CONTROL OF PMBLDCM FED FROM PFC SEPIC CONVERTER FOR HOUSEHOLD APPLICATIONS

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ABSTRACT

Thispaper apportion with a Cuk dc–dc converter as asingle-stage power-factor-correction converter for a permanentmagnet (PM) brushless dc motor (PMBLDCM) fed between a diode bridge rectifiers from a single-phase ac mains. In order to run an electronic commutator the three phase voltage source inverter is used as PMBLDCM driving an air-conditioner compressor. The speed of the compressor is managed to achieve excellent air-conditioning using a concept of the voltage control at dc link corresponding to the desired speed of the PMBLDCM. The stator currents of the PMBLDCM through step change in the reference speed are managed within the defined limits by an addition of a rate limiter in the reference dc link voltage. The proposed PMBLDCM drive (PMBLDCMD) is designed and modeled, and its performance is estimated in Mat labSimulink environment. Simulated results are presented to indicate an improved power quality at ac mains of the PMBLDCMD system in a wide range of speed and supply ac voltage. Test results of a developed controller are also introduced to endorse the design and model of the drive.

Index Terms: Air-Conditioner, Cuk Converter, Power Factor (PF) Correction (PFC), Permanent-Magnet (PM) Brushless Dc Motor (PMBLDCM), Voltage Control, Voltage-Source Inverter (VSI).

I. INTRODUCTION

The use of a permanent-magnet (PM) brushless dc motor (PMBLDCM) in low-power appliances is growing because of its characteristics of high effectiveness, vast speed range, and low maintenance. It is airregular three-phase synchronous motor due to the use of PMs on the rotor. The commutation in a PMBLDCM is experienced 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 effectiveness of the system if operated under speed control while maintaining the temperature in the air conditioned zone at the set reference steadily. The Air-Con employs constant torque (i.e., rated torque) on the PMBLDCM while operated in speed control mode. The Air-Condition system with PMBLDCM having low running cost, long life, and limited mechanical and electrical stresses compared to a single-phaseremarkably reduced. A PMBLDCM has the developed torqueequal to itsphase current and its back electromotive force (EMF), whichis corresponding to the speed. Hence, a constantcurrent in its stator windings with variable voltage across itsterminals maintains constant torque in aPMBLDCM undervarious speed operating conditions. A speed control scheme is suggestedwhich uses a reference voltage at dc link equivalent to therequired speed of the permanent-magnet brushless direct current(PMBLDC) motor. Though, the control of VSI is only usedfor electroniccommutation based on the rotor position signalsof the PMBLDC motor. There are very few publications regarding PFC in PMBLDCMDs in spite of many PFC topologies for switched mode power supply and battery charging applications. This paper gives out with an application of a PFC converter for the speed control of a PMBLDCMD. For the suggested voltage controlled drive, a PFC converter is used asSepic dc–dc converter because of its continuous supply and load currents, short output filter, and extensive output voltage range as compared to other single switch converters. Furthermore, apart from PQ betterment at ac mains, it controls the voltage at dc link for the required speed of the Air-Con.The comprehensive modeling, design, and concert evaluation of the proposed drive are given out for an air-conditioner run by a 0.816-kW 1500-r/min PMBLDC motor.

II. SUGGESTEDSPEED CONTROL SCHEME OF PMBLDC MOTOR

Fig. 1 shows the proposed speed control strategy which is based on the control of the dc link voltage reference as an equivalent to the reference speed. However, the rotor position signals received by Hall-effect sensors are used by an electronic commutator to produce switching sequence for the VSI feeding the PMBLDC motor, and hence, rotor position is desired only at the commutation points.

The Sepic dc–dc converter compensate the dc link voltage by make use of capacitive energy transfer which gives in non-pulsating input and output currents. The suggested PFC converter is performed at a high switching frequency for fast and effective control with additional benefits of a short size filter. For huge-frequency operation, a metal–oxide–semiconductor field-effect transistor (MOSFET) is used in the proposed power factor correction converter, and insulated gate bipolar transistors (IGBTs) are used in the VSI bridge feeding the PMBLDCM becauseerror (V),acquired after the comparison of sensed dc link voltage (Vdc) and a voltage (*V* of its operation at lower frequency compared to the PFC converter.

The PFC control scheme uses a current multiplier near with a current control loop inside the speed control loop for continuous-conduction-mode operation of the converter. The control loop starts with the processing of voltage ($I*dc$) equivalent to the reference speed, through a proportional–integral (PI) controller to give the modulating control signal(Ic). This signal (Ic) is multiplied with a unit template of input ac voltage to get the reference dc current ($I*d$) and compared with the dc current (Id) sensed after the DBR. The obtained current error (Ie) is amplified and compared with a saw tooth carrier wave of fixed frequency (fs) to produce the pulse width modulation (PWM) pulse for the Cuk converter. Its duty ratio (D) at a switching frequency (fs) controls the dc link voltage at the required value.

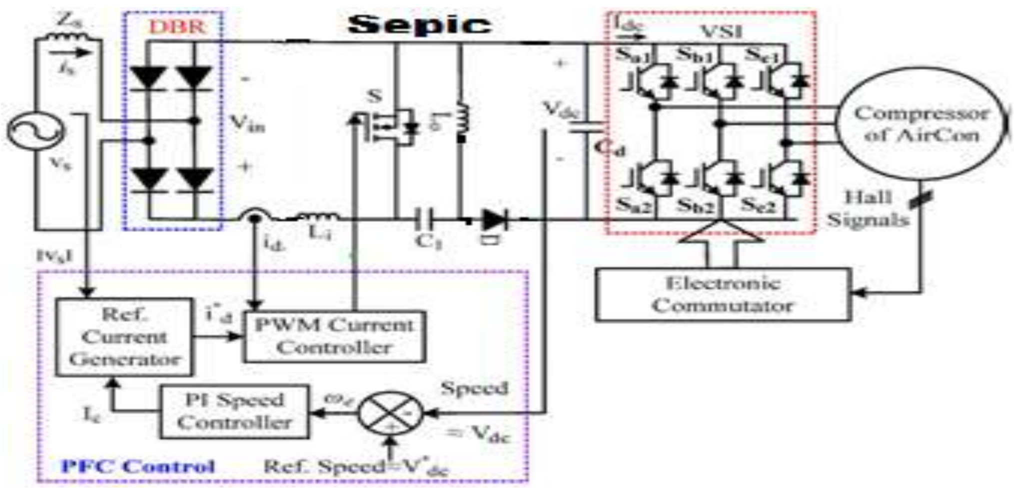

Fig.1Control Scheme of the Proposed Sepic PFC Converter-Fed VSI-Based PMBLDCMD

For the balancing the current to PMBLDCM to the other side of VSI throughout the step change of the reference voltage due to the change in the reference speed, a rate limiter is commenced, which controls the stator current of the PMBLDCM within the identify value which is considered as double the rated current.

III. DESIGN OF PFC CONVERTER-BASED PMBLDCMD

The PFC converter and PMBLDCMD are the mainimportant components of the suggested drive, which are modeled by mathematical equations, and a combination of these models shows the complete model of the drive.

3.1 PFC Converter

The modeling of the PFC converter contains the modeling of a speed controller, a reference current generator, and a PWM controller as given.

3.1.1 Speed Controller

The speed controller is a PI controller which traces the reference speed as an equivalent source voltage. If, at the kthextant of time, $V * dc(k)$is the resource dc link voltage and $Vdc(k)$ is the voltage found at the dc link.

3.1.2 Reference Current Generator

The mentioned current at the input of the cuk converter $(i * d)$is

$I_d^* = Ic\ (k)u\ Vs$

3.1.3 PWM Controller

The reference input current of the Sepic converter $(I * d)$ is contrast with its current (*id*) found after DBR to produce the current *error*$\Delta Id = (I * d - Id)$. This current error is magnified by gain kd and compared with fixed frequency fssaw tooth carrier waveform $md(t)$ to get theswitching signal for the MOSFET of the PFC Sepic converter as

$if\ kd\Delta\ id > md(t) then\ S = 1\ else\ S = 0$

Where *S* distinguish the switching of the MOSFET of the Sepic

Converter as shown in Fig. 2 and its values "1" and "0"represent "on" and "off" conditions, respectively.

3.2 PMBLDCMD

The PMBLDCMD having main functioning blocks are anelectroniccommutator, a VSI, and a PMBLDCM.

3.2.1 Electronic Commutator Signal

The electronic commutator which can make use of signals from Hall-effect position sensors to results the triggering pulse sequence for the VSI as shown.

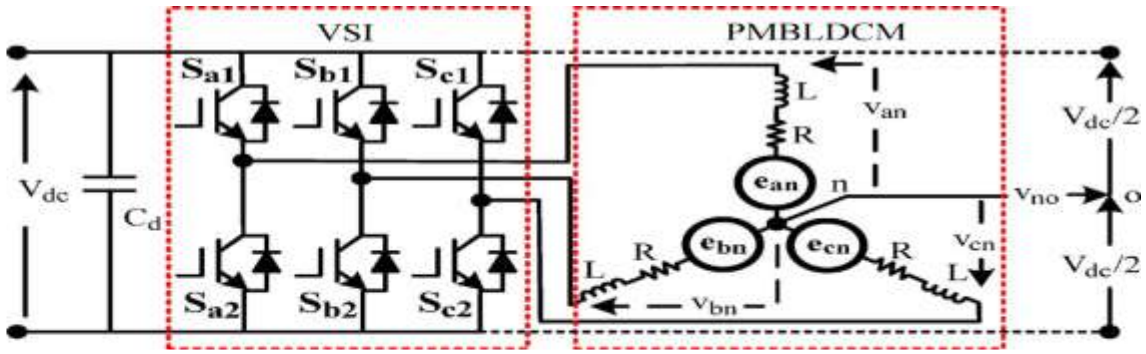

Fig.2Equivalent Circuit of a VSI-Fed PMBLDCMD

3.2.2 VSI

The output of VSI to be fed to phase "a" of thePMBLDC motor is calculated from the equivalent circuit of a VSI-fed PMBLDCM.

$$va0 = \left(\frac{Vdc}{2}\right) for\ Sa1 = 1$$

$$va0 = \left(\frac{-Vdc}{2}\right) for\ Sa2 = 1$$

$$vao = 0\ for\ Sa1 = 0, and\ Sa2 = 0$$

$$van = vao - vno$$

Where vao, vbo, vco, and vno are the voltages the three phases(a, b, and c) and neutral point (n) with respect to the virtualmidpoint of the dc link voltage. Thevoltages van, vbn, and vcn are the voltages of the three phaseswith respect to the neutral terminal of the motor (n), and Vdc isthe dc link voltage. The values 1 and 0 for *S*a1 or *S*a2 denotesthe "on" and "off" conditions of respective IGBTs of the VSI.

The voltages for the other two phases of the VSI is connected thePMBLDC motor, which are the individual phase voltage switching sequence vao,van,vbn,and vcn, and the switchingpattern of the other IGBTs of the VSI (i.e., *S*b1, *S*b2, *S*c1, and*S*c2) are generated in a same manner.

3.2.3 PMBLDC Motor

The PMBLDCM ischaracterized in theform of a set of differential equations given as

$$van = Ria + p\ \lambda a + ean$$

$$vbn = Rib + p\ \lambda b + ebn$$

$$vcn = Ric + p\ \lambda c + ecn$$

Besides, the flux linkages can be represented as

$$\lambda a = Lsia - M(ib + ic)$$

$$\lambda b = Lsib - M(ia + ic)$$

$$\lambda c = Lsic - M(ib + ia)$$

Let *Ls*is the self-inductance/phase and *M* is the mutual Inductance of PMBLDCM winding/phase.The torque *Te*producedin the PMBLDCM is given as

$$Te = (eania + ebnib + ecnic)/\omega r$$

$\omega r$is the speed of the motor in radians per second.

In these equations, *p* denotes the differential operator(d/dt), ia, ib, and ic are currents, λa, λb, and λc are fluxlinkages, and ean, ebn, and ecn are phase-to-neutral back EMFsof PMBLDCM, in respective phases; *R* is the resistance ofmotor windings/phase.

IV. PERFORMANCE EVALUATION OF PMBLDCMD

The suggested PMBLDCMD is developed in Mat labsimulink environment, and its operating performance is evaluated for anAir-Con compressor load. The compressor load is speculated asa constant torque load equal to the rated torque (5.2 Nm) withfluctuating speed as desired by an Air-Con system setup. A 0.816-kWrating PMBLDCM is treated to drive the air-conditioner, thespeed of which is controlled completely by controlling the dclink voltage.

The performance of the recommended PFC drive isevaluated on the basis of numerous parameters such as THD andCF of the ac mains current and displacement power factor(DPF) and PF at different speeds of the motor as well asvariable input ac voltage. For the performance evaluation ofthe suggested drive under input ac voltage changes, the dclink voltage is kept constant at 298 V which is equivalent to a1500-r/min speed of the PMBLDCM. Recommended PMBLDCMD in a wide range of the speed and the input ac voltage.

4.1 Performance of PMBLDCMD during Starting

The performance of the PMBLDCMD during starting isevaluated while feeding it from 220-V ac supply mains with thereference speed set at 1000 r/min and rated torque. Starting performance of the drive illustrating voltage(vs) and current (*is*) at ac mains, voltage at dc link(Vdc),speed of motor (*N*), electromagnetic torque (*Te*), and statorcurrent of phase "a" (ia). A rate limiter is introduced in thereference voltage to limit the starting current of the motor at the same time the charging current of the dc link capacitor. The PIcontroller brings to zero the reference speed so that the motor reachesreference speed evenly within 0.375 s while keeping thestator current within the required limits, i.e., double the ratedvalue. The current waveform at input ac mains is in phasewith the supply voltage indicating near unity PF during thestarting.

4.2 Performance of PMBLDCMD Under Speed Control

4.2.1Transient Condition

The operating performance of the drive duringthe speed transients is evaluated for acceleration and retardation of the compressor.The reference speed is changed from 1000 to 1500 r/min andfrom 1000 to 500 r/min for the performance evaluation of thecompressor at rated load under speed control. It is noticed that the speed control is fast and smooth in both directions, i.e., acceleration or retardation, with PF controlled at near unity value. Also, the stator current of PMBLDCM is less than VOLTAGE-CONTROLLED PFC SEPIC CONVERTER-BASED PMBLDCM DRIVEtwice the rated current due to the rate limiter discussed in thereference voltage.

4.2.2 Steady-State Condition

The performance of PMBLDCMD under steady-state speed condition is achieved at different speeds as given in Table II which explains the effectiveness of the suggested drive in a broad speed range. The linear relation between motor speed and dc link voltage. Since the constant required reference speed is decided by the reference voltage at dc link, it is noticed that the control of the reference dc link voltage controls the speed of the motor.

4.3 PQ Performance of the PMBLDCMD

The performance of PMBLDCMD in terms of PQ indices, i.e.,$THDi$, CF, DPF, and PF, is achieved for various speeds as well as loads. THD of ac mains current in extensivespeed range of the PMBLDCM. The $THDi$and harmonic content of ac mains current drawn by the prospective drive at500- and 1500-r/min speeds confirming less than 5% $THDi$in a huge range of speed.

4.4 Performance of the PMBLDCMD Under Varying Input AC Voltage

The operating performance of the proposed PMBLDCMD is evaluated under different varying input ac voltage at rated load (i.e., rated torque and rated speed) to demonstrate the effectiveness of the proposed drive for Air-

Con system in various practical situations as presented the current and its THD at ac mains supply for the PMBLDCmachine, DPF, and PF with ac input voltage. The THD of ac mains current is within detailed limits of international norms at near unity PF in a wide range of ac input voltage.

V. HARDWARE IMPLEMENTATION

The designed suggested PFC controller is approved on a developedprototype of the drive in the laboratory. The implementedhardware design for the speed control of PMBLDCMD usesa VSI along with a single-phase DBR and a dc capacitor. Thedata a PMBLDC motor used for hardware implementationare given in the Appendix. The shaft of the PMBLDCM isconnected with a separately excited dc generator for application of mechanical load in terms of an equivalent electrical load.

For the construction of the PWM current control algorithm,a digital signal processor (DSP) developed by Microchipnamed as dsPIC 30F6010 is considered in this system, which alsoproduce switching signals for VSI acting as an electronic commutator for the PMBLDCM. The gate pulse for the VSIare obtained using the PWM channels of the dsPIC 30F6010,and the PWM signal for the PFC switch is generated at one of the I/O ports. The output which send back to the supply side, i.e. acts as a feedbackSignals of current and voltageare obtained using voltage and current sensor circuits modeledin the voltage range of analog-to-digital converters of theprocessor. The unit template is producedmake use of a zero-crossingdetector circuit from the input ac mains voltage.Theoperating frequency of the PWM signal is kept constant at40 kHz, and it is the fundamental frequency correspondingto the speed of the motor for the electronic commutatorrcoupled with VSI.

Test results are stored using a power analyzer of Flukemake and a four-channel digital storage oscilloscope of Agilent make. Test results are shown for variousperformance parameters which as starting, speed control, and PQbetterment. Smooth speed control is acquired during accelerationand deceleration by controlling the voltage at dc link asdetermined.Demonstrates thetest results during steady-state condition at a 1500-r/min speedwhile the THD of current at input ac mains is documented within5% as shown. These test results show consentwith the simulation results and demonstrate the proposed voltagecontrol scheme for speed control of PMBLDCMD along withPQ betterment at input ac mains while using a single DSP.

VI. CONCLUSION

A new speed control strategy for a PMBLDCMD using thereference speed as an identical voltage at dc link has beensimulated for an air-conditioner exploit a Sepic PFC converterand experimentally confirmed on animplemented controller.The speed of PMBLDCM has been found to be comparative to the dc link voltage; so that, a continuous speed control is noticed while compensating the dc link voltage. The presentation of limiter in the reference dc link voltage effectively controls the motor current within the required value during the transientconditions.

The PFC Sepic converter has observed near unity P Fin a extensive range of the speed and the input ac voltage. Likewise,PQ indices of the suggested PFC drive are in conformity to the International Standard IEC 61000-3-2. The suggestedPMBLDCMD has been found as a assuring variable speed drive for the Air-Con system. As well, it may also be usedin the fans with PMBLDC motor drives on the trains recently popularized in Indian Railways. These fans also have inrush current complications. All these PQ complications ofpoor PF, inrush current, and speed control in these fans on the trains in Indian Railways may be mitigated by the suggested voltage-controlled PFC Sepic converter-based PMBLDCMD.

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