Grenze International Journal of Engineering and Technology, Jul 2019

An Analysis of an Adjustable Speed PFC BL-SEPIC and ZETA Converter Fed PMBLDCM

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***Abstract*—This paper presents an analysis of speed control of a permanent magnet brushless DC motor (PMBLDCM) by using Bridgeless Single Ended Primary Inductor Convertor (BL-SEPIC) and ZETA converter. A SEPIC converter is buck converter followed by buck-boost converter and ZETA converter is basically buck-boost converter. The proposed schemes combine the PFC and DC link voltage control at one stage. A DC link voltage is control to achieve better speed control of PMBLDCM. A controlled DC link voltage is proportional to desired speed of PMBLDCM. The proposed schemes are design to achieve power factor near to unity. Current multiplier approach is used in proposed scheme. A power factor correction (PFC) controller is designed in discontinuous Current Mode (DCM).A rate limiter is used for control torque and current in PMBLDCM at DC link. Conduction losses are less due to implementation of this scheme. The proposed PFC convertor provides better power quality at input AC mains. From the various results obtained after simulation of BL-SEPIC as well as ZETA converter different parameters also explain. BL-SEPIC gives better speed control of PMBLDCM as compare to ZETA converter. The proposed schemes are designed and results are shown in Matlab Simulink Environment.**

***Index Terms*— PMBLDCM, BL-SEPIC, ZETA, PFC, DCM, POWER QUALITY, VSI.**

I. Introduction

The permanent magnet brushed less DC motors are being used in low power as well as high torque applications. "Ref. [1-4]" PMBLDCM's have features like high efficiency and wide speed range. Maintenance required for PMBLDCM's is also low as compare to other motors. Permanent magnet brushed less DC motors are more reliable as compare to other, one of them reasons are, they have better speed versus torque characteristics, high speed response and noiseless operation [1-4]. "Ref. [5]" Permanent magnet DC motors are classified in different types such as, permanent magnet brushed less DC motors and permanent magnet synchronous motors (PMSM). Permanent magnet synchronous motors have sinusoidal back emf waveform and permanent magnet brushed less DC motors have trapezoidal back emf waveform. BLDC motors are electronically commuted. Brushes are not used for commutation. Due to this construction, many losses such as sparking, wear and tear of brushes, noise and electromagnetic interference can be neglected. For detection of rotor position, hall sensors are being employed in BLDC motors. The BLDC motors are fed from single phase ac mains through diode bridge rectifier. Due to this, pulsed current having a peak value higher than the amplitude of fundamental input current of AC mains [5]. "Ref. [6]"DC link capacitor results various power quality issues, such as poor power factor, increased distortion at input side etc.[6] due to uncontrolled charging of DC link capacitor. A bridgeless single ended

Grenze ID: 01.GIJET.5.2.2_1

primary inductor converter (BL-SEPIC) based power factor correction (PFC) converter is implemented in this work for PMBLDCM's. The proposed scheme is more advantageous because only one controller is required for operation [6].“Ref. [7]”A ZETA converter is also used for the speed control of PMBLDCM. Basically ZETA converter is a buck boost converter. A ZETA converter also operates in discontinuous current mode for power factor correction at input side [7].“Ref. [8]” there are two modes of operation for power factor correction converter. These operational modes are continuous current mode and discontinuous current mode. In proposed scheme discontinuous current mode is implemented as it gives [8]. “Ref. [8-9]” Speed control of PMBLDC motor has lots of advantages. PMBLDC motor can be used in home appliances as well as in industrial appliances. Use of PMBLDC motor gives reliable results in various applications. One of the common applications are aerospace as well as in automation industries [8-9]. “Ref. [10]”PMBLDC motor can also be used in air conditioner. In order to increase reliability of motor for using various applications stated above, it is recommended to do smooth speed control of PMBLDC motor. In proposed scheme, this is achieved by using bridgeless rectifier as conduction losses can be minimizing due to implementation of this scheme. Due to use of bridgeless rectifier power quality issues like power factor, harmonic distortion as well as switching losses can be minimized [10].

II. Proposed Model of BL-Sepic&Zeta Converter

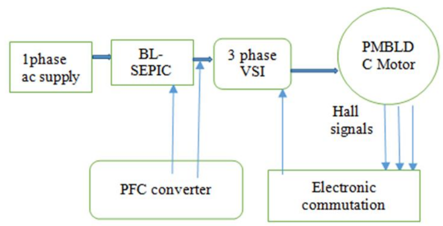


Figure.1 Block diagram of BL-SEPIC fed PMBLDCM

“Fig.1” shows proposed BL-SEPIC fed PMBLDCM's. A single phase supply feeds a VSI driving a PMBLDCM's through a filter and BL-SEPIC. The speed of PMBLDCM's is controlled by adjusting a DC link voltage. DC-DC convertor is used to control the voltage of DC link capacitor. Due to this, VSI is operated at fundamental frequency. The output of DC link is fed to control speed. The voltage follower technique is used for speed control of PMBLDCM with the help of BL-SEPIC and PFC converter is used in discontinuous current mode. A ZETA converter fed permanent magnet brushed less DC motor is also work in same manner. But, as compare to proposed scheme, a diode bridge rectifier followed by a ZETA converter is used instead of bridgeless single ended primary inductor converter.

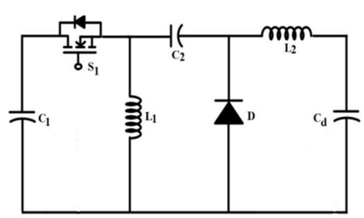


Figure.2 ZETA converter

“Fig.2” shows ZETA converter for operation of proposed scheme. ZETA converter is basically buck-boost converter. This ZETA converter is used to control the speed of permanent magnet brushless DC motor. It consists of only one MOSFET switch. Two capacitors as well as inductors are also connected for the operation of ZETA converter.

III. Operation of BL-Sepic

“Fig.3” shows bridgeless rectifier for operation of proposed scheme. Bridgeless rectifier is used to convert ac supply into dc output.

Bridgeless rectifier circuit is connected to SEPIC operated in two half cycle i.e. Positive half cycle and negative half cycle. Bridgeless rectifier operated at two stages ie. When switch S1 is at ON state and switch S1 is at OFF

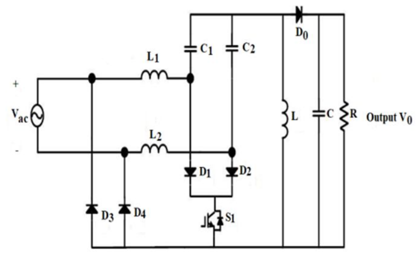


Figure.3Bridgeless SEPIC Converter

state. During positive half cycle, BL-SEPIC circuit is active through diode D4. Diode D4 is used to connect input side to output ground. During negative half cycle, BL-SEPIC is active through diode D3. Diode D3 is also used for connecting input side to output ground. When switch S1 is at ON stage then that time rectifier gets operated through diode D4 and diode D3 gets reversed biased due to input voltage.

When S1 is at ON stage: -

When S1 is at ON stage then that time diode D1 is at turned OFF stage. From input AC voltage side inductor gets charged then C1 also gets charged and it transfers energy into output side L0. At this stage, inductor L0 is remain in charging state. Output of capacitor C0 is load current.

When S1 is at OFF stage: -

When S1 is at OFF stage then that time diode D1 is also at ON stage. From input AC voltage side inductor L1 gets charged. At that time, Capacitor C1 also gets charged and it due to this it provides load current. When output capacitor C0 gets charged then L2 is connected to the load side for providing a load current.

IV. Designing and Modeling of Proposed Scheme

A. Voltage of BL-SEPIC

$$Vdc = Vin \times \frac{D}{1-D}, Where, Vin = 2\sqrt{2} \times \frac{Vs}{\pi} \quad (1)$$

B. Input Voltage to PFC Converter for BL-SEPIC

$$Vs = Vm \times \sin(2\pi ft)\ , Where, Vm = rms\ value\ of\ voltage\ \times \sqrt{2} \ \&\ f = 50Hz \quad (2)$$

C. Filter Output

$$Vin = |Vm \times \mathrm{Sin}(2\pi ft)|, Where, || = representation\ in\ modulus\ form \quad (3)$$

D. Equation for Duty Ratio

$$D = \frac{Vdc}{Vin + Vdc}\ Where, Vin = Vm \times Sin(\omega t) \ \&\ \omega = 2 \times 3.14 \times 50 \quad (4)$$

E. Input voltage of ZETA converter

$$Vin = 2\sqrt{2} \times \frac{Vs}{\pi} \quad (5)$$

F. Input voltage to PFC converter ZETA converter

$$Vs = Vm \times Sin(2\pi ft), Where, Vm = rms\ value\ of\ voltage\ \times \sqrt{2} \ \&\ f = 50Hz \quad (6)$$

G. Various parameters for both BL-SEPIC converter

Cd= 2200 micro Farad&C1=C2=C3=220 nano Farad,L0= 70 micro Henry&L1=L2=Lf2=3.77 milli Henry.

H. Various parameters for both ZETA converter

C1= 10 micro Farad &C2= 2200 micro Farad,
L1=L2= 2.5 milli Henry &Cd= 2000 micro Henry

I. Reference voltage generator

The output of permanent magnet brushed less DC motor is proportional to voltage which is generated by reference voltage generator.

J. Voltage controller

It is a proportional integral controller. PI controller is used to provide controlled output. The value of gain is set by taking trial in MATRIX LABORATORY.

K. Rate limiter

In transient condition, voltage error at DC link is kept constant by using rate limiter. So that, it is very useful for proposed scheme to control speed of PMBLDC motor.

L. PWM Generator

The output of proportional integral controller is given to a PWM generator. This PWM generator is used to produces a PWM signal of fixed frequency and varying duty ratio.

M. Electronic Commutation

In most cases, brushless DC motor consists of stator windings. In a brushed less DC motors, commutation process is an important process for enabling rotor rotation. Stator windings of PMBLDCM drive gets energized to positive power for each commutation. It indicates that, current enters in the winding. Second winding as a negative. For the running purpose of motor, it is necessary to shift the position of magnetic field produced by windings. For maintaining rotor in running condition it is necessary to excite winding sequentially. This can be done with the help of electronic switches, ON and OFF sequentially. In other words, process of activating current flow in six directions through appropriate motor phase windings to produce an output torque is called as electronic commutation.

V. PROPOSED SCHEMESFOR SPEED CONTROLAND POWER FACTOR CORRECTION OF PMBLDC MOTOR.

In proposed work, speed control of permanent magnet brushed less DC motor drive is done with the help of Zeta converter as well as Bridge Less Single Ended Primary Inductor converter. Basically Zeta converter is Buck-Boost converter. There are two types of modes for operation for both power factor correction converters. One of them is continuous current mode and another mode is discontinuous current mode. Depending upon the application of motor, mode of operation can be decided. For low power application discontinuous current mode is mostly preferred because of low amount of sensing. “Ref. [10]”Continuous current mode can be used for medium power application. Operation of both converter i.e. BL-SEPIC as well as ZETA converter takes place in discontinuous current mode. Due to implementation of this discontinuous current mode sensing required is less. Speed control of permanent magnet brushed less DC motor drive is totally depending on dc link voltage. So, by adjusting DC link voltage we can we can control the speed of PMBLDCM drive. Switching sequence of VSI fed permanent magnet brushed less DC motor drive is generated by using hall sensors. Hall sensor are used for identifying the position of rotor for commutation process [10].“Ref. [11]”A BL-SEPIC is operated in discontinuous current mode. Voltage controller is also used in proposed scheme for providing controlled output. Voltage controller tracks the error voltage between reference voltage and sensed voltage at DC link and generates control signal based on proportional integral controller [11].

VI. SIMULATION RESULT OF BL-SEPIC AND ZETA CONVERTER

“Fig.4” shows MATLAB simulation diagram of bridgeless single ended primary inductor conveter.A 150V to 220V, 50Hz AC supply is fed to BLDC motor. A BL-SEPIC is used to control the speed of brushless DC motor and improved power quality at input side. Fig.4 shows power factor at input side when brushless DC motor is connected to BL-SEPIC. From fig.4, it is observed that power factor remains constant at input side.
“Fig.6” it is observed that, rotor speed of PMBLDCM gets control quickly when a 150V to 220V, 50Hz AC supply is given to a motor. Similarly, “Fig.6 and fig.7” shows, stator back emf and stator current of BL-SEPIC fed PMBLDCM respectively. “Fig.8” shows, elctromagnetic torque of brushless DC motor.
“Fig.7” shows stator back emf of BL-SEPIC fed PMBLDCM. Similarly, “Fig.9 and Fig.10” shows stator current and electromagnetic torque of BL-SEPIC fed permanent magnet brushed less DC motor.
“Fig.10” shows, MATLAB simulation model of ZETA converter fed PMBLDCM. From various results obtained after simulation, it is observed that, power factor remains near unity.

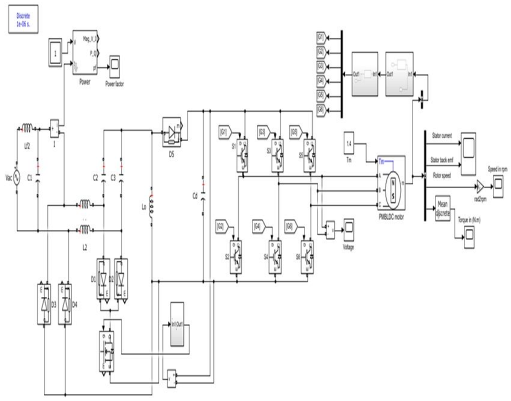


Figure.4Simulation diagram BL-SEPIC Converter Fed Brushless DC Motor

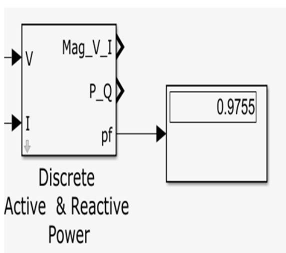


Figure.5 Power factor of BL-SEPIC fed PMBLDCM

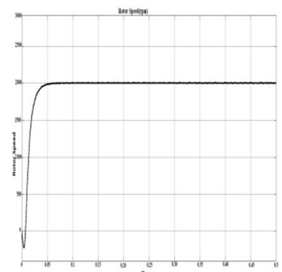


Figure.6Rotor speed of BL-SEPIC fed PMBLDCM

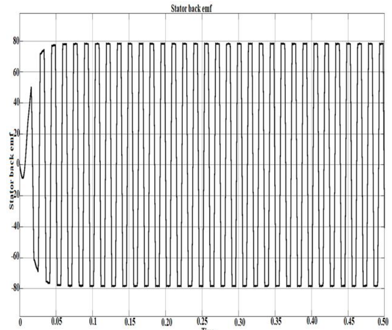


Figure.7 Stator back emf of BL-SEPIC fed PMBLDCM

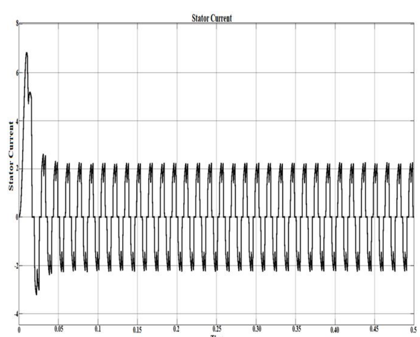


Figure.8 Stator current of BL-SEPIC fed PMBLDCM

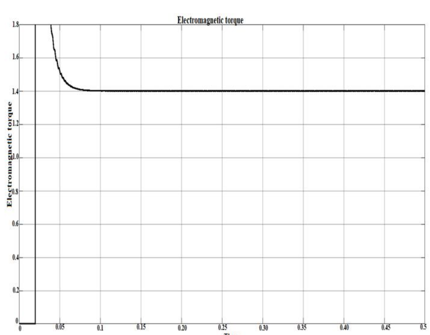


Figure.9Electromagnetic torque of BL-SEPIC fed PMBLDCM

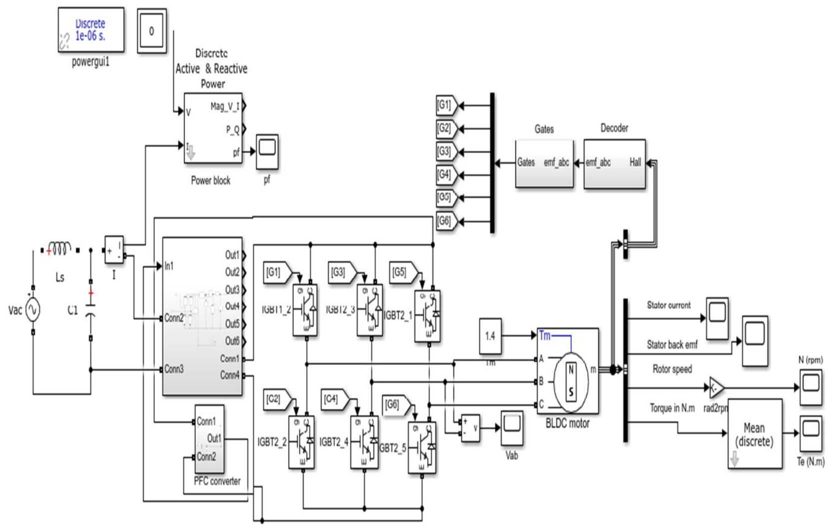
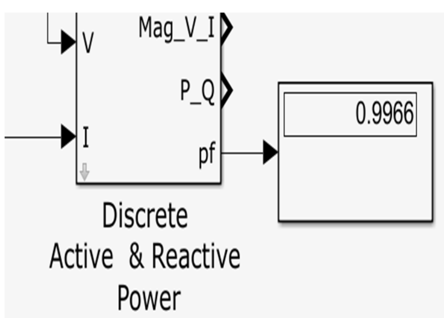


Figure.10 Simulation diagram BL-SEPIC Converter Fed Brushless DC Motor



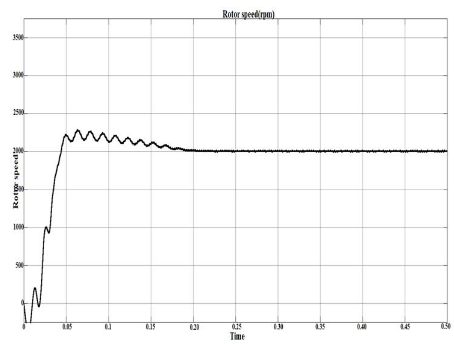
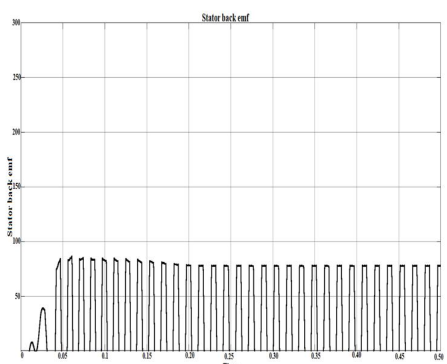


Figure.11Power factor of Zeta converter fed PMBLDC

Figure.12 Speed of Zeta converter fed PMBLDCM

It is observed from "fig.11 and fig.12"that, power factor will remain near to unity and control speed of ZETA converter fed BLDC motor. From both figures, it is observed that, BL-SEPIC converter fed PMBLDCM motor provides more speed control as compare to ZETA converter at 150V to 220V, 50Hz AC supply.



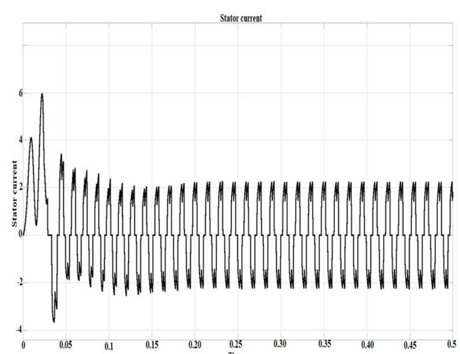


Figure.13 Stator back emf of ZETA converter fed PMBLDCM

Figure.14 Stator current of ZETA converter fed PMBLDCM

"Fig.12, Fig.13 and Fig.14" shows stator back emf, stator current and electromagnetic torque respectively.

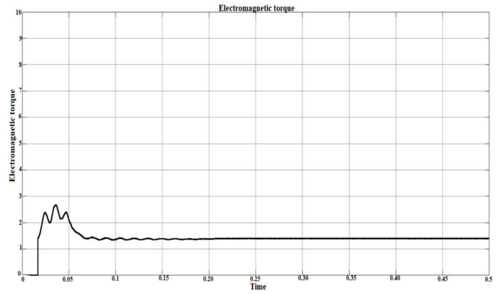


Figure.15 Electromagnetic torque of ZETA converter fed PMBLDCM

TABLE I. TABLE FOR SPEED AND POWER FACTOR AT DIFFERENT VALUE OF APPLIED VOLTAGE FOR BL-SEPIC FED PMBLDCM AT CONSTANT LOAD.1

Applied voltage(V)	Frequency (HZ)	Power factor	Speed (RPM)
150 V	50 HZ	0.975	2000
170 V	50 HZ	0.975	2000
190 V	50 HZ	0.97	2000
220 V	50 HZ	0.965	2000

TABLE II. TABLE FOR SPEED AND POWER FACTOR AT DIFFERENT VALUE OF APPLIED VOLTAGE FOR ZETA CONVERTER FED PMBLDCM AT CONSTANT LOAD

Applied voltage(V)	Frequency (HZ)	Power factor	Speed(RPM)
150 V	50 HZ	0.97	2000
170V	50 HZ	0.97	2000
190 V	50 HZ	0.98	2050
220 V	50 HZ	0.996	2050

VII. CONCLUSION

A PFC BL-SEPIC as well as PFC ZETA converter fed permanent magnet brushed less DC motor drive is simulated in MATLAB/Simulink environment and implemented. Power factor correction converters are operated in discontinuous current mode. The conduction losses also be reduced due to proposed scheme of BL-SEPIC. The speed control of PMBLDCM can be achieved smoothly with the help BL-SEPIC as compare to ZETA converter. Speed control of PMBLDCM drive can be achieved with help of proposed schemes. For speed control operation reference speed is used. A BL-SEPIC as well as ZETA converters ensured near unity power factor at input ac mains. For maintaining power factor at input side, it is observed that ZETA converter is slightly useful as compare to BL-SEPIC converter.However, considering overall performance of converter, BL-SEPIC fed PMBLDCM is more reliable. Depending upon the applications both converters can be used.

APPENDIX

Rated torque= 1.4 N.m & Rated speed= 2000 rpm

ACKNOWLEDGMENT

I wish to thanks, Prof. Omkar S. Pawaskar for his valuable guidance and thanks to electrical department of PVG’s COET, Pune. I wish to thanks, GRENZE Scientific Society for give me a opportunity to express my idea in front of all scholars who interested in research.

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