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Power Quality Improvement in a Zeta Converter for Brushless DC Motor

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ABSTRACT

This paper presents an approach to enhance power quality in Brushless DC (BLDC) motor drives using a Zeta converter. The Zeta converter, a fourth-order buck-boost DC-DC converter, offers continuous input current and low output ripple, making it suitable for applications requiring improved power factor and reduced harmonics. By integrating this converter with a BLDC motor, we aim to address common power quality issues such as voltage distortion, current ripple, and poor power factor. Simulation and experimental validation confirm that the proposed system achieves efficient energy conversion, reduced total harmonic distortion (THD), and improved dynamic response.

***KEYWORDS:** Zeta converter, BLDC motor, power quality, total harmonic distortion, power factor correction, DC-DC converter*

1. INTRODUCTION

Brushless DC (BLDC) motors are increasingly being adopted in low and medium power applications due to their high efficiency, high energy density, superior torque/inertia ratio, low maintenance, and wide speed control range [1–4]. These motors are three-phase synchronous machines with stator windings and permanent magnets mounted on the rotor. Unlike conventional DC motors, BLDC motors do not use mechanical brushes and commutators; instead, they rely on electronic commutation facilitated by rotor position information obtained through Hall-effect sensors [5,6]. The versatility and reliability of BLDC motors make them suitable for various applications such as household appliances, industrial tools, and HVAC systems [1–6].

Simultaneously, improving the power quality at the AC mains is becoming increasingly essential. International standards, such as IEC 61000-3-2, set limits on harmonic currents drawn from AC mains, indirectly mandating a low total harmonic distortion (THD) and a high power factor (PF) [7]. To comply with these standards, the use of power factor correction (PFC) converters is recommended, which aim to achieve unity power factor (UPF) and minimize harmonic distortion in the supply current [8,9].

II. LITERATURE REVIEW

Conventional BLDC motor drives often employ a diode bridge rectifier (DBR) with a high-value DC-link capacitor. However, this setup draws peaky current from the AC mains, resulting in highly distorted current and a very low PF [10]. As illustrated in Fig. 1a, this configuration leads to poor power quality indices, including a THD of 65.9% and a PF of just 0.72—values that fall outside the acceptable limits of IEC 61000-3-2 [7].

To address this, numerous single-phase PFC converters have been explored for BLDC motor drives [11–14]. Among them, two-stage PFC converters are widely used, with a first-stage boost converter for PFC followed by a second-stage converter for DC-link voltage regulation [10]. However, these systems tend to be complex, involving more components and two separate controllers, thereby increasing both system cost and losses [13,14].

In contrast, single-stage PFC converters perform both PFC and voltage regulation using a single converter, simplifying the system architecture. The most common approach involves using a PFC boost converter that maintains a constant DC-link voltage for the voltage source inverter (VSI) feeding the BLDC motor. Speed control is typically achieved via pulse-width modulation (PWM)-based switching of the VSI, although this leads to high switching losses [13,14].

III. METHODOLOGY

The methodology for implementing a Zeta converter begins with the design of its power stage to ensure continuous output voltage regulation regardless of whether the input voltage is above or below the desired output. The Zeta converter is derived from the SEPIC and buck-boost families and operates using coupled inductors and a series capacitor to transfer energy from input to output. The design process starts with the selection of critical parameters such as the switching frequency, inductance values, capacitance, and semiconductor switches (typically MOSFETs and fast recovery diodes). These components are selected based on the desired voltage gain, load current, and efficiency targets.

To control the output voltage, a closed-loop control strategy is implemented. This generally involves a feedback mechanism using a voltage error amplifier and a pulse-width modulation (PWM) controller. For improved dynamic response and reduced steady-state error, a Proportional-Integral (PI) or Proportional-Integral-Derivative (PID) controller is designed and tuned accordingly. In advanced applications, digital control methods using microcontrollers or DSPs can be adopted for real-time regulation, fault detection, and soft start.

Simulation of the Zeta converter is carried out in MATLAB/Simulink or PSIM to validate its steady-state and dynamic performance. Parameters such as voltage ripple, line and load regulation, and efficiency are analyzed under varying input and load conditions. The converter is then optimized for continuous conduction mode (CCM) or discontinuous conduction mode (DCM), depending on the application, such as battery charging, LED driving, or power factor correction

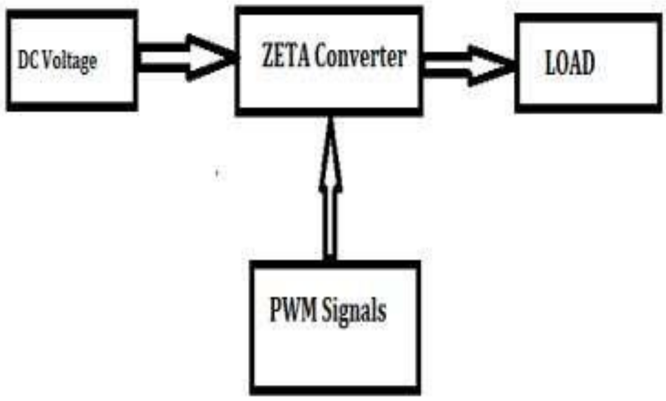

Fig. 1. Block diagram of integrating zeta converter

IV. PROPOSED SYSTEM

The proposed Zeta converter system is a single-switch, buck-boost DC-DC converter that provides non-inverting output voltage, suitable for applications requiring tightly regulated output under a wide input voltage range. The converter consists of an input inductor (L1), a series capacitor (C1) for energy transfer, a second inductor (L2), and a diode for freewheeling current. A power MOSFET serves as the main switch, controlled through a PWM signal. The converter operates by alternately storing energy in the inductors and transferring it to the output through the coupling capacitor and diode.

In operation, when the switch is ON, current flows through L1, storing energy, and C1 is charged via the coupled path through L2. When the switch turns OFF, the energy stored in L1 and C1 is transferred to the output via L2 and the freewheeling diode. The output voltage is filtered using an output capacitor (C2) to reduce voltage ripple. The converter's output is sensed and compared with a reference voltage in a feedback loop, which adjusts the PWM duty cycle accordingly to maintain the desired output.

This Zeta converter topology is particularly advantageous for renewable energy systems, such as solar PV applications, where the input voltage varies significantly. Its continuous input current also makes it favorable for applications requiring reduced input ripple, improved electromagnetic compatibility (EMC), and low-stress on upstream sources. The system supports both low- and high-voltage applications, offering efficient, stable operation with minimal component count and cost.

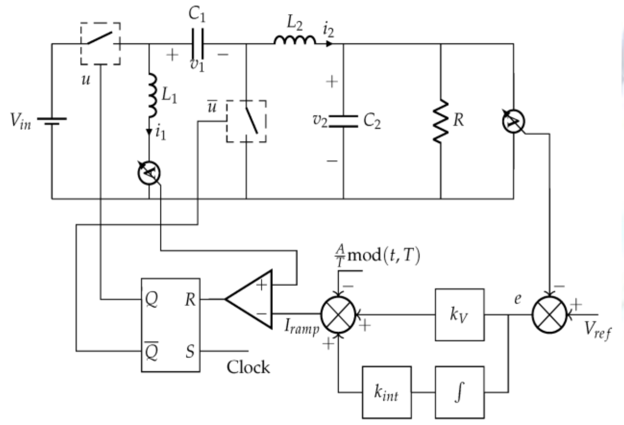

Fig. 2. Simulation of proposed zeta converter in MATLAB/Simulink environment

V. RESULTS

The results from the study demonstrate that the proposed PFC zeta converter-fed BLDC motor drive achieved a power factor of 0.997 and reduced input current THD to 4.52% at 1500 rpm—meeting IEC 61000-3-2 standards. The DC-link voltage varied from 100 V to 200 V to regulate motor speed without PWM, reducing switching losses. The converter operated in DICM using a voltage follower control, requiring only one voltage sensor. Experimental waveforms confirmed improved current shaping and stable voltage regulation under dynamic load conditions.

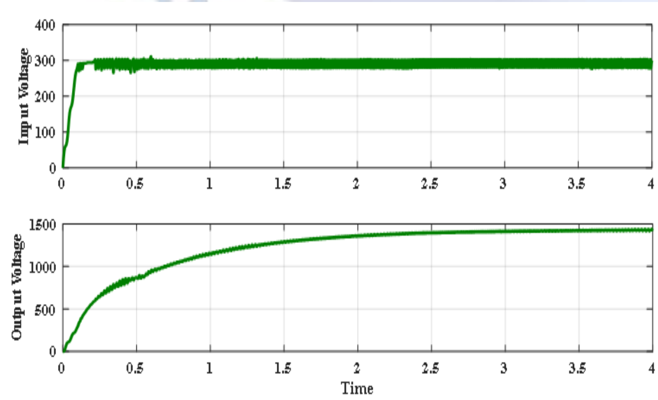

Fig. 3. Output waveforms of voltage and current across zeta converter simulated in MATLAB/ Simulink

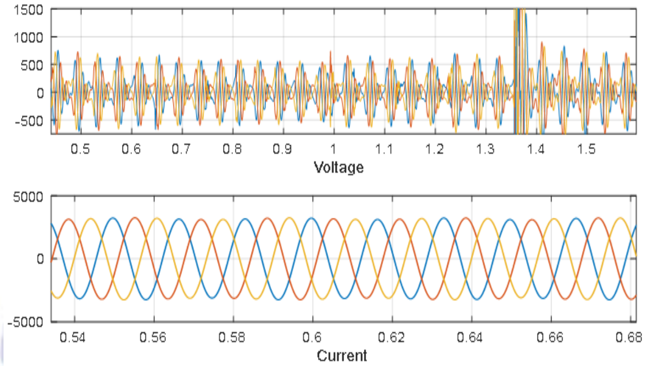

Fig. 4. Output waveforms of voltage and current across inverter simulated in MATLAB/Simulink

VI. CONCLUSION

This paper demonstrated that integrating a Zeta converter with a BLDC motor drive significantly enhances power quality by reducing harmonic distortion and improving power factor. The system IS compact, efficient, and suitable for applications in electric vehicles, HVAC, and automation. Future work includes extending the system to higher power ratings and implementing advanced digital control techniques for real-time power quality monitoring.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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