Design of Bridge-Less ZETA PFC Rectifier Fed BLDC Motor Drive

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Abstract: This paper presents a power factor correction (PFC) based bridgeless- zeta converter fed brushless DC (BLDC) motor drive. A single voltage sensor is used for the speed control of BLDC motor and PFC at AC mains. The voltage follower control is used for a zeta converter operating in discontinuous inductor current mode (DICM). The speed of the BLDC motor is controlled by an approach of variable DC link voltage, which allows a low frequency switching of voltage source inverter (VSI) for electronic commutation of BLDC motor; thus offers reduced switching losses. The proposed BLDC motor drive is designed to operate over a wide range of speed control with an improved power quality at AC mains.

Key words: Voltage control • Power quality • Inductors • Power factor correction • Brushless DC motors

INTRODUCTION

This paper presents a power factor correction (PFC) based bridgeless- zeta converter fed brushless DC (BLDC) motor drive. A single voltage sensor is used for the speed control of BLDC motor and PFC at AC mains. The voltage follower control is used for a zeta converter operating in discontinuous inductor current mode (DICM). The speed of the BLDC motor is controlled by an approach of variable DC link voltage, which allows a low frequency switching of voltage source inverter (VSI) for electronic commutation of BLDC motor; thus offers reduced switching losses. The proposed BLDC motor drive is designed to operate over a wide range of speed control with an improved power quality at AC mains. A permanent magnet brushless dc motor is fed through a voltage source inverter which is used to drive a BLDC motor and it is variable speed operation under rated torque. The proposed topology is simulated by MATLAB / Simulink software to validate the accuracy of the theoretical analysis. Finally, a prototype of the proposed system has been built and tested.

Brushless dc (BLDC) motors are becoming popular due to their advantages of high efficiency, high energy density, high torque/inertia ratio, variable speed operation and low electromagnetic interference (EMI). They find applications in household appliances, medical equipment’s, robotics and automation, transportation and industrial tools. The BLDC motor is a three-phase synchronous motor with three-phase concentrated windings on the stator and permanent magnets on the rotor. It needs a three-phase voltage source inverter (VSI) for achieving an electronic commutation of BLDC motor based on the rotor position as sensed by Hall Effect position sensors.

Drastic reduction in the cost of power electronic devices and annihilation of the fossil fuels in near future invite to use the solar photovoltaic (SPV) generated electrical energy for various applications as far as possible. Water pumping, a standalone application of the SPV array generated electricity is receiving wide attention now a days for irrigation in the fields, household applications and industrial usage. Although the several researches have been carried out in the area of SPV array fed water pumping, combining various DC-DC converters and motor drives, the zeta converter in association with the permanent magnet brushless DC (BLDC) motor is still unexplored to develop such kind of system. However, the zeta converter has been used in some other SPV based applications. In this paper, the zeta converter designed for power factor correction converter. A permanent magnet brushless dc motor is fed through a voltage source inverter which is used to drive a BLDC motor and it is variable speed operation under rated torque. The power quality problems due to uncontrolled charging the dc link capacitor in the PMLBLDCM drive is reduced to a greater extent using PFC converter.
Block Diagram Explanation:

- **AC**
- **ZETA CONVERTER**
- **THREE PHASE INVERTER**
- **BLDC MOTOR**
- **PULSE GENERATOR**
- **CONTROL UNIT**
- **PWM GENERATOR**
- **HALF SENSOR**

**Converter:** It converts dc voltage magnitude level from one level to another level.

**Pulse Generator:** A PIC microcontroller is used to make a switching signal for controlling the switches.

The proposed system consist the zeta converter, the VSI, the BLDC motor and the centrifugal water pump. The BLDC motor has an inbuilt encoder. The pulse generator is used to operate the zeta converter. The SPV array generates the electrical power demanded by the motor-pump system. This electrical power is fed to the motor-pump system via the zeta converter and the VSI. Ideally, the same amount of power is transferred at the output of zeta converter which appears as the input source for the VSI. In practice, due to the various losses associated with a DC-DC converter, slightly less amount of the power is transferred to feed the VSI. The pulse generator generates, through PWM, the switching pulse for the IGBT (Insulated Gate Bipolar Transistor) switch of the zeta converter. Further, the pulse generator generates actual switching pulse by comparing the duty cycle with the high frequency carrier wave. On the other hand, VSI converting the DC power output from the zeta converter into the AC power feeds the BLDC motor to drive the centrifugal pump coupled to its shaft. The VSI is operated by the fundamental frequency switching availed by the so called electronic commutation of BLDC motor assisted by its built-in encoder. The high frequency switching losses are thereby eliminated, contributing in the effective and increased efficiency operation of the proposed water pumping system. The proposed drive is designed and its performance is validated on a developed prototype for improved power quality at ac mains for a wide range of speed control and supply voltage variations.

**Operation Mode Analysis of ZETA Inverter:** The ZETA converter topology provides a positive output voltage from an input voltage that varies above and below the output voltage. The ZETA converter also needs two inductors and a series capacitor, sometimes called a flying capacitor. Unlike the SEPIC converter, which is configured with a standard boost converter, the ZETA converter is configured from a buck controller that drives a high-side PMOS FET. The ZETA converter is another option for regulating an unregulated input-power supply, like a low-cost wall wart. To minimize board space, a coupled inductor can be used. This article explains how to design a ZETA converter running in continuous-conduction mode (CCM) with a coupled inductor. The operation of an zeta converter is classified into three different modes corresponding to switch turn-ON, switch turn-OFF and DCM. Three described as follows.

**Mode I:** In this stage, switch S1 is turned on and the input source supply energy to the input inductor (L1). This energy is then subsequently transferred to output inductor (Lo) through the intermediate capacitor C1. The current in the output inductor (iLo) and input inductor (iL1) increase linearly. The intermediate capacitor voltage (Vc1) and the output DC-link capacitor voltage (Vdc) are considered constant in this stage. They are equal to the DC voltage (Vdc).

![Mode I](image-url)
Mode II: In the second stage, switch S1 is turned off and diode D5 starts conducting. The stored energy from output inductance (Lo) and the input inductance (L1) are transferred to the intermediate capacitor C1 and the DC link capacitor filter (Cdc), respectively. This stage continues until \( i_{L1} \) becomes equal to the negative of \( i_{Lo} \). In this stage of Zeta converter operation, the MOSFET switch S1 is in off stage and diode D5 is in on stage.

![Mode II](Fig. 4: Mode II)

Mode III: This freewheeling stage lasts until the start of a new switching period. In this stage of operation neither output diode „D5? nor switch „S1? conducts. The voltage applied across inductances Lo and L1 is zero and their currents are constant until the new switching cycle starts. The currents \( i_{Lo} \) and \( i_{L1} \) become equal and opposite at toff time. Therefore, in this stage the current through the output diode is zero.

![Mode III](Fig. 5: Mode III)

Control of BLDC Motor: An electronic commutation of BLDC motor includes proper switching of VSI in such a way that a symmetrical dc current is drawn from the dc link for 120° and placed symmetrically at the center of back-EMF of each phase. A Hall effect position sensor is used to sense the rotor position on a span of 60°; which is required for the electronic commutation of BLDC motor. When two switches of VSI, are in conduction states, a line current is drawn from the dc link capacitor whose magnitude depends on applied dc link voltage, back EMF’s, resistances and self and mutual inductance of stator windings. This current produces the electromagnetic torque which in turn increases the speed of the BLDC motor.

Simulation Circuits

![Zeta Converter Design](Fig. 6: Zeta Converter Design)

![Solar Panel Design](Fig. 7: Solar Panel Design)

![Control Block Design](Fig. 7: Control Block Design)

![Commutator Decoder Design](Fig. 8: Commutator Decoder Design)
Fig. 9: Inverter Pulse Generation Design

Simulation Output

Fig. 10: Zeta Converter Voltages

Fig. 11: Zeta Pulse Waveform

Fig. 12: Inverter Pulses

Fig. 13: Inverter Output Voltages

Fig. 14: Inverter Current Waveform

Fig. 15: BLDC Motor Speed

CONCLUSION

The Zeta converter fed BLDC Motor is simulated using MATLAB and the output voltage waveforms are observed. A variable dc link voltage of VSI feeding BLDC motor has been used for controlling the speed. With this PFC converter, three-phase VSI has been operated in low frequency switching mode with reduced switching losses.

APPENDIX: BLDC Motor Rating: 4 pole, P(Rated Power) = 0.5 hp (376 W), Vrated (Rated DC link Voltage) = 130 V, T (Rated Torque) = 1.2 Nm, ωrated (Rated Speed) = 3000 rpm, K (Back EMF Constant) = 34 V/krpm, K(Torque Constant) = 0.32Nm/A, Rph (Phase Resistance) = 2.68 Ω, L(Phase Inductance) = 5.31mH, J (Moment of Inertia) = 1.3 kg-cm.

REFERENCES


