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SOFT COMPUTING-BASED DESIGN AND ANALYSIS OF A BL-SEPIC FED PMBLDC MOTOR FOR HIGH-EFFICIENCY APPLICATIONS

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ABSTRACT

This paper presents a comparative study on the speed control of a Permanent Magnet Brushless DC Motor (PMBLDCM) using a Bridgeless Single-Ended Primary Inductor Converter (BL-SEPIC). The BL-SEPIC converter combines the functionalities of a buck converter followed by a buck-boost converter. The proposed configuration integrates Power Factor Correction (PFC) and DC link voltage regulation into a single stage, improving the PMBLDC motor's speed control. By adjusting the DC link voltage proportionally to the required motor speed, the system achieves enhanced efficiency and performance.
A current multiplier technique is employed to achieve near-unity power factor, while a PFC controller operating in Discontinuous Conduction Mode (DCM) ensures system stability. Additionally, a rate limiter is implemented for torque and current control at the DC link, reducing conduction losses. The study evaluates the converters' voltage regulation capabilities, efficiency, ripple performance, and suitability for various power electronic applications.
Simulation results obtained from MATLAB/Simulink demonstrate the effectiveness of the BL-SEPIC converter in PMBLDC motor drive applications. The findings indicate that the BL-SEPIC converter offers superior speed control compared to other topologies. The proposed schemes are designed and validated through detailed simulations, confirming their ability to achieve high efficiency and improved motor performance.

Keywords: Voltage Source Inverter (VSI), SEPIC Converter, Buck Converter, Pulse Width Modulation (PWM), Electronic Commutation

1. INTRODUCTION

Permanent Magnet Brushless DC Motors (PMBLDCMs) are widely used in both low-power and high-torque applications due to their high efficiency, wide speed range, and minimal maintenance requirements. These motors offer superior reliability, excellent speed-to-torque characteristics, fast dynamic response, and quiet operation. PMBLDC motors belong to the permanent magnet motor family, which also includes Permanent Magnet Synchronous Motors (PMSMs). The key difference between the two lies in their back electromotive force (EMF) waveforms—PMBLDC motors exhibit a trapezoidal back EMF, whereas PMSMs produce a sinusoidal back EMF. Unlike conventional brushed DC motors, BLDC motors employ electronic commutation instead of mechanical brushes, eliminating issues such as sparking, brush wear, and electromagnetic interference. Hall effect sensors are typically used for rotor position sensing in these motors.

When PMBLDC motors are powered through a diode bridge rectifier (DBR) from a single-phase AC mains supply, they draw pulsed current with a peak value exceeding the fundamental input current amplitude. This uncontrolled charging of the DC link capacitor leads to power quality issues, including poor power factor and increased harmonic distortion at the input. To address these challenges, this study proposes a Bridgeless Single-Ended Primary Inductor Converter (BL-SEPIC)-based Power Factor Correction (PFC) converter for PMBLDCM applications. This approach simplifies control by requiring only a single controller for efficient operation. Additionally, a ZETA converter (a buck-boost topology) is employed for speed control while operating in Discontinuous Conduction Mode (DCM), enhancing power factor correction at the input side.

PFC converters typically operate in either Continuous Conduction Mode (CCM) or Discontinuous Conduction Mode (DCM). In the proposed scheme, DCM is preferred due to its inherent power factor correction capability and reduced control complexity. Efficient speed control of PMBLDC motors is crucial across various applications, including home appliances, industrial automation, aerospace, and HVAC systems. The use of a bridgeless rectifier in the proposed scheme significantly reduces conduction losses, improving overall system efficiency. Furthermore, this configuration mitigates power quality issues such as low power factor, harmonic distortion, and switching losses, ensuring enhanced performance and reliability in PMBLDC motor drives.

2. WORKING OF BRIDGELESS SEPIC CONVERTER FOR PMBLDC MOTOR DRIVES:

The Bridgeless Single-Ended Primary Inductor Converter (BL-SEPIC) is a high-efficiency topology designed for Power Factor Correction (PFC) in Permanent Magnet Brushless DC (PMBLDC) motor drives. By eliminating the conventional diode bridge rectifier (DBR), the BL-SEPIC reduces conduction losses and enhances overall system efficiency. This converter enables direct AC-to-DC conversion with minimized power dissipation, as it avoids the voltage drop and losses associated with a full-bridge rectifier.

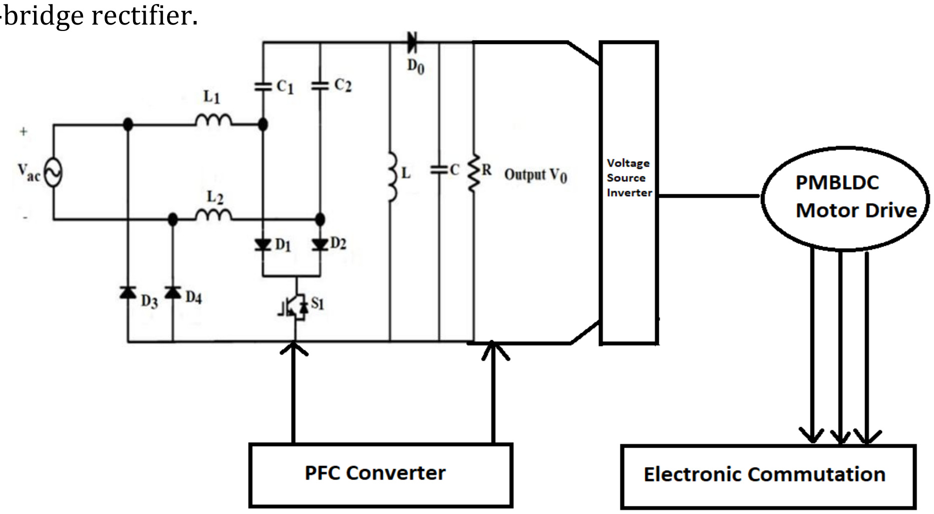


Fig. 1 Proposed BL-SEPIC Fed PMBLDC Motor Drive

Operating in Discontinuous Conduction Mode (DCM), the BL-SEPIC ensures that the input current waveform closely tracks the AC supply voltage, achieving near-unity power factor. The reduced number of simultaneously conducting components further decreases conduction losses. The topology comprises two inductors (L_1, L_2), two capacitors (C_1, C_{ss}), a power switch (MOSFET), and diodes (D_1, D_2). Functionally analogous to a buck-boost converter, the BL-SEPIC provides bidirectional voltage conversion (step-up/step-down), making it adaptable to varying motor speed requirements.

3. MODES OF OPERATION

SWITCH ON MODE (MOSFET CONDUCTING):

When the MOSFET turns ON, inductors L1 and L2 store energy from the AC supply: Meanwhile, the output capacitor (Cdc) supplies power to the BLDC motor, ensuring continuous operation.

SWITCH OFF MODE (MOSFET TURNED OFF):

When the MOSFET turns OFF, the energy stored in L1 and L2 is released and transferred to Cdc, which regulates the DC link voltage. This controlled DC voltage is then supplied to the Voltage Source Inverter (VSI) for motor operation.

The Discontinuous Conduction Mode (DCM) operation of the BL-SEPIC converter ensures that the input current remains in phase with the supply voltage, thereby achieving near-unity power factor. A Power Factor Correction (PFC) controller continuously monitors the voltage and adjusts the MOSFET's duty cycle to ensure optimal energy conversion. By reducing Total Harmonic Distortion (THD), this topology improves the overall power quality at the AC mains input.

The regulated DC output from the BL-SEPIC converter is fed to the VSI, which converts it into a three-phase AC supply for the PMBLDC motor. The motor's speed is directly controlled by adjusting the DC link voltage, enabling precise speed regulation. Additionally, a torque control mechanism is implemented to reduce inrush currents, ensuring smooth motor operation.

The Bridgeless SEPIC Converter Fed PMBLDC Motor Drive provides an energy-efficient solution for applications requiring high power quality and precise speed control. By integrating power factor correction and voltage regulation into a single-stage conversion process, this topology is ideal for home appliances, industrial automation, and HVAC systems. It ensures low power losses, improved reliability, and enhanced performance.

4. DESIGN

A. Voltage of BL-SEPIC

$$Vdc = Vin \times \frac{D}{1-D}, \text{ Where, } Vin = 2\sqrt{2} \times \frac{Vs}{\pi} \quad (1)$$

B. Input Voltage to PFC Converter for BL-SEPIC

$$Vs = Vm \times \sin(2\pi ft), \text{ Where, } Vm = \text{rms value of voltage} \times \sqrt{2} \;\&\; f = 50Hz \quad (2)$$

C. Filter Output

$$Vin = |Vm \times \sin(2\pi ft)|, \text{ Where, } |\,| = \text{representation in modulus form} \quad (3)$$

D. Equation for Duty Ratio

$$D = \frac{Vdc}{Vin + Vdc} \quad \text{Where, } Vin = Vm \times (\omega t) \;\&\; \omega = 2 \times 3.14 \times 50 \quad (4)$$

E. Various parameters for both BL-SEPIC converter:

Cd= 2400 micro Farad& C1=C2=C3=240 nano Farad,L0= 70 micro Henry&L1=L2=Lf2=3.77 milli Henry

CONTROL COMPONENTS OF THE BL-SEPIC CONVERTER FED PMBLDC MOTOR DRIVE

REFERENCE VOLTAGE GENERATOR

The reference voltage generator produces a voltage signal that determines the operating voltage of the Permanent Magnet Brushless DC (PMBLDC) motor. The motor's output voltage is directly influenced by the reference voltage generated at this stage, ensuring proper speed control.

VOLTAGE CONTROLLER

A Proportional-Integral (PI) controller is employed as the voltage controller to regulate the output voltage. The PI controller maintains a stable and controlled voltage level by minimizing steady-state errors. The controller's gain values are determined through iterative tuning and optimization in MATLAB to achieve optimal performance.

RATE LIMITER

During transient conditions, the rate limiter plays a crucial role in maintaining the voltage error at the DC link within a controlled range. By limiting sudden voltage fluctuations, it ensures smooth speed regulation of the PMBLDC motor and enhances overall system stability.

PWM GENERATOR

The Pulse Width Modulation (PWM) generator receives the control signal from the PI controller and generates a PWM signal with a fixed frequency and a varying duty cycle. The duty cycle variation determines the voltage applied to the motor, enabling precise speed and torque control.

SOFT COMPUTING ELECTRONIC COMMUTATION

The electronic commutation process in a brushless DC motor replaces the mechanical commutation used in traditional brushed motors. Instead of brushes, electronic switches sequentially energize the stator windings to produce the required rotating magnetic field. During commutation, one winding is supplied with positive power while another acts as the return path. To keep the rotor in continuous motion, the stator windings must be energized in a specific sequence, which is managed through electronic switches. This controlled switching process ensures efficient motor operation by directing current flow in six different patterns through the motor windings to generate output torque.

The switching sequence of VSI for different positions of the rotor is shown in Table I and II. Decoder module in the simulation diagram implements the following truth table

h_a	h_b	h_c	Emf_a	Emf_b	Emf_c
0	0	0	0	0	0
0	0	1	0	-1	+1
0	1	0	-1	+1	0
0	1	1	-1	0	1
1	0	0	+1	0	-1
1	0	1	+1	-1	0
1	1	0	0	+1	-1
1	1	1	0	0	0

The gate pulse generation for inverter implements the Following truth table. Truth table for gate pulse generation

emf a	emf b	emf c	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6
0	0	0	0	0	0	0	0	0
0	-1	+1	0	0	0	1	1	0
-1	+1	0	0	0	1	1	0	0
-1	0	1	0	1	0	0	1	0
+1	0	-1	1	0	0	0	0	1
+1	-1	0	1	0	0	1	0	0
0	+1	-1	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0

5. PROPOSED SCHEME

In the proposed system, the speed regulation of a Permanent Magnet Brushless DC Motor (PMBLDCM) drive is achieved using a Bridgeless Single-Ended Primary Inductor Converter (BL-SEPIC). Converters operate in two distinct modes:

Continuous Current Mode (CCM) and Discontinuous Current Mode (DCM). The selection of the operating mode depends on the power rating of the application. For low-power applications, DCM is preferred due to its simplified control and reduced sensing requirements. Conversely, CCM is typically used in medium-power applications to ensure a smoother current waveform. In this system, BL-SEPIC is configured to operate in DCM to minimize the need for complex sensing circuits. The speed control of the PMBLDC motor drive is directly linked to the DC link voltage. By modulating the DC link voltage, the speed of the motor can be adjusted accordingly. The Voltage Source Inverter (VSI) responsible for driving the PMBLDC motor generates a switching sequence based on signals received from Hall sensors. These Hall sensors are used to determine the rotor position, enabling accurate electronic commutation. Additionally, a voltage controller is integrated into the system to ensure a stable and controlled output voltage. It continuously monitors the difference between the reference voltage and the actual DC link voltage, and generates an appropriate control signal using a Proportional-Integral (PI) controller. This helps in maintaining the desired motor speed and improving system efficiency.

SIMULATION RESULTS

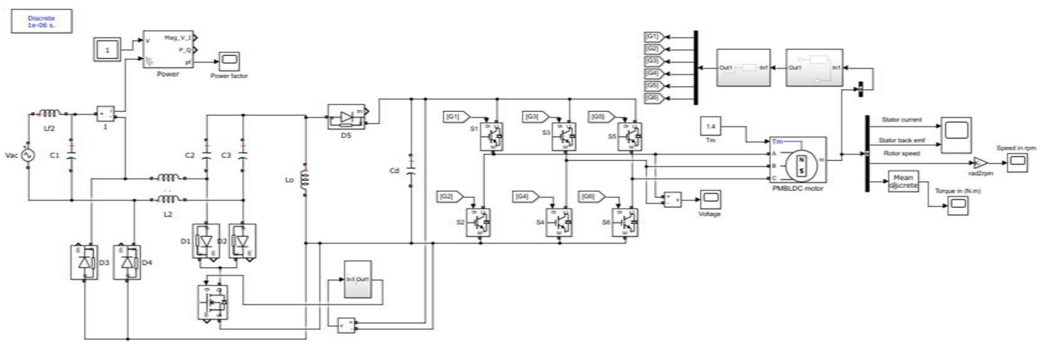
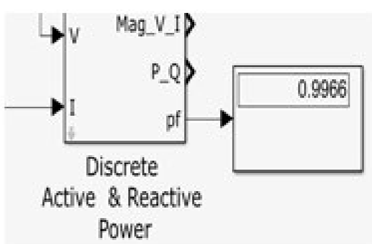


Fig. 1 Simulation of BL-SEPIC Fed PMBLDC Motor Drive



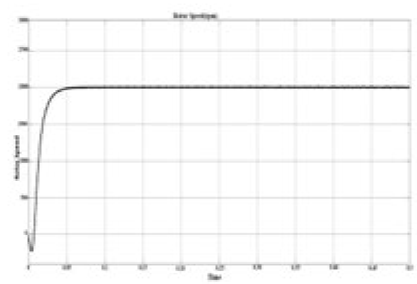
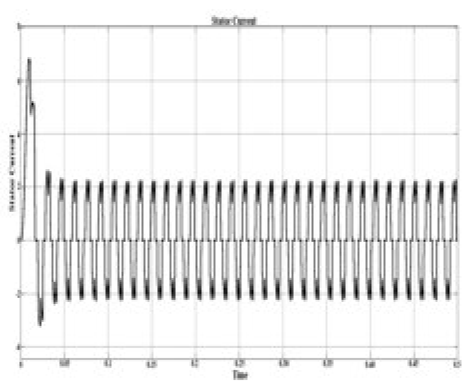


Fig. 2 Power Factor

Fig. 3 Rotor Speed



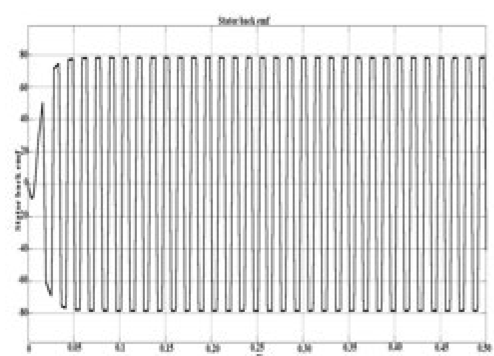


Fig. 4 Stator Current ***Fig. 5 Back Emf***

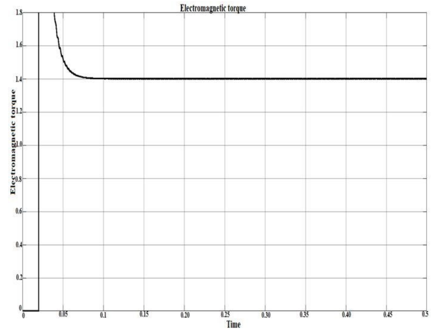


Fig. 6 Electromagnetic Torque

6. CONCLUSION

In conclusion, the Bridgeless SEPIC converter offers a significant improvement in power factor correction for BLDC motors by eliminating the need for a traditional diode bridge rectifier. This design not only enhances the efficiency of the power conversion process but also reduces the total harmonic distortion (THD), leading to better power quality. The Bridgeless SEPIC's ability to achieve high efficiency across a wide load range makes it an excellent choice for applications involving BLDC motors, particularly in scenarios requiring reduced energy consumption and lower operational costs. Furthermore, its compact nature and simplified control strategies contribute to its practicality in modern power electronic systems, presenting a promising solution for next-generation motor drives.

7. LATEST DEVELOPMENT AND FUTURE TRENDS

The future trends for the Bridgeless SEPIC converter in power factor correction for BLDC motors are poised to witness significant advancements driven by the growing demand for energy-efficient solutions and the continued evolution of power electronics. One key trend is the integration of advanced control algorithms, such as model predictive control (MPC) and adaptive control strategies, to further optimize the performance of Bridgeless SEPIC converters, especially under varying load conditions. Additionally, the development of wide-bandgap semiconductor materials, such as silicon carbide (SiC) and gallium nitride (GaN), will enable the converters to operate at higher frequencies and temperatures, improving efficiency and reliability. As electric vehicles (EVs) and renewable energy systems become more prevalent, the need for highly efficient power conversion will drive the adoption of Bridgeless SEPIC converters. These converters will be increasingly integrated into integrated motor drive systems, offering compact, cost-effective solutions that meet the power quality and efficiency demands of next-generation applications. Furthermore, future advancements may focus on reducing the complexity of the converter’s design and control, making it more accessible and scalable for a variety of industries, including robotics, HVAC systems, and industrial automation. Overall, the Bridgeless SEPIC converter will continue to play a pivotal role in enhancing the performance and sustainability of BLDC motor drives in diverse applications.

APPENDIX

Rated torque= 1.4 N.m & Rated speed= 2000 rpm

CONFLICT OF INTERESTS

None.

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