

A BL-CSC Converter fed BLDC Motor Drive with Power Factor Correction

L.Pattathurani¹, Rajat Kumar Dwibedi², Dr.P.Sivachidambaranathan³

¹(Assistant Professor/EEE, Jeppiaar Institute of Technology, Sriperumbudur, Chennai, India)

²(Assistant Professor/ECE, SRR Engineering College, India)

³(Professor & Head /EEE, Sathyabama university, India)

Abstract : This paper presents a power factor correction (PFC) based bridgeless-canonical switching cell (BL-CSC) converter fed brushless DC (BLDC) motor drive. The proposed BL-CSC converter operating in a discontinuous inductor current mode is used to achieve a unity power factor at the AC mains using a single voltage sensor. The speed of BLDC motor is controlled by varying the DC bus voltage of the voltage source inverter (VSI) feeding BLDC motor via a PFC converter. Therefore, the BLDC motor is electronically commutated such that the VSI operates in fundamental frequency switching for reduced switching losses. Moreover, the bridgeless configuration of CSC converter offers low conduction losses due to partial elimination of diode bridge rectifier at the front end. The proposed configuration shows a considerable increase in efficiency as compared to the conventional scheme, a combination of switch, capacitor (C1) and diode (D) is known as a 'canonical switching cell' and this cell combined with an inductor (Li) and a DC link capacitor (Cd) is known as a CSC converter. With proper design and selection of parameters, this combination is used to achieve PFC operation when fed by a single phase supply via a DBR (Diode Bridge Rectifier) and a DC filter.

Keywords: Brushless DC motors; Power factor correction; Voltage Source Inverter; Canonical Switching Cell; Diode Bridge Rectifier; Continuous Conduction Mode; Discontinuous Conduction Mode; Electromagnetic Interference.

I. Introduction

The proposed scheme is BL-CSC converter based VSI fed BLDC motor drive. The DBR is eliminated in this BL-CSC converter; thereby reducing the conduction losses associated with it. A diode bridge rectifier (DBR) followed by a high value of the DC link capacitor feeding a voltage source inverter (VSI) based BLDC motor, draws peaky current from supply and injects a high amount of harmonics in the supply system. Therefore, power factor correction (PFC) converters are used for improving the power quality at the AC mains. These converters have less number of components and thus have low losses associated with them. The cost of these converters becomes an important parameter which is primarily decided by the amount of sensing requirement which depends on the mode of operation of PFC converter.

A current multiplier approach is used for the PFC converter operating in continuous conduction mode (CCM) which offers low stresses on PFC converter's switch but requires three sensors. Whereas, a single voltage sensor is required for PFC converter operating in discontinuous conduction mode (DCM) using the voltage follower approach but at the cost of high stresses on PFC converter's switch. Therefore, the choice of operating mode is a trade-off between the cost and permitted stress on switch.

II. BLDC Motor

Brushless DC (BLDC) motor drives have gained importance in the last decade due to power quality improvements that have also resulted in exceptional performance compared to other conventional drives. The advantages of high efficiency, high reliability, high ruggedness, low EMI problems and excellent performance over a wide range of speed control have made this motor popular in the industry. The BLDC motor is suited to many low and medium power applications ranging from household appliances, medical equipments, position actuators, heating, ventilation and air conditioning (HVAC), motion control and transportation .

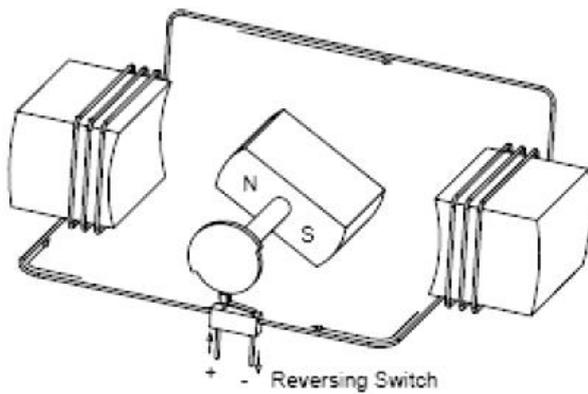
BLDC motors are synchronous motors having permanent magnets on the rotor, and three phase windings on the stator. An electronic commutation based on the rotor position sensed by Hall Effect sensors is used which eliminates the problems associated with conventional DC motors such as sparking, noise, electromagnetic interference (EMI) and maintenance problems. Therefore, power factor correction (PFC) converters are used for improving the power quality at the AC mains. These converters have less number of components and thus have low losses associated with them.

2.1 Principle

BLDC motors are basically inside-out DC motors. In a DC motor the stator is a permanent magnet. The rotor has the windings, which are excited with a current. The current in the rotor is reversed to create a rotating or moving electric field by means of a split commutator and brushes. On the other hand, in a BLDC motor the windings are on the stator and the rotor is a permanent magnet. Hence the term inside-out DC motor.

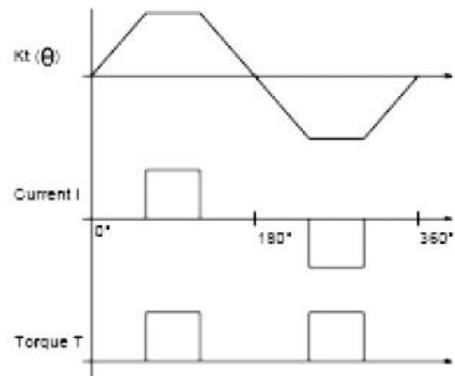
Many motor types can be considered brushless; including stepper and AC-induction motors, but the term **brushless** is given to a group of motors that act similarly to DC brush type motors without the limitations of a physical commutator. To build a brushless motor, the current-carrying coils must be taken off the rotating mechanism. In their place, the permanent magnet will be allowed to rotate within the case. The current still needs to be switched based on rotary position; here, shows a reversing switch is activated by a cam.

This orientation follows the same basic principle of rotary motors; the torque produced by the rotor varies trapezoidal with respect to the angle of the field. As the angle θ increases, the torque drops to an unusable level. Fig.1 shows the basic operation of BLDC Motor. Fig.2 shows the current and torque of BLDC Motor.



(a)

Fig.1 Basic operation of BLDC motor



(b)

Fig.2 Waveform of current and torque

2.2 Construction

2.2.1 Stator

The stator of a BLDC motor consists of stacked steel laminations with windings placed in the slots that are axially cut along the inner periphery traditionally, the stator resembles that of an induction motor; however, the windings are distributed in a different manner.

Most BLDC motors have three stator windings connected in star fashion. One or more coils are placed in the slots and they are interconnected to make a winding. Each of these windings is distributed over the stator periphery to form an even numbers of poles. There are two types of stator windings variants: trapezoidal and sinusoidal motors. This differentiation is made on the basis of the interconnection of coils in the stator windings to give the different types of back Electromotive Force (EMF). Fig.3 shows the stator of BLDC Motor.



Fig.3 BLDC motor Stator

2.2.2 Rotor

The rotor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) and South (S) poles. Based on the required magnetic field density in the rotor, the proper magnetic material is chosen to make the rotor. Ferrite magnets are traditionally used to make permanent magnets. As the technology advances, rare earth alloy magnets are gaining popularity. The ferrite magnets are less expensive but they have the disadvantage of low flux density for a given volume. In contrast, the alloy material has high magnetic density per volume and enables the rotor to compress further for the same torque. Also, these alloy magnets improve the size to- weight ratio and give higher torque for the same size motor using ferrite magnets. Some rotor constructions are shown in the fig.4.

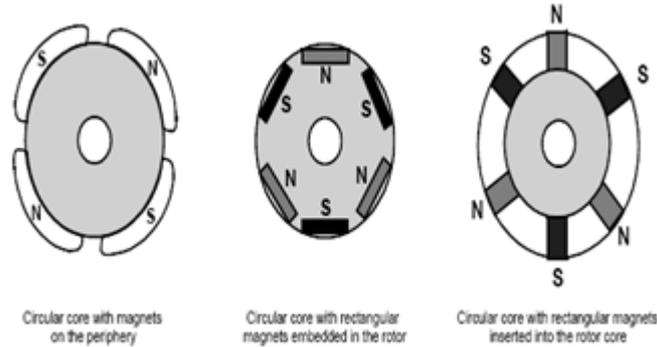


Fig.4 BLDC motor Rotor

2.2.3 Rotor Position Sensor

Unlike a brushed DC motor, the commutation of a BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a sequence. Rotor position is sensed by Hall Effect sensors embedded into the stator which gives the sequence of phase energization. Most of BLDC motors have three Hall sensors embedded into the stator on the non-driving end of the motor. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating the N or S pole is passing near the sensors. Based on the Combination of these three Hall sensor signals, the exact sequence of commutation can be determined.

2.2.4 Structure and Operation

As their names suggest, the rotor is the rotational part of the motor while the stator is the stationary part. Structurally the stator assembly surrounds the rotor. Embedded into the side of the rotor are permanent magnets; external is the fan propeller blade. The motor coil is part of the stator assembly, and is placed inside the rotor. Brushless DC motors utilize Hall-effect sensors to provide positional and rotational information, which informs the LOGICAL INVERTER how to drive the motor coil. Brushless DC motors usually come in fixed voltage types, such as 5V, 6V, 12V, 24V, 48Vetc, with one of the most common ones in use being the 12V type. When the rated voltage is applied to the motor it will rotate with maximum speed, but by changing this applied voltage the motor speed can be controlled.

Naturally, the voltage is higher and then speed is higher and vice versa. The brushless DC motor is essentially configured as a permanent magnet rotating past a set of current carrying conductors. In this respect, it is equivalent to an inverted DC commutator motor, in that the magnet rotates while the conductors remain stationary. In both cases, the current must reverse polarity every time a magnet pole passes by, in order that the torque is unidirectional.

In the DC commutator motor, the commutator and brushes perform the polarity reversal. In the brushless DC motor, the polarity reversal is performed by power MOSFETS, which must be switched in synchronism with the rotor position.

The stator is normally 3-phase star connected. Each commutation sequence has one of the windings energized to positive power (current entering into the winding) and the second winding energized to negative power (current exits the winding) and third winding non-energized. Torque is produced by the interaction of the magnetic field produced by the stator windings and the permanent magnets. Fig.5 shows the disassembled view of a brushless dc motor.

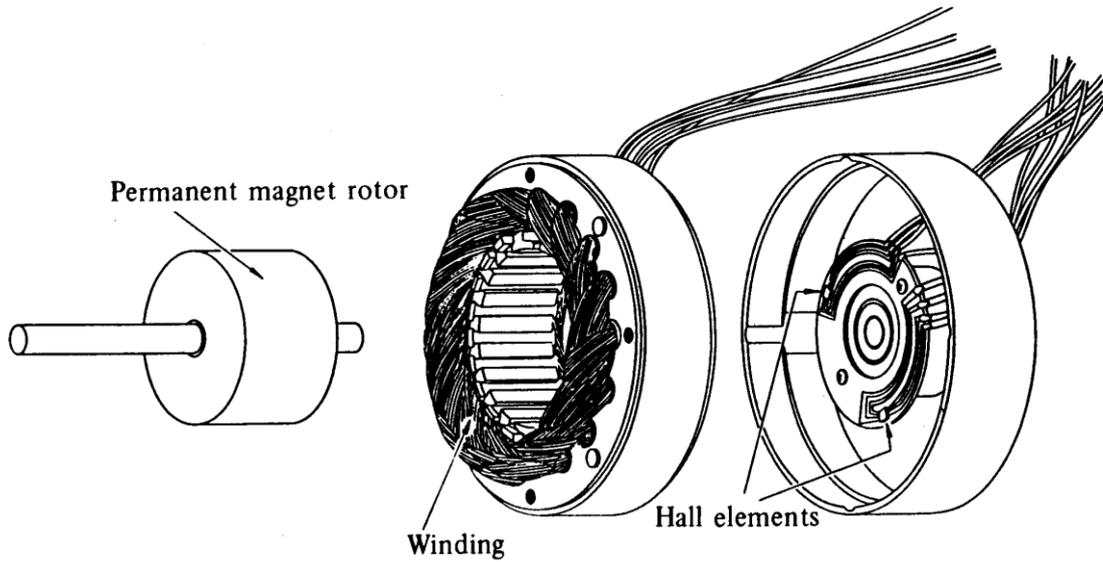


Fig.5 Disassembled view of a brushless dc moto

III. Block Diagram of Proposed Method

When ac supply is given to diode bridge rectifier (DBR) , it converts ac signal to dc signal .The dc filter has the function to reduce the harmonic from the DBR. The bridgeless canonical switching cell (BL-CSC) is used to reduce the usage of diodes ,no conduction loss occurs .From BL-CSC converter ,the voltage source inverter is fed into the BLDC motor ,the motor rotates .The PIC microcontroller and driver units are used to trigger the voltage source inverter . The PIC microcontroller has the voltage of minimum 5v , so driver unit is connected to the BL-CSC and VSI .Fig.6 shows the block diagram of proposed method.

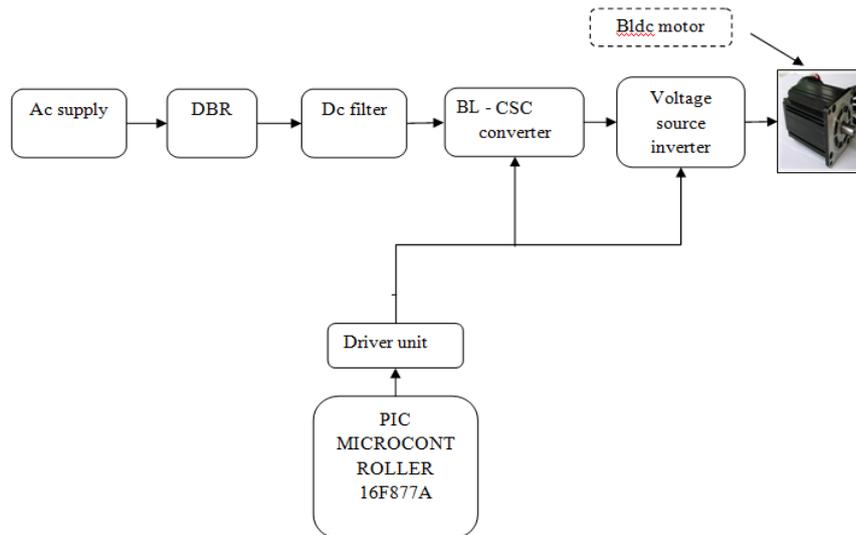


Fig.6 Block diagram of proposed method

IV. Switching Modes

4.1 Mode I

When switch Sw1 is turned on, the input side inductor Li1 starts charging via diode Dp and current iLi increases. Whereas, the intermediate capacitor C1 starts discharging via switch Sw1 to charge the DC link capacitor Cd. Therefore, the voltage across intermediate capacitor VC1 decreases, while DC link voltage, Vdc increases. Fig.7 shows the operation of mode I.

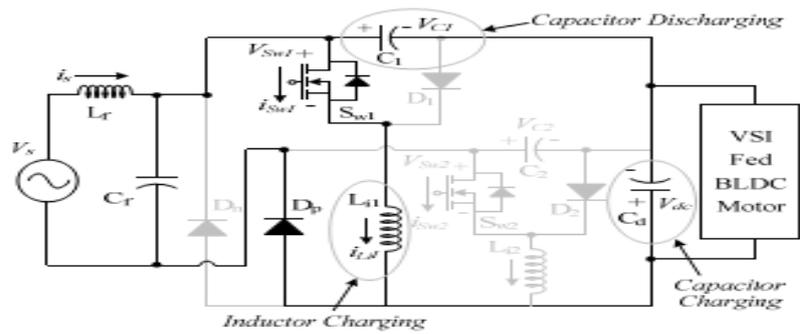


Fig.7 Mode I

4.2 Mode II

When switch S_{sw1} is turned off, the energy stored in inductor L_{i1} discharges to DC link capacitor C_d via diode D_1 . The current i_{L1} reduces, whereas the DC link voltage continues to increase in this mode of operation. Intermediate capacitor C_1 starts charging and the voltage V_{C1} increases. Fig.8 shows the operation of mode II.

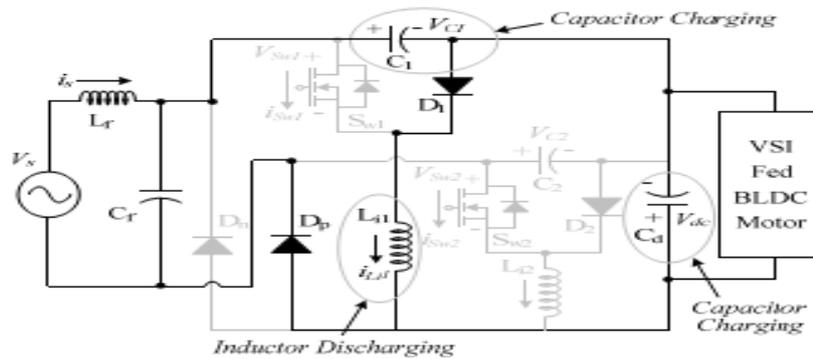


Fig.8 Mode II

4.3 Mode III

This mode is the discontinuous conduction mode of operation as the current in input inductor L_{i1} becomes zero. The intermediate capacitor C_1 continues to hold energy and retains its charge, while the DC link capacitor C_d supplies the required energy to the load. The similar behavior of the converter is realized for the other negative half cycle of supply voltage. Fig.9 shows the operation of mode III.

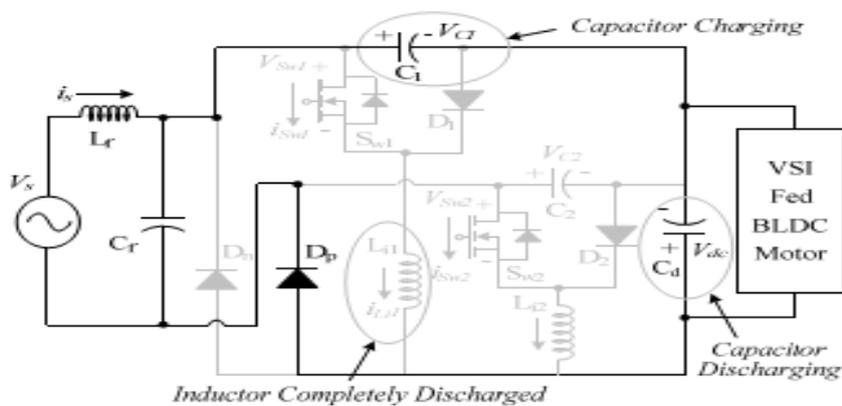


Fig.9 Mode III

4.4 Mode IV

When switch S_{sw2} is turned on, the input side inductor L_{i2} starts charging via diode D_p and current i_{L2} increases. Whereas, the intermediate capacitor C_2 starts discharging via switch S_{sw1} to charge the DC link capacitor C_d . Therefore, the voltage across intermediate capacitor V_{C2} decreases, while DC link voltage, V_{dc} increases. Fig.10 shows the operation of mode IV.

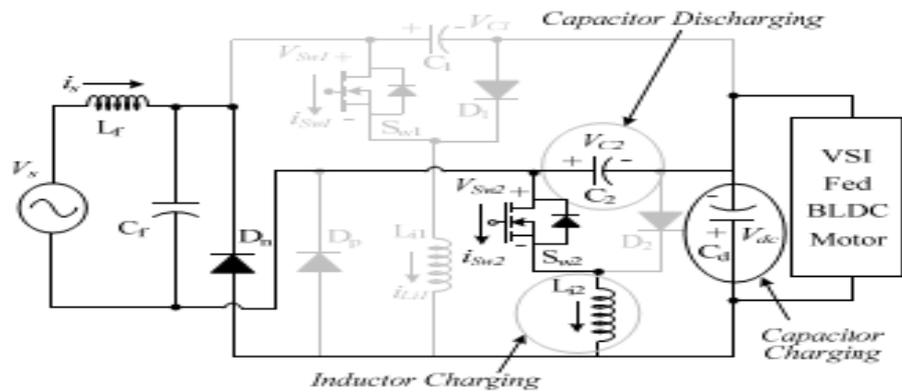


Fig.10 Mode IV

4.5 Mode V

When switch S_{sw2} is turned off, the energy stored in inductor L_{i2} discharges to DC link capacitor C_d via diode D_2 . The current i_{L2} reduces, whereas the DC link voltage continues to increase in this mode of operation. Intermediate capacitor C_1 starts charging and the voltage V_{C2} increases. Fig.11 shows the operation of mode V.

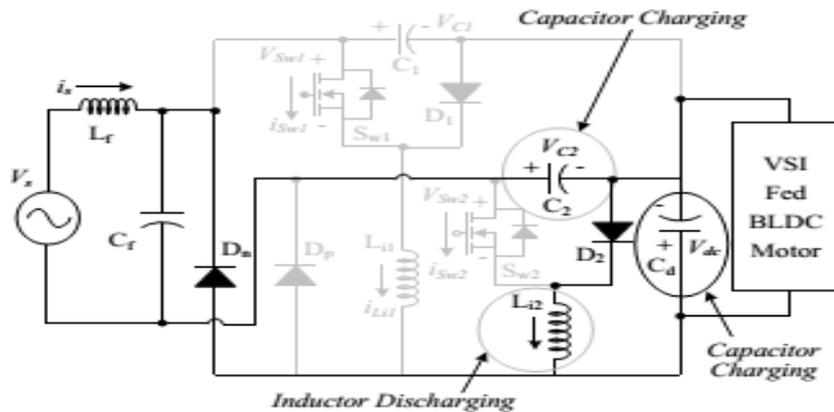


Fig.11 Mode V

4.5 Mode VI

This mode is the discontinuous conduction mode of operation as the current in input inductor L_{i2} becomes zero. The intermediate capacitor C_2 continues to hold energy and retains its charge, while the DC link capacitor C_d supplies the required energy to the load. The similar behavior of the converter is realized for the other negative half cycle of supply voltage. Fig.12 shows the operation of mode VI.

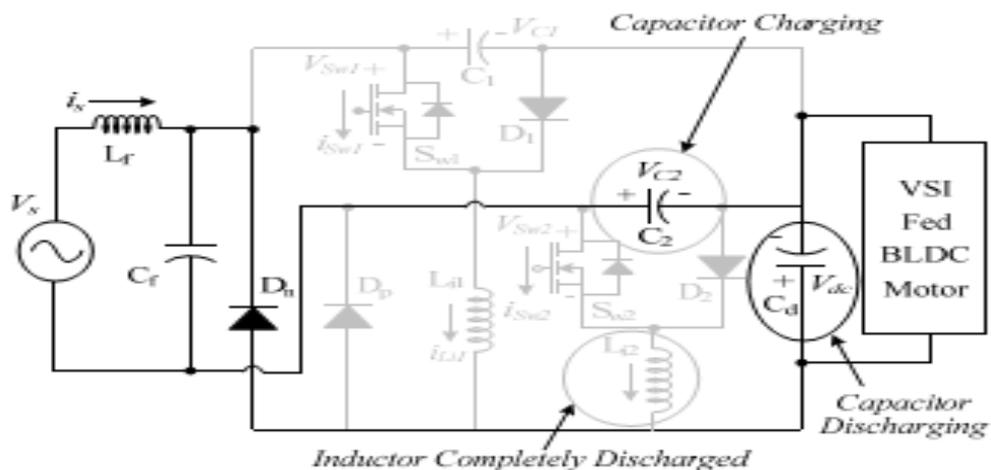


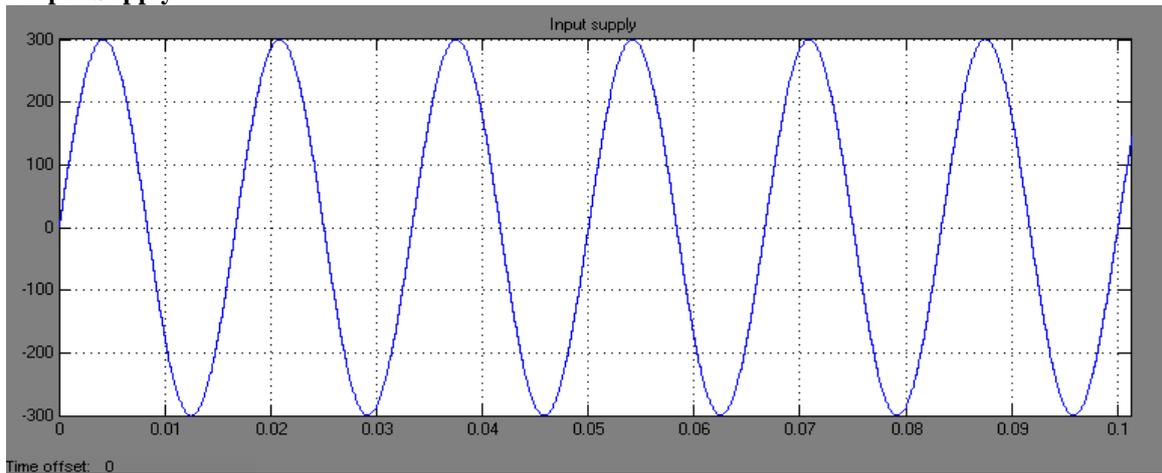
Fig.12 Mode VI

V. Switching Mode Proposed Scheme

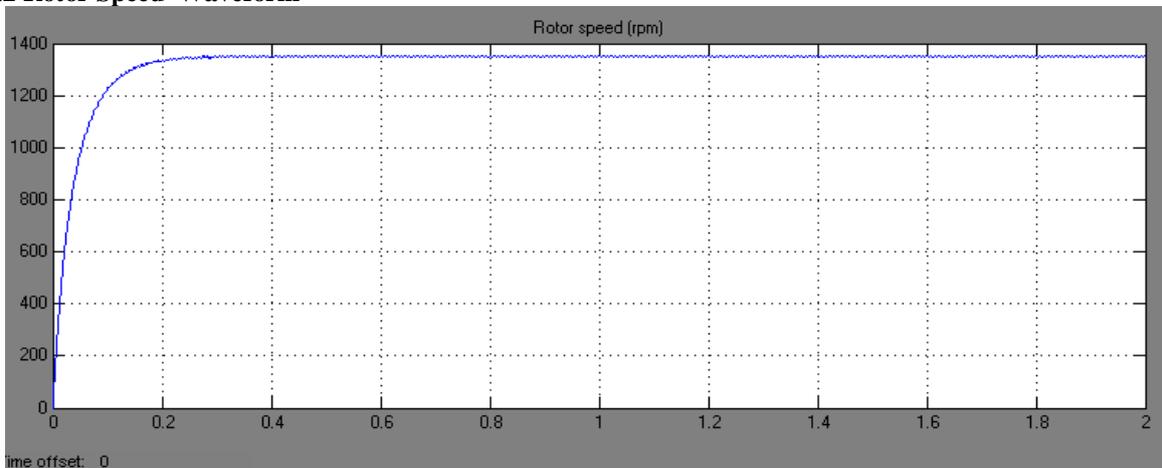
$\theta(^{\circ})$	Hall Signals			Switching States					
	H_a	H_b	H_c	S_1	S_2	S_3	S_4	S_5	S_6
NA	0	0	0	0	0	0	0	0	0
0-60	0	0	1	1	0	0	0	0	1
60-120	0	1	0	0	1	1	0	0	0
120-180	0	1	1	0	0	1	0	0	1
180-240	1	0	0	0	0	0	1	1	0
240-300	1	0	1	1	0	0	1	0	0
300-360	1	1	0	0	1	0	0	1	0
NA	1	1	1	0	0	0	0	0	0

VII. Simulation Results

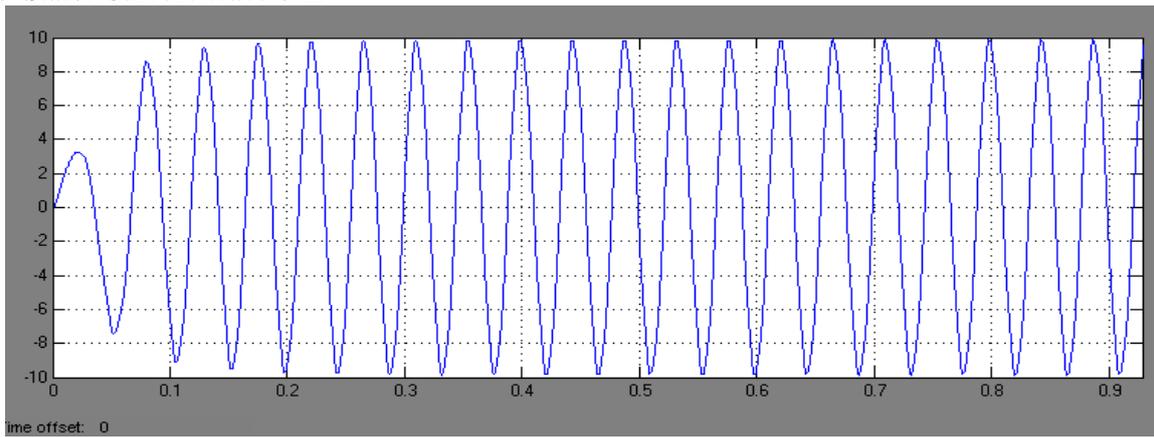
7.1 Input Supply



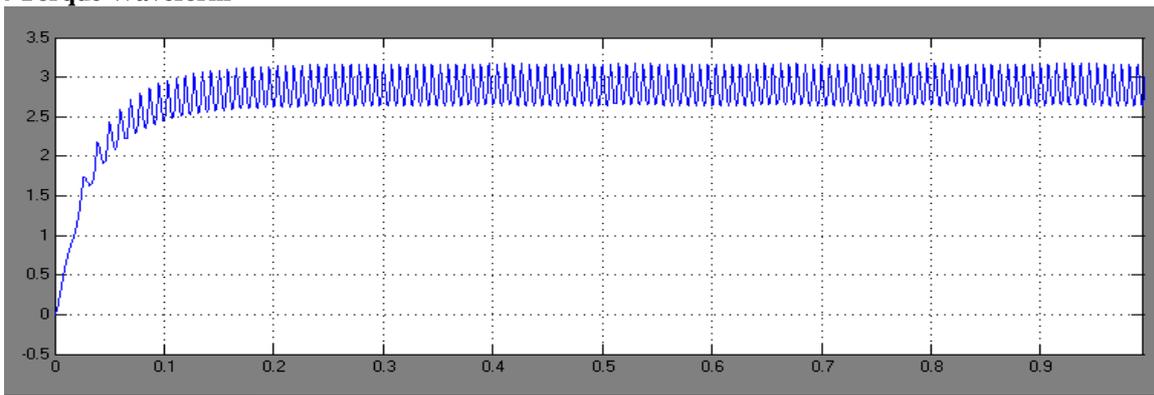
7.2 Rotor Speed Waveform



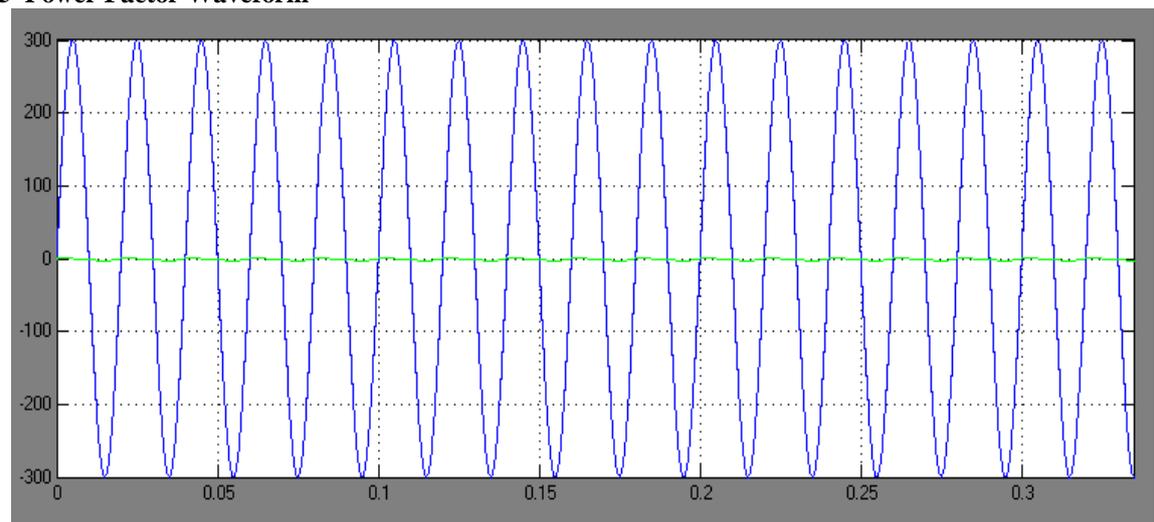
7.3 Stator Current Waveform



7.4 Torque Waveform



7.5 Power Factor Waveform



VIII. Conclusion

A PFC based BL-CSC converter fed BLDC motor drive has been proposed with improved power quality at the AC mains. A bridgeless configuration of a CSC converter has been used for achieving reduced conduction losses in PFC converter. The speed control of BLDC motor and power factor correction at AC mains has been achieved using a single voltage sensor. The switching losses in the VSI have been reduced by the use of fundamental frequency switching by electronically commutating the BLDC motor. Moreover, the speed of BLDC motor has been controlled by controlling the DC link voltage of the VSI. The proposed drive has shown an improved power quality at the AC mains for a wide range of speed control and supply voltages. A satisfactory performance of the proposed drive has been obtained and it is a recommended solution for low power application.

References

- [1]. A. Barkley, D. Michaud, E. Santi, A. Monti and D.Patterson, "Single Stage Brushless DC Motor Drive with High Input Power Factor for Single Phase Applications," 37th IEEE Power Electr. Spec. Conf., (PESC), pp.1-10, 18-22 June 2006.
- [2]. T. Gopalarathnam and H.A.Toliat, "A new topology for unipolar brushless DC motor drive with high power factor," IEEE Trans. Power Elect., vol.18, no.6, pp. 1397-1404, Nov. 2003.
- [3]. A.Fardoun, E. H. Ismail, A. J. Sabzali, M. A. Al-Saffar, "New Efficient Bridgeless Cuk Rectifiers for PFC Applications," IEEE Trans. Power Electron., vol.27, no.7, pp.3292-3301, July 2012.
- [4]. B. Singh and V. Bist, "An Improved Power Quality ridgeless Cuk Converter Fed BLDC Motor Drive for Air Conditioning System", IET Power Elect., Volume 6, issue 5, pp. 902-913, 2013.
- [5]. M.Mahdavi and H. Farzaneh-Fard, "Bridgeless CUK power factor correction rectifier with reduced conduction losses," IET power Electron. Vol.5 no.9,pp 1733-1740,Nov.2012.
- [6]. A. J. Sabzali, E. H. Ismail, M. A. Al-Saffar and A. A. Fardoun, "New Bridgeless DCM Sepic and Cuk PFC Rectifiers With Low Conduction and Switching Losses," IEEE Trans. Ind. Appl., vol.47, no.2, pp.873- 881,March-April2011.
- [7]. M. Mahdavi and H. Farzanehfard, "Bridgeless SEPIC PFC Rectifier with Reduced Components and Conduction Losses," IEEE Trans. Ind Electron., vol 58 no,9,pp 4153-4160,Sept.2011.
- [8]. V. Bist and B. Singh, "A Reduced Sensor PFC BL-Zeta Converter Based VSI Fed BLDC Motor Drive", Electric Power System Research, vol.98,pp.11-18,May 2013.
- [9]. B. Williams, "Generation and Analysis of Canonical Switching Cell DCto-DC Converters," IEEE Trans. Ind. Electron,vol.61,no.1,pp.329-346,Jan.2014.