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PFC BRIDGELESS ZETA CONVERTER-FED BLDC MOTOR DRIVE

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ABSTRACT

Several application of BLDC motors are increasing day by day, with change in technology and improvement of efficiency. This project proposes a novel DC to DC converter topology with reduced ripple content in the output voltage. The output voltage of the DC-DC converter is fed to the VSI (Voltage source inverter) controlling the operation of the BLDC motor using Hall Effect sensors. The control strategy utilizes a speed feedback from the system converts the speed to reference DC voltage values and employs PWM technique to control the output voltage. Normally the BLDC motors fed with diode bridge rectifiers a high value of dc link capacitor draws peaky current which can lead to a high THD of supply current and reduce the PF power factor of motor. By using bridgeless zeta converter power factor is improved and losses associate with the diode bridge rectifier such that conduction losses and switching losses decreases and thermal stability is improved

The total design and analysis is done in MATLAB Simulink with complete graphical representations.

***Keywords*: BLDC MOTOR, VSI (Voltage Source Inverter), Zeta Converter, MATLAB.**

I. INTRODUCTION

The BLDC motor is widely used in applications including appliances, automotive, aerospace, consumer, medical, automated industrial equipment and instrumentation. The BLDC motor is electrically commutated by power switches instead of brushes. Compared with a brushed dc motor or an induction motor, the BLDC motor has many advantages: higher efficiency and reliability, lower acoustic noise, smaller and lighter, greater dynamic response, better speed versus torque characteristics, higher speed range, longer life. These BLDC motors are not limited to household applications, but these are suitable for other applications such as medical equipment, transportation, HVAC, motion control, and many industrial tools [1]–[3].

Single phase ac-dc PFC converters have received much attention due to the dramatic growth in the use of electronic equipment and these ac-dc converters introduce harmonic currents. These harmonic currents cause a lower power factor at the ac mains, voltage distortion and noise [4]-[6]. To comply with harmonic standards and to increase transmission efficiency in power systems, PFC techniques are necessary in ac-dc power converters [5], [6]. Most of the proposed bridgeless PFC converters utilize a boost topology because of its high efficiency, improved power factor, and simple control scheme.

When compared to the boost ac–dc PFC topology, the bridgeless PFC converter solves the heat problem generated by the input bridge rectifier. In addition, current flows through two semiconductor devices during each switching cycle which significantly reduces the total conduction losses. However, the rectifier has the same drawbacks as the boost converter. Furthermore, a complex circuit is needed to sense the current in the MOSFET and diode paths separately, and this topology has the problem of a high start up inrush current [7].

To overcome these constraints, a new single phase bridgeless PFC topology based on Zeta converter is proposed by placing a BLDC motor as load in this paper. The conduction losses are reduced in the proposed converter topology when compare to the conventional PFC converter due to the reduced number of semiconductors in the flowing current path. In addition, a wider operation range (up-and-down voltage conversion) can be achieved. The proposed converter is operated in DCM. Therefore, current loop is not required to shape the input current. As a result, the control circuit is simplified. In addition, the main switch is turned on and the output diode is turned off under zero current switching condition due to the DCM operation.

Furthermore, this converter is capable of protecting itself against overload and inrush current. The proposed rectifier topology utilizes four inductors, which are described as a drawback of the topology. However, implementation of the coupled inductor technique can be used to reduce the magnetic components count.

A BLDC motor when fed by a diode bridge rectifier (DBR) with a high value of dc link capacitor draws peaky current which can lead to a THD of supply current of the order of 65% and power factor as low as 0.8 [8]. Hence, a DBR followed by a power factor corrected (PFC) converter is utilized for improving the power quality at ac mains. Many topologies of the single-stage PFC converter are reported in the literature which has gained importance because of high efficiency as compared to two-stage PFC converters due to low component count and a single switch for dc link voltage control and PFC operation [9], [10].

The choice of mode of operation of a PFC converter is a critical issue because it directly affects the cost and rating of the components used in the PFC converter. The continuous conduction mode (CCM) and discontinuous conduction mode (DCM) are the two modes of operation in which a PFC converter is designed to operate [9], [10].

In CCM, the current in the inductor or the voltage across the intermediate capacitor remains continuous, but it requires the sensing of two voltages (dc link voltage and supply voltage) and input side current for PFC operation, which is not cost-effective. On the other hand, DCM requires a single voltage sensor for dc link voltage control, and inherent PFC is achieved at the ac mains, but at the cost of higher stresses on the PFC converter switch; hence, DCM is preferred for low-power applications [9], [10].

II. CONCEPT OF ZETA CONVERTER

In DC-DC converters the Zeta topology is a lesser known relative of the SEPIC topology. Both converters provide a positive output voltage that can be greater than, equal to or less than V_{IN} while avoiding the complexity and cost of a buck-boost converter.

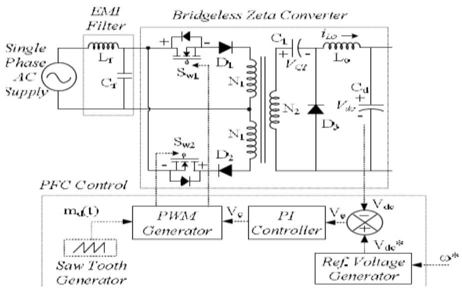

Fig.1: Block Diagram of Zeta Converter.

The Zeta converter however, has the advantage of significantly reduced output ripple voltage below figure represents the basic structure of Zeta converter which is many drive applications.

III. PFC BL ZETA CONVERTER –FED BLDC MOTOR DRIVE

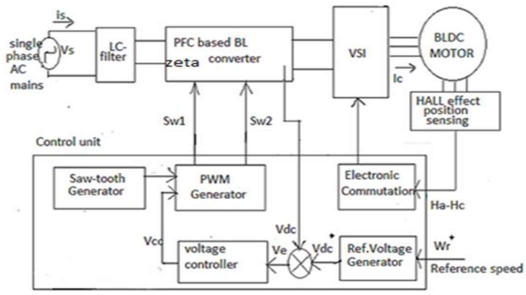

Fig. 2: Block Diagram of PFCbl Zeta Converter –fed BLDC Motor

Single stage PFC converters have gained importance due to simplicity in design and low amount of losses due less count of components Single stage isolated PFC converters use high frequency isolation transformer which is compact in size and thus reducing the space requirement of the PFC converter and provides isolation between input and output Bridgeless converters have gained importance due to elimination of DBR at the input which consequently reduce the conduction losses of diodes and thus improve the overall efficiency of the converter . Elimination of two diodes or complete elimination of diodes In a DBR depend support configuration of the converter. A bridgeless topology utilizing SEPIC and Cuk converter have been widely used for the development of the PFC converter with improved power quality at the AC mains .An isolated Zeta converter operating in CCM (Continuous Conduction Mode) or DCM (Discontinuous Conduction Mode) is widely used for PFC applications . DCM is preferred for low and medium power applications because it utilizes an approach of voltage follower which requires a single voltage sensor for DC link voltage control and PFC operation.

IV. SYSTEM CONFIGURATIONS

CCM uses a current multiplier technique, which requires three sensors (one current and two voltage sensors) for operation and thus increases the overall cost of drive system. This paper explores the potential of Zeta converter for BLDC motor drive targeting special class of applications.

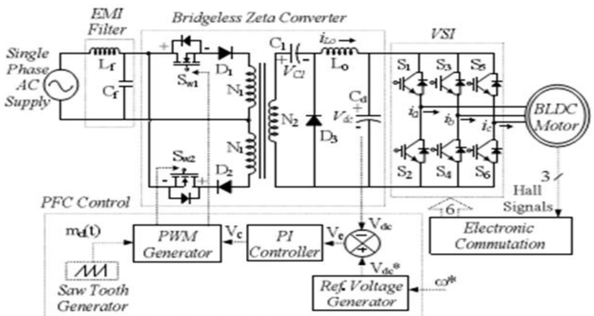

Fig.3: Bridgeless Zeta Converter fed BLDC Motor Drive

Moreover, possibilities of employing a bridgeless configuration in Zeta converter are still unexplored. The drive system is needed to be developed which must incorporate features like low cost, high efficiency and satisfactory performance with improved power quality at the AC mains for a wide range of speed control. This work is targeted to achieve all these objectives in the proposed drive.

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V. OPERATION OF BRIDGELESS ZETA CONVERTER

A bridgeless topology is designed such that two switches conduct independently for the positive and negative half cycle of the supply voltage. The conduction losses of the DBR are reduced to half as compared to conventional topology due to the bridgeless configuration. Moreover, this also improves the thermal utilization of switches since switch rms current is divided into two switches.

i) Operation during Complete Cycle of Supply Voltage:

In this switch Sw1 and diode D1 (fig.3) conduct for the positive half cycle of the supply voltage and diode D2 remains reversed biased during this period. Similarly for the negative half cycle of the supply voltage, switch Sw2 and diode D2 conduct and no current flows through switch Sw1 and diode D1.

The energy is transferred through HFT (High Frequency Transformer) which turns ratio is given as N1:N1:N2. The magnetizing inductance (Lm) is designed to operate in DCM such that a discontinuous conduction is achieved for a wide range of DC link voltage control to achieve an inherent power factor correction.

ii) Operation during Complete Switching Cycle:

In this switch Sw_1 is on (Fig.3), the energy is stored in the HFT, intermediate capacitor C_1 and inductor L_o; whereas DC link capacitor C_d supplies the required energy to the load. When switch is turned off, the HFT discharges through Diode D and inductor Lo supplies the required energy to the DC link capacitor.

In the DCM mode the HFT is completely discharged, whereas inductor L_o continues to supply the required energy to the DC link capacitor.

VI. CONTROL OF BLDC MOTOR: ELECTRONIC COMMUTATION

An electronic commutation of the BLDC motor includes the proper switching of VSI in such a way that a symmetrical dc current is drawn from the dc link capacitor for 120◦ and placed symmetrically at the centre 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 the BLDC motor.

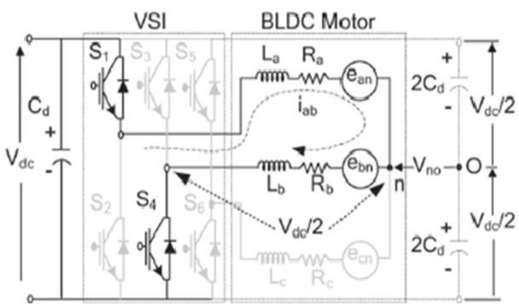


Figure 3: Operation of a VSI-fed BLDC Motor When Switchs S1 and S4 are Conducting

The conduction states of two switches (*S*1 and *S*4) are shown in Fig. 3. A line current *i*ab is drawn from the dc link capacitor, whose magnitude depends on the applied dc link voltage (*V*dc),

Table 3.1 Switching States for Achieving Electronic Commutation of BLDC Motor Based on Hall- Effect Position Signals

$\theta\,(^0)$	Hall Signals			Switching States					
	H_a	H_b	H_c	S_1	S_2	S_3	S_4	S_5	S_6
NA	0	0	0	0	0	0	0	0	0
0-60	0	0	1	1	0	0	0	0	1
60-120	0	1	0	0	1	1	0	0	0
120-180	0	1	1	0	0	1	0	0	1
180-240	1	0	0	0	0	0	1	1	0
240-300	1	0	1	1	0	0	1	0	0
300-360	1	1	0	0	1	0	0	1	0
NA	1	1	1	0	0	0	0	0	0

Back electromotive forces (EMFs) (*e*an and *e*bn), resistances (*Ra* and *Rb*), and self inductance and mutual inductance (*La*, *Lb*, and M) of the stator windings. Table II shows the different switching states of the VSI feeding a BLDC motor based on the Hall-effect position signals ($Ha - Hc$).

VII. DESIGN OF BRIDGELESS ZETA CONVERTER FED BLDC MOTOR DRIVE

The input voltage Vs is given as

$$Vs = V_m \sin(2\pi f_L t) = 311 \sin(341t) \text{..........................(1)}$$

Where V m is peak input voltage, fLis line frequency i.e. 50 Hz.

The input average voltage is given as

$$Vin = \frac{2V_m}{\pi} = \frac{2*311}{\pi} = 197.96V \approx 198V \text{.........(2)}$$

The output voltage, Vdc of isolated Zeta converter is given as

$$V_{dc} = \left(\frac{N2}{N1}\right)\frac{D}{1-D}V_{in} \text{..(3)}$$

where D is the duty ratio. From above equation, duty ratio D is calculated as,

$$D = \frac{V_{dc}}{V_{dc}+(N2/N1)Vin} = \frac{130}{130+0.5*198} = 0.5677$$

The value of equivalent load resistance (RL) is calculated as,

$$R_L = \frac{{V_{dc}}^2}{P_O} = \frac{130^2}{500} = 33.8\ \Omega$$

The critical value of magnetizing inductance Lm (critical) of HFT to operate at boundary of CCM and DCM is given as

$$L_{mc} = \frac{RL(1-D)^2}{2Dfs\left(\frac{N2}{N1}\right)^2} = \frac{33.8*(1-0.5677)^2}{2*0.5677*45000*0.5^2}$$

$$L_{mc} = 494.52\ \mu H$$

The value of magnetizing inductance Lm is selected such that,

$$L_m << L_{mc}$$

Hence from above equation, the value of Lm is selected as 300µH for its operation in DCM.

The value of output inductor Lo is calculated as

$$L_o = \frac{V_O}{fs\Delta i\,Lo} = \frac{130*(1-0.5677)}{45000*0.1*3.486} = 3.247\ mH$$

Hence a value of 3.3mH is selected for output inductor Lo.

The value of intermediate capacitor C1 is given and calculated as ,

$C_1 = \frac{Vdc\ D}{\Delta V\ Cin\ RLfs} = \frac{Vdc\ D}{Vm\ RL\ fs} = \frac{130*0.5677}{311*33.8*45000}$=156 nF

The value of intermediate capacitor is selected as 150nF.

The value of DC link capacitor is given and calculated as

$C_d = \frac{Idc}{2\omega L \Delta Vdc} = \frac{3.846}{2*314*0.02*130}$= 2355.55 µF

Hence the value of DC link capacitor is selected as 2200µF.

An EMI filter is designed to avoid the reflection of high switching frequency in the supply system.

The maximum value of filter capacitance C_m axis given and calculated as

$$C_{max} = \frac{Ipeak}{\omega L\ peak}\tan(\theta) = \frac{\frac{500\sqrt{2}}{220}}{314*311}\tan(1^0) = 574.5\ \text{nF}$$

Where I_{peak} is the peak input current, V_{peak} is the peak input voltage and θ is the displacement angle. The value of filter capacitance C_f is selected such that C_f is lower than C_{max}; hence the value of C_f is selected as 330nF

The expression for the calculation of filter inductance Lf is given as

$$L_f = \frac{1}{4\pi^2 fc^2 Cf} = \frac{1}{4\pi^2 * 4500 * 330 * 10^{-9}} = 3.76\ \text{Mh}$$

Where f_c is the cut-off frequency such that $f_c = f_s/10$. Hence the filter inductance is selected as 4mH.

VIII. SIMULATION CIRCUIT OF PFC BRIDGELESS ZETA CONVERTER FED BLDC MOTOR DRIVE

BL Zeta is a dc-dc converter similar to BL buck-boost the below shown fig 4 &4.1 represents the matlab simulation circuit of PFC BL zeta converter fed BLDC motor drive. In this circuit shows the performance of BLDC motor, motor speed is directly proportional to voltage of dc link capacitor.

VSI (voltage source inverter) is used to supply the voltage to the motor by means of electronic commutation. In frontend the BL zeta converter is operated as both PFC and ac-dc converter.

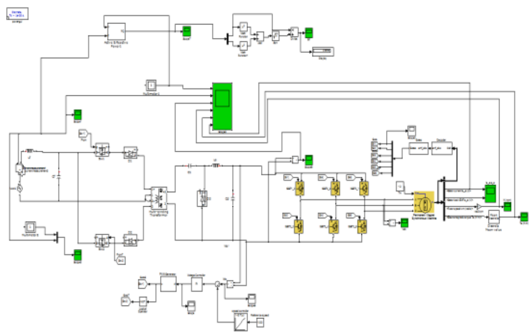


Fig.4: Simulation Circuit of PFC Zeta Converter

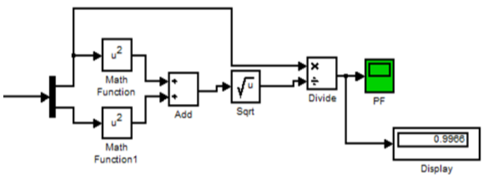


Fig.4.1: Power Factor at Speed 1200 RPM

The switches s1 and s2 of BL buck-boost converter are operated independently for positive and negative half cycles of supply voltage. Then the output voltage of buck-boost converter is greater than or less then to input voltage. The speed control of BLDC motor is obtained by voltage follower approach. As per our speed requirement the output voltage of BL buck-boost converter is changed. By sensing the output voltage of the BL buck-boost converter and comparing with reference voltage, then remaining voltage is again fed to switches by using the PWM technique. By this speed control of motor the performance of the converter can be achieved.

IX. SIMULATED STEADY-STATE PERFORMANCE OF BLDC MOTOR DRIVE USING PFC BL ZETA CONVERTER

The performance evaluation of BLDC motor drive is categorized in terms of the performance of the BLDC motor motor and BL Zeta converter and achived power quality indicesatacmains.The parameters such as speed (N),torque (Te), source voltage(Vs),sourec current (Is) are determined, demonstated proper funtioning of BLDC motor.

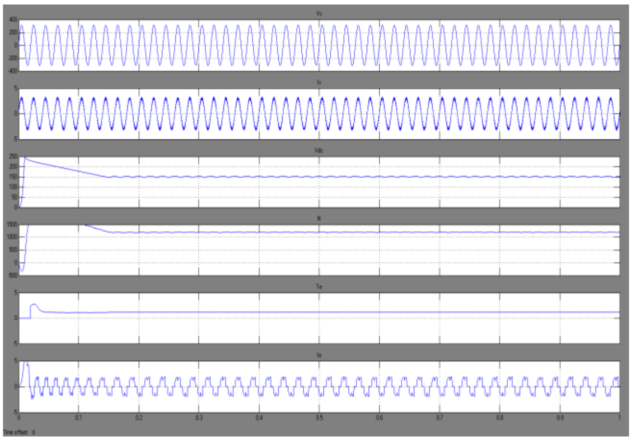


Fig.5: Steady- State Performance of BLDC Motor at Rated Condition

X. SIMULATED DYNAMIC PERFORMANCE OF BLDC MOTOR UNDER SPEED CONTROL

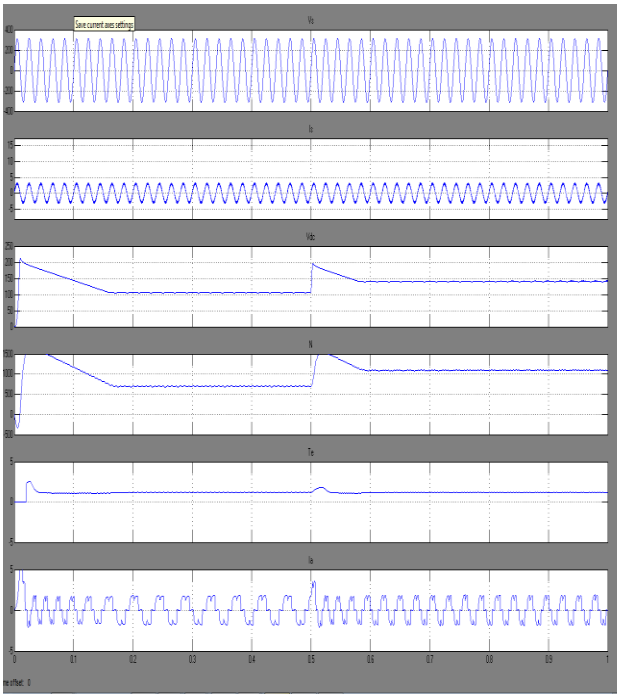
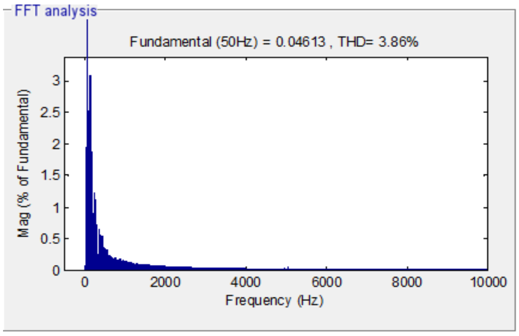
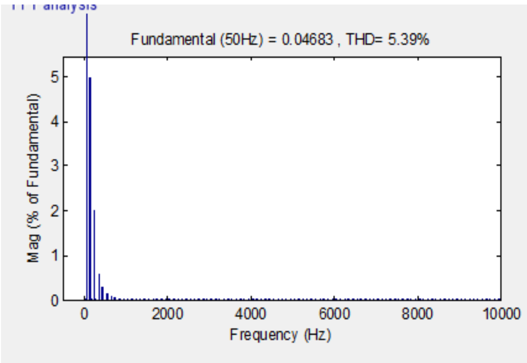


Fig.6: Dynamic Performance of BLDC Motor During Speed Control with BL Zeta Converter

5.5 % Thd Values of Source Current (Is) in Bl Buck-Boost Converter



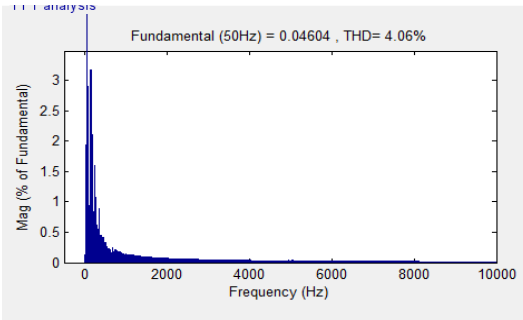
(a)



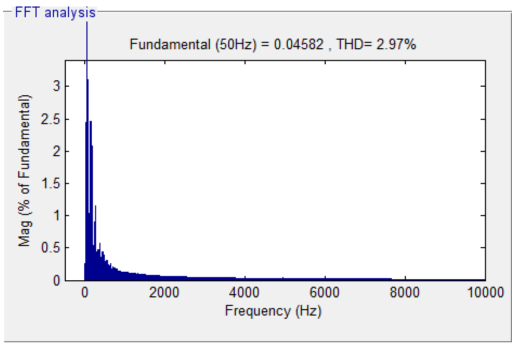
(b)

Fig.7:Harmonic Spectra of Supply Current at Rated Supply Voltage and Rated Loading on BLDC Motor for a DC Link Voltage of (a) 200v and (b)70v (BL Buck-Boost)

5.6 % Thd Values of Source Current (Is) in Bl Zeta Converter



(a)



(b)

Fig.8: Harmonic Spectra of Supply Current at Rated Supply Voltage and Rated Loading on BLDC Motor for a Dc Link Voltage of (a) 70v and (b)200v(BL Zeta).

XI. CONCLUSION

The performance and analysis of BLDC motor with BL zeta converter is an effective cost solution for low and medium power applications. A new method of speed control has been utilized by controlling the voltage at dc bus and operating the VSI at fundamental frequency for electronic commutation of BLDC motor for reducing switching losses. The steady –state and dynamic performance of BLDC motor analysed by comparing with BL Buck-boost converter fed BLDC motor drive. Power factor is almost same in topologies. The transient and ripple content of output wave forms decreases in BL Zeta converter topology.

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