Open access Journal International journal of Emerging Trends in Science and Technology

A PFC Zeta Converter for Speed Control of PMBLDC Motor Drive

Authors

K.S. Geerthiga[1], D.Kavitha[2]

[1](M.E.) Power Electronics and Drives, Scholar,
[2]Asst. Professor
Electrical and Electronics Engineering Department, Sri Venkateshwara Engineering College
Sriperumpudur , India
Email: *geeraueee@gmail.com*

Abstract
This paper presents a Zeta DC-DC converter as a power factor correction (PFC) converter which is operated in voltage control mode for speed control of a permanent magnet brushless DC motor (PMBLDCM). The proposed converter performs the PFC action and DC link voltage control in single stage and needs only one controller. The proposed PMBLDCM drive (PMBLDCMD) is designed and modeled, and its performance is evaluated in PSIM environment. Simulated results are presented to demonstrate an improved power quality at ac mains of the PMBLDCM system in a wide range of speed and input ac voltage. Test results of a developed controller are also presented to validate the design and model of the drive.

Index Terms— *Power factor correction PFC, Permanent magnet (PM) brushless dc motor (PMBLDCM) ,Zeta converter, voltage – source inverter (VSI), voltage control.*

I.INTRODUCTION

International concern of power quality (PQ) problems and pollution has prompted the use of power factor correction converters with a permanent magnet brushlessDC motors (PMBLDCM) for numerous low power applications. Since, the Brushless DC motor is the ideal choice for the applications that require high reliability, high efficiency, low maintainence and high power-to-volume ratio [1] – [4]. Since it does not have any brushes to wear out and replace, generally speaking , BLDC motor is considered to be a high performance motor that is capable of providing large amounts of torque and speed performance curve characteristics. When operated in rated conditions, the life expectancy is over 10000 hours. For long term applications, this can be a tremendous benefit. These PMBLDCMs are fed from single phase AC mains through diode bridge rectifier (DBR) followed by a DC capacitor. However this will results in pulsed AC current which will affect the power factor results in power quality disturbances(PQ). This is due to uncontrolled charging of the DC capacitor leading to peak value higher than the amplitude of the fundamental input current at AC mains. In order to drive the PMBLDC motor with power quality improvement it needs PFC converter topology among various available topologies [5],[6].

The basic DC-DC converter topologies [5],[6] using Buck – converter , Boost converter and Buck - Boost converter have their intrinsic limitations when used for active power factor correction along with voltage regulation purposes .In common PFC converters a front end boost converter for PFC and a flyback or forward converter as second state for voltage control. Among the new classes of DC-DC converters CUK, SEPIC and Zeta, in the proposed model a Zeta converter is used for active PFC and voltage regulation having advantages of being naturally isolated structure, can operate as both step up/ down voltage converter and having only one stage processing for both voltage regulation and PFC has reported in literature [7-9] .

A Zeta converter is a fourth order non linear system performs a non-inverting buck-boost function. But in application which implies high power, the operation of a converter in discontinuous mode is not attractive because it results in high rms values of the current causing high levels of stress in the semiconductors. In this paper, an active power factor correction PFC is performed by using a Zeta converter operating in continuous conduction mode (CCM),where the inductor current must follow a sinusoidal voltage waveform. This method provides nearly unity power factor with low THD. The proposed model improves the power factor and wide range of speed control of PMBLDC motor drive.

II. PROPOSED PFC CONVERTER OF PMBLDC MOTOR

Fig.1 shows the proposed scheme of speed control via voltage control of dc link voltage as an equivalent to reference speed. The PMBLDC motor rotor position signals are sensed by Hall-effect sensors which is used by electronic commutator to generate switching sequence for the VSI feeding the PMBLDC motor. The Zeta DC-DC converter controls the dc link voltage using capacitive energy transfer by controlling duty cycle (D) of the zeta converter. For fast control and high switching frequency is used , Metal oxide field effect transistors (MOSFET) is employed as the switching device. The VSI fed PMBLDC motor uses switching device as IGBTs to reduce the switching stress, as

it operates at lower switching frequency compared to PFC switch.

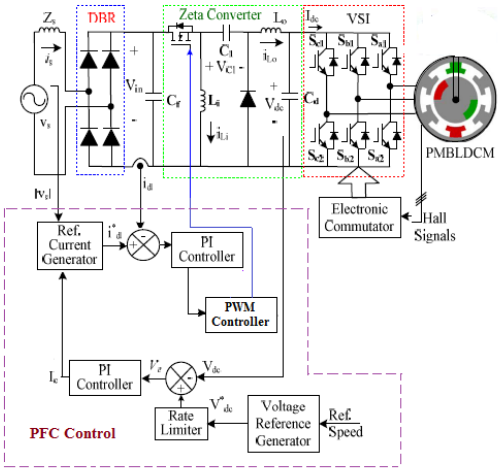

Fig.1 Proposed Zeta converter for PMBLDC motor drive

In the proposed topology the feedback loop consists of current multiplier approach with current control loop inside the speed control loop for continuous–conduction–mode operation of the converter. The control loop starts with comparing sensed DC link voltage (V_{dc}) and reference voltage (V_{dc}^*) equivalent to the reference speed gives voltage error (V_e). This voltage error (V_e) through a proportional-Integral controller(PI) gives the modulating control signal I_c. This signal I_c is multiplied with unit template of ac voltage to give the reference input current(I_d^*). This reference current (I_d^*) is compared with actual input current (I_d) which is sensed after the DBR. The obtained current error (I_e) is passes through another Proportional-Integral controller(PI). The resultant current error is amplified and compared with saw tooth carrier wave of fixed frequency (f_s) to generate pulse width modulation PWM pulse for the MOSFET of the Zeta converter. For the control of current to PMBLDCM through VSI during the step change of the reference voltage due to the change in the reference speed, a rate limiter is introduced, which limits the stator current of the PMBLDCM within the specified value.

III. DESIGN OF PFC CONVERTER BASED PMBLDCM DRIVE

The proposed PFC Zeta converter is designed for a PMBLDCM drive with main considerations on the speed control of the motor drive and power factor correction of the ac mains. The design equations for DC link voltage of the PFC converter (Vdc), intermediate inductor (Li) and capacitor (C1), filter inductor (Lo) and capacitor (Cd) are summarized below.

The PFC zeta converter is designed for PMBLDC motor on the basis of speed control via dc link voltage is taken as consideration for power factor improvement at ac mains The dc link voltage of the PFC converter is given as

$$V_{dc} = V_{in}\, D/(1-D) \qquad (1)$$

Where V_{in} is the average output voltage of DBR for a given ac input voltage (V_s) which is calculated as,

$$V_s = V_{in}\, \pi /2\sqrt{2} \qquad (2)$$

The zeta converter has boost inductor (L_i) and a capacitor (C_1) for energy transfer and their equation can be written as ,

$$Li = D\ Vin\ /\ fs(\Delta\ ILi) \qquad (3)$$

$$C1 = Idc\ /\ (2\ \omega\ \Delta Vcd) \qquad (4)$$

Where ΔI_{Li} is specified inductor current ripple, ΔV_{c1} is a specified voltage ripple in the intermediate capacitor (C_1) and I_{dc} is the current drawn by the PMBLDCM from the dc link.

To obtain a ripple free voltage at the dc link of Zeta converter ripple filter is designed as ripple inductance L_0 and ripple capacitance (C_d) which is given by the equation given below,

$$L_0 = (1\text{-}D)\ V_{dc}/\{f_s(\Delta I_{L0})\} \qquad (5)$$

$$C_d = I_{dc}\ /\ (2\ \omega \Delta V_{cd}) \qquad (6)$$

Where ΔI_{L0} is filter inductor peak-to-peak ripple;e current and ΔV_{cd} is ripple voltage of the filter capacitor.

Therefore the PFC converter is designed for a base DC link voltage of Vd c=298V at Vs=220V for fs =40kHz, Is = 4.12A, specified input inductor current ripple ΔILi =0.82A (20% of Idc), Idc =3.5A, peak to peak filter inductor ripple current ΔILo =3.5A (?Idc), ripple in the DC link voltage ΔVCd =5.96V (2% of Vdc), voltage ripple in the intermediate capacitor ΔVC1 =220V (?Vs). The design values are obtained as Li =3.6 mH, C1 =239nF, Lo =0.85 mH, Cd =935μF.

IV. PERFORMANCE EVALUATION OF PMBLDC MOTOR DRIVE

The performance of the Open loop Zeta converter without PFC control, driving PMBLDC motor is simulated using PSIM software.

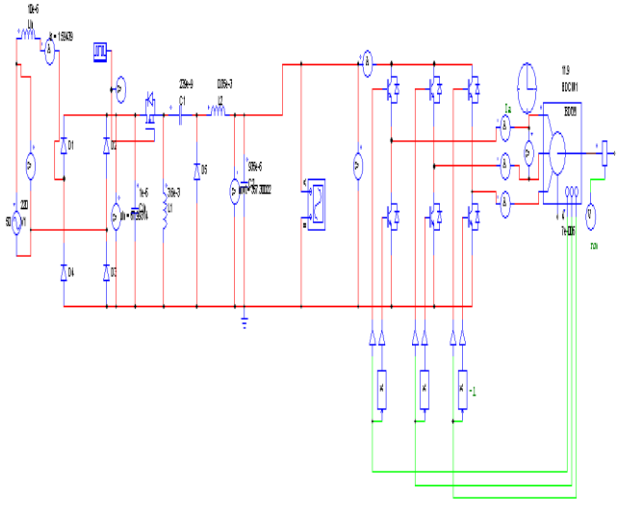

Fig.2 Open loop Zeta converter for PMBLDC motor drive

At AC mains voltage of 220V , 50Hz supply , the zeta converter gives the output dc link voltage of 308V, Speed 2900 rpm with a duty cycle of 0.6. The output voltage and speed waveform is shown in fig.3

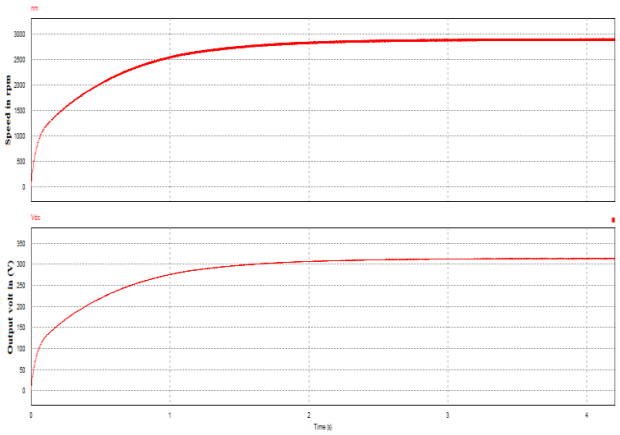

Fig.3 Output voltage and speed waveform

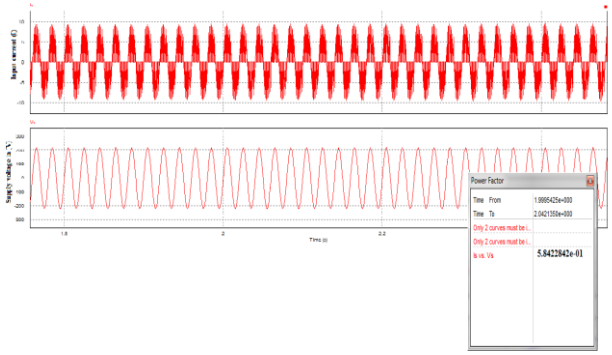

Fig.4 Input current and Input voltage Waveform

Therefore in open loop PFC Zeta converter for PMBLDC drive , from the above fig.4, it is clear that input current and input voltage waveform PF is very low(0.58).As we know already this will reduces the power quality of the system. So in order to make the PMBLDC motor speed and voltage as a controllable one and make the power quality improvement PFC control block is added in the feedback loop to obtain optimum performance of the PMBLDC motor with PFC Zeta converter.

The Proposed PMBLDC drive with the combination of PFC converter is simulated in PSIM software is shown in fig.5

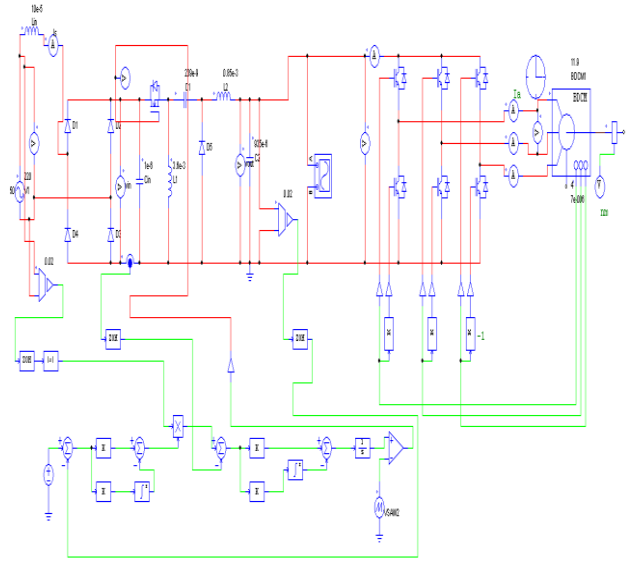

Fig.5 Closed loop Zeta converter for PMBLDC motor drive

A. In closed loop PFC zeta converter for PMBLDC motor, the input AC voltage is set at 220V, 50Hz and the power factor is improved to 0.96 and the output voltage is maintained at 298V by controlling duty cycle of MOSFET switch of zeta converter by PWM controller and PI controller as 0.6. The speed of PMBLDC motor is 2800rpm at 298V which is shown in fig.6

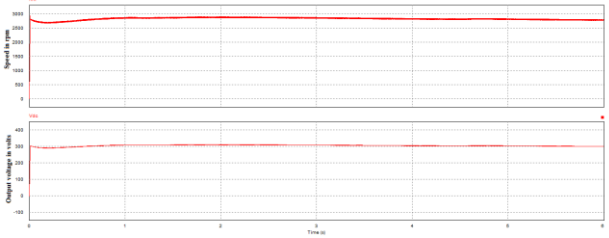

Fig.6 Output voltage and speed waveform

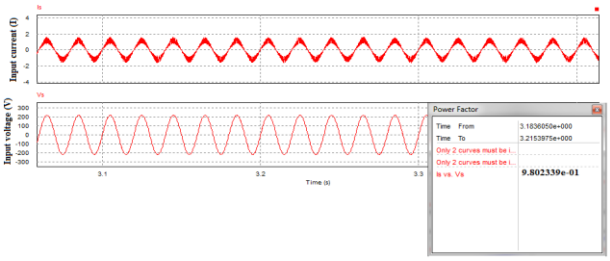

Fig.7 Input current and Input voltage waveform

It is clearly shown in the fig.7 the input voltage and input current power factor is 0.96 so the power quality and performance of the PMBLDC motor drive is improved . By adjusting the reference speed equivalent to DC link voltage wide range of speed control can be obtained which is shown in the Table I.

The performance of PFC zeta converter at dc link voltage of 150V gives speed of 1400 rpm and the power factor is maintained as 0.91 is shown in fig .8 and fig.9

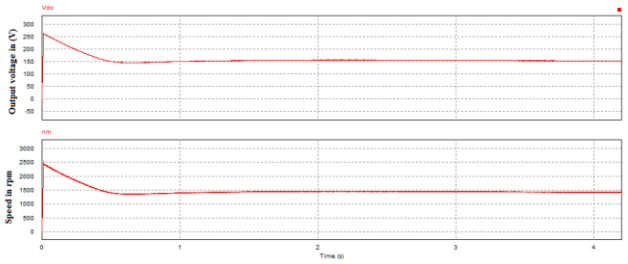

Fig.8 Output voltage and Speed waveform

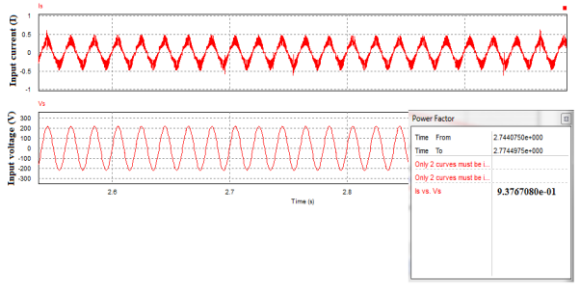

Fig.9 Input current and Input voltage waveform

TABLE I
PERFORMANCE OF THE PROPOSED PMBLDC MOTOR DRIVE UNDER SPEED CONTROL AT 220-V INPUT AC VOLTAGE

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

V.HARDWARE

A single stage PFC Zeta converter has been implemented in hardware for new speed control strategy of a PMBLDC drive. The speed of the PMBLDC motor drive is found to be proportional to the DC link voltage, thereby smooth speed control of PMBLDC drive is obtained by controlling the DC link voltage. The PFC Zeta converter has ensured nearly unity PF in a wide range of speed and DC link voltage. The hardware circuit of the PFC zeta converter driving the PMBLDC motor drive is shown in fig.8. In Hardware fabrication input 230 V DC has been stepped down to 30V and the 30V dc is fed to Zeta converter and drives the PMBLDC motor drive. The rating of the PMBLDC motor drive which is connected to the zeta converter is 6.22 watts, 24V, 3000 rpm motor. The output dc link voltage has been controlled from 15V to 24V and correspondingly speed has been changed. The PF remains nearby unity and the power quality of the proposed PFC drive is improved.

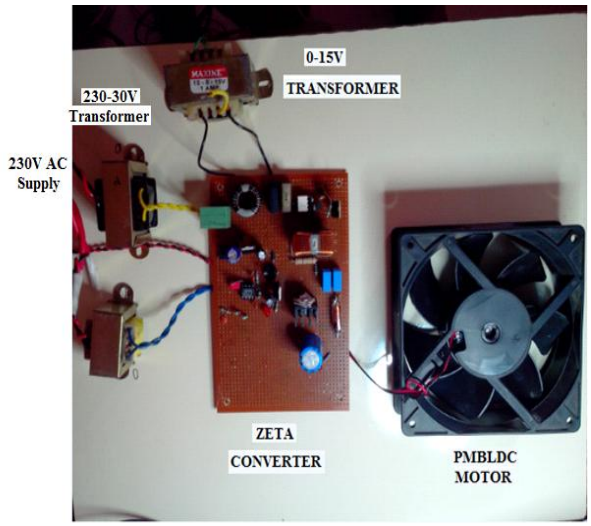

fig. 8 Hardware implementation

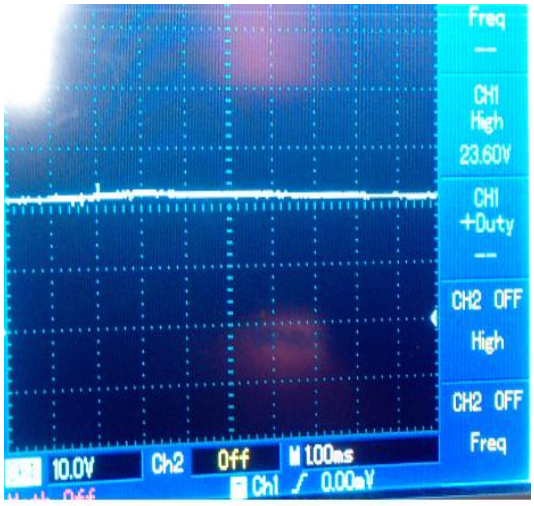

Fig. 9 Output voltage waveform

Fig. 10 Input Pulse waveform

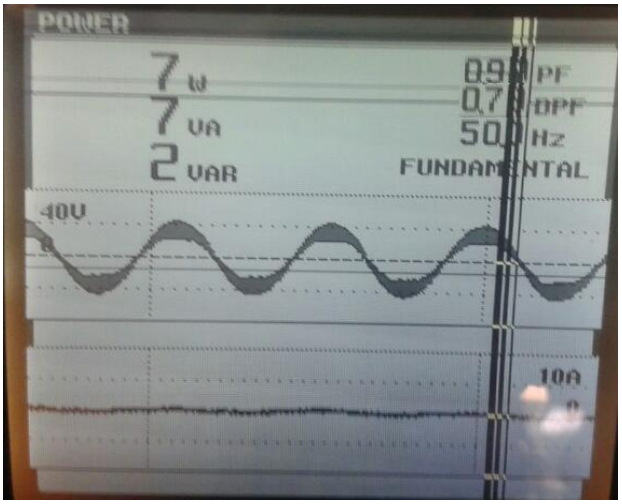

Fig. 11 Power Factor waveform

Hereby the output of the hardware implementation is shown in the above waveforms. They are controllable and adjustable to get variable speed performance of the PMBLDC motor drive. The DC link voltage of the zeta converter has been adjusted and the differents speeds obtained is tabulated below. Therefore the performance of the PMBLDC motor drive using PFC zeta converter is implemnted in hardware and the results are comparable with the simulation results.

PERFORMANCE OF THE PROPOSED PMBLDC MOTOR DRIVE UNDER SPEED CONTROL AT 30-V INPUT AC VOLTAGE

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

VI. CONCLUSION

A new speed control strategy is employed for PMBLDC motor drive using PFC zeta converter. The performance is based on controlling the DC link voltage by controlling the duty cycle (D) of the MOSFET switch. The reference speed is equivalent to the DC link voltage so by varying the DC link voltage different speed can be achieved and it is experimentally achieved in the developed controller. The PFC zeta converter is ensured nearly unity power factor in a wide range of speed and the input ac voltage. On comparison with PFC cuk converter, Zeta converter provides non inverting output voltage therefore diode bridge inversion is not needed. And also its basic configuration is buck boost configuration.Therefore a single stage PFC 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. Hence we got nearly unity power factor with appropriate voltage regulation.

APPENDIX

Rated power: 6.22 KW; Rated torque: 5.2Nm; switching frequency (f_x): 40KHz; PI controller gains (K_p): 1; (K_i): 1; rated voltage 30V; rated rpm 3000

REFERENCES

1. T. Kenjo and S. Nagamori, *Permanent Magnet Brushless DC Motors*.Oxford, U.K.: Clarendon, 1985.
2. T. J. Sokira and W. Jaffe, *Brushless DC Motors: Electronic Commutation and Control*. New York: Tab, 1989.
3. J. R. Hendershort and T. J. E. Miller, *Design of Brushless Permanent- Magnet Motors*. Oxford, U.K.: Clarendon, 1994.
4. J. F. Gieras and M. Wing, *Permanent Magnet Motor Technology—Design and Application*. New York: Marcel Dekker, 2002.
5. Singh, B. N. Singh, A. Chandra, K. Al-Haddad, A. Pandey, and D. P. Kothari, "A review of single-phase improved power quality ac–dc converters," *IEEE Trans. Ind. Electron.*, vol. 50, no. 5, pp. 962–981, Oct. 2003.
6. N. Mohan, M. Undeland, andW. P. Robbins, *Power Electronics: Converters,Applications and Design*. Hoboken, NJ: Wiley, 1995.
7. Bhim Singh, B.P.Singh and Sanjeet Dwivedi, "AC-DC Zeta Converter for Power Quality Improvement of Direct Torque Controlled PMSM Drive", Korean Journal of Power Electronics, Vol. 6, No. 2, pp.146-162, April 2006.
8. J. Uceeda, J. Sebastian and F.S. Dos Reis, "Power Factor Preregulators Employing the Flyback and Zeta Converters in FM Mode", in Proceedings of IEEE CIEP'96, 1996, pp.132-137.
9. D.C. Martins, "Zeta Converter Operating in Continuous Conduction Mode Using the Unity Power Factor Technique" , in Proceedings of IEE PEVSD'96, 1996, pp.7-11.
10. Paul P. Acarnley and John F. Watson, "Review of Position-Sensorless Operation of Brushless Permanent-Magnet Machines", IEEE Transactions on Industrial Electronics, Vol. 53, no. 2, April 2006.
11. James P. Johnson, M. Ehsani and Yilcan Guzelgunler, "Review of Sensorless Methods for Brushless DC" Industry Applications Conference, 34th IAS Annual Meeting, 1999, Vol. 1, pp. 143-150.