Buck-Boost Converter for BLDC Motor Drive to Improve Power Factor

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Abstract— *This paper presents an influence issue improved by victimisation buck-boost convertor for BLDC motor drive as a value effective answer for low power applications. AN approach of speed management of BLDC motor by dominant the DC link voltage of VSI (Voltage supply Inverter) is employed. This facilitates the operation of VSI at fundamental change by victimisation the electronic commutation of BLDC motor that offers reduced change losses. A buck-boost convertor is meant to work in DICM (Discontinuous electrical device Current Mode) to supply AN unity Power issue at AC mains. The performance of the projected drive is evaluated over a good vary of speed management and ranging offer voltages with improved power quality at AC mains. The performance of projected drive is simulated in MATLAB/Simulink atmosphere.*

Keywords— *Buck-Boost converter, power factor correction (PFC), permanent-magnet brushless dc motor (PMBLDCM), voltage control, voltage source inverter (VSI).*

I. INTRODUCTION

The use of a permanent-magnet brushless dc motor (PMBLDCM) in low-power appliances is increasing as a result of its options of high potency, wide speed vary, and low maintenance[1]–[4]. it's a rugged 3 part electric motor thanks to the employment of PMs on the rotor. The commutation in an exceedingly PMBLDCM is accomplished by solid state switches of a 3 part voltage supply electrical converter (VSI). Its application leads to AN improved potency of the system if operated beneath speed management. the assorted load area unit exerts constant torsion (i.e., rated torque) on the PMBLDCM whereas operated in speed management mode. The PMBLDCM has low running price, long life, and reduced mechanical and electrical stresses compared to one part induction motor. A PMBLDCM has developed torsion proportional to its part current and its back electrical phenomenon (EMF), that is proportional to the speed. Therefore, a relentless current in its mechanical device windings with variable voltage across its terminals maintains constant torsion in an exceedingly PMBLDCM beneath variable speed operation.

A speed management theme is projected that uses a reference voltage at dc link proportional to the required speed of the static magnet brushless electrical energy (PMBLDCM) motor. However, the management of VSI is just used for electronic commutation supported the rotor position signals of the PMBLDC motor. The PMBLDCMD is fed from one part ac offer through a diode bridge rectifier (DBR) followed by a electrical device at dc link. It attracts a periodic current with a peak more than the amplitude of the elemental input current at ac mains thanks to AN uncontrolled charging of the dc link electrical device. This leads to poor power quality (PQ) at ac mains in terms of poor power issue (PF) of the order of zero.728, high total harmonic distortion (THD) of ac mains current at the worth of eighty one.54%. Therefore, a PF correction (PFC) device among varied obtainable convertor topologies is sort of inevitable for a PMBLDCMD.

These area unit only a few publications relating to greenhouse gas in PMBLDCMDs despite several greenhouse gas topologies for switched mode power offer.This paper deals with AN application of a greenhouse gas convertor for the speed management of a PMBLDCMD. For the projected voltage controlled drive, a Buck-Boost dc-dc convertor is employed as a greenhouse gas convertor as a result of its continuous input and output currents, tiny output filter, and wide output voltage vary as compared to alternative single switch converters[5]–[7]. Moreover, except PQ improvement at ac mains, it controls the voltage at dc link for the required speed of the load. The elaborate modelling, design, and performance analysis of the projected drive area unit given..

II. PROPOSED SPEED CONTROL SCHEME

Figure.1 shows the projected speed management theme that is predicated on the management of the dc link voltage reference as the same to the reference speed. However, the rotor position signals nonheritable by Hall impact sensors area unit utilized by AN electronic electric switch to come up with change sequence for the The Buck-Boost dc-dc convertor controls the dc link voltage victimisation electrical phenomenon energy transfer which ends up is non-pulsating input and output currents[8]–[10]. The projected greenhouse gas convertor is operated at a high change frequency for quick and effective management with extra advantage of alittle size filter. For high-frequency operation, a metal-dioxide-semiconductor FET (MOSFET) is employed within the projected greenhouse gas convertor, whereas insulated gate bipolar transistors (IGBTs) area unit employed in the VSI Bridge feeding the PMBLDCM as a result of its operation at lower frequency compared to the greenhouse gas device.

The greenhouse gas management theme uses a current multiplier factor approach with a current management loop within the speed management loop for continuous conductivity mode operation of the convertor. The management loop begins with the process of voltage error (Ve), obtained once the comparison of detected dc link voltage (Vdc) and a voltage (V*dc) admire the reference speed, through a proportional-integral (PI) managementler to administer the modulating control signal (Ic). This signal (Ic) is increased with a unit templet of input ac voltage to induce the reference dc current (I*d) and compared with the dc current (Id) detected once the DBR. The resultant current error (Ie) is amplified and compared with a saw tooth radio emission of mounted frequency (fs) to come up with the heart beat dimension modulation (PWM) pulse for the Buck-Boost device. Its duty magnitude relation (D) at a change frequency (fs) controls the dc link voltage at the required price. For the management of current to PMBLDCM through VSI throughout the step amendment of the reference voltage thanks to the amendment within the reference speed, a rate electric circuit is introduced, that limits the mechanical device current of the PMBLDCM among the required price that is taken into account as double the speed current during this work.

III. DESIGN OF PFC BUCK-BOOST CONVERTER

The projected greenhouse gas Buck-Boost convertor is meant for a PMBLDCMD with main issues on the speed management of the assorted load and PQ improvement at ac mains. The dc link voltage of the greenhouse gas convertor is given as,

$$Vdc = VinD / (1-D) \quad (1)$$

Where Vin is the average output of the DBR for a given ac input voltage (Vs) related as,

$$Vin = 2\sqrt{2}Vs/\pi \quad (2)$$

The Buck-Boost converter uses a boost inductor (Li) and a capacitor (C1) for energy transfer. Their values are given as,

$$Li = DVin / \{fs(\Delta ILi\} \quad (3)$$

$$Ci = DIdc / \{fs\Delta VC1\} \quad (4)$$

Where ΔILi may be a specific electrical device current ripple, ΔVC1 may be a specific voltage ripple within the intermediate electrical device (C1), and Idc is that the current drawn by the PMBLDCM from the dc link. A ripple filter is meant for ripple-free voltage at the dc link of the Buck-Boost convertor. The inductance (Lo) of the ripple filter restricts the electrical device peak-to-peak ripple current (ΔILo) among a specific price for the given change frequency (fs), whereas the capacitance (Cd) is calculator for the allowed ripple within the dc link voltage (ΔVCd). The values of the ripple filter electrical device and electrical device area unit given as,

$$L0 = (1-D)\ Vdc / \{fs(\Delta IL0)\} \quad (5)$$

$$Cd = Idc / (2w\Delta VCd) \quad (6)$$

The PFC converter is designed for a base dc link voltage of Vdc = 297.1 V at Vs = 220 V for fs = 40 kHz, Is = 4.5A, ΔILi = 0.45 A (10% of Idc), Idc = 3.5 A, ΔILo = 3.5 A (≈ Idc), ΔVCd = 4 V (1% of Vo), and ΔVCi = 220 V (≈ Vs). The design values are obtained as Li = 6.6 mH, C1 = 0.24 μF, Lo = 0.84mH, and Cd = 1591 μF.

IV. MODELING OF PFC CONVERTER-BASED PMBLDCMD

The PFC converter and PMBLDCMD are the main components of the proposed drive, which are modelled by mathematical equations, and a combination of these models represents the complete model of the drive.

A. PFC Converter

The modeling of the PFC converter consists of the modeling of a speed controller, a reference current generator, and a PWM controller as given here in after.

1) Speed Controller: The speed controller is a PI controller which tracks the reference speed as an equivalent reference voltage. If, at the kth instant of time, V*dc(k) is the reference dc link voltage and Vdc (k) is the voltage sensed at the dc link, then the voltage error Ve(k) is given as,

$$Ve(k)=V^*dc(k)–Vdc(k) \quad (7)$$

The PI controller output Ic (k) at the kth instant after processing the voltage error Ve (k) is given as,

$$Ic(k)=Ic(k-1)+Kp\{Ve(k)–Ve(k-1)\}+KiVe(k) \quad (8)$$

where Kp and Ki are the proportional and integral gains of the PI controller.

2) Reference Current Generator: The reference current at the input of the Buck-Boost converter (i*d) is,

$$i^*d=Ic(k)\upsilon Vs \quad (9)$$

Where υVs is the unit template of the ac mains voltage, calculated as,

$$\upsilon Vs=\upsilon d/Vsm;\upsilon d=|\upsilon s|;\upsilon s=Vsmsinwt \quad (10)$$

Where Vsm and w are the amplitude (in volts) and frequency (in radians per second) of the ac mains voltage.

3) PWM controller: The reference input current of the Buck-Boost converter (i*d) is compared with its current (id) sensed after DBR to generate the current error Δid = (i*d – id). This current error is amplified by gain kd and compared with fixed frequency (fs) saw tooth carrier waveform md (t) (6) to get the switching signal for the MOSFET of the PFC Buck-Boost converter as,

if, kdΔid›md(t) then S=1 else S=0 (11)

where S denotes the switching of the MOSFET of the Buck-Boost converter and its values “1” and “0” represent “on” and “off” conditions, respectively.

B. PMBLDCMD

The PMBLDCMD consists of an electronic commutator a VSI, and a PMBLDCM.

1) Electronic Commutator: The electronic commutator uses signals from Hall-effect position sensors to generate the switching sequence for the VSI as shown in the Table I

TABLE I
ELECTRONIC COMMUTATOR OUTPUT BASED ON THE HALL-EFFECT SENSOR SIGNALS

Hall Signals			Switching Signals					
H_a	H_b	H_c	S_{a1}	S_{a2}	S_{b1}	S_{b2}	S_{c1}	S_{c2}
0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	1	1	0
0	1	0	0	1	1	0	0	0
0	1	1	0	1	0	0	1	0
1	0	0	1	0	0	0	0	1
1	0	1	1	0	0	1	0	0
1	1	0	0	0	1	0	0	1
1	1	1	0	0	0	0	0	0

2) VSI: The output of VSI to be fed to phase "a" of the PMBLDC motor is calculated from the equivalent circuit of a VSI-fed PMBLDCM shown in Figure.2 as,

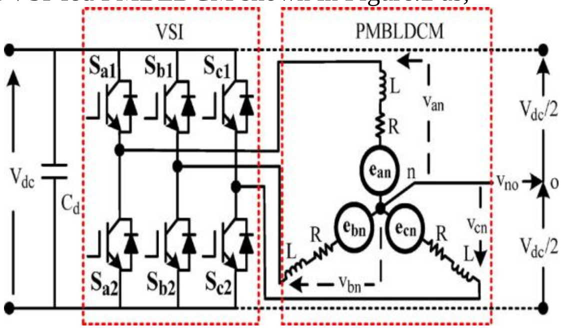

Figure.2. Equivalent circuit of a VSI-fed PMBLDCMD

$\upsilon ao = (Vdc/2)$ for $Sa1 = 1$ (12)

$\upsilon ao = (-Vdc/2)$ for $Sa2 = 1$ (13)

$\upsilon ao = 0$ for $Sa1 = 0$, and $Sa2 = 0$ (14)

$\upsilon an = \upsilon ao - \upsilon no$(15)

whereυao, υbo, υco, and υno are the voltages the three phases (a, b, and c) and neutral point (n) with respect to the virtual midpoint of the dc link voltage shown as "o" in Fig. The voltages υan, υbn, and υcn are the voltages of the three phases with respect to the neutral terminal of the motor (n), and Vdc is the dc link voltage. The values 1 and 0 for Sa1 or Sa2 represent the "on" and "off" conditions of respective IGBTs of the VSI.

The voltages for the other two phases of the VSI feeding the PMBLDC motor, i.e., υbo, υco, υbn, and υcn, and the switching pattern of the other IGBTs of the VSI (i.e., Sb1, Sb2, Sc1, and Sc2) are generated in a similar way.

3) PMBLDC motor: The PMBLDCM is modeled in the form of a set of differential equations (11) given as,

$\upsilon an = Ria + p\lambda a + ean$(16)

$\upsilon bn = Rib + p\lambda b + ebn$ (17)

$\upsilon cn = Ric + p\lambda c + ecn$(18)

In the equations, p represents the differential operator (d / dt), ia, ib and ic are currents, λa, λb, and λc are flux linkages, and ean, ebn, and ecn are phase-to-neutral back EMFs of PMBLDCM, in respective phases; R is the resistance of motor windings / phase.

Moreover, the flux linkages can be represented as,

$\lambda a = Lsia - M (ib + ic)$ (19)

$\lambda b = Lsib - M (ia + ic)$ (20)

$\lambda c = Lsic - M (ib + ia$(21)

Where Ls is the self-inductance / phase and M is the mutual inductance of PMBLDCM winding / phase. The developed torque Te in the PMBLDCM is given as,

$Te = (eania + ebnib + ecnic) / wr$ (22)

Where wr is the motor speed in radians per second.

Since PMBLDC has no neutral connection

$ia + ib + ic = 0$ (23)

From (15) – (21) and (23), the voltage (υno) between the neutral point (n) and midpoint of the dc link (o) is given as,

$\upsilon no=\{ \upsilon ao+ \upsilon bo+ \upsilon co-(ean+ebn+ecn)\}/3$ (24)

From (19) – (21) and (23), the flux linkages are given as,

$\lambda a=(Ls+M)ia, \lambda b=(Ls+M)ib, \lambda c=(Ls+M)ic$(25)

From (16) – (18) and (25), the current derivatives in generalized state space form are given as,

$pix = (\upsilon xn - ixR - exn) / (Ls + M)$ (26)

where x represents phase a, b, or c.

The back EMF is a function of rotor position (θ) as,

$exn = Kbfx (\theta) wr$(27)

where x can be phase a, b, or c and accordingly fx (θ) represents a function of rotor position with a maximum value ±1, identical to trapezoidal induced EMF, given as

$fa (\theta) = 1$for $0<\theta<2\pi$ (28)

$fa (\theta)=1\{(6/\pi)(\pi-\theta)\}-1$ for $2\pi/3 <\theta<\pi$ (29)

$fa (\theta) = -1$ for $\pi<\theta<5\pi/3$ (30)

$fa (\theta)=\{(6/\pi)(\pi-\theta)\}+1$ for $5\pi/3<\theta<2\pi$ (31)

The functions fb (θ) and fc (θ) are similar to fa (θ) with phase differences of 1200 and 2400, respectively.

Therefore, the electromagnetic torque expressed as,

$Te = Kb \{fa (\theta) ia + fb + fc (\theta) ic\}$ (32)

The mechanical equation of motion in speed derivative form is given as,

$Pwr = (P/2) (Te - Tl - Bwr) / (J)$ (33)

Where wr is the derivative of rotor position θ, P is the number of poles, Tl is the load torque in newton meters, J is the moment of inertia in kilogram square meters, and B is the friction coefficient in newton meter seconds per radian.

The derivative of rotor position is given as,

$p\theta = wr$(34)

Equations (16) – (34) represent the dynamic model of the PMBLDC motor.

V. PERFORMANCE EVALUATION OF PMBLDCMD

The projected PMBLDCMD is modelled in Matlab-Simulink atmosphere, and its performance is evaluated for load. The fan load is taken into account as a relentless torsion load up to the rated torsion with variable speed. The performance of the projected greenhouse gas drive is evaluated on the idea of assorted parameters like Doctor of Theology of the ac mains current and displacement power issue (DPF) and PF at totally different speeds of the motor in addition as variable input ac voltage. For the performance analysis of the projected drive beneath input ac voltage variation, the dc link voltage is unbroken constant at 298 V that is admire a 1500-r/min speed of the PMBLDCM. Figs. 3.1-3.6 and Table IIshow the obtained results of the projected PMBLDCMD in an exceedingly wide selection of the speed and also the input ac voltage

A. *Performance of PMBLDCMD throughout beginning*

The performance of the PMBLDCMD throughout beginning is evaluated whereas feeding it from 220-V ac mains with the reference speed set at one thousand r/min and rated torsion. It shows the beginning performance of the drive portrayal voltage (υs) and current (is) at ac mains, voltage at dc link (Vdc), speed of motor (N), magnetic force torsion (Te), and mechanical device current of part "a" (ia). A rate electric circuit is introduced within the reference voltage to limit the beginning current of the motor in addition because the charging current of the dc link electrical device. The PI controller tracks the references speed so the motor attains reference speed swimmingly among zero.375s whereas keeping the mechanical device current among the required limits, i.e., double the rated price. the present wave form at input ac mains is in part with the provision voltage demonstrating close to unity PF throughout the startingas shown within the Table II.

TABLE II
PERFORMANCE OF THE PROPOSED DRIVE UNDER SPEED CONTROL AT 220-V INPUT AC VOLTAGE (Vs)

V_{DC} (V)	Speed (rpm)	THD_i (%)	DPF	PF	I_s (A)
104.0	300	5.55	0.9990	0.9975	1.82
119.0	400	4.74	0.9990	0.9979	2.05
135.5	500	4.00	0.9992	0.9984	2.30
151.5	600	3.55	0.9993	0.9987	2.55
167.5	700	3.25	0.9993	0.9988	2.79
183.5	800	2.97	0.9994	0.999	3.04
200.0	900	2.75	0.9995	0.9991	3.29
216.5	1000	2.63	0.9995	0.9992	3.54
233.0	1100	2.43	0.9996	0.9993	3.79
249.5	1200	2.33	0.9996	0.9993	4.15
265.5	1300	2.24	0.9997	0.9994	4.29
282.0	1400	2.23	0.9996	0.9994	4.53
298.0	1500	2.22	0.9996	0.9994	4.79

B. *Performance of PMBLDCMD under Speed Control*

Figures shows the performance of PMBLDCMD for speed control at constant rated torque (5.2 N.m) and 220-V ac mains voltage during transient and steady-state conditions of the PMBLDCMD.

1) *Transient Condition*

The performance of the drive throughout the speed transient is evaluated for acceleration and retardation of the mechanical device. The reference speed is modified from one thousand to 1500-r/min and from one thousand to 500-r/min for the performance analysis of the mechanical device at rated load beneath speed management. it's ascertained that the speed management is quick andsmooth in either direction, i.e., acceleration or retardation, with PF maintained at close to unity price. Moreover, the mechanical device current of PMBLDCM is a smaller amount than double the speedd current thanks to the rate electric circuit introduced within the reference voltage.

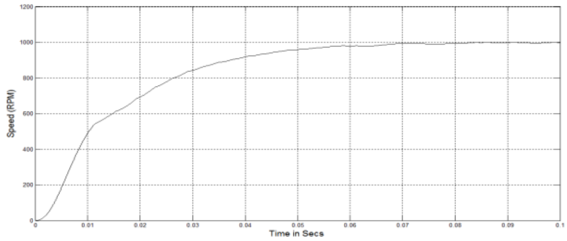

Figure.3.1. Speed Response for PMBLDCM

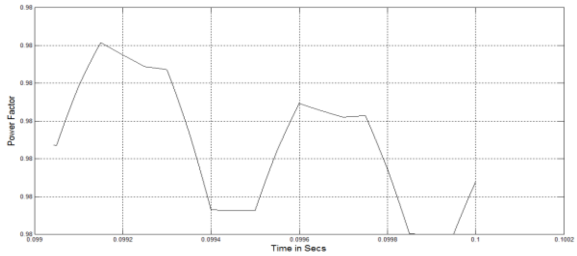

Figure.3.2. Power Factor

2) *Steady-State Condition*

The performance of PMBLDCMD beneath steady-state speed condition is obtained at totally different speeds as summarized in Table I that demonstrate the effectiveness of the projected drive in an exceedingly wide speed vary. Fig.3.3 shows the linear relation between motor speed and dc link voltage. Since the reference speed is set by the reference voltage at dc link, it's ascertained that the management of the reference dc link voltage controls the speed of the motor.

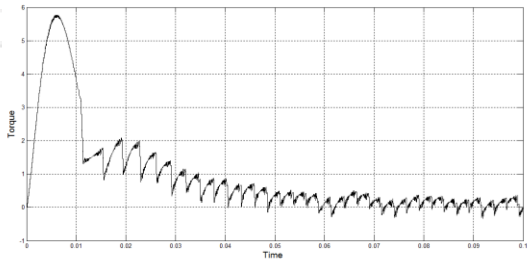

Figure.3.3. Electromagnetic Torque

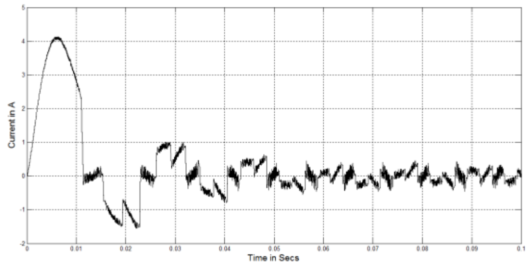

Figure.3.4. Stator Current of PMBLDC Motor

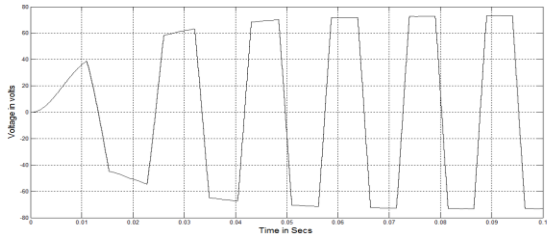

Figure.3.5. Stator Back EMF

C. *PQ Performance of the PMBLDCMD*

The performance of PMBLDCMD in terms of PQ indices, i.e., THD and PF, is obtained for various speeds in addition as hundreds. These results area unit close to unity PF and reduced Doctor of Theology of ac mains current in wide speed vary of the PMBLDCM. The Doctor of Theology and harmonic spectra of ac mains current drawn by the projected drive at five hundred and 1500-r/min speeds demonstrating but five-hitter Doctor of Theology in an exceedingly wide selection of speed.

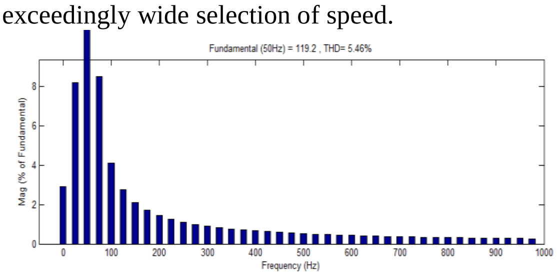

Figure.3.6. Total Harmonic Distortion

D. *Performance of the PMBLDCMD under Varying Input AC Voltage.*

The performance of the projected PMBLDCMD is evaluated beneath variable input ac voltage at rated load (i.e. rated torsion and rated speed) to demonstrate the effectiveness of the projected drive for a friend in varied sensible things. the present and its Doctor of Theology at ac mains and PF with ac input voltage. The Doctor of Theology of ac mains current is among specific limits of international norms at close to unity PF in an exceedingly wide selection of ac input voltage.

VI.CONCLUSION

A improve power issue by victimisation buck-boost convertor based mostly VSI fed BLDC motor drive has been projected targeting low power applications. a brand new methodology of speed management has been utilised by dominant the voltage at DC bus and operational the VSI at fundamental for electronic commutation of BLDC motor for reducing the change losses in VSI. The buck-boost convertor has been operated in DICM for achieving a unity power issue at AC mains. the issues of poor power issue and speed management within the BLDC Motor has been mitigated by the projected voltage controlled Buck-Boost convertor based mostly PMBLDCM drive.

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