International Journal on Applications in Electrical and Electronics Engineering
Volume 2: Issue 4: April 2016, pp 9-13. www.aetsjournal.com ISSN (Online) : 2395-3527

DC MOTOR DRIVE USING ZETA CONVERTER

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Abstract:

A Zeta converter fed DC motor drive using a single voltage sensor is proposed for fan applications. A single phase supply followed by diode bridge rectifier and a Zeta converter is used to control the voltage fed to the VSI. Output of Zeta converter is controlled to achieve the speed control of DC motor. A sensorless control of DC motor is used to eliminate the requirement of position sensors. A MATLAB Simulation is used to simulate the developed model to achieve a wide range of speed control with high Power Factor and improved Power Quality at the supply.

Index Terms: DC motor, Sensorless, Voltage Control, VSI, Zeta.

I. INTRODUCTION

The day by day increasing demand for energy can create problems for the power distributors, like grid instability. In recent years brushless dc (BLDC) motors are widely used applications including appliances, automotive, aerospace, consumer, medical, automated industrial equipment and instrumentation because of their high starting torque, high efficiency, reliability, lower maintenance compared to its brushed dc motor. In a BLDC motor, the rotor magnets generate the magnetic flux, so BLDC motors achieve higher efficiency. [1] [2] Therefore, BLDC motors may be used in high end white goods (refrigerators, washing machines, dishwashers, etc.), high-end fans, and pumps and in other appliances which require high reliability and efficiency. BLDC motors have many advantages over brushed DC motors and induction motors, like higher efficiency and reliability, lower acoustic noise, smaller and lighter, greater dynamic response, better speed versus torque characteristics, higher speed range, longer life. Since the specific torque is higher it can be very useful in the applications were space and weight are critical factors. And also the BLDC motor is electrically commutated by power switches instead of brushes it has so many advantages such as no brushes/commutator maintenance, no brush friction to reduce useful torque, no mechanical limitation imposed by brushes or commutator, no arcs from brushes to generate noise, causing EMI problems.[3] The BLDC motor drive is fed from single-phase ac supply through a diode bridge rectifier (DBR) followed by a high value of smoothening capacitor at dc link which draws a pulsed current, with a peak higher than the amplitude of the fundamental input current at ac mains due to an uncontrolled charging and discharging of the dc link capacitor.[4] This causes in poor power quality (PQ) at ac mains in terms of poor power factor (PF), high total harmonic distortion (THD) of ac mains current, and high crest factor (CF). Therefore, a Power Factor correction (PFC) converter is inevitable for Brushless DC Motor Drive in order to improve the power quality. [5] There are many existing topologies regarding power factor correction in BLDC motor drive. Some of the existing topologies consist of a Single Ended Primary Inductance Converter (SEPIC) and buck-boost converter based BLDC motor drive which has higher losses in the voltage source inverter due to conventional PWM switching and large number of voltage and current sensors are used that additionally adds to the cost of the converter. And in another topology a cuk converter fed BLDC motor drive with a variable DC link voltage is used that reduces the switching losses since it uses only the fundamental switching frequency, but it has a major disadvantage that it requires three sensors. So it is not used for low power rating and low-cost applications.[6]-[8] The above used topologies consist of bridge converters and it also contributes switching losses so bridgeless topologies are preferred. The usage of diode rectifiers that cause more switching stresses are eliminated by bridgeless converters.[9] And also some topologies with bridgeless converters like bridgeless boost, cuk, buck-boost, SEPIC converters are there. But all these power factor correction techniques have some limitations.

II. ZETA COVERTER

A. OPERATION

This converter is the latest type of single-stage input current shapers. It also uses single switching device and inherently provides an overload, short circuit, and inrush current protections. Since zeta converters behave as a resistive load to input AC mains, this converters are also called resistance emulators. Zeta converter is fourth order converters that can step down or step up the input voltage. The ZETA converter also have a series capacitor sometimes called a flying capacitor and two inductors. The ZETA converter topology gives a positive output voltage from an input voltage.

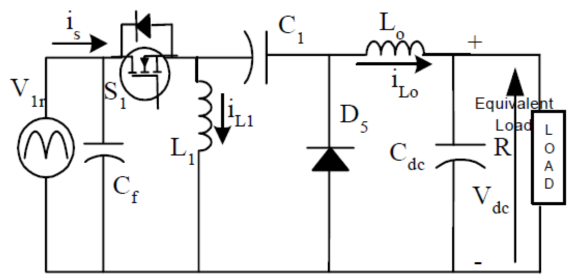

Fig. 1: Circuit of Zeta Converter

The Zeta converter has many advantages, such as buck-boost capability, and continuous output current, input to output DC insulation, so it can be used in high reliability system. This topology offer high efficiency, especially by using the synchronous rectification. The synchronous rectification can be easily implemented in this converter, because this topology, unlike the SEPIC converter, uses a low-side rectifier. The equivalent circuit of the Zeta converter is shown in Fig.1

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MODE I : In this stage, switch S1 is turned on and the input source supply energy to the input inductor (*L*1). 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*). This stage is shown in Fig.2(a)(i).

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 iL1 becomes equal to the negative of *iLo* as shown in Fig.2(a)(ii). In this stage of Zeta converter operation, the MOSFET switch S1 is in off stage and diode *D5* is in on stage.

MODE III : This freewheeling stage lasts until the start of a new switching period and is shown in Fig.2(a)(iii). 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 *iLo* and *iL1* become equal and opposite at *toff* time. Therefore, in this stage the current through the output diode is zero.

III. DESIGN OF ZETA COVERTER

The design of zeta converter for power factor correction and speed controlled in BLDC motor drive has the main objective of the PQ improvement at AC mains. The design equations of zeta converter are given below.

The expression for output DC Link Voltage of zeta converter

$$V_{dc} = \left(\frac{N_2}{N_1}\right) V_{in} \frac{D}{(1-D)} \quad (1)$$

$$V_{in} = \frac{2\sqrt{2}}{\pi} V_s \quad (2)$$

where *Vin* is the input voltage applied to zeta converter, *Vs* is the source voltage and *D* is the duty cycle of converter The Critical value of Magnetizing Inductor is expressed

$$L_{mc} = \left(\frac{V_{dc}^2}{P_i}\right) \frac{\{1-D\}}{2D\, f_s \left(\frac{N_2}{N_1}\right)^2} \quad (3)$$

$$L_o = \frac{V_{dc}\{1-D\}}{f_s (k\, I_o)} \quad (4)$$

where *D* represents the duty ratio and *N2/N1* is the turns ratio of the HFT. the value of *L1* is selected around 1/10th of *Lmc* and *fs* is the switching frequency (which is taken as 20 kHz) and *Lo* is the expression for output inductor and *k* represents the percentage ripple of the output inductor current which is taken as 40% of output inductor current.

An expression for intermediate capacitor (*C1*) is as

$$C_1 = \frac{V_{dc}\, D}{\eta\{\sqrt{2}V_s + V_{dc}\} f_s} \left(\frac{P_i}{V_{dc}^2}\right) \quad (5)$$

where *Pi* is the instantaneous power and □ is the permitted ripple voltage across intermediate capacitor The value of DC link Capacitor is

$$C_d = \left(\frac{P}{V_{dc}}\right) \frac{1}{2\,\omega(\eta V_{dc})} \quad (6)$$

IV. PROPOSED PFC-BASED BLDC MOTOR DRIVE WITH ZETA CONVERTER

Fig.3 shows the proposed zeta converter-fed BLDC motor drive. A single-phase ac supply is converted to DC by using DBR followed by a large value capacitive filter and zeta converter. The filter is is used to reduce DC voltage ripples, which produces an increased THD of input AC mains current and excessive peak input currents that leads to poor power factor. The zeta converter is designed to operate in DCM to act as an inherent power factor correction converter.

This combination of DBR and PFC zeta converter is used to feed a BLDC motor drive through a three-phase VSI as shown in Fig.3. The speed of BLDC motor is directly proportional to the DC link voltage of the VSI. The reference voltage generator produces a voltage by multiplying the speed with the voltage constant (*Kb*) of the BLDC motor drive.

An error voltage obtained by comparing the measured dc link voltage and reference voltage is fed to PI controller. The Proportional Integral controller is used to minimize the error signal and also it produce a controlled output to the PWM generator to produce a PWM signal of fixed frequency and varying duty ratio.

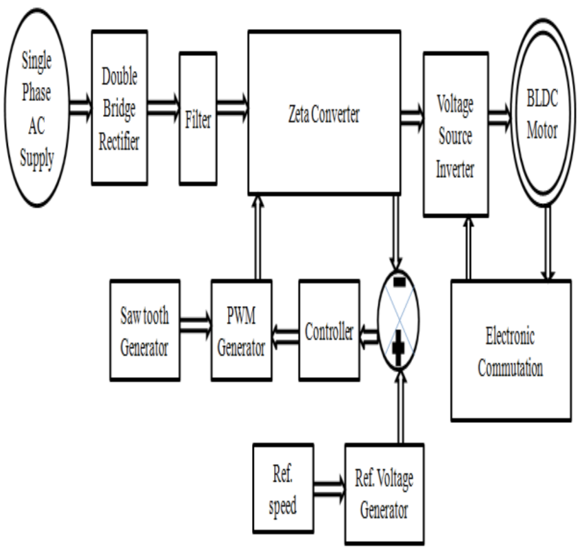

Fig.2 Proposed PFC-based zeta converter fed BLDC motor drive

V. RESULTS AND DISCUSSIONS

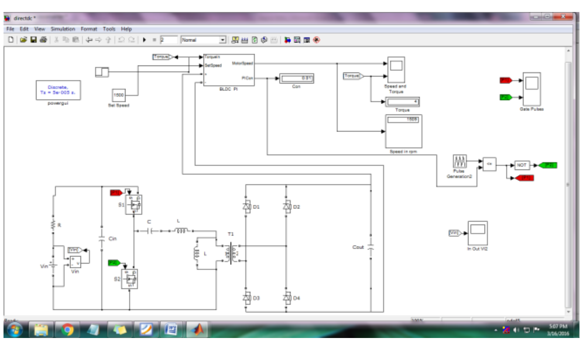

Fig.3 DC motor drive without PFC Converter

the simulation model of the BLDC Motor Drive without Power Factor Correction Converter. The operation of the proposed topology has been verified by simulations. The simulations are done in Matlab/Simulink platform.

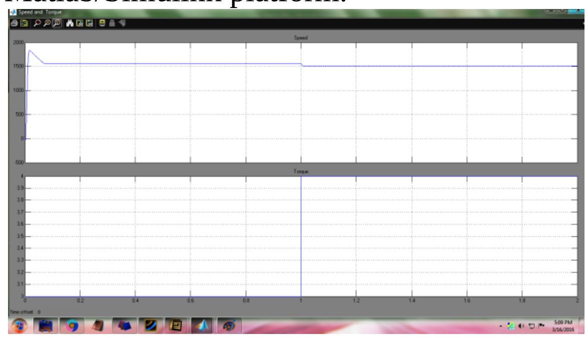

Fig.4 Speed and Torque waveform

The BLDCMD is fed from a single-phase ac supply through a diode bridge rectifier (DBR) followed by a capacitor at dc link. It draws a pulsed current as shown in Fig. 6, with a peak higher than the amplitude of the fundamental input current at ac mains due to an uncontrolled charging of the dc link capacitor.

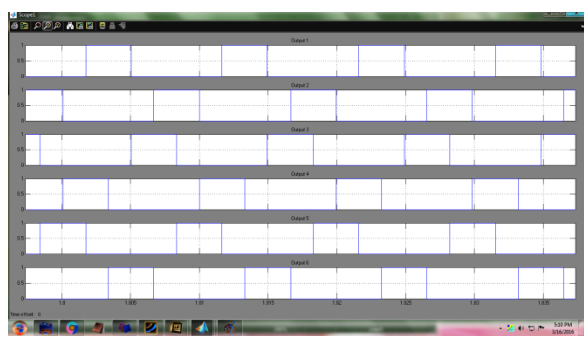

Fig.5 Inverter Gate pulse

VI. Conclusion

A fuzzy controlled zeta converter-fed BLDC motor drive has been proposed for targeting low-power household appliances. 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. An isolated zeta converter operating in DCM has been used for dc link voltage control and with PFC at ac mains. Performance of proposed drive has been found quite satisfactory for speed control over a wide range. The simulated results shows improved performance of the proposed Zeta converter fed BLDC Motor drive in terms of low THD of supply current and improved power quality at the AC mains.

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