ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 3, March 2017

Zeta Converter Fed Brushless DC Motor for Power Factor Correction and Speed Control

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ABSTRACT: Usages of commutation less motors have been increasing in various applications and to save the energy consumption of devices, it leads to the development of Permanent Magnet Brushless DC Motor (PMBLDCM). To improve the power factor and speed control in such motors Zeta converter is used. Both the Power Factor Correction (PFC) and voltage regulation are done in a single stage process operating in a Continuous Conduction Mode. Naturally it has an isolated structure and can operate as both bucking and boosting voltage converter. Speed control of PMBLDC motor can be achieved by controlling the voltage of the DC link capacitor. It eliminates the torque ripples and controls the speed of the Permanent Magnet Brushless DC (PMBLDC) motor.

KEYWORDS: BLDC motor, power factor correction, speed control, zeta converter, continuous conduction mode.

I. INTRODUCTION

Brushless DC motors find more increasingly in many applications. Some limitations of brushed DC motors can be overcome by brushless DC motor. They include high efficiency, lower susceptibility of the commutator assembly to mechanical wear. BLDC motors are more popular for their high energy, high efficiency, high torque, inertia, variable speed and low electromagnetic interference. It attracts a distorted current from AC mains because of uncontrolled charging and discharging of the dc link capacitor and has a terribly high Total Harmonic Distortion (THD) within the order of 65%–70% that results in a poor Power Factor (PF) within the order of 0.7–0.72 at AC mains. Another major drawback in such drive is that the price of current sensors, which is needed for current management and speed management. The speed is controlled by varying the dc link voltage of VSI. This reduces the switching losses of VSI and eliminates the need of current sensors for PWM-based current management of BLDC motor for speed control.

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 for voltage regulation which can be any converter topology depending upon the requirement. This two-stage topology is complex, results in higher cost and more losses. Hence a single stage Zeta converter is proposed which is used for DC link voltage control, power factor correction and bucking and boosting the voltage. It is a naturally isolated structure. ZETA converter is designed to control using a PI controller and the corresponding output response is simulated using MATLAB software. Also, the response of ZETA converter, when it is subjected to line and load variations is simulated. The proposed idea presents the study of the Zeta converter operating in continuous conduction mode for power factor correction.

II. PROPOSED SYSTEM

The proposed system can be simulated with the help of the following block diagram. An input supply of AC is rectified using diode bridge rectifier and fed to the Zeta converter. The rectified dc is given to voltage source inverter. Inverted AC supply is given to the Brushless DC Motor. The gate pulse to the MOSFET switches is fed from the driver circuit. The PIC microcontroller is programmed to control the speed of the BLDC motor to the reference speed.

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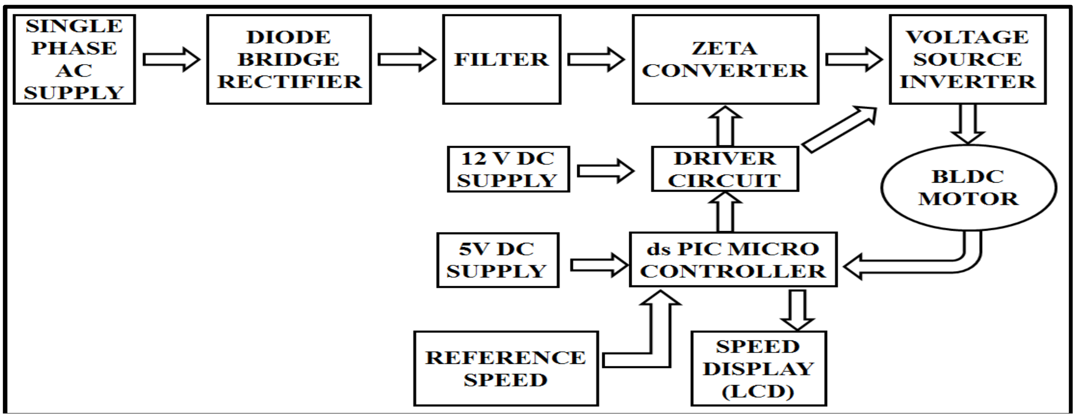

Fig.1 Block Diagram

III. ZETA CONVERTER

The ZETA Converter is the heart of the proposed system, which rectifies and improves the power quality of the entire system. The zeta converter block consists of input supply of 18V which is fed from step down transformer of 230/18V. The diode bridge rectifier rectifies the input AC supply to DC supply. The DC output of the Diode Bridge Rectifier (DBR) is fed to the Zeta converter circuit. The DC supply from DBR has some ripples which are being eliminated by the low pass filter C_f in Zeta converter. Thus, eliminating harmonic distortion in the circuit.
The MOSFET acts as a switch here, the gate signals for the MOSFET are given from the driver circuit using Pulse Width Modulation method. In Zeta converter, three modes of operation take place based on the MOSFET switch S1.

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 (L_o) through the intermediate capacitor C_1. The current in the output inductor (i_{Lo}) and input inductor (i_{L1}) increase linearly. The intermediate capacitor voltage (V_{c1}) and the output DC-link capacitor voltage (V_{dc}) are considered constant in this stage. They are equal to the DC voltage (Vdc).

MODE II:

In the second stage, switch S_1 is turned off and diode D1 starts conducting. The stored energy from output inductance (L_o) and the input inductance (L_1) are transferred to the intermediate capacitor C_1 and the DC link capacitor filter (C_{dc}), 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 D1 is in on stage.

MODE III:

This freewheeling stage lasts until the start of a new switching period. In this stage of operation neither output diode D1 nor switch S_1 conducts. The voltage applied across inductances L_o and L_1 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 t_{off} time. Therefore, in this stage the current through the output diode is zero.
Thus, a non-pulsating and boosted DC output is derived from the converter which is again filtered at the capacitor filter C_{dc}. The output DC supply is fed to the motor through the voltage source inverter circuit.

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IV. DESIGN OF ZETA CONVERTER

The parameters that are associated with the design calculation of zeta converter are as follows.

Duty Cycle Calculation (D)

Duty Cycle $= V_{out} / (V_{out} + V_{in})$
$= 30 / (30 + 18)$
Duty Cycle $= 0.63$ or 63 %

Maximum Input Current ($I_{in(max)}$)

$I_{in\ (max)} = I_{out} * (\text{Duty cycle} / (1 - \text{Duty cycle}))$
$= 1\ A * (0.63 / (1 - 0.63)$
$I_{in\ (max)} = 1\ A * 1.7 = 1.7\ A$

Desired Ripple Current (ΔI_L)

$\Delta I_L = K * I_{in}$
$= 0.2 * 1.7 = 0.34\ A$

Inductance Value (L)

$L = (V_{in} * D) / (2 * \Delta I_L * f_{sw})$
Switching Frequency $(f_{sw}) = 5KHz$
$= (18 * 0.63) / (2 * 0.34 * 5*10^3)$
$L = 0.1\ mH$

Capacitance Value (C)

$C = I / (2\square * f * V)$
$= 1.7 / (2\square * 50 * 18)$
$\approx 300 \mu F$
$C = 1000 \mu F$

V. SIMULATION MODULE

The simulation is done using MATLAB Simulink and the results are discussed in detail. To monitor the power factor and to control speed, simulation is done. The entire zeta converter module and its controller module feeding the Brushless DC motor is simulated and shown in the Fig.2

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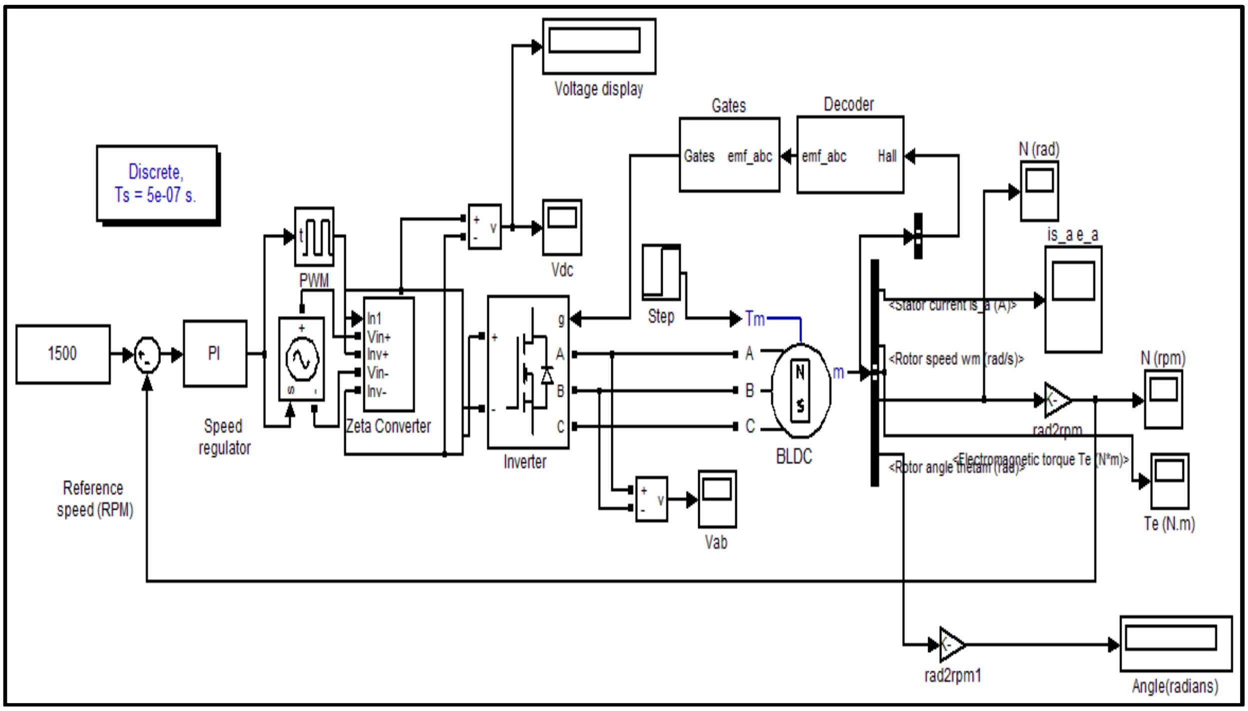

Fig.2 Simulation Diagram

VI. ZETA CONVERTER MODULE

The ZETA Converter is the heart of the proposed system which rectifies the power factor and improves the power quality of the entire system. The inner view of the zeta converter module is shown in the Fig.3. In this Port 1 and 3 acts as the input pin supplying input voltage of 12V to the Zeta converter circuit. The inductor and capacitor value remains the same as calculated in designing. The gate signal to the MOSFET switch is fed from the Pulse Width Modulation unit. The operation takes place in three modes of operation. The input dc ripples are eliminated by the capacitor C and output ripples by the C_2 capacitor. Providing an elimination of ripples and reducing the total harmonic distortion amount in the circuit. The boosted and non-pulsating DC voltage is taken from the Port 2 and 4 to the Voltage Source Inverter circuit.

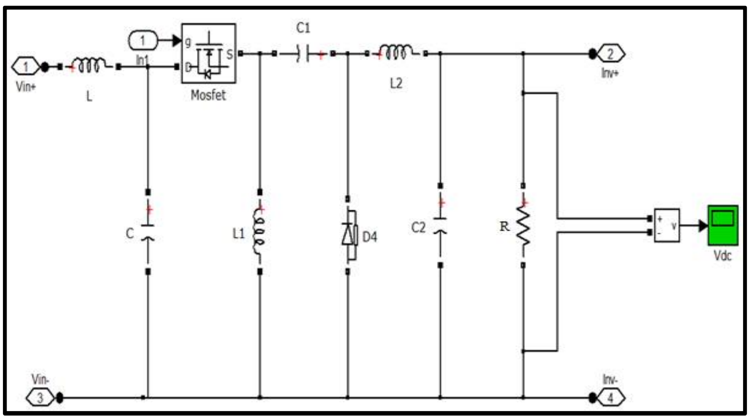

Fig.3 ZETA Converter Simulation Circuit

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VI. SIMULATION RESULTS

The simulation module of the proposed system is evaluated to get the estimated outputs. They include rated torque, rated speed, and power factor.

Performance of the proposed Brushless DC Motor drive under speed control at 220-vinput AC voltage

The Table 1 shows the simulated performance of the proposed system module simulated using MATLAB Simulink. The DC link voltage (V_{dc}) is set and their corresponding set speed is tabulated with the obtained power factor for the input of 220V AC voltage.
The performance of the BLDC Motor is tabulated. With the increasing DC link voltage (V_{dc}) and speed of the motor, the power factor increases and maintains nearly to Unity Power Factor (UPF).

Table 1 Performance of BLDC at 220V AC

DC LINK VOLTAGE (V_{DC})	SPEED (RPM)	POWER FACTOR (PF)
152	1400	0.947217
180	1700	0.960406
205	2000	0.965479
230	2150	0.962827
252	2350	0.968745
285	2650	0.975680
300	2900	0.972350

Performance of the proposed Brushless DC Motor drive under speed control at 30-v input AC voltage

The Table 2 shows the simulated performance of the proposed system module simulated using MATLAB Simulink. The DC link voltage (V_{dc}) is set and their corresponding set speed is tabulated with the obtained power factor for the input of 30V AC voltage.
As the DC Link voltage (V_{dc}) increases the speed of the motor increases with the power factor increasing and maintaining nearly to Unity Power Factor (UPF).

Table 2 Performance of BLDC at 30V AC

DC LINK VOLTAGE (V_{DC})	SPEED (RPM)	POWER FACTOR (PF)
16.7	1200	0.85
18.9	1600	0.87
21.2	2200	0.88
22.7	2350	0.91
23.6	2550	0.92
24.5	2700	0.92
26.2	2950	0.93

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Simulated Torque Output

The torque ripple is eliminated and clearly shown in the Fig.4. It shows the torque which remains constant throughout the operation. Torque ripple occurs just for a 0.1 sec due to the inrush of current.

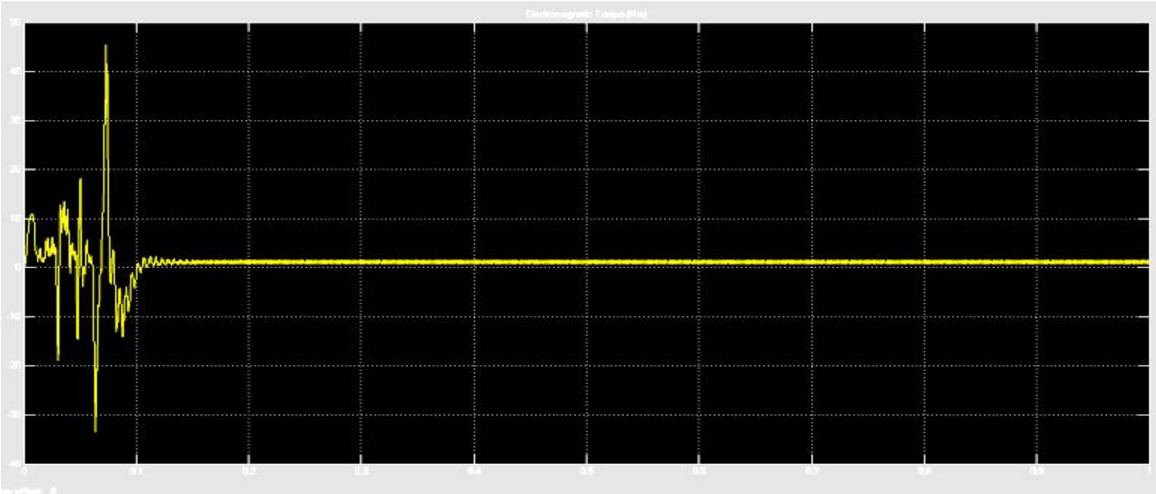

Fig.4Simulated Torque Output

Simulated Speed Output

The reference speed is set as 1500 rpm. From the simulation output received output of 1500 rpm of the brushless dc motor is shown in the Fig.5.

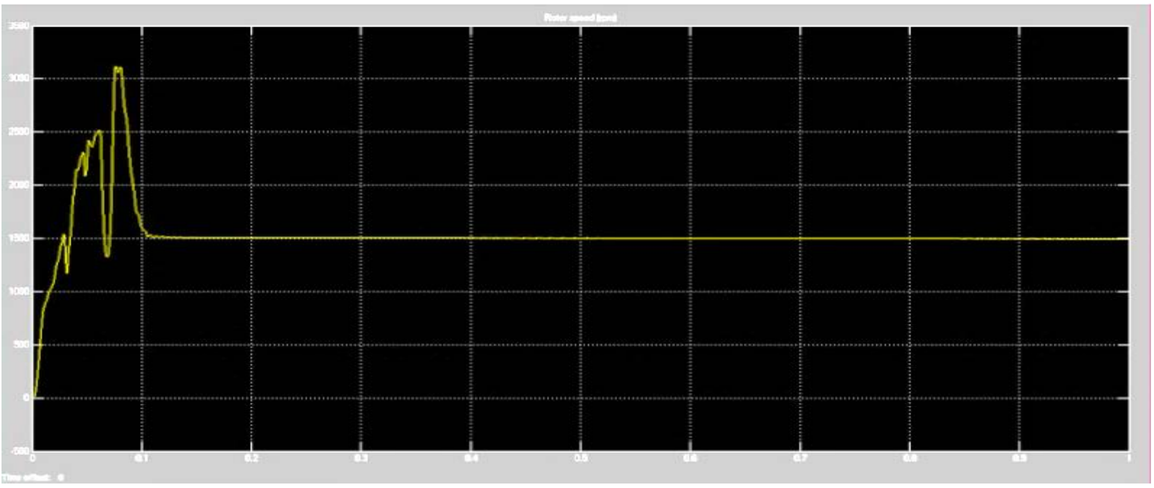

Fig.5 Simulated Speed Output

Power Factor Result

From the simulation module of the proposed system obtained the degree value of 2.795. The power factor is calculated using the formula,

$$\text{Power factor} = \cos \Phi$$
$$\text{Power factor} = \cos (2.795)$$

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Power factor =0.9988

The Fig.6 shows the power factor output of degree angle (2.795).

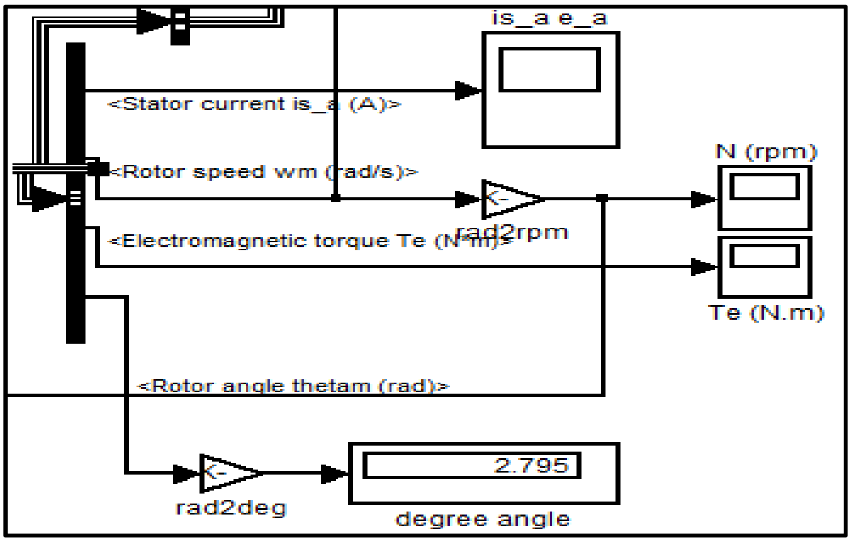

Fig.6 Power Factor Output

VII. CONCLUSION

Thus, the improvement of Power factor correction and the control of speed have been achieved for the BLDC motor using the simulation. The performance of the proposed system is also being evaluated for varying input ac voltages. The issues incorporated with the power quality systems have been mitigated**.** It is inferred from the Table 1 and 2 that, the improved power factor of about 0.95 which is nearly to unity power factor. The power factor increases along with the speed of the motor which results in the improved power quality of the system.

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