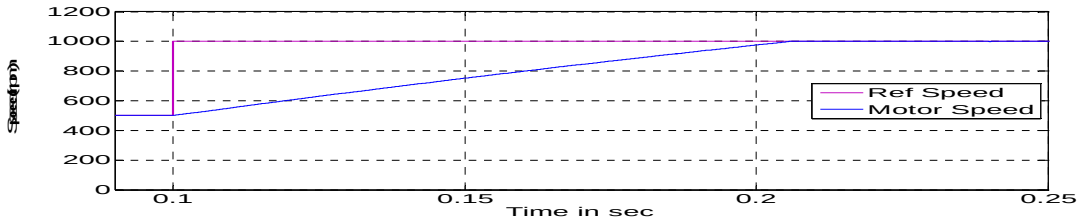
(d). Stator current response during starting

Figure 6. Performance of BLDCM drive during starting

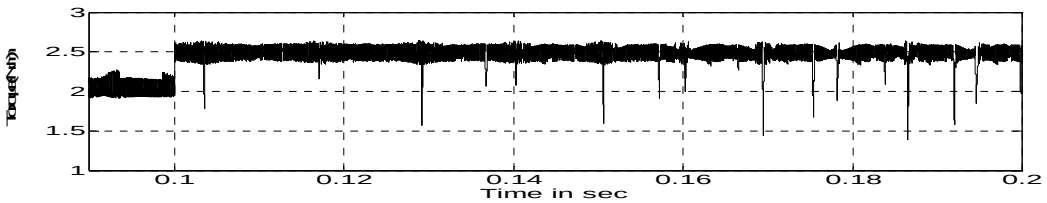
b. Performance of the drive when speed increase from 500 rpm to 1000 rpm



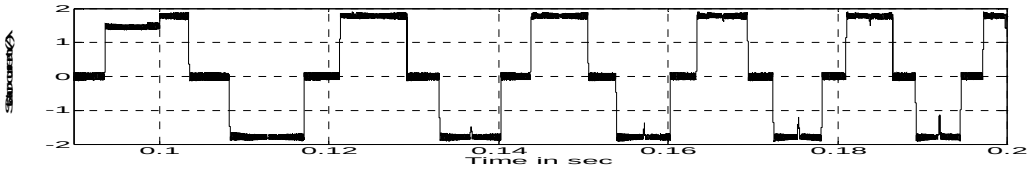
(a). AC source voltage and source current response



(b). Speed response



(c). Torque response

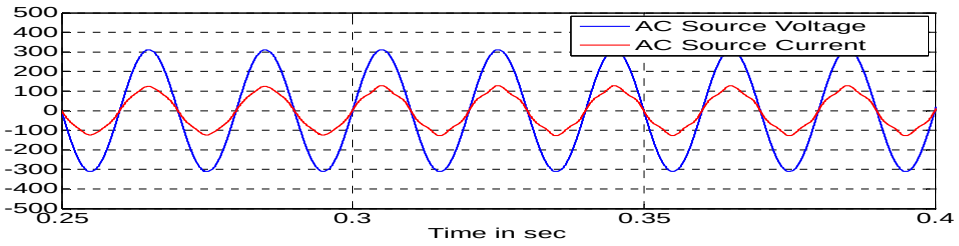


(d). Stator current response

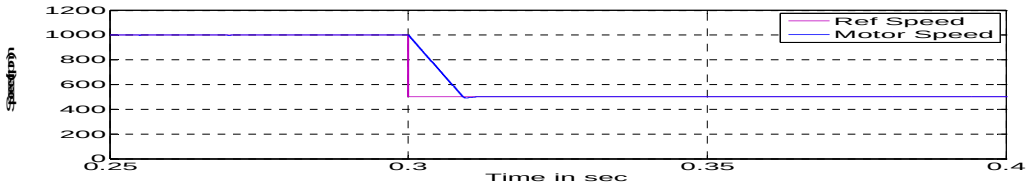
Figure 7. Performance of BLDCM drive when speed increase from 500rpm to 1000 rpm

Figure 7 shows the performance behavior of PFC cuk fed BLDCM drive with two dc supply during speed variation from 500 rpm to 1000 rpm at rated torque of 2 Nm. The drive reaches to a set speed of 1000 rpm in 0.1 sec. in this case also Ac voltage waveform and source current are in phase means nearly unity power factor .

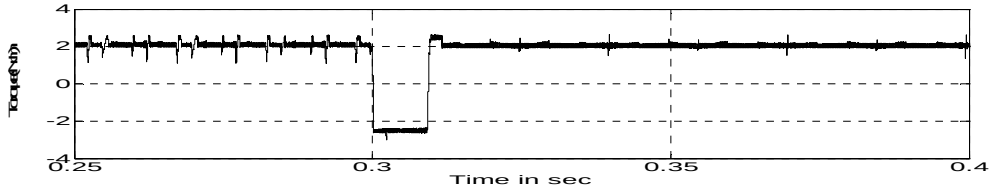
c. Performance of the Drive when Speed Decrease from 1000 rpm to 500 rpm



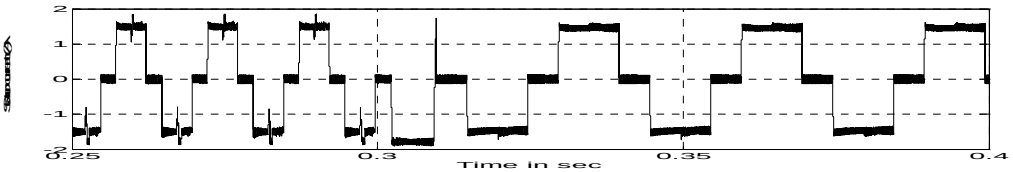
(a). AC source voltage and source current response



(b). Speed response



(c). Torque response



(d). Stator current response

Figure 8. Performance of BLDCM drive when speed decreases from 1000rpm to 500 rpm

Figure 8 shows the performance behavior of PFC cuk two leg inverter fed BLDCM drive with two dc supply during speed variation from 1000 rpm to 500 rpm at rated torque of 2 Nm. The drive reaches to a set speed of 500 rpm in 0.05 sec. in this case also Ac voltage waveform and source current are in phase means nearly unity power factor .

d. Performance under Steady State Condition

AC source current and harmonic spectra of PFC cuk two leg inverter fed BLDCM drive with two dc supply during steady-state condition at rated torque, speed at 500rpm and 1000rpm is found. A THD of 7% is observed at a speed of 500 rpm and when the speed is 1000rpm THD is 3.5%. Moreover, an improved performance of the PMBLDCM drive is observed in terms of reduced ripples in torque, current and speed during steady state conditions.

6. CONCLUSION

Brushless DC motor (BLDCM) is popular for its high efficiency, high torque to weight ratio, small size, and high reliability, ease of control and low maintenance etc and replacing the conventional motor in so many applications. In this paper a PFC cuk based two leg inverter PMBLDCM drive with split DC source is analyzed and validated for applications. A smooth speed control is observed while controlling the dc link voltage. The performance of the drive is good and satisfactory in the wide range of input ac voltage and maintaining good power factor with less torque ripple, smooth speed control of the PMBLDCM drive. The THD of ac mains current is observed well below 7% in most of the cases and satisfies the international standards.

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