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Implementation of PMBLDC motor using Cuk PFC converter

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Abstract: This paper aims at an improve speed quality employing Cuk DC-DC converter is used as a power factor correction (PFC) converter for feeding a voltage source inverter (VSI) based permanent magnet brushless DC motor (PMBLDCM) driven air condition. This PFC converter is front end diode bridge rectifier (DBR) fed from single-phase AC mains and connected to a three phase voltage source (VSI) feeding the permanent magnet brushless DC motor (PMBLDCM). The PMBLDC Motor is used to drive a compressor load of an air conditioner through a three-phase VSI fed from a controlled DC link voltage. The speed of the compressor is controlled to achieve energy conservation using a concept of the voltage control at DC link proportional to the desired speed of the PMBLDC Motor. Therefore the VSI is operated only as an electronic commutator of the PMBLDCM. The stator current of the PMBLDCM during step change of reference speed is controlled by a rate limiter for the reference voltage at DC link. The proposed PMBLDCM drive with voltage control based PFC converter is designed, modeled and its performance is simulated in Matlab-Simulink environment for an air conditioner compressor driven PMBLDC motor.

Index Terms: Cuk Converter, Air Conditioner, Permanent Magnet Brushless DC Motor, Power Factor Correction, Voltage Control, Voltage Source Inverter.

I. INTRODUCTION

PMBLDCM is used to drive the air conditioner compressor, speed of which is controlled effectively by controlling the DC link voltage [1]–[4]. Permanent Magnet Brushless Direct Current (PMBLDC) motors are one of the motor types rapidly gaining popularity. Permanent Magnet Brushless Direct Current (PMBLDC) is Air conditioning systems are typically the largest consumers of electrical energy in homes and office buildings. The most common type of air conditioning that we see is technically referred to as direct expansion, mechanical, vapor-compression refrigeration system. BLDC motors are used in industries such as Appliances, Automotive, Aerospace, Consumer, Medical, Industrial Automation Equipment and Instrumentation. The compressor load is considered as a constant torque load equal to rated torque with the speed control required by air conditioning system. A 1.5 kW rating A few of these are: Better speed versus torque characteristics, High dynamic response, High efficiency, Long operating life, Noiseless operation, Higher speed ranges.

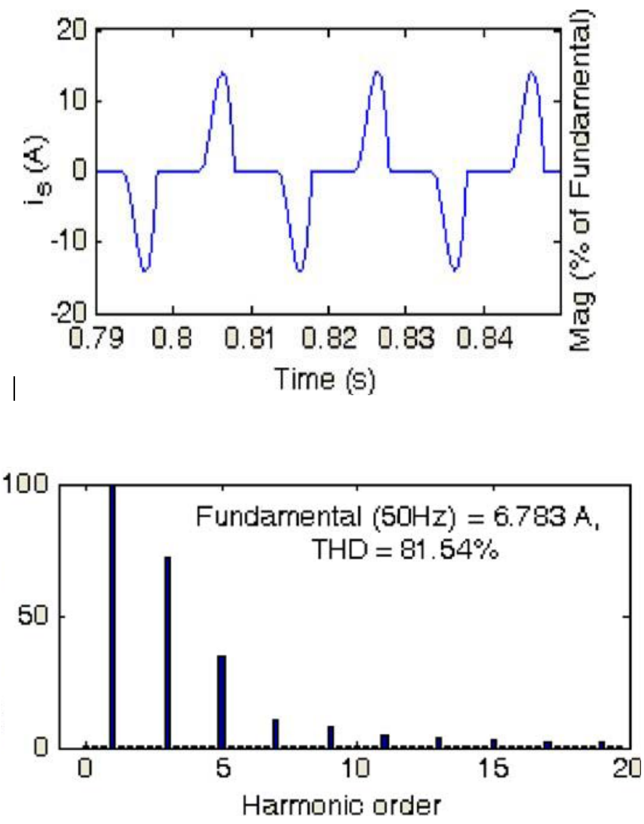

Figure 1: Current waveform at AC mains and its harmonic spectra for the PMBLDCMD without PFC.

As the PMBLDC machine has nonlinear model, the linear PI may no longer be suitable. This has resulted in the increased demand for modern nonlinear control structures like self-tuning controllers, state-feedback controllers, model reference adaptive systems and use of multi-variable control structure. A major economic advantage of PFC converter is that the consumer cuts down on energy costs. In addition, power factor correction reduces the amount of current flowing in the transmission and distribution networks. Reduced current levels mean lower power losses in the distribution network, savings in electrical energy and hence reduced CO2 emissions.PFC converter are used in Stabilized voltage levels, increased capacity of your existing system and equipment, improved profit ability, Lowered expenses. Air conditioning systems are typically the largest consumers of electrical energy in homes and office buildings. In a fixed speed air conditioning system the compressor is cycled on and off to keep the temperature within a set band. For heavy load conditions the compressor operates at a high duty cycle and system efficiency is at its highest. However when the load is lighter, the compressor operates with a lower duty cycle and a much lower system efficiency.

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The PMBLDCMD is fed from a single-phase ac supply through a diode bridge rectifier (DBR) followed by a capacitor at dc link. It draws a pulsed current as shown in Figure 1, with a peak higher than the amplitude of the fundamental input current at ac mains due to an uncontrolled charging of the dc link capacitor. This results in poor power quality (PQ) at ac mains in terms of poor power factor (PF) of the order of 0.728, high total harmonic distortion (THD) of ac mains current at the value of 81.54%, and high crest factor (CF) of the order of 2.28. Therefore, a PF correction (PFC) converter among various available converter topologies [5], [6] is almost inevitable for a PMBLDCMD. Moreover, the PQ standards for low power equipments, emphasize on low harmonic contents and near unity PF current to be drawn from AC mains by these drives. This paper deals with an application of a PFC converter for the speed control of a PMBLDCMD. For the proposed voltage controlled drive, a Cuk 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 of the Air-Con.

II. PROPOSED SPEED CONTROL OFPMBLDC MOTOR FOR AIR CONDITIONER USING CUK PFC CONVERTER

Figure 2 shows details diagram of the proposed speed control reference voltage at DC link as an equivalent reference speed, there by replaces the conventional control of the motor speed and a stator current involving various sensors for voltage and current signals. It has two control loops namely speed control loop and voltage control loop. Moreover, the rotor position signals acquired by Hall-effect sensors are used to generate the switching sequence for the voltage source inverter as an electronic commutator (switching sequence generator) of the Permanent Magnet Brushless Direct Current (PMBLDC) motor [1]–[4].

The Cuk 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.

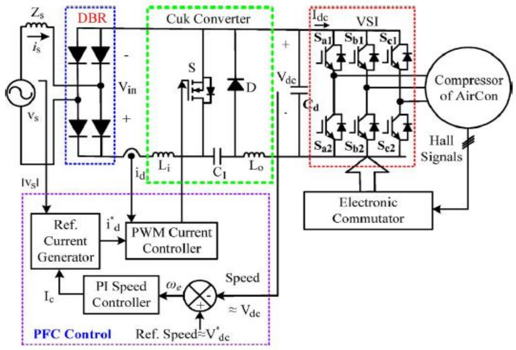

Figure 2: Control scheme of the proposed Cuk PFC converter-fed VSI-based

The PFC control scheme uses a current multiplier approach with a current control loop inside the speed control loop for continuous-conduction-mode operation of the converter. The control loop begins with the processing of voltage error (*Ve*), obtained after the comparison of sensed dc link voltage (V_{dc}) and a voltage (V_{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 (I_d) sensed after the diode bridge rectifier (DBR).The resultant current error (*Ie*) is amplified and compared with a sawtooth carrier wave of fixed frequency (*fs*) to generate 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 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.

III. DESIGN OF PFC CUK CONVERTER-BASED PMBLDCMD

The proposed PFC Cuk converter is designed for a PMBLDCM drive with main considerations on the speed control of the Air-Con, allowable ripple in DC link voltage. and PQ improvement at ac mains. The dc link voltage of the PFC converter is given as:

$$V_{dc} = V_{in}D/(1 - D) \quad (1)$$

where *Vin* is the average output of the diode bridge rectifier for a given ac input voltage (*Vs*) related as

$$V_{in} = 2\sqrt{2}V_s/\pi. \quad (2)$$

Switch mode DC-DC converters inherently produce ripple at the switching system and its harmonics. This unwanted signals, which appears at the both the input and the output, is undesirable for electromagnetic compatibility. Filtering must generally be employed to reduce it to an acceptable level. The Cuk converter uses a boost inductor (*Li*) and a capacitor (*C*1) for energy transfer. Their values are given as

$$L_i = DV_{in}/\{f_s(\Delta I L_i)\} \quad (3)$$

$$C_1 = DI_{dc}/\{f_s \Delta V C_1\} \quad (4)$$

where $\Delta I L_i$ is a specified inductor current ripple, ΔV_{c1} is a specified voltage ripple in the intermediate capacitor (C_1), and I_{dc} is the current drawn by the PMBLDCM from the dc link.

A ripple filter is designed for ripple-free voltage at the dc link of the Cuk converter. The inductance (L_o) of the ripple filter restricts the inductor peak-to-peak ripple current (ΔIL_o) within a specified value for the given switching frequency (*fs*), whereas the capacitance (C_d) is calculated for the allowed ripple in the dc link voltage (ΔVC_d) [7], [8]. The values of the ripple filter inductor and capacitor are given as

$$L_o = (1 - D)\, V_{dc} / \{f_s(\Delta IL_o)\} \quad (5)$$

$$C_d = I_{dc}/(2\omega\Delta V\, C_d) \quad . (6)$$

The PFC converter is designed for a base dc link voltage of V_{dc} = 298 V at *Vs* = 220 V for *fs* = 40 kHz, *Is* = 4.5 A, Δ*I*Li = 0.45 A (10% of *I*dc), I_{dc}= 3.5 A, ΔIL_o = 3.5 A (≈I_{dc}), ΔV_{dc} = 4 V (1% of *Vo*), and ΔV_{c1} = 220 V (≈ *Vs*). The design values are obtained as L_i = 6.61 mH, C_1= 0.3 μF, L_o= 0.82 mH, and C_d= 1590 μF,

IV. MODELING OF PFC CONVERTER-BASED PMBLDCMD

The main components of the proposed Speed Control of PMBLDCM drive are the PFC Cuk converter and voltage source inverter based PMBLDCM drive, which are modeled by mathematical equations and the complete drive is represented as a combination of these models.

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 below.

1) Speed Controller:

The speed controller is a PI controller which tracks the reference speed as an equivalent reference voltage. If, at the k^{th} instant of time, $V^{*}_{dc}(k)$ is the reference dc link voltage and $V_{dc}(k)$ is the voltage sensed at the dc link, then the voltage error $V_e(k)$ is calculated as:

$$Ve(k) = V^{*}_{dc}(k) - V_{dc}(k) \quad (7)$$

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

$$I_c(k) = I_c(k-1) + K_p\{V_e(k) - V_e(k-1)\} + KiV_e(k) \quad (8)$$

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 Cuk converter (i^{*}_{d}) is

$$i^{*}_{d} = Ic(k)u_{Vs} \quad (9)$$

where u_{Vs} is the unit template of the ac mains voltage, calculated as:

$$u_{Vs} = vd/V_{sm};\ vd = |vs|;\ vs = V_{sm} \sin \omega t \quad (10)$$

where V_{sm} is the amplitude of the voltage and ω is frequency in rad/sec at AC mains.

TABLE I
ELECTRONIC COMMUTATOR OUTPUT BASED ON THE HALL-EFFECT SENSOR SIGNALS [6, 11]

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

3) PWM Controller:

The reference input current of the Cuk converter (i^{*}_{d}) is compared with its current (i_d) sensed after diode bridge rectifier to generate the current error $\Delta i_d = (i^{*}_{d}) - i_d$). This current error is amplified by gain k_d and compared with fixed frequency (fs) sawtooth carrier waveform $m_d(t)$ [6] to get the switching signal for the MOSFET of the PFC Cuk converter as:

$$\text{if } k_d \Delta id > m_d(t) \text{ then } S = 1 \text{ else } S = 0 \quad (11)$$

where S denotes the switching of the MOSFET of the Cuk converter as shown in Fig. 2 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 Table I [6, 11].

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 3 as:

$$v_{ao} = (V_{dc}/2) \text{ for } S_{a1} = 1 \quad (12)$$

$$v_{ao} = (-V_{dc}/2) \text{ for } S_{a2} = 1 \quad (13)$$

$$v_{ao} = 0 \text{ for } S_{a1} = 0, \text{ and } S_{a2} = 0 \quad (14)$$

$$v_{an} = v_{ao} - v_{no} \quad (15)$$

where v_{ao}, v_{bo}, v_{co}, and v_{no} 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 Figure 3. The voltages v_{an}, v_{bn} and v_{cn} 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 S_{a1} or S_{a2} 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., vbo, vco, vbn, and vcn, and the switching pattern of the other IGBTs of the VSI (i.e., S_{b1}, S_{b2}, S_{c1}, and S_{c2}) are generated in a similar way.

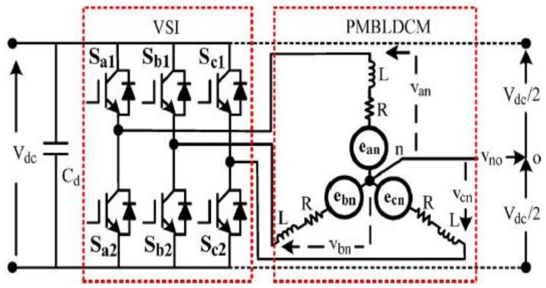

Figure 3: Equivalent circuit of a VSI-fed PMBLDCMD

3) PMBLDC Motor:

The PMBLDCM is modeled in the form of a set of differential equations [11] given as:

$$v_{an} = Ri_a + p\lambda_a + e_{an} \quad (16)$$

$$v_{bn} = Ri_b + p\lambda_b + e_{bn} \quad (17)$$

$$v_{cn} = Ri_c + p\lambda_c + e_{cn}. \quad (18)$$

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In these equations, p represents the differential operator (d/dt), i_a, i_b, and i_c are currents, λ_a, λ_b, and λ_c are flux linkages, and e_{an}, e_{bn} and e_{cn} 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:

$$\lambda_a = L_s i_a - M(i_b + i_c) \quad (19)$$

$$\lambda_b = L_s i_b - M(i_a + i_c) \quad (20)$$

$$\lambda_c = L_s i_c - M(i_b + i_a) \quad (21)$$

where L_s 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:

$$T_e = (e_{an} i_a + e_{bn} i_b + e_{cn} i_c)/\gamma\, \omega_r \quad (22)$$

where ω_r is the motor speed in radians per second. Since PMBLDCM has no neutral connection.

$$i_a + i_b + i_c = 0 \quad . (23)$$

From (15)–(21) and (23), the voltage (v_{no}) between the neutral point (n) and midpoint of the dc link (o) is given as:

$$v_{no} = \{v_{ao} + v_{bo} + v_{co} - (e_{an} + e_{bn} + e_{cn})\}/3. \quad (24)$$

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

$$\lambda_a = (Ls + M)\, i_a,\ \lambda_b = (Ls + M)\, i_b,\ \lambda_c = (Ls + M)\, i_c. \quad (25)$$

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

$$p i_x = (v_{xn} - i_x R - e_{xn})/(Ls + M) \quad (26)$$

where x represents phase a, b, or c. The back EMF is a function of rotor position (θ) as:

$$e_{xn} = K b f x(\theta)\omega_r \quad (27)$$

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

$$f_a(\theta) = 1 \text{ for } 0 < \theta < 2\pi/3 \quad (28)$$

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

$$f_a(\theta) = -1 \text{ for } \pi < \theta < 5\pi/3 \quad (30)$$

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

The functions $f_b(\theta)$ and $f_c(\theta)$ are similar to $f_a(\theta)$ with phase differences of 120◦ and 240◦, respectively. Therefore, the electromagnetic torque expressed as:

$$T_e = K_b\{f_a(\theta)\, i_a + f_b(\theta)\, i_b + f_c(\theta)\, i_c\} \quad (32)$$

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

$$p\omega_r = (P/2)(Te - T_l - B\omega_r)/(J) \quad (33)$$

where ω_r is the derivative of rotor position θ, P is the number of poles, T_l 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:

$$p\theta = \omega_r \quad (34)$$

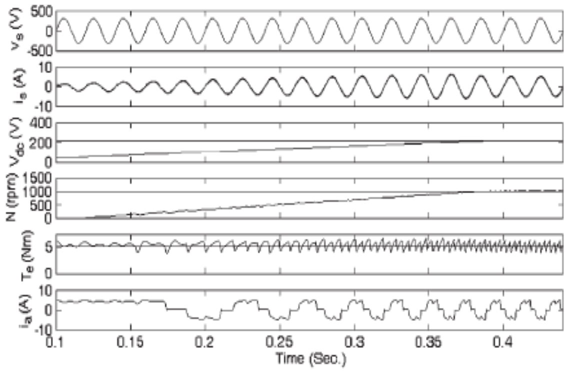
Equations (16)–(34) represent the dynamic model of the PMBLDC motor.

V. PERFORMANCE EVALUATION OF PMBLDCMD

The proposed PMBLDCMD is modeled in Matlab–Simulink environment, and its performance is evaluated for an Air-Con compressor load. The compressor load is considered as a constant torque load equal to the rated torque with variable speed as required by an Air-Con system. A 0.816-kW rating PMBLDCM is used to drive the air-conditioner, the speed of which is controlled effectively by controlling the dc link voltage. The detailed data of the motor are given in the Appendix. The performance of the proposed PFC drive is evaluated on the basis of various parameters such as THD and CF of the ac mains current and displacement power factor (DPF) and PF at different speeds of the motor as well as variable input ac voltage. For the performance evaluation of the proposed drive under input ac voltage variation, the dc link voltage is kept constant at 298 V.

A. Performance of PMBLDCMD during Starting

The performance of the PMBLDCMD during starting is evaluated while feeding it from 220-V ac mains with the reference speed set at 1000 r/min and rated torque. Figure 4(a)



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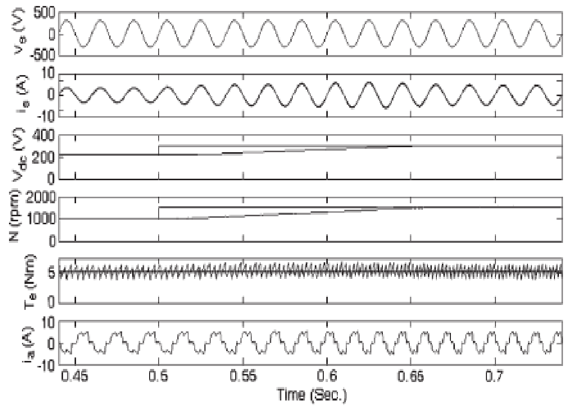

(b)

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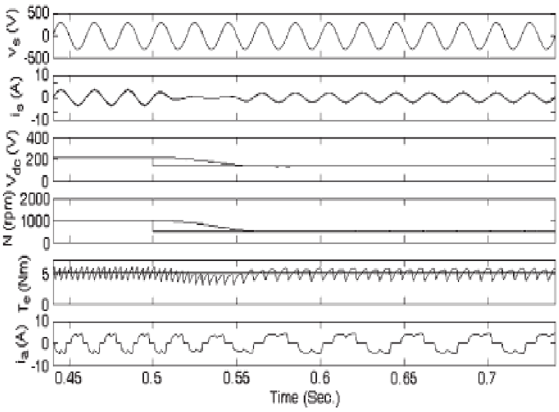


(c)

Figure 4: Performance of the proposed PFC drive under speed control at 220-V ac input. **(a)** Starting performance of the proposed drive at 1000 r/min. **(b)** Proposed drive under speed control from 1000 to 1500 r/min. **(c)** Proposed drive under speed control from 1000 to 500 r/min.

shows the starting performance of the drive depicting voltage (*vs*) and current (*is*) at ac mains, voltage at dc link (*V*dc), speed of motor (*N*), electromagnetic torque (*Te*), and stator current of phase "a" (*ia*). A rate limiter is introduced in the reference voltage to limit the starting current of the motor as well as the charging current of the dc link capacitor. The PI controller tracks the reference speed so that the motor attains reference speed smoothly within 0.375 s while keeping the stator current within the desired limits, i.e., double the rated value. The current waveform at input ac mains is in phase with the supply voltage demonstrating near unity PF during the starting.

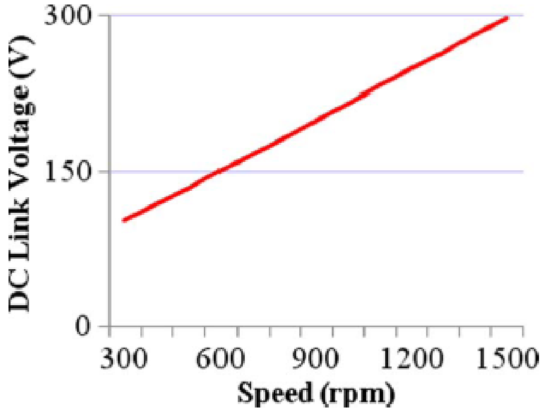
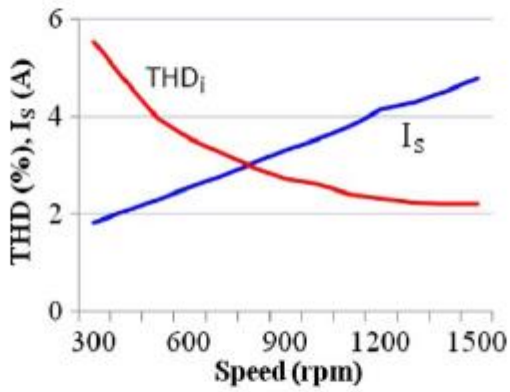


Figure 5: Variation of dc link voltage with speed for proposed PFC drive at rated torque and 220-V ac input.



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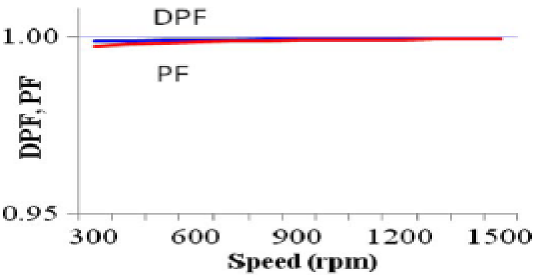
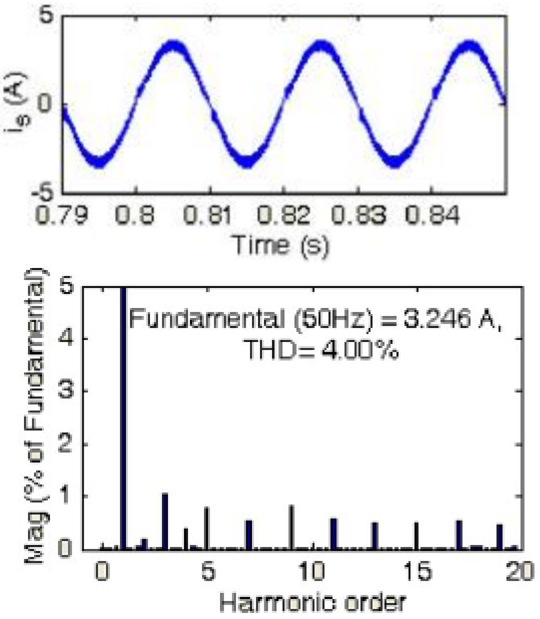


(b)

Figure 6: PQ indices of proposed drive under speed control at rated torque and 220 V ac input. **(a)** Variation of *Is* and its THD. **(b)** Variation of DPF and PF.



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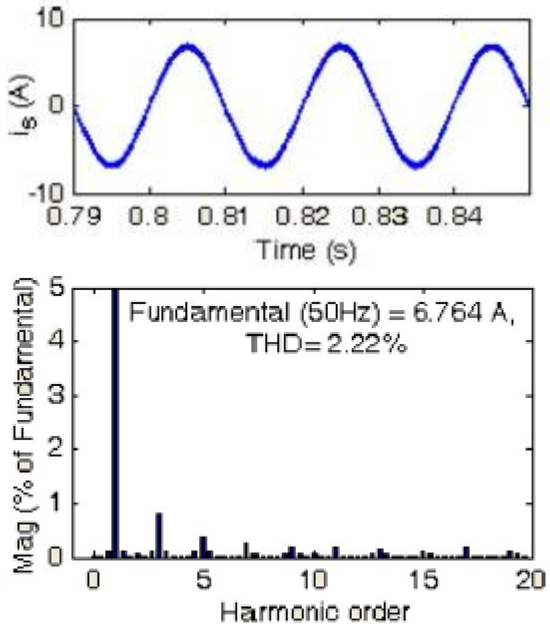

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Figure 7: Current waveform at input ac mains and its harmonic spectra for the proposed drive under steady-state condition at rated torque and 220 V ac input. **(a)** *Is* and THD at 500 r/min. **(b)** *Is* and THD at 1500 r/min.

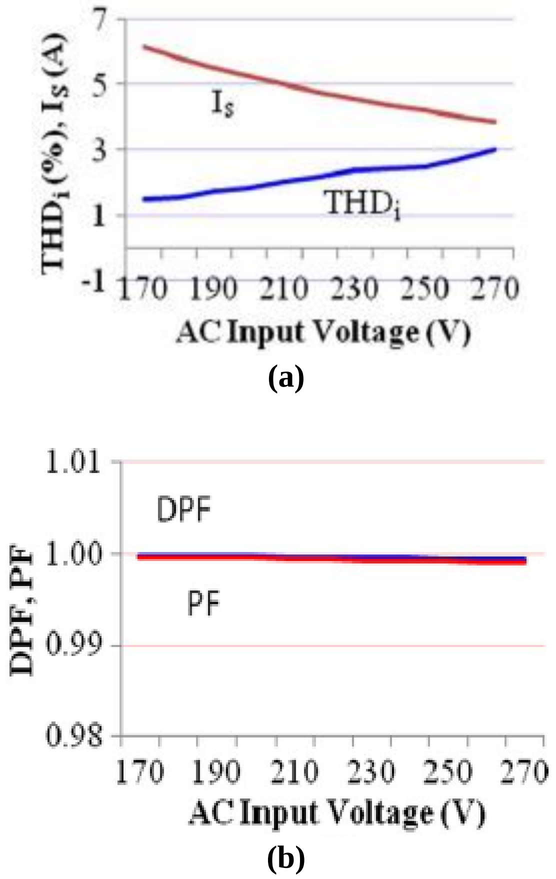

Figure 8: PQ indices with input ac voltage variation at a constant dc link voltage of 298 V (≈1500 r/min). **(a)** Variation of *Is* and its THD. **(b)** Variation of DPF and PF.

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)	LOAD (%)
140.0	300	5.55	0.9990	0.9975	1.82	20.0
119.0	400	4.74	0.9990	0.9979	2.05	26.7
135.5	500	4.00	0.9992	0.9984	2.30	33.3
151.5	600	3.55	0.9993	0.9987	2.55	40.0
167.5	700	3.25	0.9993	0.9988	2.79	46.7
183.5	800	2.97	0.9994	0.999	3.04	53.4
200.0	900	2.75	0.9995	0.9991	3.29	60.0
216.3	1000	2.63	0.9995	0.9992	3.54	66.7
233.0	1100	2.43	0.9996	0.9993	3.79	73.4
249.5	1200	2.33	0.9996	0.9993	4.15	80.0
265.5	1300	2.24	0.9997	0.9994	4.29	86.7
282.0	1400	2.23	0.9996	0.9994	4.53	93.4
298.0	1500	2.22	0.9996	0.9994	4.79	100.0

TABLE III
PQ INDICES WITH INPUT AC VOLTAGE (*Vs*) VARIATION AT 1500 r/min

V_{dc} (V)	THD_I (%)	DPF	PF	I_S (A)	LOAD (%)
170	1.51	0.9998	0.9997	1.41	6.19
180	.1.55	0.9998	0.9997	1.41	5.85
190	1.73	0.9997	0.9996	1.41	5.54
200	1.87	0.9998	0.9996	1.41	5.26
210	2.06	0.9997	0.9995	1.41	5.01
220	2.22	0.9996	0.9994	1.41	4.79
230	2.39	0.9996	0.9993	1.41	4.58
240	2.47	0.9996	0.9993	1.41	4.39
250	2.49	0.9995	0.9992	1.41	4.22
260	2.77	0.9995	0.9991	1.41	4.05
270	3.04	0.9995	0.999	1.41	3.90

B. Performance of PMBLDCMD Under Speed Control

Figure 4–6 show 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 PMBLDCM.

1) Transient Condition:

The performance of the drive during the speed transients is evaluated for acceleration and retardation of the compressor and shown in Fig. 4(b) and (c). The reference speed is changed from 1000 to 1500 r/min and from 1000 to 500 r/min for the performance evaluation of the compressor at rated load under speed control. It is observed that the speed control is fast and smooth in either direction, i.e., acceleration or retardation, with PF maintained at near unity value. Moreover, the stator current of PMBLDCM is less than twice the rated current due to the rate limiter introduced in the reference voltage.

2) Steady-State Condition:

The performance of PMBLDCMD under steady-state speed condition is obtained at different speeds as summarized in Table II which demonstrates the effectiveness of the proposed drive in a wide speed range. Fig. 5 shows the linear relation between motor speed and dc link voltage. Since the reference speed is decided by the reference voltage at dc link, it is observed that the control of the reference dc link voltage controls the speed of the motor.

C. PQ Performance of the PMBLDCMD:

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The performance of PMBLDCMD in terms of PQ indices, i.e., THD*i*, CF, DPF, and PF, is obtained for different speeds as well as loads. These results are shown in Figure 6 and 7 and Table II. Figure 6(a) and (b) shows near unity PF and reduced THD of ac mains current in wide speed range of the PMBLDCM. The THD*i* and harmonic spectra of ac mains current drawn by the proposed drive at 500- and 1500-r/min speeds are shown in Figure 7(a) and (b) demonstrating less than 5% THD*i* in a wide range of speed.

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

The performance of the proposed PMBLDCMD is evaluated under 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 summarized in Table III. Fig. 8(a) and (b) shows the current and its THD at ac mains, DPF, and PF with ac input voltage. The THD of ac mains current is within specified limits of international norms [7] at near unity PF in a wide range of ac input voltage.

VI. CONCLUSION

A new speed control strategy for a PMBLDCMD using the reference speed as an equivalent voltage at dc link has been simulated for an air-conditioner employing a Cuk PFC converter and experimentally validated on a developed controller. 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 introduction of a rate limiter in the reference dc link voltage effectively limits the motor current within the desired value during the transient conditions. The PFC Cuk converter has ensured near unity PF in a wide range of the speed and the input ac voltage. Moreover, PQ indices of the proposed PFC drive are in conformity to the International Standard IEC 61000-3-2 [7]. The proposed PMBLDCMD has been found as a promising variable speed drive for the Air-Con system. Moreover, it may also be used in the fans with PMBLDC motor drives on the trains recently introduced in Indian Railways.

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