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POWER CONVERTER TOPOLOGY OF SEPIC-FED BRUSHLESS DC MOTOR DRIVE FOR IMPROVEMENT OF POWER QUALITY

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ABSTRACT: The article presents an overview of various control schemes and Power Factor Correction techniques used for Brushless DC (BLDC) motor drives. It aims to provide a basis for choosing the appropriate Power Factor Correction topology for a specific application. The study compares the performance of different AC-DC converter-based Power Factor Correction techniques, such as Buck, Boost, Cuk, and SEPIC convertor fed through BLDC drive. A bridgeless SEPIC converter is used as the front-end for DC link voltage control and PFC operation, operating in discontinuous inductor current mode for a simple control scheme. The BLDC motor uses electronic commutation for low-frequency operation and reduced switching losses in the voltage source inverter (VSI). The bridgeless topology also reduces conduction losses and increases efficiency. The study also considers bi-directional extension converter and unipolar inverter topologies. The proposed Power Factor Correction Converter techniques show improvement in worldwide power quality measures, such as reduced AC mains current harmonics, close unity power factor, and reduced speed and torque fluctuations. PSIM Version 9.0.3 software has been used for simulation purpose.

KEYWORDS

Brushless Direct Current, Voltage Source Inverter, Total Harmonic Distortion, Power Factor Correction Permanent magnet brushless DC motor, SEPIC.

Introduction

The Brushless Direct Current Motor (BLDC) is rapidly gaining popularity and is being used in various industries such as electrical devices, manufacturing automation equipment, automotive, aerospace, medical devices, and instrumentation. BLDC motors are electronically commutated, eliminating the need for brushes. In comparison to brushed DC motors and induction motors, BLDC motors offer several benefits, including higher speed and torque, better dynamic response, high efficiency, silent and smooth operation, low maintenance costs, and a longer operating life. BLDC motors can be controlled with high-speed ranges and closed-loop speed control, making them highly reliable and energy efficient. BLDC motors come in a range of ratings, from fractional horsepower to several horsepower, and are used in a variety of applications, including automobiles, washing machines, computer drives, and toys.

Permanent magnet materials used in PMBLDC Motors come in three types: Alnicos, Ferrites, and rare earth magnets. Alnicos are suitable for applications with low current and high voltage, due to their low coercive magnetizing intensity and high residual flux density. Cost-sensitive applications, such as air conditioners, refrigerators, and compressors, make use of Ferrites. Rare earth magnets, made of samarium-cobalt and neodymium-ion-boron, are favored for their high residual flux and high coercive magnetizing intensity. (Singh &Singh, 2010)

CONSTRUCTION OF BRUSHLESS DC MOTOR

A Permanent Magnet Brushless DC Motor (PMBLDC) is a type of DC motor that employs permanent magnets in its rotor, while the stator acts as the magnetic field's return path. The magnets are devoted to the internal surface of the cylindrical steel stator. The rotor, on the other hand, is composed of multiple commutator segments and brushes.

BLDC motors are commonly controlled using a three-phase power electronics device and are commutated based on the rotor position having an interval of 60º. Unlike brushed motors, which utilize brushes to commutate the armature current, PMBLDC motors eliminate the problems of

commutator segment sparking and brush wear, making them a more efficient option.

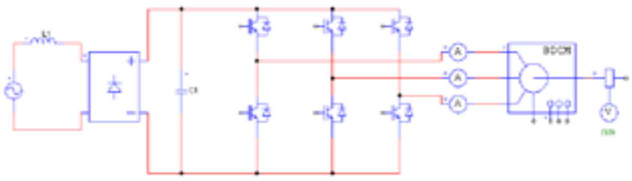


FIGURE1: Block Diagram of Single-Phase Diode Bridge Rectifier fed Voltage Source Inverter based BLDC Motor drive [2]

The speed and torque of a BLDC motor can be controlled by armature voltage control, armature rheostat control, and chopper control. However, it's not possible to control its speed by the flux control method since the flux remains constant. These control methods have uses in certain applications where a reduced base speed is necessary, but the motor cannot function beyond this base speed.

A. BLDC motor modeling

To control the speed of a BLDC motor, modeling is necessary and different power electronics-based modeling is essential. Mathematical equations can be used to model each component of the BLDC drive, and their combination characterizes the complete BLDC drive. The modeling of the speed controller is critical as the performance of the system depends on it. The speed error can be calculated as the difference between the reference speed ($\omega r^*(k)$) and the actual rotor speed ($\omega r(k)$) at the kth instant of the period interval. The formula for the speed error is,

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

This speed error is processed through a speed controller to take desired control signal.

B. Speed controller

There are several categories of speed controllers, such as PI, sliding mode, fuzzy pre-compensated PI, hybrid fuzzy PI, NN-based, and Neuro-fuzzy. The most used controller is the PI controller. The output of a PI controller at a given time interval is determined by controlling the drive.

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

The output of a PI controller at the kth instant, T(k), is given by the equation, where K_P and K_I are the proportional and integral gains of the controller, respectively.

Let $I^* = T(k)/K_b$, where K_b is the back-EMF constant of the Motor.

C. 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 duration of 0 to 60 degrees, the reference currents can be given as,

$i_a^* = I^*,\ i_b^* = -I^*,\ i_c^* = 0$… (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,

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

D. Current Controller

The current controller generates a switching sequence for the Voltage Source Inverter by connecting the current error of each phase with a carrier waveform of a fixed frequency. The current errors ΔIa, ΔIb, ΔIc are amplified by a gain k1 before being associated with the carrier waveform g(t). The switching sequence is determined based on the logic applied to phase as give below equations.

Condition-1 $k_1\ \Delta i_a > g(t)$ then $T_a = 1$

Condition-2 $k_1\ \Delta i_a \leq g(t)$ then $T_a = 0$

CONTROL STRATEGIES OF SINGLE PHASE DBR FED VSI BASED BLDC MOTOR

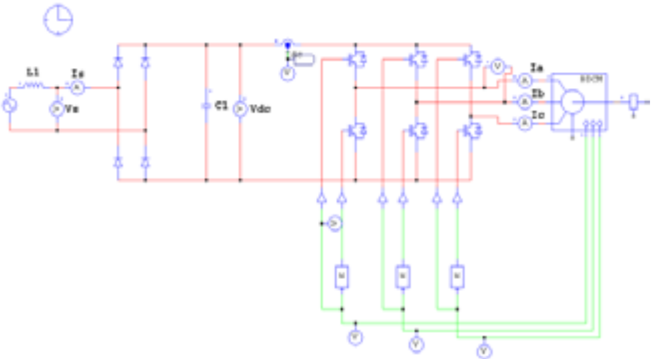


FIGURE 2: PSIM Simulation of BLDC Motor Single Phase Diode Bridge Rectifier fed Voltage Source Inverter

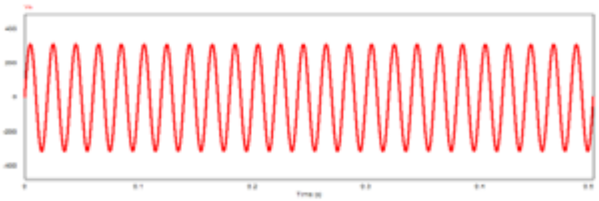


FIGURE 3: Source Voltage of BLDC Motor.

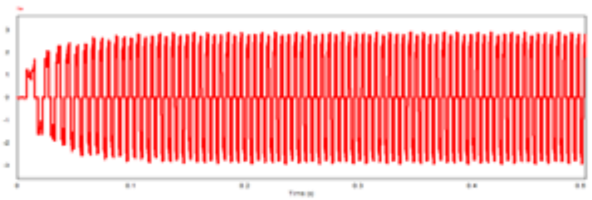


FIGURE 4: Current Waveform of Phase A(Ia)

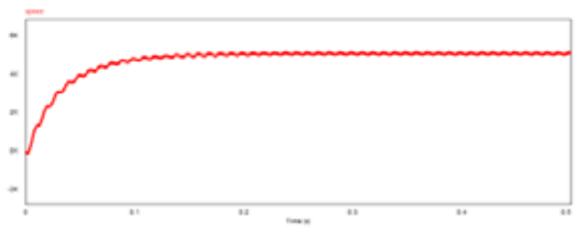


FIGURE 5: Speed waveform of BLDC motor

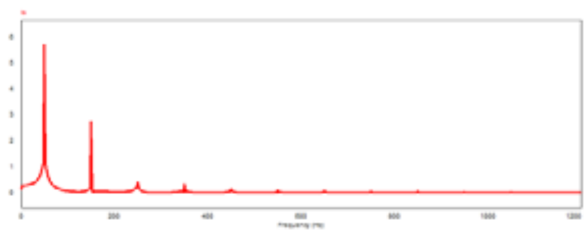


FIGURE 6: FFT Analysis of Supply current (Is)

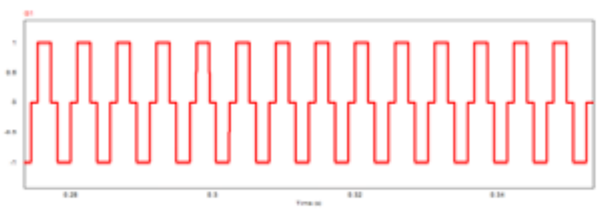


FIGURE 7: Getting pulse g(t)

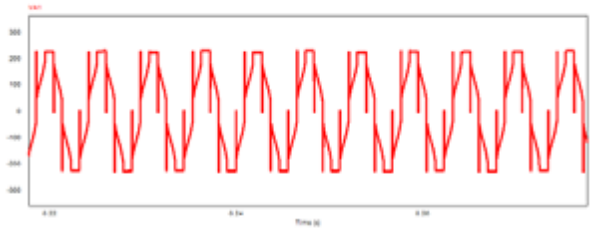


FIGURE 8: Output voltage of BLDC Motor

By simulation result analysis of single-phase, diode bridge rectifier fed VSI based BLDC Motor is Input Source Voltage 230V & Input Source Current (Is) 3.74 A. The Fundamental frequency is 50 Hz. Total Harmonic Distortion of (Is) 62.53% Power Factor is 0.84.

BUCK CONVERTER CONTROL STRATEGIES OF VSI BASED BLDC MOTOR

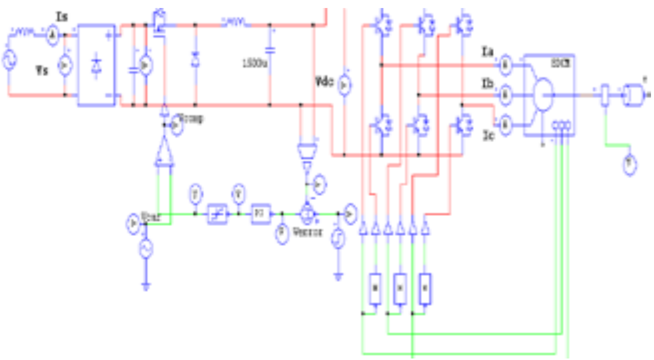


FIGURE 9: PSIM Simulation of BLDC Motor Drive with Buck converters.

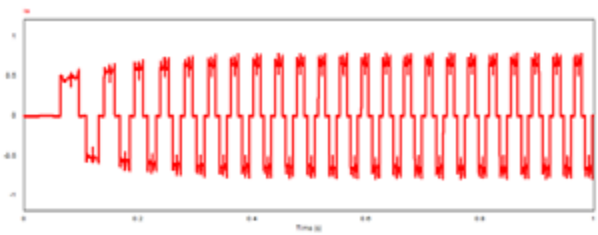


FIGURE 10: Current Waveform of Phase A(Ia)

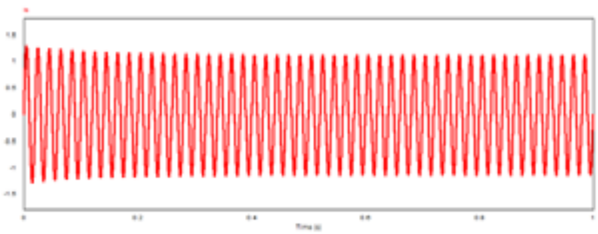


FIGURE 11: Input Source Current

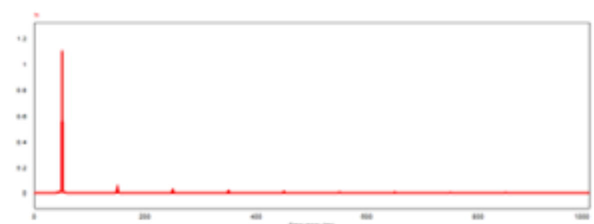


FIGURE 12: FFT Analysis of Source Current

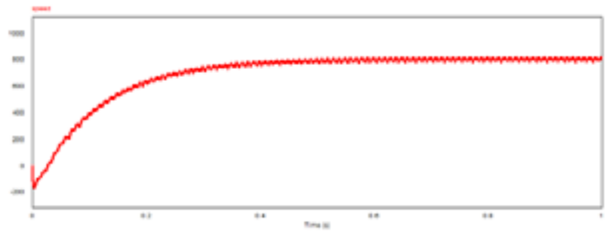


FIGURE 13: Speed Waveform of BLDC Motor

By Simulation Result analysis of BLDC Motor Drive Buck Converter is Source Voltage (Vs) 230V Source Current (Is) 0.8A.The Fundamental frequency is 50 Hz. Total Harmonic Distortion of (Is) 8.39%, 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

BOOST CONVERTER CONTROL STRATEGIES OF VSI BASED BLDC MOTOR

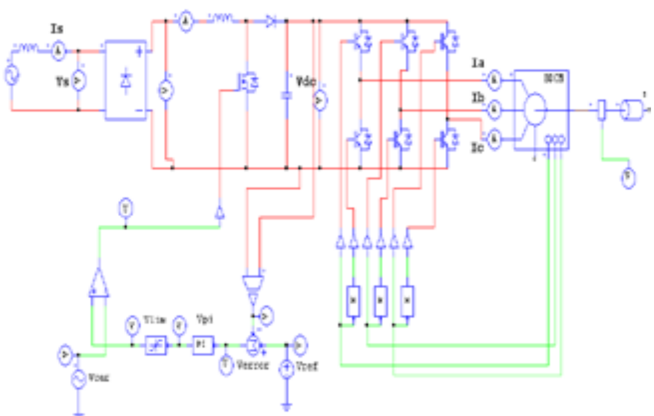


FIGURE 14: PSIM Simulation of BLDC Motor Drive Boost converter

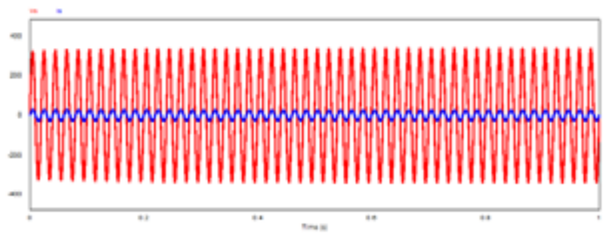


FIGURE 15: Supply current and voltage waveform.

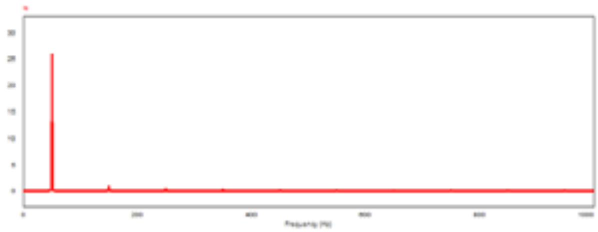


FIGURE 16: FFT Analysis of Source Current

The PSIM Simulation Result demonstrations that using Boost Converter the THD of Source current is decreased to 4.8% and Power Factor is 0.98.

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 FOR CUK CONVERTER FED BLDC MOTOR

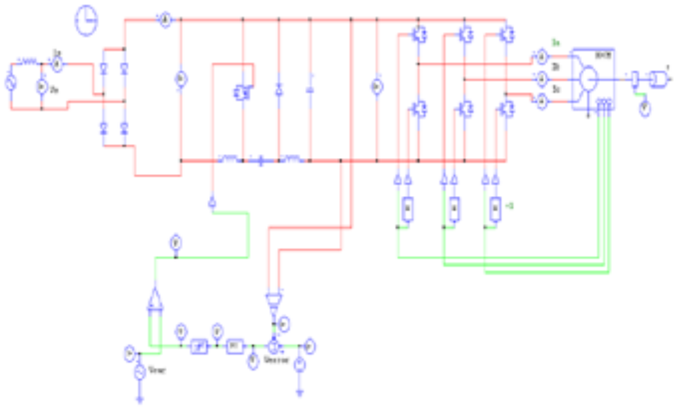


FIGURE 17: PSIM Simulation of BLDC Motor Drive Cuk converters

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

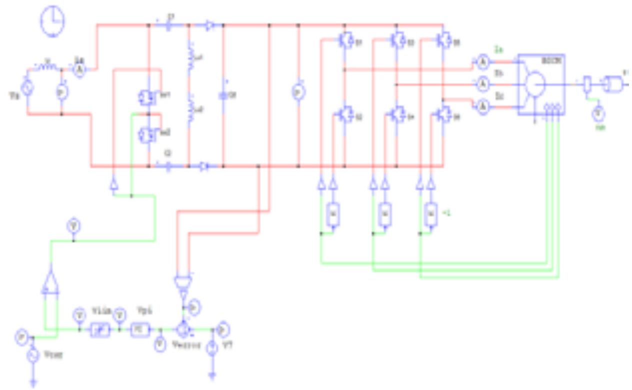
Table 5: Power Quality Parameters at Different Load Condition for Cuk Converter fed VSI Based BLDC Motor.

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.

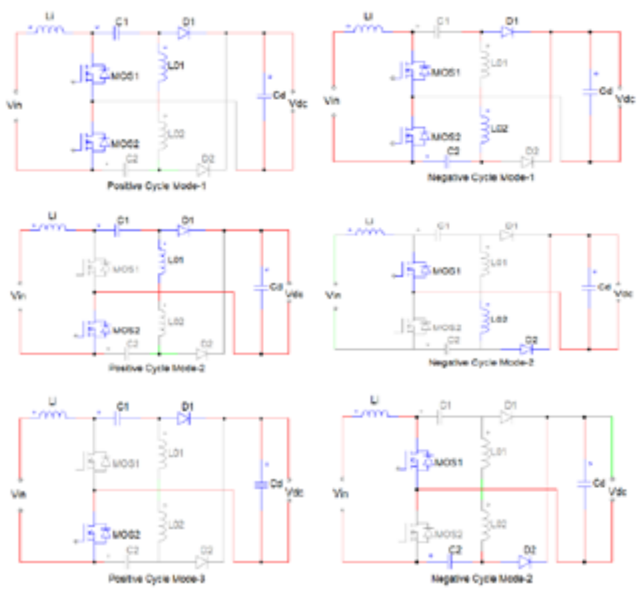
The PSIM Simulation outcome is demonstrations that Cuk converter fed VSI based BLDC Motor is Source Voltage (Vs) 230V Source Current (Is) 30. 47A.The Fundamental frequency is 50 Hz. Total Harmonic Distortion of source current is 3.98% and Power Factor is 0.99.

SIMULATION ANALYSIS FOR SEPIC-Fed CONVERTER FED BLDC MOTOR



Power Rating (P)	690 Watt
DC Link Voltage Rating	310V
Current Rating	5 Amp
Stator Resistance(R)	5.5 Ω
Self-Inductance of Stator winding (L)	15.41mH
Rated Torque	2.2
Number of Machine Pole(P)	4
Moment of Inertia	0.18
Back EMF Constant	78

Table 7 shows specification of BLDC MOTOR used in the design of bridgeless SEPIC-fed BLDC Motor drive.



The input side circuitry is completed during the positive half cycle of the supply voltage by the anti-parallel diode of switch Sw1, when switch Sw1 conducts, and by the anti-parallel diode of switch Sw2 during the negative half cycle when switch Sw2 conducts, as shown in Figure 17(a-c) and (d-f), respectively.

The operation of the converter during both positive and negative half cycles of the supply voltage is conducted by intermediate capacitors C1 and C2, output inductors Lo1 and Lo2, and diodes D1 and D2. Input inductor Li is always conducting throughout the supply voltage cycle to maintain a desired DC link voltage (Vdc) across capacitor Cd.

In the Positive cycle mode-I, when switch Sw1 is turned on, Li starts charging, and C1 begins discharging to charge Lo1. D1 remains non-conducting, and the energy required by the load is supplied by the DC link capacitor.

In the Positive cycle mode-II, Li and Lo1 start discharge, and C1 and Cd start charging when switch Sw1 is turned off. Li has a much higher value than Lo1 or Lo2 due to its continuous conduction mode, making the rate of decrease in iLi slower compared to the rate of decrease in iLo1 or iLo2.

In the Positive cycle mode-III, Lo1 is completely discharged to enter the discontinuous inductor current mode (DICM) of operation, and C1 continues to receive energy from Li, causing the VC1 voltage to increase, as shown in the figure 17.

The operation of the bridgeless SEPIC during the negative half cycle of the supply voltage is also divided into three different modes, which are depicted in Figure 17(d-f). (Singh &Singh, 2010)

Vdc(v)	Speed(rpm)	THD Is (%)	DPF	PF	Is(A)
150	1165	2.92	0.9987	0.9983	1.976
170	1360	2.76	0.9991	0.9987	2.238
190	1555	2.53	0.9995	0.9992	2.504
210	1750	2.41	0.9997	0.9994	2.77
230	1940	2.27	0.9998	0.9995	3.04
250	2130	2.19	0.9999	0.9997	3.314
270	2320	2.09	1	0.9998	3.589
290	2500	1.99	1	0.9998	3.868

Table 7: Performance of bridgeless SEPIC-fed BLDC motor drive under speed control.

Vs(v)	THD Is (%)	DPF	PF	Is(A)	CF
170	1.52	0.9993	0.9992	5.31	1.412
180	1.58	0.9996	0.9995	5.028	1.412
190	1.7	0.9998	0.9997	4.776	1.412
200	1.77	0.9999	0.9992	4.574	1.412
210	1.85	1	0.9992	4.336	1.412
220	1.96	1	0.9992	4.157	1.412
230	2.02	1	0.9992	3.999	1.412
240	2.12	0.9999	0.9992	3.818	1.412
250	2.17	0.9999	0.9992	3.675	1.412
260	2.28	0.9998	0.9992	3.54	1.412
270	2.39	0.9997	0.9992	3.415	1.412

Table 8: Performance of bridgeless SEPIC-fed BLDC motor drive under varying input voltage.

APPENDIX

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 (Kpdc, Kidc)	0.05, 4.5
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 (Kp, Ki)	0.004, 0.45
Switching Frequency	20 kHz
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
Design data of Sepic Converter	
Inductor Li,Lo1,Lo2	6mH,50 uH
C1,C2	1.6 uH
DC link Capacitor Cd	4000uF
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
Design data BLDC Motor. (For Buck, Boost, Cuk Application)	
Power Rating (P)	1500 Watt
Voltage Rating	300V
Current Rating	5 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

Conclusions

In this Paper Different comparison of Power Converter topologies of BLDC has been simulated. The simulation results, obtained using PSIM and optimized design of power converters, showed improvement in power quality at the AC mains for a wide range of speeds and source AC voltages. The study proposed a bridgeless SEPIC-fed VSI-based BLDC motor drive for improved speed control, which reduces conduction losses and increases overall efficiency. The proposed drive showed improved power quality, with power-quality indices such as THD of supply current, DPF, and PF within recommended standards. The drive's performance under practical conditions was also satisfactory, with good results for supply voltage variation. The study concluded that the proposed SEPIC-fed BLDC drive is a suitable technique for speed control of BLDC motors with improved power quality at the AC mains.

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