BLDC Motor Drive with Power Factor Correction Using PWM Rectifier

P. Sarala, S.F. Kodad and B. Sarvesh

Abstract Major constraints while using motor drive system are efficiency and cost. Commutation in the conventional DC motors is carried out by commutator which is rotating part placed on the rotor and brushes. Due to these mechanical parts, conventional DC motor consist high amount of losses. Brushless DC (BLDC) Motors are very extensively used motors these days because of its advantages over conventional DC motors. Commutation is carried out with the help of solid-state switches in BLDC motor instead of mechanical commutator as in conventional DC motor. This improves the performance of the motor. BLDC motor draws non-linear currents from the source affecting the loads connected at the source point due to harmonic production. This harmonic production reduces the system efficiency and mainly stresses the loads connected at source point. BLDC drive system with power factor (PF) correction was discussed in this paper. BLDC with normal AC-DC diode bridge rectifier and the performance of BLDC drive with PWM rectifier for power factor correction was discussed. BLDC drive system with PWM rectifier for power factor correction was validated by considering different cases. BLDC motor without power factor correction, BLDC drive with PF correction at starting condition, at steady state and with step-change in DC link voltage models was developed. Torque ripple in BLDC motor drive for these cases were compared. Models were developed and results were obtained using Matlab/Simulink software.

Keywords BLDC · Conventional · DC · Commutator · Solid-state switch · Hall sensor · Power factor (PF)

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1 Introduction

For a DC motor, supply will be DC type but the EMF should be AC type. This operation is done by commutator and brushes in a conventional DC motor. Commutator is mechanical part placed on the rotor segment for the purpose of commutation. This commutator along with brushes produces wear and tear on the commutator surface and hence commutation might not be effective. Also this mechanical commutator produces high amount of losses. Since both brushes and commutator are good conductors, they produce copper losses. The wear and tear of the commutator surface produces sparks due to uneven current distribution. Sparks produces heat which is a major drawback. The above said disadvantages are mainly due to the presence of commutation process by commutator and brushes. Thus the disadvantages in a conventional DC motor can be overcome by eliminating brushes. This led to the realization of motors without brushes called brushless DC (BLDC) motor [1, 2]. Electrical commutation in BLDC motor is carried out by electronic solid-state switches. Due to the usage of electronic switches for commutation, the drawbacks in conventional DC motor are eliminated thus improving the system performance. DC motors have very good speed control and especially BLDC exhibits many advantages [3, 4] over conventional DC motor like high efficiency, reliability, low acoustic noise, good dynamic response, lighter, improved speed-torque characteristics, higher speed range and requires very less maintenance.

BLDC motor shown in Fig. 1 is typically a combination of permanent magnet (PM) AC machine with electronic commutator. Sensor less operation [5–7] of BLDC is also possible with the help of monitoring back EMF signals. Back EMF is proportional to the speed of the rotor. So, at starting condition of the motor or low speeds, sensor less operation needs additional set-up to control the rotor position. Basically BLDC motor has DC input supply. This input of DC supply needs to be inverted to AC type to drive stator windings of BLDC motor [8–12].

Power factor is a major concern in power system. Power factor should be maintained nearer to unity. Generally drive system draws non-linear currents

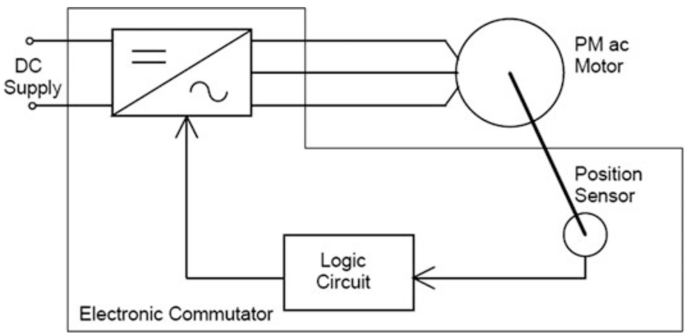

Fig. 1 Typical BLDC motor

affecting the power factor of the system. Many power factor correction techniques [13–16] were discussed. For the operation of BLDC motor, the available AC supply is to be rectified. Elimination of harmonics affecting power factor at the source side due to rectifier is an important task. Effective switching of devices in rectifier can improve power factor. Use of IGBT based pulse width modulation (PWM) rectifier can improve power factor at the source side. The same rectifier rectifies AC-DC and drives supply to converter of BLDC.

In this paper, BLDC motor drive without PWM rectifier was discussed but here in this case a simple diode bridge rectifier was used for AC-DC conversion. Models of BLDC motor drive with PWM rectifier for power factor correction was developed and validated by considering different conditions. BLDC motor with PWM rectifier at starting, at steady-state and with step variation in DC-link voltage was also discussed validating the operation of BLDC motor with PWM rectifier for power factor correction. Simulation work was carried out by Matlab/Simulink and the results were discussed in detail for each case showing the motor characteristics for the respective cases.

2 BLDC Motor Operation

The general available supply is AC. But the supply required for BLDC motor should be DC. So when AC supply is given, this AC supply should be rectified and sent to the BLDC motor. The internal electronic commutation of BLDC motor takes this DC supply through a DC link capacitor. This DC link capacitor maintains constant DC voltage at the input of inverter circuit before actually exciting BLDC motor. By proper switching of inverter switches, the current in the stator windings can be controlled. The rotor position is sensed by using the hall sensors. This is open loop type of BLDC motor without current control (Fig. 2).

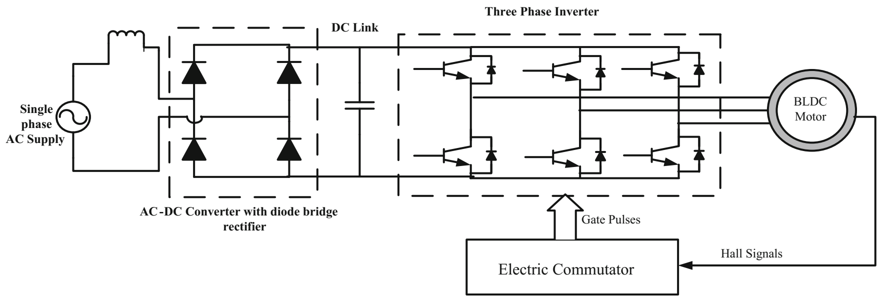

Fig. 2 Diagram of BLDC motor drive with diode bridge rectifier fed from AC supply

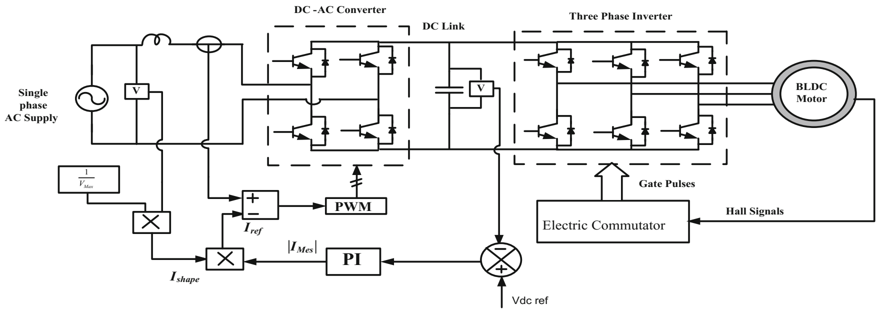

Fig. 3 Diagram of closed-loop speed control of BLDC motor

3 Power Factor Correction for BLDC Motor Drive System

In the operation of BLDC motor, the diode bridge rectifier is replaced with a pulse width modulation (PWM) rectifier which performs a task of rectifier correcting the power factor at source side shown in Fig. 3. This is achieved by switching the IGBT's in rectifier through pulse width modulation.

For power factor correction, the IGBT based rectifier is operated through PWM. The source voltage is measured and is multiplied to inverse of maximum voltage resulting in a current shape. The DC-link voltage is measured and is compared with the reference DC link voltage producing error voltage. This error signal is fed to a PI controller giving out current signal. This current signal is multiplied to current shape obtained earlier producing reference current signal. This reference current signal is measured with the actual current in the line and the error signal obtained is fed to a PWM generator. The PWM generator generates pulses switching ON respective IGBT thus improving power factor at the source side. The IGBT based rectifier performs dual task like rectifying the AC supply to DC feeding converter of BLDC through DC link capacitor and correcting the power factor improving the efficiency of the system when compared to the system employing simple diode bridge rectifier. Diodes are uncontrolled devices and cannot control switching ON or OFF. Replacing diodes with IGBT in bridge rectifier and by switching IGBT's with PWM generator improves system power factor and efficiency as a result.

4 Matlab/Simulink Results and Discussions

Case 1: BLDC motor drive without PFC

Figure 4 shows the model of BLDC motor drive without PFC. Figure 5 shows the source voltage and source current waveforms of BLDC motor drive without

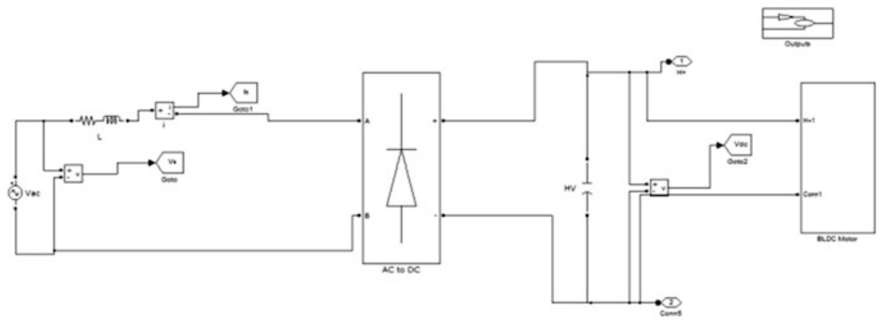

Fig. 4 Simulation model of BLDC motor drive without PFC

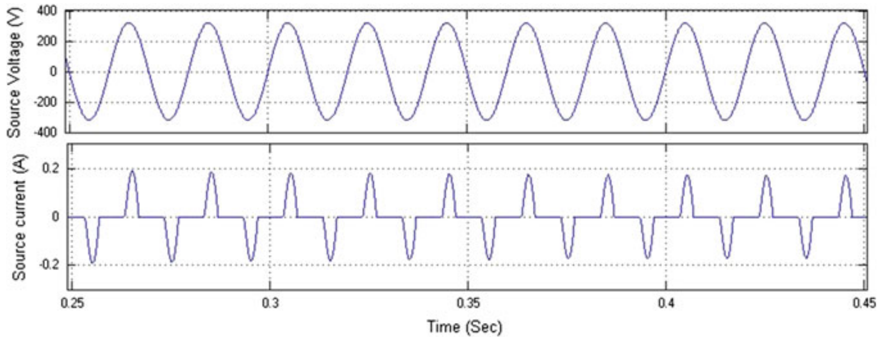

Fig. 5 Source voltage and source current

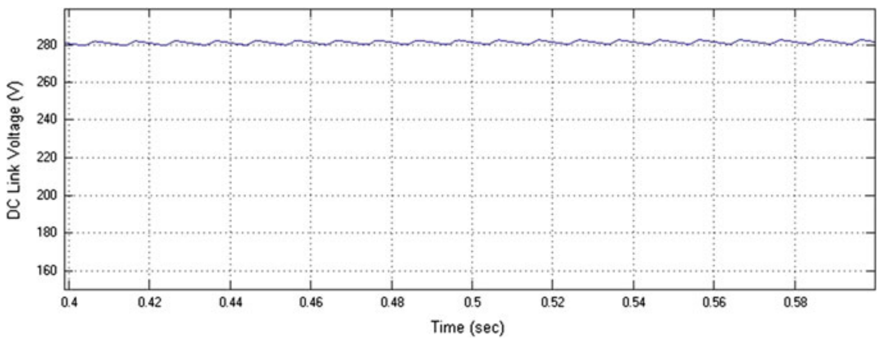

Fig. 6 Simulation result of DC link voltage

PFC. Input source current contains harmonics which can be clearly observed. DC link voltage driving converter of BLDC is shown in Fig. 6.

Figure 7 shows the stator phase currents drawn by BLDC motor. Figure 8 shows the speed of BLDC motor. The torque produced in the BLDC motor was shown in Fig. 9. Source current contains harmonics if BLDC motor drive was operated without PFC. The source current contains 95.89 % of THD as shown in Fig. 10.

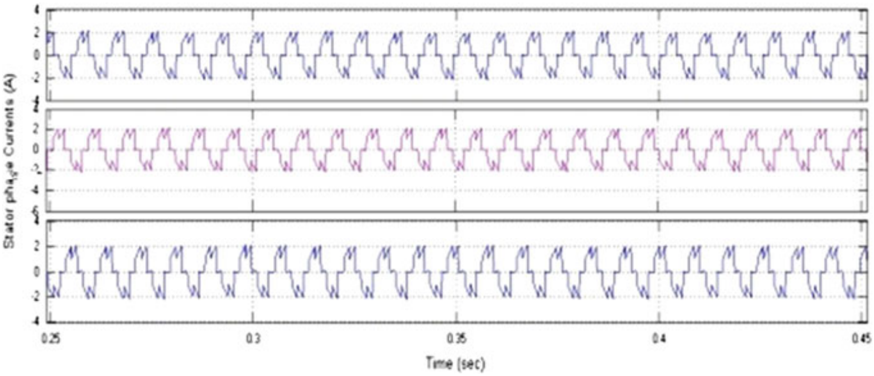

Fig. 7 Simulation result of stator currents

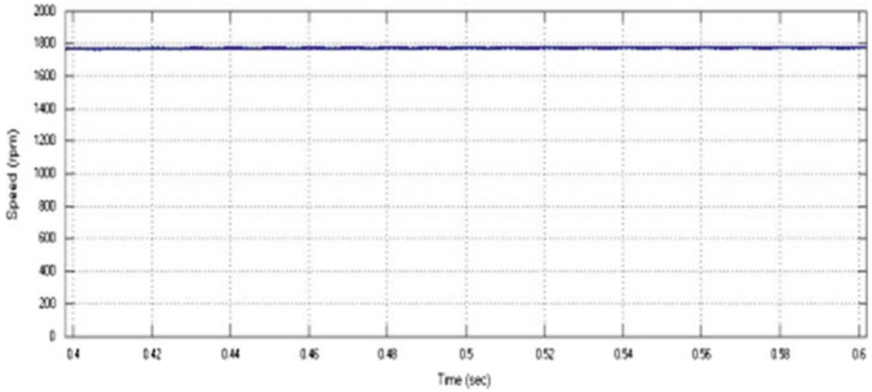

Fig. 8 Simulation result of speed

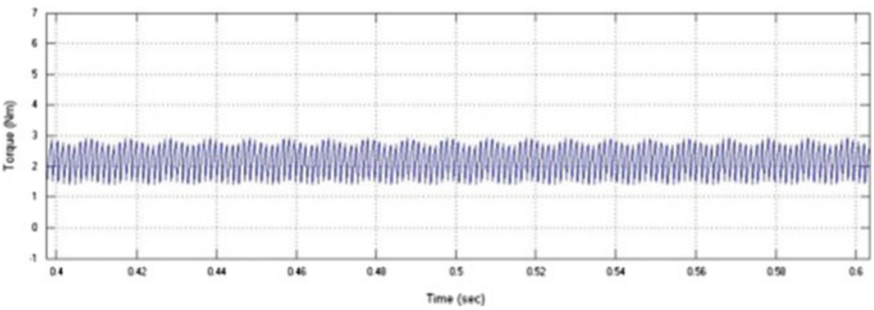

Fig. 9 Torque of BLDC motor without PFC

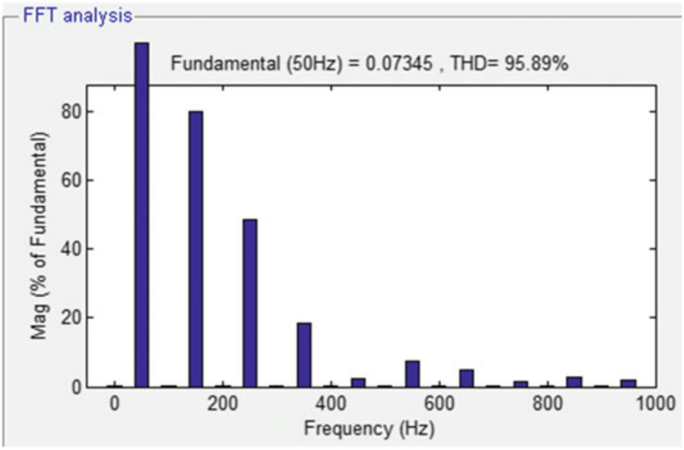

Fig. 10 THD in current of without PFC

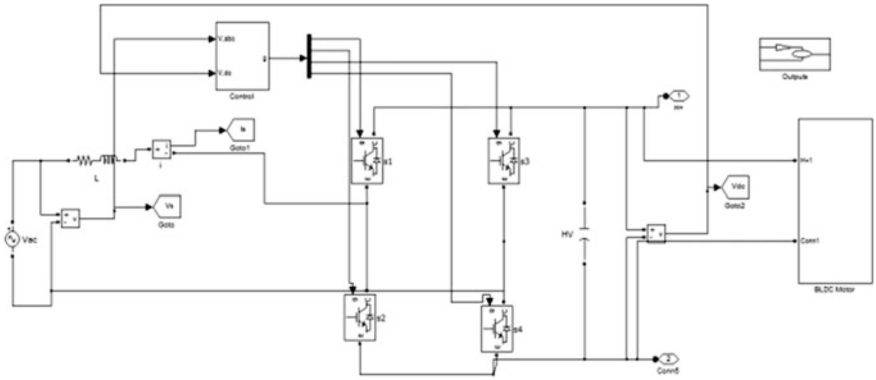

Fig. 11 Simulation model of BLDC motor drive with PFC at starting

Case 2: BLDC motor drive with PFC at starting, $V_{dc} = 50$ *V*

Figure 11 shows the model of BLDC motor drive with PFC and motor at starting. Figure 12 shows the source voltage and source current waveforms of BLDC motor drive with PFC. Input source current contains very less harmonics which can be clearly observed. DC link voltage driving converter of BLDC is shown in Fig. 13. DC link voltage is maintained constant at 50 V.

Figure 14 shows the stator phase currents drawn by BLDC motor. Figure 15 shows the speed of BLDC motor. The torque produced in the BLDC motor was shown in Fig. 16. Source current contains very less harmonics if BLDC motor drive was operated with PFC.

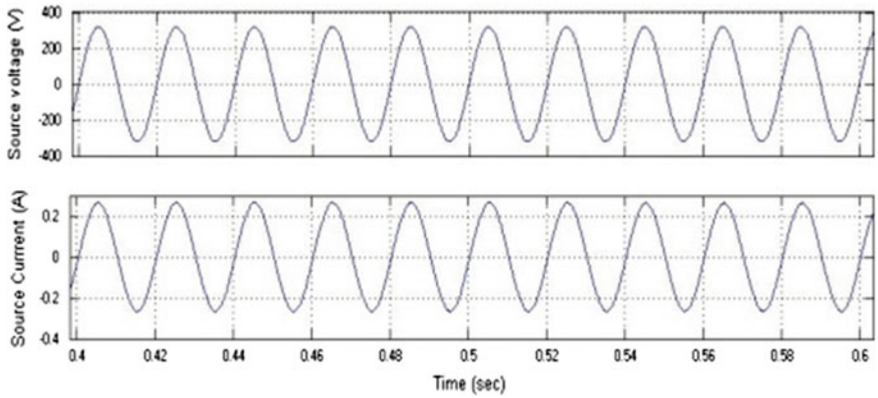

Fig. 12 Source voltage and source current

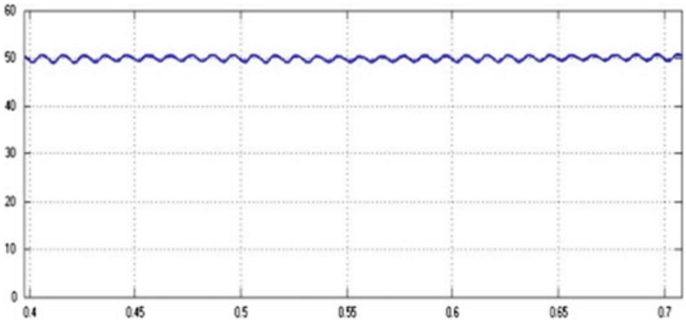

Fig. 13 DC link voltage

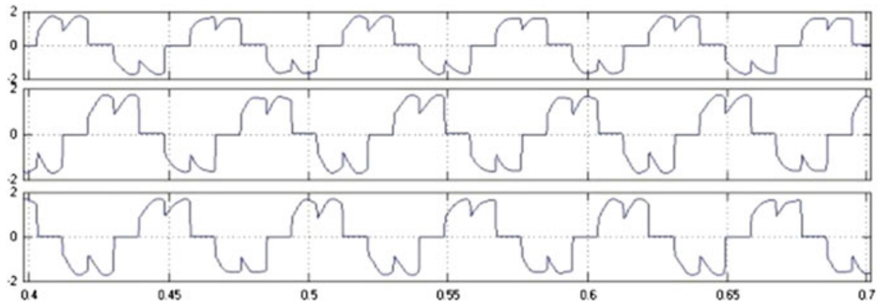

Fig. 14 Simulation result of stator currents

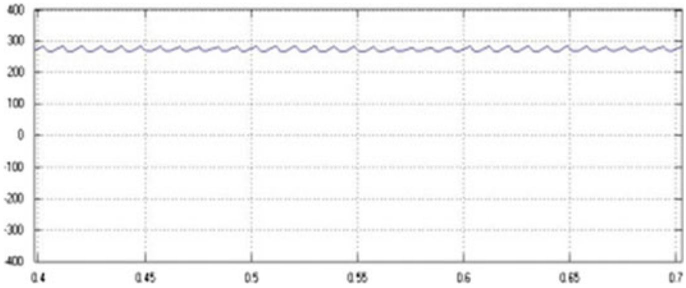

Fig. 15 Simulation result of speed

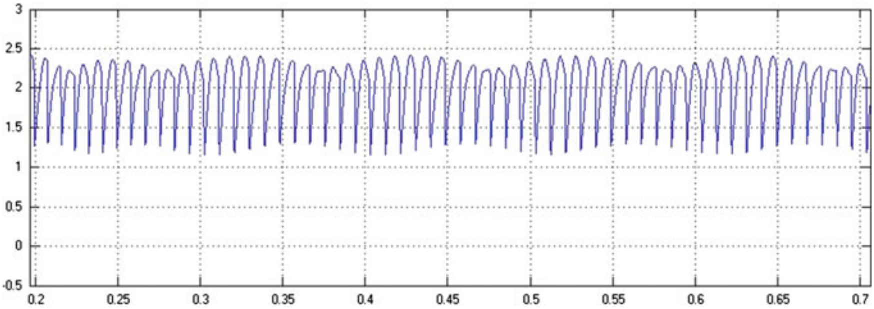

Fig. 16 Simulation result of torque of BLDC motor with PFC at starting

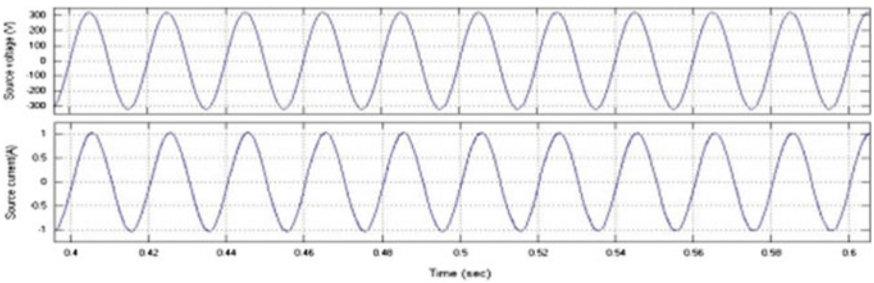

Fig. 17 Source voltage and source current

Case 3: BLDC motor with PFC at steady state condition and V_{dc} = 200 V

Figure 17 shows the source voltage and source current waveforms of BLDC motor drive at steady state with PFC. DC link voltage driving converter of BLDC is shown in Fig. 18 maintained constant at 200 V.

Figure 19 shows the stator phase currents drawn by BLDC motor. Figure 20 shows the speed of BLDC motor. The torque produced in the BLDC motor was shown in Fig. 21.

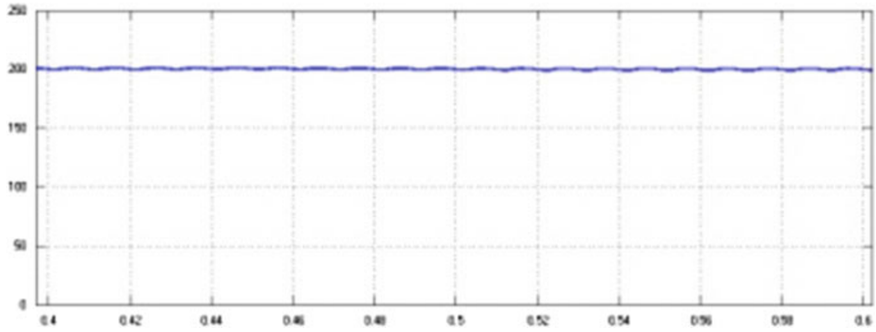

Fig. 18 DC link voltage

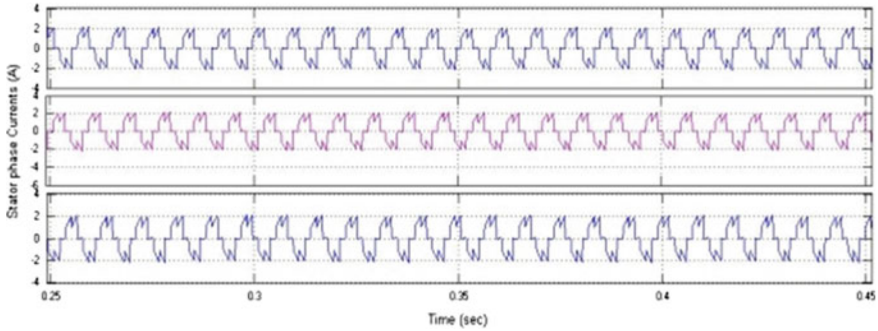

Fig. 19 Simulation result of stator currents

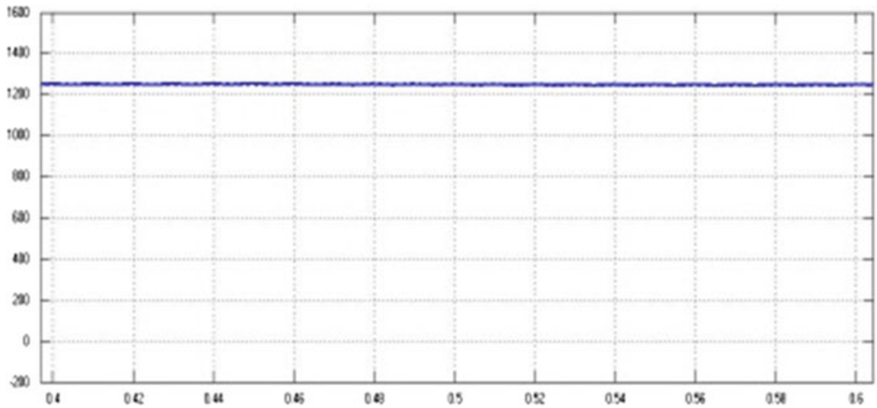

Fig. 20 Simulation result of speed

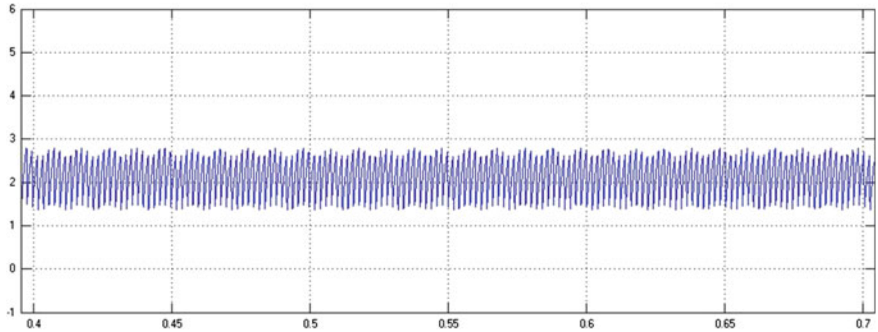

Fig. 21 Simulation result of torque of BLDC motor with PFC at steady-state

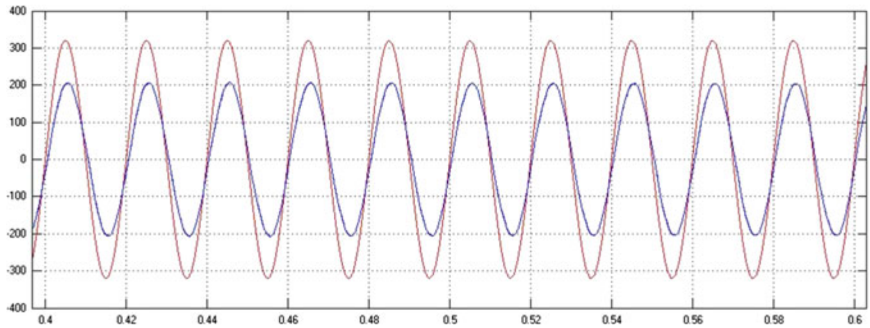

Fig. 22 Simulation result of power factor of system with PFC

Figure 22 shows the power factor of the system with PFC and is maintained nearer to unity. THD in source current is maintained very less at almost 1.5 % as shown in Fig. 23.

Case 4: BLDC motor with PFC with step-change in DC link voltage

Figure 24 shows the source voltage and source current waveforms of BLDC motor drive. The step change is switched at 0.6 s and change in source current can be observed after 0.6 s. Step change in DC link voltage driving converter of BLDC is shown in Fig. 25 maintained constant at 100 V up to 0.6 s and at 0.6 s the DC link voltage is stepped to 150 V.

Figure 26 shows the stator phase currents drawn by BLDC motor. Figure 27 shows the speed of BLDC motor. The torque produced in the BLDC motor was shown in Fig. 28. Step change in DC link voltage is switched at 0.6 s and thus the change in speed and torque characteristics can be observed after 0.6 s when compared to the time before 0.6 s. Table 1 represents the respective THD's in source current with and without PFC.

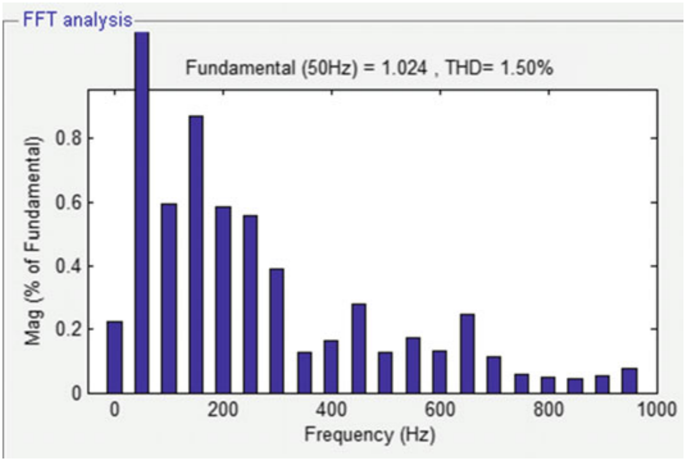

Fig. 23 Simulation result showing THD in source current of system with PFC

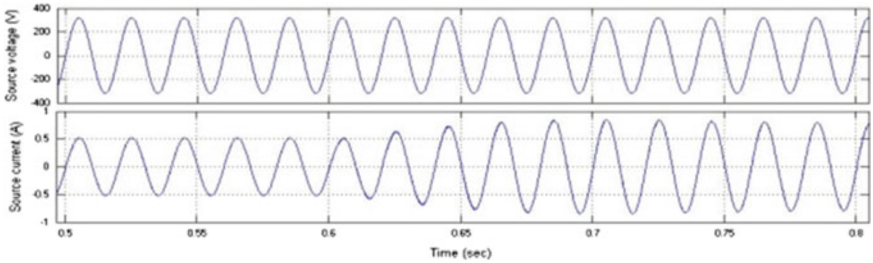

Fig. 24 Source voltage and source current

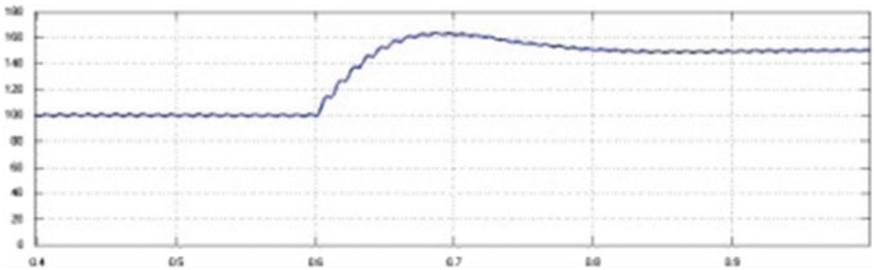

Fig. 25 DC link voltage

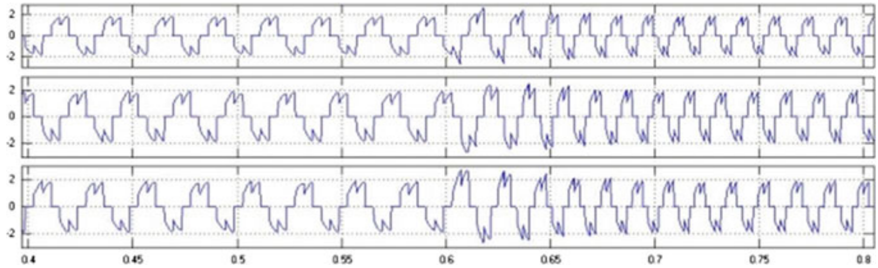

Fig. 26 Simulation result of stator currents

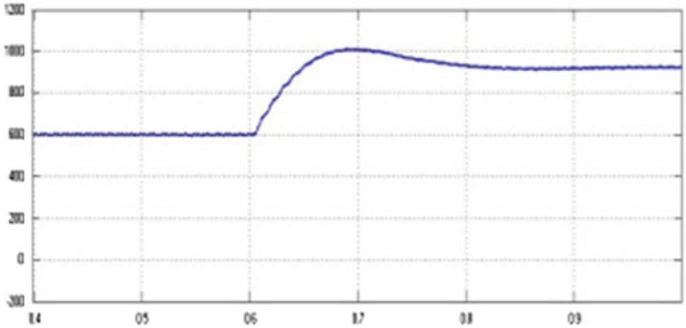

Fig. 27 Simulation result of speed

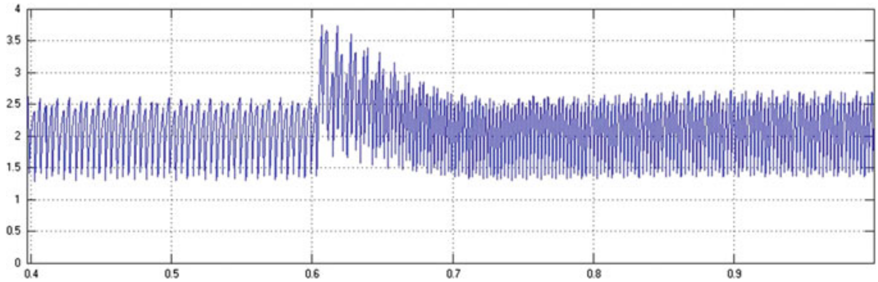

Fig. 28 Simulation result of torque of BLDC motor with PFC with step-change

Table 1 Torque ripple

BLDC motor	THD (%)
System without PFC	95.89
System with PFC	1.5

5 Conclusion

DC motors have very good speed-torque characteristics. DC motors are very much accommodated in many of the industrial drives. Commutation in conventional DC motors was carried out by mechanical parts like brushes and commutator. Presence of brushes for commutation can lead to sparks, losses, reduced efficiency. DC Motors were realized without brushes and mechanical commutator for the commutation purpose called brushless DC (BLDC) motors. BLDC motors eliminate all the disadvantages in conventional DC motors due to the absence of brushes and can give better performance characteristics with smooth speed torque characteristics. BLDC motors use electronic commutator for the purpose of commutation. A converter with solid-state switches was employed to convert DC to AC EMF inside the machine. Models of BLDC motor drive with and without drive system were developed and their respective characteristics were also shown. With power factor correction (PFC) converter, motor was made to run at different operating conditions like motor at starting, motor at steady state and motor with step change in DC link voltage. Characteristics were shown for all cases. Results obtained were simulated using Matlab/Simulink. Results validate the use of BLDC motor drive system with PFC at different motor conditions. THD in source current for the system with and without PFC was compared.

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