ADAPTIVE POWER QUALITY IN BLDC MOTOR FOR BUCK DC-DC CONVERTER

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ABSTRACT

The techniques to improve the power quality of BLDC motor drive by power factor correction play an important role in the energy saving during energy conversion. The ac-dc conversion of electric power is usually required for BLDC motor drive; nevertheless, it causes many current harmonics and results in the poor power factor at input ac mains. This paper deals with a buck dc-dc converter as a single-stage power factor correction (PFC) converter for a permanent magnet brushless dc Motor (PMBLDCM) fed through a diode bridge rectifier (DBR) from a single-phase AC mains. The buck converter show conformity to international power quality standards with improved performance of PMBLDC Motor drive, such as reduction of AC main current harmonics, near unity power factor and reduction of speed and torque ripples. A Three-phase voltage source inverter is used as an electronic commutator to operate the PMBLDC Motor. The proposed PMBLDC Motor drive is designed, Modeled and its performance is evaluated in PSIM. The obtained results are presented to demonstrate an improved power quality (PQ) at AC mains of the PMBLDC Motor drive system.

Keywords: Brushless dc Motor (BLDCM), Diode bridge rectifier (DBR), Power factor correction (PFC), Voltage source inverter (VSI), Total Harmonic Distortion (THD).

I. INTRODUCTION:

In recent year brushless dc (BLDC) motors are widely used in a Aerospace, Automotive, Consumer, Medical, Industrial automation equipment and Instrumentation, because of their high efficiency, high starting torque, reliability, lower maintenance compared to its brushed dc motor [2].

A BLDC motor has permanent magnets which rotate and a fixed armature, eliminating the problems of connecting current to the moving armature. The brushless dc motor is actually a permanent magnet AC motor whose torque- current characteristics mimic the dc motor. Instead of commutating the armature current using brushes, electronic commutation is used. This eliminates the problems associated with the brush and the commutator arrangement, thereby making a BLDC more rugged as compared to a dc motor. Having the armature on the stator makes it easy to conduct heat away from the windings and if desired, having cooling arrangement for the armature windings is much easier as compared to the dc motor. The commutation in a BLDC Motor is accomplished by solid state switches of a three-phase voltage source inverter (VSI). Brushless DC Motors can in many cases replace conventional DC Motors. BLDC motors are available in many different power ratings from very small motors as used in hard disk drives to large motors in electric vehicles.

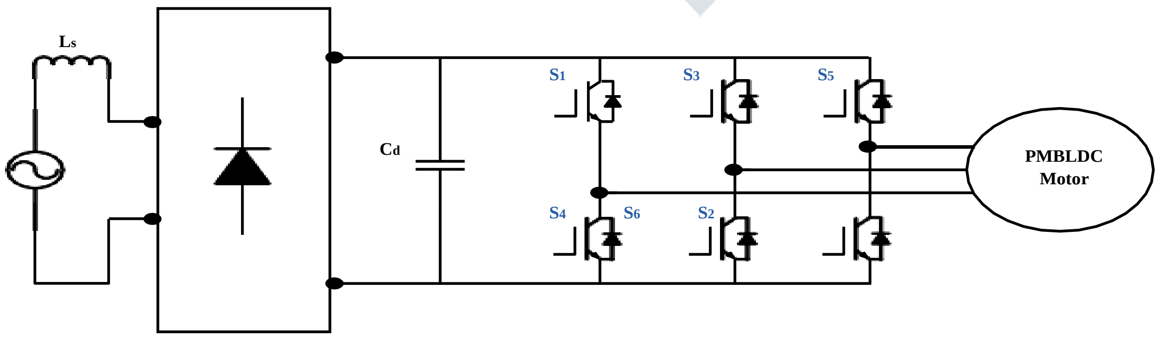


Figure 1: Single phase DBR fed VSI based PMBLDC Motor drive

A BLDC motors are powered from single-phase AC mains through a diode bridge rectifier (DBR) with smoothening DC capacitor and voltage source inverter (VSI). Figure-1 shows the DBR-VSI fed BLDC motor drive with DC link capacitor. The motor drive draws a pulsed current from AC mains because of DC link capacitor. However, it draws a large current when the AC voltage is higher than the dc link voltage. Therefore, many Power Quality (PQ) problems arise at input AC mains and they are undesirable. The requirement of improved power quality at the AC mains is becoming essential for any appliance as imposed by the International Power Quality Standards like IEC 61000-3-2, IEEE-519, and IEC 555-2[3].

In this paper a buck DC-DC converter is used as a PFC converter because of its input and output filters improve its performance in terms of THD of AC mains and ripples at DC output voltage[3].

PSIM is a simulation package specifically designed for power electronics and motor control, with fast simulation, friendly user interface and waveform processing. PSIM provides a powerful simulation environment for power converter analysis, control loop design, and motor drive system studies. PSIM supports links to third-party software like JMAG, MATLAB through Simcoupler blocks. And also we can use the C code in either the power circuit or the control circuit through DLL (Dynamic Link Library) block. The external DLL blocks allow writing one's C language, compiling it into DLL using either Microsoft C/C++ or Borland C++, and linking it with PSIM[6].

1. BUCK CONVERTER FED PMBLDC MOTOR

Buck converters are known as step down converters. In a step-down converter the input voltage always exceed the output voltage for the devices to remain in regulation. Figure 2 shows circuit diagram of Buck converter.

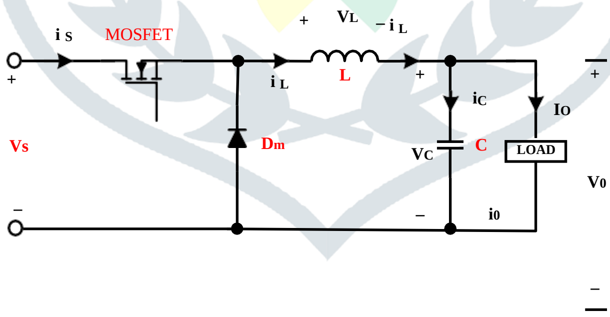


Figure 2: Circuit diagram of Buck Converter

The circuit operation can be divided into two modes. Mode 1 begins when transistor is switched ON, the input current, which rises, flow through filter inductor L, filter capacitor C, and Load. Mode 2 begins when transistor is switched OFF, the freewheeling diode D_m conducts due to energy stored in the inductor and the inductor current continues to flow through L, C, load and diode D_m. The inductor current falls until transistor is switched ON again in the next cycle[4].

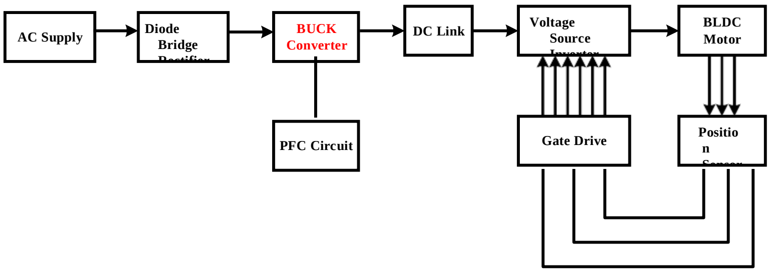


Figure 3: Block Diagram of Buck Converter Fed BLDC Motor Drive

Figure 3 shows the block diagram for power factor corrected BLDC Motor drive. The Buck DC-DC converter controls the dc link voltage. In this topology, a conventional DBR fed from single-phase AC mains. Its output is given to a DC-DC converter, and a VSI is used to feed the BLDC Motor. The DC-DC converter provides a controlled DC voltage from uncontrolled DC output of DBR, while controlling the power factor through high frequency switching of the PFC switch.

II. MATHEMATICAL MODELING OF PMBLDC MOTOR

The PMBLDC Motor is modeled in the form of a set of differential equations given as,

$$V_{an} = Ri_a + p\lambda_a + e_{an} \quad (1)$$
$$V_{bn} = Ri_b + p\lambda_b + e_{bn} \quad (2)$$
$$V_{cn} = Ri_c + p\lambda_c + e_{cn} \quad (3)$$

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 resistance per phase, i_a, i_b and i_c are currents, e_{an}, e_{bn}, e_{cn} represents back emf and λ_a, λ_b, λ_c represents flux linkages. , V_{an}, V_{bn} and V_{cn} is also given as,

$$V_{an} = V_{ao} - V_{no}, V_{bn} = V_{bo} - V_{no}, \text{ and } V_{cn} = V_{co} - V_{no} \quad (4)$$

Where V_{ao}, V_{bo}, V_{co} are the three phase voltages and V_{no} is the neutral voltage referred to the zero reference potential as shown in Figure 4.

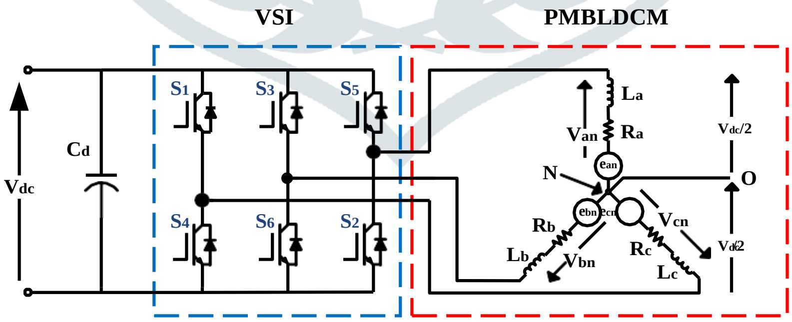


Figure 4: Equivalent circuit of a VSI fed PMBLDC Motor drive

Moreover, the flux linkages can be represented as,

$$\lambda_a = L_s I_a - M (i_b + i_c) \quad (5)$$
$$\lambda_b = L_s I_b - M (i_a + i_c) \quad (6)$$
$$\lambda_c = L_s I_c - M (i_b + i_a) \quad (7)$$

Where L_s is the self inductance per phase and M is the mutual inductance of the windings.
Since PMBLDC Motor has no neutral connection, so,

$$i_a + i_b + i_c = 0 \tag{8}$$

The potential of neutral terminal with respect to zero potential (V_{no}) is required to be considered in order to avoid unbalance in applied voltage. Substituting equation (4) in (1) to (3) and adding them together give,

$$V_{ao} + V_{bo} + V_{co} - 3V_{no} = R(i_a + i_b + i_c) + (L_s + M)(pi_a + pi_b + pi_c) + (e_{an} + e_{bn} + e_{cn}) \tag{9}$$

Substituting equation (8) in equation (9) one gets,

$$V_{ao} + V_{bo} + V_{co} - 3V_{no} = (e_{an} + e_{bn} + e_{cn}) \tag{10}$$

From (5) – (8), the flux linkages are given as,

$$\lambda_a = (L_s + M)\, i_a, \quad \lambda_b = (L_s + M)\, i_b, \quad \lambda_c = (L_s + M)\, i_c \tag{11}$$

From generalized equation by using equations (1)-(3) and (11).

$$pi_a = \frac{(V_{an} - Ri_a - e_{an})}{(L_s + M)} \tag{12}$$

$$pi_b = \frac{(V_{bn} - Ri_b - e_{bn})}{(L_s + M)} \tag{13}$$

$$pi_c = \frac{(V_{cn} - Ri_c - e_{cn})}{(L_s + M)} \tag{14}$$

The developed electromagnetic torque T_e in the PMBLDC Motor is given as,

$$T_e = \frac{(e_{an} i_a + e_{bn} i_b + e_{cn} i_c)}{\omega_r} \tag{15}$$

The expression for the torque faces computational difficulty at zero speed as induced emf are zero. Hence, it is reformulated by expressing back-emf as a function of rotor position θ, which can be written as,

$$e_{an} = K_b f_a(\theta)\, \omega_r \tag{16}$$

$$e_{bn} = K_b f_b(\theta)\, \omega_r \tag{17}$$

$$e_{cn} = K_b f_c(\theta)\, \omega_r \tag{18}$$

Substituting equation (16)-(18) into equation (15) the torque expression become,

$$T_e = K_b\{f_a(\theta)\, i_a + f_b(\theta)\, i_b + f_c(\theta)\, i_c\} \tag{19}$$

Where K_b is the back emf constant and $f_a(\theta)$, $f_b(\theta)$, and $f_c(\theta)$ are rotor position function having a maximum magnitude of plus or minus 1 and given as,

$$f_a(\theta) = 1 \qquad \text{for } 0 < \theta < 120^{\circ} \tag{20}$$

$$f_a(\theta) = \{(6/\pi)(\pi - \theta)\} - 1 \qquad \text{for } 120^{\circ} < \theta < 180^{\circ} \tag{21}$$

$$f_a(\theta) = -1 \qquad \text{for } 180^{\circ} < \theta < 300^{\circ} \tag{22}$$

$$f_a(\theta) = \{(6/\pi)(\theta - 2\pi)\} + 1 \qquad \text{for } 300^{\circ} < \theta < 360^{\circ} \tag{23}$$

The functions $f_b(\theta)$, $f_c(\theta)$, are similar to $f_a(\theta)$ with a phase difference of 120° and 240° respectively.
The Mechanical equation of motion in speed derivative form is given as,

$$p\omega_r = (P/2)(T_e - T_L - B\omega_r)/(J) \tag{24}$$

Where ω_r is the derivative of rotor position θ, P is number of poles, T_L is load torque in Nm. J is moment of inertia in Kg-m^2 and B is friction coefficient in Nms/Rad. The derivative of rotor position is given as,

$$p\theta = \omega_r \tag{25}$$

Equations (1)-(25) represent the dynamic model of PMBLDC Motor.

III. SIMULATION RESULTS AND DISCUSSION

Figure-5 shows the VSI fed BLDC motor with speed and position feedback. The AC input voltage 220V is converted to DC by using rectifier circuit. The BLDC motor is given supply through the three phase inverter. The controller requires position information from the Hall Effect sensors, as well as monitoring the motor speed. From that information, the controller must be able to determine the appropriate firing angles of the three phase inverter.

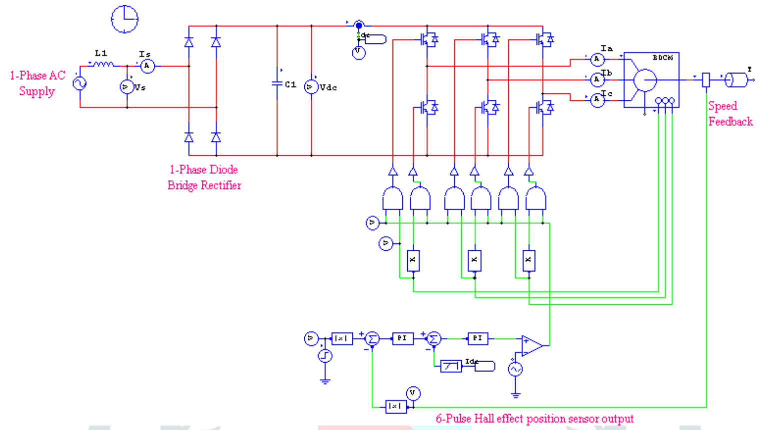
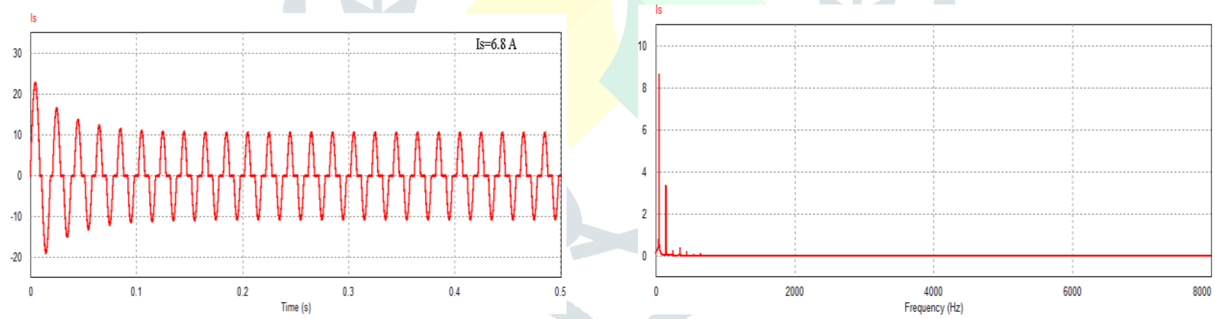


Figure 5: Single-phase DBR fed VSI based PMBLDC Motor drive

The simulation results of supply current waveform are shown in Figure-6.



FFT analysis of Supply Current Is (THD=45.2%)

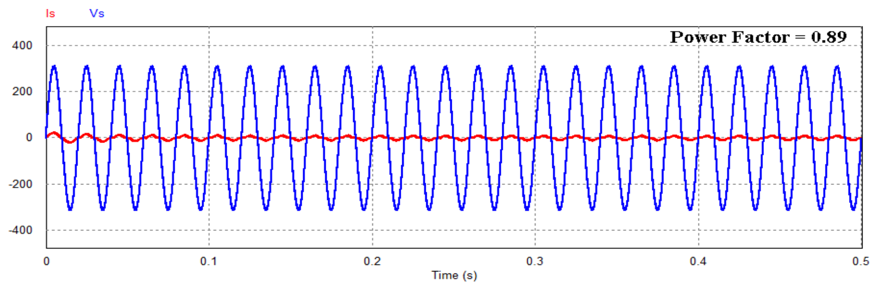


Figure 6: simulation results

Figure 6 shows the simulation of single-phase DBR-VSI fed PMBLDC motor with DC link capacitor. The AC mains current waveform, as shown in Figure 6, 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 peaky current when the AC voltage is higher than the DC link voltage. This results in pulsed input current waveform featuring a peak value higher than the peak of the fundamental input current, thereby, 45.2% total harmonic distortion (THD) in the input current and power factor (PF) of 0.89 at AC mains. The PMBLDC motor have to be operated from utility supply, therefore they should conform to the international Power Quality standards such as IEC 555-2, and IEC 61000-3-2. Total Harmonic Distortion is measured in PSIM using FFT analysis.

A Buck converter forces the drive to draw sinusoidal supply current in phase with the supply voltage. The buck PFC converter is a combination of diode rectifier and step-down current chopper. It uses input and output filters to improve its performance in terms of THD of AC mains and ripples at DC output voltage.

Figure 7 shows the complete simulation model of Buck converter based VSI fed PMBLDC motor.

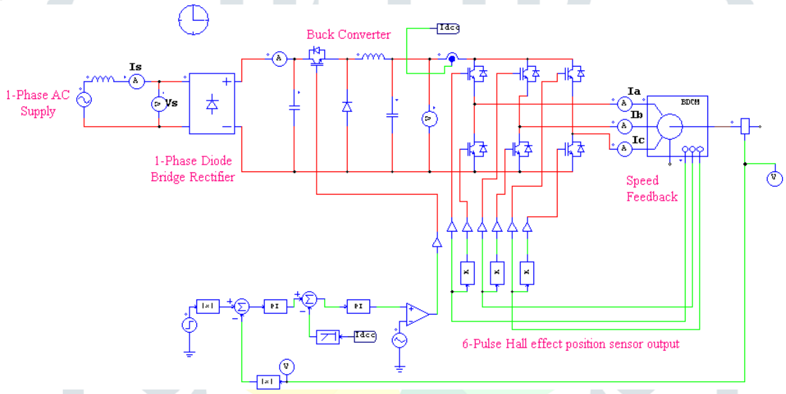
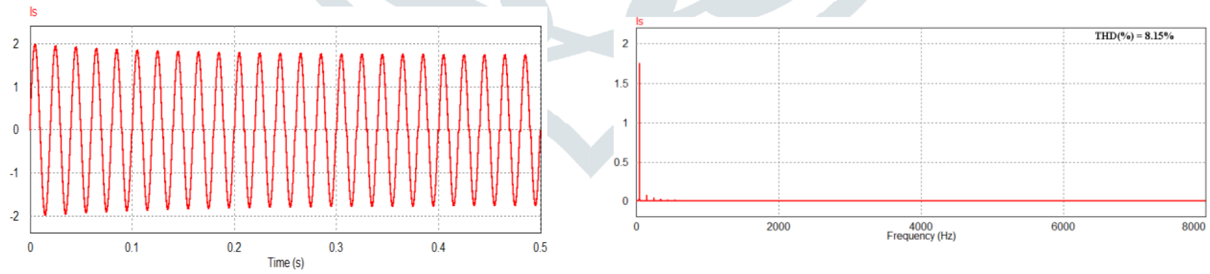


Figure 7: Buck converter based VSI fed PMBLDC motor

The supply current waveform of buck converter based VSI fed PMBLDC motor are shown in Figure-8.



FFT analysis of Supply Current Is (THD=8.15%)

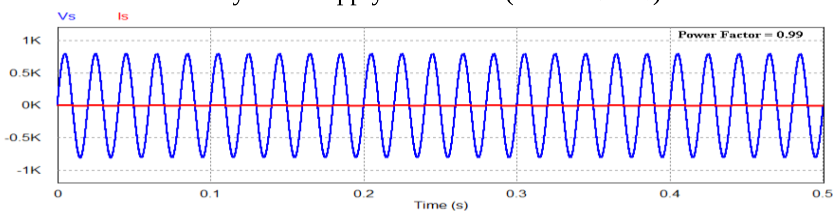


Figure 8: Simulation Results of Buck converter based VSI fed PMBLDC motor

IV. Conclusion

In this paper, the design of a Buck converter fed BLDC motor drive is performed and the study is verified with the simulation results using PSIM software. The speed of BLDC motor drive can be varied by changing the dc link voltage of Buck converter. The results of simulation shows that Total harmonic distortion in AC supply current is reduce and power factor is improved near unity with the help of PFC Buck converter. Moreover, power quality indices of the proposed PFC drive are in conformity to the International Standard IEC 61000-3-2[1].

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