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## A Single Phase to Three Phase PFC Half-Bridge Converter Using BLDC Drive with SPWM Technique.

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### Abstract

In this paper, a buck half-bridge DC-DC converter is used as a single-stage power factor correction (PFC) converter for feeding a voltage source inverter (VSI) based permanent magnet brushless DC motor (BLDC) drive. The front end of this PFC converter is a diode bridge rectifier (DBR) fed from single-phase AC mains. The BLDC 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 BLDC. Therefore the VSI is operated only as an electronic commutator of the BLDC. The stator current of the BLDC during step change of reference speed is controlled by a rate limiter for the reference voltage at DC link. The proposed BLDC 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 through a 1.5 kW, 1500 rpm BLDC motor. The evaluation results of the proposed speed control scheme are presented to demonstrate an improved efficiency of the proposed drive system with PFC feature in wide range of the speed and an input AC voltage.

**Index Terms**— PFC, BLDC, Air conditioner, Buck Half- bridge converter, Voltage control, VSI.

### I. INTRODUCTION

Permanent Magnet Brushless DC motors (BLDCs) are preferred motors for a compressor of an air-conditioning (Air-Con) system due to its features like high efficiency, wide speed range and low maintenance requirements [1-4]. The operation of the compressor with the speed control results in an improved efficiency of the system while maintaining the temperature in the air-conditioned zone at the set reference consistently. Whereas, the existing air conditioners mostly have a single-phase induction motor to drive the compressor in ‘on/off’ control mode. This results in increased losses due to frequent ‘on/off’ operation with increased mechanical and electrical stresses on the motor, thereby poor efficiency and reduced life of the motor. Moreover, the temperature of the air conditioned zone is regulated in a hysteresis band. Therefore, improved efficiency of the Air-Con system will certainly reduce the cost of living and energy demand to cope-up with ever-increasing power crisis.

A BLDC which is a kind of three-phase synchronous motor with permanent magnets (PMs) on the rotor and trapezoidal back EMF waveform, operates on electronic commutation accomplished by solid state switches. It is powered through a three-phase voltage source inverter (VSI) which is fed from single-phase

AC supply using a diode bridge rectifier (DBR) followed by smoothening DC link capacitor. The compressor exerts constant torque (i.e. rated torque) on the BLDC and is operated in speed control mode to improve the efficiency of the Air-Con system.

Since, the back-emf of the BLDC is proportional to the motor speed and the developed torque is proportional to its phase current [1-4], therefore, a constant torque is maintained by a constant current in the stator winding of the BLDC whereas the speed can be controlled by varying the terminal voltage of the motor. Based on this logic, a speed control scheme is proposed in this paper which uses a reference voltage at DC link proportional to the desired speed of the BLDC motor. However, the control of VSI is only for electronic commutation which is based on the rotor position signals of the BLDC motor.

The BLDC drive, fed from a single-phase AC mains through a diode bridge rectifier (DBR) followed by a DC link capacitor, suffers from power quality (PQ) disturbances such as poor power factor (PF), increased total harmonic distortion (THD) of current at input AC mains and its high crest factor (CF). It is mainly due to uncontrolled charging of the DC link capacitor which results in a pulsed current waveform having a peak value higher than the amplitude of the

fundamental input current at AC mains. Moreover, the PQ standards for low power equipments such as IEC 61000-3-2 [5], emphasize on low harmonic contents and near unity power factor current to be drawn from AC mains by these motors. Therefore, use of a power factor correction (PFC) topology amongst various available topologies [6-14] is almost inevitable for a BLDC drive.

Most of the existing systems use a boost converter for PFC as the front-end converter and an isolated DC-DC converter to produce desired output voltage constituting a two-stage PFC drive [7-8]. The DC-DC converter used in the second stage is usually a fly back or forward converter for low power applications and a full-bridge converter for higher power applications. However, these two stage PFC converters have high cost and complexity in implementing two separate switch-mode converters, therefore a single stage converter combining the PFC and voltage regulation at DC link is more in demand. The single-stage PFC converters operate with only one controller to regulate the DC link voltage along with the power factor correction. The absence of a second controller has a greater impact on the performance of single-stage PFC converters and requires a design to operate over a much wider range of operating conditions.

For the proposed voltage controlled drive, a half-bridge buck DC-DC converter is selected because of its high power handling capacity as compared to the single switch converters. Moreover, it has switching losses comparable to the single switch converters as only one switch is in operation at any instant of time. It can be operated as a single-stage power factor corrected (PFC) converter when connected between the VSI and the DBR fed from single-phase AC mains, besides controlling the voltage at DC link for the desired speed of the Air-Con compressor. A detailed modeling, design and performance evaluation of the proposed drive are presented for an air conditioner compressor driven by a BLDC motor of 1.5 kW, 1500 rpm rating.

## II. PROPOSED SPEED CONTROL SCHEME OF BLDC MOTOR FOR AIR CONDITIONER

The proposed speed control scheme (as shown in Fig. 1) Controls reference voltage at DC link as an equivalent reference speed, thereby replaces the conventional control of the motor speed and a stator current involving various sensors for voltage and current signals. Moreover, the rotor position signals are used to generate the switching sequence for the VSI as an electronic commutator of the BLDC motor. Therefore, rotor-

position information is required only at the commutation points, e.g., every 60°electrical in the three- phase [1-4]. The rotor position of BLDC is sensed using Hall effect position sensors and used to generate switching sequence for the VSI as shown in Table-I.

The DC link voltage is controlled by a half-bridge buck DC-DC converter based on the duty ratio (D) of the converter. For a fast and effective control with reduced size of magnetics and filters, a high switching frequency is used; however, the switching frequency ( $f_s$ ) is limited by the switching device used, operating power level and switching losses of the device. Metal oxide field effect transistors (MOSFETs) are used as the switching device for high switching frequency in the proposed PFC converter. However, insulated gate bipolar transistors (IGBTs) are used in VSI bridge feeding BLDC, to reduce the switching stress, as it operates at lower frequency compared to PFC switches.

The PFC control scheme uses a current control loop inside the speed control loop with current multiplier approach which operates in continuous conduction mode (CCM) with average current control. The control loop begins with the comparison of sensed DC link voltage with a voltage equivalent to the reference speed. The resultant voltage error is passed through a proportional-integral (PI) controller to give the modulating current signal. This signal is multiplied with a unit template of input AC voltage and compared with DC current sensed after the DBR. The resultant current error is amplified and compared with saw-tooth carrier wave of fixed frequency ( $f_s$ ) in unipolar scheme (as shown in Fig.2) to generate the PWM pulses for the half-bridge converter. For the current control of the BLDC during step change of the reference voltage due to the change in the reference speed, a voltage gradient less than 800 V/s is introduced for the change of DC link voltage, which ensures the stator current of the BLDC within the specified limits (i.e. double the rated current).

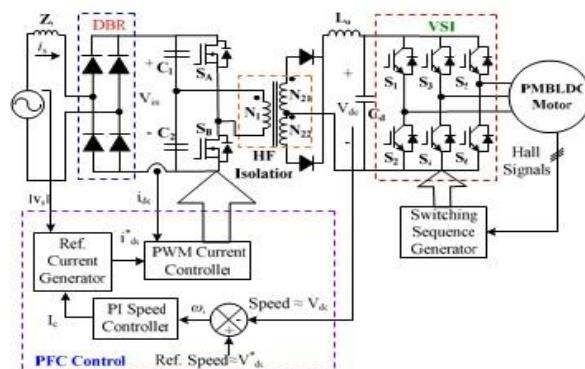


Figure 1. Control schematic of Proposed Bridge-buck PFC converter fed BLDC drive

### III. DESIGN OF PFC BUCK HALF-BRIDGE CONVERTER BASED BLDC DRIVE

The proposed PFC buck half-bridge converter is designed for a BLDC drive with main considerations on PQ constraints at AC mains and allowable ripple in DC link voltage. The DC link voltage of the PFC converter is given as,

$V_{dc} = 2(N_2/N_1) V_{in}$  D and  $N_2 = N_{21} = N_{22}$  (1)  
where  $N_1, N_{21}, N_{22}$  are number of turns in primary, secondary upper and lower windings of the high frequency (HF) isolation transformer, respectively.

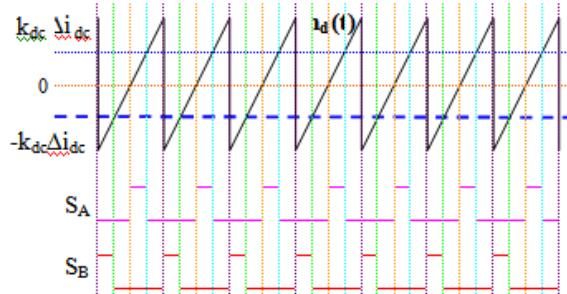


Figure 2. PWM control of the buck half-bridge converter

$V_{in}$  is the average output of the DBR for a given AC input voltage ( $V_s$ ) related as,

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

A ripple filter is designed to reduce the ripples introduced in the output voltage due to high switching frequency for constant of the buck half-bridge converter. The inductance ( $L_o$ ) of the ripple filter restricts the inductor peak to peak ripple current ( $\Delta I_{Lo}$ ) within specified value for the given switching frequency ( $f_s$ ), whereas, the capacitance ( $C_d$ ) is calculated for a specified ripple in the output voltage ( $\Delta V_{Cd}$ ) [7-8]. The output filter inductor and capacitor are given as,

$$L_o = (0.5-D)V_{dc}/\{f_s(\Delta I_{Lo})\} \quad (3)$$

$$C_d = I_o/(2\omega\Delta V_{Cd}) \quad (4)$$

The PFC converter is designed for a base DC link voltage of  $V_{dc} = 400$  V at  $V_{in} = 198$  V from  $V_s = 220$  Vrms. The turns ratio of the high frequency transformer ( $N_2/N_1$ ) is taken as 6:1 to maintain the desired DC link voltage at low input AC voltages typically at 170V. Other design data are  $f_s = 40$  kHz,  $I_o = 4$  A,  $\Delta V_{Cd} = 4$  V (1% of  $V_{dc}$ ),  $\Delta I_{Lo} = 0.8$  A (20% of  $I_o$ ). The design parameters are calculated as  $L_o = 2.0$  mH,  $C_d = 1600$   $\mu$ F.

TABLE I. VSI Switching Sequence based on the Hall Effect Sensor signals

H <sub>a</sub>	H <sub>b</sub>	H <sub>c</sub>	E <sub>a</sub>	E <sub>b</sub>	E <sub>c</sub>	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	S <sub>4</sub>	S <sub>5</sub>	S <sub>6</sub>
0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	-1	+1	0	0	0	1	1	0
0	1	0	-1	+1	0	0	1	1	0	0	0
0	1	1	-1	0	+1	0	1	0	0	1	0
1	0	0	+1	0	-1	1	0	0	0	0	1
1	0	1	+1	-1	0	1	0	0	1	0	0
1	1	0	0	+1	-1	0	0	1	0	0	1
1	1	1	0	0	0	0	0	0	0	0	0

### IV. MODELING OF THE PROPOSED BLDC DRIVE

The main components of the proposed BLDC drive are the PFC converter and BLDC 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, the prime component of this control scheme, is a proportional-integral (PI) controller which closely tracks the reference speed as an equivalent reference voltage. If at  $k^{th}$  instant of time,  $V_{dc}^*(k)$  is reference DC link voltage,  $V_{dc}(k)$  is sensed DC link voltage then the voltage error  $V_e(k)$  is calculated as,

$$V_e(k) = V_{dc}^*(k) - V_{dc}(k) \quad (5)$$

The PI controller gives desired control signal after processing this voltage error. The output of the controller  $I_c(k)$  at  $k^{th}$  instant is given as,

$$I_c(k) = I_c(k-1) + K_p\{V_e(k) - V_e(k-1)\} + K_i V_e(k) \quad (6)$$

Where  $K_p$  and  $K_i$  are the proportional and integral gains of the PI controller.

2) *Reference Current Generator:* The reference input current of the PFC converter is denoted by  $i_{dc}^*$  and given as,

$$i_{dc}^* = I_c(k) u_{Vs} \quad (7)$$

where  $u_{Vs}$  is the unit template of the voltage at input AC mains, calculated as,

$$u_{Vs} = v_d/V_{sm}; v_d = |v_s|; v_s = V_{sm} \sin \omega t \quad (8)$$

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

3) **PWM Controller:** The reference input current of the buck half-bridge converter ( $i_{dc}^*$ ) is compared with its sensed current ( $i_{dc}$ ) to generate the current error  $\Delta i_{dc} = (i_{dc}^* - i_{dc})$ . This current error is amplified by gain  $k_{dc}$  and compared with fixed frequency ( $f_s$ ) saw-tooth carrier waveform  $m_d(t)$  (as shown in Fig.2) in unipolar switching mode [7] to get the switching signals for the MOSFETs of the PFC buck half-bridge converter as,

$$\begin{aligned} \text{If } k_{dc} \Delta i_{dc} &> m_d(t) \text{ then } S_A = 1 \\ \text{else } S_A &= 0 \end{aligned} \quad (9)$$

$$\begin{aligned} \text{If } -k_{dc} \Delta i_{dc} &> m_d(t) \text{ then } S_B = 1 \\ \text{else } S_B &= 0 \end{aligned} \quad (10)$$

Where  $S_A$ ,  $S_B$  are upper and lower switches of the half-bridge converter as shown in Fig. 1 and their values '1' and '0' represent 'on' and 'off' position of the respective MOSFET of the PFC converter.

#### B. BLDC Drive

The BLDC drive consists of an electronic commutator, a VSI and a BLDC motor.

1) **Electronic Commutator:** The electronic commutator uses signals from Hall Effect position sensors to generate the switching sequence for the voltage source inverter based on the logic given in Table I.

2) **Voltage Source Inverter:** Fig. 3 shows an equivalent circuit of a VSI fed BLDC. The output of VSI to be fed to phase 'a' of the BLDC motor is given as,

where  $v_{ao}$ ,  $v_{bo}$ ,  $v_{co}$ , and  $v_{no}$  are voltages of the three-phases and neutral point (n) with respect to virtual mid-point of the DC link voltage shown as 'o' in Fig. 3. The voltages  $v_{an}$ ,  $v_{bn}$ ,  $v_{cn}$  are voltages of three-phases with respect to neutral point (n) and  $V_{dc}$  is the DC link voltage. S=1 and 0 represent 'on' and 'off' position of respective IGBTs of the VSI and considered in a similar way for other IGBTs of the VSI i.e.  $S_3$ -  $S_6$ .

Using similar logic  $v_{bo}$ ,  $v_{co}$ ,  $v_{bn}$ ,  $v_{cn}$  are generated for other two phases of the VSI feeding BLDC motor.

3) **BLDC Motor:** The BLDC is represented in the form of a set of differential equations [3] given as,

$$v_{an} = R_{ia} + p\lambda_a + e_{an} \quad (15)$$

$$v_{bn} = R_{ib} + p\lambda_b + e_{bn} \quad (16)$$

$$v_{cn} = R_{ic} + p\lambda_c + e_{cn} \quad (17)$$

where  $p$  is a differential operator ( $d/dt$ ),  $i_a$ ,  $i_b$ ,  $i_c$

are three-phase currents,  $\lambda_a$ ,  $\lambda_b$ ,  $\lambda_c$  are flux linkages and  $e_{an}$ ,  $e_{bn}$ ,  $e_{cn}$  are phase to neutral back emfs of BLDC, in respective phases,  $R$  is resistance of motor windings/phase.

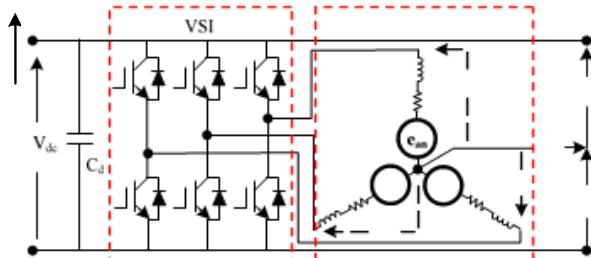


Figure 3. Equivalent Circuit of a VSI fed BLDC Drive

The flux linkages are represented as,

$$\lambda_a = L_{ia} - M(i_b + i_c) \quad (18) \quad \lambda_b = L_{ib} - M(i_a + i_c) \quad (19)$$

$$\lambda_c = L_{ic} - M(i_b + i_a) \quad (20)$$

where  $L$  is self-inductance/phase,  $M$  is mutual inductance of motor winding/phase. Since the BLDC has no neutral connection, therefore,  $i_a + i_b + i_c = 0$  (21) From Eqs. (14-21) the voltage between neutral terminal (n) and mid-point of the DC link (o) is given as,

$$v_{no} = \{v_{ao} + v_{bo} + v_{co} - (e_{an} + e_{bn} + e_{cn})\}/3 \quad (22)$$

From Eqs. (18-21), the flux linkages are given as,  $\lambda_a = (L+M) i_a$ ,  $\lambda_b = (L+M) i_b$ ,  $\lambda_c = (L+M) i_c$ , (23)

From Eqs. (15-17 and 23), the current derivatives in generalized state space form is given as,

$$p_i x = (v_{xn} - i_x R - e_{xn})/(L+M) \quad (24)$$

Where  $x$  represents phase a, b or c.

The developed electromagnetic torque  $T_e$  in the BLDC is given as,

$$T_e = (e_{an} i_a + e_{bn} i_b + e_{cn} i_c)/\omega \quad (25)$$

Where  $\omega$  is motor speed in rad/sec,

The back emfs may be expressed as a function of rotor position ( $\theta$ ) as,

$$e_{xn} = K_b f_x(\theta) \omega \quad (26)$$

Where  $x$  can be phase a, b or c and accordingly  $f_x(\theta)$  represents function of rotor position with a maximum value  $\pm 1$ , identical to trapezoidal induced emf given as,

$$f_a(\theta) = 1 \text{ for } 0 < \theta < 2\pi/3 \quad (27)$$

$$f_a(\theta) = \{(6/\pi)(\pi - \theta)\}-1 \text{ for } 2\pi/3 < \theta < \pi \quad (28)$$

$$f_a(\theta) = -1 \text{ for } \pi < \theta < 5\pi/3 \quad (29)$$

$$f_a(\theta) = \{(6/\pi)(\theta - 2\pi)\}+1 \text{ for } 5\pi/3 < \theta < 2\pi \quad (30)$$

The functions  $f_b(\theta)$  and  $f_c(\theta)$  are similar to  $f_a(\theta)$

with a phase difference of  $120^\circ$  and  $240^\circ$  respectively.

Therefore, the electromagnetic torque is expressed as,

$$T_e = K_b \{f_a(\theta) i_a + f_b(\theta) i_b + f_c(\theta) i_c\} \quad (31)$$

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

$$P\omega = (P/2) (T_e - T_L - B\omega)/(J) \quad (32)$$

The derivative of the rotor position angle is given as,  $p\theta = \omega$  (33) where P is no. poles,  $T_L$  is load torque in Nm, J is moment of inertia in  $\text{kg}\cdot\text{m}^2$  and B is friction coefficient in  $\text{Nms}/\text{Rad}$ .

These equations (15-33) represent the dynamic model of the BLDC motor.

## V. PERFORMANCE EVALUATION OF PROPOSED PFC DRIVE

The proposed BLDC drive is modeled in Matlab- Simulink environment and evaluated for an air conditioning compressor load. 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 BLDC is used to drive the air conditioner compressor, speed of which is controlled effectively by controlling the DC link voltage. The detailed data of the motor and simulation parameters are given in Appendix. The performance of the proposed PFC drive is evaluated on the basis of various parameters such as total harmonic distortion (THDi) and the crest factor (CF) of the current at input AC mains, displacement power factor (DPF), power factor (PF) and efficiency of the drive system ( $\eta_{drive}$ ) at different speeds of the motor. Moreover, these parameters are also evaluated for variable input AC voltage at DC link voltage of 416 V which is equivalent to the rated speed (1500 rpm) of the BLDC. The results are shown in Figs. 4-9 and Tables II- III to demonstrate the effectiveness of the proposed BLDC drive in a wide range of speed and input AC voltage.

### A. Performance during Starting

The performance of the proposed BLDC drive fed from 220 V AC mains during starting at rated torque and 900 rpm speed is shown in Fig. 4a. A rate limiter of 800 V/s 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 closely tracks the reference speed so that the motor attains reference speed smoothly within 0.35 sec while keeping the stator current within the desired limits i.e. double the

rated value. The current ( $i_S$ ) waveform at input AC mains is in phase with the supply voltage ( $v_S$ ) demonstrating nearly unity power factor during the starting.

### B. Performance under Speed Control

Figs. 4-6 show the performance of the proposed BLDC drive under the speed control at constant rated torque (9.55 Nm) and 220 V AC mains supply voltage. These results are categorized as performance during transient and steady state conditions.

1) *Transient Condition:* Figs. 4b-c shows the performance of the drive during the speed control of the compressor.

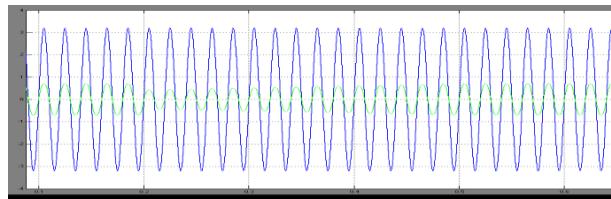


Fig.4.Single phase Grid Voltage & Current wave forms

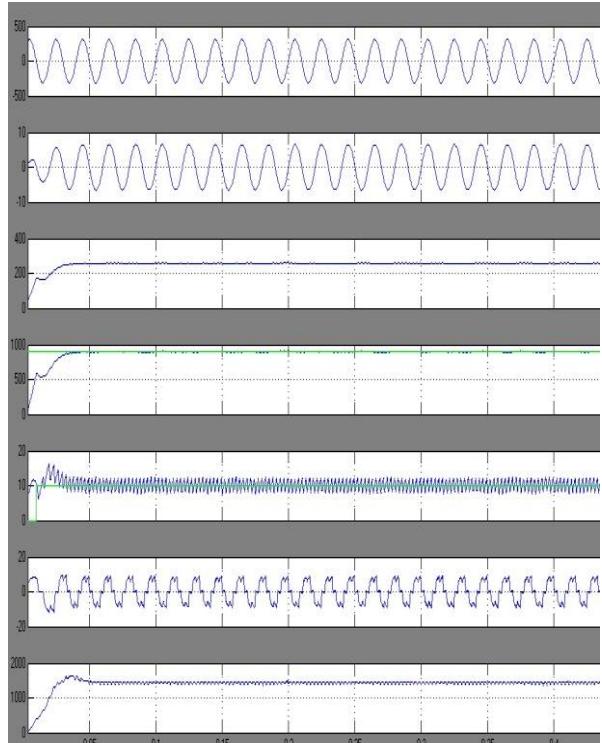


Fig.5.Starting performance of the BLDC drive at 900 rpm

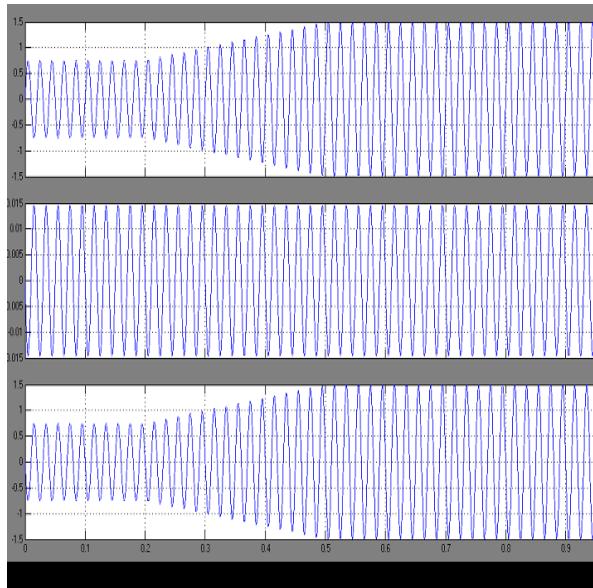


Fig.6.Three phase Current wave forms

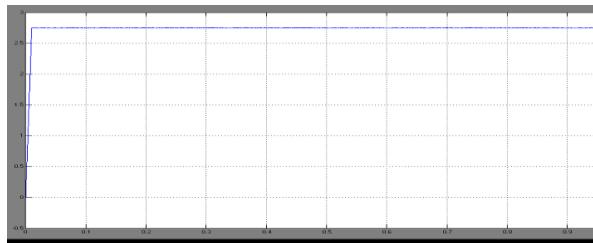


Fig.7.Capacitor voltage (Vc)

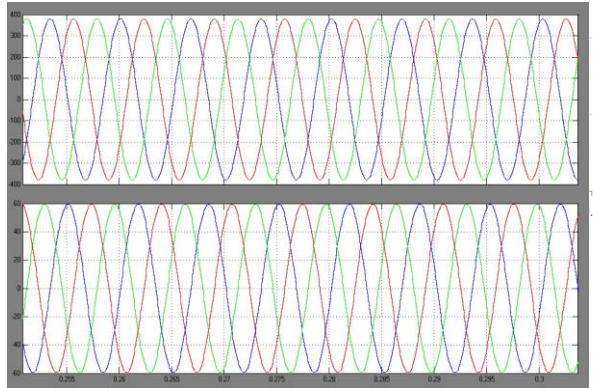


Fig.8.Single phase Grid Voltage & Current wave forms

Reference speed is changed from 900 rpm to 1500 rpm for the rated load performance of the compressor; from 900 rpm to 300 rpm for performance of the compressor at light load. It is observed that the speed control is fast and smooth in either direction i.e. Acceleration or retardation with power factor maintained at nearly unity value. Moreover, the stator current of BLDC is within the allowed limit (twice the rated current) due to the introduction of a rate limiter in the reference voltage.

**2) Steady State Condition:** The speed control of the BLDC driven compressor under steady state condition is carried out for different speeds and the results are shown in Figs. 5-6 and Table-II to demonstrate the effectiveness of the proposed drive in wide speed range. Figs.5a-c show voltage ( $v_s$ ) and current ( $i_s$ ) waveforms at AC mains, DC link voltage ( $V_{dc}$ ), speed of the motor ( $N$ ), developed electromagnetic torque of the motor ( $T_e$ ), the stator current of the BLDC motor for phase 'a' ( $I_a$ ), and shaft power output ( $P_o$ ) at 300 rpm, 900 rpm and 1500 rpm speeds. Fig. 6a shows 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 instantaneously. Fig. 6b shows the improved efficiency of the drive system ( $\eta_{drive}$ ) in wide range of the motor speed.

### C. Power Quality Performance

The performance of the proposed BLDC drive in terms of various PQ parameters such as THD<sub>i</sub>, CF, DPF, PF is summarized in Table-II and shown in Figs. 7-8. Nearly unity power factor (PF) and reduced THD of AC mains current are observed in wide speed range of the BLDC as shown in Figs. 7a-b. The THD of AC mains current remains less than 5% along with nearly unity PF in wide range of speed as well as load as shown in Table-II and Figs. 8a-c.

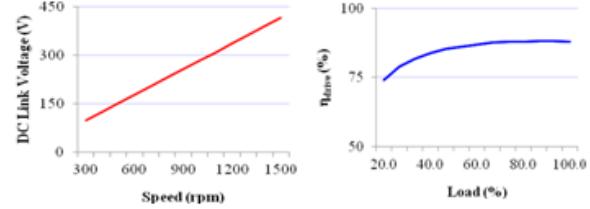


Fig. 6a. DC link voltage with speed

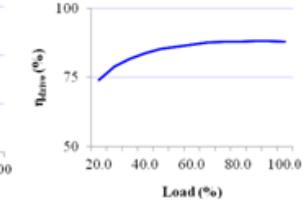


Fig. 6b. Efficiency with load

Figure 6. Performance of the proposed PFC drive under speed control at rated torque and 220 VAC

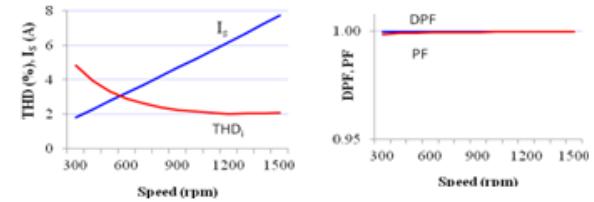


Fig. 7a. THD of current at AC mains

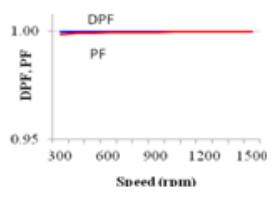


Fig. 7b. DPF and PF

Figure 7. PQ parameters of BLDC drive under speed control at rated torque and 220 VAC input

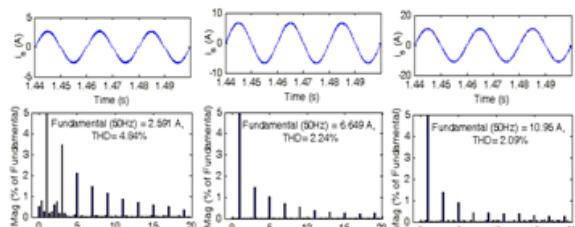


Fig. 8a. At 300 rpm      Fig. 8b. At 900 rpm  
 Fig. 8c. At 1500 rpm

Figure 8. Current waveform at AC mains and its harmonic spectra of the BLDC drive under steady state condition at rated torque and 220 VAC

TABLE II. PERFORMANCE OF DRIVE UNDER SPEED CONTROL AT 220 V AC INPUT

Speed (rpm)	VDC (V)	THDi (%)	DPF	PF	$\eta_{drive}$ (%)	Load (%)
300	100	4.84	0.9999	0.9987	74.2	20.0
400	126	3.94	0.9999	0.9991	79.1	26.7
500	153	3.33	0.9999	0.9993	81.8	33.3
600	179	2.92	0.9999	0.9995	83.8	40.0
700	205	2.63	0.9999	0.9996	85.3	46.6
800	232	2.40	0.9999	0.9996	86.1	53.3
900	258	2.24	0.9999	0.9996	87.0	60.0
1000	284	2.16	0.9999	0.9997	87.6	66.6
1100	310	2.09	0.9999	0.9997	88.1	73.3
1200	337	2.03	0.9999	0.9997	88.1	80.0
1300	363	2.05	0.9999	0.9997	88.2	86.6
1400	390	2.07	0.9999	0.9997	88.1	93.3
1500	416	2.09	0.9999	0.9997	88.1	100.0

#### D. Performance under Variable Input AC Voltage

Performance evaluation of the proposed BLDC drive is carried out under varying input AC voltage at rated load (i.e. rated torque and rated speed) to demonstrate the operation of proposed BLDC drive for air conditioning system in various practical situations as summarized in Table-III.

Figs. 9a-b show variation of input current and its THD at AC mains, DPF and PF with AC input voltage. The THD of current at AC mains is within specified limits of international norms [5] along with nearly unity power factor in wide range of AC input voltage.

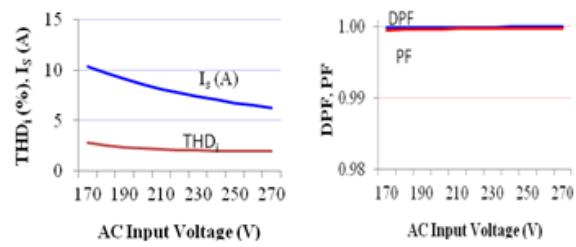


Fig. 9a. Current at AC mains and its THD      Fig. 9b. DPF and PF Figure

9. PQ parameters with input AC voltage at 416 VDC (1500 rpm)

TABLE III. VARIATION OF PQ PARAMETERS WITH INPUT AC VOLTAGE (VS) AT 1500 RPM (416 VDC)

VAC (V)	THDi (%)	DPF	PF	CF	I <sub>s</sub> (A)	$\eta_{drive}$ (%)
170	2.88	0.9999	0.9995	1.41	10.4	84.9
180	2.59	0.9999	0.9996	1.41	9.7	85.8
190	2.40	0.9999	0.9996	1.41	9.2	86.3
200	2.26	0.9999	0.9996	1.41	8.6	87.2
210	2.14	0.9999	0.9997	1.41	8.2	87.6
220	2.09	0.9999	0.9997	1.41	7.7	88.1
230	2.07	0.9999	0.9997	1.41	7.4	88.2
240	2.02	1.0000	0.9998	1.41	7.1	88.4
250	1.99	1.0000	0.9998	1.41	6.8	88.7
260	2.01	1.0000	0.9998	1.41	6.5	88.7
270	2.01	1.0000	0.9998	1.41	6.2	89.0

#### VI. CONCLUSION

A new speed control strategy of a BLDC drive is validated for a compressor load of an air conditioner which uses the reference speed as an equivalent reference voltage at DC link. The speed control is directly proportional to the voltage control at DC link. The rate limiter introduced in the reference voltage at DC link effectively limits the motor current within the desired value during the transient condition (starting and speed control). The additional PFC feature to the proposed drive ensures nearly unity PF in wide range of speed and input AC voltage. Moreover, power quality parameters of the proposed BLDC drive are in conformity to an International standard IEC 61000-3-2 [5]. The proposed drive has demonstrated good speed control with energy efficient operation of the drive system in the wide range of speed and input AC voltage. The proposed drive has been found as a promising candidate for a BLDC driving Air-Con load in 1-2 kW power range.

#### VII. APPENDIX

Rated Power: 1.5 kW, rated speed: 1500 rpm, rated current: 4.0 A, rated torque: 9.55 Nm, number of poles: 4, stator resistance (R): 2.8

$\Omega/\text{ph.}$ , inductance ( $L+M$ ): 5.21 mH/ph., back EMF constant ( $K_b$ ): 0.615 Vsec/rad, inertia ( $J$ ): 0.013 Kg-m<sup>2</sup>. Source impedance ( $Z_s$ ): 0.03 pu, switching frequency of PFC switch ( $f_s$ ) = 40 kHz, capacitors ( $C_1 = C_2$ ): 15nF, PI speed controller gains ( $K_p$ ): 0.145, ( $K_i$ ): 1.45.

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