ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

A Single-Stage PFC Half-Bridge Converter Controlled Adjustable Speed PMBLDCM Drive

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ABSTRACT: The PMBLDCM is used to drive a compressor load of an air conditioner through a three-phase VSI fed from a controlled DC link voltage. **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 (PMBLDCM) drive. The front end of this PFC converter is a Diode Bridge Rectifier (DBR) fed from single-phase AC mains. 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 PMBLDCM. 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 Mat lab- Simulink environment for an air conditioner compressor driven through a 1.5 kW, 1500 rpm PMBLDC 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.

KEYWORDS: Power Factor Correction (PFC), Voltage Source Inverter (VSI), Permanent Magnet Brushless DC Motor (PMBLDCM), Mat lab- Simulink, Diode Bridge Rectifier (DBR)

I.INTRODUCTION

Permanent magnet brushless DC motors (PMBLDCMs) 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. 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 [1]. 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.

The PMBLDCM 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 equipment's emphasize on low harmonic contents and near unity power factor current to be drawn from AC mains by these motors [2].

Therefore, the proposed scheme for use of a power factor correction (PFC) topology amongst various available topologies is almost inevitable for a PMBLDCM 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. 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,

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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 [3]. In this paper a detailed modeling, design and performance evaluation of the proposed drive are presented for an air conditioner compressor driven by a PMBLDC motor of 1.5 kW, 1500 rpm rating.

In order to improve the power factor, some device taking leading power should be connected in parallel with the load. One of such devices can be a capacitor. The capacitor draws a leading current and partly or completely neutralizes the lagging reactive component of load current. This raises the power factor of the load. Despite the use of good quality test meter instrumentation, high current flow can often remain undetected or under estimated by as much 40%. This severe underestimation causes overly high running temperatures of equipment and nuisance tripping. This is simply because the average reading test meters commonly used by maintenance technicians are not designed to accurately measure distorted currents and can only provide indication of the condition of the supply at the time of checking. Power quality conditions change continuously and only instruments offering true RMS measurement of distorted waveforms and neutral currents can provide the correct measurements to accurately determine the ratings of cables, bus bars and circuit breakers. High harmonic environments can produce unexpected and dangerous neutral currents. In a balanced system, the fundamental currents will cancel out, but, triple-N's will add, so harmonic currents at the 3rd, 9th, 15th etc. will flow in the neutral. Traditional 3 phase system meters are only able to calculate the vector of line to neutral current measurements, which may not register the true reading. Integra 1530, 1560 and 1580 offer a 3 phase 4 wire versions with a neutral 4th CT allowing true neutral current measurement and protection in high harmonic environments.

II.BRUSHLESS D.C MOTOR

Brushless Direct Current (BLDC) motors are one of the motor types rapidly gaining popularity. BLDC motors are used in industries such as Appliances, Automotive, Aerospace, Consumer, Medical, Industrial Automation Equipment and Instrumentation. As the name implies, BLDC motors do not use brushes for commutation; instead, they are electronically commutated. BLDC motors have many advantages over brushed DC motors and induction motors. A few of these are:

- Better speed versus torque characteristics
- High dynamic response
- High efficiency
- Long operating life
- Noiseless operation
- Higher speed ranges

In addition, the ratio of torque delivered to the size of the motor is higher, making it useful in applications where space and weight are critical factors. In this application note, we will discuss in detail the construction, working principle, characteristics and typical applications of BLDC motors.

BLDC motors are a type of synchronous motor. This means the magnetic fields generated by the stator and by the rotor rotate at the same frequency. BLDC motors do not experience. BLDC motors come in single-phase, 2-phase and 3-phase configurations. Corresponding to its type, the stator has the same number of windings. Out of these, 3-phase motors are the most popular and widely used. This application note focuses on 3-phase motors. The stator of a BLDC motor consists of stacked steel laminations with windings placed in the slots that are axially cut along the inner periphery as shown in Fig.1 [4]. Traditionally, the stator resembles that of an induction motor; however, the windings are distributed in a different manner. Most BLDC motors have three stator windings connected in star fashion. Each of these windings are constructed with numerous coils interconnected to form a winding. One or more coils are placed in the slots and they are interconnected to make a winding. Each of these windings are distributed over the stator periphery to form an even numbers of poles. There are two types of stator windings variants: trapezoidal and sinusoidal

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motors. This differentiation is made on the basis of the interconnection of coils in the stator windings to give the different types of back Electromotive Force (EMF).

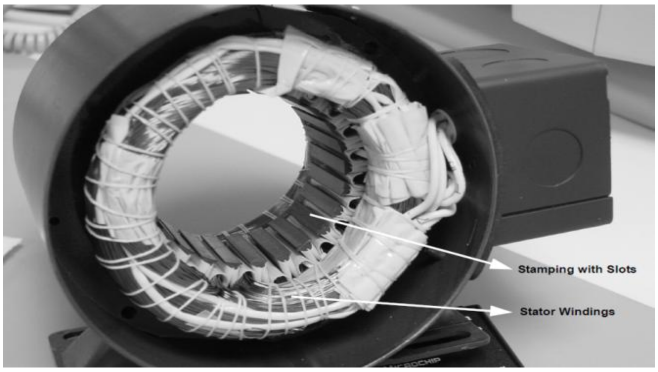

Fig. 1 Stator of BLDC motor

As their names indicate, the trapezoidal motor gives a back EMF in trapezoidal fashion and the sinusoidal motor's back EMF is sinusoidal, as shown in Fig. 2 and Fig. 3. In addition to the back EMF, the phase current also has trapezoidal and sinusoidal variations in the respective types of motor. This makes the torque output by a sinusoidal motor smoother than that of a trapezoidal motor. However, this comes with an extra cost, as the sinusoidal motors take extra winding interconnections because of the coils distribution on the stator periphery, thereby increasing the copper intake by the stator windings. Depending upon the control power supply capability, the motor with the correct voltage rating of the stator can be chosen. Forty-eight volts, or less voltage rated motors are used in automotive, robotics, small arm movements and soon. Motors with 100 volts, or higher ratings, are used in appliances, automation and in industrial applications.

The rotor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) and South (S) poles. Based on the required magnetic field density in the rotor, the proper magnetic material is chosen to make the rotor. Ferrite magnets are traditionally used to make permanent magnets. As the technology advances, rare earth alloy magnets are gaining popularity. The ferrite magnets are less expensive but they have the disadvantage of low flux density for a given volume. In contrast, the alloy material has high magnetic density per volume and enables the rotor to compress further for the same torque. Also, these alloy magnets improve the size-to-weight ratio and give higher torque for the same size motor using ferrite magnets. Neodymium (Nd), Samarium Cobalt (SmCo) and the alloy of Neodymium, Ferrite and Boron (NdFeB) are some examples of rare earth alloy magnets. Continuous research is going on to improve the flux density to compress the rotor further.

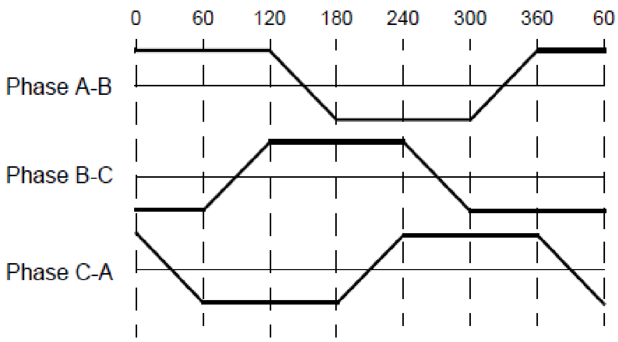

Fig. 2 Trapezoidal back EMF

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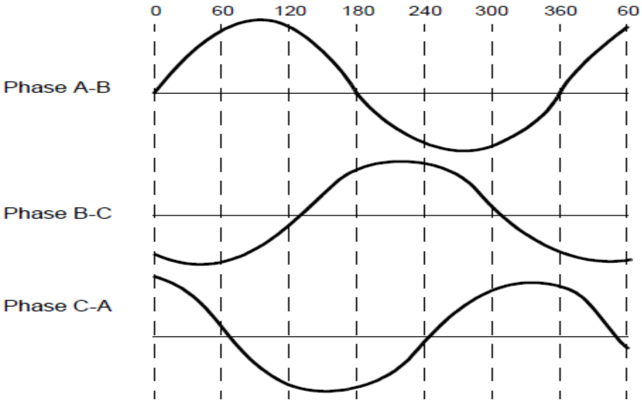

Fig .3 Sinusoidal back EMF

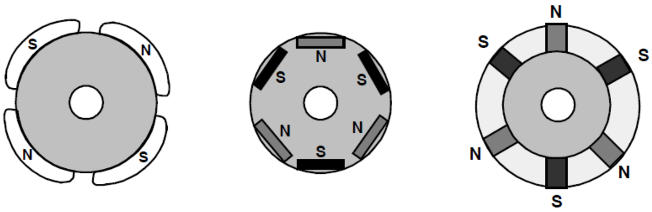

Fig. 4 Rotor magnet cross sections

Unlike a brushed DC motor, the commutation of a BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a sequence. It is important to know the rotor position in order to understand which winding will be energized following the energizing 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. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined [5].

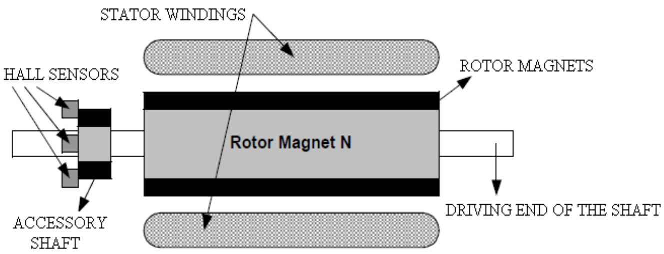

Fig. 5 BLDC motor transverse section

To simplify the process of mounting the Hall sensors onto the stator, some motors may have the Hall sensor magnets on the rotor, in addition to the main rotor magnets. These are a scaled down replica version of the rotor. Therefore, whenever the rotor rotates, the Hall sensor magnets give the same effect as the main magnets. The Hall sensors are normally mounted on a PC board and fixed to the enclosure cap on the non-driving end. This enables users to adjust the complete assembly of Hall sensors, to align with the rotor magnets, in order to achieve the best performance. Based on the physical position of the Hall sensors, there are two versions of output. The Hall sensors may be at 60° or 120° phase shift to each other. Based on this, the motor manufacturer defines the commutation sequence, which should be followed when controlling the motor. Each commutation sequence has one of the windings energized to positive power (current enters into the winding), the second winding is negative (current exits the winding) and the third is in a non-energized

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condition. Torque is produced because of the interaction between the magnetic field generated by the stator coils and the permanent magnets. Ideally, the peak torque occurs when these two fields are at 90° to each other and falls off as the fields move together. In order to keep the motor running, the magnetic field produced by the windings should shift position, as the rotor moves to catch up with the stator field.

III. SINGLE STAGE P.F.C CONVERTER

The PMBLDCM 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 equipment's emphasize on low harmonic contents and near unity power factor current to be drawn from AC mains by these motors [2].

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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 [3].

IV. PROPOSED SPEED CONTROL SCHEME OF PMBLDC MOTOR FOR AIR CONDITIONER

The simulation circuit of proposed drive for permanent magnet brushless dc motor is shown in below fig. 5. The PMBLDCM drive, fed from a single-phase AC mains through a diode bridge rectifier (DBR) followed by a DC link capacitor. 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. 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.

The proposed PMBLDCM drive is modeled in Mat lab- 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 PMBLDCM 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 (THD) 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 (η_{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 PMBLDCM. The results are shown in Fig. 6 and Fig. 7 and Tables 1 &.2 to demonstrate the effectiveness of the proposed PMBLDCM drive in a wide range of speed and input AC voltage.

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(An ISO 3297: 2007 Certified Organization)

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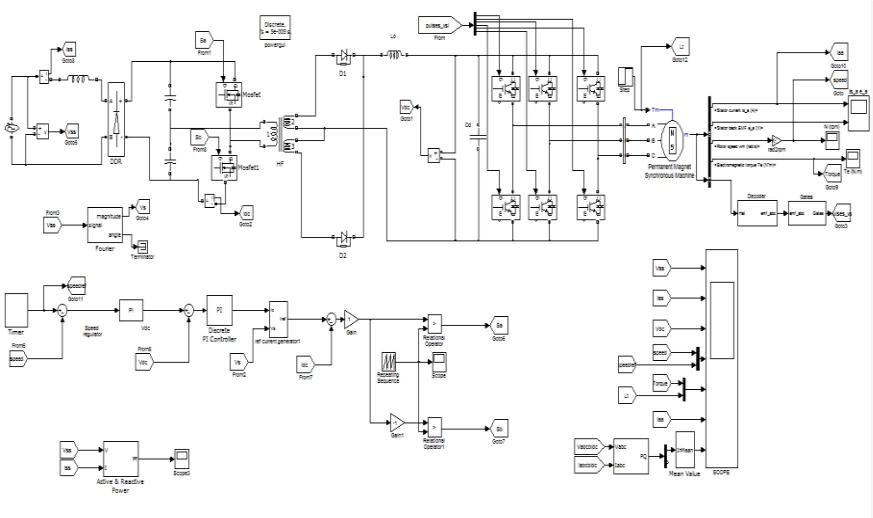

Fig. 5 Simulation circuit for proposed PMBLDCM DRIVE

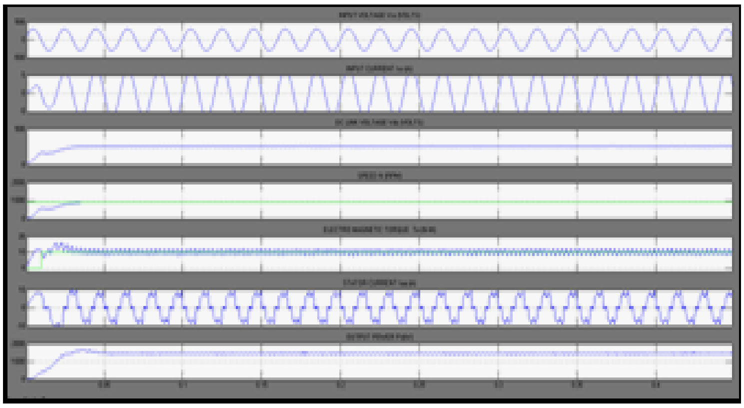

Fig. 6 Starting performance of the PMBLDCM drive at 900 rpm

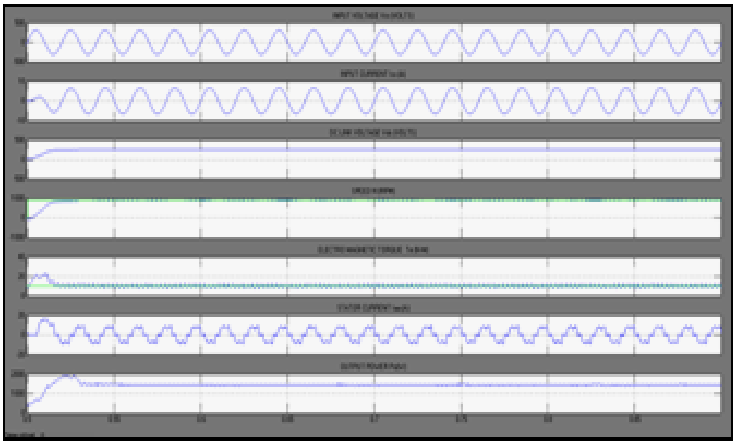

Fig. 7 PMBLDCM drive under speed variation from 900 rpm to 300 rpm

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

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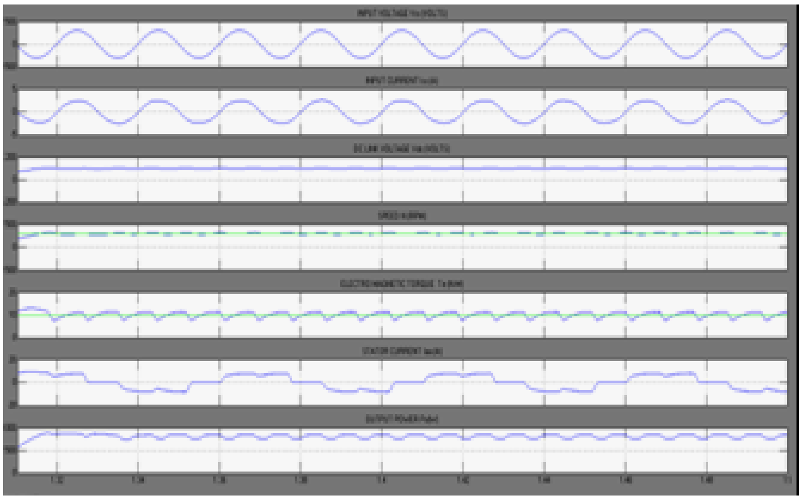

Fig. 8 Performance of PMBLDCM drive at 300rpm

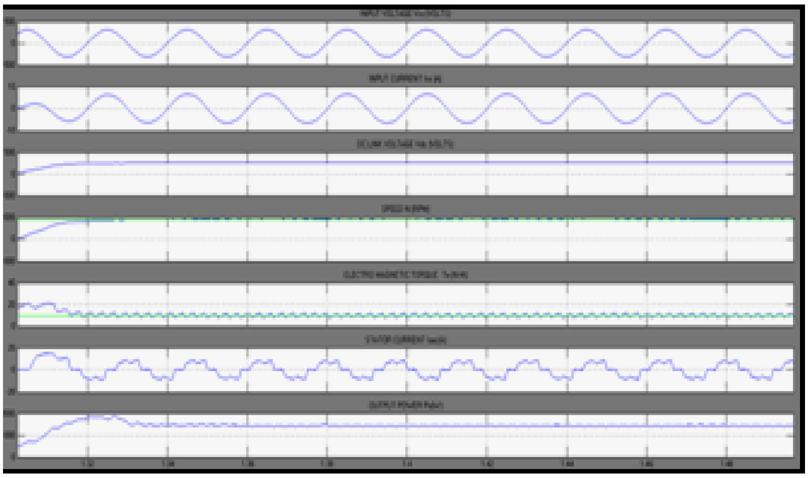

Fig. 9 Performance of PMBLDCM drive at 900rpm

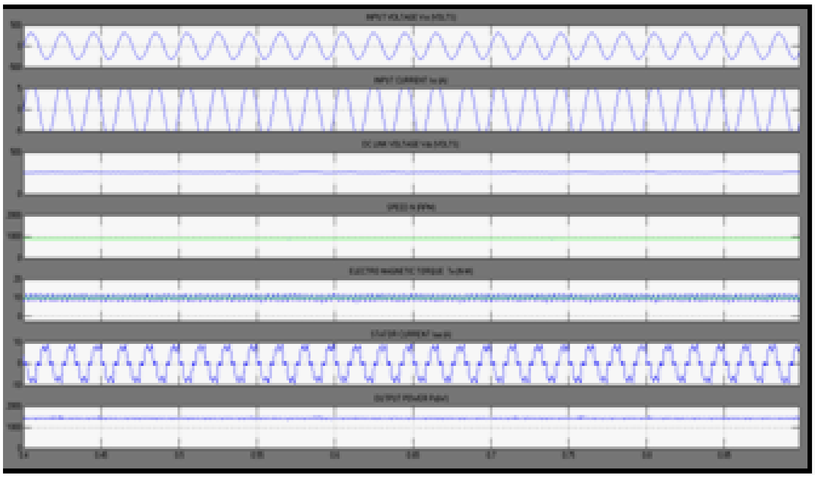

Fig. 10 PMBLDCM drive under speed variation from 900 rpm to 1500 rpm

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Table 1Performance of drive under speed control at 220V AC input

Speed (rpm)	Vdc(v)	THD I	DPF	PF	Efficiency of 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	334	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

Table 2 Variation of PQ parameters with input 200V AC input at 1500 rpm

Vdc(v)	THDi(%)	DPF	PF	CF	Efficiency of drive (%)	Load (%)
170	2.88	0.9999	0.9995	1.41	84.9	20.0
180	2.59	0.9999	0.9996	1.41	85.8	26.7
190	2.40	0.9999	0.9996	1.41	86.3	33.3
200	2.26	0.9999	0. 9996	1.41	87.2	40.0
210	2.07	0.9999	0.9997	1.41	87.6	46.6
220	2.09	0.9999	0.9997	1.41	88.1	53.3
230	2.07	0.9999	0.9997	1.41	88.2	60.0
240	2.02	1.0000	0.9998	1.41	88.4	66.6
250	1.99	1.0000	0.998	1.41	88.7	73.3
260	2.01	1.0000	0.9998	1.41	88.7	80.0
270	2.01	1.0000	0.9998	1.41	89.0	86.6

VI.CONCLUSION

A new speed control strategy of a PMBLDCM 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

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International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

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to the proposed drive ensures nearly unity PF in wide range of speed and input AC voltage. Moreover, power quality parameters of the proposed PMBLDCM drive are in conformity to an International standard IEC 61000-3-2. 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 PMBLDCM driving Air-Con load in 1-2 kW power range.Through this project work we have made an attempt to analyze Power Factor Correction converter with the help of simulations. In future the hardware implementation of the PFC circuit can be done and its results obtained in real – time situations can be compared with the simulation results.

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