International Journal of Latest Trends in Engineering and Technology
Vol.(10)Issue(1), pp.019-026
DOI: http://dx.doi.org/10.21172/1.101.04
e-ISSN:2278-621X

INVESTIGATIONS FOR POWER FACTOR IMPROVEMENT OF BLDC MOTOR DRIVE

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Abstract- This paper presents the analysis of Power Factor Improvement (PFI) and speed control of (Brushless) BLDC motor drive using Power Factor Improvement – Canonical switching Cell (PFI-CSC) converter. The proposed PFI-CSC converter is used to achieve unity power factor by closed loop control of the BLDC motor drive. The speed control is achieved by varying the dc link voltage of the proposed converter through closed loop control of the BLDC motor drive. The proposed converter eliminates the rectifier bridge thereby reduces the conduction losses. The performance of the proposed PFI-CSC converter for BLDC motor drive is improved by power factor correction and speed control of the BLDC motor. The Power Quality is maintained in AC mains for wide range of speed control. The performance analysis of the BLDC motor drive is carried out using the proposed converter with and without closed loop control through MATLAB simulink. The operating principle, simulation results and comparative analysis of the proposed converter BLDC motor drive are presented in this paper.
Keywords – Power Factor Improvement – Canonical switching Cell (PFI-CSC) converter, Brushless DC (BLDC motor), Power Quality, Power Factor Improvement.

1. INTRODUCTION

In the recent years, Brushless DC (BLDC) motor drives have become industrially popular since it offers several advantages such as compact size, high ruggedness, high reliability, high power density, high efficiency, low electromagnetic interference (EMI) problems and its exceptional performance over a wide range of speed control [1], [2]. These motor drives marked their presence due to their improvements in the power quality that have also presented the excellent performance in comparison with other conventional drives [3]. BLDC motor drives have found their applications in electrical vehicle and aerospace applications etc.[4], [5], [6].

BLDC motor based on voltage source inverter (VSI) fed by diode-bridge rectifier followed by high dc link capacitor draws high peaky current that is rich in harmonics. This configuration also leads to a very low power factor of 0.7 and high total harmonic distortion (THD) of 65% at the AC mains [7]. Such power quality indices increases the EMI in the power factor correction (PFC) converter and are not acceptable by international power quality standard IEC 61000-3-2. Hence, improved power quality converters (IPQC's) are used to reduce EMI problems which affect the entire performance and efficiency of the system. These converters are comprised of minimum components and hence associated with less loss [8].

In the literature survey, many configurations of PFC converter fed BLDC motor drives have been reported. The topology of BLDC motor drive fed by boost-PFC converter utilizes the constant dc link voltage and Pulse Width Modulation (PWM) based VSI for the BLDC motor speed control [9]. This configuration has the disadvantage of high switching losses because of high switching frequency PWM pulses for VSI. A BLDC motor drive fed by a three-phase VSI on the basis of active-rectifier has been proposed in [10]. This configuration requires a complex control. A buck-chopper fed BLDC motor drive has been proposed in [11]. In this topology, high frequency switching of VSI resulted in very high switching losses. Further using the concept of variable dc-link voltage control for the speed control of BLDC motor, a single-ended primary inductance converter (SEPIC) fed BLDC motor drive has been designed [12]. This scheme has high switching losses because of PWM based control of VSI. Each bridgeless converter configuration has its unique characteristics. A bridgeless-buck converter has its voltage conversion ratio limited to less than one, whereas the voltage conversion ratio of bridgeless-boost converter is limited to greater than one [14]. Hence, these are not suitable for the wide voltage control.

From the literature, it is observed that most of the work concentrates on the PFC for BLDC motor drive with the rectifier bridge. As the bridgeless buck converter [14] is not suitable for wide voltage control, here a canonical switching cell (CSC) converter is proposed. The proposed converter has exceptional performance as a power factor pre-regulator, better load regulation and minimal number of components. A CSC converter comprises of a combination of switch, inductor and diode known as canonical switching cell in combination with a dc link capacitor and an inductor. The project aims at configuring the Power Factor Improvement – Canonical switching Cell (PFI-CSC) converter fed BLDC motor drive in order to develop a

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lesser cost solution for low power application. The operating principle of the proposed PFI-CSC converter has been discussed and is analysed for both open loop and closed loop through MATLAB simulation. The simulation results are discussed and comparative analysis is presented in tabular form.

2. CONVENTIONAL PFC CONVERTER FED BLDC MOTOR DRIVE

The block diagram of a conventional PFC converter fed BLDC motor drive is shown in Fig.1. A single phase ac source followed by diode bridge rectifier is used to feed the PFC converter based BLDC motor drive. The rectifier based BLDC motor drive fed by three phase VSI requires complex control. The front-end diode bridge rectifier results in high conduction losses. This configuration uses the PWM based VSI control for the speed control of BLDC motors which results in high switching loss due to high switching frequency of the PWM pulses for the VSI. This in turn reduces the entire performance and efficiency of the system.

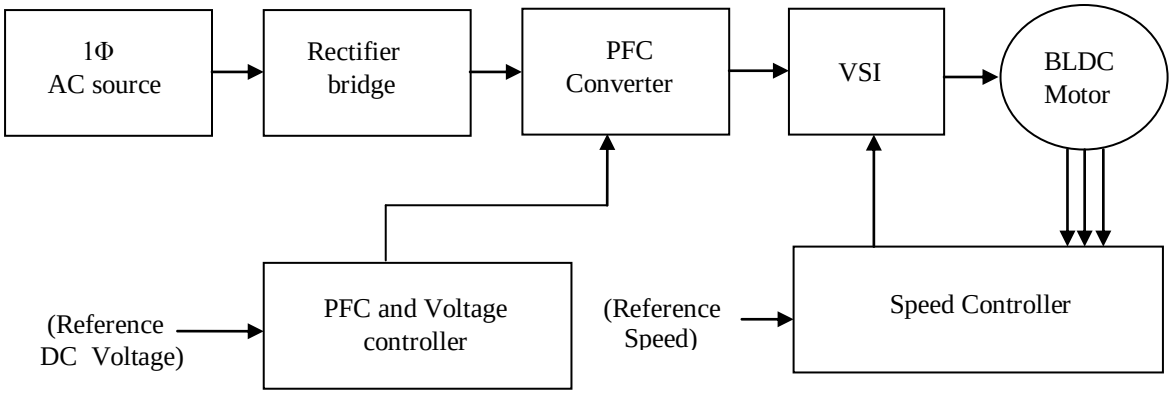

Figure 1. Block diagram of Conventional PFC converter fed BLDC motor drive.

3. PROPOSED PFI-CSC CONVERTER FED BLDC MOTOR DRIVE

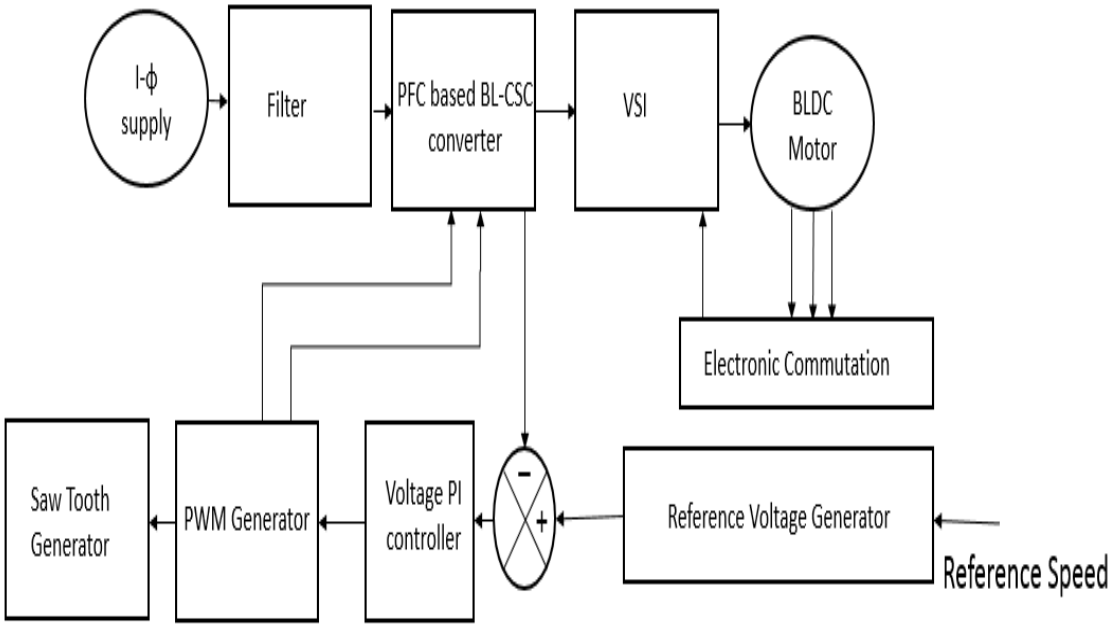

Figure 2. Functional block diagram of Proposed PFC-CSC converter fed BLDC motor drive.

The block diagram of proposed PFI-CSC converter fed BLDC motor drive is shown in Fig.2. In this configuration, the front end rectifier bridge is eliminated and by this means, the conduction losses are reduced. This converter is configured to function in a discontinuous inductor current mode (DICM) such that the inductor currents iLi1 and iLi2 are discontinuous, whereas the intermediate capacitor voltages V_{C1} and V_{C2} remains continuous in a switching period. For controlling the speed of the BLDC motor, an approach of variable dc link voltage is used. It is also electronically commutated for resulting in reduced switching losses of VSI.

4. OPERATING PRINCIPLE OF PROPOSED PFI-CSC CONVERTER

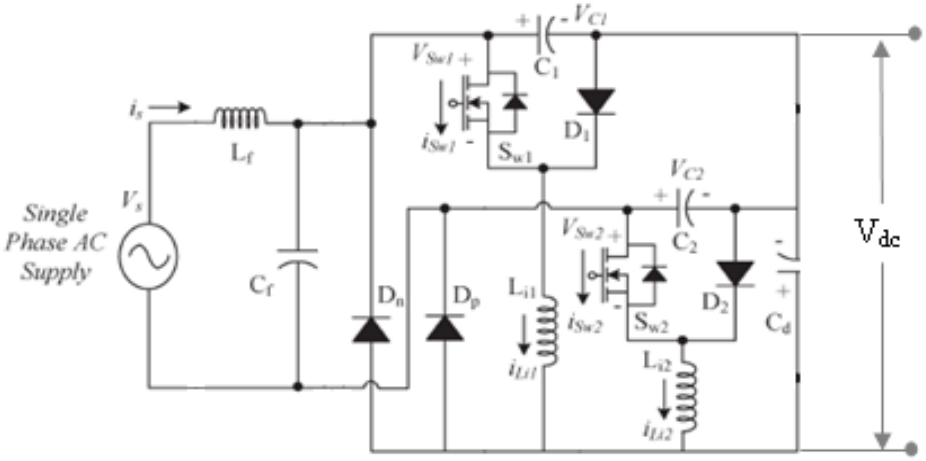

Figure 3. Proposed PFI-CSC converter for BLDC motor drive

The proposed PFI-CSC converter is shown in Fig.3. The proposed PFI-CSC converter is majorly eyed at generating a lesser inrush current and lower switching stress. The modified PFI-CSC converter mainly consists of two semiconductor switches that are connected in the current flow path, which results in reduced current stress across switches. Hence the overall circuit efficiency is enhanced in comparison with the existing techniques in terms of lower switching losses, inrush current, improved unity power factor, noise interference and dc link voltage.

4.1 Principle of operation:

The proposed PFI-CSC converter is configured in such a way that two different switches operate for positive and negative half cycles of supply voltages. The switch S_{w1}, inductors L_{i1} and fast recovery diode Dp conduct during the positive half cycle of supply voltage. The switch Sw2, inductors Li2, and fast recovery diode Dn conduct during the negative half cycle of supply voltage. The operation of the proposed PFI-CSC converter for positive and negative half cycles of supply voltage are shown in Fig. 4(a)–(c) and (d)–(f).

4.2 Operation during complete switching cycle:

The switching cycle operation of the proposed PFI-CSC converter in different modes is described here. The proposed PF-CSC converter has been designed to operate in discontinuous inductor current conduction (DICM) such that current in inductors L_{i1} and L_{i2} becomes discontinuous within a switching period. The converter's operation is divided into three different modes of operation in positive and negative half cycles of supply voltage respectively.

Mode P-I: When the switch S_{w1} is turned on, the input side inductor L_{i1} starts charging through diode D_p resulting in increase of current i_{Li1}. While the intermediate capacitor starts discharging through switch Sw1 in order to charge the dc link capacitor C_d. Hence the voltage across intermediate capacitor V_{C1} decreases, while the dc link voltage V_{dc} increases as shown in the Fig.4 (a).

Mode P-II: When the switch S_{w1} is turned off, the energy stored in inductor L_{i1} discharges through diode D_1 to DC link capacitor C_d. In this mode of operation, the current i_{Li1} decreases, while the dc link voltage continues to increase. Also, intermediate capacitor C_1 starts charging and hence the voltage across it increases as shown in the Fig.4 (b).

Mode P-III: This mode is the DICM of operation because the current in the input inductor L_{i1} becomes zero. The intermediate capacitor C_1 continues to retain energy and hold its charge, while the dc link capacitor C_d supplies the energy required by the load as shown in the Fig.4(c).

The converter operates for the negative half cycle of the supply voltage in a similar manner as depicted in the Fig. 4(d)-(f). During the negative half cycle, an inductor L_{i2}, an intermediate capacitor C_2, and diodes D_n and D_2 conducts in a same way. The associated waveforms during the complete switching period are shown in Fig.5.

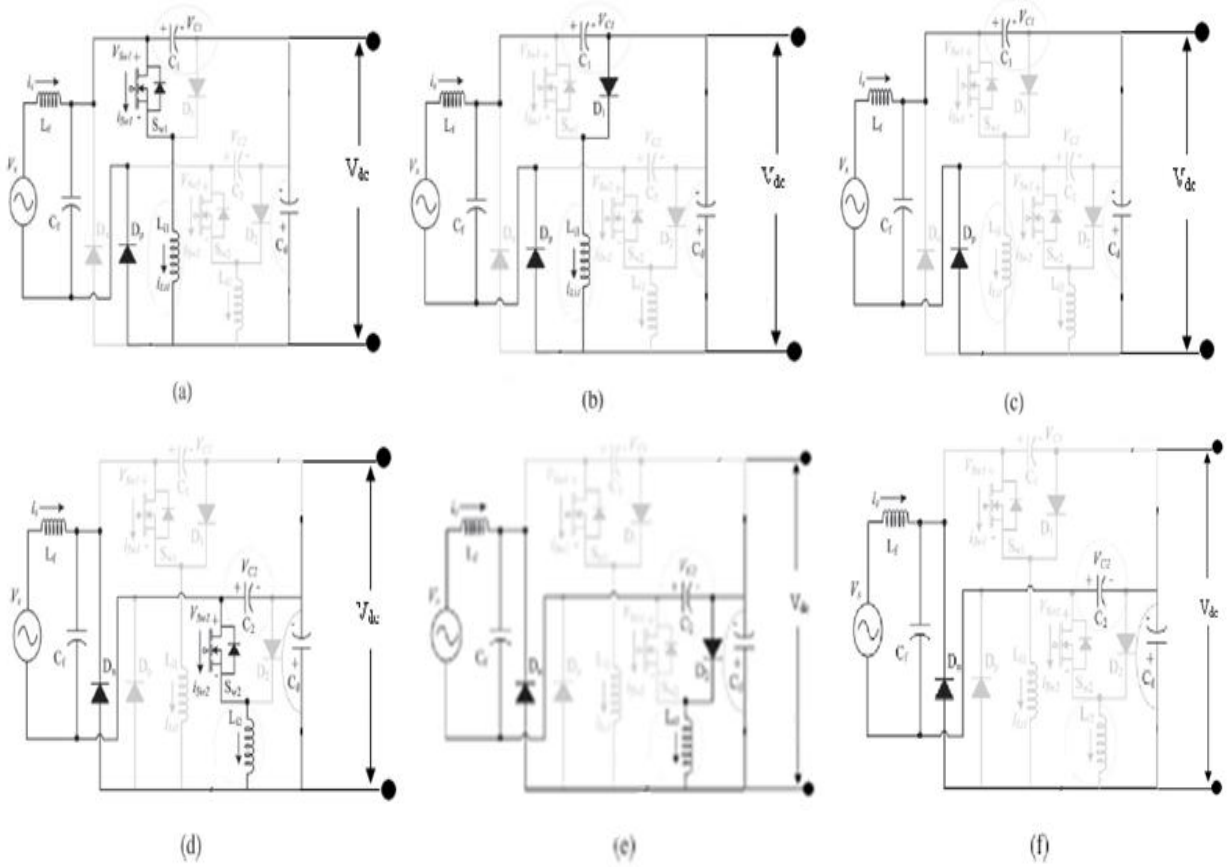

Figure 4. (a)-(f) Different modes of operation of the proposed PFI-CSC converter

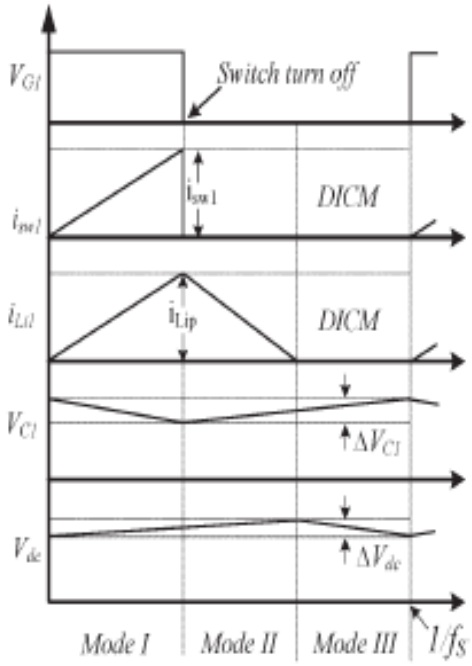

Figure 5. Waveforms of proposed PFI-CSC converter in a complete switchi

5. SIMULATION RESULTS AND DISCUSSION

The proposed PFI-CSC converter fed BLDC motor drive has been analyzed in both open loop and closed loop. Fig.6 shows the simulink model of the proposed PFI-CSC converter fed BLDC motor drive in closed loop analysis. The system parameters for the proposed converter are given in the Table I.

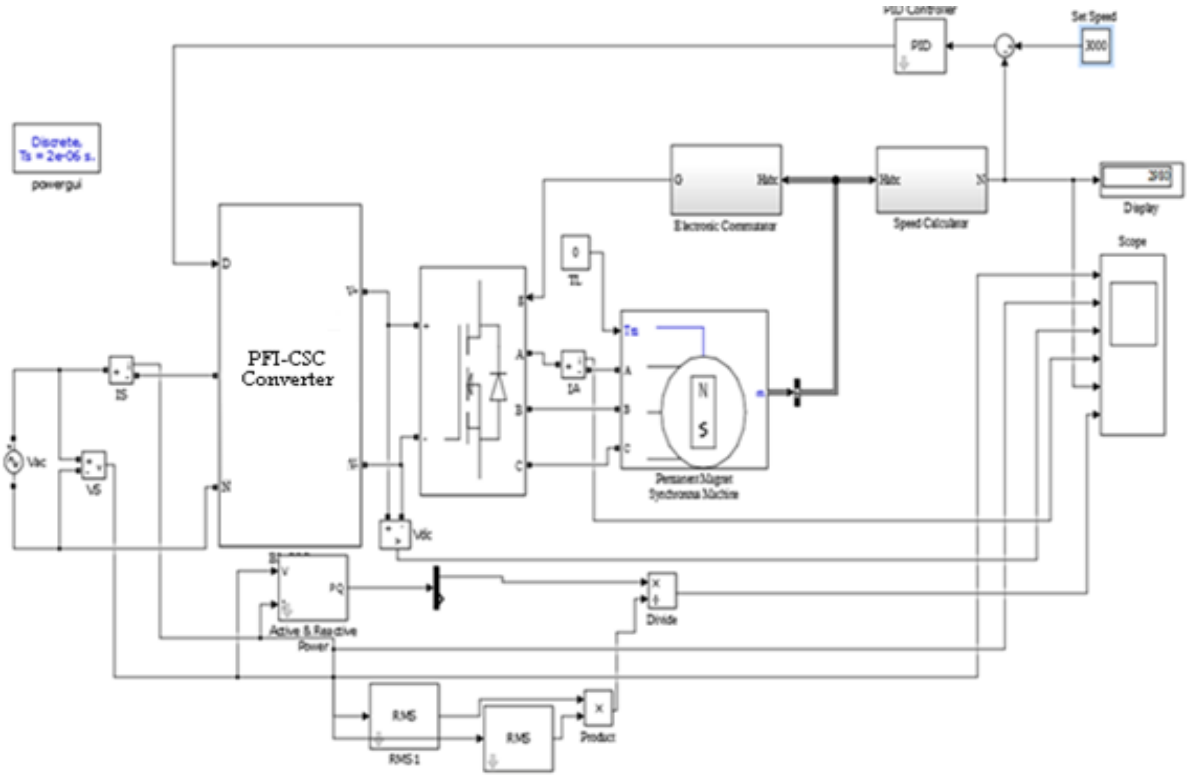

Fig.6. Simulink model of the proposed PFI-CSC converter fed BLDC motor drive.

Table-1 Simulation Parameters of The Proposed Converter

Parameters	Value
Input voltage	220V
Output voltage	310V
Output Power	500 W
Duty cycle	0.5
Switching frequency	20KHz
Switches	MOSFET
Inductors L1, L2	70µH
Capacitors C1, C2	0.66µF
DC link capacitor C_d	2200µF
Filter inductor L_f	3.77mH
Filter capacitor C_f	330nF

Fig.7. (a)-(h) shows the simulation waveforms of the proposed PFI-CSC converter fed BLDC motor drive (closed loop operation). Fig.8. (a)-(f) shows the simulation waveforms of the proposed PFI-CSC converter fed BLDC motor drive (open loop operation). The AC voltage to the converter is 220V. The peak voltage = 220*sqrt (2) V= 311.2V as shown in fig. 7(a). The input current of the proposed converter with closed loop control is 2A. The open loop analysis resulted in high inrush current of 10A. Hence, it can be concluded that the proposed PFI-CSC converter fed BLDC motor drive results in very low inrush current. Fig. 7(c) shows the output dc link voltage of the converter with closed loop control, which is V_{dc} =262.1V. And we can achieve wide range of voltage control and thereby speed control of BLDC motor.

Fig.7 (d) shows the output speed of the BLDC motor drive with closed loop control. For the set speed of 3000 rpm, the actual speed of the motor is 2980 rpm which is close to 3000 rpm. The open loop analysis resulted in output speed of 3071 rpm. For different set speed, we can achieve the required speed in the closed loop control. Therefore with the proposed PFI-CSC converter fed BLDC motor drive, better speed control is achieved. Fig.7 (e) shows the power factor of the AC mains. The proposed converter with closed loop control achieves the power factor of 1 with the settling time Ts=23ms. The open loop analysis resulted in power factor of 0.9 with the settling time Ts=25ms. Hence, it is observed that the proposed PFI-CSC converter with closed loop control improved the power factor of the BLDC motor drive.

Fig.7 (f) shows the voltage stresses on all the switches of the proposed PFI-CSC converter. The voltage stresses across both the switches are 400V. VSw1 = VSw2= 400V. The open loop analysis resulted in voltage stresses of VSw1 = VSw2= 500V. Hence, it can be concluded that the proposed PFI-CSC converter fed BLDC motor drive with closed loop control results in low voltage stress on the switches in comparison with the open loop analysis of the converter. Fig.7 (g) shows the ripple in the inductor currents i.e, ΔiLi1=ΔiLi2= 25A. The open loop analysis resulted in inductor ripple current of ΔiLi1=ΔiLi2= 50A. Hence, it can be concluded that the proposed PFI-CSC converter fed BLDC motor drive with closed loop control resulted in lesser ripple in the inductor current. Fig.7 (h) shows the voltage across the coupling capacitor. The change in voltage ΔVC1 = ΔVC2 =80V. The open loop analysis resulted in ΔVC1 = ΔVC2 =100V.

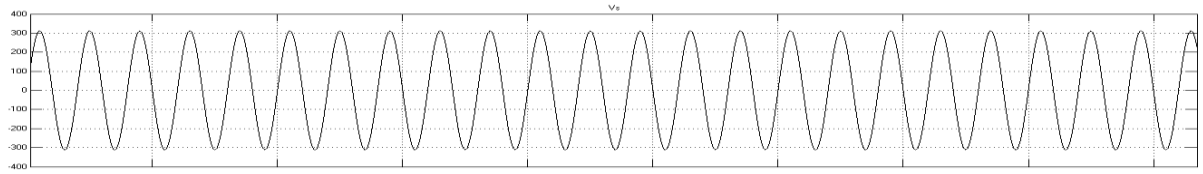

Figure 7 (a). Input voltage

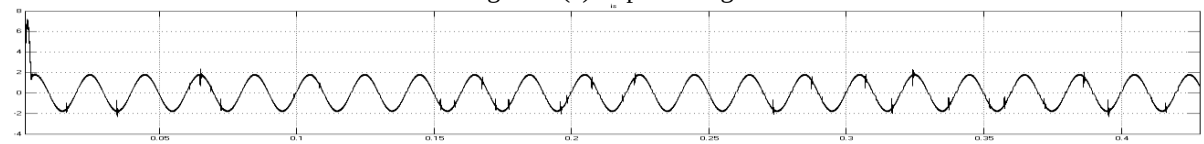

Figure 7 (b). Input current

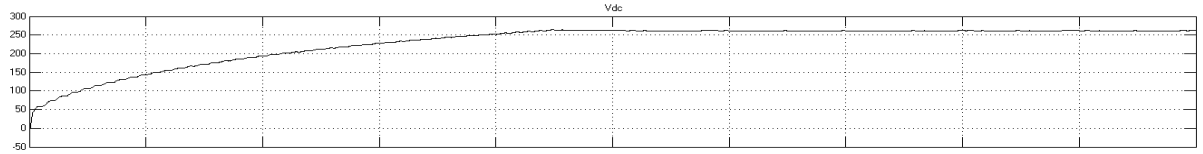

Figure 7 (c). DC link voltage

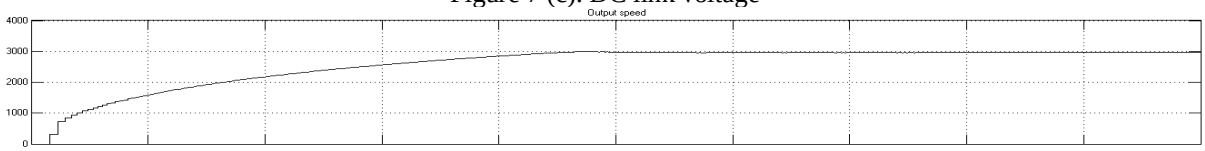

Figure 7 (d). Speed of BLDC motor

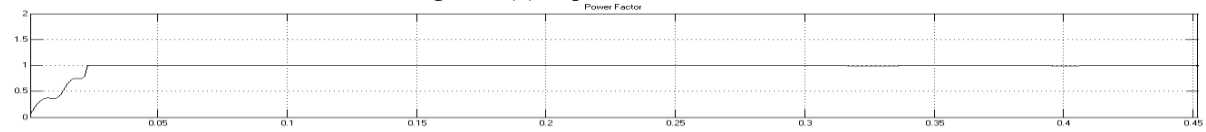

Figure 7 (e). Power Factor

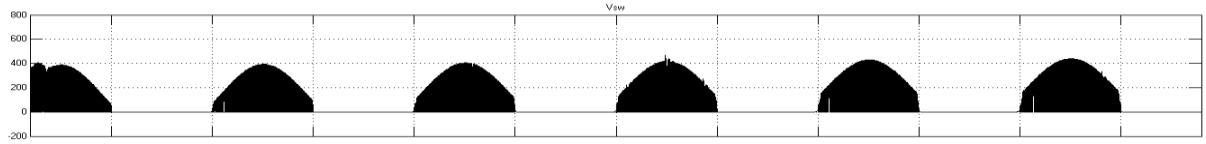

Figure 7 (f). Voltage stress across the switch

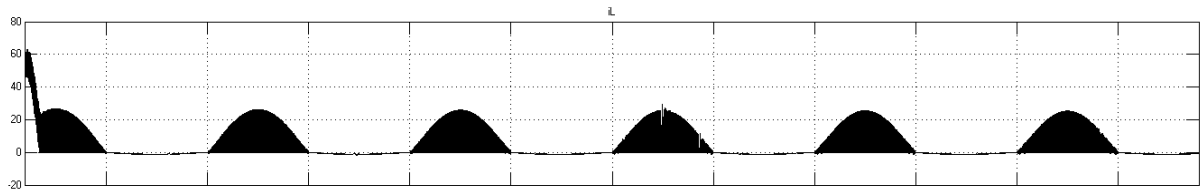

Figure 7 (g). Inductor current ripple

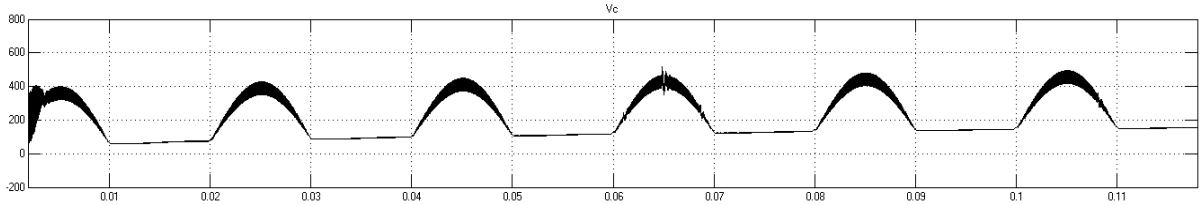

Figure 7 (h). Voltage across the capacitor

Figure 7. Waveforms associated with the closed loop analysis of the proposed PFI-CSC converter fed BLDC motor drive.

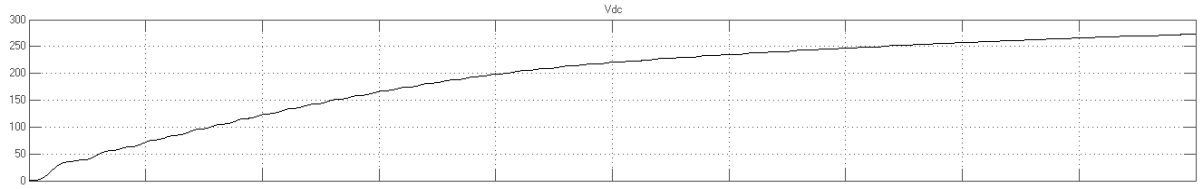

Figure 8 (a). DC link voltage

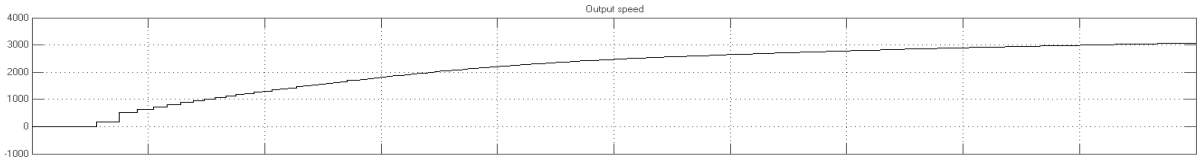

Figure 8 (b). Speed of BLDC motor

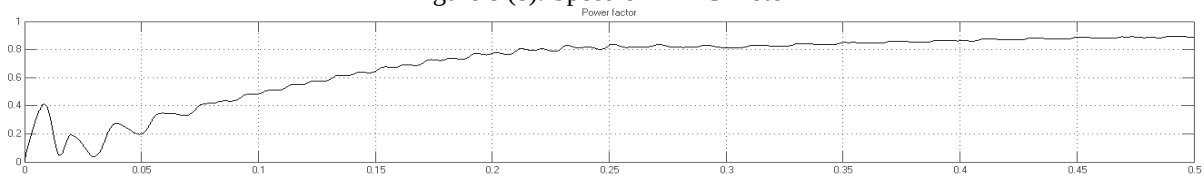

Figure 8 (c). Power Factor

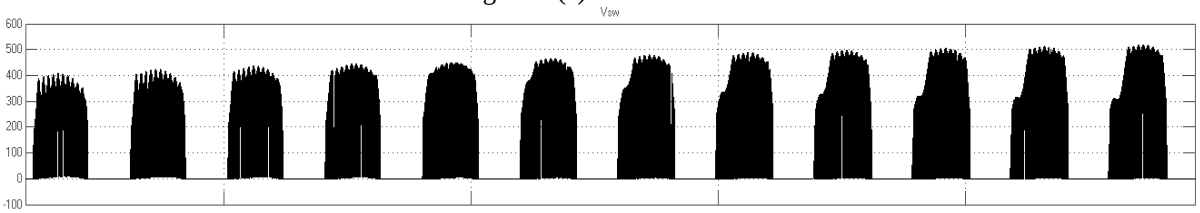

Figure 8 (d). Voltage stress across the switch

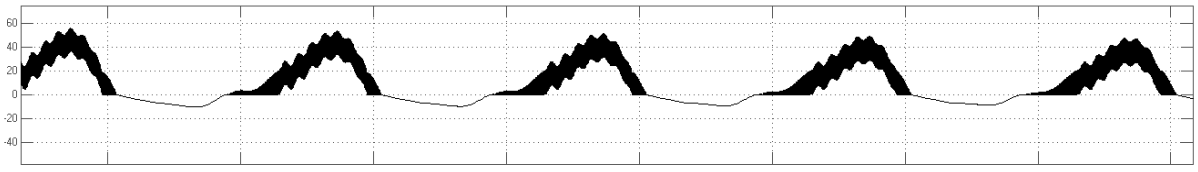

Figure 8 (e). Inductor current ripple

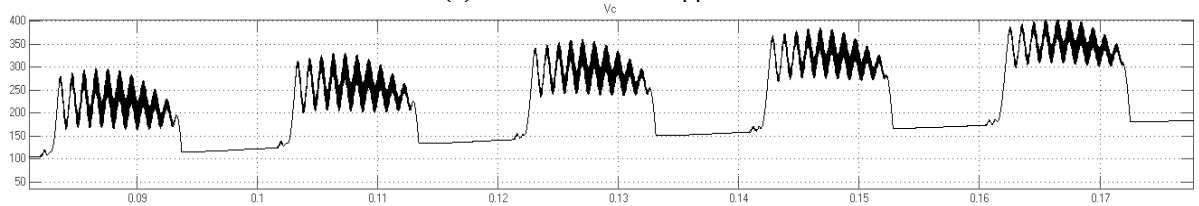

Figure 8 (f). Voltage across the capacitor

Figure 8. Waveforms associated with the open loop analysis of the proposed PFI-CSC converter fed BLDC motor drive.

6. CONCLUSION

This paper presents the analysis of Power Factor Improvement (PFI) and speed control of (Brushless) BLDC motor drive using Power Factor Improvement – Canonical switching Cell (PFI-CSC) converter. From the simulation results, it is observed that the proposed PFI-CSC converter improved the unity power factor of the BLDC motor drive by closed loop control. The speed control is achieved by varying the dc link voltage of the proposed converter through closed loop control of the BLDC motor drive. Wide range of speed control can be achieved by varying the DC link voltage of the proposed converter with closed loop control. The proposed converter eliminates the rectifier bridge thereby reduces the conduction losses. The performance of the proposed PFI-CSC converter for BLDC motor drive with closed control was improved by power factor correction and speed control of the BLDC motor. The Power Quality is maintained in AC mains for wide range of speed control. The BLDC motor drive using the proposed converter with and without closed loop control is carried out for comparative analysis and presented in this paper.

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