Research article Available online www.ijsrr.org ISSN: 2279–0543

International Journal of Scientific Research and Reviews

Performance Improvement of BLDC Motor Using Power Factor Improved CUK Converter

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ABSTRACT-

This project presents a Power factor correction based Cuk converter fed brushless DC motor (BLDC) drive as a cost effective solution for low power applications. The speed of the BLDC motor is controlled by varying the DC bus voltage of voltage source inverter (VSI) which uses low frequency switching. Conventionally, the Brushless direct current motor is fed by a diode bridge rectifier which results in poor power factor and highly distorted supply current with high total harmonic distortion. To overcome such problems a power factor correction (PFC) Cuk converter is proposed for improving power quality inverter. A diode bridge rectifier (DBR) followed by a Cuk converter working in discontinuous conduction mode (DCM) is used for controlling of DC link voltage of the inverter. Performance of the PFC Cuk converter is evaluated in three different operating conditions of discontinuous conduction mode. The performance of the proposed system is simulated in MATLAB/Simulink environment and a hardware prototype of proposed drive is developed to validate its performance over the simulation.

KEY WORDS-Cuk converter, DCM, PFC, BLDCMotor, Power Quality

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1. INTRODUCTION

The Brushless DC motor is the ideal choice for applications that require high reliability, high efficiency, low maintenance, low EMI problems, high ruggedness, wide range of speed control and high power to volume ratio. A BLDC motor is considered to be a high performance motor that is capable of providing large amount of torque over a vast speed range. BLDC motor do not have brushes and must be electronically commutated motor since electronic commutation based on the Hall-effect rotor position signals is used rather than a mechanical commutation. A BLDC motor is highly reliable since it does not have any brushes to wear out and replace. When operated in rated conditions, the life expectancy is over 10,000 hours. The BLDC motor applied in numerous areas such as household applications, transportation, aerospace, heating, ventilation, and air conditioning, motion control and robotics, etc.

The necessities of enhanced power quality as per the international power quality standard IEC 61000-3-2 which recommends a high power factor and low total harmonic distortion of AC mains current for class-A applications. A high value of DC link capacitors draws a non-sinusoidal current, from AC mains which is rich in harmonics such that the THD of supply current is as high as 65% which results in power factor as low as 0.8[1,2] has proposed the conventionally used PFCs are the Boost. It presents a smoothly varying input current, but a relatively high DC bus voltage that may cause high voltage stresses on the device.[3] have proposed a PFC boost half-bridge-fed BLDC motor drive using a four switch VSI. This uses a constant dc link voltage with PWM switching of VSI and has high switching losses.[4] have proposed a single ended primary inductance converter (SEPIC) as a front end converter for PFC with DC link voltage control approach, but utilizes a PWM switching of VSI which has high switching losses.[5, 6] have been developed and are enforced on the consumers. However, power quality at AC mains can be improved using filters in existing installations but increase cost, size, weight and losses in the system.[7] have proposed to achieve a balanced operation among the motor phases, the hall sensors much placed exactly 120 electrical degrees apart. However, in many low-precision motors, the sensor positioning could be quite inaccurate.[8] have proposed a boost PFC converter based direct torque controlled (DTC) BLDC motor drive. They have the disadvantages of using a complex control which requires large amount of sensors and higher end digital signal processor (DSP) for attaining a DTC operation with PFC at AC mains. Hence, this scheme is not suited for low cost applications.[9] have proposed a few simple switching structures are inserted in classical cuk converter, leading to less energy in the magnetic field.[10] have proposed a systematic review of the bridgeless PFC boost rectifier implementations that have received the most attention is presented along with their performance comparison with the conventional PFC boost rectifier. The bridgeless boost rectifier has the same drawbacks as the conventional boost converter. Such that the dc output voltage is always higher than the peak input voltage, input-output isolation cannot easily be implemented, the startup inrush current is high.[11] have proposed a low power PMBLDC motor is fed from a single-phase AC supply through a diode bridge rectifier followed by a DC capacitor and a voltage source inverter. This results in power quality disturbances at AC mains such as poor power factor, increased total harmonic distortion and high crest factor.[12] have proposed a double-stage PFC configuration is a conventional class of PFC converters, which consist of a PFC stage followed by a dc-dc converter. Despite appreciable improvements in power factor, issues such as higher cost, relatively complex converter and control circuitry.[13] have proposed a cascaded buck-boost converter fed BLDC motor drive, which utilizes two switches for PFC operation. This offers high switching losses in the front end converter due to double switch and reduces the efficiency of overall system.[14] have proposed the large electrolytic capacitor in dc link is usually installed to stabilize the dc voltage in such a way to supply the clean voltage source for the inverter. However, the large capacitor causes the current distortion. [15, 16] have proposed the basic modes of operation of a PFC converter. To operate a PFC converter in CCM, one requires three sensors (two voltage, one current).[17] have proposed an active power factor correction (APFC) scheme which uses a PWM switching of VSI and hence has high switching losses. [18] have proposed a BLDC motor when fed by a DBR with 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. Bridgeless configurations of PFC buck-boost, Cuk, SEPIC and Zeta converters have been proposed in [19, 20] respectively.

A Voltage follower approach is one of the control techniques is used for a PFC converter operating in DCM. In this approach requires a single voltage sensor for controlling the DC link voltage with a unity power factor. Therefore, voltage follower control has an advantage over a current multiplier and hysteresis current control. The voltage follower is a simple way to achieve PFC and DC link voltage control. On the other hand current multiplier approach offers low stresses on the PFC switch, but requires three sensors for PFC and DC link voltage control and hysteresis current control approach have variable switching frequency and control sensitive to commutation noises. PFC cuk converter operated inthree modes of operation to control wide range of speed power factor at AC mains.

2. BLOCK DIAGRAM

Fig.2.1 shows the block diagram of PFCcuk converter fed BLDC motor.The AC machine is connected to the uncontrolled rectifier circuit. That converts alternating current (AC), which periodically reverses direction, to direct current which flows in only one direction. The output of the rectifier pulsating in nature, it consists of desired DC component of voltage and unwanted ripple components. These ripple components are removed by placing filter circuit at the output of the rectifier.

The output from the rectifier is given to the cuk converter. Itis operating under the discontinuous mode. When switch is turn on the input inductor stores energy while capacitor discharges through switch to transfer its energy to the DC link Capacitor. Input inductor current increase while the voltage across the capacitor decreases.

When switch is turned off, then the energy stored in inductor is transferred to intermediate capacitor via diode D, till it is completely discharged to enter DCM operation.The output of the cuk converter is given to the voltage source inverter.

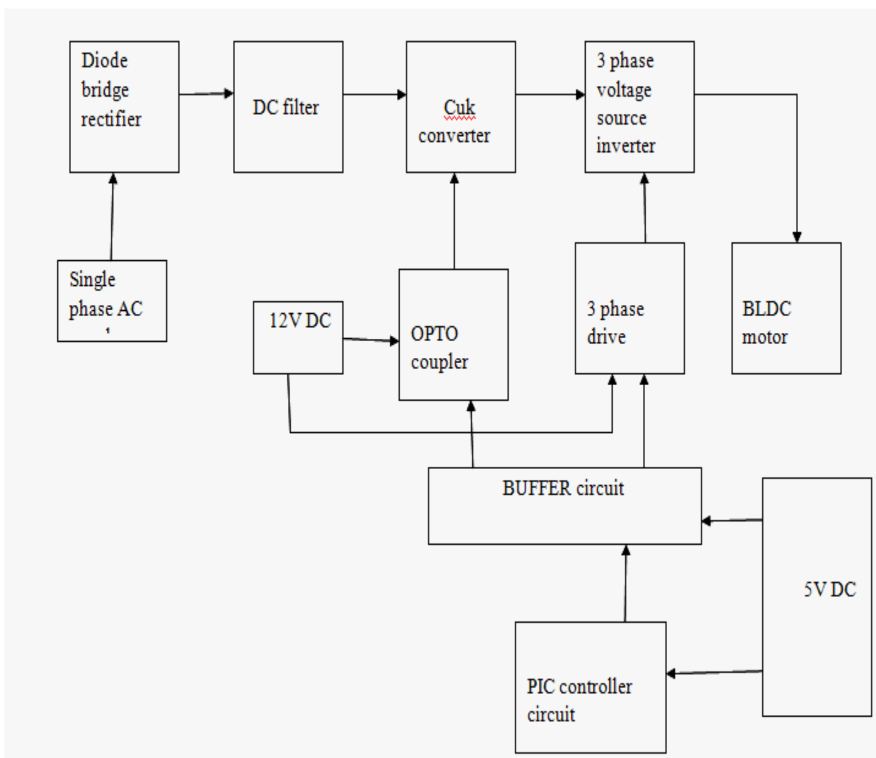

Fig.2.1Block diagram

A capacitor is included in parallel to the dc supply to ensure a low internal resistance for the dc source.The output voltage is obtained by alternately closing the switch pairs $S_{1,}$ S_3 and S_2, S_4. When S1, S3 are closed, the upper output terminal is positive with respect to the lower and vice-versa when S2, S4 are closed. Thus the inverter produces an acvoltage.By varying the voltage of the dc link capacitor to controlled the performance of the load.

3. SIMULATED PERFORMANCE OF PROPOSED CUK CONVERTER FED BLDC MOTOR DRIVE

The AC supply system is connected to the uncontrolled rectifier circuit. That converts alternating current (AC), which periodically reverses direction, to direct current which flows in only one direction. The output of the rectifier pulsating in nature, it consists of desired DC component of voltage and unwanted ripple components. These ripple components are removed by placing filter circuit at the output of the rectifier.

The output from the rectifier is given to the cuk converter which is operating under the discontinuous mode. When switch is turn on the inductor L_1 stores energy while capacitor C_1 discharges through switch S_1 to transfer its energy to the DC link Capacitor C_2. Input inductor current I_{Li} increase while the voltage across the capacitor C_1 decreases.

When switch S1 is turned off, then the energy stored in inductor L1is transferred to intermediate capacitor C1 via diode D, till it is completely discharged to enter DCM operation

The output of the cuk converter is given to the voltage source inverter. The voltage source inverter is supplied from a DC voltage source. A capacitor is included in parallel to the dc supply to ensure a low internal resistance for the dc source.

The output voltage is obtained by alternately closing the switch pairs $S_{1,}$ S_3 and S_2, S_4. When S1, S3 are closed, the upper output terminal is positive with respect to the lower and vice-versa when S2, S4 are closed. Thus the inverter produces an ac voltage.

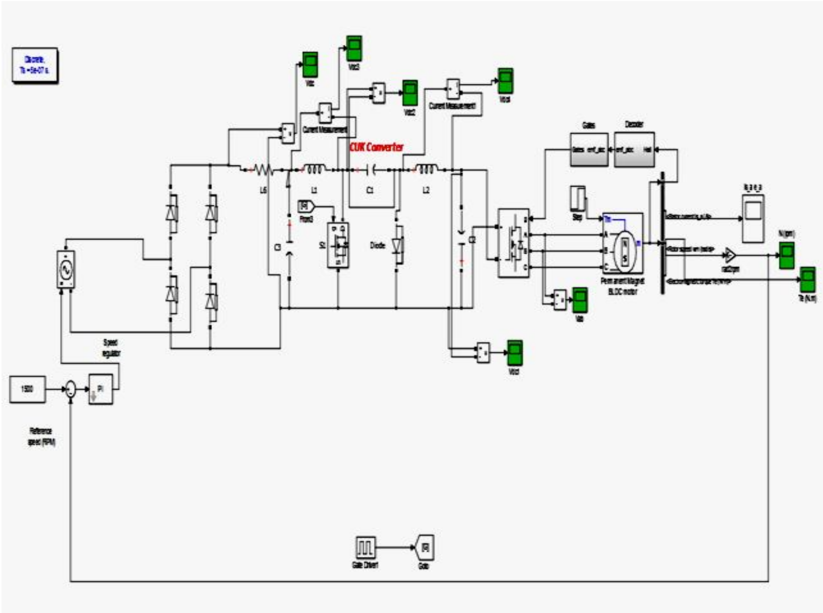

Fig.3.1 simulation circuit of PFC cuk converter fed BLDC motor

3.1 Simulation result

3.1.1 Mode I

The parameters selected for this converter to operate in Discontinuous Inductor Current mode (L1) are as follows: Input inductor (L1) = 100μH, output inductor (L2) = 4.3mH, intermediate capacitor (C1) = 0.66μF and DC link capacitor (C2) = 2200μF.

Switch S_1 is turn on the input inductor L_1 starts to charge. The C_1 energy transferred to C_2. The input inductor current increase and the C_1 voltage get decrease.Switch S_2 is turn off the input inductor L_1energy transferred to C_1. The output inductor L_2 energy transferred to C_2. Input inductor current becomes zero. Output inductor L_2 energy transferred to C_2. The output inductor L_2 operated in continuous conduction mode.

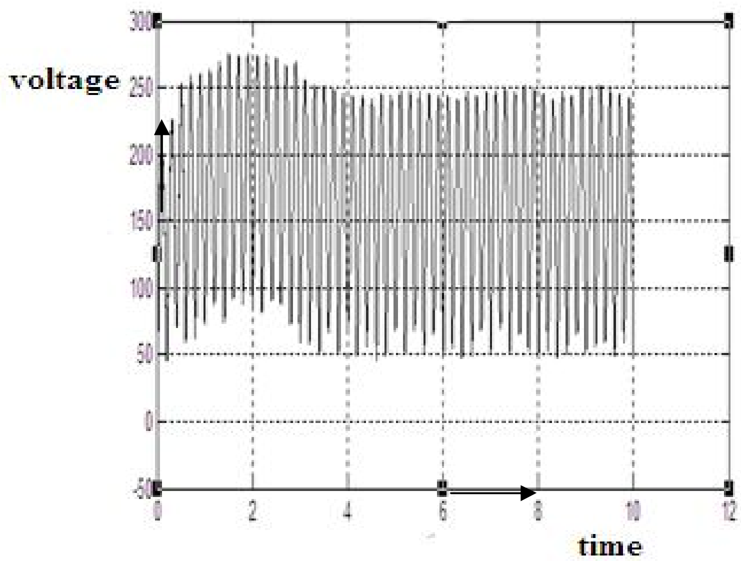

Fig.3.2output voltage of cuk converter

3.1.2 Mode II

The parameters selected for this converter to operate in Discontinuous Inductor Current mode (L2) are as follows:Input inductor (L1) = 2.5mH, output inductor (L2) = 70µH, intermediate capacitor (C1) = 0.66µF and DC link capacitor (C2) = 2200µF.

Switch S_1 is turned on the input inductor L_1 gets charging, C_1 starts to discharge. The C_1 energy transferred to C_d. Switch S_1 is turn off the input inductor L_1 energy transferred to $C_{1,}$ output inductor L_o energy transferred to C_2. The output inductor current I_{Lo} becomes zero. The input inductor energy transferred to C_1. The input inductor current I_{Lo}operating continuous conduction.

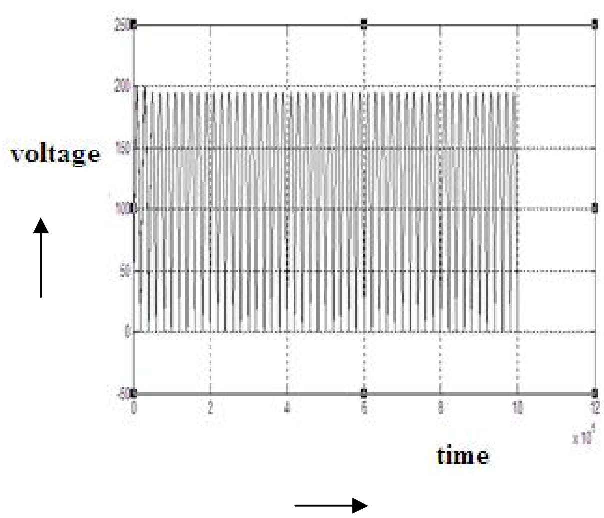

Fig.3.3.DC link voltage

3.1.3 Mode III

The parameters selected for this converter to operate in Discontinuous Capacitor Voltage mode (C1) are as follows:Input inductor (L1) = 2.5mH, output inductor (L2) = 4.3mH, intermediate capacitor (C1) = 9.1nF and DC link capacitor (C2) = 2200μF.

Switch S_1 is turn on, the input inductor L_1 gets charging. C_1 gets discharge. The C_1 energy transferred to C_2. The C_1 is completely discharge. The voltage across the capacitor C_1 becomes zero. The L_o is continuously transferring the energy to DC link capacitor C_2. Switch S_1 is turn off, the input inductor is starts to discharge the energy. The capacitor C_1 starts to charge. Output inductor energy transferred to capacitor C_2.

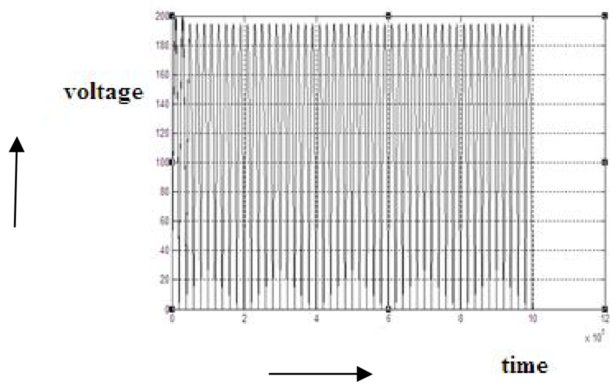

Fig.3.4 output voltage Vs time

3.2 Speed

The speed of BLDC motor is depending on the input voltage. Input voltage of BLDC motor is varied. For variable voltage to produced the variable speed of the BLDC motor. In this system variation DC capacitor voltage to produced the variable speed.

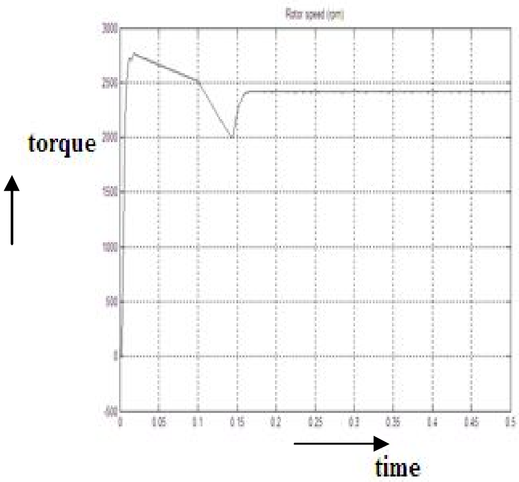

Fig.3.5 speed Vs time waveform

3.3 Torque

The torque of the BLDC motor is depending on the speed of the motor. During continuous operation, the motor can be loaded up to the rated torque. In a motor, the torque remains constant for a speed range up to the rated speed.

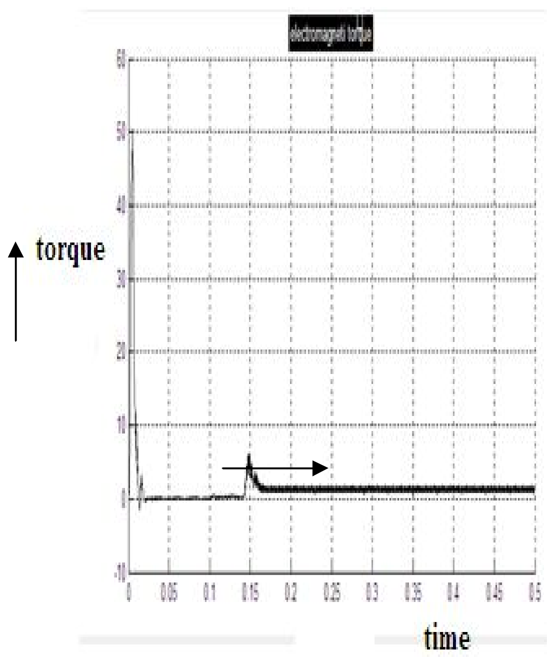

Fig.3.6 torque Vs time

4.HARDWARE IMPLEMENTATION

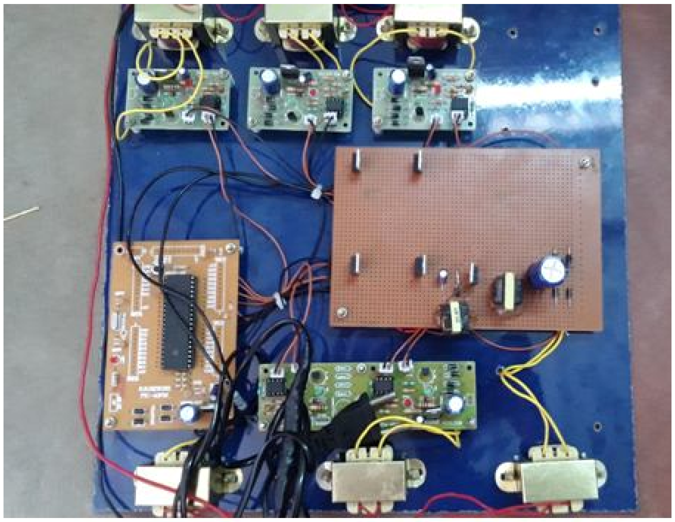

Fig.4.1 Hardware implementation of cuk converter fed BLDC motor

A single phase AC supply is given to the diode bridge rectifier. It converts alternating current (AC), which periodically reverses direction, to direct current which flows in only one direction. The dc voltage is given to the PFC cukconverter.Cuk converter operated in discontinuous mode. The switch turn on turn off by using the drive circuit. The pulse given to the switch the switch getting turn on. The input inductor starts to charging and intermediate capacitor start to discharging. The output inductor stars discharge and the energy transferred to the output capacitor.

When switch is turn off the input inductor starts to discharge and the intermediate capacitor starts to discharge. The output inductor starts discharge and the inductor energy transferred to the output capacitor.

The output voltage is given to the voltage source inverter. By turn on and turn off the switch of voltage source inverter to supply the BLDC drive.

A DSP (Digital Signal Processor) is used for the development of proposed BLDC motor drive. Isolation between the DSP based controller and gate drivers of solid state switches of VSI and PFC converter is provided using an opto-coupler. The pre-filtering and isolation circuitsfor Hall Effect position sensor are also developed for sensing the rotor position signals.

The operation of proposed BLDC motor has a DC link voltage. The supply current (I_s) achieved is sinusoidal in nature and is in phase with the supply voltage (vs) demonstrating the unity power factor at AC mains. AC supply is given to the rectifier. It converts the AC into DC. Dc supply is given to cuk converter. It produced output without distortion. The output is give as the input to BLDC motor. It controls the speed of the BLDC motor.

5. HARDWARE RESULT

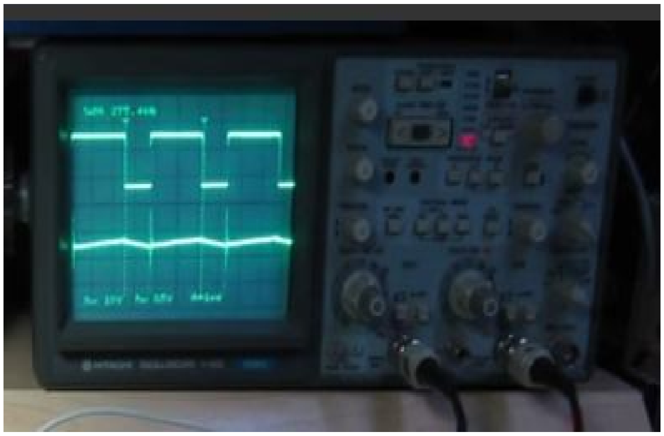

Fig.5.1 output of cuk converter

In cuk converter the gate pulse given to the switch S1 turns on and the output voltage gets generated with low frequency and harmonics. When the BLDC motor is connected, it is supplied with high PF and voltage so that the torque produced is constant. Harmonics are very less and performance is improved.

6. CONCLUSION

Power factor correction based low operating frequency cuk converter with discontinuous mode of operation has been developed for driving the adjustable speed drive BLDC motor. Variable voltage required to drive the BLDC motor have been achieved from the DC link capacitor of the VSI. Different mode of operation of the cuk converter under discontinuous conduction mode was implemented and the power factor improvement also tested. The cuk converter output is suitable to drive the ASD drive with reduced torque ripple and increased efficiency.

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