A Fuzzy Based Power Factor Corrected Bridgeless Converters Fed Bldc Motor

M.V. Dhivya Lakshmi, S.P.G.Bhavani

***Abstract:** This paper presents a power factor corrected (PFC) bridgeless (BL) converters-fed brushless direct current (BLDC) motor drive as a cost-effective solution for low-power applications. An approach of speed control of the BLDC motor is by controlling the dc link voltage of the voltage source inverter (VSI).This facilitates the operation of VSI at fundamental frequency switching by using the electronic commutation of the BLDC motor which offers reduced switching losses. A Bridgeless configuration of the various non-isolated converters such as (Buck-boost, CUK, SEPIC) are proposed which offers the elimination of the diode bridge rectifier thus reducing the conduction losses associated with it. The performance of the proposed drive is studied and simulated in MATLAB/Simulink environment.*

***Keywords**: Bridgeless (BL) converters, Power factor correction (PFC), Brushless dc motor, PI controller, Fuzzy controller.*

I. INTRODUCTION

Power supplies with active power factor correction (PFC) techniques are becoming necessary for many types of electronic equipment. Efficiency and cost are the major concerns in the development of low-power motor drives targeting household applications such as fans, water pumps, blowers, mixers, etc. The use of the brushless direct current (BLDC) motor in these applications is becoming very common due to features of high efficiency, high flux density per unit volume, low maintenance requirements, and low electromagnetic-interference problems. 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. A bridgeless PFC circuit allows the current to flow through a minimum number of switching devices compared to the conventional PFC circuit. Accordingly, the converter conduction losses can be significantly reduced, and higher efficiency and lower cost can be obtained. Power quality problems have become important issues to be considered due to the recommended limits of harmonics in supply current by various international power quality standards. The proposed topology has simple structure, low component count, galvanic isolation capability and Hence, the proposed converter is cost effective, especially for low power applications.

Revised Version Manuscript Received on June 06, 2016.

M.V. Dhivya Lakshmi, PG Student, Department of Electrical and Electronics Engineering, Meenakshi College of Engineering, Anna University, Chennai (Tamil Nadu). India.

S.P.G. Bhavani, Assistant Professor, Department of Electrical and Electronics Engineering, Meenakshi College of Engineering, Anna University, Chennai (Tamil Nadu). India.

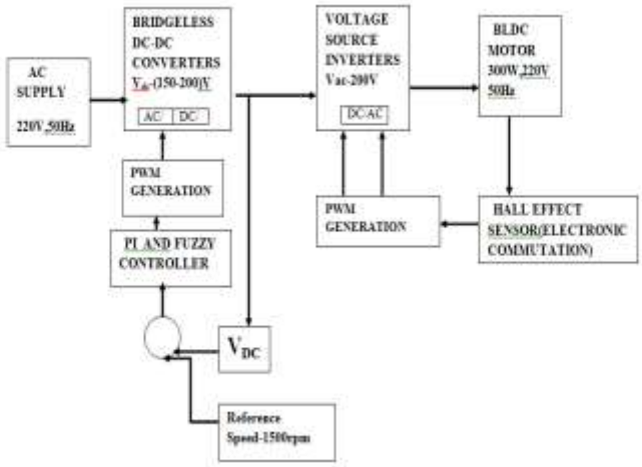


Fig-1 Block Diagram of Power Factor Corrected Bridgeless converters based BLDC motor drive.

The rectifier fed drives have power quality problems and poor power factor at input AC mains as they are mostly fed through diode bridge rectifier based voltage source inverters. In this paper, a permanent magnet brushless DC motor(PMBLDCM) fed through a three-phase voltage source inverter (VSI) is used to drive a load. Therefore the VSI performs only as an electronic commutator for the PMBLDCM. The stator current of the PMBLDCM during step change of the reference speed is controlled within the specified limits by an addition of a rate limiter in the reference DC link voltage. BLDC motors have trapezoidal back emf and uses Hall Effect position sensors to determine the position of the rotor field.

In this proposed method, various bridgeless converters are employed and the obtained DC link voltage of around 200V is given to BLDC motor via VSI whose output is around 220V. Power factor is maintained around 0.98 at input by using PFC circuit. The seed obtained from BLDC motor is around 1800rpm.

II. PROPOSED PFC BL DC-DC CONVERTERS FED BLDC MOTOR

A bridgeless PFC circuit allows the current to flow through a minimum number of switching devices compared to the conventional PFC circuit. Accordingly, the converter conduction losses can be significantly reduced, and higher efficiency and lower cost can be obtained.

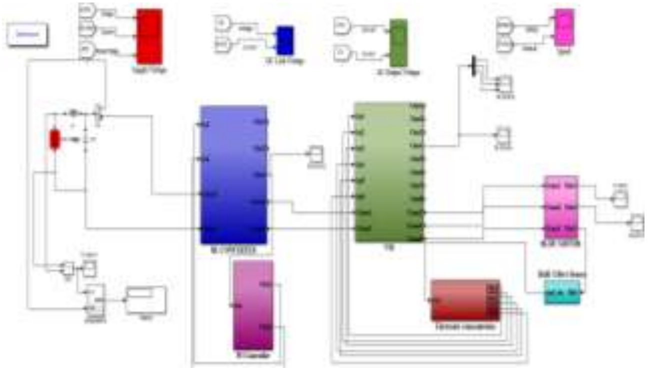


Fig-2 Overall simulation Diagram of Power Factor Corrected Bridgeless converters based BLDC motor.

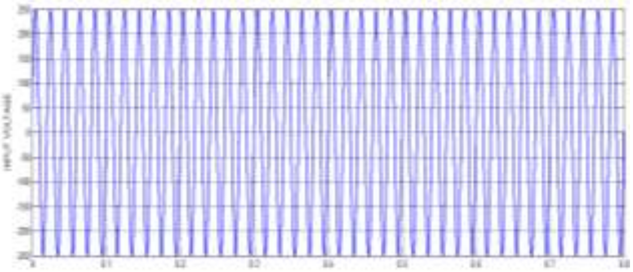


Fig-3 Input Supply Voltage.

Fig-3 shows the source voltage of around 220V to be given to DC-DC converters. The Power Factor is 0.9925 at the input supply.

A. Proposed PFC BL Buck-Boost converter fed BLDC Motor

The proposed configuration of the BL buck–boost converter has the minimum number of components and least number of conduction devices during each half cycle of supply voltage which governs the choice of the BL buck–boost converter for this application.

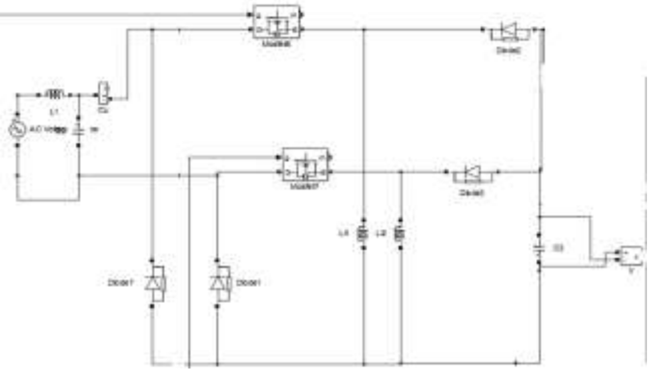
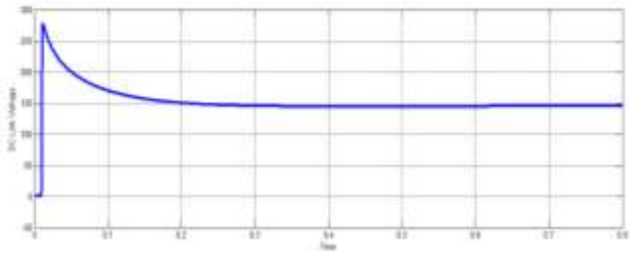


Fig-4 BL Buck-boost converter

A PFC BL buck–boost converter is designed to operate in DICM such that the current in inductors Li1 and Li2 becomes
discontinuous in a switching period**.** The relation governing the voltage conversion ratio for a buck–boost converter is given as



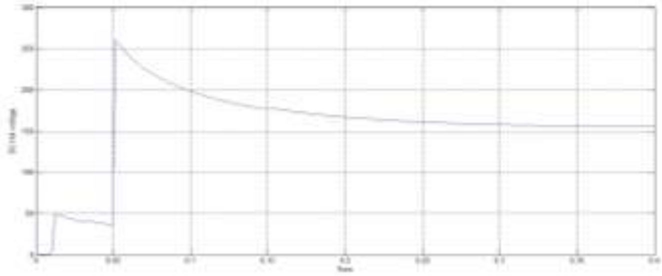


Fig-5 BL Buck-Boost Converter Output Voltage

B. Proposed PFC BL CUK converter fed BLDC Motor

The proposed converter utilizes two switches (Q_1 & Q_2). Q_1 is turned on/off during the positive half-line cycle while Q_2 is switched on/off during the negative half cycle. The converter has inherent high power factor when operating in discontinuous inductor conduction mode (DICM) because

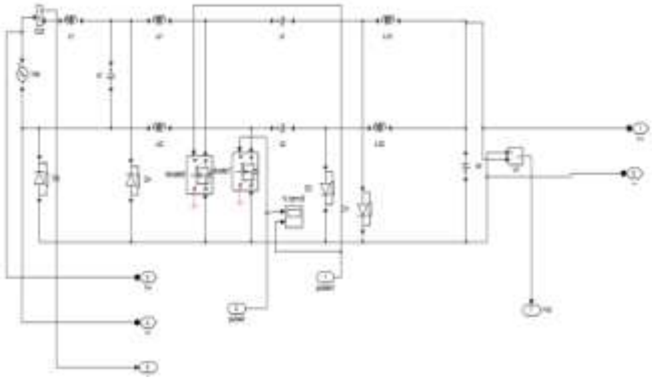


Fig-6 Bridgeless CUK converter circuit

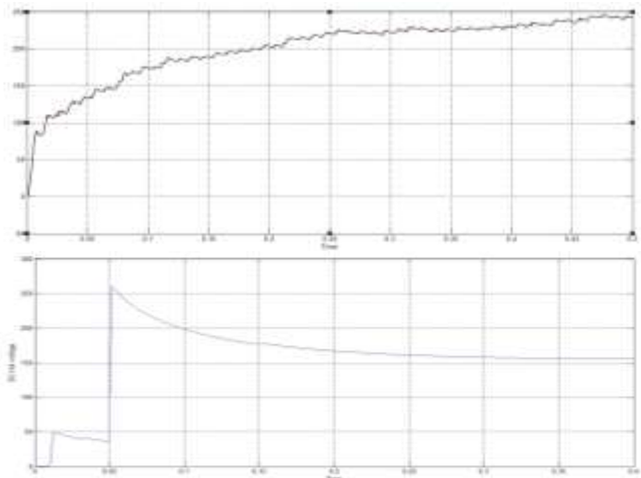


Fig-7 BL CUK Converter Output Voltage

It is inferred from the figure that 200V is the DC link output using both PI and FUZZY controller.

C. Proposed PFC BL Sepic converter fed BLDC Motor

The bridgeless PFC circuits based on SEPIC with low conduction losses, is shown. Unlike the boost converter, the SEPIC converters offer several advantages in PFC applications, such as easy implementation of transformer isolation, inherent inrush current limitation during start-up and overload conditions, lower input current ripple, and less electromagnetic interference (EMI) associated with the DCM topology.

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication

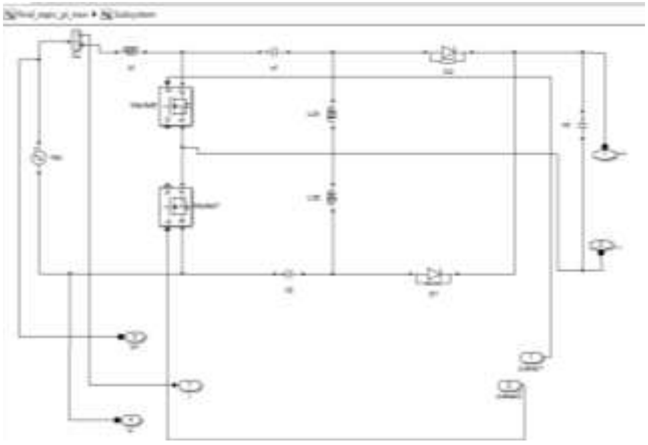


Fig-8 Bridgeless SEPIC converter.

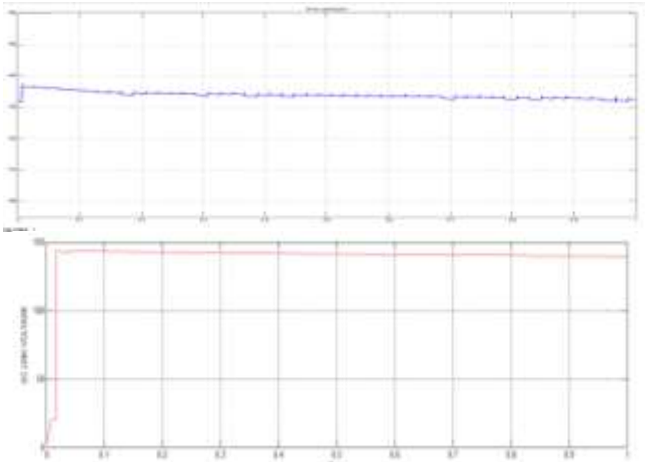


Fig-9 BL SEPIC Converter Output Voltage

It is inferred from the figure that 150V is the DC link output using both PI and FUZZY controller.

POWER FACTOR

The power factor of an AC electric power system is defined as the ratio of the real power flowing to the load to the apparent power in the circuit, and is a dimensionless number between 0 and 1. Real power is the capacity of the circuit for performing work in a particular time. Apparent power is the product of the current and voltage of the circuit. Due to energy stored in the load and returned to the source, or due to a non-linear load that distorts the wave shape of the current drawn from the source, the apparent power will be greater than the real power.. The devices for correction of the power factor may be at a central substation, spread out over a distribution system, or built into power-consuming equipments.

III.MODELING OF PFC CONVERTER BASED PMBLDC MOTOR DRIVE

The PFC converter and PMBLDCMD are the main components of the proposed drive, which are modeled by mathematical equations, and a combination of these models represents the complete model of the drive.

MODELLING OF POWER FACTOR CORRECTION CONVERTER

1) PFC CONVERTER
Speed controller → PI CONTROLLER
Speed controller → FUZZY CONTROLLER
Reference current generator
2) PMBLDC MOTOR

A. PFC Converter

The modeling of the PFC converter consists of the modeling of a speed controller, a reference current generator, and a PWM controller

A i) Speed Controller

The speed controller is a PI controller which tracks the reference speed as an equivalent reference voltage. If, at the k_{th} instant of time, is the reference dc link voltage and Vdc(k) is the voltage sensed at the dc link, then the voltage error Ve(k) is given as

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

A ii) Reference Current Generator

The reference current at the input of the converter id^* is

$$I_d* = I_c(k)\,uV_s \qquad (2)$$

A iii) PWM Controller

The reference input current of the converter is compared with its current (id) sensed after DBR to generate the current error □$I_d = I*_d - I_d$ .This current error is amplified by gain kd and compared with fixed frequency (fs) sawtooth carrier waveform md(t) to get the switching signal for the MOSFET of the PFC converter as If $kd \triangle id > md(t)$ then S=1 else S=0 where S denotes the switching of the MOSFET of the converter as shown and its values "1" and "0" represent "on" and "off" conditions, respectively.

B. PMBLDC MOTOR DRIVE

The PMBLDCMD consists of an electronic commutator, a VSI, and a PMBLDC Motor drive.

B i) Electronic Commentator

The electronic commentator uses signals from Hall-effect position sensors to generate the switching sequence for the VSI as shown in Table.

TABLE-1. Switching states for achieving electronic commutation.

h_a	h_b	h_c	Emf a	Emf b	Emf c
0	0	0	0	0	0
0	0	1	0	-1	1
0	1	0	-1	1	0
0	1	1	-1	0	1
1	0	0	1	0	0
1	0	1	1	-1	-1
1	1	0	0	1	0
1	1	1	0	0	-1

B ii) VSI

The output of VSI to be fed to phase "a" of the PMBLDC motor is calculated from the equivalent circuit of a VSI-fed PMBLDCM shown.v_{ao}, v_{bo}, v_{co}, and v_{no} are the voltages the three phases (a, b, and c) and neutral point(n) with respect to the virtual midpoint of the dc link voltage.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

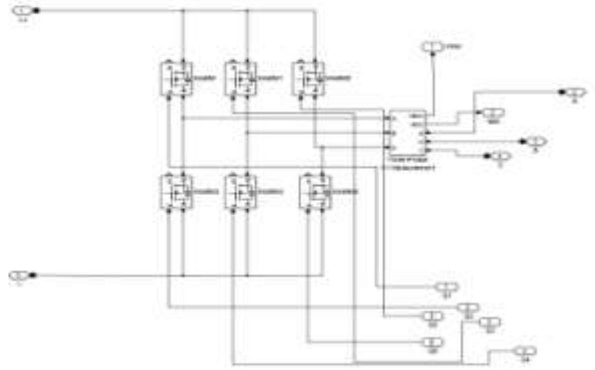


Fig-10 Voltage source inverter diagram.

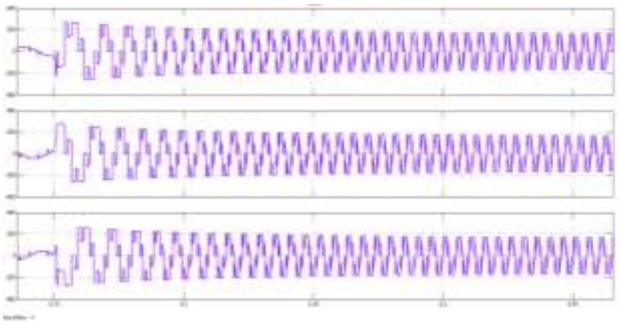
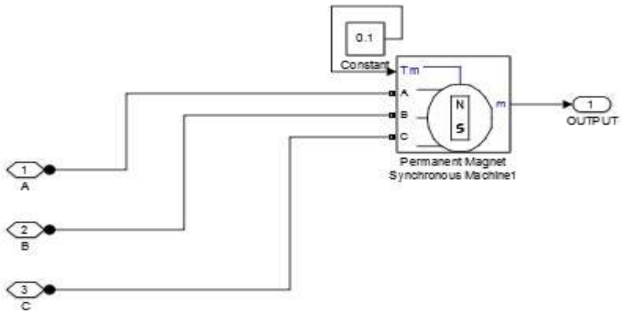


Fig-11 Input Supply to BLDC Motor from VSI

B iii) PMBLDC Motor:

A BLDC motor is that which retains the characteristics of a dc motor but eliminates the commutator and the brushes. Brushless DC motors can in many cases replace conventional DC motors. BLDC motors have trapezoidal back emf and uses Hall Effect position sensors to Determine the positon of the rotor.



.

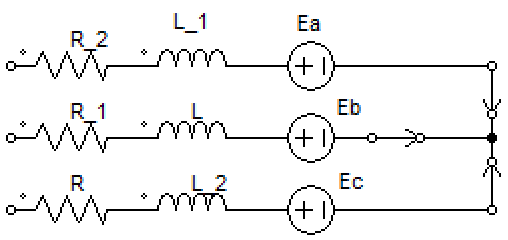


Fig-12 equivalent circuit of BLDC Motor

The PMBLDCM is modeled in the form of a set of differential equations given as

$$V_{an} = Ri_a + p\lambda_a + e_{an} \quad (3)$$

$$V_{bn} = Ri_b + p\lambda_b + e_{bn} \quad (4)$$

$$V_{cn} = Ri_c + p\lambda_c + e_{cn} \quad (5)$$

In these equations, p represents the differential operator (d/dt), ia, ib, and ic are currents, λa, λb, and λc are flux linkages, and ean, ebn, and ecn are phase-to-neutral back EMFs of PMBLDCM, in respective phases; R is the resistance of motor windings/phase. The developed torque Te in the PMBLDCM is given as

$$T_e = \frac{\left(e_{an}i_a + e_{bn}i_b + e_{cn}i_c\right)}{W_r} \quad (6)$$

Where ωr is the motor speed in radians per second. Since PMBLDCM has no neutralConnection

$$i_a + i_b + i_c = 0\,. \quad (7)$$

The functions $f_b(\theta)$ and $f_c(\theta)$ are similar to $f_a(\theta)$ with phase differences of 1200 and 2400, respectively. Therefore, the mechanical equation of motion in speed derivative form is given as

$$pw_r = \left(p/2\right)\left(T_e - T_L - Bw_r\right)/J \quad (8)$$

Where ω_r is the derivative of rotor position θ, P is the number of poles, T_l is the load torque in newton meters, J is the moment of inertia in kilogram square meters, and B is the friction coefficient in newton meter seconds per radian Where ω_r is the derivative of rotor position θ, P is the number of poles, T_l is the load torque in newton meters, J is the moment of inertia in kilogram square meters, and B is the friction coefficient in newton meter seconds per radian.

IV. PI CONTROLLER AND FUZZY CONTROLLER

A. Proportional integral controller

To remove the steady state error in controlled variable of a process, an extra amount of intelligence must be added to the proportional controller. The extra intelligence is the integral (or) reset action. The PI controller produces a output signal consisting of two terms- one proportional to error signal and other proportional to the integral of error signal. The equation describing a PI controller is

$$U(s) = k_c\left[1 + 1/T_1(s).E(s)\right] \quad (9)$$

Where T1 is integral (or) reset time

The integral (or) reset action in this controller removes the steady state error in the controlled variable. However, the integral mode of control has a considerable destabilizing effect, which in most of the situations, can be compensated by adjusting the gain (K_c).

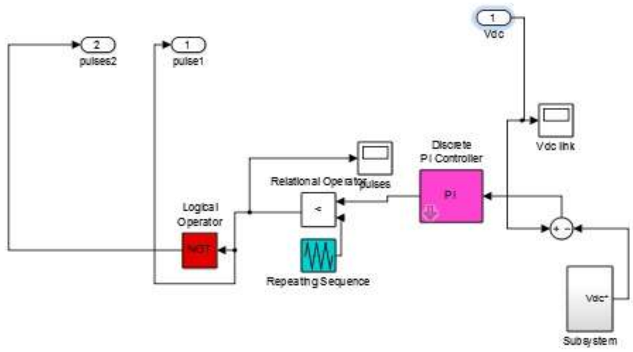


Fig-13 PI Controller sub system

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

$$K_i = \left(J w_n^2 \right) / K_t \tag{10}$$

$$K_p = \left(2 J w_n - B \right) / K_t \tag{11}$$

It follows from the above analysis that the desired tracking specifications can be completely achieved by using the simple PI controller.PI controller reduces the steady state error and also increases the stability.

B. Fuzzy Logic Controller

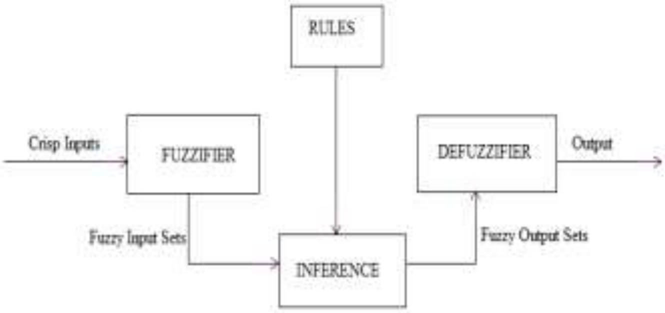


Fig 14 Fuzzy logic controller block diagram

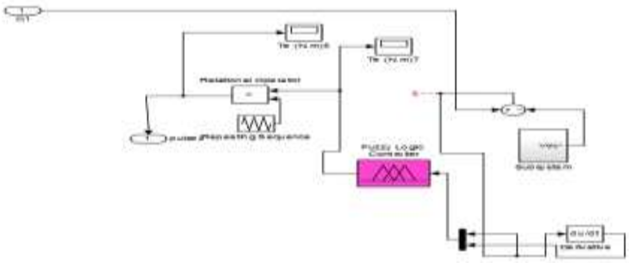


Fig 15 Fuzzy logic controller diagram

The control scheme consists of Fuzzy controller, limiter, and three phase sine wave generator for reference current generation and generation of switching signals. The peak value of reference currents is estimated by regulating the DC link voltage. The actual capacitor voltage is compared with a set reference value. The error signal is then processed through a Fuzzy controller, which contributes to zero steady error in tracking the reference current signal. A fuzzy controller converts a linguistic control strategy into an automatic control

strategy, and fuzzy rules are constructed by expert experience or knowledge database. Firstly, input voltage *Vdc* and the input reference voltage *Vdc-ref* have been placed of the angular velocity to be the input variables of the fuzzy logic controller. Then the output variable of the fuzzy logic controller is presented by the control Current *I*max. To convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as:

The input and output linguistic variables of the three fuzzy controllers have been quantized in the following subsets.

NB- Negative Big ; (-1 to -0.2)
NS – Negative Small; (-0.4 to 0)
ZE – Zero ; (-0.2 to +0.2)
PS – Positive Small; (0 to 0.4)
PB – Positive Big ; (0.6 to 1)
PM – Positive Medium (0.2 to 1)

TABLE II. Membership Function Table

	Error "e"							
Change of error "ce"		NB	NM	NS	Z	PS	PM	PB
	NB	NB	NB	NB	NB	NM	NS	Z
	NM	NB	NB	NB	NM	NS	Z	PS
	NS	NB	NB	NM	NS	Z	PS	PM
	Z	NB	NM	NS	Z	PS	PM	PB
	PS	NM	NS	Z	PS	PM	PB	PB
	PM	NS	Z	PS	PM	PB	PB	PB
	PB	Z	PS	PM	PB	PB	PB	PB

The fuzzy controller is characterized as follows:
1) Seven fuzzy sets for each input and output;
2) Fuzzification using continuous universe of discourse;
3) Implication using Mamdani's "min"operator;
4) De-fuzzification using the "centroid" method.

$$X^* = \frac{\sum_{i=1}^{n} x_i . \mu\left(x_i\right)}{\sum_{i=1}^{n} \mu\left(x_i\right)} \tag{12}$$

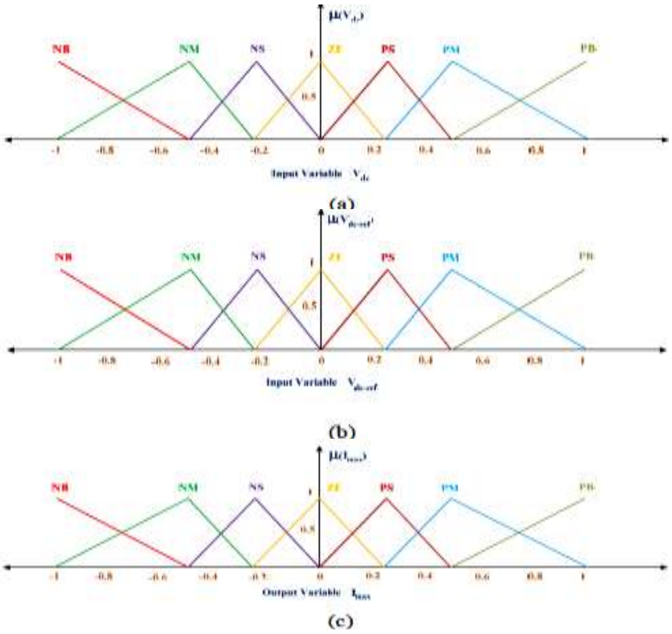
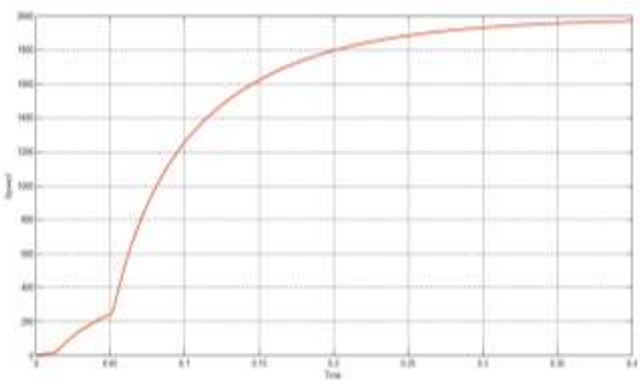


Fig-16 (a) Input Vdc normalized membership function; (b) Input Vdc-ref Normalized Membership Function; (c) Output Imax Normalized Membership Function.



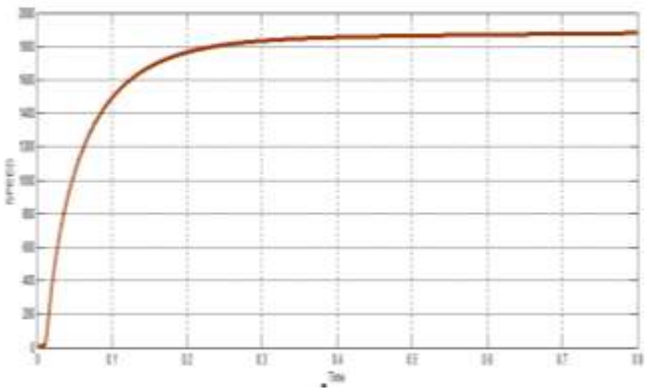


Fig-17 Speed Output Voltage of Buck-boost voltage

It is inferred from the figure that 1800rpm is the speed output from BLDC Motor using both PI and FUZZY controller from Bridgeless Buck-Boost converter.

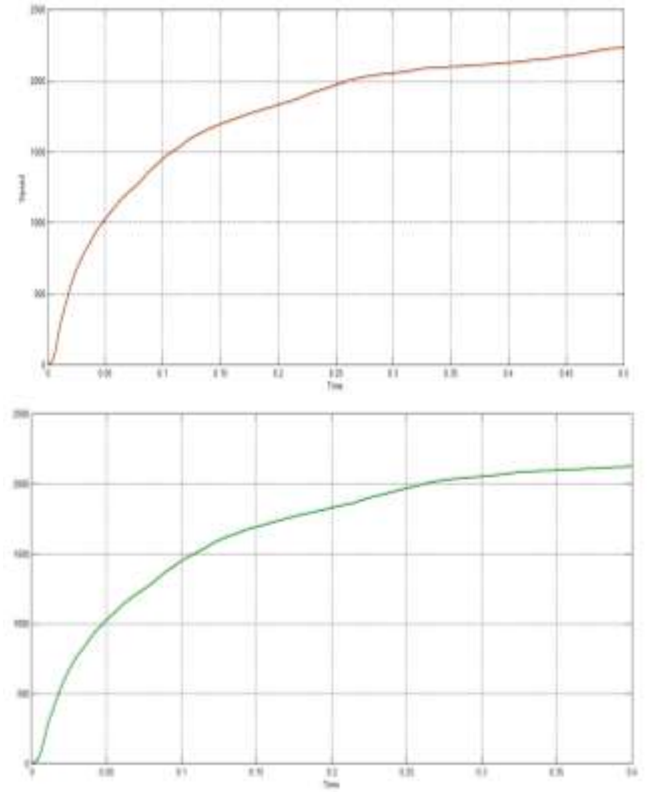
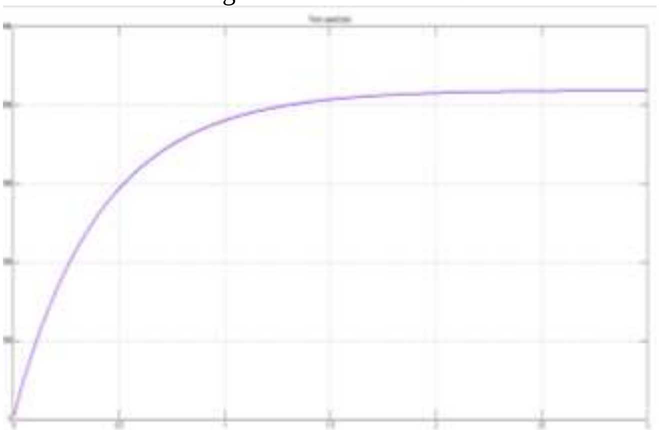


Fig-18 Speed Output Voltage of CUK Converter.

It is inferred from the figure that 1800rpm is the speed output from BLDC Motor using both PI and FUZZY controller from Bridgeless CUK converter.



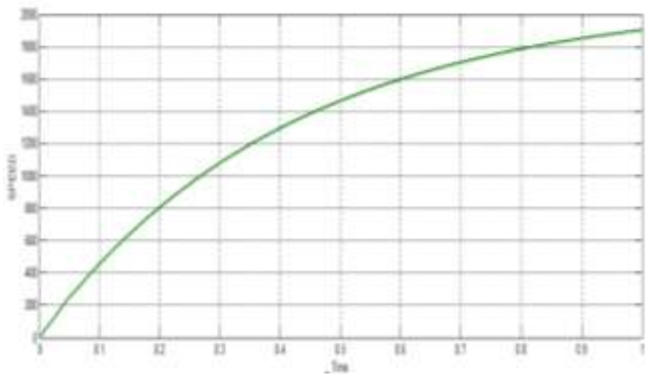


Fig-19 Speed Output Voltage of SEPIC Converter.

It is inferred from the figure that 1800rpm is the speed output from BLDC Motor using both PI and FUZZY controller from bridgeless SEPIC converter.

V. SIMULATION PARAMETERS

Fuzzy based intelligent controller. Firstly, the simulation of PI based controller is designed and implemented. The efficiency of all converters are analysed and compared.

TABLE III Simulation Parameters and Values

A. BL Buck-Boost Converter

LC FILTER-Inducatance, L -Capacitance, C	1.6e-3 H 330e-9 F
Inducatance,L	$442.67e^{-6}$ H
Capacitance,C	$2200e^{-6}$ F
Diode-Resistance -Forward voltage -Snuber resistance - Snubber capaitance	0.001Ω 0.8 V 500 Ω $250e^{-9}$ F
PI Controller-Kp -Ki	0.1 5

B. BL Cuk Converter

LC FILTER -Inducatance, L -Capacitance,C	$1.98e^{-3}$ H $574e^{-6}$ F
Inducatance,L1	$1.918e^{-6}$ H
Inducatance,L2	$254.56e^{-6}$ H
Capacitance,C1	0.327e-^{6} F
Capacitance,Cd	$2200e^{-6}$ F
Diode-Resistance -Forward voltage -Snuber resistance - Snubber capaitance	0.001Ω 0.8 V 500 Ω $250e^{-9}$ F
PI Controller-Kp -Ki	0.4 2

C. BL Sepic Converter

LC FILTER -Inducatance,L - -Capacitance,C	$1.98e^{-3}$ H $574e^{-6}$ F
Inducatance,L1	$1.918e^{-6}$ H
Capacitance,C1	$0.4E^{-3}$ F
Capacitance,C2	63e-^{6} F
Capacitance,Cd	$200e^{-6}$ F

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Diode-Resistance -Forward voltage -Snuber resistance - Snubber capaitance	0.001Ω 0.8 V 500 Ω $250e^{-9}$ F
PI Controller-Kp -Ki	0.4 2

D. BL DC Motor

Simulation Block	System Block	Parameter value
BLDC	Stator phase resistance Armature inductance Frequency Inertia pole pairs Speed Voltage Current	0.18Ω 0.00875 H 50 Hz $1.3e^{-4}Kgm^2$ 4 2000 rpm 170 V 7.2 A

VI. CONCLUSION

A. Comparison of Results

PARAMETER	BL BUCK-BOOST	BL CUK	BL SEPIC
Supply volt(V)	220	220	220
Vdc volt(V)	180	170	170
Powerfactor	0.976	0.935	0.9417
3ph Vac(V)	200	200	180
Speed(rpm)	1900	1600	1800

Comparison of switches used for various non-isolated converters.

CONVERTER	SWITCH	DIODE	L	C	TOT	Half conduction
BL BUCK-BOOST	2	4	2	1	9	5
BL CUK	2	3	3	2	10	8
BL SEPIC	2	3	2	2	9	7

VII. RESULT

"As Efficiency is at a premium in a Power Electronic converter, the losses that a power electronic device generates should be as low as possible".

The Buck-Boost Converter operated without Diode Bridge Rectifier regulates the DC link Voltage effectivelyBL CUK and BL SEPIC converters produces equivalent DC link voltage but efficient for higher power applications. The speed obtained around 1800rpm for V_{DC} of 150V Also, this converter uses less switches to correct Power factor and regulates the DC voltage than other converters.So, it acts as an efficient converter for medium and high power applications.

REFERENCES

1. "An Adjustable-Speed PFC Bridgeless Buck–Boost Converter-Fed BLDC Motor Drive", Vashist Bist, Student Member, IEEE, and Bhim Singh, IEEE transactions on industrial electronics, vol. 61, no. 6, june 2014.
2. "Performance Analysis of BLDC Motor Using Basic Switching Converters",Bikram Das, Suvamit Chakraborty, Abanishwar Chakraborti, Prabir Ranjan Kasari, International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-2, Issue-1, December 2012
3. Somanatham.R, Prasad.P.V.N, Rajkumar.A.D, "Modelling and Simulation of Sensorless Control of PMBLDC Motor Using Zero-Crossing Back EMF Detection" IEEE SPEEDAM 2006 International Symposium on Power Electronics, Drives, Automotive and Motion.
4. Bimal K Bose, "Modern Power Electronics and AC Drives", Pearson Education Asia 2002.
5. Miller. T.J.E., "Brushless permanent magnet and reluctance motor drives ", Clarendon Press, Oxford, 1989.
6. " Buck-Boost Converter for BLDC Motor Drive to Improve Power Factor", Besten, Stepanov, Research Script International Journal of Research in Electrical Engineering.
7. "A Novel Approach of Position Estimation, PFC based Buck Boost Converter and Energy generation in BLDC Motor Drive", Selamparasan. S, Shyamalagowri.M, International Journal of Emerging Technology and Advanced Engineering , Volume 4, Issue 4, April 2014.
8. "PFC Bridge Converter for Voltage-controlled Adjustable-speed PMBLDCM Drive", Sanjeev Singh,Bhim Singh, Journal of Electrical Engineering & Technology Vol. 6, No. 2, 2011.
9. "A Comparative Analysis of PI & Fuzzy PFC CUK Converter Based PMBLDCM Drive for Air-Conditioner Application", I.Lakshmana Rao, S.Srikanth, IJEAR Vol. 4, Issue Spl-1, Jan - June 2014
10. "High efficiency Bridgeless Unity Power factor CUK converter Topology", Aysha Kemaidesh AL-Kaabi, Abbas A. Fardoun and Esam H. Ismail, International Conference on Renewable Energies and Power Quality (ICREPQ'13).
11. "Simulation Of Bridgeless SEPIC Converter With Power Factor Correction Fed DC Motor", Dr.T. Govindaraj, H.Ashtalakshmi, International Journal Of Innovative Research In Electrical, Electronics, Instrumentation And Control Engineering Vol. 2, Issue 1, January 2014.
12. "An Efficient Closed Loop Controlled Bridgeless CUK Rectifier For PFC Applications", Shalini.K, Murthy.B, International Journal Of Innovative Research In Electrical, Electronics, Instrumentation And Control Engineering Vol. 2, Issue 2, February 2014 .
13. "An Efficient Bridgeless PFC Converter Based PMBLDCM Drive", Jomy Joy, Amal M.R, Rakesh R, Kannan S.A, Anna Raina, International Journal Of Innovative Research In Electrical, Electronics, Instrumentation And Control Engineering Vol. 2, Issue 2, February 2014
14. "A Voltage-Controlled PFC CUK Converter-Based PMBLDCM Drive Using Fuzzy Logic Controller", Dr.B.SANJIVA RAO, Phd, Mr.M.KONDALU,(Phd).
15. " Bridgeless Discontinuous Conduction Mode SEPIC Power Factor Correction Rectifier",Saravanan..S, P. Usha Rani, Vargheese.A, International Journal of Automation and Power Engineering, 2012,.
16. Ramesh.M.V, Amarnath.J, Kamakshaiah.S and Rao.G.S, "Speed control of Brushless DC Motor by using Fuzzy Logic PI Controller", ARPN Journal of Engineering and Applied Sciences, Vol.6, No.9, September 2011.

AUTHOR PROFILE

M.V. Dhivya Lakshmi, has obtained her B.E. degree in Electrical and Electronics Engineering from Sri Sairam Institute of Technology, Chennai in 2013 and pursuing ME in Power Electronics And Drives from Meenakshi College of Engineering, Chennai (2013-2015).

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication