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A BRUSHLESS DC MOTOR DRIVE WITH POWER FACTOR CORRECTION USING ISOLATED ZETA CONVERTER

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Abstract: **A brushless DC motor when fed by uncontrolled diode bridge rectifier results in highly distorted supply current which forcing in low Power Factor and high Total Harmonic Distortion; hence zeta converter fed BLDC motor drive is proposed here. Zeta converter is fourth order DC-DC converter which is capable of operating either in step up or step down mode. A single phase AC supply is connected single phase diode bridge full wave rectifier and a Zeta converter is used to control the voltage of a DC link capacitor. DC link capacitor is connected in between the Zeta converter and Voltage Source Inverter. The Voltage of a DC link capacitor of Zeta converter is controlled to achieve the speed control of BLDC motor. The DC link capacitor of the Zeta converter is followed by a VSI which is feeding a BLDC motor. The basic zeta allows operating in Continuous Conduction Mode (CCM) without any isolation. The circuit is modified here with high frequency isolation using isolated transformer. Here Discontinuous Conduction Mode is used. The circuit model is simulated using PSIM environment. The gate pulses are generated by the feedback method using PSIM, The PWM signal generation requires only a sin wave/ saw tooth waveform and a comparator in simulation model, also can generate the required PWM by PIC16F877A in Proteus.**

Keywords: **Brushless DC Motor (BLDC), Zeta converter, Discontinuous conduction mode (DCM).**

I. INTRODUCTION

BLDC motor when fed by an uncontrolled bridge rectifier with DC link capacitor results in highly distorted supply current which results in low PF (Power Factor) and high THD (Total Harmonic Distortion); hence various improved power quality AC-DC converters are used in these drives. The requirement of improved power quality at the AC mains is becoming essential for any appliance as imposed by the International PQ (Power Quality) standards. The requirement of power factor above 0.9 and THD (Total Harmonic Distortion) below 5 percent, Class-D(that is under 600W, 16A, single phase) applications recommends the use of improved power quality converters for BLDC (Brush Less DC) motor drive. From all literature reviews, the conventional rectifiers are developed using diodes and thyristors to provide controlled and uncontrolled dc power with unidirectional and bidirectional power flow. They have the demerits of poor power quality in terms of injected current harmonics, caused voltage distortion and poor power factor at input ac mains and slow varying rippled dc output at load end, low efficiency and large size of ac and dc filters.

Power factor correction (PFC) converters are widely used for improving the power quality at AC mains. The cost of these PFC converters is primarily decided by the sensing requirements which in-turn depends upon the mode of operation of the PFC converter. PFC converter operating in Discontinuous Conduction Mode requires single voltage sensor for DC link voltage control and inherent power factor correction is achieved at AC mains. Two stage PFC converters are widely in practice in which first stage is used for the power factor correction which is preferably a boost converter and second stage

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for voltage regulation which can be any converter topology depending upon the requirement. This two stage topology is complex and results in higher cost and more losses; hence a single stage Zeta converter is included in this paper which is used for DC link volt- age control and power factor correction. The operation is studied for a Zeta converter working in DICM (Discontinuous Inductor Current Mode) hence a voltage follower approach is used.

II. CONFIGURATION AND OPERATION OF ZETA CONVERTER

A zeta converter is a fourth order nonlinear system being that, with regard to energy input, it can see as buck-boost-buck converter and with regard to the output, it can be seen as buck-boost converter. Zeta converter is a fourth-order DC-DC converter made up of two inductors and two capacitors and capable of operating in either step-up or step-down mode. The ZETA converter topology provides a positive output voltage from an input voltage that varies above and below the output voltage. The ZETA converter is configured from a buck controller that drives a high-side PMOSFET. 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

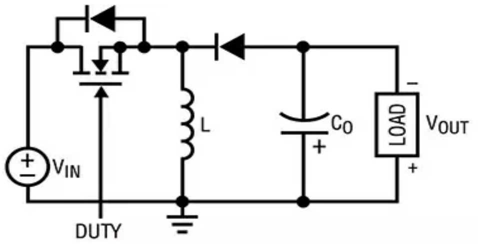
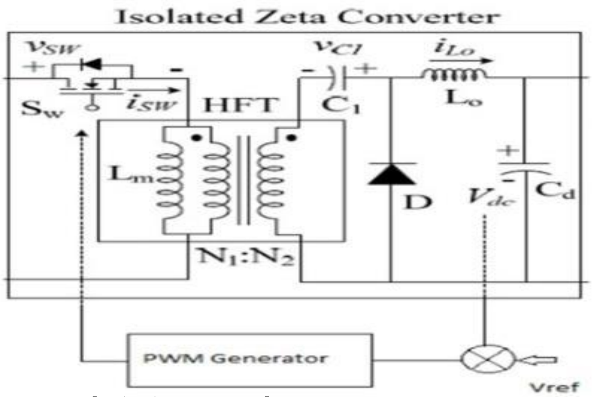


Fig 1. Configuration of Zeta converter.

In isolated zeta converter the isolation is done by using a high frequency transformer. The isolated zeta converter works in three different modes where switch ON and OFF are the first two and Discontinuous conduction mode is the third mode. This mode is the most important mode here. An isolation transformer is a transformer used to transfer electrical power from a source of alternating current (AC) power to some equipment or device while isolating the powered device from the power source, usually for safety reasons. Isolation transformers provide galvanic isolation and are used to protect against electric shock, to suppress electrical noise in sensitive devices, or to transfer power between two circuits which must not be connected. A transformer sold for isolation is often built with special insulation between primary and secondary, and is specified to withstand a high voltage between windings.



In the first mode of operation switch (S_w) is turned on, a current in magnetizing inductance (L_m) of high frequency transformer (HFT) increases. The intermediate capacitor (C_1) supplies energy to an output inductor (L_0) and the DC link capacitor (C_d). Hence, voltage across intermediate capacitor (V_{C1}) reduces and the current in output inductor (i_{L0}) and DC link voltage (V_{dc}) are increased.

In next mode operation the switch (S_w) is turned off, the current in magnetizing inductance (L_m) of HFT and output inductor (L_0) starts reducing. This energy of HFT is transferred to the intermediate capacitor (C_1) and therefore voltage across it increases. Diode (D) conducts in this mode of operation and the DC link voltage (V_{dc}) increases.

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In the last mode operation that is discontinuous mode of conduction, the energy of HFT is completely discharged. The intermediate capacitor (C_1) and the DC link capacitor (C_d) supply the energy to the output inductor (L_0) and the load, respectively. Hence, the DC link voltage (V_{dc}) and intermediate capacitors voltage (V_{C1}) are reduced and the output inductor current (i_{L0}) increases. In this work BLDC motor is selected. The BLDC motor drive via a three phase voltage source inverter. The single phase supply is first converted to DC by ordinary diode bridge rectifier. Then it passes through a filter to smoothen the DC output.

Fig.3 shows the PFC isolated-Zeta converter fed BLDC motor drive. A single-phase supply is used to feed a DBR followed by a filter and an isolated-Zeta converter. The filter is designed to avoid any switching ripple in the DBR and the supply system. An isolated-Zeta converter is designed to operate in DCM to act as an inherent power factor corrector. This combination of DBR and PFC converter is used to feed a BLDC motor drive via a three-phase VSI as shown in Fig. 1. The DC link voltage of the VSI is controlled by varying the duty ratio of the PWM pulses of PFC converter switch. However, VSI is operated in a low frequency switching to achieve an electronic commutation of BLDC motor for reduced switching losses. A single voltage sensor is used at the front-end converter for the control of DC link voltage for speed control of BLDC motor. 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.

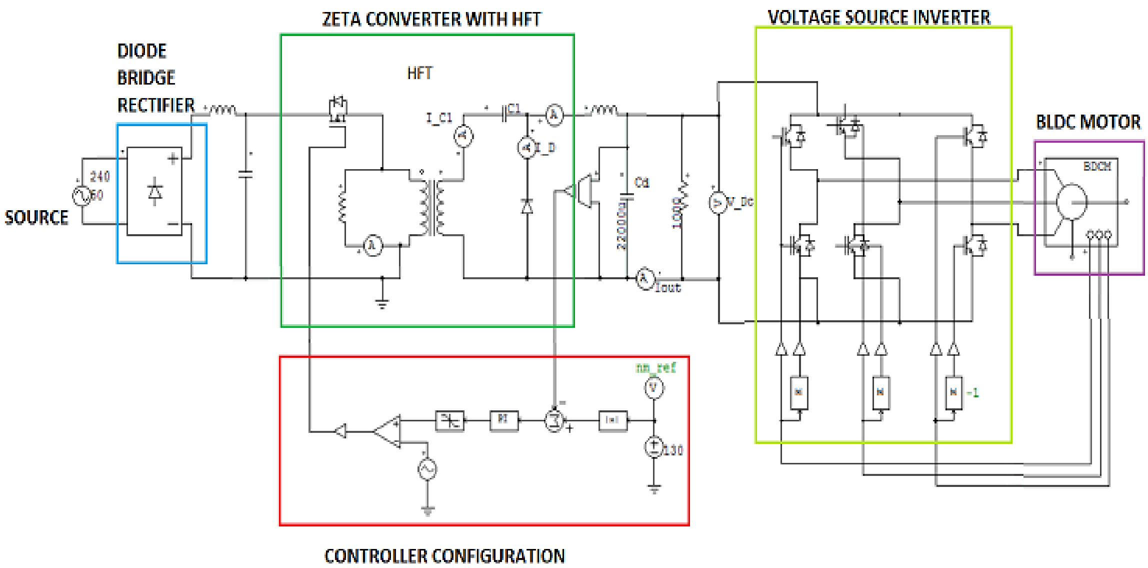

Fig3. PFC Based Isolated Zeta Converter

The DC link voltage of the VSI is controlled by varying the duty ratio of the PWM pulses of PFC converter switch. However, VSI is operated in a low frequency switching to achieve an electronic commutation of BLDC motor for reduced switching losses.

TABLE I: SIMULATION PARAMETERS

COMPONENTS	SPECIFICATION
HFT winding (L_{mc})	2.52Mh
Output capasitor (C_1)	456.6nF
DC link capasitor (C_d)	2441.6µF
Output inductor(L_o)	4.188mH
Filter inductor (L_f)	377mH
Filter capasitor (C_f)	330nF

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III. SIMULATION RESULT

A single stage PFC using ZETA converter system has been designed and validated for the speed control with improved power quality at the AC mains for a wide range of speed. The performance of the proposed drive system has also been evaluated for varying input AC voltages and found satisfactory. PSIM Tools was used for simulation.

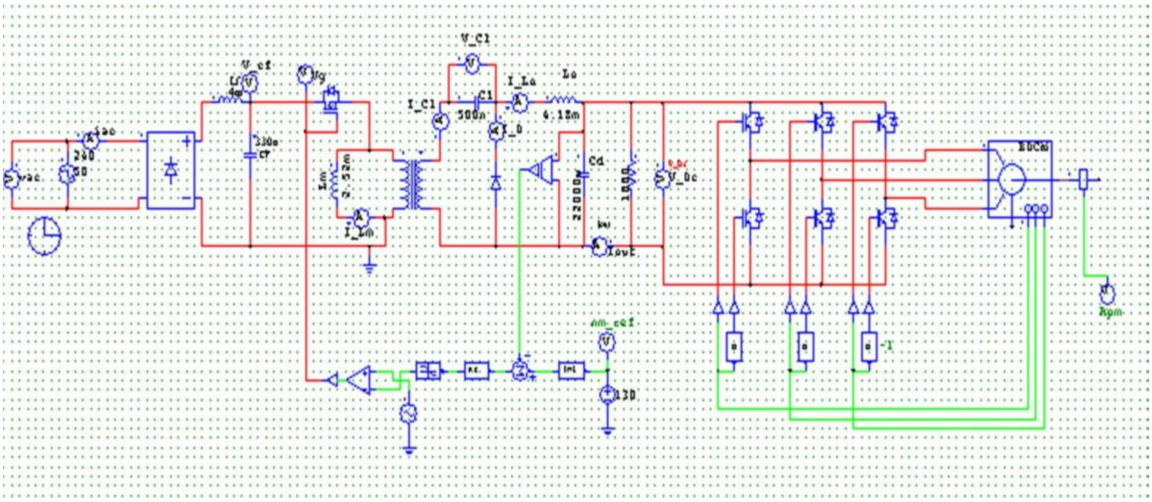

Fig.4 Simulation Diagram

The input supply voltage is taken as 240 V AC, 50Hz. The voltage sensor is sensing the DC link voltage and this voltage is compared with a reference voltage. This is nothing but SPWM. This is the gate signal for the switch.

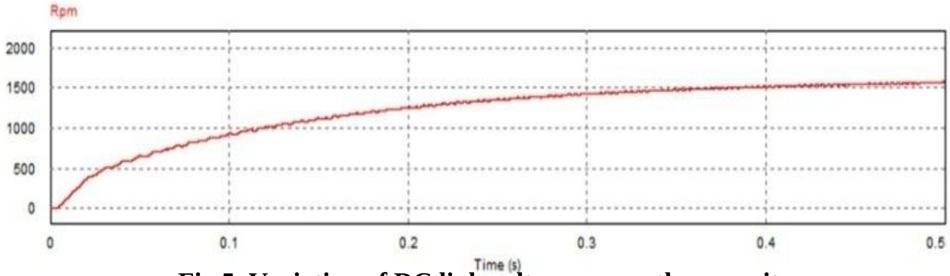

Fig.5 Variation of DC link voltage across the capacitor

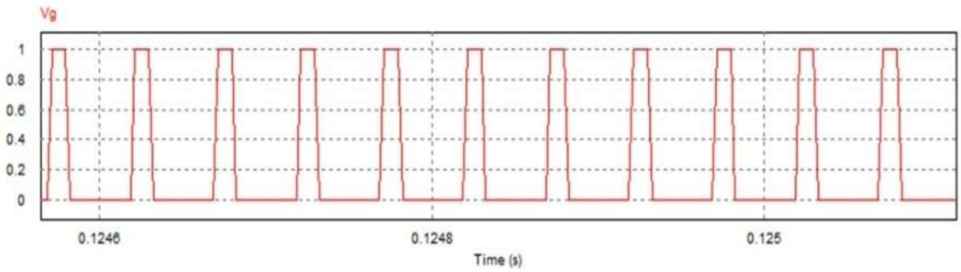

Fig.6 Gate pulse applied to MOSFET

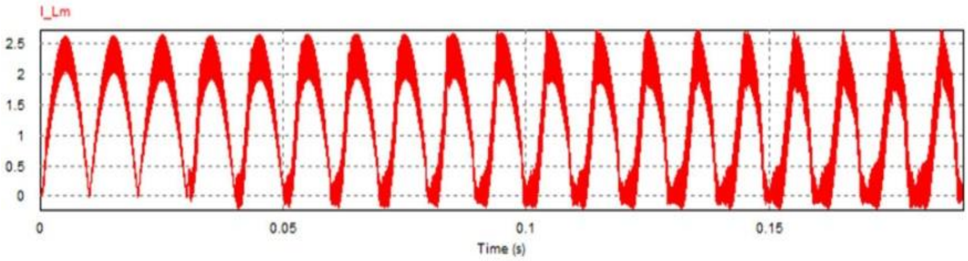

Fig.7 Magnetizing current in high frequency transformer

During an increase in DC bus voltage of the VSI, the magnitude and frequency of the stator current (*ia*) of BLDC motor are increasing which confirms that the motor is gaining speed. Moreover, dynamic behavior of proposed drive during supply voltage fluctuations corresponding to step change in supply voltage (270 V to 200 V) is also noted. A smooth variation of DC link voltage with limited stator current is obtained in all mentioned cases; which demonstrate a satisfactory closed loop performance of this BLDC motor drive

TABLE II: Variation of motor speed with DC link voltage

DC LINK VOLTAGE (V)	SPEED OF BLDC MOTOR(RPM)
50	530
90	1000
130	1440

IV. CONCLUSION

A front-end isolated-Zeta converter operating in DCM has been used for DC link voltage control and with power factor correction at AC mains. Performance of proposed drive has been found quite satisfactory for speed control over a wide range. The performance of this drive system has also been evaluated for varying the voltages and found satisfactory. The power quality indices for the speed control and power factor correction have been obtained within the limits. This model is simulated using PSIM Environment. The gate signal is generated by PIC16F877A microcontroller through programming. It is found that the BLDC motor drive system work satisfactorily for a wide variation of voltage.

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