# Converter fed PMBLDCM Drive with Reduced Switches for Adjustable Speed Applications

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***Abstract*** **–This paper presents a buck-boost converter configuration, control scheme, reduction of switches on inverter and design of single phase power factor controller for permanent magnet brushless DC motor (PMBLDCM) drive. PMBLDC motors are the latest choice of researchers, due to the high efficiency, silent operation, compact size, high reliability, and low maintenance requirements. The proposed Power Factor Controller topology improves power quality by improving performance of PMBLDCM drive, such as reduction of AC main current harmonics, near unity power factor. PFC converter forces the drive to draw sinusoidal supply current in phase with supply voltage. The buck boost converter is operated with voltage follower control in discontinuous conduction mode (DCM) operation for sensor reduction to obtain unity power factor with improved performance. The system includes a speed controller for PMBLDC drive and a voltage controller for buck-boost converter .The voltage or speed controllers can be realized using proportional integral (PI) controller. Simulations are done using MATLAB SIMULINK software.**

**Keywords –** *PFC converter, reduced sensor, reduced switches, speed controller, PMBLDC motor.*

## I.INTRODUCTION

BLDC motors are widely used in industries such as Appliances, Consumer, Automotive, Medical, Aerospace, Industrial Automation and Instrumentation. Usually, the low-power adjustable speed drives are powered from single-phase AC mains through a diode bridge rectifier with smoothening DC capacitor and voltage source inverter. The AC mains current waveform, is far from sinusoidal, because of the fact that, the DBR does not draw any current from the AC network when the AC voltage is less than the DC link voltage, as the diodes are reverse biased during that period; however, it draws a peak current when the AC voltage is higher than the DC link voltage. This result in a pulsed input current Waveform featuring a peak value higher than the peak of the fundamental input current, thereby total harmonic distortion (THD) increases .In this paper a buck boost fed PFC converter is connected between the VSI and the DBR fed from a single phase AC supply to provide controlled voltage at DC link. The power factor (PF) at AC mains is improved through high frequency switching. The buck boost PFC converter is designed for DCM operation to result in reduced sensor requirement with the desired speed control. To minimize the cost of the drive the switches are reduced on inverter topology.

## II. PFC CONTROLLER FOR BUCK-BOOST CONVERTER BASED PMBLDCM DRIVE

The proposed PFC control scheme consists of a voltage control loop only and operated using voltage follower approach with discontinuous mode (DCM) operation of the DC-DC converter. Fig 1 shows the schematic of the proposed buck-boost PFC converter based PMBLDCM drive with voltage follower control. The proposed controller is operated to maintain a constant DC link voltage $V_{dc}$ with PFC action at AC mains. The DC link voltage $V_{dc}$ is sensed and compared with a reference voltage $V^*_{dc}$ which results in a voltage error. The voltage error is passed through a voltage controller to give the modulating current signal which is amplified and compared with saw-tooth carrier wave of fixed frequency ($f_s$) to generate a pulse width modulated (PWM) signal for the switching device of the DC-DC converter. The voltage follower control has inherent feature of power factor correction when operated under steady state condition.

For the speed control, the speed signal derived from rotor position of the PMBLDCM, sensed using Hall effect sensors, is compared with a reference speed. The resultant speed error is passed through a speed controller to get the torque equivalent which is converted to an equivalent current signal using motor’s torque constant.

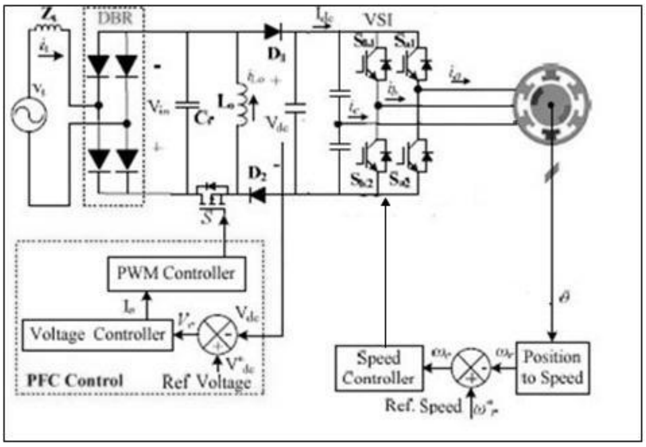


Fig. 1: Control schematic of non-isolated buck-boost PFC converter fed PMBLDCM drive with voltage follower control

This current signal is multiplied with a rectangular unit template waveform which is in phase with top flat portion of motor's back EMF so that reference three phase currents of the motor are generated. These reference currents are compared with the sensed motor currents and current errors are generated which is amplified and compared with triangular carrier waves to generate the PWM signals for the VSI switches.

## III. OPERATION OF THE PROPOSED PMBLDCM DRIVE

The modelling of proposed PMBLDCM drive involves modelling of the PFC converter and PMBLDCM drive. These components are modelled in the form of mathematical equations and the complete drive is represented as a combination of these models.



1. DIODE BRIDGE RECTIFIERS

The entire circuit comprises of VSI-based topology, employed to execute PFC operation involves outer voltage loop. The complete control scheme circuit diagram is shown in with a DBR connected to single-phase AC mains, followed by a Buck-Boost Converter and output ripple filters**.** This diode bridge rectifier converts ac supply to dc supply which follows the equation

$$V_{in} = 2\sqrt{2}V_s/\pi \quad (1)$$

2. BUCK BOOST CONVERTER

A Buck-Boost converter is used as a PFC converter, connected between the VSI and the DBR fed from a single phase AC supply to provide controlled voltage at DC link while improving the power factor (PF) at AC mains

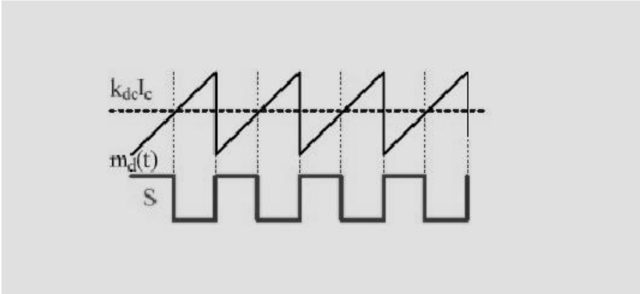


Fig. 2: PWM controller signals of buck-boost PFC converter

through high frequency switching. The buck-boost PFC converter is designed for DCM operation to result in reduced sensor requirement with the desired speed control. The output voltage (V dc) of the buck-boost PFC converter is given as,

$$V_{dc} = D\,V_{in}/(1-D) \quad (2)$$

D-Duty cycle of the converter

3. VOLTAGE CONTROLLER

For the Voltage Controller, the DC link voltage is sensed and compared with the reference DC link voltage. The error voltage is passed through a PI Controller, and multiplied with a unit template of absolute input voltage so as to generate the reference current signal. This signal is compared with sensed converter current which gives the modulating wave for the PWM. This current error is the modulating signal and a triangular wave is taken as the carrier signal so as to generate the PWM gate pulses for turning on/off the Buck Boost converter switch.

$$V_e(k) = V^*_{dc}(k) - V_{dc}(k) \quad (3)$$

The output of the controller $I_c(k)$ at $k^{th}$ instant is given as,

$$I_c(k) = I_c(k-1) + K_{pv}\{V_e(k) - V_e(k-1)\} + K_{iv}V_e(k) \quad (4)$$

The output of PI controller is amplified by gain k dc and compared with fixed frequency (f s) saw-tooth carrier waveform $m_d(t)$ to get the switching signals for the MOSFET of the buck-boost PFC converter.

4. VOLTAGE SOURCE INVERTER

The control of PMBLDC motors can be accomplished by control algorithms using conventional six pulse inverters which can be either VSI or CSI. The control of these inverters for PMBLDCM needs rotor position information only at the commutation points, for example, every 60° electrical in the three phases; therefore comparatively simple controller is required for commutation and control. The rotor position is sensed using Hall Effect sensors. The speed of the motor is measured and is compared with the reference speed. The error signal is passed through a PI controller to give a reference signal. This reference signal is compared with the Buck-Boost converter output current so as to give modulating signal for PWM. This signal is compared with triangular carrier signal to generate the PWM pulses for turning on/off the VSI switches.

5. SPEED CONTROLLER

The modelling of PMBLDC motor drive includes the modelling of a speed controller. Each of the above components of PMBLDCM drive can be modelled by mathematical equations and combination of such models represent complete PMBLDCM drive. The modelling of a speed controller is of prime importance as the performance of the system depends on this controller. Assuming that at $k^{th}$ instant of time $w_r$ (k) is the actual rotor speed, $w_r$*(k) is the reference speed, then the speed error $w_e$ (k) can be calculated as

$$W_e(k) = w_r^*(k) - w_r(k) \quad (5)$$

A speed controller is used to process this speed error to obtain desired control signal. The speed controller's output at kth instant T (k) is givenas,

$$T(k) = T(k-1) + k_{pw}\{w_e(k) - w_e(k-1)\} + k_{iw}\, w_e(k) \quad (6)$$

where $k_{pw}$ and $k_{iw}$ are the proportional and integral gain of the PI speed controller.Thus the Operation of PMBLDC motor at constant torque and a variable speed is achieved by the above circuit operation.

## IV.CIRCUIT AND SIMULATION

The proposed PMBLDCM drive is modelled in Matlab-Simulink environment and performance evaluation is shown below.For performance of the non-isolated buck-boost PFC converters fed PMBLDCM drive a PMBLDCM of 2 hp, 5.2 Nm rated torque is considered in this work. The performance of the PFC converters based PMBLDCM drive is simulated for the rated torque (5.2 Nm) at various speeds and input AC voltages while keeping DC link voltage constant at 300 V. The controller parameters are tuned to get the desired PQ indices. The performance evaluation is made on the basis of various PQ indices i.e. current total harmonic distortion ($THD_i$) at input AC mains, distortion factor (DF), displacement power factor (DPF), power factor (PF), crest factor (CF) and voltage ripple at DC link ($V_{dc}$). The results are presented in Figs. 4-8 to demonstrate the effectiveness of the proposed PFC drive under speed controloperation of the induction motor in which the motor's actual running speed is compared with a base speed, in this case 1150 rpm.

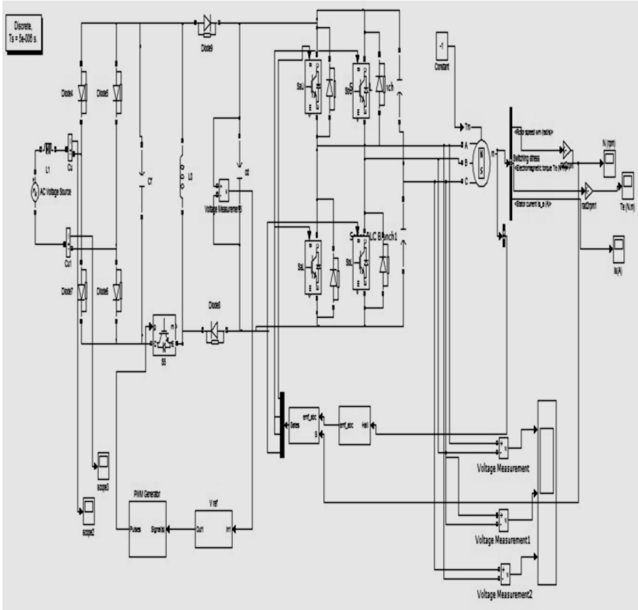

Fig. 3: Simulation Diagram



A. Performance during Starting

The performance of the proposed PMBLDCM drive fed from a 220 V AC mains during starting at rated torque and1150 rpm speed is shown in Fig.5. It is observed that themotor attains a reference speed smoothly while keeping the stator current and electromagnetic torque within the specified limits i.e. double the rated value. The current waveform atinput AC mains ($i_s$) is in phase with the supply voltage ($v_s$) and the buck-boost PFC converter maintains good power factor during the starting period.

B. Performance under Speed Control

Fig.5 shows the performance of the proposed PMBLDCM drive under the speed control at a constant rated torque (5.2 Nm) and at a 220 V AC mains supply voltage. The results are presented for speed control for 1150 rpm. The speed is controlled smoothly in either direction while maintain power factor near unity under these conditions.

C. Power Quality Performance

The performances of the proposed PMBLDCM drive in terms of THDi at AC mains are shown in Fig. 6 under steady state conditions at 1150 rpm.

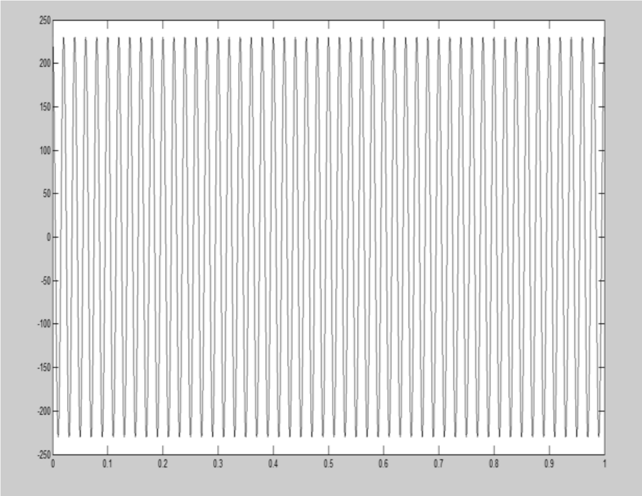

Fig. 4: Input voltage waveform

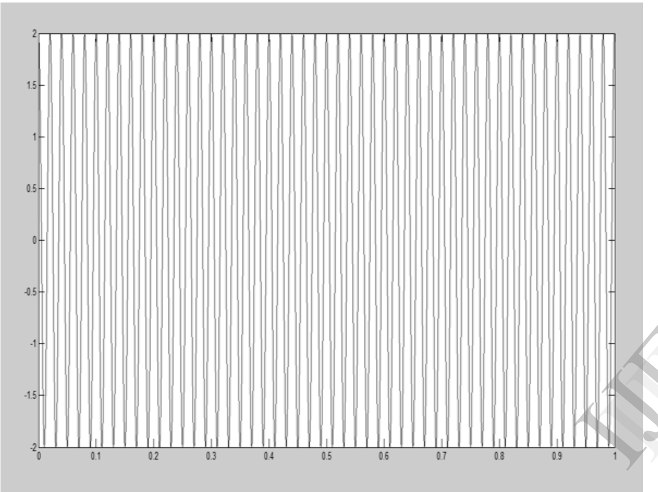

Fig. 5: Input current waveform

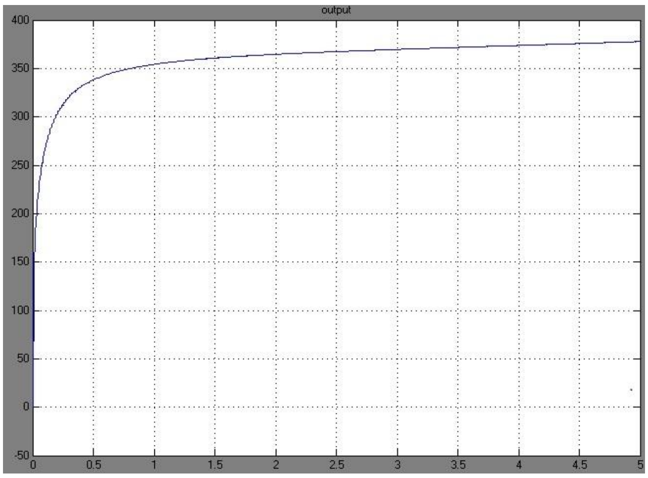


Fig 6: Output voltage of Buck Boost converter.

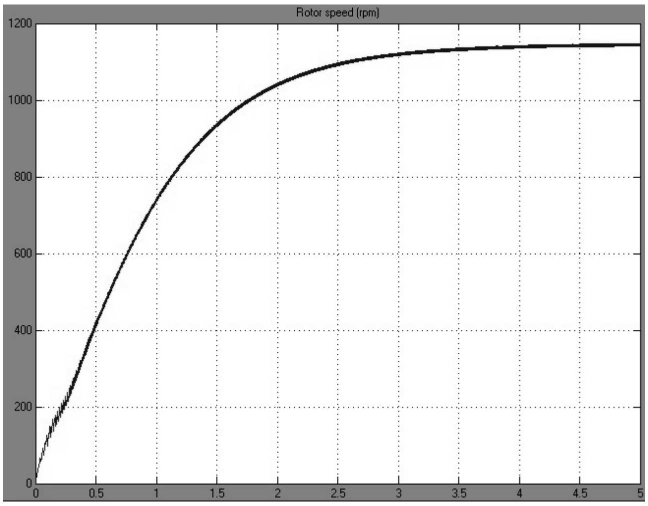


Fig. 7: Output speed waveform

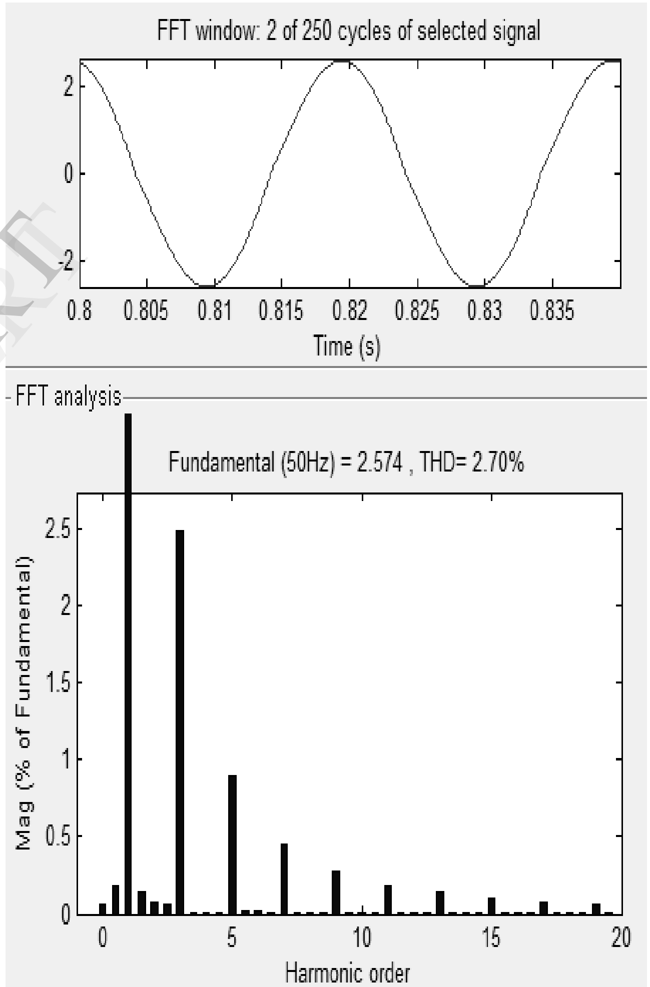


Fig. 8: Current at AC mains and its harmonic spectra of Buck Boost PFC converter Feeding PMBLDCMdrive.

## IV.ADVANTAGES AND APPLICATIONS

A. Advantages

**1.)**The proposed buck-boost PFC converter based PMBLDCM drive is operated with voltage follower control does not require input current template sensor and input current sensor as required for the PMBLDCM drive with current multiplier control. The proposed controller is operated to maintain a constant DC link voltage (V dc) with PFC action at AC mains.

2.)High efficiency

3.)Long life

4.) The qualities of a permanent magnet brushless DC motor (PMBLDCM) such as wide speed range, high efficiency, rugged construction and ease of control, make it suitable for air-conditioning compressor application.

5.) Low operating cost

6.) Easy to charge

7.) High power quality

B. Applications

BLDC motors find applications in every segment of the market:

1.)Automotive

2.)Appliance

3.) Industrial controls

4.) Automation

5.) Aviation

## V.CONCLUSION

The PFC converter topology for Power quality improvement in PMBLDC motor drives is designed and their performance is simulated to provide in depth understanding on various aspects of these drives. The performance of this topology has been evaluated through simulation for validation of their designs. Buck Boost PFC topology is used as this is the best option for applications having rated DC voltage higher than single phase supply RMS voltage. The PFC feature of the buck-boost converter has ensured near unity power factor in wide range of the speed and an input AC voltage. Moreover, Power quality parameters of the proposed PMBLDCM drive are in conformity to the international standard IEC 61000-3-2. The proposed drive has demonstrated very good performance with reduced sensor as a variable speed drive for small air conditioner having improved power quality at input AC mains.

The reduction of switches on inverter topology further reduces the cost of drives. The PMBLDCM drives incorporating PFC converter can be a milestone towards the widespread application of these drives.

## APPENDIX

PMBLDCM rating; power:2hp, rated torque: 5.2 Nm, poles:4,resistance:1.78 ohm/ph., inductance(L+M):0.01859 H/ph., back EMF constant ($K_b$):1.23Vsec/rad, moment of inertia (J)=0.013Kg-m$^2$.Source impedance ($Z_s$): 0.03 pu, switching frequency of PFC switch ($f_s$) = 40kHz, filter inductor ($L_f$) =15mH, capacitor ($C_f$) = 150nF.

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