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Modeling and Control of PMBLDCM Using PFC Half &Full Bridge Converter

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Abstract: The techniques to improve the efficiency of motor drive by power factor correction play an important role in the energy saving during energy conversion. The ac-dc conversion of electric power is usually required for the BLDC motor drive, it causes many current harmonics and results in the poor power factor at the input ac mains. The use of permanent-magnet brushless dc motor (PMBLDCM) in low-power appliances is increasing because of its features of high efficiency, wide speed range, and low maintenance. In this paper, *The proposed Power Factor Controller topology improves power quality by improving performance of PMBLDCM drive, such as reduction of AC main current harmonics, near unity power factor. PFC converter forces the drive to draw sinusoidal supply current in phase with supply voltage It uses a forward buck converter to obtain unity power factor with improved performance.* ***In this proposed system a conventional pi controlled based forward buck DC-DC converter is used after the DBR and it performs power factor correction (PFC) at input AC mains and voltage control at DC link, in a single-stage with the reduction of THD in converter, speed control PMBLDCM was done in two different converters i.e..HALF&FULL BRIDGE converter with comparison. The proposed PMBLDCM drive is designed, modeled its performance is compared with evaluation in Matlab-Simulink.***

Index Terms— **PFC, PMBLDCM, DBR, Buck Half bridge converter, Buck full bridge converter, Voltage control, VSI.**

I. INTRODUCTION

For the past two decades several Asian countries such as Japan, which have been under pressure from high energy prices, have implemented variable speed PM motor drives for energy saving applications such as air conditioners and refrigerators . On the other hand, the U.S.A. has kept on using cheap induction motor drives, which have around 10% lower efficiency than adjustable PM motor drives for energy saving applications. Therefore recently, the increase in energy prices spurs higher demands of variable speed PM motor drives. Also, recent rapid proliferation of motor drives into the automobile industry, based on hybrid drives, generates a serious demand for high efficient PM motor drives, and this was the beginning of interest in BLDC motors.BLDC motors, also called Permanent Magnet DC Synchronous motors, are one of the motor types that have more rapidly gained popularity, mainly because of their better characteristics and performance .The brushless DC motor is a synchronous electric motor that, from a modeling perspective, looks exactly like a DC motor, having a linear relationship between current and torque, voltage and rpm. It is an electronically controlled commutation system, instead of having a mechanical commutation, which is typical of brushed motors.

The control of BLDC motors can be done in sensor or sensor less mode, but to reduce overall cost of actuating devices, sensorless control techniques are normally used. The disadvantages of sensor less control are higher requirements for control algorithms and more complicated electronics. Brushless permanent magnet (PM) machines, which can be categorized based on the PMs Mounting and the back-EMF shape. According to the back-EMF shape, *PM AC synchronous motors* (PMAC or PMSM) have sinusoidal back-EMF and *Brushless DC motors* (BLDC or BPM) have trapezoidal back-EMF. A PMAC motor is typically excited by a three-phase sinusoidal current, and a BLDC motor is usually powered by a set of currents having a quasi-square waveform.

Position and Speed Control of BLDC Motors Using Sensors

PM motor drives require a rotor position sensor to properly perform phase commutation and/or current control. For PMAC motors, a constant supply of position information is necessary; thus a position sensor is used. For BLDC motors, only the knowledge of six phase-commutation instants per electrical cycle is needed; therefore, low-cost *Hall-effect sensors* are usually used. The commutation of a BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a sequence. Rotor position is sensed using Hall Effect sensors embedded into the stator. Most BLDC motors have three Hall sensors embedded into the stator on the non-driving end of the motor. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined

Every 60 electrical degrees of rotation, one of the Hall sensors changes the state. It takes six steps to complete an electrical cycle. In Synchronous, with every 60 electrical degrees, the phase current switching should be updated. So, the number of electrical cycles/rotations equals the rotor pole pairs. A 3-phase bridge inverter is used to control the BLDC motor. There are six switches and these switches should be switched based on the Hall sensor inputs. The Pulse width modulation techniques are used to switch ON or OFF the switches.

II. BASIC CONTROL SCHEME FOR PFC CONVERTER

The proposed control scheme for improved PQ converter i.e. the forward buck converter or PFC converter is shown in Figure 1 which uses average current control with current multiplier approach. The forward buck converter controls the DC link voltage as well as performs PFC action by its duty ratio (D) at a constant switching frequency (fs). The proposed PFC control scheme employs a current control loop inside the voltage control loop in the continuous conduction mode (CCM) operation of the PFC converter. A proportional-integral (PI) controller forms an integral part of this controller which processes the voltage error resulting from the comparison of set voltage reference and sensed voltage at DC link. The resultant control signal of PI controller 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 a saw-tooth carrier wave of fixed frequency (fs) for generating the PWM pulses for controlling switch of PFC converter. A metal oxide field effect transistor (MOSFET) is used as the switching device for the proposed PFC converter.

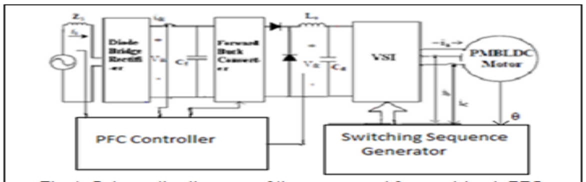


Fig.1. Schematic diagram of the proposed forward-buck PFC Converter fed PMBLDCM drive

III. MODELING OF THE PROPOSED PMBLDCM DRIVE

The main components of the proposed PMBLDCM drive are the PFC converter and PMBLDCM 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 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 kth instant of time, V*dc(k) is reference DC link voltage, Vdc(k) is sensed DC link voltage then the voltage error Ve(k) is calculated as,

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

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

$$I_c(k)=I_c(k-1)+k_p\{V_e(k)-V_e(k-1)\}+K_iV_e(k)$$

Where Kp and Ki 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 idc* and given as,

$$I^*_{dc}=I_c(k)u_{vs}$$

Where uVs is the unit template of the voltage at input AC mains, calculated as,

$$u_{vs}=V_d/V_{sm};V_d=|V_s|;V_s=V_{sm}\sin\omega t$$

Where Vsm is the amplitude of the voltage and ω is frequency in rad/sec at AC mains.

3) PWM Controller: The reference input current of the buck half/full bridge converter (idc*) is compared with its sensed current (idc) to generate the current error Δidc=(idc* - idc). This current error is amplified by gain kdc and compared with fixed frequency (fs) saw-tooth carrier waveform md(t) (as shown in Fig.2) in unipolar switching mode to get the switching signals for the MOSFETs of the PFC buck half/full bridge converter as,

If kdc Δidc > md1 (t) then SA1 = SA2 = 1 else 0

If kdc Δidc > md2 (t) then SB2 = SB1 = 1 else 0

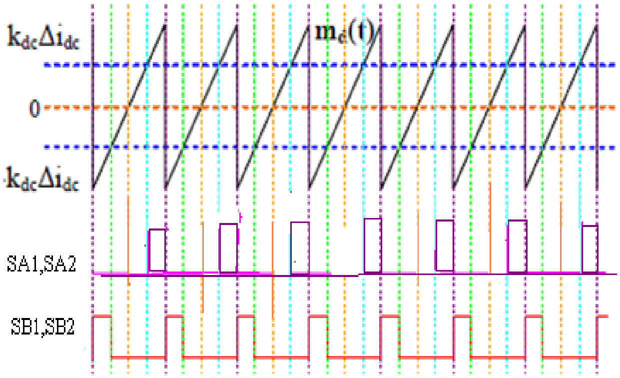
Where SA(1&2), SB(1&2) are switches of the half-bridge and full-bridge converter as shown below and their values ‘1’ and ‘0’ represent ‘on’ and ‘off’ position of the respective MOSFET’ of the PFC converter.

PMBLDCM DRIVE

The PMBLDCM drive consists of electronic commutators, a VSI and a PMBLDC motor.

1) Electronic Commutator: The electronic commutators 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: The output of VSI to be fed to phase ‘a’ of the PMBLDC motor is given as,



fig(2)

$V_{ao}=(V_{dc}/2)$ for $S_1=1$

$V_{ao}=(-V_{dc}/2)$ for $S_2=1$

$V_{ao}=0$ for $S_1=0$ and $S_2=0$

$V_{an}=V_{ao}-V_{no}$

Where vao, vbo, vco, and vno are voltages of the three-phases and neutral point (n) with respect to virtual mid-point of the DC link voltage .

3) Mathematical model of the PMBLDC drive

Modeling and simulation play an important role in the design of power electronics system. The below mentioned are mathematical equations of BLDCM.

Electrical equations of BLDC motor:

$$V_a(s)-E_a(s)=(sL+R)I_a(s)$$
$$V_b(s)-E_b(s)=(sL+R)I_b(s)$$
$$V_c(s)-E_c(s)=(sL+R)I_c(s)$$

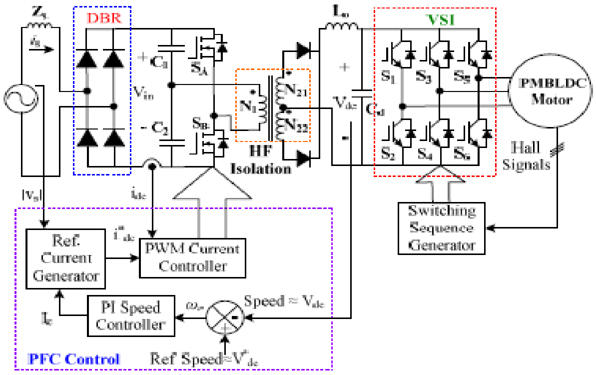
Mechanical equation of BLDC motor:

$$T_e(s) - T_l(s) = (sJ + \beta)\omega_m(s)$$

It makes the BLDC motor model more simple and convenient for various control techniques implementation.

IV. MODELING OF PFC BUCK HALF-BRIDGE CONVERTER BASED PMBLDCM DRIVE

The proposed PMBLDCM drive is modeled in Mat lab- Simulink, 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) of the current at input AC mains, power factor (PF) and efficiency of the drive system (ηdrive) at different speeds of the motor.



Fig(3)

A. Performance during Starting

The performance of the proposed PMBLDCM drive fed from 220 V AC mains during starting at rated torque and 600 rpm speed is shown in Fig. 3a. A rate limiter of 560 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 0.3 sec while keeping the stator current within the desired limits i.e. double the rated value. The current (is) waveform at input AC mains is in phase with the supply voltage (vs) demonstrating nearly unity power factor during the starting.

B. Performance under Speed Control

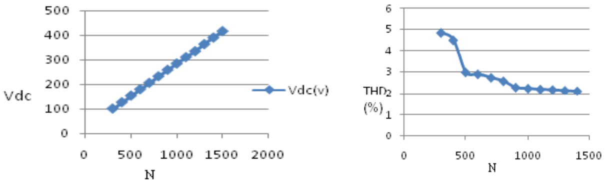
Figs. 3(b)-3(d) show the performance of the proposed PMBLDCM drive under the speed control at constant rated torque (9.55 Nm) and 220 V AC mains supply voltage. These results are categorized as performance during transient and steady state conditions.

1) Transient Condition: Figs. 3b-c shows the performance of the drive during the speed control of the compressor. The reference speed is changed from 600 rpm to 1500 rpm for the rated load performance of the compressor; from 1500 rpm to 900 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 PMBLDCM 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 PMBLDCM driven compressor under steady state condition is shown below Table-II to demonstrate the effectiveness of the proposed drive in wide speed range. Figs of voltage (vs) and current (is) waveforms at AC mains, DC link voltage (Vdc), speed of the motor (N), developed electromagnetic torque of the motor (Te), the stator current of the motor for phase 'a' (Ia), and shaft power output (Po) at 1500 rpm speed are below.

Power Quality Performance: The performance of the proposed PMBLDCM drive in terms of various PQ parameters such as THDi, and PF is summarized in Table (II)The following graphs shows the speed with all the parameters which are drawn from tabular column

(a) Speed vs Vdc (b) Speed vs thd



(c)Speed vs pf (d) Speed vs efficiency

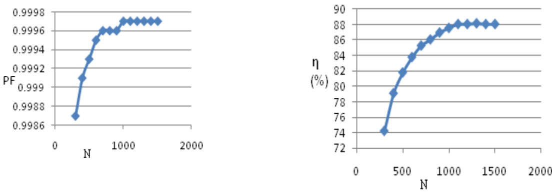


Table (II)

Speed (rpm)	Vdc (v)	THDi (%)	PF	Efficiency (%)
300	100	4.84T	0.9987	74.2
400	126	4.50	0.9991	79.1
500	153	2.99	0.9993	81.8
600	179	2.90	0.9995	83.8
700	205	2.74	0.9996	85.3
800	232	2.58	0.9996	86.1
900	258	2.29	0.9996	87.0
1000	284	2.24	0.9997	87.6
1100	310	2.20	0.9997	88.1
1200	334	2.18	0.9997	88.1
1300	363	2.14	0.9997	88.2
1400	390	2.11	0.9997	88.1
1500	416	2.09	0.9997	88.1

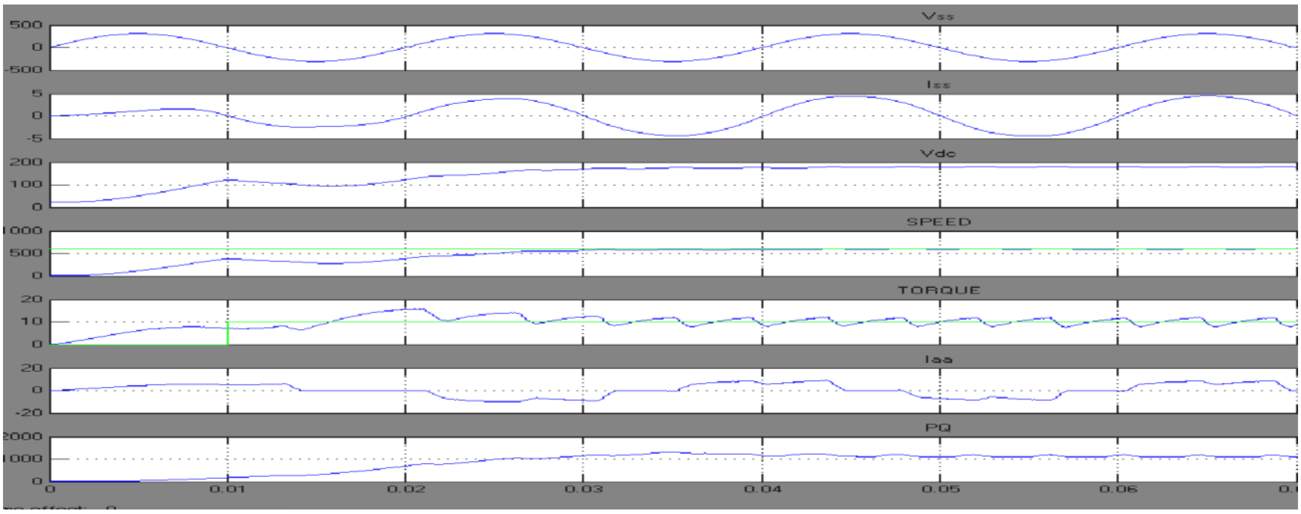


Fig 3(a) Starting performance of the PMBLDCM drive at 600 rpm

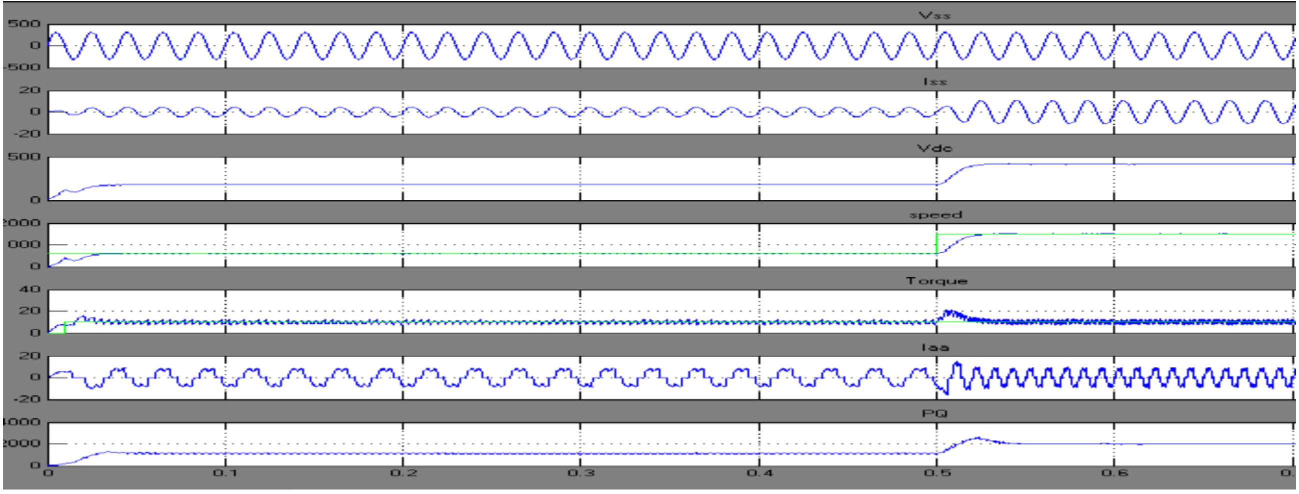


Fig 3(b)PMBLDCM drive under speed variation from 600 rpm to 900 rpm

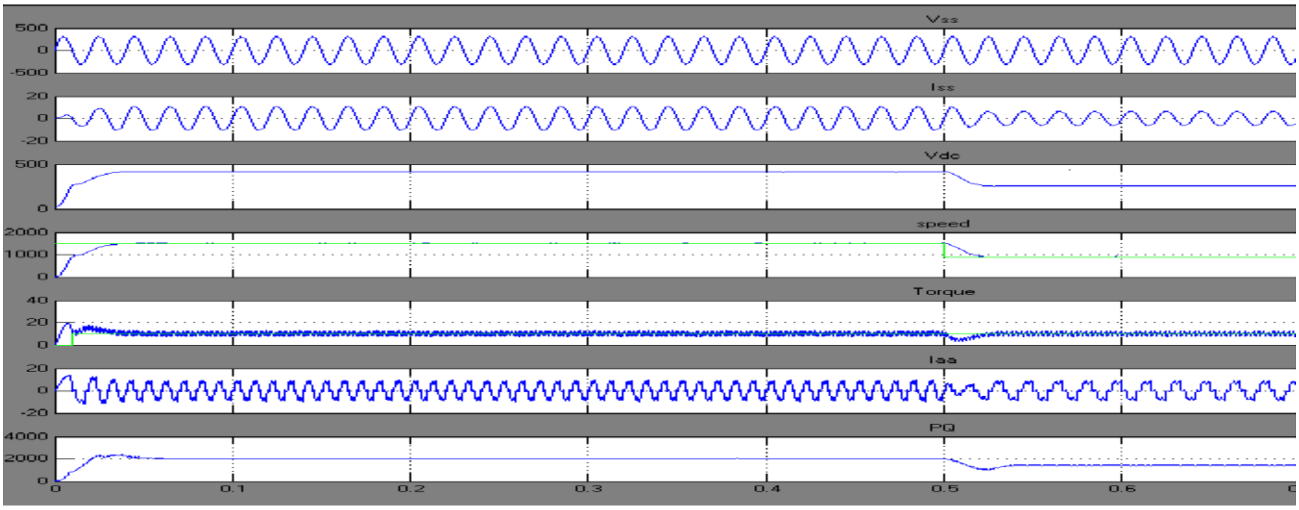


Fig 3(c)PMBLDCM drive under speed variation from 1500 rpm to 900 rpm

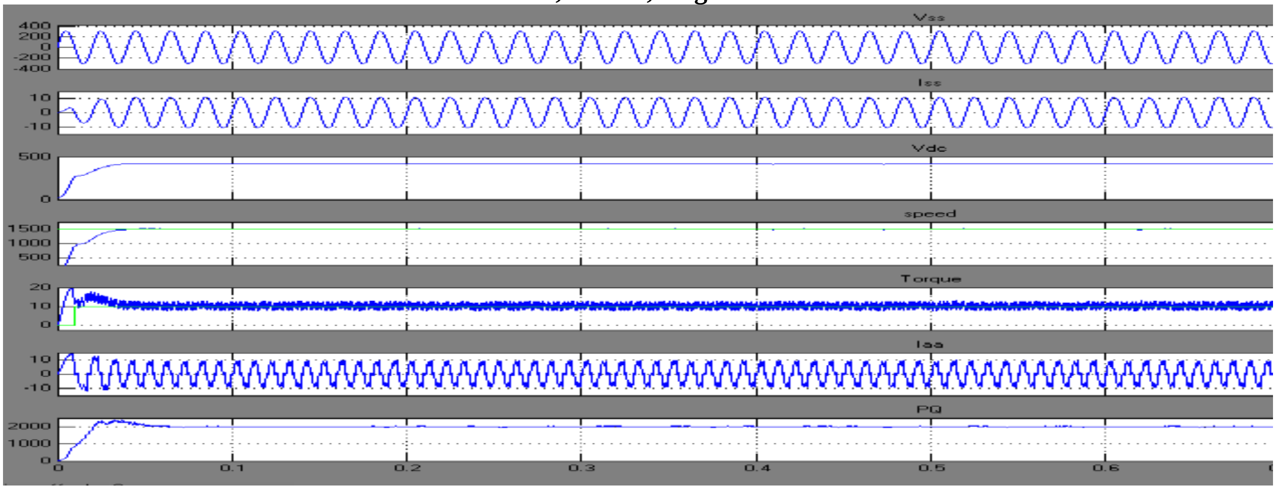
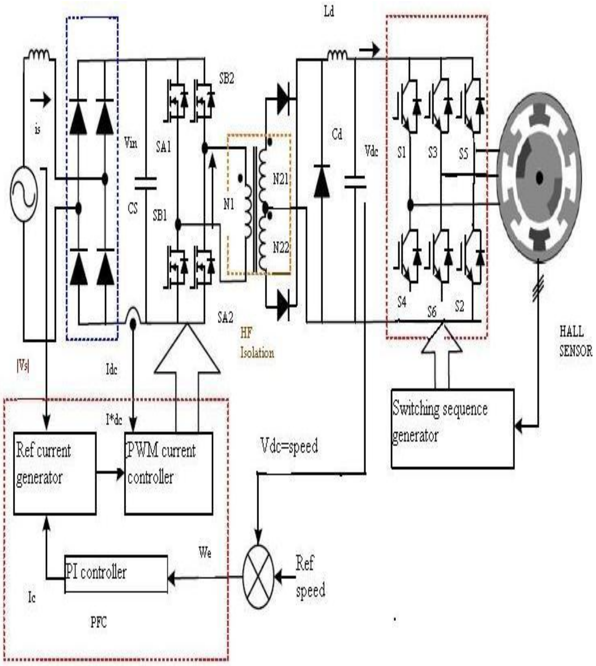


Fig 3(d) Performance of the PMBLDCM drive at 1500 rpm

V. MODELING OF PFC BUCK FULL-BRIDGE CONVERTER BASED PMBLDCM DRIVE

The proposed PMBLDCM drive is modeled in Mat lab- Simulink, 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) of the current at input AC mains, power factor (PF).



A. Performance during Starting

The performance of the proposed PMBLDCM drive fed from 220 V AC mains during starting at rated torque and 600 rpm speed is shown in Fig. 4a. A rate limiter of 500 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 0.26 sec while keeping the stator current within the desired limits i.e. double the rated value. The current (is) waveform at input AC mains is in phase with the supply voltage (vs) demonstrating nearly unity power factor during the starting.

B. Performance under Speed Control

Figs. 4(b)-(d)show the performance of the proposed PMBLDCM 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. The reference speed is changed from 600 rpm to 1500 rpm for the rated load performance of the compressor; from 1500 rpm to 900 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.

2) Steady State Condition: The speed control of the PMBLDCM driven compressor under steady state condition is shown below Table-III to demonstrate the effectiveness of the proposed drive in wide speed range. Fig show voltage (vs) and current (is) waveforms at AC mains, DC link (Vdc), speed of the motor (N), developed electromagnetic torque of the motor (Te), the stator current of the motor of the motor (Te), the stator current of the motor for phase ‘a’ (Ia), and shaft power output (Po) at 1500 rpm speed show.

Power Quality Performance

The performance of the proposed PMBLDCM drive in terms of various PQ parameters such as THDi, and PF is summarized in Table (III).

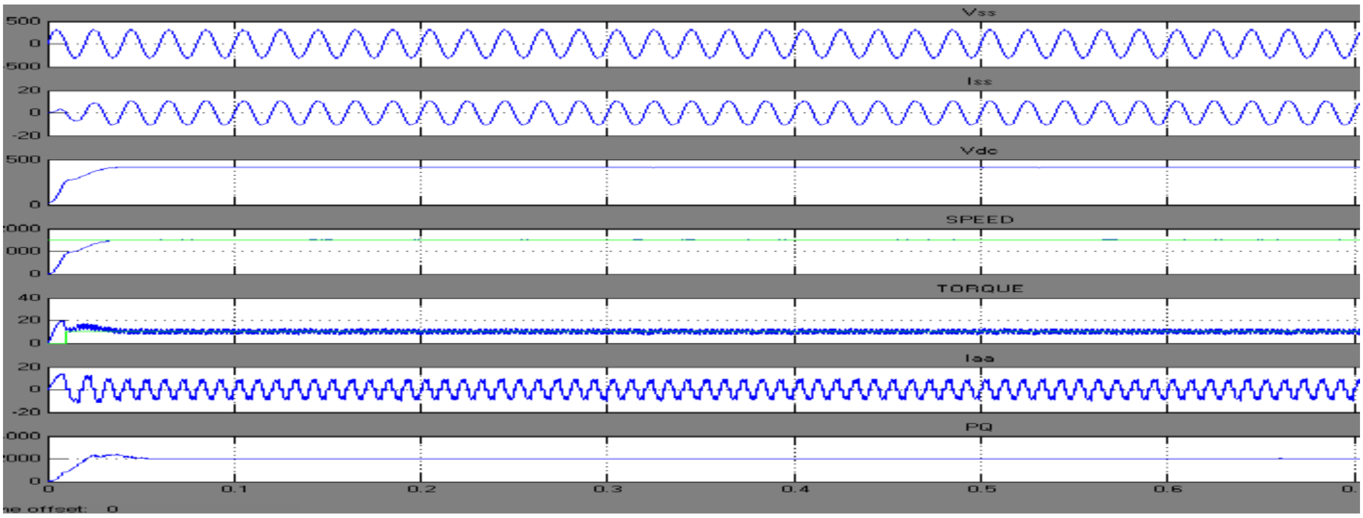


Fig 4(a) Starting performance of the PMBLDCM drive at 600 rpm

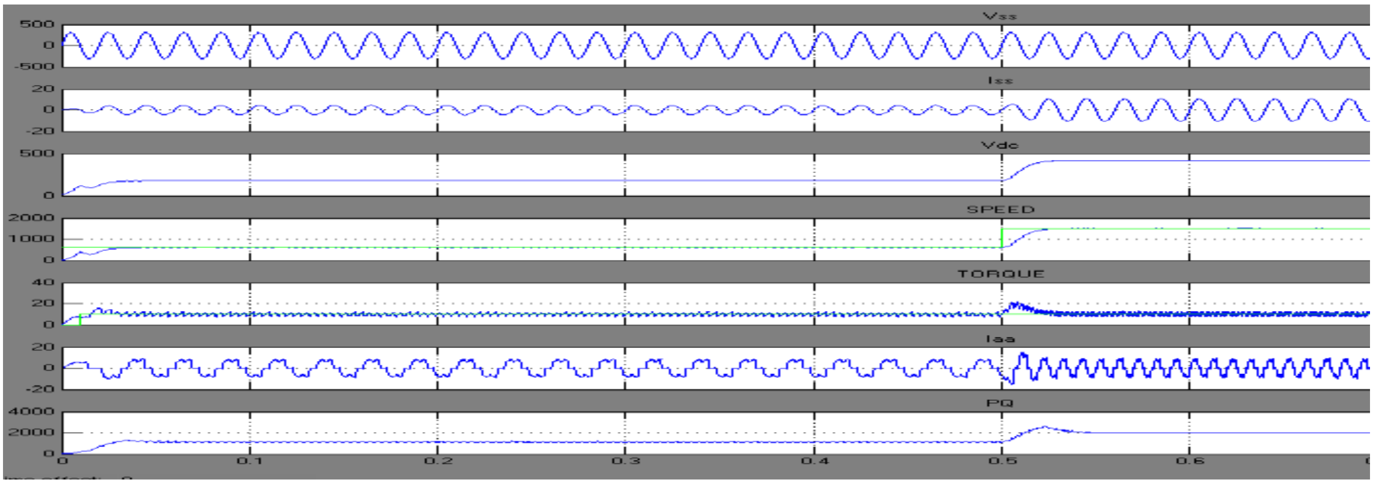


Fig 4(b) PMBLDCM drive under speed variation from 600 rpm to 900 rpm

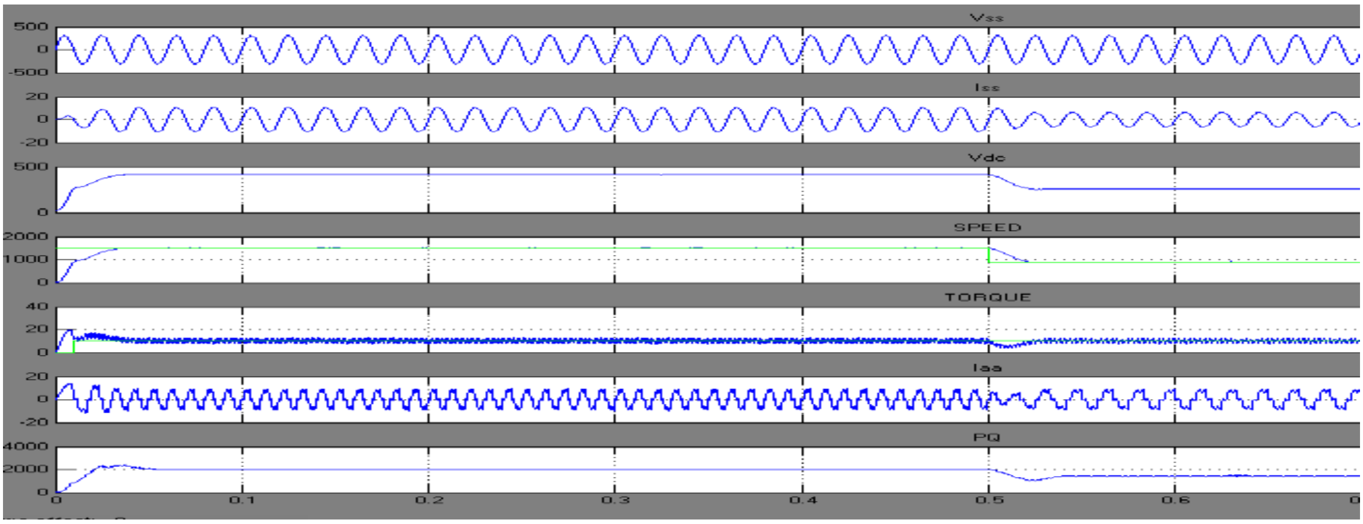


Fig 4(c)PMBLDCM drive under speed variation from 1500 rpm to 900 rpm

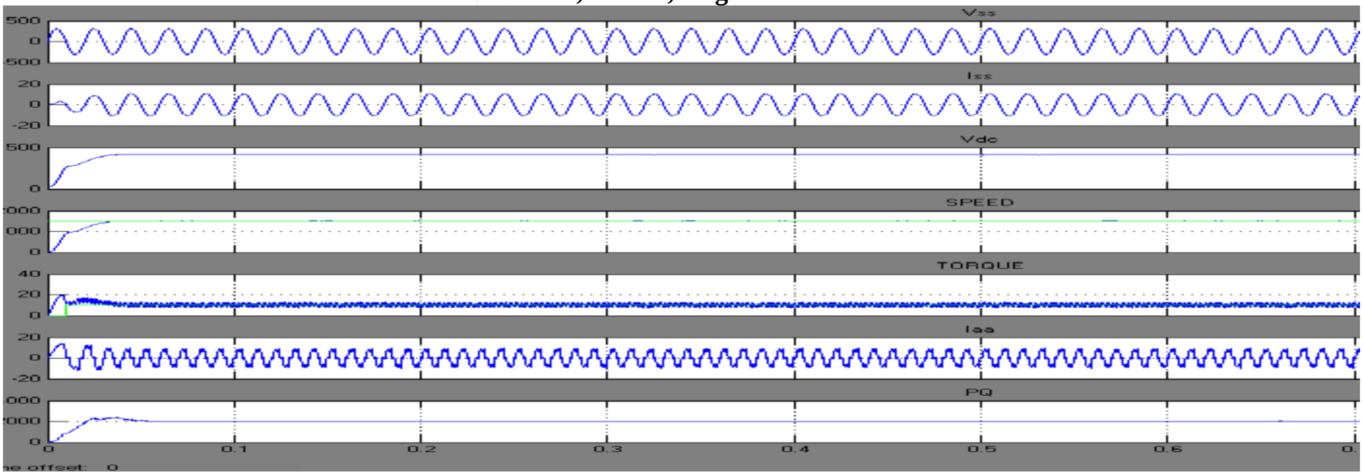


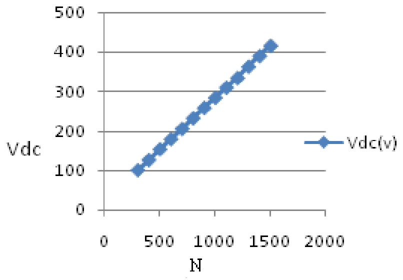
Fig 4(d) Performance of the PMBLDCM drive at 1500 rpm

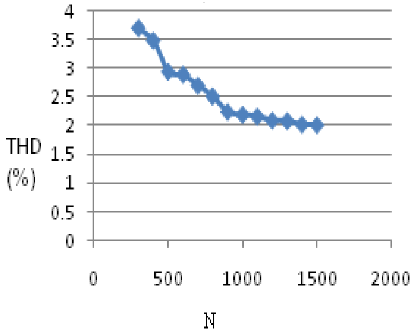
Performance of drive under speed control at 220 v ac input.

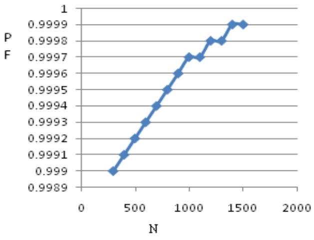
Speed (rpm)	Vdc (v)	THDi (%)	PF	Efficiency drive (%)
300	100	3.71	0.9990	63.7
400	126	4.49	0.9991	68.0
500	153	2.95	0.9992	71.1
600	179	2.90	0.9993	75.7
700	205	2.71	0.9994	76.6
800	232	2.52	0.9995	77.4
900	258	2.25	0.9996	78.3
1000	284	2.20	0.9997	80.2
1100	310	2.17	0.9997	85.2
1200	334	2.10	0.9998	86.3
1300	363	2.09	0.9998	87.0
1400	390	2.03	0.9999	88.5
1500	416	2.02	0.9999	89.0

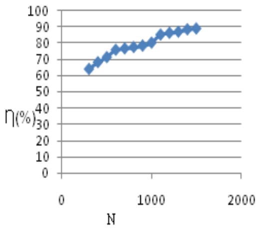
Table (III).

The following graphs (a) speed vs Vdc (b)Speed vs thd (c)Speed vs pf (d)Speed vs efficiency are shown below.







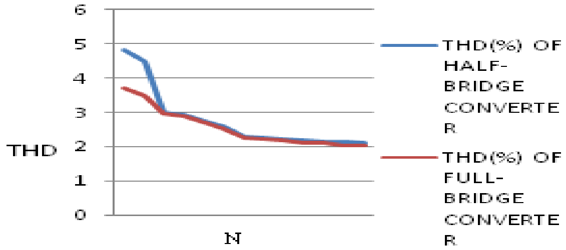


VI. CONCLUSION

Modeling, design, and performance evaluation of the proposed speed control scheme with the PFC converter for an air conditioner compressor is presented to demonstrate high efficiency and reduced energy consumption with desired speed control. The features of the speed control using the DC link voltage control, power factor correction at input AC mains, and reduced THD of AC mains current. Modeling, design, and performance evaluation of the proposed speed control scheme with the PFC converter for an air conditioner compressor is presented to demonstrate.

Table (IV)

SPEED OF MOTOR	THD(%) OF HALF-BRIDGE CONVERTER	THD(%) OF FULL-BRIDGE CONVERTER
300	4.84	3.71
400	4.50	3.49
500	2.99	2.95
600	2.90	2.90
700	2.74	2.71
800	2.58	2.52
900	2.29	2.25
1000	2.24	2.20
1100	2.20	2.17
1200	2.18	2.10
1300	2.14	2.09
1400	2.11	2.03
1500	2.09	2.02



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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 Ω/ph., inductance (L+M): 5.21 mH/ph., back EMF constant(Kb):0.615 Vsec/rad, inertia (J):0.013 Kg-m2. Source impedance (Zs): 0.03 pu, switching frequency of PFC switch (fs) = 40 kHz, capacitors (C1= C2):
15nF, PI speed controller gains (Kp): 0.145, (Ki): 1.45.

Ha	Hb	Hc	Ea	Eb	Ec	S1	S2	S3	S4	S5	S6
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

Table 1