International Journal of
Scientific Engineering and Technology Research

ISSN 2319-8885
Vol.05,Issue.14
June-2016,
Pages:2846-2853

www.ijsetr.com

Enhancement of Power Factor with Fuzzy Controlled Bridgeless Buck-Boost Converter-Fed BLDCM Drive

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Abstract: This paper presents a power factor corrected (PFC) bridgeless (BL) buck–boost converter-fed brushless direct current (BLDC) motor drive with fuzzy logic controller as a cost-effective solution for low-power applications. An approach of speed control of the BLDC motor by controlling the dc link voltage of the voltage source inverter (VSI) is used with a single voltage sensor. 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 BL configuration of the buck–boost converter is proposed which offers the elimination of the diode bridge rectifier, thus reducing the conduction losses associated with it. A PFC BL buck–boost converter is designed to operate in discontinuous inductor current mode (DICM) to provide an inherent PFC at ac mains. The obtained power quality indices are within the acceptable limits of international power quality standards such as the IEC 61000-3-2. The performance of the proposed drive is simulated in MATLAB/Simulink.

Keywords: Bridgeless (BL) Buck–Boost Converter, Brushless Direct Current (BLDC) Motor, Discontinuous Inductor Current Mode (DICM), Power Factor Corrected (PFC), Power Quality, Fuzzy Logic Controller.

I. INTRODUCTION

In the development of low-power motor drives targeting household applications such as fans, water pumps, blowers, mixers, etc. [1], [2] have the major concerns are efficiency and cost. Because of the features of high efficiency, high flux density per unit volume, low maintenance requirements, and low electromagnetic-interference problems [1], the use of the brushless direct current (BLDC) motor in these applications is becoming very common. 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 [2]–[4]. A BLDC motor has three phase windings on the stator and permanent magnets on the rotor [5], [6]. An electronic commutation based on rotor position is used rather than a mechanical commutation which has disadvantages like sparking and wear and tear of brushes and commutator assembly [5], [6]. That's why the BLDC motor is also known as an electronically commutated motor. Because of the recommended limits of harmonics in supply current by various international power quality standards such as the International Electrotechnical Commission (IEC) 61000-3-2 [7] Power quality problems have become important issues to be considered. For class-A equipment (< 600 W, 16 A per phase) which includes household equipment, IEC 61000-3-2 restricts the harmonic current of different order such that the total harmonic distortion (THD) of the supply current should be below 19% [7]. A BLDC motor when fed by a diode bridge rectifier (DBR) with a high value of dc link capacitor draws peaky current which can lead to a THD of supply current of the order of 65% and power factor as low as 0.8 [8]. Hence for improving the power quality at ac mains, there will be a DBR followed by a power factor corrected (PFC) converter is utilized.

As compared to two-stage PFC converters due to low component count and a single switch for dc link voltage control and PFC operation [9], [10],single-stage PFC converter having high efficiency and it reported in the literature which means single-stage PFC converter has gained importance in many topologies. The cost and rating of the components used in the PFC converter is directly affected by the choice of mode of operation of a PFC converter which is a critical issue. A PFC converter is designed to operate [9], [10] in two modes of operation. They are continuous conduction mode (CCM) and discontinuous conduction mode (DCM). In CCM, the current in the inductor or the voltage across the intermediate capacitor remains continuous, but it requires the sensing of two voltages (dc link voltage and supply voltage) and input side current for PFC operation, which is not cost-effective. On the other hand, DCM requires a single voltage sensor for dc link voltage control, and inherent PFC is achieved at the ac mains, but at the cost of higher stresses on the PFC converter switch; hence, DCM is preferred for low-power applications [9], [10]. A pulse-width-modulated voltage source inverter (PWM-VSI) for speed control with a constant dc link voltage is utilized in the conventional PFC scheme of the BLDC motor drive. This offers higher switching losses in VSI as the switching losses increase as a square function of switching frequency. The speed control is achieved by the variable dc link voltage of VSI because the speed of the BLDC motor is directly proportional to the applied dc link voltage. This allows the fundamental frequency switching of VSI (i.e., electronic commutation) and offers reduced switching losses. This paper presents a BL buck–boost converter fed BLDC motor drive with variable dc link voltage of VSI for improved power quality at ac mains with reduced components and superior control.

II. CONVENTIONAL SYSTEM

The proposed BL buck–boost converter based VSI fed BLDC motor drive is shown in fig.4. The parameters of the BL buck–boost converter are made such that it operates in discontinuous inductor current mode (DICM) to attain an inherent power factor correction at ac mains. The speed control of BLDC motor is accomplished by the dc link voltage control of VSI using a BL buck–boost converter. This reduces the switching losses in VSI because of the low frequency operation of VSI for the electronic commutation of the BLDC motor.

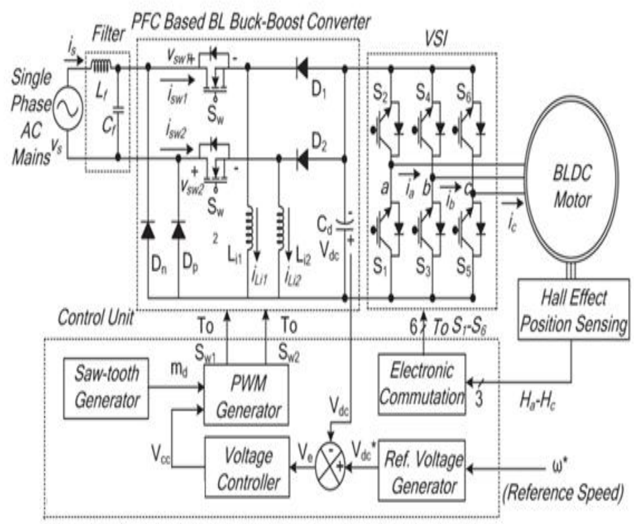


Fig.1. Block diagram of PFC based BL Buck-Boost converter fed BLDC motor drive.

In the proposed arrangement of bridgeless buck help converter has the base number of parts and slightest number of conduction gadgets amid every half cycle of supply voltage which administers the decision of BL buck boost converter for this application. The operation of the PFC bridgeless buck-help converter is ordered into two parts which incorporate the operation amid the positive and negative half cycles of supply voltage and amid the complete exchanging cycle.

A. Operation during Positive and Negative Half Cycle of Supply Voltage

In this mode converter switches Sw1 and Sw2 are work in positive and negative half cycle of supply voltage individually. A mid positive half cycle switch SW1, inductor Li1 and diodes D1 and D2 are worked to exchange vitality to DC join capacitor Cd. Thus in negative half cycle of supply voltage switches Sw2, inductor Li2 and diode D2 In Irregular Inductor Current Mode(DICM) operation of converter the present in the inductor Li gets to be irregular for certain term in an exchanging period.

B. Operation during Complete Switching Cycle

In this exchanging cycle there are three methods of operation.

Mode I: In this mode, switch Sw1 conducts for charging the inductor Li1, thus the inductor current iLi1 increments in this mode. Diode D1 finishes the information side and the DC join capacitor Cd is released by VSI nourished BLDC engine.

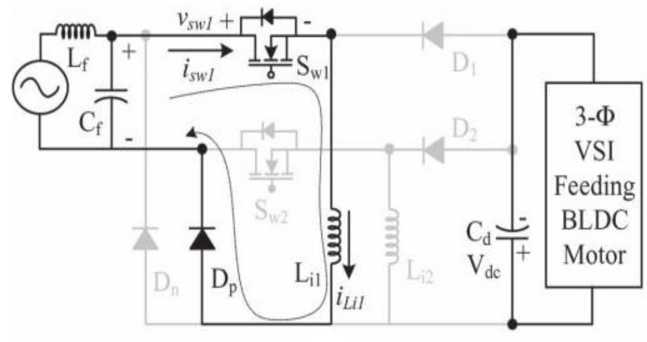


Fig.2. Mode 1 operation.

Mode II: In this method of operation switch Sw1 is killed furthermore, the put away vitality from the inductor Li1 is exchanged to DC join capacitor Cd till the inductor is completely released furthermore, current in the inductor is completely lessened to zero.

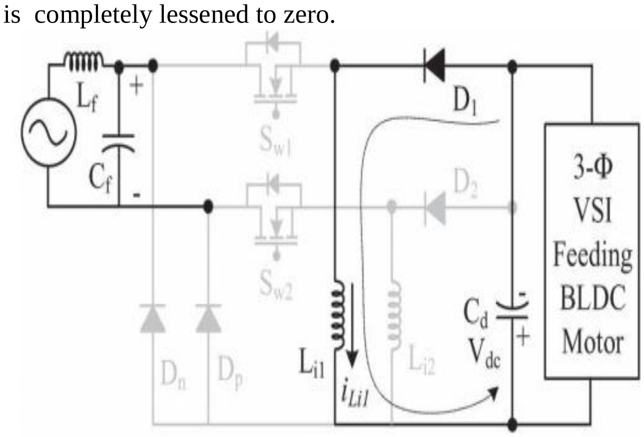


Fig.3. Mode 2 operation.

Mode III: In this method of operation inductor Li1 work in intermittent conduction mode and diodes and switch are in off condition. As of now DC join capacitor Cd begins releasing. This operation can be proceeding up to switch Sw1 is turned on once more. Similarly, for the negative half cycle of the supply voltage, switch Sw2, inductor Li2, and diodes Dn and D2 operate for voltage control and PFC operation. A PFC BL buck–boost converter is designed to operate in DICM such that the current in inductors *Li*1 and *Li*2 becomes discontinuous in a switching period. For a BLDC of power rating 251 W a power converter of 350 W (*Po*) is designed. For a supply voltage with an rms value of 220V.

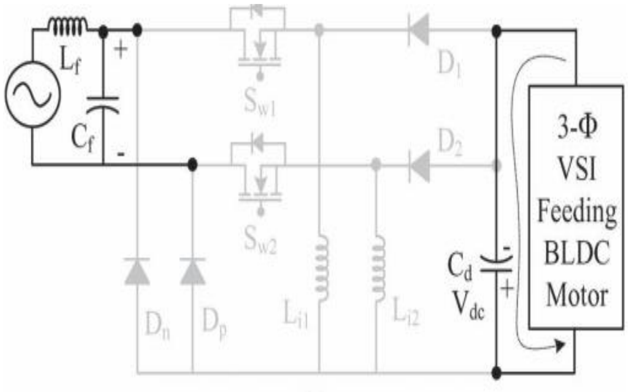
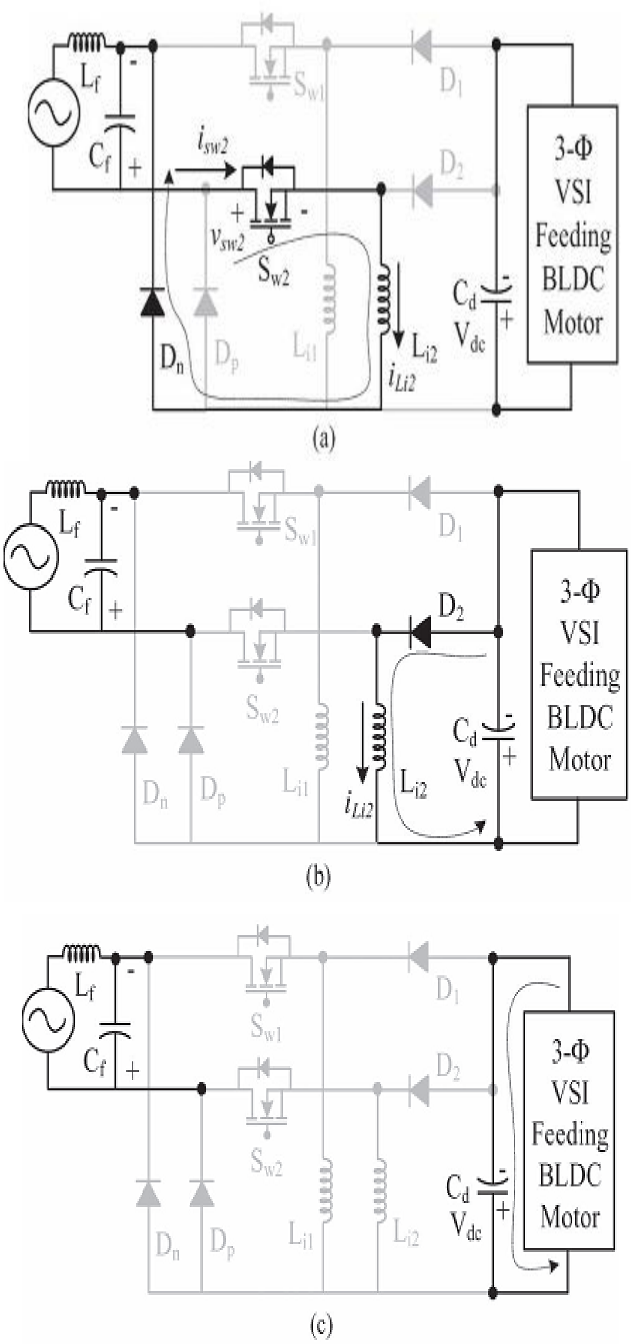


Fig.4. Mode 3 operation.



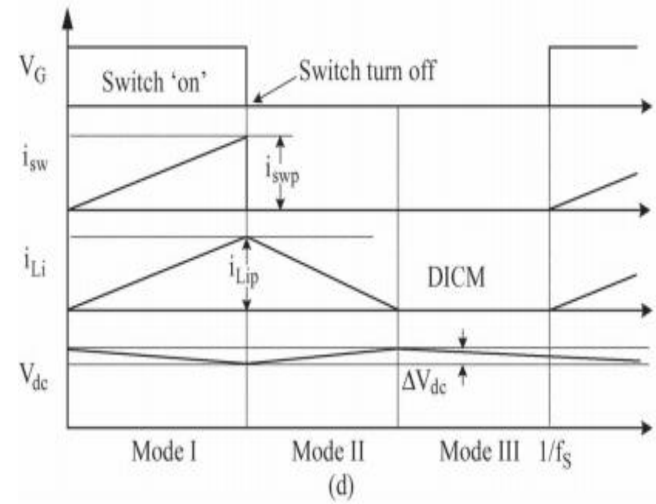


Fig.5. Operation of the proposed converter in different modes (a)–(c) for a negative half cycles of supply voltage and (d) the associated waveforms. (a)Mode I. (b) Mode II. (c) Mode III.(d) Waveforms during complete switching cycle.

III. CONTROL OF PFC BL BUCK–BOOST CONVERTER-FED BLDC MOTOR DRIVE

A. Control of Front-End PFC Converter

1. Voltage Follower Approach

The control of the front-end PFC converter generates the PWM pulses for the PFC converter switches (*Sw*1 and *Sw*2) for dc link voltage control with PFC operation at ac mains. A single voltage control loop (voltage follower approach) is utilized for the PFC BL buck–boost converter operating in DICM. A reference dc link voltage (*V*dc) is generated as

$$V_{dc}^{*} = k_v \omega^{*} \quad (1)$$

where *kv* and $\omega*$ are the motor's voltage constant and the reference speed, respectively. The voltage error signal (*Ve*) is generated by comparing the reference dc link voltage (*V*dc) with the sensed dc link voltage (*V*dc) as

$$V_e(k) = V_{dc}^{*}(k) - V_{dc}(k) \quad (2)$$

where *k* represents the *k*th sampling instant.

This error voltage signal (*Ve*) is given to the voltage proportional–integral (PI) controller to generate a controlled output voltage (*V*cc) as

$$V_{cc}(k) = V_{cc}(k-1) + k_p\{V_e(k) - V_e(k-1)\} + k_i V_e(k) \quad (3)$$

where *kp* and *ki* are the proportional and integral gains of the voltage PI controller. Finally, the output of the voltage controller is compared with a high frequency saw tooth signal (*md*) to generate the PWM pulses as

$$For\ v_s > 0; \quad \begin{cases} if\ m_d < V_{cc}\ then\ S_{w1} = 'ON' \\ if\ m_d \geq V_{cc}\ then\ S_{w1} = 'OFF' \end{cases} \quad (4)$$

$$For\ v_s < 0; \quad \begin{cases} if\ m_d < V_{cc}\ then\ S_{w2} = 'ON' \\ if\ m_d \geq V_{cc}\ then\ S_{w2} = 'OFF' \end{cases} \quad (5)$$

where *Sw*1 and *Sw*2 represent the switching signals to the switches of the PFC converter.

B. Control of BLDC Motor: Electronic Commutation

An electronic commutation of the BLDC motor includes the proper switching of VSI in such a way that a symmetrical dc current is drawn from

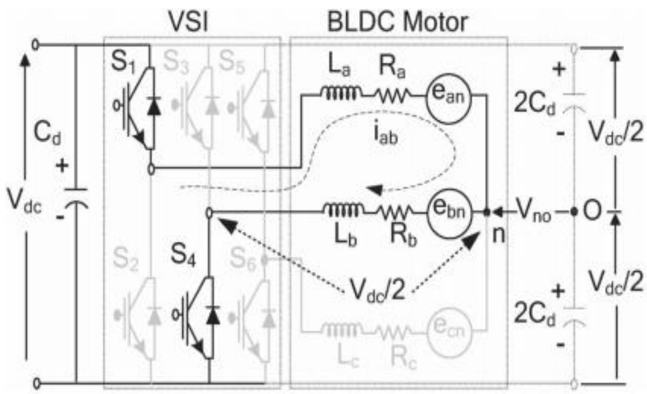


Fig.6. Operation of a VSI-fed BLDC motor when switches *S*1 and *S*4 are conducting.

Table I. Switching States for Achieving Electronic Commutation of BLDC Motor Based On Hall-Effect Position Signals

θ (°)	Hall Signals			Switching States					
	H_a	H_b	H_c	S_1	S_2	S_3	S_4	S_5	S_6
NA	0	0	0	0	0	0	0	0	0
0-60	0	0	1	1	0	0	0	0	1
60-120	0	1	0	0	1	1	0	0	0
120-180	0	1	1	0	0	1	0	0	1
180-240	1	0	0	0	0	0	1	1	0
240-300	1	0	1	1	0	0	1	0	0
300-360	1	1	0	0	1	0	0	1	0
NA	1	1	1	0	0	0	0	0	0

the dc link capacitor for 120◦ and placed symmetrically at the center of each phase. A Hall-effect position sensor is used to sense the rotor position on a span of 60◦, which is required for the electronic commutation of the BLDC motor. The conduction states of two switches (*S*1 and *S*4) are shown in Fig. 5. A line current *i*ab is drawn from the dc link capacitor whose magnitude depends on the applied dc link voltage (*V*dc), back electromotive forces (EMFs) (*e*an and *e*bn), resistances (*Ra* and *Rb*), and self-inductance and mutual inductance (*La*, *Lb*, and M) of the stator windings. Table II shows the different switching states of the VSI feeding a BLDC motor based on the Hall-effect position signals(*Ha*−*Hc*).

IV. PROPOSED FUZZY LOGIC CONTROLLER

The control framework is in light of fuzzy logic. FL controller is an one sort non straight controller and programmed. This kind of the control drawing is closer to the human thinking that makes the utilization of the acknowledgement, vulnerability, imprecision and fluffiness in the choice making procedure, figures out how to offer an exceptionally tasteful execution, without the need of a definite numerical model of the framework, just by fusing the specialists' learning into the fluffy. Fig. 11 demonstrates the FL controller piece outline. This fluffy rationale control framework is in view of the MAMDHANI fluffy model. This framework comprises of four principle parts. To begin with, by utilizing the info enrollment capacities, inputs are Fuzzified then in view of standard bases and the inferencing framework, yields are delivered lastly the fluffy yields are Defuzzified and they are connected to the principle control framework.

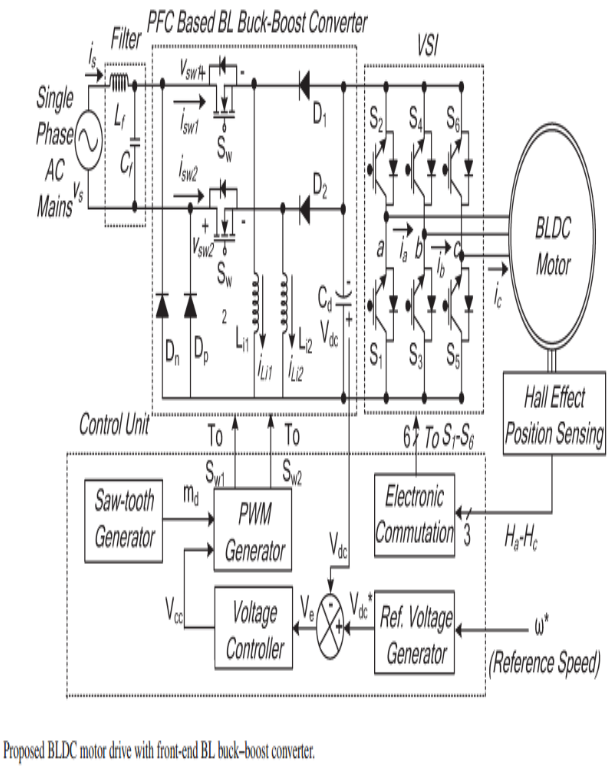


Fig.7. Circuit diagram of PFC based BL Buck-Boost converter fed BLDC motor drive with fuzzy controller.

Error of inputs from their references and error deviations in any time interval are chosen as MATLAB. The output of fuzzy controller is the value that should be added to the prior output to produce new reference output.

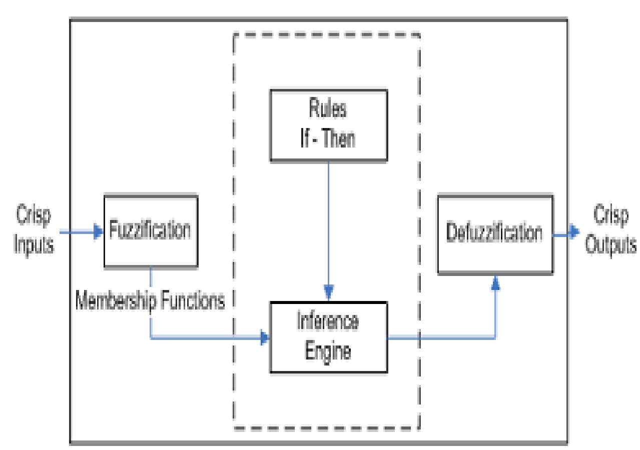


Fig.8. Block Diagram of fuzzy logic controller.

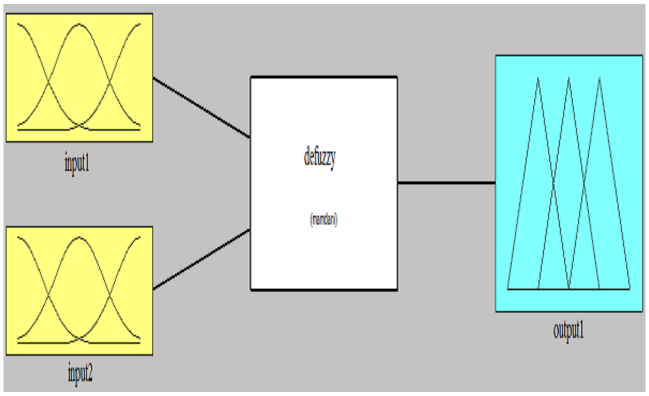


Fig.9. Selection of input and output variables.

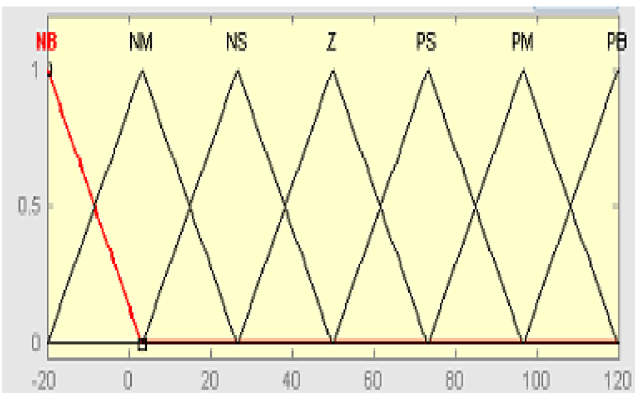


Fig.10. Input1 membership function.

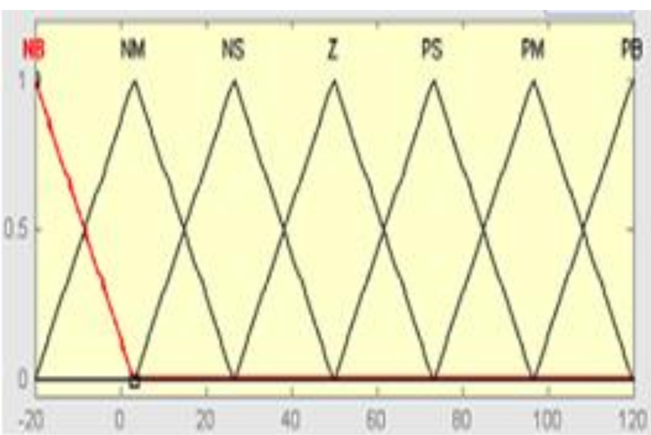


Fig.11. Input 2 membership function.

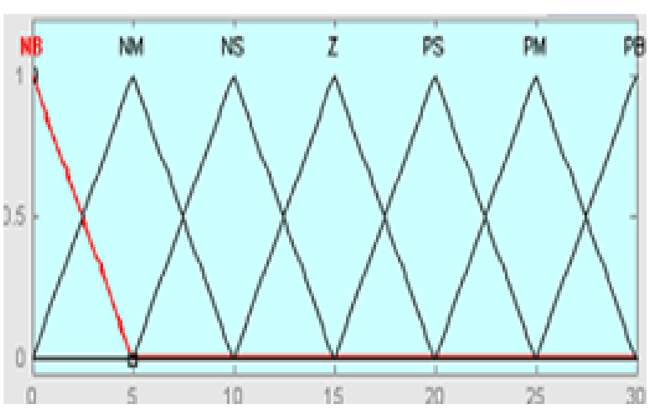


Fig.12. Output membership function.

V. MATLAB/SIMULINK RESULTS

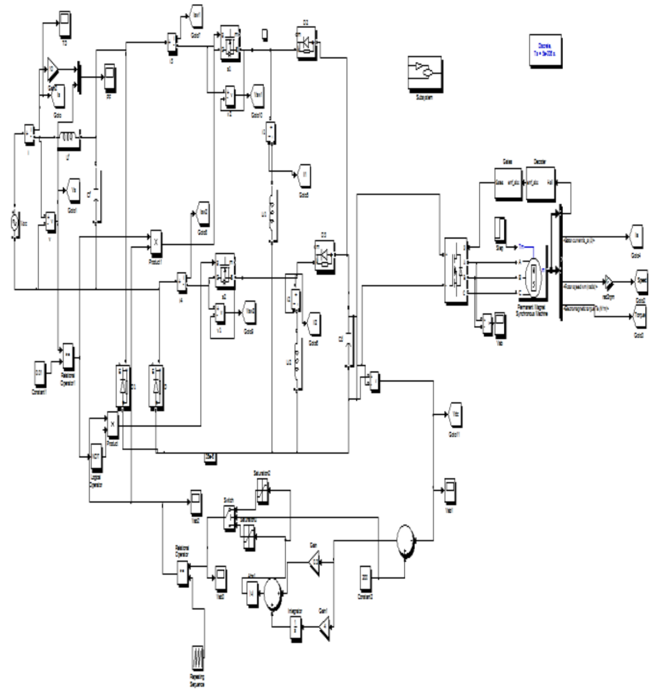


Fig.13.Simulink circuit for BLDC drive with bridgeless PFC based buck boost converter.

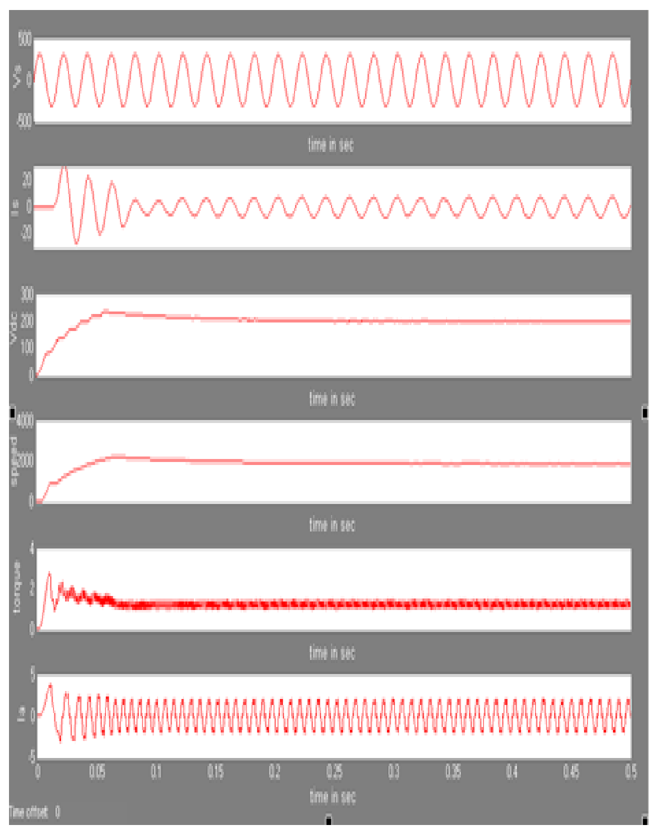


Fig.14.Siumulation results for source voltage, current, dc link voltage, and speed, torque, stator current of BLDC motor under steady state performance.

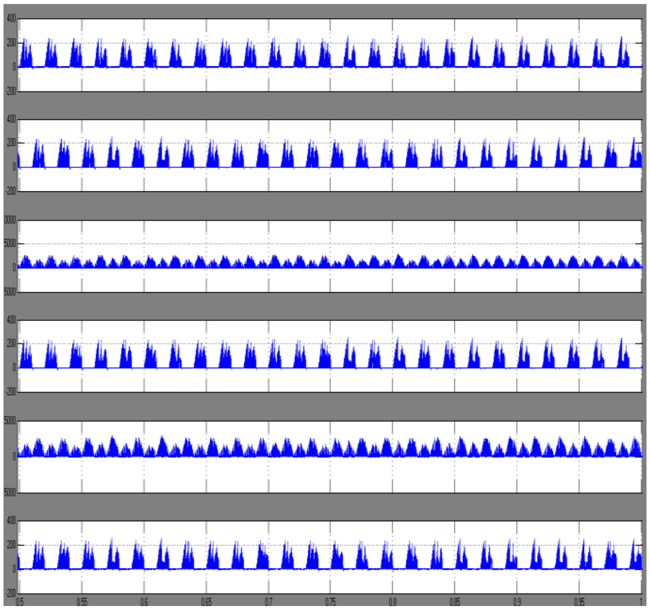


Fig.15.Simulation results for i_{Li1}, i_{Li2}, V_{sw1}, i_{sw1}, V_{sw2}, i_{sw2} of PFC converter under steady state performance.

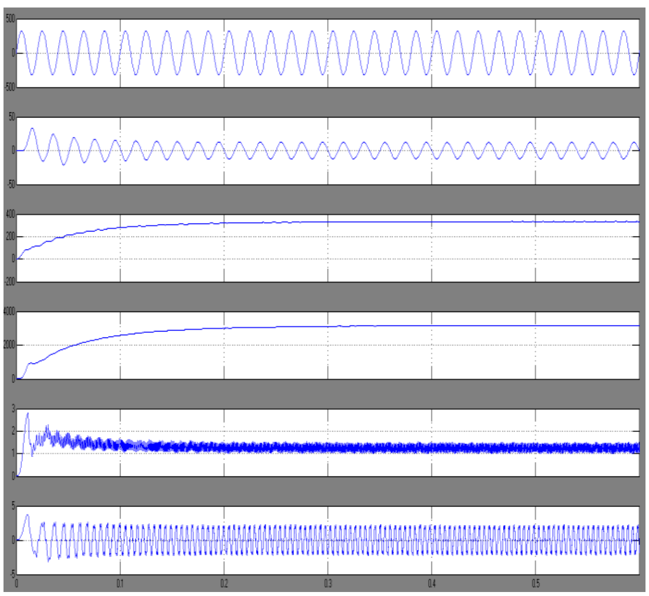


Fig.16.Simulation result of dynamic performance of system during starting.

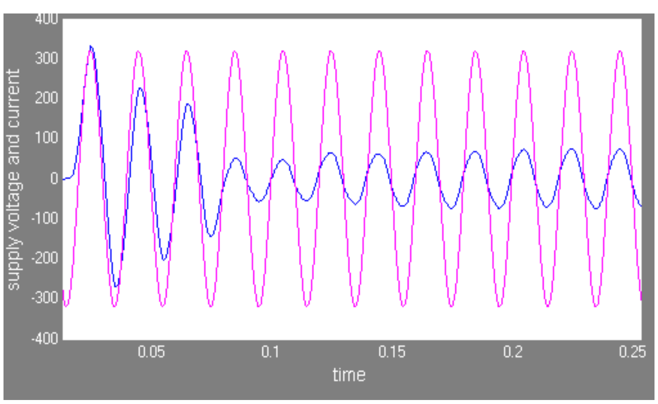


Fig.17. Simulation of input power factor.

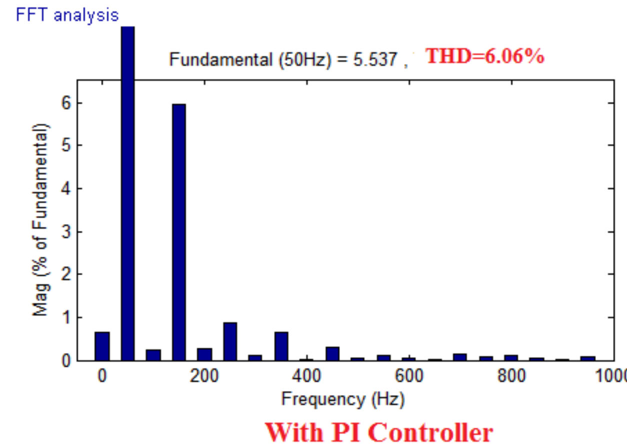


Fig.18. Harmonic spectra in supply current by using PFC based BL Buck-Boost converter fed BLDC motor.

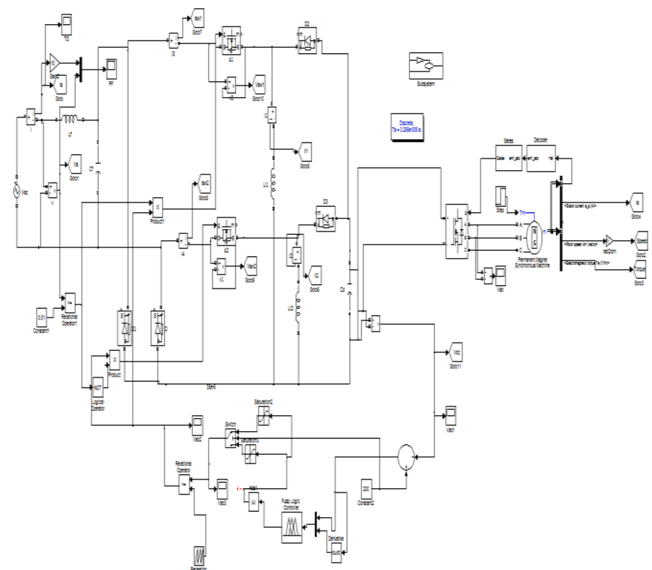


Fig.19. Simulink circuit for proposed system by using fuzzy controller.

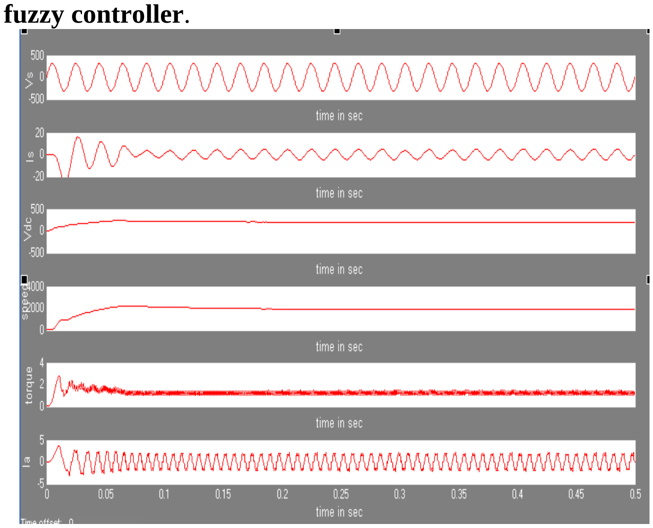


Fig.20. Simulation results for source voltage, current, dc link voltage, and speed, torque, when (w*=2000rpm) stator current using fuzzy logic controller under steady state performance.

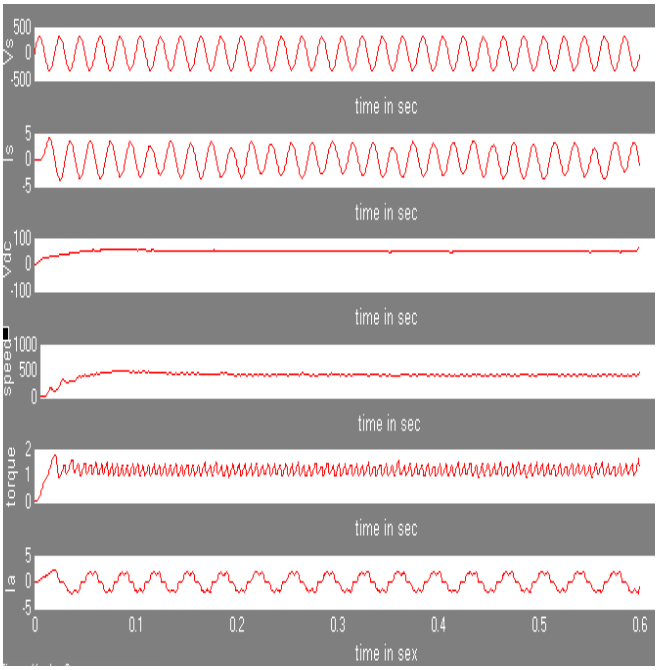


Fig.21. Simulation results for source voltage, current, dc link voltage, and speed, torque, when (w*=500rpm) stator current using fuzzy logic controller.

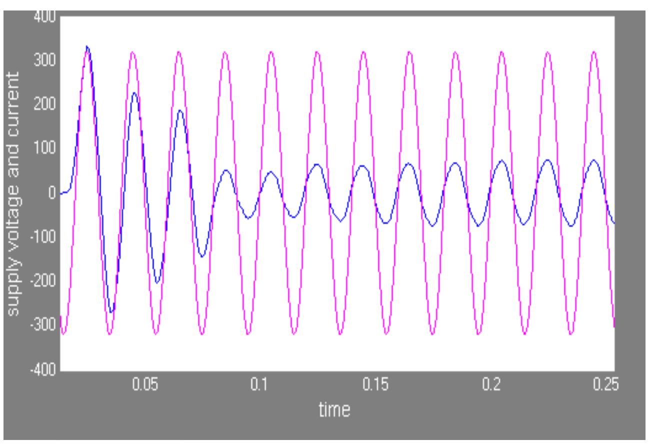


Fig.22. Simulation result of input power factor.

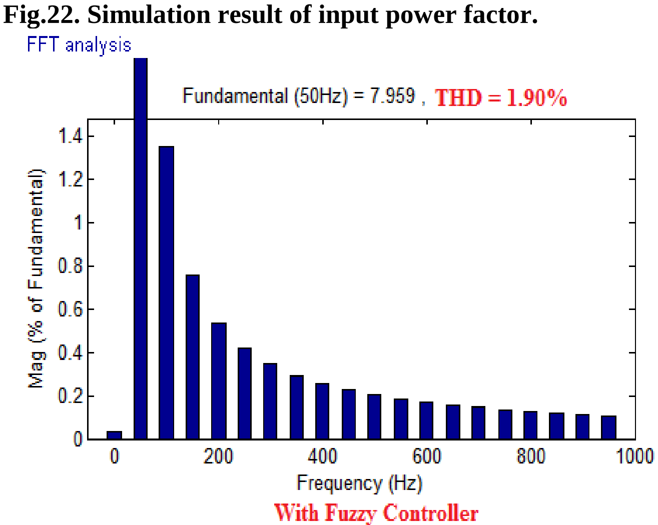


Fig.23. Harmonic spectra in supply current using PFC BL-Buck-Boost converter and fuzzy logic controller.

VI. CONCLUSION

A PFC based BL buck–boost converter-based VSI-fed BLDC motor drive using fuzzy logic controller has been proposed targeting low-power applications. A new method of speed control has been utilized by controlling the voltage at dc bus and operating the VSI at fundamental frequency for the electronic commutation of the BLDC motor for reducing the switching losses in VSI. The front-end BL buck–boost converter has been operated in DICM for achieving an inherent power factor correction at ac mains. A satisfactory performance has been achieved for speed control and supply voltage variation with power quality indices within the acceptable limits of IEC 61000-3-2. Moreover, voltage and current stresses on the PFC switch have been evaluated for determining the practical application of the proposed scheme. By comparing the both the controllers with their THD's observe that using Fuzzy logic controller THD is reduced from 6.06% to1.90% and power factor is maintained near to unity.

VII. APPENDIX

BLDC Motor Rating: four poles, Prated (rated power) = 251.32W, Vrated (rated dc link voltage)=200V, Trated (rated torque)= 1.2N • m, ωrated(rated speed)=2000 r/min, Kb(back EMF constant) =78 V/kr/min, Kt(torque constant=0.74 N • m/A, Rph(phase resistance)=14.56Ω, Lph (phase inductance) = 25.71 mH, and J (moment of inertia)= 1.3 ×10−4 Nm/A2.

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