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POWER CONVERTER TOPOLOGY OF BRUSHLESS DC MOTOR FOR IMPROVEMENT OF POWER QUALITY

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ABSTRACT: This study signifies different control schemes and design related power factor improvement technique used for brushless DC motor drives. It alsoprovides a base for a range of a suitable power factor correction topology for the specified application. Several AC-DC Buck, Boost, Cuk converters based power factor correction typologies are designed, modeled and analyzed to a 1.5 kW BLDC drive for the comparison of performance. Portions of the bi-directional extension converter and unipolar inverter typologies are likewise surveyed to give a total evaluation of the power factor controller topologies for BLDC drives. The proposed power factor correction converter topologies indicate modification to worldwide power quality measures with an enhanced implementation of BLDC drives. It alsoconforms to international power quality standards with improved performance of BLDCM drive, such as reduction of AC mains current harmonics, near unity power factor , and reduction of speed and torque ripples. Simulation environment with PSIM version 9.0.3.400 software has also been attempted.

KEYWORDS

Brushless direct current, Voltage source inverter, Total harmonic distortion, Power factor correction, Permanent magnet brushless DC motor

Introduction

Brushless direct current motor (BLDC), a special purpose design motor, is used in industries such as electrical device, manufacturing, automation equipment, instrumentation, automotive, aerospace, medical equipment, defense applications such as vehicle tracking, gyroscope, aircraft on board instrumentation, valves, fuel monitoring system and electric actuators because of their high efficiency, high starting torque, reliability, and lower maintenance compared to its brushed dc motor. (Karthikeyan, & DhanaSekaran, 2011). BLDC motor is electronically commutated motor and does not use of brushes for commutation. There are a few points of importance in BLDC motor compared with Brushed DC motor and Induction motor, i.e. higher speed torque characteristics, high dynamic response, higher efficiency, noiseless smooth operation, and long operating life. It needs low maintenance cost. With closed-loop speed control, it is controlled in high-speed ranges. High reliability of BLDC motors compare with other energy efficient motors. BLDC motor has wide application ranging from fraction to several horsepower. They are used in automobiles and washers to raise and lower windows, drive blowers in the heaters, and air conditioners in computer drives etc. Millions of such motors are used as toy motors all over the world.

There are three types of permanent magnet materials used for BLDC motors. Alnicos are used in low-current, and high voltage applications because of low coercive magnetizing intensity and high residual flux density. Ferrites are used in cost-sensitive applications such as air conditioners, compressors, and refrigerators. Rare-earth magnets, made of samarium cobalt, neodymium-ion-boron, have high residual flux and high coercive magnetizing intensity.

Construction of Brushless DC Motors

BLDC is of two types: one is outer rotor motor, and other is inner rotor motor. The fundamental difference between the two is only in design; their working principles are same. In an inner rotor design, the rotor is positioned in the center of the motor, and the stator winding encloses the rotor. As the rotor is positioned in the core, a rotor magnet does not insulate heat inside, and heat gets dissipated easily. Due to this, inner rotor designed motor produces a large amount of torque. In outer rotor design, the rotor surrounds the winding which is located in the core of the motor. The magnets in the rotor trap the heat of the motor inside and does not allow to dissipate from the motor. Such type of motor operates at lower rated current and has low clogging torque.

Brushes are commutated with the help of armature current. This eliminates the problem accompanying with commutator segment sparking and wearing out at the brush(Shivaraj & Jayakumar, 2014).

BLDC Motor Modelling

For the speed control of BLDC motor, modelling is the required. Each of the components of BLDC drive can be modeled by mathematical equations and the combination of such models distinguish the complete BLDC drive.

The modeling of a speed controller is of prime significance as the performance of the system is contingent on this controller. If at k^{th} instantaneous of the periodic interval, $\omega_r^*(k)$ is the reference speed, $\omega_r(k)$ is the actual rotor speed than the speed error $\omega_e(k)$ can be calculated as:

$$\omega_e(k) = \omega_r^*(k) - \omega_r(k) \quad (1)$$

This speed error is processed through a speed controller to take desired control signal.(Singh & Singh, 2010).

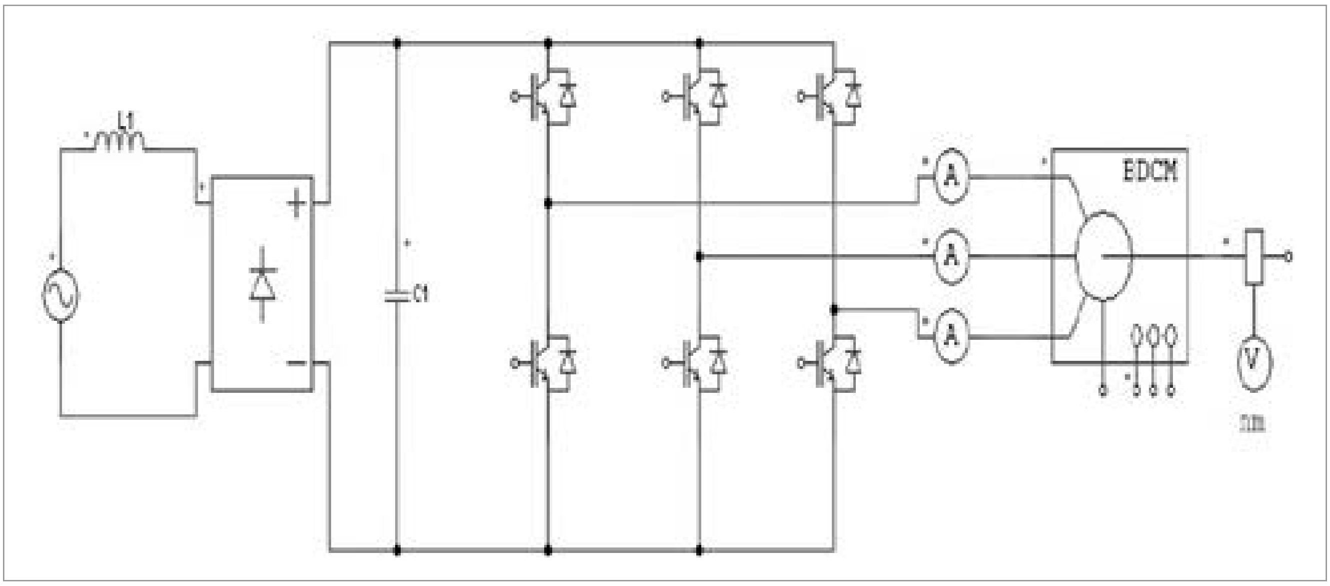

FIGURE 1. Block Diagram of Single Phase Diode Bridge Rectifier fed VSI Inverter based BLDC Motor drive

Subsequently, the flux remains constant; the speed of a BLDC motor cannot be controlled by using flux control method. The speed control and torque control of BLDC motor can be controlled by armature voltage control, armature rheostat control, and chopper control.The motor cannot be functional beyond the base speed.

Speed Controller

There can be many categories of speed controllers, for example, PI, sliding mode, Fuzzy pre-Compensated PI, Hybrid Fuzzy Proportional Integral (PI), Neural network based and Neuro-fuzzy, etc. The Proportional integral controller is the simplest and most generally used controller. For controlling drives, Proportional Integral controller output at k^{th} instant T (k) is given as,

$$T(k) = T(k-1) + K_P\{\omega_e(k) - \omega_e(k-1)\} + K_I\omega_e(k) \quad (2)$$

In above torque equation, K_P and K_I are the proportional and integral gains of the Proportional Integral controller respectively. Let I*= T(k)/K_b, where K_b is the back EMF constant of the motor.(Singh & Singh, 2010).

Reference current generation

The reference three phase currents of the motor winding are denoted by i_a, i_b, i_c for phases a, b, c, respectively. For the duration of 0 to 60 degrees, the reference currents can be given as,

$$i_a^*=I^*,\ i_b^*=-I^*,\ i_c^*=0 \tag{3}$$

Correspondingly, the reference currents through other periods can be generated, which follows the trapezoidal voltage of respective phases. These reference currents are associated with sensed phase currents to generate the current errors as,

$$\Delta I_a = (i_a^* - i_a),\ \ \Delta I_b = (i_b^* - i_b),\ \Delta I_c = (i_c^* - i_c) \tag{4}$$

Current controller

The current controller produces the switching sequence for the voltage source inverter, after associating the current error of each phase with carrier waveform of the fixed frequency. The current errors ΔI_a, ΔI_b, ΔI_c, can remain amplified by gain k1earlier associating with carrier waveform *g (t)*. The switching categorization is generated based on the logic assumed for phase 'a' as

Condition-1 k1 $\Delta i_a > g(t)$ then $T_a = 1$

Condition-2 k1 $\Delta i_a \le g(t)$ then $T_a = 0$

Simulation analysis using single phase DBR control strategy

We have conducted the first simulation analysis using single phase DBR. The simulation has been done following the parameters of BLDC motor drive as suggested by Singh and Singh, (2010) (Table.4)

Power Rating (P)	1500 Watt
Voltage Rating	400V
Current Rating	4 Amp
Stator Resistance (R)	11.9 Ω
Self-Inductance of Stator winding (L)	0.00207 H
Mutual Inductance of Stator winding (M)	-0.00069 H
Peak Voltage of BLDC Machine	32.3
Peak RMS Voltage of BLDC Machine	22.9
Number of Machine Pole (P)	4
Moment of Inertia	7e-006
Mech. Time Constant	0.006

TABLE 4. Design data BLDC Motor

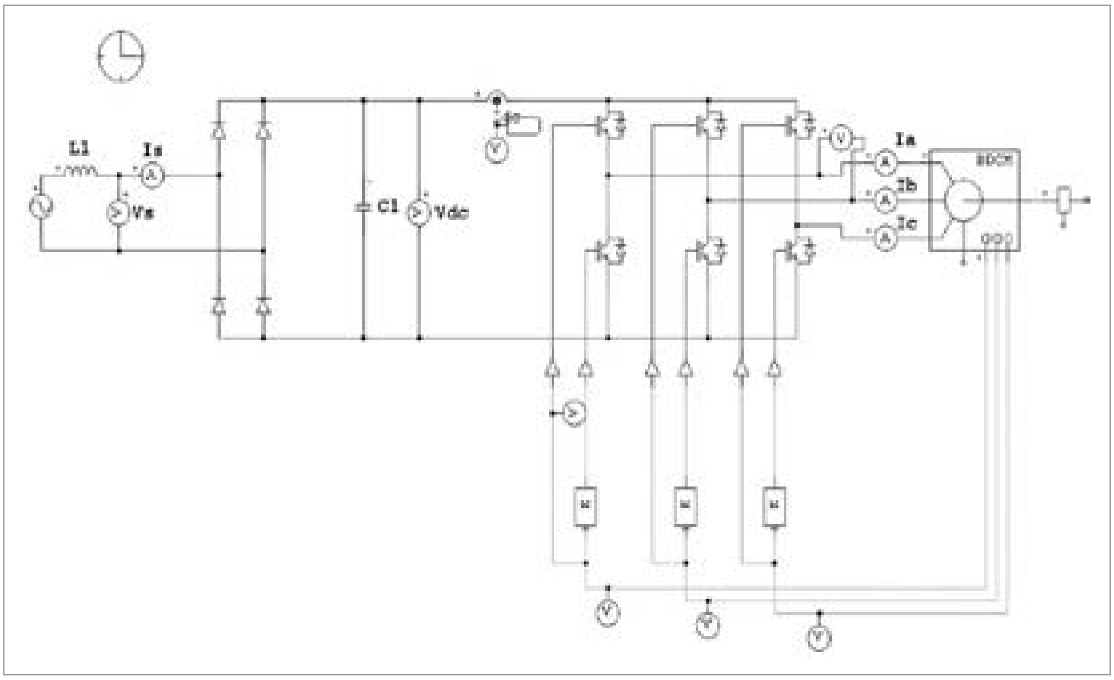

FIGURE 2. PSIM Simulation of BLDC Motor Single Phase Diode Bridge Rectifier fed Voltage Source Inverter

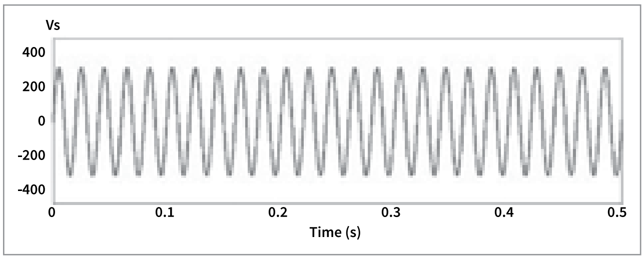

FIGURE 3. Source Voltage of BLDC Motor

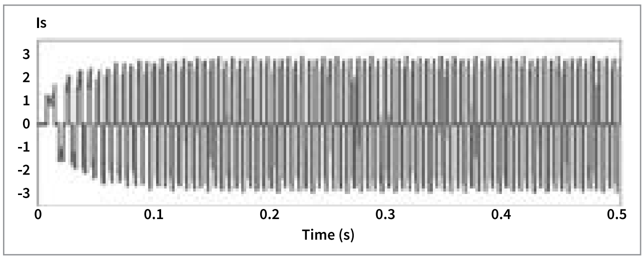

FIGURE 4. Current Waveform of Phase A(Ia)

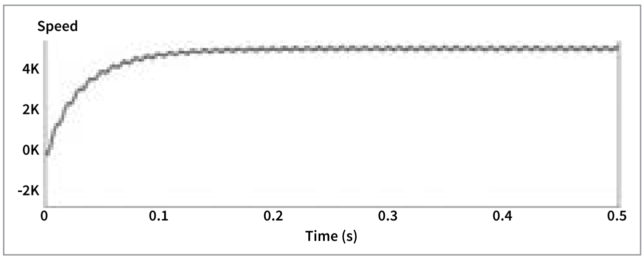

FIGURE 5. Speed waveform of BLDC motor

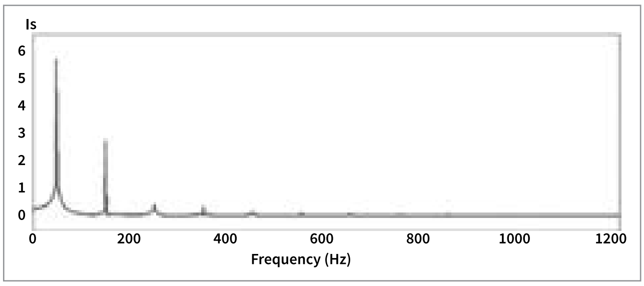

FIGURE 6. FFT Analysis of Supply current (Is)

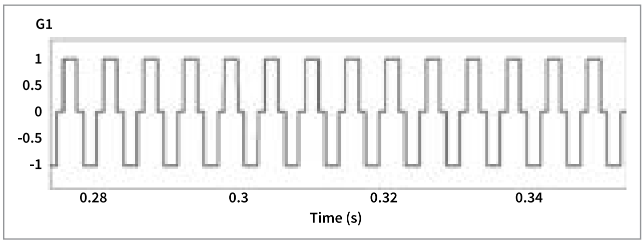

FIGURE 7. Getting pulse g(t)

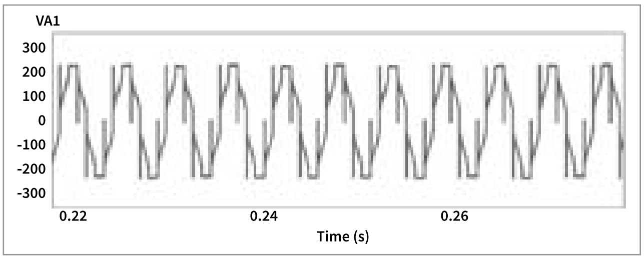

FIGURE 8. Output voltage of BLDC Motor

PSIM Simulation has been done with input source voltage of 230V and input source current of (Is) 3.74 amp. The fundamental frequency selected was 50 Hz. The simulation result shows that the total Harmonic Distortion is 62.53% and Power Factor is 0.84.

Simulation analysis using buck converter control strategy

The second simulation analysis has been conducted using Buck converter control strategy. The simulation has been done following the parameters of Buck Converter as suggested by Singh and Singh, (2010) (Table.5)

Design data of Buck Converter	
Inductor L_o	0.1mH
DC link Capacitor C_o	1500uF
Filter Capacitor C_f	7uF
PI Voltage Controller Gain (K_p, K_i)	0.01, 4.5
PI Speed Controller Gain (K_p, K_i)	0.004, 0.45
Switching Frequency	20 kHz

TABLE 5. Design data of Buck Converter

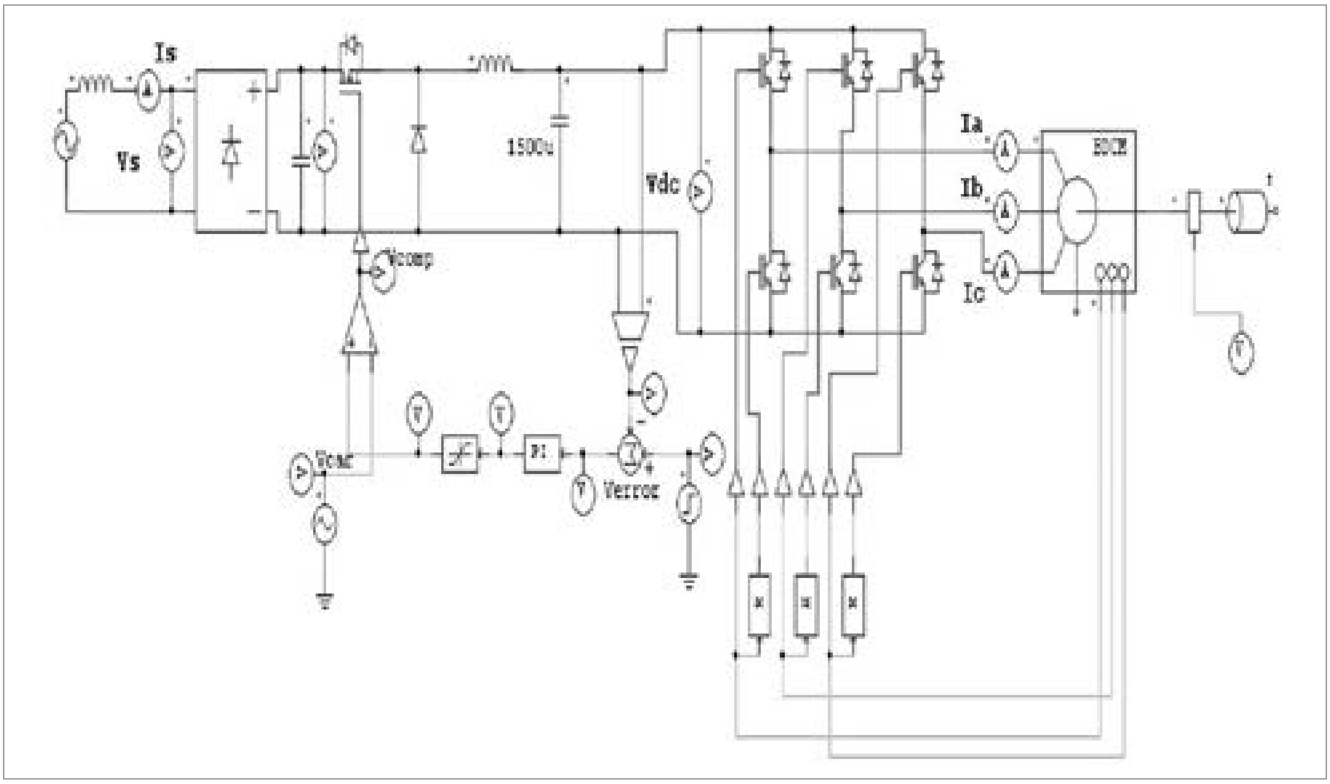

FIGURE 9. PSIM Simulation of BLDC Motor Drive with Buck converters

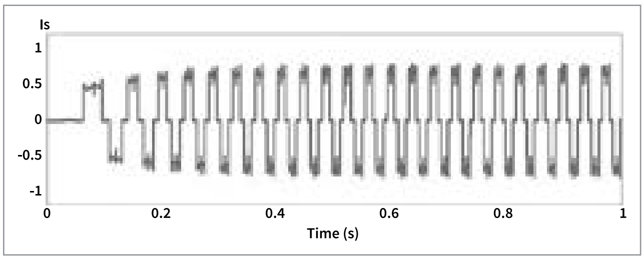

FIGURE 10. Current Waveform of Phase A(Ia)

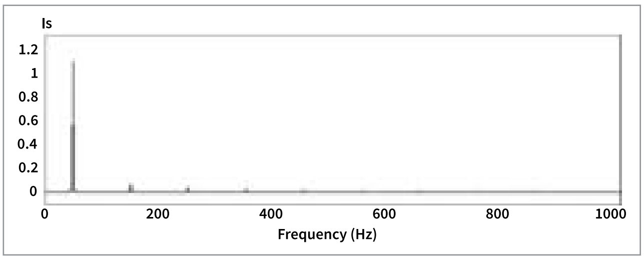

FIGURE 12. FFT Analysis of Source Current

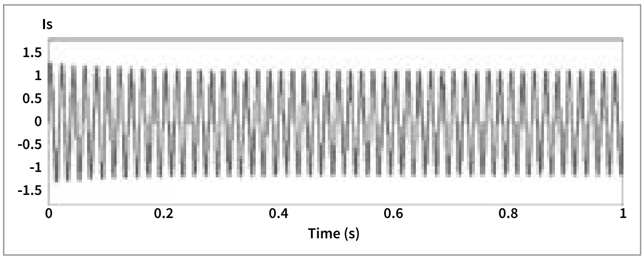

FIGURE 11. Input Source Current

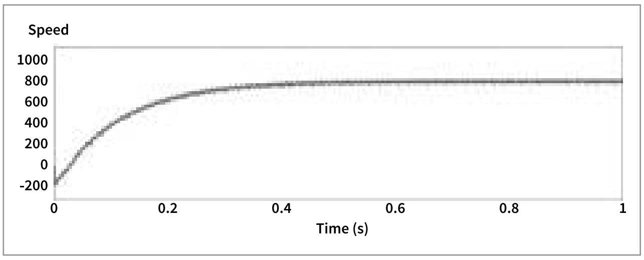

FIGURE 13. Speed Waveform of BLDC Motor

PSIM Simulation has been done with input source voltage of 230V and input source current of (Is) 0.8 amp. The fundamental frequency selected was 50 Hz. The simulation result shows that the total Harmonic Distortion is 8.39% and Power Factor is 0.9963.

Load (%)	THD(I) (%)	PF
10	11.93	0.9924
20	11.58	0.9929
30	11.18	0.9934
40	10.77	0.9939
50	10.37	0.9943
60	9.97	0.9948
70	9.58	0.9952
80	9.18	0.9956
90	8.78	0.9959
100	8.39	0.9963

TABLE 1. Power Quality Parameters at Different Load Condition for Buck Converter fed VSI Based BLDC Motor

Vs	THD(I) (%)	PF
170	7.2	0.9973
180	7.5	0.9970
190	7.7	0.9968
200	8.0	0.9966
210	8.2	0.9964
220	8.3	0.9963
230	8.5	0.9961
240	8.7	0.9960

TABLE 2. Power Quality Parameter with Input AC Voltage Variation for Buck Converter fed VSI based BLDC Motor

Simulation analysis using boost converter control strategy

The third simulation analysis has been conducted using Boost converter control strategy. The simulation has been done following the parameters of Boost converter as suggested by Singh and Singh, (2010) (Table.6)

Design data of Boost Converter	
Inductor L_o	5mH
DC link Capacitor C_o	1500uF
PI Voltage Controller Gain ($K_p$dc, $K_i$dc)	0.05, 1.5
PI Speed Controller Gain (K_p, K_i)	0.01, 0.1
Switching Frequency	20 kHz

TABLE 6. Design data of Boost Converter

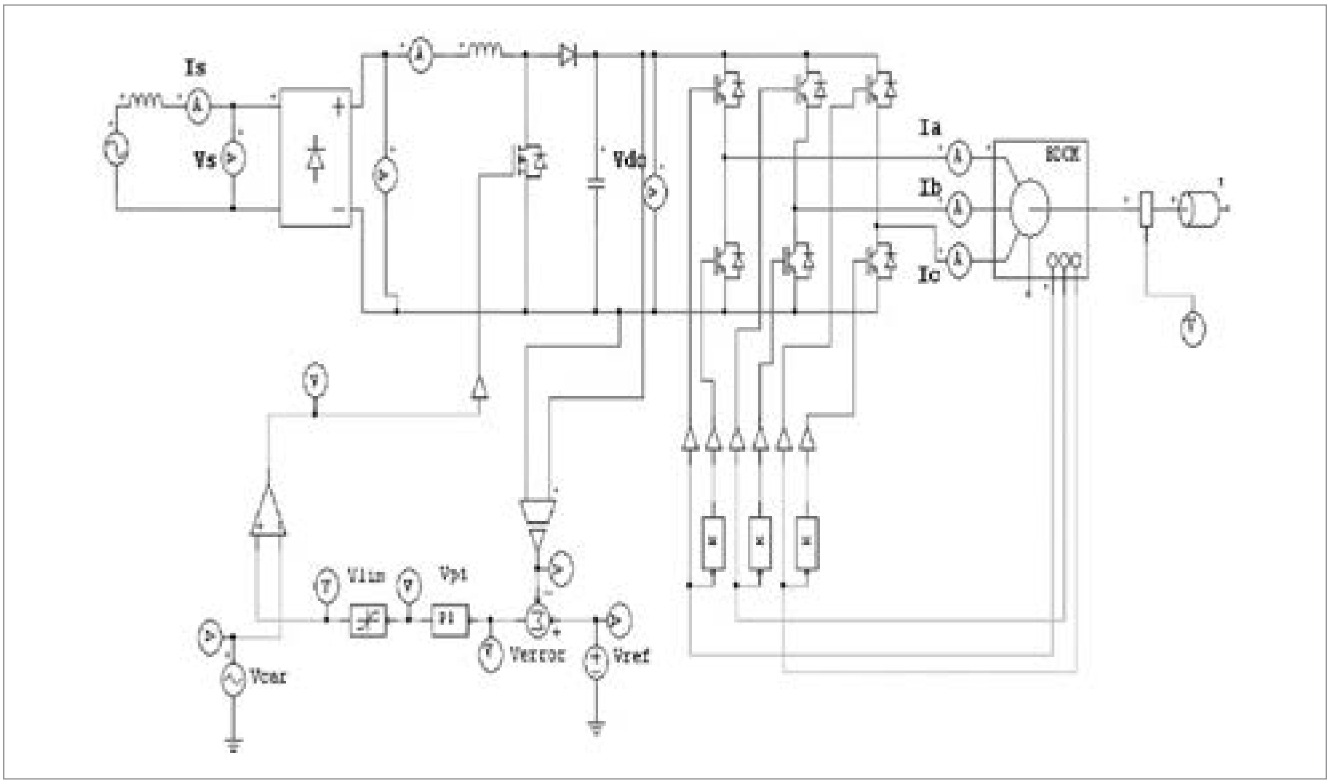

FIGURE 14. PSIM Simulation of BLDC Motor Drive Boost converter

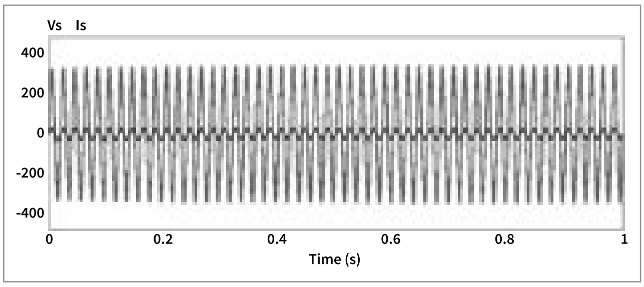

FIGURE 15. Supply current and voltage waveform

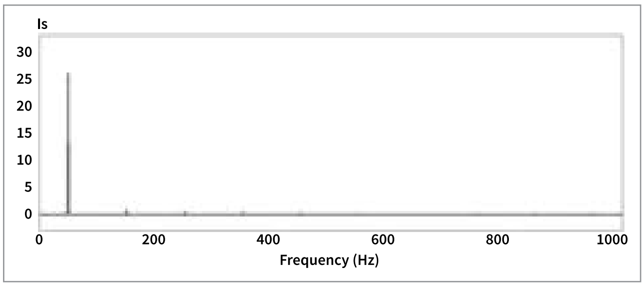

FIGURE 16. FFT Analysis of Source Current

PSIM simulation result demonstrate that using Boost Converter, the total harmonic distortion of source current is decreased to 4.77 % and Power Factor is 0.99.

Load (%)	**THD(I) (%)**	**PF**
10	5.09	0.99
20	5.07	0.99
30	5.01	0.99
40	4.96	0.99
50	4.95	0.99
60	4.90	0.99
70	4.86	0.99
80	4.84	0.99
90	4.81	0.99
100	4.77	0.99

TABLE 3. Power Quality Parameters at Different Load Condition for Boost Converter fed VSI Based BLDC Motor

Vs	THD(I) (%)	PF
170	4.67	0.99
180	4.77	0.99
190	4.81	0.99
200	4.86	0.99
210	4.86	0.99
220	4.87	0.99
230	4.89	0.99
240	4.90	0.99

TABLE 4. Power Quality Parameter with Input AC Voltage Variation for Boost Converter fed VSI based BLDC Motor

Simulation analysis using CUK converter strategy

Finally, simulation analysis has been conducted using CUK converter strategy. The simulation has been done following the parameters of CUK converter as suggested by Singh and Singh, (2010) (Table.7)

Design data of CUK Converter	
Inductor L_1	1.1mH
Inductor L_2	0.5mH
Inductor L_s	0.3mH
Capacitor C_1	0.2μF
Capacitor C_2	1590μF
Switching Frequency	20 kHz
PI Voltage Controller Gain ($K_p dc$, $K_i dc$)	0.05, 4.5

TABLE 6. Design data of CUK Converter

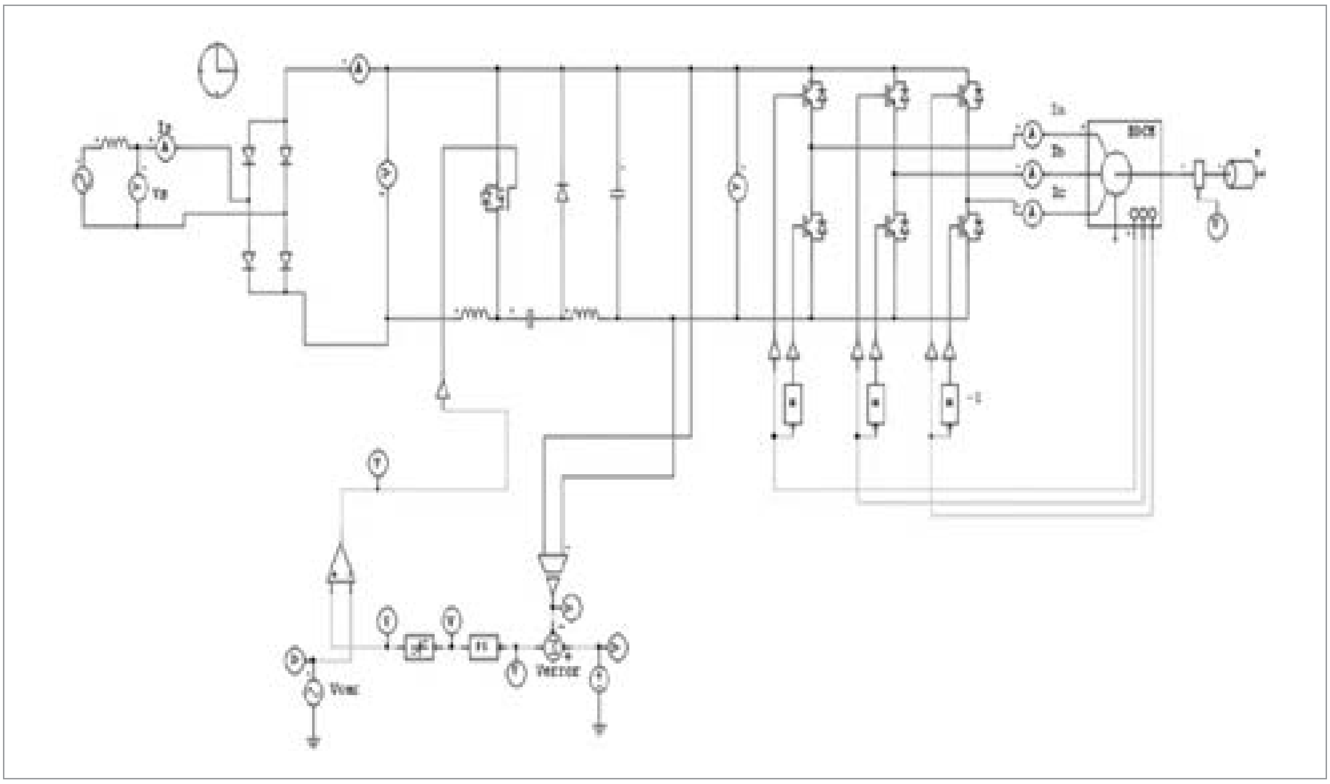

FIGURE 17. PSIM Simulation of BLDC Motor Drive Cuk converters

Bridgeless isolated cuk converter has the following Advantages: (Pireethi & Balamurugan 2016)

(1) It withstands high voltage and vibration.

(2) It withstands high voltage between windings.

(3) It avoid unwanted current loop.

(4) There is an electrical isolation and no electron flow between two circuits.

Load (%)	**THD(I) (%)**	**PF**
10	6.11	0.99
20	5.73	0.99
30	5.63	0.99
40	5.63	0.99
50	5.22	0.99
60	4.88	0.99
70	4.55	0.99
80	4.54	0.99
90	4.26	0.99
100	3.98	0.99

TABLE 5. Power Quality Parameters at Different Load Condition for Cuk Converter fed VSI Based BLDC Motor

Vs	**THD(I) (%)**	**PF**
170	3.52	0.99
180	3.54	0.99
190	3.67	0.99
200	3.83	0.99
210	3.94	0.99
220	3.98	0.99
230	4.23	0.99
240	4.27	0.99

TABLE 6. : Power Quality Parameters at Different Load Condition for Cuk Converter fed VSI Based BLDC Motor

The PSIM Simulation result demonstrates that Cuk converter fed VSI based BLDC motor is having source voltage (Vs) 230V and source current (Is) 30.47A. The fundamental frequency is 50 Hz. Total harmonic distortion of source current is 3.98% and Power Factor is 0.99.

Conclusion and Scope for Future Work

The paper explained different Power Converter typologies of BLDC using simulation through PSIM software. The speed of the motor has been found proportional to the DC link voltage, therefore a smooth speed control is observed while controlling the DC link voltage. The simulation result shows that total harmonic distortion in AC supply current is reduced and power factor is improved near unity with the help of optimum Cuk converter design as per International power quality standards. Since these motors do not require field winding, they do not have field-circuit copper losses. This increases efficiency, and also because no space is required for field winding, these motor are smaller than corresponding wound-pole motors. The decrease in low-order harmonics and developed displacement power factor is accomplished without the utilized of any voltage or current sensors.

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