IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

A Voltage-Controlled PFC Boost Converter Fed PMBLDCM Drive

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Abstract

This paper deals with Simulation of Boost dc–dc converter as a single-stage power-factor-correction converter for a permanent magnet (PM) brushless dc motor (PMBLDCM) fed through a diode bridge rectifier from a single-phase ac mains. In this paper, a systematic review of bridge power factor correction (PFC) boost rectifiers, also called dual boost PFC rectifiers, is presented. Simulated results are presented to demonstrate an improved power quality at ac mains of the PMBLDCMD system in a wide range of speed and input ac voltage. The circuit has advantages like reduced harmonics and improved power factor.

Keywords: Boost converter, power factor (PF) correction (PFC), permanent-magnet (PM) brushless dc motor (PMBLDCM), voltage control, voltage-source inverter (VSI).

Introduction

THE use of a permanent-magnet (PM) brushless dc motor (PMBLDCM) in low-power appliances is increasing because of its features of high efficiency, wide speed range, and low maintenance [1]–[4]. It is a rugged three-phase synchronous motor due to the use of PMs on the rotor. The commutation in a PMBLDCM is accomplished by solid state switches of a three-phase voltage-source inverter (VSI). Its application to the compressor of an air-conditioning (Air-Con) system results in an improved efficiency of the system if operated under speed control while maintaining the temperature in the air-conditioned zone at the set reference consistently. The Air-Con exerts constant torque (i.e., rated torque) on the PMBLDCM while operated in speed control mode. The Air-Con system with PMBLDCM has low running cost, long life, and reduced mechanical and electrical stresses.

A PMBLDCM has the developed torque proportional to its phase current and its back electromotive force (EMF), which is proportional to the speed [1]–[4]. Therefore, a constant current in its stator windings with variable voltage across its terminals maintains constant torque in a PMBLDCM under variable speed operation. A speed control scheme is proposed which uses a reference voltage at dc link proportional to the desired speed of the permanent-magnet brushless direct current (PMBLDC) motor. However, the control of VSI is only used for electronic commutation based on the rotor position signals.

Electromagnetic pollution of the power line introduced by power electronic systems include harmonic distortion due to nonlinear loads, typically, rectifiers [1]. So, various types of single phase PFC converter circuits to improve the AC current waveform have been developed and used [2] – [7]. A boost chopper circuit constructs the PFC converter with a switching device in the DC side of the diode bridge rectifier circuit. Good characteristics such as a sinusoidal current waveform in phase with the AC line voltage and the constant DC voltage can be obtained from the PFC converter. The use of a permanent-magnet (PM) brushless dc motor (PMBLDCM) in low-power appliances is increasing because of its features of high efficiency, wide speed range, and low maintenance. The commutation in a PMBLDCM is accomplished by solid state switches of a three-phase voltage-source inverter (VSI). This paper deals with an application of a PFC converter for the speed control of a PMBLDCMD. For the proposed voltage controlled drive, a Boost dc–dc converter is used as a PFC converter because of its continuous input and output currents, small output filter, and wide output voltage range as compared to other single switch converters [8]–[10]. Moreover, apart from PQ improvement at ac mains, it controls the voltage at dc link for the desired speed.

Boost Converter Based Speed Control Schem of PMLDC Motor.

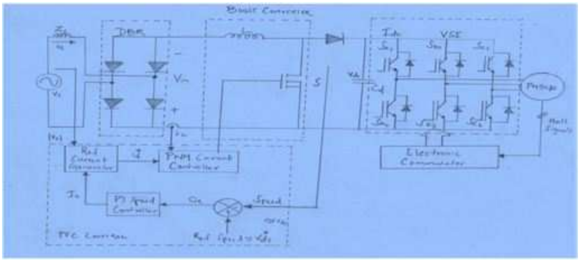

Fig.01. BOOST PFC converter-fed VSI-based PMBLDCMD.

Fig.01. shows the proposed speed control scheme which is based on the control of the dc link voltage reference as an equivalent to the reference speed. However, the rotor position signals acquired by Hall-effect sensors are used by an electronic commutator to generate switching sequence for the VSI feeding the PMBLDC motor, and therefore, rotor position is required only at the commutation points [1]–[4]. The Boost dc–dc converter controls the dc link voltage using capacitive energy transfer which results in non pulsating input and output currents [8]. The proposed PFC converter is operated at a high switching frequency for fast and effective control with additional advantage of a small size filter. For high-frequency operation, a metal–oxide–semiconductor field-effect transistor (MOSFET) is used in the proposed PFC converter, whereas insulated gate bipolar transistors (IGBTs) are used in the VSI bridge feeding the PMBLDCM because of its operation at lower frequency compared to the PFC converter.

The voltage impressed across the inductor during on period is Vd. During this period, the current rises linearly from a minimum level I1 to a maximum level I2.

Therefore the voltage across inductor is,

$$VL = Vd \quad (1)$$

Also,

$$VL = L\,(I2 - I1) / Ton = L\,(\Delta I) / Ton \quad (2)$$

From (1) and (2),

$$Ton = L\,(\Delta I) / Vd \quad (3)$$

The voltage impressed across the inductor during off period is (Vo – Vd) and the current drops linearly from the maximum level I2 to the minimum level I1.

Therefore the voltage across the inductor is,

$$VL = (Vo - Vd) \quad (4)$$

Also,

$$VL = L\,(I2 - I1) / Toff = L\,(\Delta I) / Toff \quad (5)$$

From (4) and (5).

$$Toff = L\,(\Delta I) / (Vo - Vd) \quad (6)$$

From (3), $L(\Delta I) = Ton * Vd$ (7)

From (6) $L(\Delta I) = Toff * (Vo - Vd)$ (8)

From (7) and (8)

$Ton * Vd = Toff * (Vo - Vd)$

Or $Vo = (Ton + Toff) * Vd / Toff$

Or $Vo = T * Vd / Toff$

Or $Vo = Vd / (1 - \alpha)$ (9)

where α = delay angle of the boost converter. As firing angle increase from 0 to 1, the output voltage ideally increases from Vd to infinity. Hence, the output voltage is boosted. Its duty ratio (*D*) at a switching frequency (*fs*) controls the dc link voltage at the desired value. For the control of current to PMBLDCM through VSI during the step change of the reference voltage due to the change in the reference speed, a rate limiter is introduced, which limits the stator current of the PMBLDCM within the specified value which is considered as double the rated current in this work.

Simulation Result

The converter has been simulated using MATLAB Simulink for the following input and output data

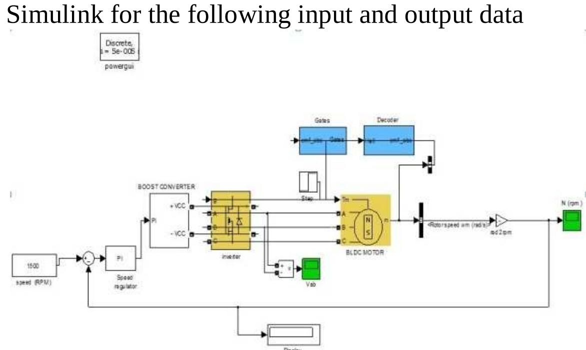

Fig.02: Simulation of BOOST PFC converter-fed VSI-based PMBLDCMD

Specifications

Proposed: Vac = 90 V, Vdc = 250V.

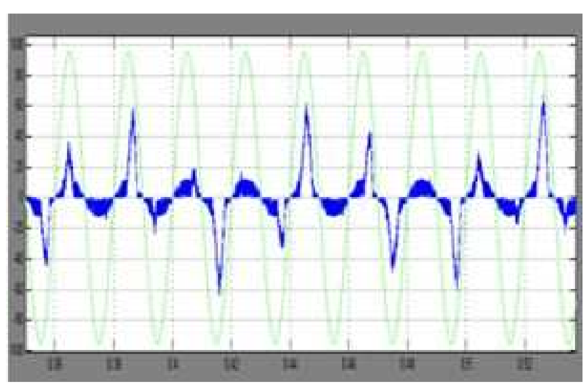

Fig.03: Input AC Voltage and Current

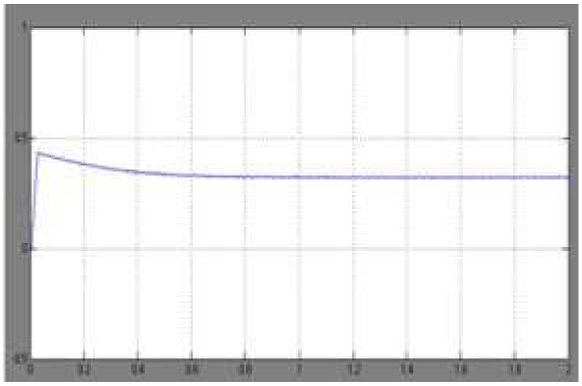

Fig.04: Output DC Current

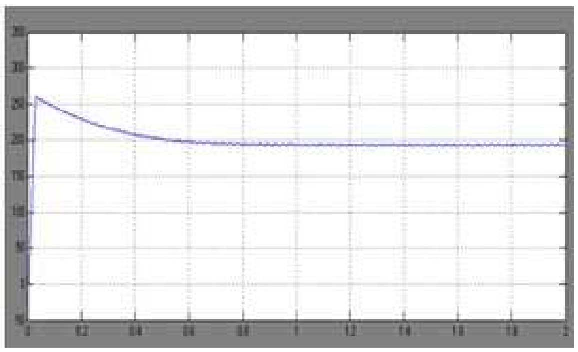

Fig.04: Output DC Voltage

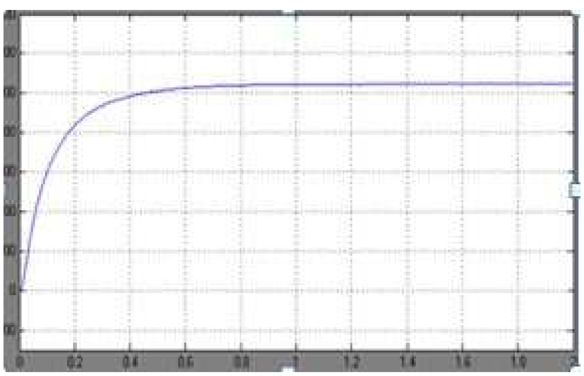

Fig.05: Speed of PMBLDCMD

The simulation of Boost converter is shown in Fig.02. It is assumed that a controlled switch is implemented as the power MOSFET with its inherently slow body diode. AC input voltage and current are shown in Fig.03. The introduction of a rate limiter in the reference dc link voltage effectively limits the motor current within the desired value during the transient conditions. A ripple filter is designed for ripple-free voltage at the dc link of the boost converter. DC output current and output voltage are shown in Fig.04 and Fig.05 respectively. The performance of the drive during the speed transients is evaluated for acceleration and retardation. The set speed waveform is shown in Fig.06. These test results show conformity with the simulation results and validate the proposed voltage control scheme for speed control of PMBLDCMD.

Conclusion

A new speed control strategy for a PMBLDCMD using the reference speed as an equivalent voltage at dc link has been simulated. The speed of PMBLDCM has been found to be proportional to the dc link voltage; thereby, a smooth speed control is observed while controlling the dc link voltage. The proposed PMBLDCMD has been found as a promising variable speed Drive. Simulated results are presented to demonstrate an improved power quality at ac mains of the PMBLDCMD system in a wide range of speed and input ac voltage. The simulation results are in line with the predictions.

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 ISSN: 2277-9655

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