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Power Factor Correction in Zeta Converter Fed PMBLDCM Drive for an Air Conditioner

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--ABSTRACT--
In this paper, the isolated zeta converter designed for power factor correction converter. A permanent magnet brushless dc motor is fed through a voltage source inverter which is used to drive a compressor load of an air conditioner and it is variable speed operation under rated torque. Conventional air conditioner uses single phase induction motor to drive the compressor, it provides inefficient temperature control operation. Now a day PMBLDCM drive rapidly increasing the popularity due to its operation, efficiency, ease of control, maintenance and size. The power quality problems due to uncontrolled charging the dc link capacitor in the PMBLDCM drive is reduced to a greater extent using PFC converter. The proposed PFC converter results in an improved power quality in AC mains in a wide range of speed control and input AC voltage.

INDEX TERMS*: Zeta converter, PFC, Power quality, VSI, Air-conditioner.*

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I. INTRODUCTION

The permanent magnet brushless dc motor is rapidly gaining the popularity because of its performance, reliability, efficiency, wide speed control and also suitable for low power applications. The improved power quality converters required for many applications involving power converters [1-4].BLDC diode bridge rectifier and a smoothening DC link capacitor, which results pulsed currents from AC mains and various power quality disturbances such as poor power factor, total harmonic distortion, and high crest factor of current [5].Moreover, various international PQ standards for low power applications such as IEC 61000-3-2[6] emphasize on low THD of AC mains current and power factor is near unity, and therefore various PFC converter topology for PMBLDCM drive is essential[7].The air-conditioner uses single phase induction motor which is an intensive energy application, efficiency of these motor is between 70-80% in the low power range which can be improved by replacing the PMBLDCM drive. The air-conditioner compressor load drives by PMBLDCM and the efficiency are improved.

Two-stage PFC converters commonly known as power factor pre regulators(PFP) and voltage control of DC-DC converters are reported in literature [8].mostly the power factor correction converters used boost converter at front end fly back or forward converter at the second stage of voltage control. These two stage power factor correction converter has high cost and complexity. In this proposed work contains to avoid the complexity and cost by using single stage isolated zeta converter. The proposed converter configuration is shown in figure1.It combines the PFC and dc link voltage control in a single stage and is operated by only a controller. The variation of input voltage can tolerate by converter and maintaining the DC link voltage control. Many variations of zeta converter topology with zero voltage or zero switching are reported in literature [9-11].The proposed drive are presented for air conditioner driven by PMBLDCM of5.2 Nm rate torque at 1500 rpm speed. The results are also presented to demonstrate the effectiveness of the controller for speed control of the motor in the wide range of input voltage along with various power quality indices.

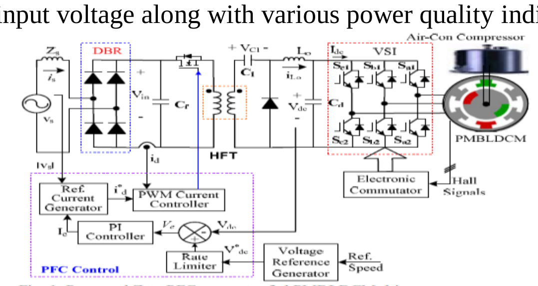

Fig. 1. Proposed Zeta PFC converter fed PMBLDCM drive.

II Proposed Scheme for PFC Converter

An isolated zeta converter as a power factor correction converter, inherits continues conduction mode of operation. Therefore, a zeta converter is proposed for PFC in a PMBLDCM drive used to air conditione.Figure1 shows the proposed zeta converter fed PMBLDCM drive [1-4], therefore stable winding current results in a constant torque and the speed is controlled by the terminal voltage of PMBLDCM drive. The rotor position signals are required only for electronic commutation of the PMBLDCM drive. The proposed zeta converter maintains the power quality at input AC mains and controlling the dc link voltage at set reference by controlling the duty ratio(D).Metal oxide field effect transistor (MOSFET) is employed as a switching device in zeta converter. The insulated gate bipolar transistors (IGBTS) are used in voltage source inverter and to reduce the switching stress and operate low switching frequency. The high frequency transformer (HFT) is used to isolation between the input and output stages. It also provides flexibility for use of large voltage ratio. Table of electronic commutator output based on hall sensor signals is given in Table-1.

Table I
Electronic Commutator Output Based On Hall Sensors 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

The PFC controller has outer voltage control loop and inner current control loop. CCM operation of zeta converter is considered for PMBLDCM drive and an average current control scheme with current multiplier approach is used in this topology. The control loop starts with sensing of dc link voltage and it is compared with reference dc link voltage. The error dc voltage is passed through a voltage of PI controller to give the modulating current signal. This signal is multiplied with a unit template of input voltage and the resultant signal is compared with DC current sensed after the diode bridge rectifier to give current error is amplified with amplified signal is then compared with saw-tooth carrier wave to generate the PWM switching pulse for the DC-DC converter.

III. DESIGN OF ZETA CONVERTER

The design of isolated zeta converter for power factor correction and speed controlled in PMBLDCM drive has the main objective of the PQ improvement at AC mains. The design equations of zeta converter are given below.

DC Link voltage: $V_{dc}= (N_2/N_1)V_{in}D/ (1\text{-}D)$

Where $V_{in}=2\sqrt{2}\ V_s/\pi$

Magnetizing Inductor: $Lm=D\ V_{in}/\{f_s\triangle I_{lm}\}$

Intermediate capacitor: $C1=DI_{dc}/\{f_s\triangle V_{c1}\}$

Output Filter: $L_o= (1\text{-}D_{dC}/\{f_s\triangle I_{Lo}\}$

The designing parameters are PFC based zeta converter DC link voltage of V_{dc}=298V at V_s=220V for f_s=40 kHz, Is=4.1 A, specified input inductor current ripple I_{Lm}=0.82 A (20% of Is), I_{dc}=3.5 A,
Peak to peak filter inductor ripple current I_{Lo}=3.5 A (I_{dc}), ripple in DC link voltage V_{Cd}=5.96V (2% of V_{dc}), voltage ripple in intermediatecapacitorV_{C1}=220V (Vs). The design values are obtained for (N_2/N_1) =1.5 for variation of input AC voltage as L_m=3.6mH, C_1=199nF, L_o=1.06mH, C_d=935μF.

IV MODELLING OF PROPOSED PMBLDCM DRIVE

A.PFC CONVERTER

The modeling of proposed isolated Zeta converter based PMBLDCM drive which is modeled by the mathematical equations of its various components.

1) Voltage Reference Generator:

The reference speed of the PMBLDCM drive is equivalent to the DC link voltage. Back EMF from PMBLDCM drive is obtained from the tests while operating the various speeds. The reference DC link voltage is equivalent to depend upon the speed control.

2)Rate Limiter:

$\triangle I_{dc}=(\triangle V_e)/R_{eq}, \triangle V_e=(V_T-2Ra Idcmax)/\tau m$

Where V_e voltage error,

V_T Terminal voltage,

R_a Winding resistance per phase,

τ_m mechanical time constant,

$\triangle V_e$ Incremental voltage raise,

I_{dc} Motor current rises within the specified limits.

3) Voltage Controller:

$I_c(k)=I_c(k-1)+K_p\{V_e(k)-V_e(k-1)+K_iV_i(k)$

Where, Kpv and Kiv are the proportional and integral gains of the voltage PI controller.

$V_e(k)=V^*_{dc}(k) - V_{dc}(k)$

4) Reference Current Generator:

$i^*_d=I_c(k)uV_s, uv_s=vd/V_{sm}$: vd=$|v_s|$;$V_s=V_{sm}\sin\omega$

Where i^*_d Reference input of the Zeta converter.

5) PWM Controller:

If $kd\triangle i_d > m_d(t)$ then s=1 else s=0 where $\triangle i_d=(i_d^*-i_d)$.

B. PMBLDCM drive

The PMBLDCM drive consists of VSI, Electronic commutator, PMBLDC motor and their equations are given the following tableII.

1) Electronic commutator : The voltage source inverter operate as an electronic commutator and the switching sequence is shown in the Table I. The switching sequence is generated from Hall Effect sensors.

2) Voltage Source Inverter: The below figure shows the equivalent circuit of the voltage source inverter fed PMBLDCM drive.

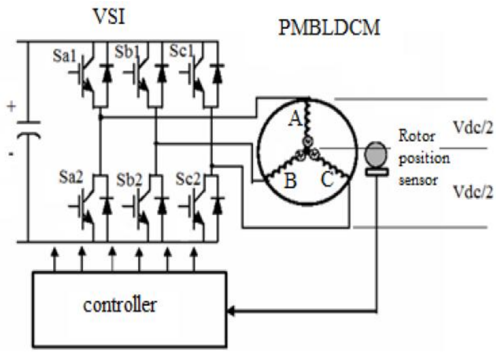

Figure.2. Equivalent Circuit of a VSI fed PMBLDCMD

3) PMBLDCM Motor: The PMBLDCM is modeled in the form of a set of differential equations as shown in Table II.

The below equations, p represents the differential operator(d/dt), i_a, i_b, i_c are currents, λ_a, λ_b and λ_c are the flux linkages, and e_{an}, e_{bn}, and e_{cn} are phase-to-neutral back EMFs of PMBLDCM, in respective phases is the resistance of the motor winding/phases is self-inductance/phase, T_e is the developed torque, ω_r is the motor speed in radians per second, x represents phases a, b or c, $f_x(\theta)$ represents a functions of the rotor position with the maximum value+1,-1, p is the number of poles, T_l is load torque in Newton meters, j is the moment of inertia, and B is the friction coefficient in Newton meters seconds per radian.

TABLE II

$$V_{an} = R\, i_a + p\, \lambda_a + e_{an}$$
$$V_{bn} = R\, i_b + p\, \lambda_b + e_{bn}$$
$$V_{cn} = R\, i_c + p\, \lambda_c + e_{cn}$$
$$\lambda_a = L_s i_a - M\,(i_b + i_c)$$
$$\lambda_b = L_s\, i_b - M\,(i_a + i_c)$$
$$\lambda_c = L_s i_c - M\,(i_b + i_a)$$
$$T_e = (e_{an} i_a + e_{bn} i_b + e_{cn} i_c) / \omega_r$$
$$i_a + i_b + i_c = 0$$
$$V_{no} = \{V_{ao} + V_{bo} + V_{co} - (e_{an} + e_{bn} + e_{cn})\} / 3$$
$$\lambda_a = (L_s + M) i_a, \quad \lambda_b = (L_s + M) i_b,$$
$$\lambda_{ac} = (L_s + M) i_c$$
$$p\, i_x = (V_{xn} - i_x R - e_{xn}) / (L_s + M)$$
$$e_{xn} = k_b\, f_x(\theta)\, \omega_r$$
$$f_a(\theta) = 1 \text{ for } 0 < \theta < 2\pi/3$$
$$f_a(\theta) = \{(6/\pi)(\pi - \theta)\} - 1 \text{ for } 2\pi/3 < \theta < \pi$$
$$f_a(\theta) = -1 \text{ for } \pi < \theta < 5\pi/3$$
$$f_a(\theta) = \{(6/\pi)(\pi - \theta)\} + 1 \text{ for } 5\pi/3 < \theta < 2\pi$$
$$T_e = K_b\{f_a(\theta) i_a + f_b(\theta) i_b + f_c(\theta) i_c\}$$
$$p\omega_r = (P/2)(T_e - T_l - B\,\omega_r) / (J)$$
$$p\theta = \omega_r$$

V. SIMULATION RESULTS

The isolated Zeta converter is fed PMBLDCM drive and it is modeled in MATLAB Simulink environment

The proposed simulation diagram is shown below

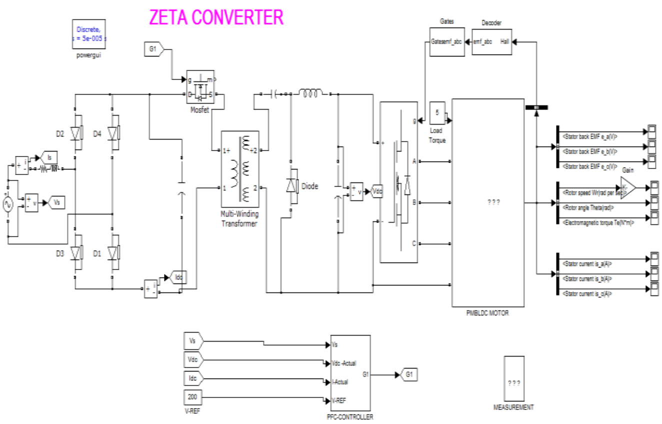

Figure.3. Proposed Simulation Circuit Diagram

The PMBLDCM driving Air-Conditioner is rated at 5.2 Nm torque and the speed is 1500 rpm and equivalent to 0.817kw.Performance of the proposed scheme is evaluated in terms of power factor, total harmonic distortion,and crest factor of AC mains current.

TABLE III

PERFORMANCE OF DRIVE UNDER SPEED CONTROL AT 220V INPUT AC VOLTAGE (V_S)

Peak Source Voltage (Vs) Volts	Peak Source Current (Is) Current	Speed (N) Rpm	Total Harmonic Distortion (Thd %)	Power Factor (Pf)
298.0	5.13	1500	2.22	0.9994
282.0	4.90	1400	2.23	0.9994
265.5	4.29	1300	2.24	0.9994
249.5	4.15	1200	2.33	0.9993
233.0	3.79	1100	2.43	0.9993
216.5	3.54	1000	2.63	0.9992
200.0	3.29	900	2.75	0.9991
183.5	3.04	800	2.97	0.999

Table III contains the performance of drive under variable speed operation and to demonstrate the operation of proposed drive for air conditioning system in various practical situations as summarized in the table.

The below figure shows the source voltage and source current of a PMBLDCM drive representing near unity power factor at peak source voltage

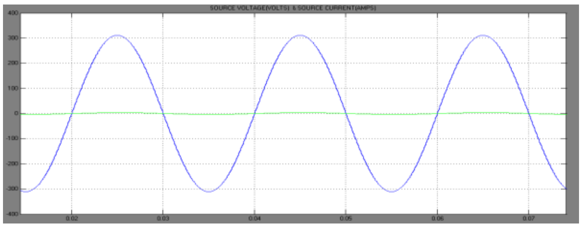

Figure.4. source voltage & source current of a PMBLDCM drive representing near unity power factor at peak source voltage of 220 V

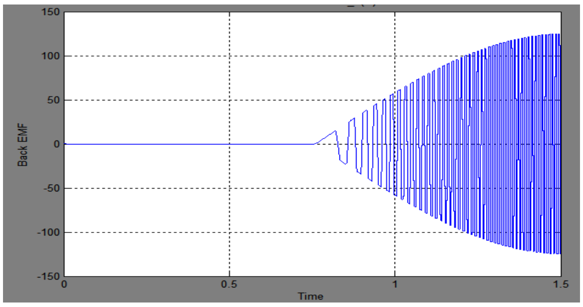

Figure.5. Trapezoidal back emf of PMBLDC motor at peak source voltage of 220 V

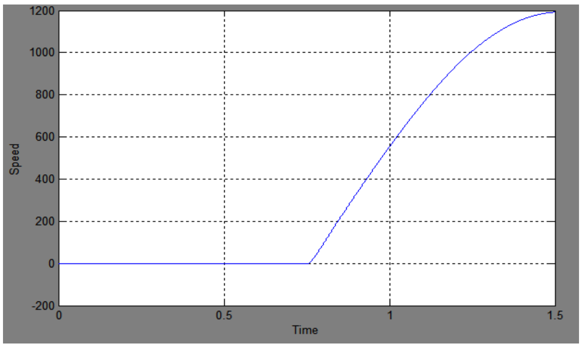

Figure.6. Speed of the PMBLDC motor at peak source voltage of 220 V

The above figure shows the trapezoidal back emf and speed of the PMBLDC motor at peak source voltage of 220 V

VI CONCLUSION

The proposed PMBLDC motor has been evaluated under variable speed drive for the air conditioning system in low power range. Single stage Zeta converter is recommended for speed control of the system by using the equivalent reference voltage at DC link. The speed of the motor is proportional to the DC link voltage and smooth speed control is observed by controlling the DC link voltage. The PFC Zeta converter has ensured near unity power factor in the wide speed range and the input AC voltage.

APPENDIX
Rated power: 0.816 kW;
Rated speed: 1500 r/min;
Rated torque: 5.2 N ·m;
Poles: 6;

Stator resistance (*R*): 3.57 Ω/ph;
Inductance(*L* +*M*): 9.165 mH/ph;
Back EMF constant (K_b):1.3 Vsec/rad;
Inertia(J): 0.068 k·m2;
Source impedance (Z_s): 0.03 p.u.;
Switching frequency of PFC switch (f_s):40 kHz;
PI speed controller gains (K_p): 0.145; (K_i): 1.85.

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