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POWER FACTOR CORRECTION CONVERTERS FOR BLDC MOTOR DRIVE SYSTEM: A COMPARATIVE EVALUATION

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ABSTRACT

AC to DC conversion with the help of power electronic converters is very much used these days in many applications. Rectification of input supply is essential in many areas of engineering especially in motor drive applications. BLDC motor is fed with DC supply and need a rectifier to convert available AC supply to DC type. Rectification from input AC supply to DC output with simple diode bridge rectifier insists for an output capacitance for stiff DC output. The presence of capacitance at the output of DC side deteriorates source power factor and reduced power factor at source side can cause serious problems in the system. This phenomenon insists for power factor correction. Power factor correction using DC-DC converters is a general practice. This paper presents a comparative evaluation of different types of power factor correction converters for BLDC motor drive application. Power factor correction converters like current follower Buck converter, Bridgeless Buck converter and Hybrid Buck converters were presented in this paper for evaluation. The Simulink models and results are developed using MATLAB/SIMULINK software. Power factor angle between source voltage and source current was presented with all three converters and THD in stator current was also depicted.

Keywords: BLDC, power factor correction (PFC), buck, hybrid buck.

INTRODUCTION

BLDC (Brushless DC) motor drives are very much in existence in many of the industrial applications replacing conventional motors owing to its advantages over conventional motors. Conventional DC motors have disadvantages due to the presence of commutator and brush assembly in their construction which causes additional losses, sparks, and wear and tear. BLDC motors do not have brush and commutator assembly and the commutation process is done using an electronic commutator. Electronic commutator uses power electronic switches for commutation and avoids mechanical switch as in the case of conventional motors [1-5]. BLDC motors drives can run at high speeds due to its constructional features.

For the operation of BLDC motor drive [6-7] as in Figure-1, the available AC type of supply is to be rectified to DC type to feed stator windings of BLDC motor through electronic commutator. For the conversion of AC to DC type, simple diode bridge rectifier (DBR) can be used. Diode bridge rectifier consists of diodes and the input supply is rectified to DC. To obtain stiff output DC, diode bridge rectifier is supported with an output capacitance. The presence of output capacitance at DBR makes input power factor on source side to deteriorate and causes power quality issues on source side. The reduced source power factor causes system to malfunction and cause many disadvantages. This phenomenon insists for power factor correction on input side using a power factor correction converter. Use of DC-DC converters are general practice for power factor correction. Many DC-DC converters for power factor correction were published in literature.

DC-DC converters have wide range of applications in area of electric drives. Converters can be used to establish dynamically boostable and well regulated output voltage for a dc motor drive. These converters are used in Electric Vehicles. Speed control of dc motor can also be achieved using dc-dc converters. Another important application of DC-DC converter is power factor correction [8-11] and mitigation of supply current harmonics for permanent magnet brushless drives. Also loss minimization of drive can be done using dc-dc converter.

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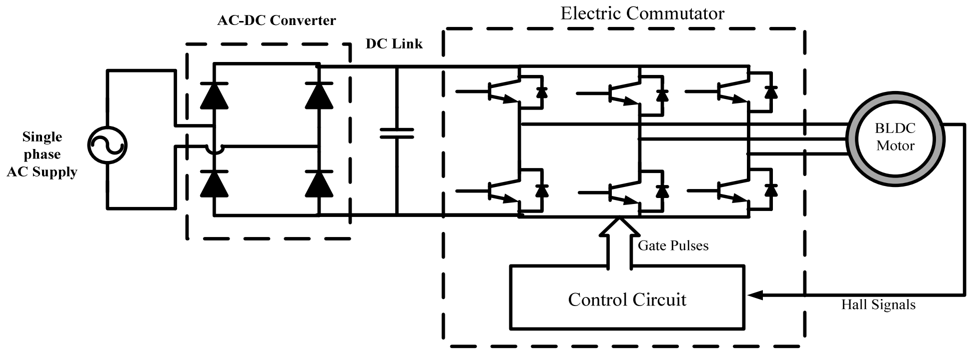

Figure-1. Block diagram of BLDC motor.

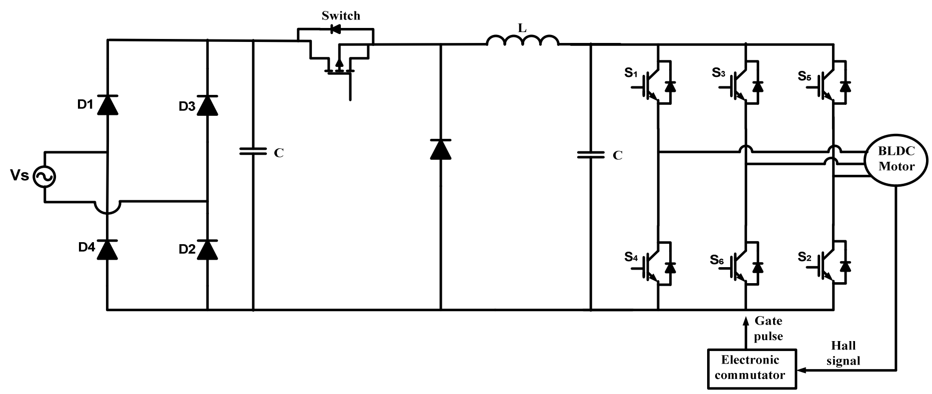

Figure-2. BLDC motor with buck converter as PFC converter without control.

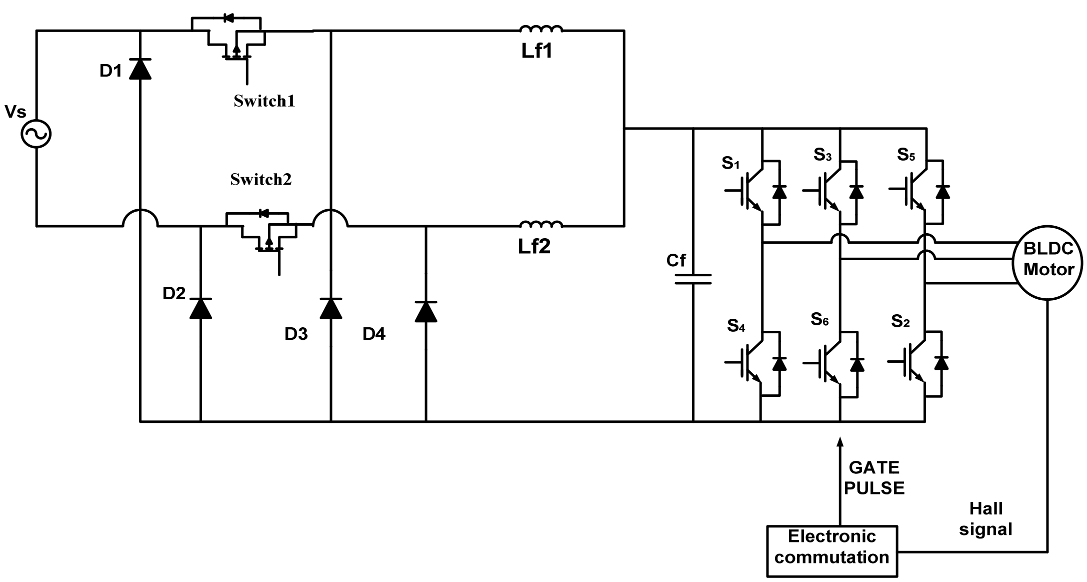

Figure-3. Bridgeless buck converter as PFC converter with BLDC load without controller.

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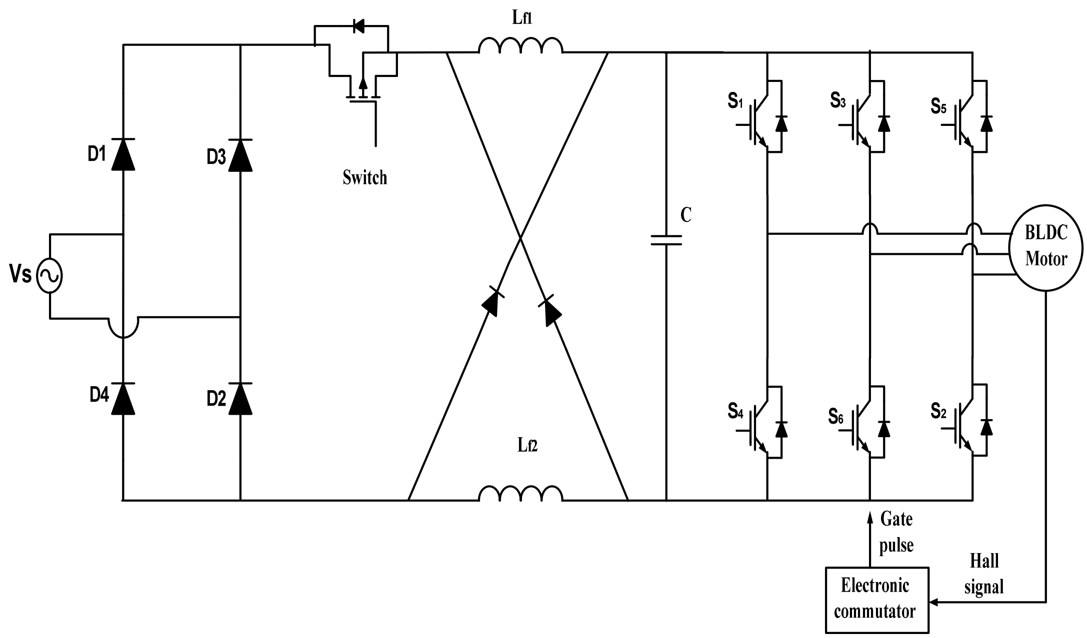

Figure-4. Hybrid buck Converter as PFC converter for BLDC drive.

This paper presents a comparative evaluation of different types of power factor correction converters for BLDC motor drive application. Power factor correction DC-DC converters like current follower Buck converter, Bridgeless Buck converter and Hybrid Buck converters were presented in this paper for evaluation. The Simulink models and results are developed using MATLAB/SIMULINK software. Power factor angle between source voltage and source current was presented with all three converters and THD in stator current was also depicted.

POWER FACTOR CORRECTION DC-DC CONVERTERS

The choice of mode of operation of a PFC converter is a critical issue because it directly affects the cost and rating of the components used in the PFC converter. The continuous conduction mode (CCM) and discontinuous conduction mode (DCM) are the two modes of operation in which a PFC converter is designed to operate.

Figure-2 represents BLDC motor with Buck converter as PFC converter without control and Figure-3 represents Bridgeless Buck converter as PFC converter with BLDC load without controller. Figure-4 represents Hybrid Buck Converter as PFC converter for BLDC drive load.

Buck converter as PFC converter

Generally the available supply is AC and for a BLDC motor to operate needs DC. For this conversion of AC to DC, a diode bridge rectifier is used. Diode bridge rectifier converts AC to DC and the DC output is fed to buck converter. Buck converter is DC-DC converter which is typically a step-down converter. A high voltage DC is stepped down to low voltage DC using a buck converter. Obtained low voltage DC is fed to inverter which is voltage source converter through a filter and DC link from capacitor. Inverter produces three phase output and the stator windings of BLDC motor are excited. When stator windings are excited rotating magnetic field is produced and due to interaction of stator and rotor fields. Torque is exerted on rotor. The rotor position is continuously sensed by sensors and sent to electronic commutation which triggers static switches of voltage source converter (front-end converter for BLDC). Due to the presence of diode bridge rectifier for conversion of AC to DC, harmonics are induced in to the system which needs corrective measures for optimal system performance.

Bridgeless buck converter as PFC converter

A bridgeless buck converter is a converter which avoids a bridge circuit before buck converter for conversion of AC supply to DC. Bridgeless buck converter directly converts AC to DC and charges the DC link capacitor directly through its operation eliminating a separate bridge circuit for AC to DC conversion. A bridgeless buck converter consists of four diodes, two coupled inductors along with a switch as shown in Figure-3. The DC source feeding bridgeless buck converter can be a DC voltage source or can be extended to renewable energy source.

Hybrid buck converter as PFC converter

Hybrid buck converter as power factor correction (PFC) converter for BLDC drive is shown in Figure-1. The input AC source is converted to DC by using a diode bridge rectifier. Hybrid buck converter is a DC-DC converter consisting of a power switch, two inductors, two diodes and a DC-link capacitor. Switch is controlled with

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a simple control such that power factor correction takes place by maintaining the power factor angle between source voltage and current as close to zero attaining nearer unity power factor.

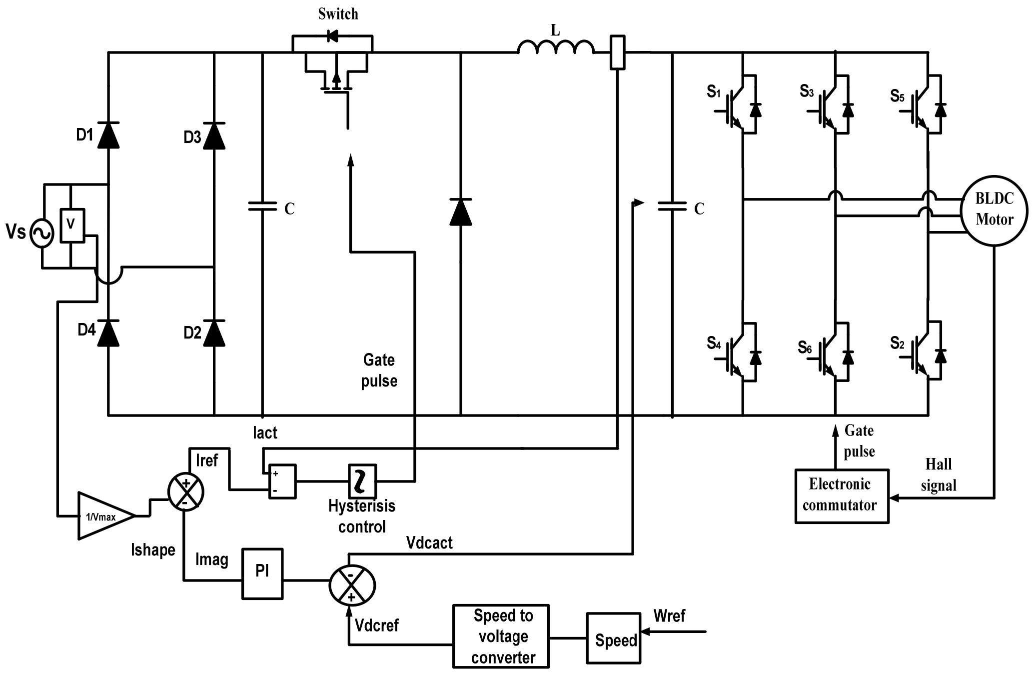

Figure-5. BLDC motor with power factor correction using current control.

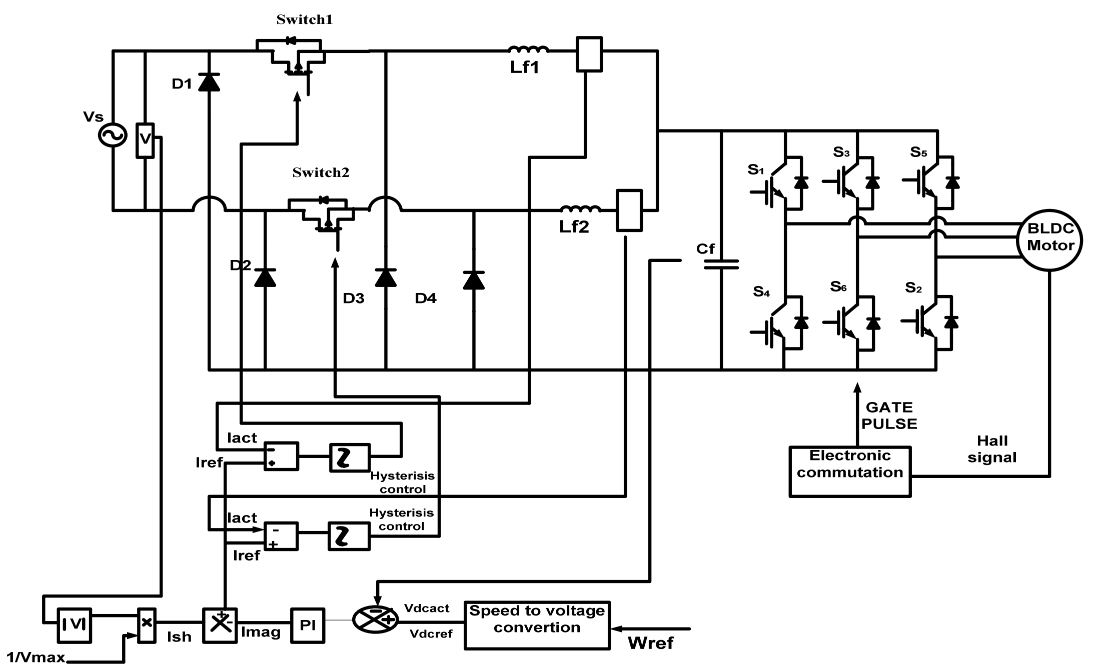

Figure-6. Bridgeless buck converter fed BLDC with controller.

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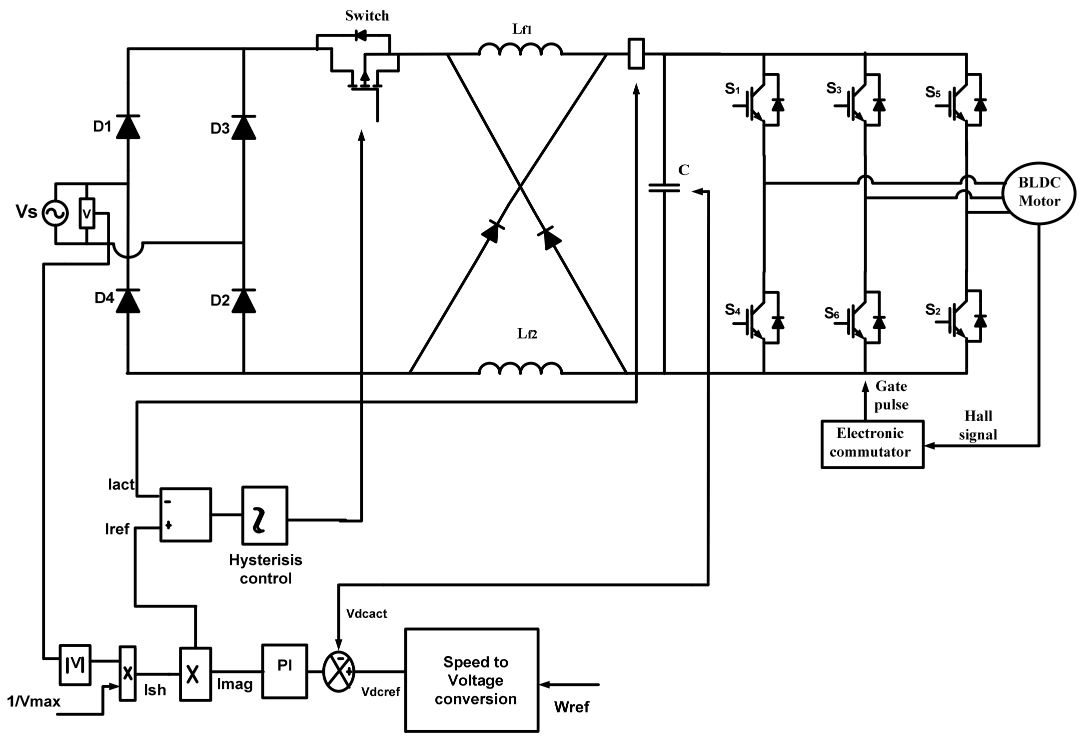

Figure-7. Hybrid buck converter with simple current control technique.

CONTROL OF PFC CONVERTERS

Simple Buck converter, Bridgeless Buck converter and Hybrid buck converter as power factor correction converters for BLDC motor drive load operated with simple current control strategy. Reference speed signal is converted to voltage type of signal to produce reference DC voltage signal using speed to voltage conversion. Actual DC-link voltage is sensed from the DC-link capacitor and is compared with reference DC-link voltage. The error signal is fed to a PI controller which gives out magnitude of current signal. From the actual voltage signal, current shape is obtained and the same is multiplied to current magnitude to obtain current reference signal. Actual current from the line is measured and is compared with reference current signal and the error is fed to hysteresis current controller to produce pulses for switch in converters. These pulses produced turns ON and OFF the switch in converters. Figure-5 shows the switch of Buck converter as PFC converter operated with simple current follower control strategy and Figure-6 represents Bridgeless Buck converter as PFC converter operated with simple current follower control strategy. Figure-7 shows Hybrid Buck converter as PFC converter operated with simple current follower control strategy.

RESULTS AND DISCUSSIONS

Case 1: Buck converter as PFC converter at V_{dc}=200V

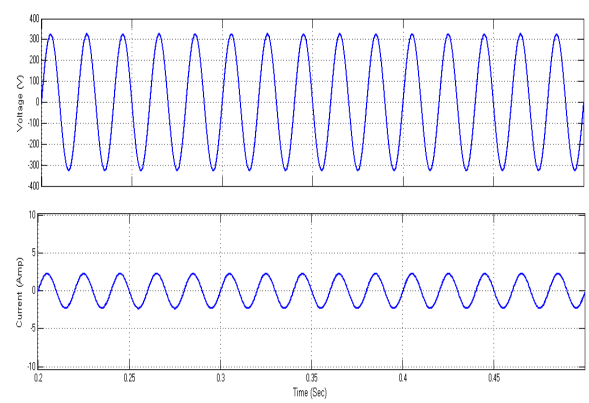

Figure-8. Source voltage and source current of system.

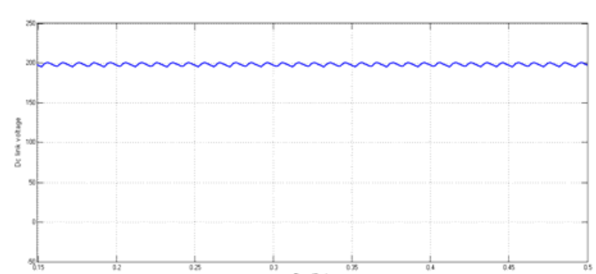

Figure-9. DC link voltage of system.

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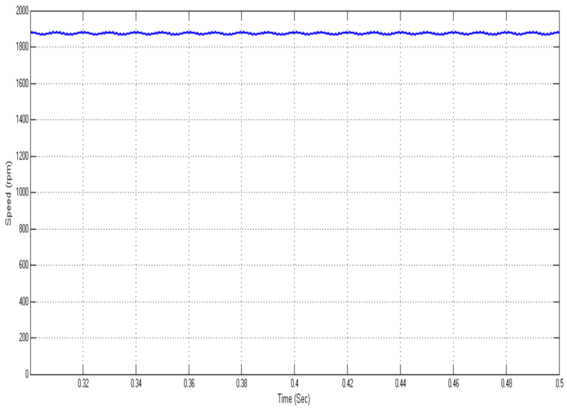

Figure-10. Speed of BLDC motor.

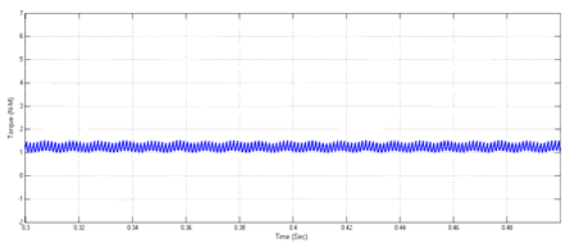

Figure-11. Torque of BLDC motor.

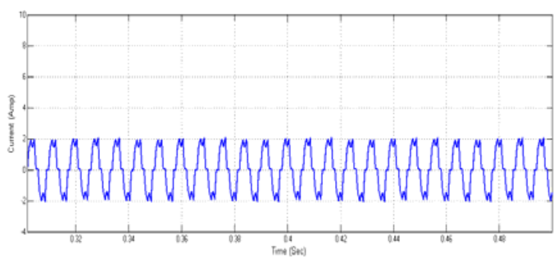

Figure-12. Stator current of BLDC motor.

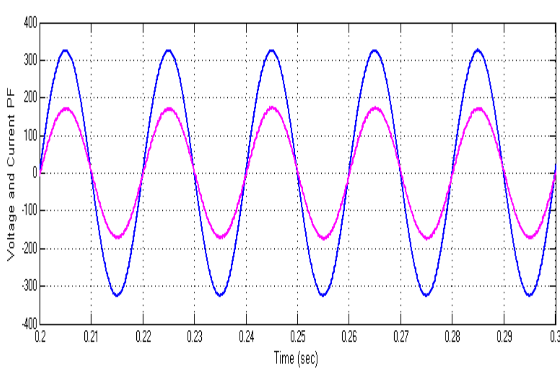

Figure-13. Power factor of system.

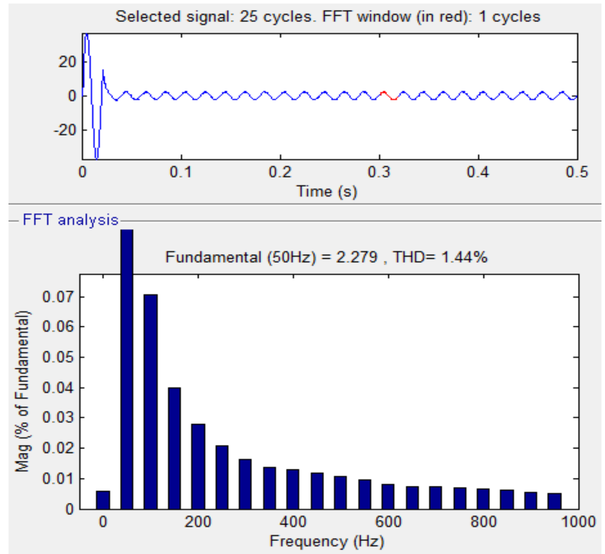

Figure-14. THD in source current.

Figure-8 shows the source voltage and current of system with DC link voltage of 200V. DC link voltage maintained at 200V was shown in Figure-9. Speed of BLDC motor when DC link voltage is maintained at 200V was shown in Figure-10, indicates motor running at constant speed of 1900 RPM. Figure 11 shows torque of BLDC motor and torque fluctuation is maintained low. Stator current drawn by BLDC motor was shown in Figure-12. Power factor of the system is shown in Figure-13 and is maintained nearer to unity as can be observed since there is no phase shift between source voltage and current waveforms. Total harmonic distortion in source current was shown in Figure-14 indicating THD as 1.44% which is nominal value below 5%. Thus power factor is maintained in system with Buck converter as power factor correction converter which can be concluded from power factor and harmonic distortion shown in results.

Case 2: Bridgeless buck converter as PFC converter at V_{dc}=200V

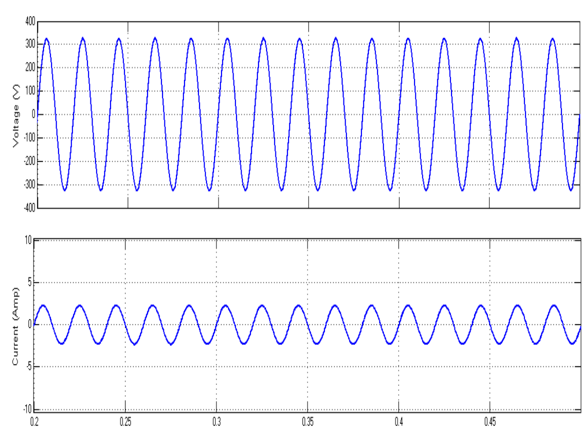

Figure-15. Source voltage and source current of system.

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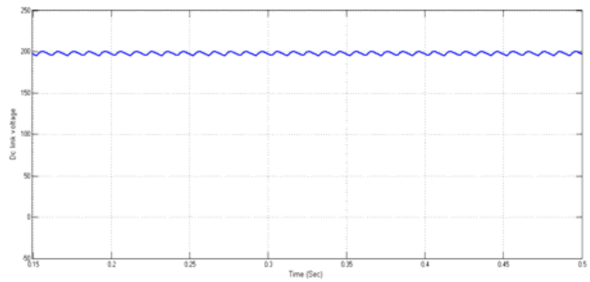

Figure-16. DC link voltage of system.

Grid currents and voltages in grid are shown in Figure-15 which is sinusoidal in shape. Voltage is maintained at 340 V and current is at 3A. In this case, DC link voltage of inverter is to be maintained tat 200 V DC and is shown in Figure-16. Constant DC link is provided to inverter.

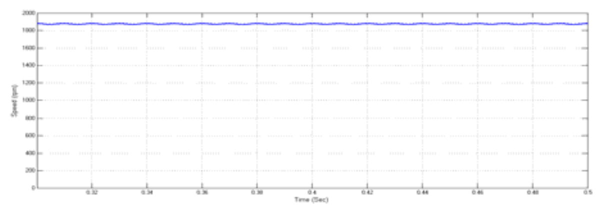

Figure-17. Speed of BLDC motor.

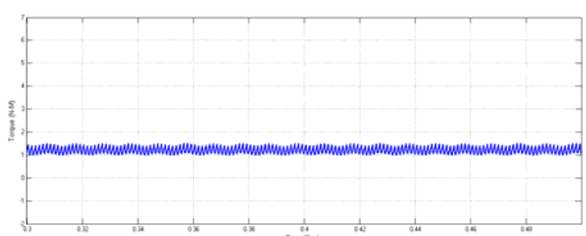

Figure-18. Torque of BLDC motor.

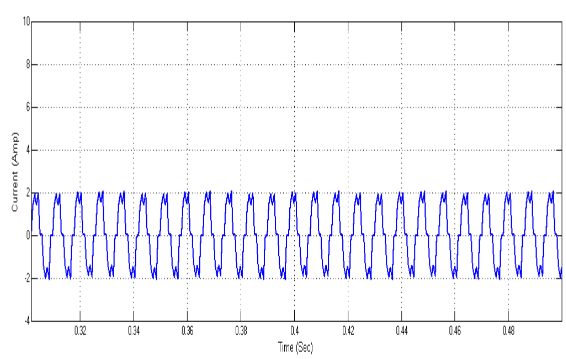

Figure-19. Stator current of BLDC motor.

Speed at which BLDC runs with 200 V DC link voltages is 1900 RPM shown in Figure-17. Speed is constantly maintained. Torque produced in BLDC is shown in figure 18 and is maintained with small ripples with 1.2 Nm. Currents in stator of BLDC is shown in Figure-19, stator currents are non-linear in shape due to their non-linear behavior.

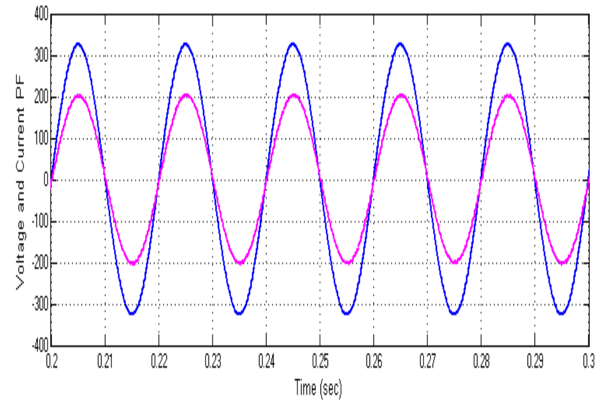

Figure-20. Power factor of system.

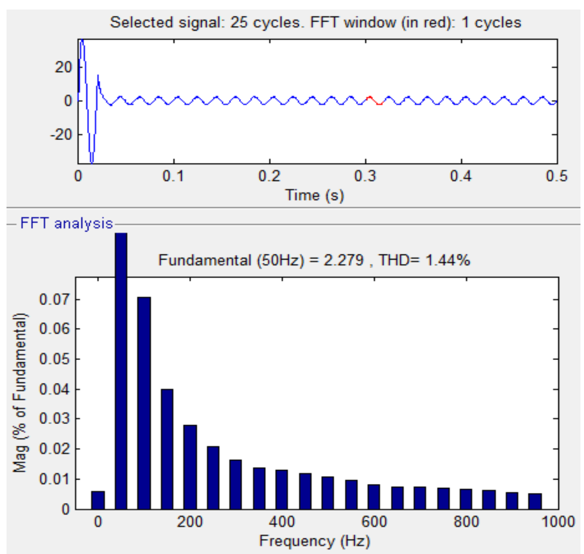

Figure-21. THD in source current.

Power factor of the system is shown in Figure-20 and is maintained nearer to unity as can be observed since there is no phase shift between source voltage and current waveforms. Total harmonic distortion in source current was shown in Figure-21 indicating THD as 1.44% which is nominal value below 5%. Thus power factor is maintained in system with power factor correction converter which can be concluded from power factor and harmonic distortion shown.

Case 3: Hybrid buck converter as PFC converter at V_{dc}=200V

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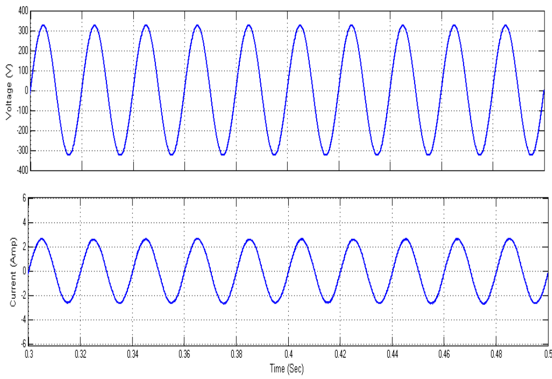

Figure-22. Source voltage and source current of distribution system to which BLDC motor is connected.

Source voltage and source current output waveform of distribution system to which BLDC motor drive is connected was shown in figure 22. Source voltage is maintained at 340V and current at 1.2A when DC link voltage is maintained at 200V. Source voltage and current are sinusoidal maintained.

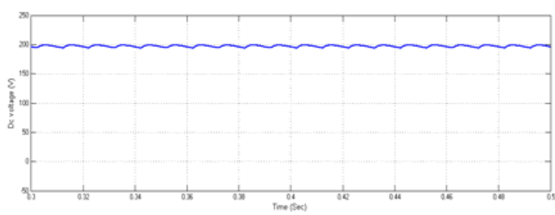

Figure-23. DC-link voltage of inverter.

DC link voltage of inverter is shown in Figure-23. DC link voltage is maintained at constant 200V in this condition and the same is shown in output plot.

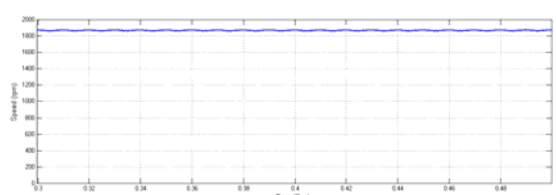

Figure-24. Speed of BLDC.

Speed at which the BLDC motor runs is shown in Figure-24. With DC link voltage of 200V, BLDC motor runs at 1900 RPM and runs at constant speed as in waveform.

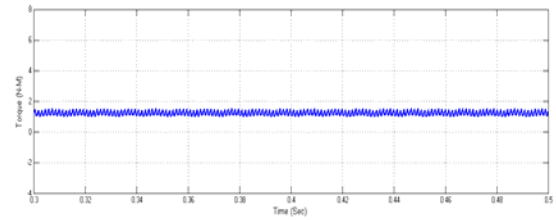

Figure-25. Torque of BLDC.

Torque produced in BLDC motor with DC link voltage of 200V is shown in Figure-25. Small torque ripples are present as observed in waveform

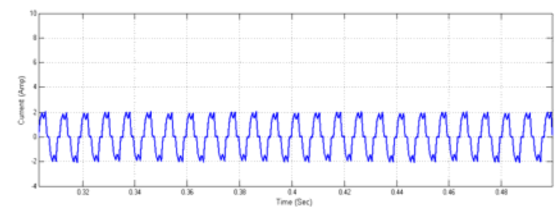

Figure-26. Stator currents of BLDC.

Stator currents drawn by BLDC motor was shown in Figure-26. As stator windings of BLDC are of non-linear nature, non-linear currents are observed in stator currents.

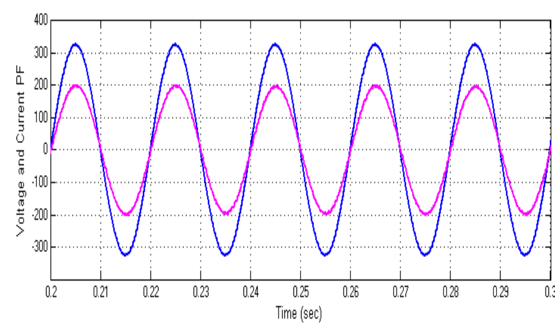

Figure-27. Power factor of distribution system.

Power factor angle between source voltage and current are shown in Figure-27. The phase angle between voltage and current is close to zero and thus indicates the power factor is maintained at nearer unity with DC link voltage of 200V.

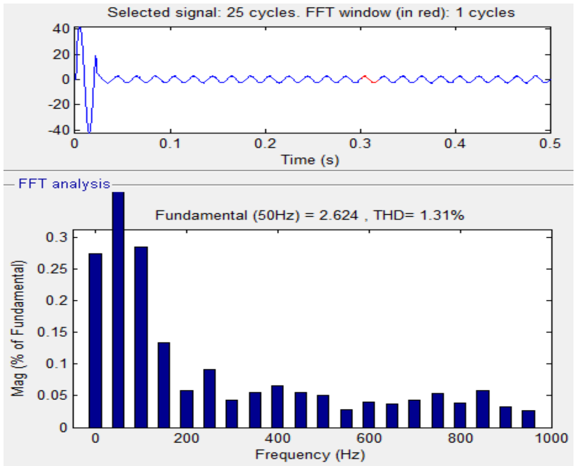

Figure-28. THD in source current.

Total harmonic distortion in source current of distribution system should be less to say that power quality with good power factor is maintained. THD in source current is shown in Figure-28 indicating 1.31% of THD in source current which is within acceptable limit.

Table-1 show the comparison of THD when BLDC motor drive system is fed from different PFC converter. THD in source current is improved when using Hybrid Buck converter when compared to other two PFC converters.

Table-1. THD comparison with different PFC converters.

Type of PFC converter	THD in source current
Buck Converter	1.41 %
Bridgeless Buck Converter	1.41 %
Hybrid Buck Converter	1.31 %

CONCLUSIONS

Due to constructional advantages of BLDC motor, it is widely used in many applications. Only stator will have windings and due to absence of windings in rotor part, BLDC motor can be employed in high speed drives. Need of front end converters for BLDC motor drive disturbs the power quality and compensation of power factor is necessary. This paper depicts simple Buck converter, Bridgeless Buck and Hybrid buck converters as power factor correction converters in BLDC motor drive applications with their performance evaluation. The simple current control scheme is used to trigger power switch in PFC converters. Power factor correction converters in BLDC motor drive system was validated with DC link voltage of 200V. THD in source current is shown for all cases and is maintained within limits. Power factor angle between source voltage and current was shown for every case which validates hybrid buck converter as power factor correction converter performs better giving less THD in source current compared to simple Buck and Bridgeless Buck converters as PFC converters which was tabulated.

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