International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)), Volume 2, Special Issue 3, February 2014)

International Conference on Trends in Mechanical, Aeronautical, Computer, Civil, Electrical and Electronics Engineering (ICMACE14)

PFC and Speed Control of BLDC Motor Using ZETA Converter

C. Christo Shijith[1], S. Sujith[2]

[1]*PG Student, Department of Power Electronics and Drives, Apollo Engineering College, Chennai, Tamil Nadu, India*
[2]*Assistant Professor, Department of Electrical and Electronics Engineering, Apollo Engineering College, Chennai, Tamil Nadu, India*

***Abstract*— A Power Factor Correction (PFC) and sensorless speed control of BLDC (Brushless DC) motor using zeta converter is presented. 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 PFC is achieved by zeta converter. Sensorless speed control of BLDC motor is achieved and the cost and wiring of sensors are reduced. A MATLAB/ Simulink environment is used to simulate the developed model to achieve a wide range of speed control with high PF (Power Factor) and improved PQ (Power Quality) at the supply.**

***Keywords*— PFC, BLDC motor, zeta converter, sensorless speed control.**

I. INTRODUCTION

International concern of power quality (PQ) problems has prompted the use of power factor correction converters with a brushless DC motors (BLDCM) for numerous low power applications. Since, the BLDCMs are employed in low power applications due to features of high efficiency and wide speed range [3]. These BLDCMs are fed from a single-phase AC supply through a diode bridge rectifier (DBR) followed by a DC capacitor. However, this practice results in a pulsed current from AC mains having various power quality (PQ) disturbances such as poor power factor (PF), increased total harmonic distortion (THD) and high crest factor (CF) of current. This is due to uncontrolled charging of the DC capacitor leading to a peak value higher than the amplitude of the fundamental input current at AC mains. Therefore, the use of a suitable power factor correction (PFC) converter topology amongst various available topologies is an essential requirement for a BLDCM drive.

A PFC converter has two categories. One is two-stage approach and the other is single-stage approach [20]. In two-stage approach, an active power factor correction stage is adopted as the front-end to force the line current tracking the line voltage. A DC/DC output stage provides the isolation and the tightly regulated output voltage to meet the load requirement. However, this approach suffers from some drawbacks in low-power cost-effective applications because it requires additional components and complicates PFC control circuit. Thus it has high cost and large size.

A low cost alternative solution to this problem is to integrate the active PFC stage with the isolated high quality output DC/DC stage into one stage. It is the single-stage PFC approach and in this approach, the PFC switch and its controller are saved while the converter still have fair input current and isolated high quality output[20]. Hence single stage zeta converter is proposed in this paper. The operation of a zeta converter is in discontinuous inductor current mode and hence voltage follower approach is used. In this approach the average input current follows the input voltage “naturally” The voltage follower does not need a specific controller. Because no multiplier is used and there is no problem using this type of control when the line frequency is higher than the usual value.

II. SENSORLESS SPEED CONTROL OF BLDC MOTOR

Brushless dc (BLDC) motors and their drives are penetrating the market of home appliances, HVAC industry, and automotive applications in recent years because of their high efficiency, silent operation, compact form, reliability, and low maintenance.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)), Volume 2, Special Issue 3, February 2014)
International Conference on Trends in Mechanical, Aeronautical, Computer, Civil, Electrical and Electronics Engineering (ICMACE14)

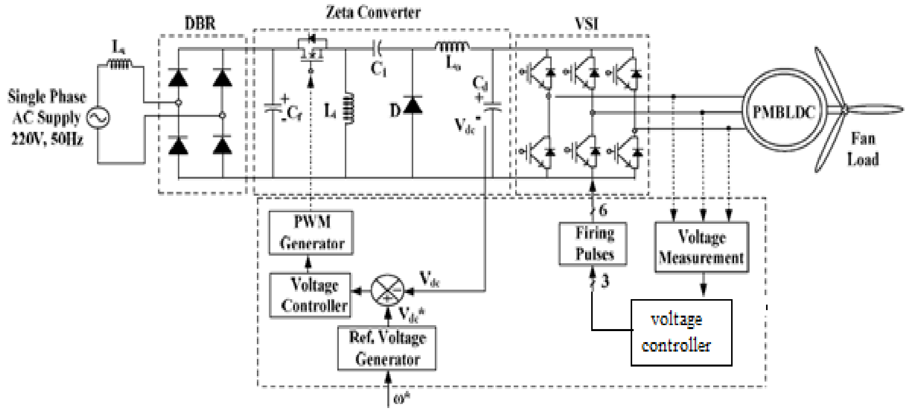

Fig.1. PFC zeta converter fed sensorless BLDC motor

Traditionally, BLDC motors are commutated in six-step pattern with commutation controlled by position sensors. To reduce cost and complexity of the drive system, sensorless drive is preferred. The existing sensorless control scheme with the conventional back EMF sensing based on motor neutral voltage for BLDC has certain drawbacks, which limit its applications. In this paper, a novel back EMF sensing scheme, direct back EMF detection, for sensorless BLDC drive is presented. For this scheme, the motor neutral voltage is not needed to measure the back EMFs. The true back EMF of the floating motor winding can be detected during off time of PWM because the terminal voltage of the motor is directly proportional to the phase back EMF during this interval. Also, the back EMF voltage is referenced to ground without any common mode noise. Therefore, this back EMF sensing method is immune to switching noise and common mode voltage. As a result, there are no attenuation and filtering necessary for the back EMFs sensing.

Basically, two types of sensorless control technique can be found in the literature. The first type is the position sensing using back EMF of the motor, and the second one is position estimation using motor parameters, terminal voltages, and currents. The second type scheme usually needs DSPs to do the complicated computation, and the cost of the system is relatively high. So the back EMF sensing type of sensorless scheme is the most commonly used method, which is the topic of this paper.

III. Functioning Of The System

BLDC motor used in applications such as computer hard drives, CD/DVD players, and small cooling fans in electronic equipments is analyzed. These BLDC motors are fed from a 220V single phase AC supply is shown in fig 3. AC-DC conversion takes place in these drive units with a diode bridge rectifier and a large value capacitive filter is used to reduce DC voltage ripples, which produces an increased THD of input AC mains current and excessive peak input currents leading to poor power factor. For power factor correction of the input AC mains, the buck, boost, buck-boost, Cuk and Sepic topologies are used as power factor preregulators (PFPs) [2]. All these converters have their own limitations. Although the buck converter is self protected from overload, its devices are subjected to high rms current stress, whereas boost converters operate only in step up voltage applications. The Cuk and Sepic converters work in buck-boost mode and have inherent power factor correction. The Zeta converter operates on the principle of a buck-boost converter and has inherent power factor correction capability. It is also known as an inverse SEPIC converter. This buck-boost type converter utilizes two approaches for their control, the multiplier approach and voltage follower approach. Due to inherent advantages of the voltage follower approach[1], such as elimination of input current and voltage sensors, a simple control scheme, with only one control loop, is used for the control of AC-DC Zeta converter.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)), Volume 2, Special Issue 3, February 2014)
International Conference on Trends in Mechanical, Aeronautical, Computer, Civil, Electrical and Electronics Engineering (ICMACE14)

The Zeta converter topology in discontinuous conduction mode (DCM) of current is employed to feed the BLDC motor. The complete scheme is shown in Fig.1, where the AC-DC Zeta converter is operating in DCM of operation with an input current in phase with AC mains voltage. Output of the Zeta converter is fed to the VSI and to BLDC motor to feed three phase currents in the stator winding of the motor. The VSI is made up of six active bi-directional switches (IGBTs with freewheeling diodes).

IV. Modelling Of The System

The PFC DC-DC Zeta converter feeding the BLDC motor is modeled and simulated. The control scheme of the improved power quality zeta converter is shown in Fig.1. The complete model of the drive is described in the following sections.

(a) Reference Voltage Generator

The reference voltage generator is required to produce an equivalent voltage corresponding to the particular reference speed of the BLDC motor. The speed of BLDC motor is proportional to the DC link voltage of the VSI. The reference voltage generator produces a voltage by multiplying the speed with a constant value known as the voltage constant (Kb) of the BLDC motor.

(b) Controller Circuit

The controller circuit used is Proportional Integral controller. This PI controller is used to minimize the error signal and also produce a controlled output to the PWM generator to trigger the switch of zeta converter.

An error voltage of Vdc* and the actual voltage fed from DC link capacitor Vdc is given to a PI (Proportional Integral) speed controller which generates a controlled output corresponding to the error signal.

The error output voltage at time k is

$$V_e(k) = V_{dc}^*(k) - V_{dc}(k) \qquad (1)$$

The output voltage $V_c(k)$ of the PI controller is given by,

$$V_c(k) = V_c(k-1) + K_p.(V_e(k) - V_e(k-1)) + K_i.V_e(k) \qquad (2)$$

Where K_p is the proportional gain and K_i is the integral gain constant.

(c) PWM Generator

The output of the PI controller is given to the PWM generator which produces a PWM signal of fixed frequency and varying duty ratio. A saw tooth waveform is compared with the output of PI controller.

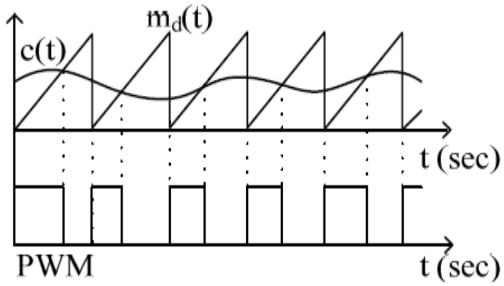

Fig.2. output of PWM signal by comparing the saw tooth signal and controlled output

(d) BLDC motor

The dynamic modeling of the BLDC motor is given by,

$$V_{an} = R_a i_a + P\lambda_a + e_{an} \qquad (2)$$

$$V_{bn} = R_b i_b + P\lambda_b + e_{bn} \qquad (3)$$

$$V_{cn} = R_c i_c + P\lambda_c + e_{cn} \qquad (3)$$

The flux linkages are given as,

$$\lambda_a = L_s i_a - M(i_b+i_c) \qquad (4)$$

$$\lambda_b = L_s i_b - M(i_a+i_c) \qquad (5)$$

$$\lambda_c = L_s i_c - M(i_a+i_b) \qquad (6)$$

Where p represents the differential operator, V_{an}, V_{bn} and V_{cn} are the per phase voltages, R_a, R_b and R_c are resistances per phase, i_a, i_b and i_c are currents, e_{an}, e_{bn} and e_{cn} represents back emf and λ_a, λ_b, λ_c represents flux linkages. L_s is the self inductance per phase M is the mutual inductance of the windings.

For star connected three phase windings of the stator,

$$ia+ib+ic = 0 \qquad (7)$$

The flux linkages can be expressed as,

$$\lambda_x = (L_s + M).i_x \qquad (8)$$

Where x denotes a, b or c (i.e. phase terminals).

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)), Volume 2, Special Issue 3, February 2014)

International Conference on Trends in Mechanical, Aeronautical, Computer, Civil, Electrical and Electronics Engineering (ICMACE14)

(e). Voltage source inverter

DC to AC converters is known as inverters. The function of an inverter is to change a DC input voltage to a symmetrical AC output voltage of desired magnitude and frequency. The output voltage could be fixed or variable at a fixed or variable frequency. A variable output voltage can be obtained by varying the input DC voltage and maintaining the gain of the inverter constant.

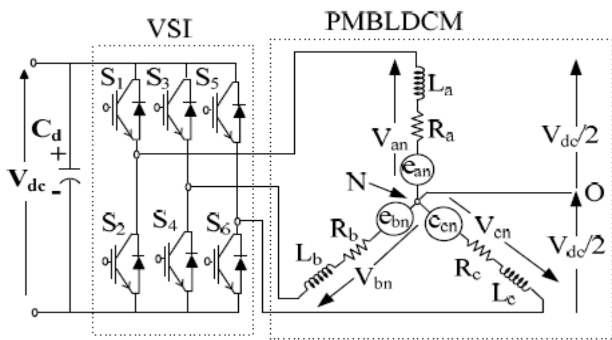

Fig.3. VSI fed BLDC motor

The output of the VSI for phase ‘a’ is expressed as,

$$V_{an} = V_{dc} / 2 \text{ for } S_1=1 \quad (9)$$

$$V_{an} = -V_{dc} / 2 \text{ for } S_2=1 \quad (10)$$

$$V_{an} = 0 \text{ for } S_1=0, S_2=0 \quad (11)$$

Where Vdc is the DC link voltage and the values for S1 and S_2 as 1 and 0 represent the on and off condition of the IGBT’s S_1 and S_2. Fig 3. Shows the equivalent circuit of BLDC motor fed by a VSI.

V. Simulation Models And Results

The PFC and speed control of BLDC motor is simulated in MATLAB/Simulink .For various speed controls the power factor of the system is determined. The simulink diagram of PFC and speed control of BLDC motor is shown in fig 4. The performance of PFC by varying the DC link voltage is determined and the speed control is achieved. This result is shown in table I.

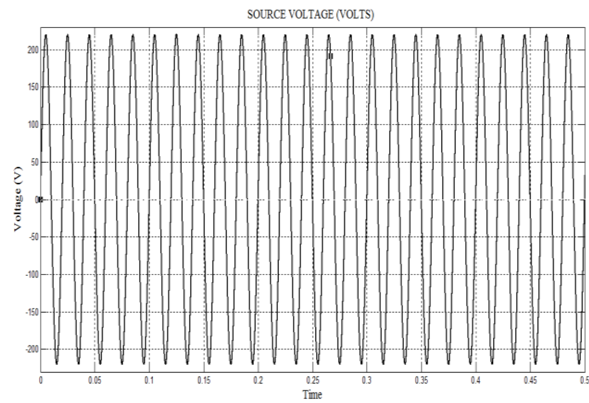

Fig.5. AC input source voltage

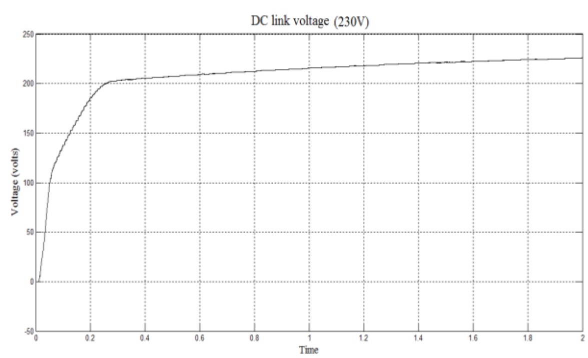

Fig.6. DC link voltage for 230v

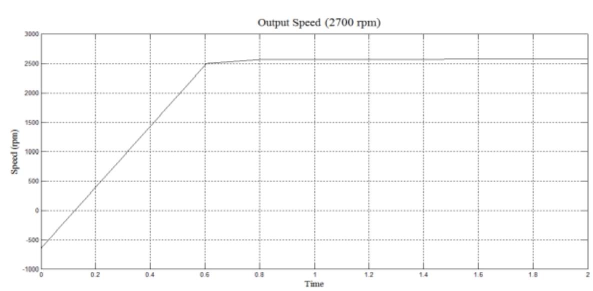

Fig.7. output speed 2700rpm

International Journal of Recent Development in Engineering and Technology

Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)), Volume 2, Special Issue 3, February 2014)

International Conference on Trends in Mechanical, Aeronautical, Computer, Civil, Electrical and Electronics Engineering (ICMACE14)

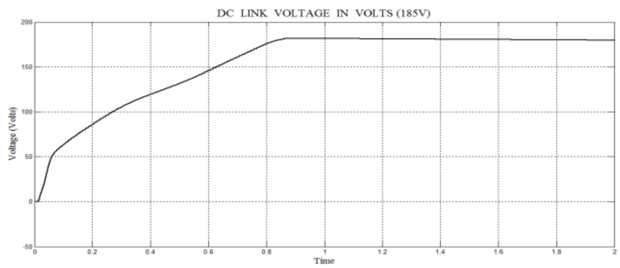

Fig.8. DC link voltage for 185V

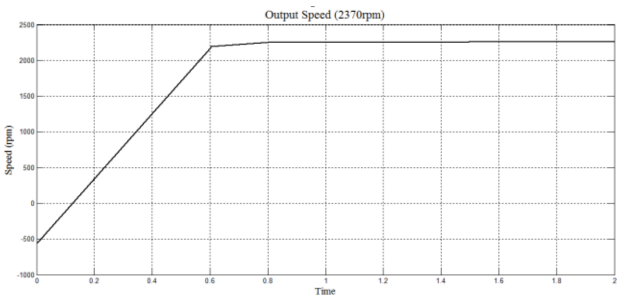

Fig.9. Output Speed of 2370rpm

Fig 4 to fig 7 shows the Power factor results and their corresponding voltages. These values are tabulated in the table I.

Table I
Performance of zeta converter fed BLDC motor for speed control.

Speed (rpm)	DC link Voltage (V)	Power Factor
1910	130	0.9979
2370	180	0.9982
2700	230	0.9986

VI. CONCLUSION

A novel scheme of PFC and speed control of BLDC motor using a single voltage sensor is proposed for a fan load. A sensorless operation for the reduction of position sensor has been used. A single stage PFC converter system is designed for reducing the system cost 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. The power quality indices for the speed control and supply voltage variation have been obtained within the limits.

APPENDIX

Table II
Parameter values of Zeta converter

SL.NO	PARAMETER	VALUE
1	C_f	300µF
2	L_i	2.463
3	C_1	330nF
4	L_0	60µH
5	C_d	2500µF
6	V_{in}	220V
7	Switching frequency	45KHZ

Acknowledgment

The authors would like to thank the guest editors and anonymous reviewers for their valuable comments.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)), Volume 2, Special Issue 3, February 2014)

International Conference on Trends in Mechanical, Aeronautical, Computer, Civil, Electrical and Electronics Engineering (ICMACE14)

REFERENCES

[1] Bhim Singh, Vashist Bist, "A Single Sensor Based PFC Zeta Converter Fed BLDC Motor Drive for Fan Applications," IEEE Trans.Ind. Appl., vol.31, no. 5, pp. Oct 2012.

[2] B. 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 Transactions on Industrial Electronics, vol. 50, no.5, pp. 962– 981, Oct. 2003.

[3] Ss. Singh and B. Singh, "Voltage controlled PFC Zeta converter based BLDC MOTOR drive for an air-conditioner," 2010 International Conference on Industrial and Information Systems (ICIIS), pp.550- 555, 29th July 2010- 1st Aug. 2010.

[4] 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.

[5] 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.

[6] 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.s

[7] 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.

[8] Denizar Cruz Martins, Fernando de Souza Campos, Ivo Barbi, " Zeta converter with high power factor operating in continuous conduction mode," In proc. PESC'94, TAIWAN, pp. 1152-1157.

[9] Denizar Cruz Martins, and Marcio Mendes Casaro, "Isolated Three-Phase Rectifier with High Power Factor Using the Zeta Converter in Continuous Conduction Mode," IEEE trans. On circuits and systems 1., vol.48, No.1. Jan 2001.

[10] Ki-Bum Park, Chong-Eun Kim, Gun-Woo Moon, and Myung-Joong Youn, " A double –ended Half-Bridge Zeta converter," IEEE trans. On power electronics, vol.23, No.6, Nov 2008.

[11] Pijit Kochcha, Sarawut Sujitjorn, "Isolated zeta converter: Principle of operation and design in continuous conduction mode," WSEAS Trans. on CIRCUITS and SYSTEMS, Issue 7, Volume 9, July 2010.

[12] Dakshina Murthy-Bellur, "Isolated Two Transistor Zeta Converter with Reduced Transistor Voltage Stress," IEEE trans. on circuits and systems-II, express briefs, vol. 58, no. 1, Jan 2011.

[13] Jitty Abraham, K.Vasanth, "Desigh and simulation of Pulse-Width Modulated zeta converter with power factor correction," International Journals, vol.2, No.2, pages: 232-238(2013).

[14] N. Sowmya Smitha Raj, Smt. B. Urmila, "PV fed Zeta converter,"International Journal of Engineering Research and Applications (IJERA). Vol. 3, Issue 4, Jul-Aug 2013, pp.2692-2696.

[15] Ki-Bum Park, Chong-Eun Kim, Gun-Woo Moon, and Myung-Joong Youn, "A Double-Ended ZVS Half-Bridge Zeta Converter," IEEE trans. Power electron., vol. 23, no. 6, Nov 2008.

[16] Hao Zhang, Yuan Zhang, and Xikui Ma, "Distortion Behavior Analysis of General pulse-width Modulated Zeta PFC converter operating in continuous conduction mode," IEEE trans. On power electronics, vol.27, No.10, Oct 2012.

[17] Sanjeev singh, Bhim singh "single- phase SEPIC based PFC converter for PMBLDC drive in Air-conditioning system", IEEE Trans. on Industrial Electronics, vol. 20, no. 5, Oct. 1999.

[18] Tae-Won chun, Quang-Vinh Tran, Hong-Hee Lee, and Heung-Geun Kim "sensorless control of BLDC motor Drive for an automotive fuel pump using a hysteresis comparator," IEEE trans. On power electronics, vol.29, No.3, Mar 2014.

[19] Alin stirban, Ion Boldea, and Gheorghe-Daniel Andreescu "Motion-sensorless control of BLDC-PM motor with offline FEM-Information-Assisted position and speed observer," IEEE trans. On industry applications, Vol.48, No.6, Nov/Dec 2012.

[20] Z.Chen, J.M Guerrero, and F.Blaabjerg, "comparision between CCM two-stage and single stage power factor correction converters,"IEEE Trans. Power electronics., Vol.24, No.8, pp1859-1875, Aug 2009.

[21] Jianwenshao, Fred c.Lee, Alex Q. Huang and Fred Wang, "direct back EMF Detection Method for Sensorless Brushless DC motor drives." IEEE Transactions on Industrial Electronics, Vol. 53, no. 2, Sep2006.