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PMBLDC Motor Drive with Boost Converter as Power Factor Correction Controller

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Abstract: *This paper presents boost converter configuration in permanent magnet brushless DC motor drive to overcome power quality problems at utility of ac mains. The use of this DC-DC boost converter will ensure near unity power factor and reduction of AC mains current harmonics. For this purpose, voltage controller is employed in input side to provide controlled DC link voltage which is applied to BLDC motor through voltage source inverter. Also speed control of PMBLDC motor with maximum torque is to be achieved by using speed controller. This is great significance in variable speed application. Both voltage controller and speed controller is to be realized by using PI controller. Simulations are done using MATLAB/SIMULINK software and result is compared with hardware implementation.*

Keyword: *Boost Converter, Voltage Controller, Speed Controller, PMBLDCM Drive, Power Factor Correction*

1. Introduction

Permanent magnet brushless DC motors are the latest choice of researchers because of its high efficiency, silent operation, compact size, high reliability and low maintenance requirements. It has number of advantage over the brushed DC motor in terms of efficiency. Near about 90% efficiency is achieved by using BLDC motor. Usually PMBLDC motor is employed for low power application which is powered from single phase AC mains through a bridge rectifier with smoothening DC capacitor and voltage source inverter (VSI).

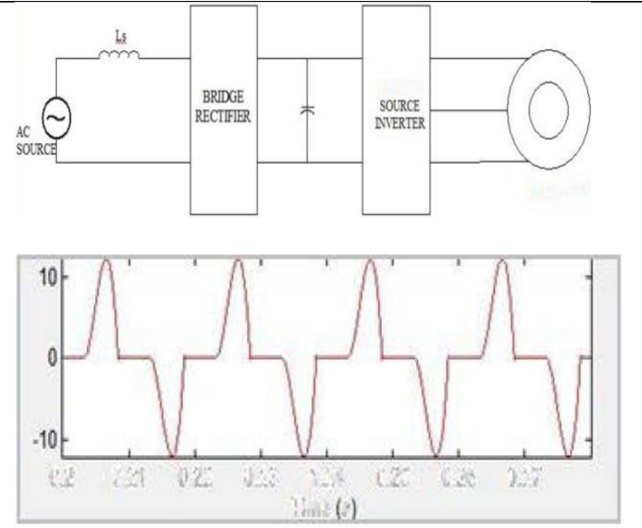

Figure 1

In this configuration, AC main current waveform is non-sinusoidal because diode in bridge rectifier does not draw any current from AC network when AC voltage is less than DC link voltage as diode are reverse biased during that period, also it draws a peaky current when AC voltage is higher than DC link voltage. This will result in pulsed input current waveform which has total harmonic distortion of 72%. So we need to prefer DC –DC converter which forces the drive to draw sinusoidal current in phase with the input AC voltage. Because of that power factor improves which obtains near about unity and also total harmonic distortion reduces to 2% which analyzed with the help of FFT analysis. There are different DC to DC converter is available i.e Boost Converter, Buck Converter, Buck-Boost Converter, Cuk Converter. From that Boost Converter is employed in this proposed work. The permanent magnet brushless DC motor belongs to the three phase synchronous family and that can be categorized as Permanent Magnet Synchronous Motor (PMSM) and PMBLDCM. The continuous rotor position feedback for supplying sinusoidal voltage and current to the motor with sinusoidal back emf is achieved with PMSM to get constant torque with low ripple. In case of PMBLDCM, supply to the motor is provided by three phase rectangular current blocks of 120^0 electrical duration in which back emf is trapezoidal. Therefore PMBLDC motor need rotor position information only at the commutation points i.e every 60^0 electrical in three phases. The rotor position can be sensed using Hall sensors, resolvers, or optical encoders.

2. Review of Boost converter

A boost converter (step up converter) is a DC to DC power converter that steps up voltage (while stepping down current) from its input (supply) to its output (load). It is a class of switched mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage element: a capacitor, inductor, or the two in combination. To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load – side filter) and input (supply –side filter).

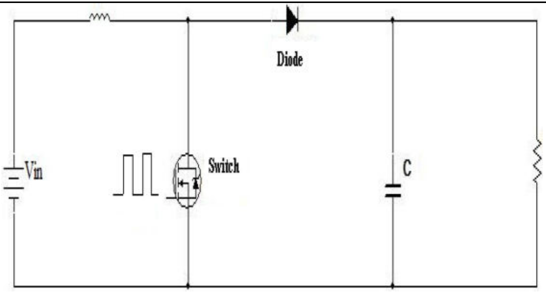

Figure 2

3. Modeling of PMBLDC Motor

The modeling of PMBLDCM drive includes modeling of voltage control loop which consists of voltage controller, PWM controller and speed control loop consists of speed controller, reference current generator and PWM current controller. The modeling of speed controller has more importance as performance of total system depends on this controller. Both voltage controller and speed controller is realized using PI controller.

A] PMBLDCM Drive

Assuming that at t^{th} instant of time, m(t) is actual rotor speed, $m^*(t)$ is the reference speed, then the speed error $m_e(t)$ can be calculated as

$$m_e(t)= m^*(t)- m(t)$$

The speed controller as PI controller is used to process this speed error to get desired control signal.

1. Speed Controller

The PI controller output at t^{th} instant T(t) is given as

$$T(t)=T(t-1)+kp\{ m_e(t)-m_e(t-1)\}+ki\, m_e(t)$$

where kp and ki are proportional and integral gains of the PI controller respectively.

Let $I^*=T(t)/Kb$ where Kb is the back emf constant of the PMBLDCM.

2. Reference Current Generation

The reference phase currents of the motor windings are Ia^*, Ib^* and Ic^* for phases a, b, c, respectively. For duration of $0\text{-}60^0$ the reference currents can be given as

$Ia^*=I^*$, $Ib^*=-I^*$ and $Ic^*=0$

Similarly, the reference currents for other duration can be generated, which will follow the trapezoidal voltage of respective phases. These reference currents are compared with sensed phase currents for error current generation as

$$\Delta Ia= (Ia^*-Ia),\ \Delta Ib= (Ib^*-Ib),\ \Delta Ic= (Ic^*-Ic).$$

3. Current Controller

The switching sequence for the VSI is generated by current controller, after comparing the current error of each phase with fixed frequency carrier waveform. The current errors ΔIa, ΔIb, ΔIc are amplified by gain k1 before comparing with carrier waveform m(t). The switching sequence is obtained based on the logic given for phase 'a' as a reference signal. This reference signal is compared with the 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.

B] PFC Converter

The PFC converter modeling consists of the modeling of a voltage controller and a PWM controller as given below.

1. Voltage Controller

The voltage controller is a proportional-integral (PI) controller which accurately monitors the voltage error and generates control signal (Ic) to minimize the voltage error. If at k^{th} instant of time, E*dc(k) is reference DC link voltage, Edc(k) is sensed DC link voltage then the voltage error Ee(k)
is calculated as,

$$Ee(k) =E^*dc(k)-Edc(k)$$

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

$$Ic (k) = Ic (k-1) + Kpv\{Ee(k) – Ee(k-1)\} + KivEe(k)$$

where Kpv and Kiv are the proportional and integral gains of the voltage PI controller.

2. PWM Controller

The output of PI controller is amplified by gain k and compared with fixed frequency (fs) saw-tooth carrier waveform p(t) to get the switching signals for the MOSFET of the boost PFC converter given as,

If Ic (k) > p(t) then S = 1
If Ic (k) <= p(t) then S = 0

where S is the switching function representing 'on' position of the MOSFET of the PFC converter with S=1 and its 'off'position with S=0.

4. Proposed Model of PMBLDC Drive with PFC Converter

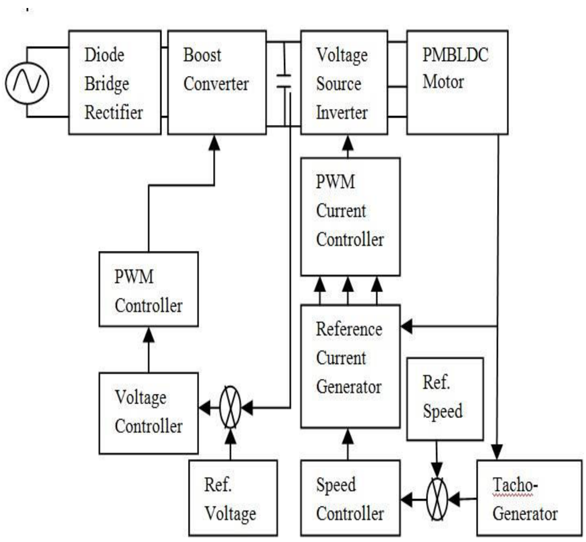

Figure 3

In the proposed PFC converter topology, the boost converter is used to boost the input voltage at appropriate voltage level which is fed to the voltage source inverter. That means voltage supply is given to the BLDC motor through this boost converter and VSI. For the control of voltage at the input side, dc link voltage is sensed and compared with reference voltage that will produce voltage error. This 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 (fs) to generate a pulse width modulated (PWM) signal for the switching device of the DC-DC converter.

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 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. Simulation Results

The proposed boost converter PFC topology for PMBLDCM drive are modeled in MATLAB/ Simulink environment for a voltage source inverter fed PMBLDC motor. Boost PFC topology is evaluated for a dc link voltage of 400V to drive PMBLDC motor with speed ranging from 500rpm to 2000rpm i.e speed is to be controlled without changing power factor in this range. The PI controller is employed for voltage as well as speed control and PWM signal is generated for VSI and PFC converter using 40 kHz triangular carrier waves. The power quality is observed through FFT analysis of source current under steady state condition. Boost PFC converter shows very good response with input AC main current THD of 0.11% along with PF of 0.9994.

The harmonic spectrum in conventional system shows near about 72% total harmonic distortion in AC main current at rated torque. So THD of AC main current is reduced to 0.11% by using Boost PFC topology. The PQ performance analysis of proposed PFC topology shows that the THD of AC mains current always remains within the limit imposed by IEC 61000-3-2 and other international PQ standards.

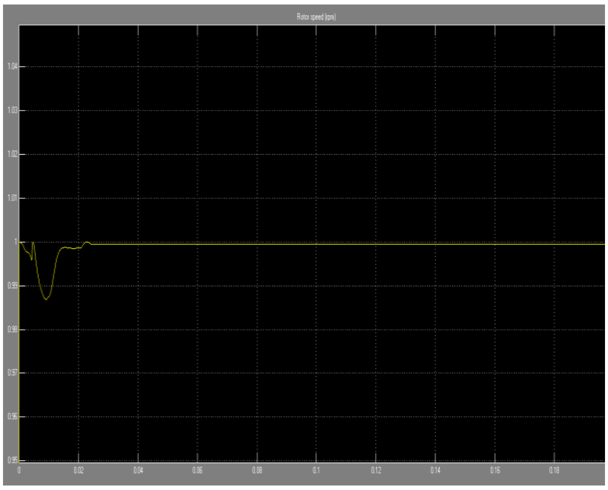

Figure 4: Power Factor

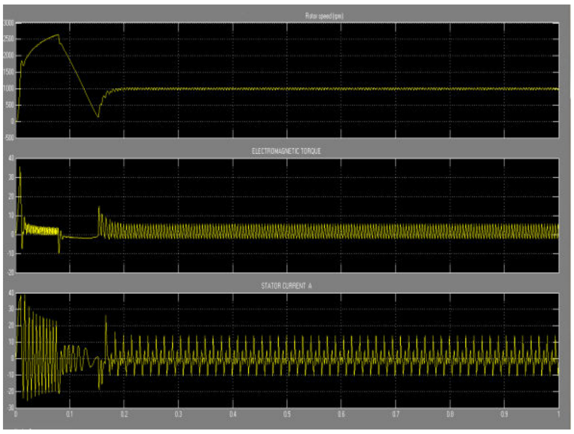

Figure 5: Rotor Speed, Torque and Stator Current

Figure 4 shows unity power at AC mains as source voltage and source current are in phase with each other. This will ensure near unity power factor in variable speed range of application of PMBLDC motor.

Also performance analysis of PMBLDC motor is observed in terms of smooth speed variation of motor, low torque ripples and reduced stator current in Figure 6.

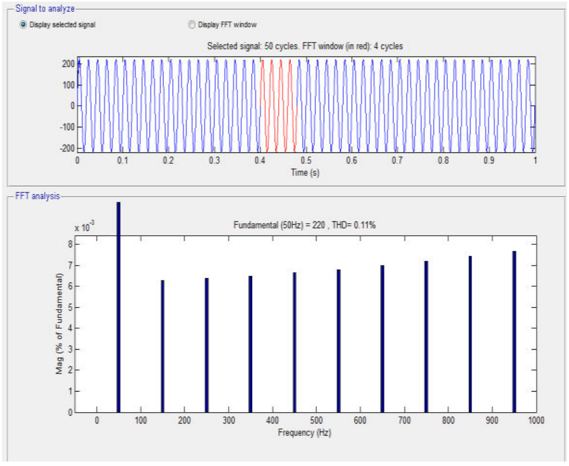

Figure 6: Current at AC mains and its harmonic spectra of Boost PFC converter feeding VSI based PMBLDCM drive.

6. Hardware of Proposed Work

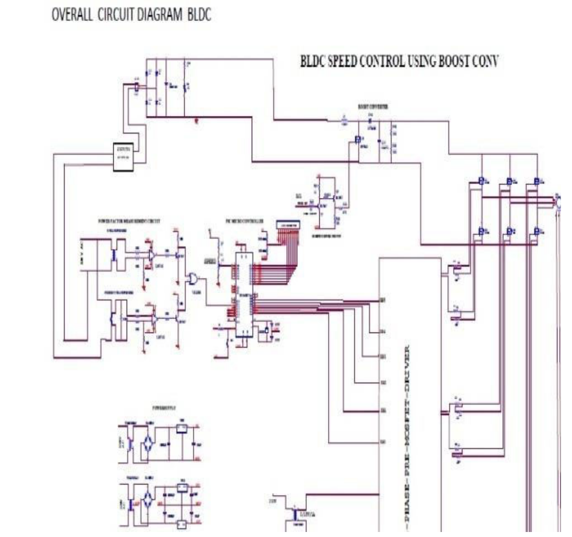

Figure 7

7. Conclusion

To provide depth understanding on every aspect parameters of PMBLDCM drive, it is designed, modeled and simulated in MATLAB/SIMULINK environment. The performance of PMBLDCM drive with PFC converter shows that boost PFC topology used in proposed work is best option for applications having rated voltage is higher than single phase supply RMS voltage. The PMBLDCM drives incorporating Boost PFC converter can be a milestone towards the widespread application of these drives.

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