Reduction of THD using CUK converter for adjustable speed PMBLDCM drive

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ABSTRACT

New Cuk converter technique is used to reduce the THD of motor drive by power factor correction play an important role in the energy saving during energy conversion. The concept of voltage control at the dc link proportional to the desired speed of the PMBLDCM is used to control the speed of the compressor. The ac-dc conversion of electric power is usually required which causes many current harmonics and results in the poor power factor at the input ac mains. The use of a permanent-magnet brushless dc motor (PMBLDCM) in low-power appliances is used because of its features of high efficiency, wide speed range, and low maintenance. This paper deals with the power factor correction of BLDC motor with Cuk dc–dc converter. A three-phase voltage-source inverter is used as an electronic commutator to operate the PMBLDCM.

It also compares the Total Harmonic Distortion (THD) of the Input AC current with PID controller in Matlab-Simulink environment.

Key words:-*Cuk converter, Permanent magnet brushless dc motor (PMBLDCM), Power factor correction (PFC),Total Harmonic Distortion (THD).*

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1. INTRODUCTION

Permanent magnet brushless dc motor is used for low power applications. The commutation in a PMBLDCM is done by solid state switches of a three phase voltage source Inverter (VSI). If air-conditioning (Air-Con) system operated under speed control results in an improved efficiency of the system. PMBLDCM has reduced electrical and mechanical stresses, low running cost, long life compared to a single phase induction motor.[1] [2] [3] A PMBLDCM has developed torque proportional to its phase current and its back electromotive force (EMF), which is proportional to the speed. Therefore, a constant torque is maintained in its stator windings. VSI is used for electronic commutation based on the rotor position signals of the PMBLDC motor. The PMBLDCM drive is fed from a single phase ac supply through a diode bridge rectifier (DBR) followed by a capacitor at dc link. Due to an uncontrolled charging of the capacitor at dc link, draws a pulsed current. With a peak higher than the amplitude of the fundamental input current at ac mains. This results in poor power quality (PQ) at ac mains in terms of poor power factor (PF), high total harmonic distortion (THD) and high crest factor (CF).Therefore, for PMBLDCMD a PF correction (PFC) converter among various available converter topologies is used.

The Cuk dc–dc converter is used as a PFC Converter. The main advantages of using a Cuk dc–dc converter compared to other single switch converters are: continuous input and output currents, small output filter, wide output voltage range, almost near unity power factor with simple control and small size.

2. PROPOSED SPEED CONTROL SCHEME OF PMBLDC MOTOR

Figure.1 shows the proposed speed control scheme is based on the control of the dc link voltage reference as a comparable to the reference speed. The rotor position signals established by Hall-effectsensors are used by an electronic commutator to generate switching sequence for the VSI which in turns feeds the PMBLDC motor. Therefore, rotor position is necessary only at the commutation point. The dc link voltage is controlled by Cuk dc-dc converter by making use of capacitive energy transfer which result is non-pulsating input and output currents. The suggested PFC converter is operated in high switching frequency for fast and effective control. It uses metal-dioxide semiconductor field effect transistor (MOSFET) for high-frequency operation. A current multiplier is used in PFC control scheme with a current control loop within the speed control loop for continuous-conduction-mode operation. By comparing sensed dc link voltage (Vdc) and a voltage (Vdc*) equivalent to the reference speed, voltage error (Vr) is obtained, The control loop begins with the processing of voltage error (Vr), through a proportional (PID) controller to give the modulating control signal (Ic). The reference dc current (I∗d) is obtained multiplying signal (Ic) with a unit template of input ac voltage. It is then compared with the dc current (Id) sensed after the DBR. The resultant current error (Ie) is amplified and compared with a saw tooth carrier wave of fixed frequency (fs) to generate the pulse width modulation (PWM) pulse for the Cuk converter. Its duty ratio (D) controls the dc link voltage at the desired value.

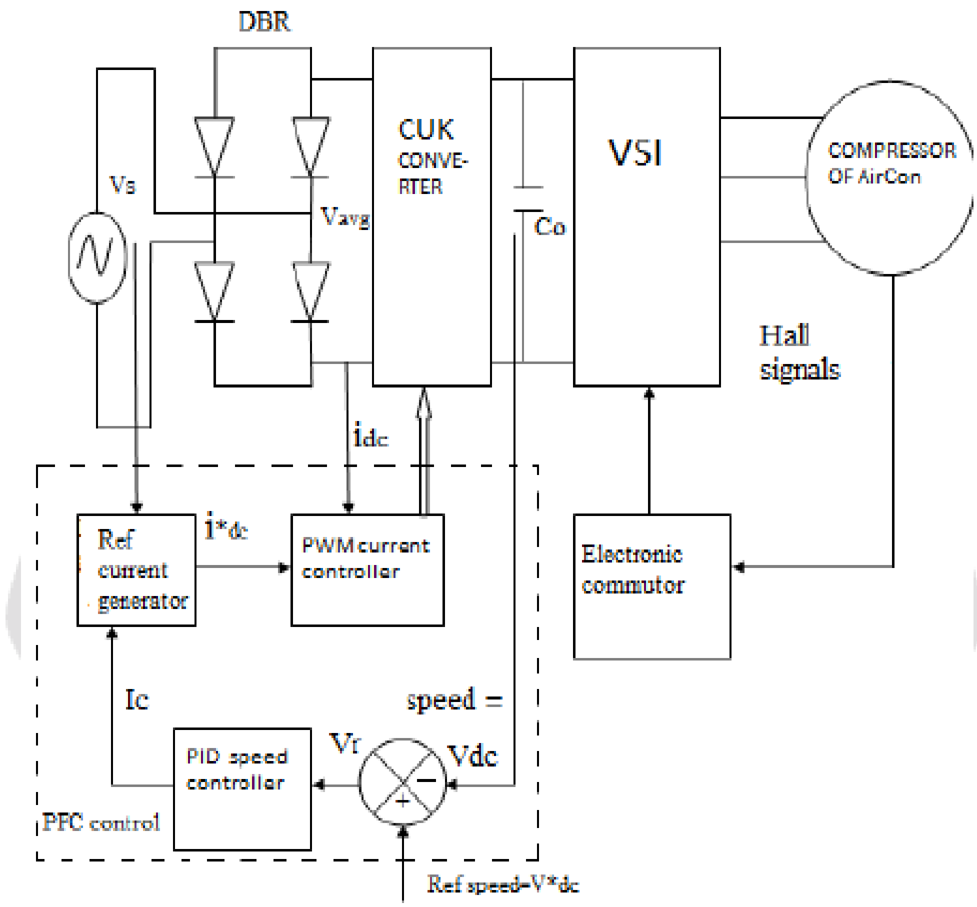

Fig-1:The proposed Cuk PFC converter-fed VSI based

3. PFC CUK CONVERTER DESIGN

In the proposed framework, the PFC Cuk converter is designed for a PMBLDCMD with main considerations on the PQ improvement at ac mains and speed control of the Air-Conditioner. DC link voltage of the PFC converter is given by the following equation.[4] [5] [6]

$$Vdc = \mathrm{Vavg}D / (1-D) \qquad (1)$$

Where Vavg is the average output of the DBR for a given ac input voltage (Vs) related as,

$$\mathrm{Vavg} = 2\sqrt{2}\ \mathrm{Vs}/\pi \qquad (2)$$

The Cuk converter uses inductor (Li) and capacitor (C) for energy transfer. Their values are given by,

$$L\mathrm{i} = D\mathrm{Vavg} / \{f\mathrm{s}\ (\Delta IL\mathrm{i})\} \qquad (3)$$

$$\mathrm{C} = DIdc / \{fs\ \Delta \mathrm{V}C\} \qquad (4)$$

Where ΔILi is inductor current ripple, Δ*V*C is voltage ripple in the capacitor (*C*), and the current drawn by PMBLDCM is denoted by Idc. A ripple filter is designed for ripple-free voltage. The inductance (L) of the ripple filter limits the inductor peak-to-peak ripple current (ΔIL) within a specified value for the given switching frequency (fs), whereas the capacitance (Co) is calculated for the allowed ripple in the dc link voltage (ΔVCo). The values of the ripple filter inductor and capacitor are given as,

$$L = (1 - D)\, Vdc / \{fs\,(\Delta IL)\} \quad (5)$$

$$Co = Idc / (2\omega \Delta VCo) \quad (6)$$

4. MODELING OF PFC CONVERTER-BASED PMBLDCM DRIVE

The main components of proposed drives are PFC converter and PMBLDCMD. They are modeled using mathematical equations. Then the complete model of the drive is obtained by combining the individual models.

4.1. PFC converter

The modeling of a PFC converter consists of modeling of the voltage controller, reference current generator and a PWM controller.

4.1.1. Voltage controller:

The modeling of a voltage controller is important since the performance of the PMBLDCM drive depends on this controller. The proportional integral derivative (PID) controller is used to control the DC link voltage. If, at the kth instant of time, V*dc(k) is the reference dc link voltage and Vdc(k) is the voltage sensed at the dc link, the voltage errorVr (k) is then given by:

$$Vr(k) = Vdc^*(k) – Vdc(k) \quad (7)$$

4.1.2. Reference current generator:

The reference current (i*dc) is

$$i^*dc = Ic(k)uvVs \quad (8)$$

Where uvvs is the unit template of the ac mains voltage, calculated as

$$uvvs= vd/vsm; \quad (9)$$

$$vd=|vs|; \quad (10)$$

$$vs= vsm\sin \omega t . \quad (11)$$

where frequency ω is in radians per second and amplitude vsmis in volts.

4.1.3. PWM controller:

The reference current of the Cuk converter (i∗dc) is compared with its current (idc) to generate the current error,

$$\Delta idc = (i^*dc - idc) \quad (12)$$

The switching signals of the MOSFET in the PFC converter are produced by relating amplified current error by gain ki with fixed frequency (fs) of the saw-tooth carrier waveform md (t) If kiΔidc> md(t) then S = 1 else

$$S = 0 \quad (13)$$

where S is the switch of the MOSFET in Cuk converter. Its values “1” and “0” represent x “on” and “off” conditions, respectively.

4.2. PMBLDCMD

The PMBLDC motor can be modeled using differential equations given by, [7] [8]

$$Vxn=Rix+ d\lambda x+ exn \quad (14)$$

$$vyn=Riy+ d\lambda y+ eyn \quad (15)$$

$$vzn=Riz+ d\lambda z+ ezn \quad (16)$$

where *d* is the differential operator (*d/dt*), *i*x, *i*y, and *i*z are currents, *λ*x, *λ*y, and *λ*z are flux linkages, and *e*xn, *e*yn, and *e*znare phase-to-neutral back EMFs ofPMBLDCM, in particular phases; *R* is the resistance of motor windings/phase. The flux linkages can be denoted as,

$$\lambda x =Lsix - M(iy + iz) \quad (17)$$

$\lambda y = Lsiy - M(ix + iz)$ (18)

$\lambda z = Lsiz - M(iy + ix)$ (19)

where self-inductance/phase is Ls and mutual inductance is M. The developed torque *Te* is given by,

$Te = (exnix + eyniy + ezniz)/\omega r$ (20)

Then PMBLDCM has no neutral connection

$ix + iy + iz = 0$ (21)

From (14)–(19) and (21), the voltage between the neutral point and midpoint of the dc link is given by,

$vno = \{vxo + vyo + vzo - (ean + ebn + ecn)\} /3$ (22)

From (15)–(17) and (19), the flux linkages are given by,

$\lambda x = (Ls + M)ix, \lambda y = (Ls + M)iy, \lambda z = (Ls + M)iz.$ (23)

From (17)–(19) and (23), the current derivatives in generalized state-space form are given by,

$dia = (van - iaR - ean)/(Ls + M)$ (24)

where*a* represents phase x, y, or z. The back EMF is a function of rotor position (*θ*) as

$ean = Kb\ fa\ (\theta)\omega r$ (25)

where*a* can be phase *x*, *y* or *z* and consequently *fa*(*θ*) denotes function of rotor position with a maximum value ±1, equal to trapezoidal induced emf given by,

$fx(\theta) = 1 \text{ for } 0 < \theta < 2\pi/3$ (26)

$fx(\theta) = 1\{(6/\pi)(\pi - \theta)\} - 1 \text{ for } 2\pi/3 < \theta < \pi$ (27)

$fx(\theta) = -1 \text{ for } \pi < \theta < 5\pi/3$ (28)

$fx(\theta) = \{(6/\pi)(\pi - \theta)\} + 1 \text{ for } 5\pi/3 < \theta < 2\pi.$ (29)

The functions fy(θ) and fz(θ) are similar to fx(θ) with phase differences of 120◦ and 240◦, respectively. Therefore, the electromagnetic torque expressed as,

$Te = Kb\ \{fx(\theta)ix + fy + fz(\theta)iz\}$. (30)

The mechanical equation of motion in speed derived form is given by,

$d\omega r = (P/2)(Te - Tl - B\omega r)/(J)$ (31)

where derivative of rotor position *θ is wr*, number of poles is P, load torque in newton meters is Tl, moment of inertia in kilogram square meters is J, and friction coefficient is B in newton meter seconds per radian. The derivative of rotor position is given by,

$d\theta = \omega r$ (32)

Equations (14)–(32) represent the dynamic model of the PMBLDC motor.

5. SIMULATION RESULTS

Proposed cuk converter using Conventional PID controller.These results are categorized as performance during transient and steady state conditions.

5.1 Performance of the PMBLDCM drive under steady state condition at 220 VAC input

During Steady State Condition: The speed control of the PMBLDCM driven compressor under steady state condition is carried out for speed at 900 rpm and the results are shown in figure-2(a) like 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).

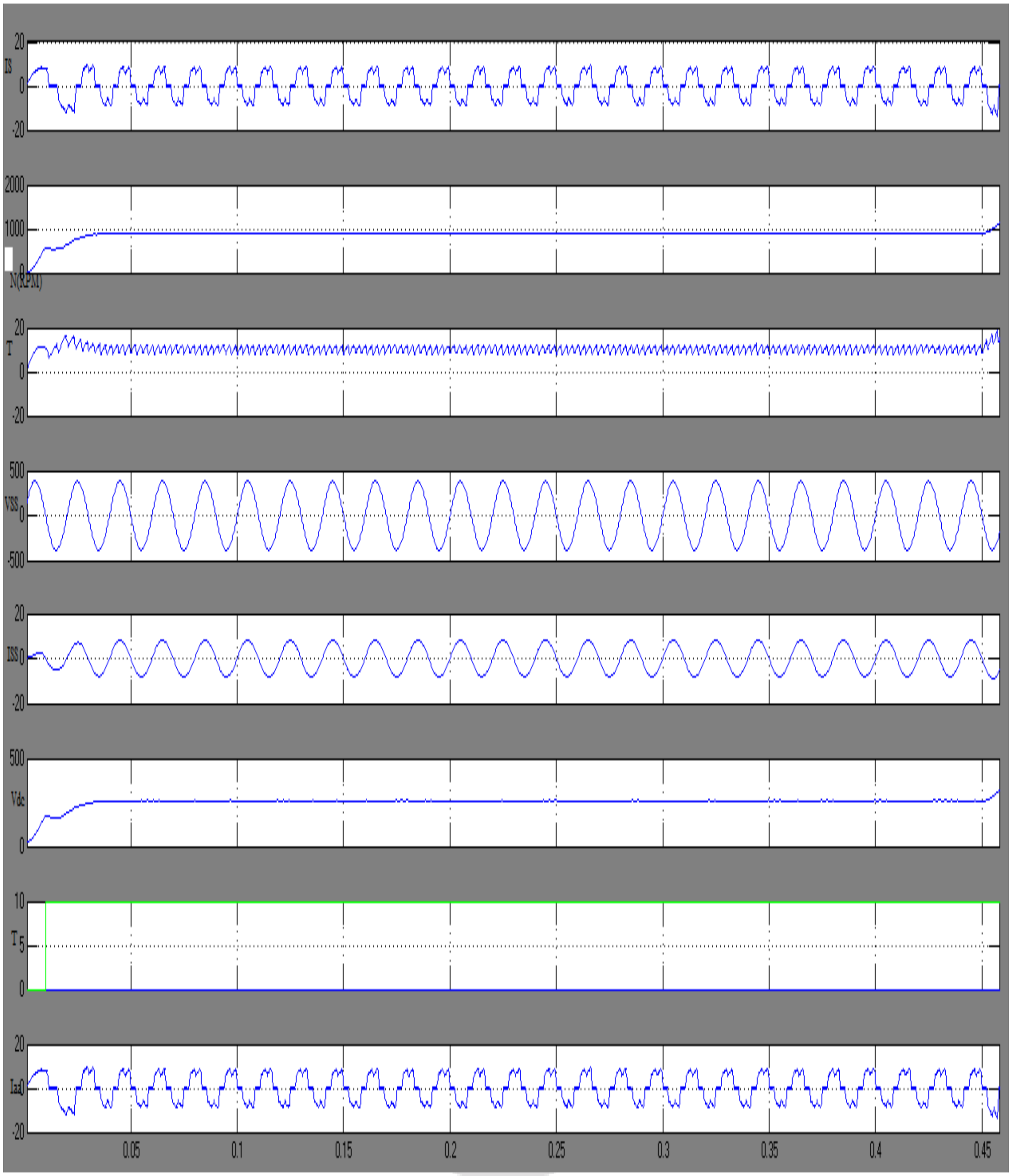

Fig-2 (a): Starting performance of the PMBLDCM drive at 900 rpm.

During Steady State Condition: The speed control of the PMBLDCM driven compressor under steady state condition is carried out for speed at **1500 rpm** and the results are shown in figure-2(b) like 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).

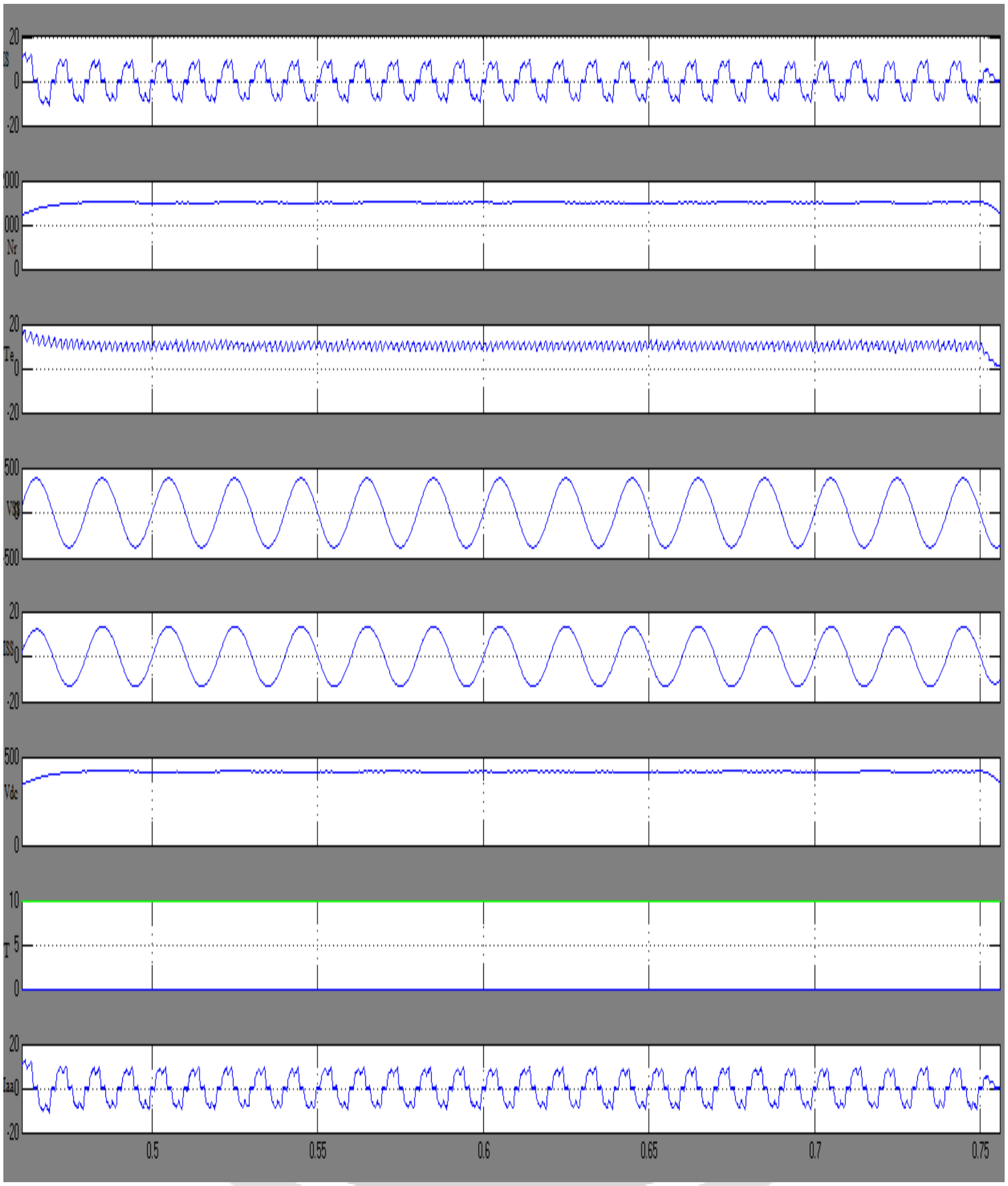

Fig-2 (b): Performance of the PMBLDCM drive at rated speed (1500 rpm).

During Steady State Condition: The speed control of the PMBLDCM driven compressor under steady state condition is carried out for speed at **300 rpm** and the results are shown in figure-2(c) like 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).

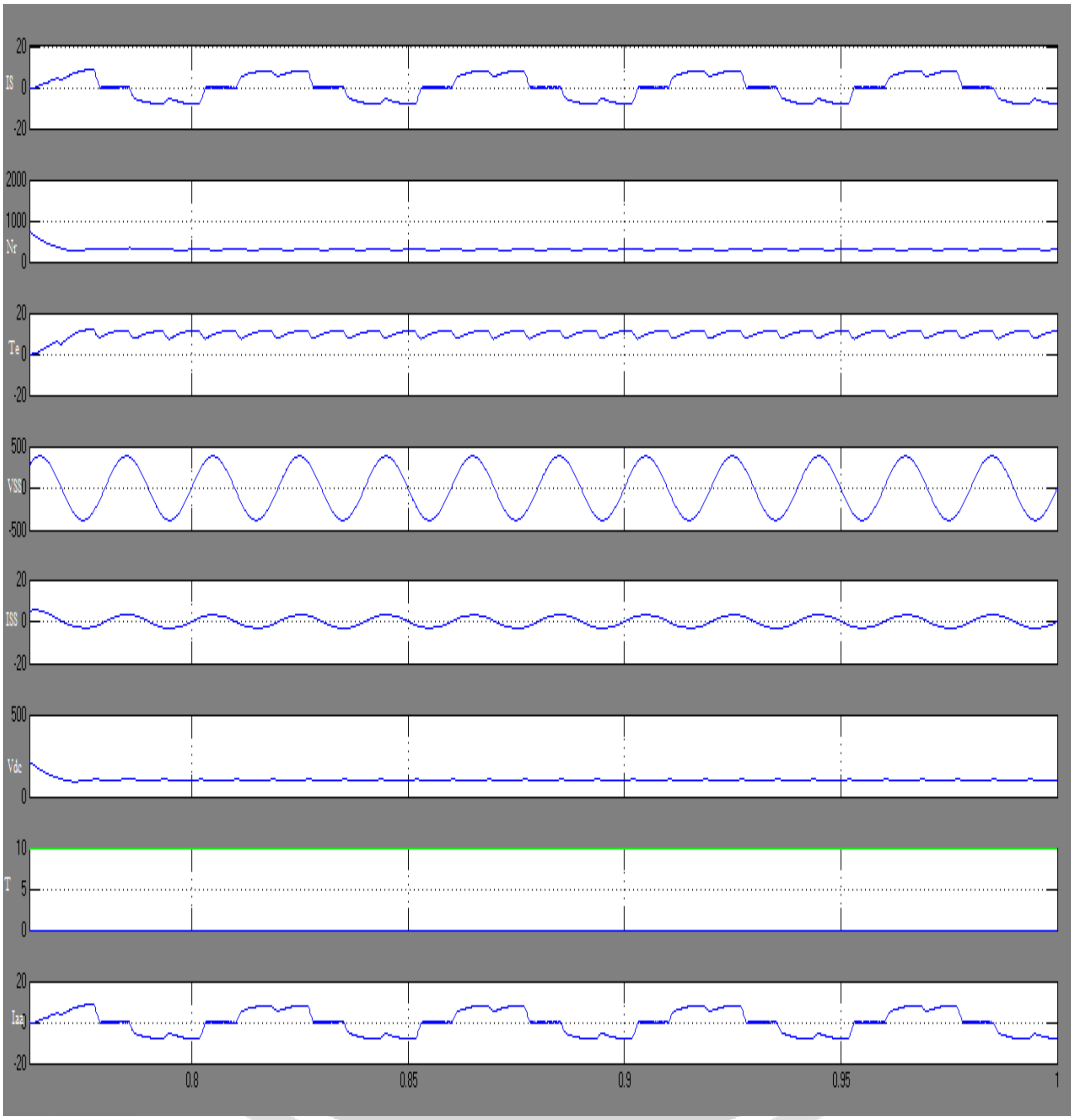

Fig-2 (c): Performance of the PMBLDCM drive at 300 rpm.

5.2 Performance of the Proposed PMBLDCM drive under speed variation at 220V AC input

During Transient Condition shows the performance of the drive during the speed control of the compressor. The reference speed is changed from 1500 rpm to 300 rpm for the rated load performance of the compressor; 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. the results are shown in figure-3(a) like 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).

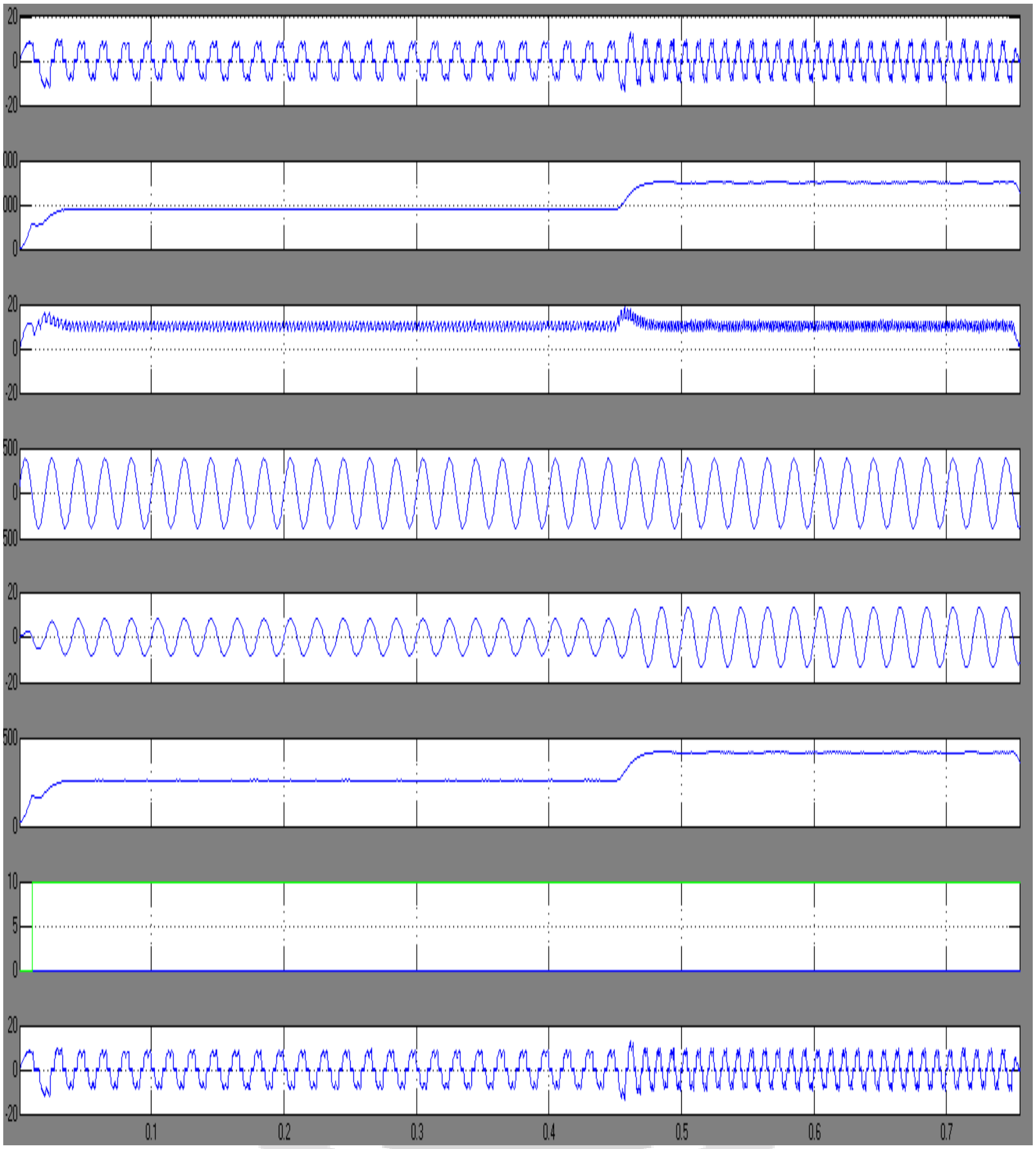

Figure: 3 (a) PMBLDCM drive under speed variation from 1500 rpm to 300 rpm.

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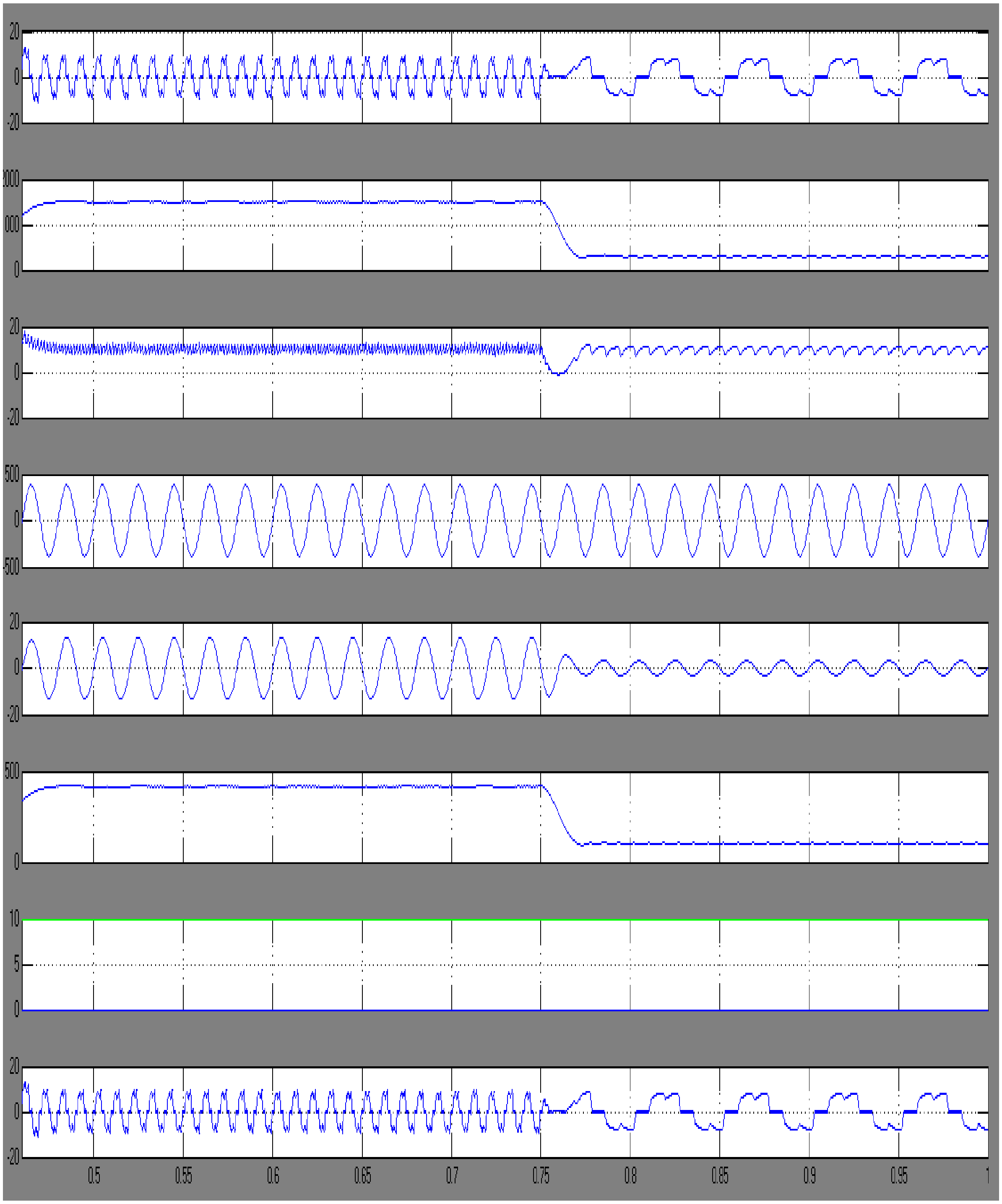

Fig-3(b): PMBLDCM drive under speed variation from 900 rpm to 1500 rpm.

5.3 FFT Analysis:

The THD of AC mains current remains less along with nearly unity PF in wide range of speed as well as load as shown in figure 4 and 5.

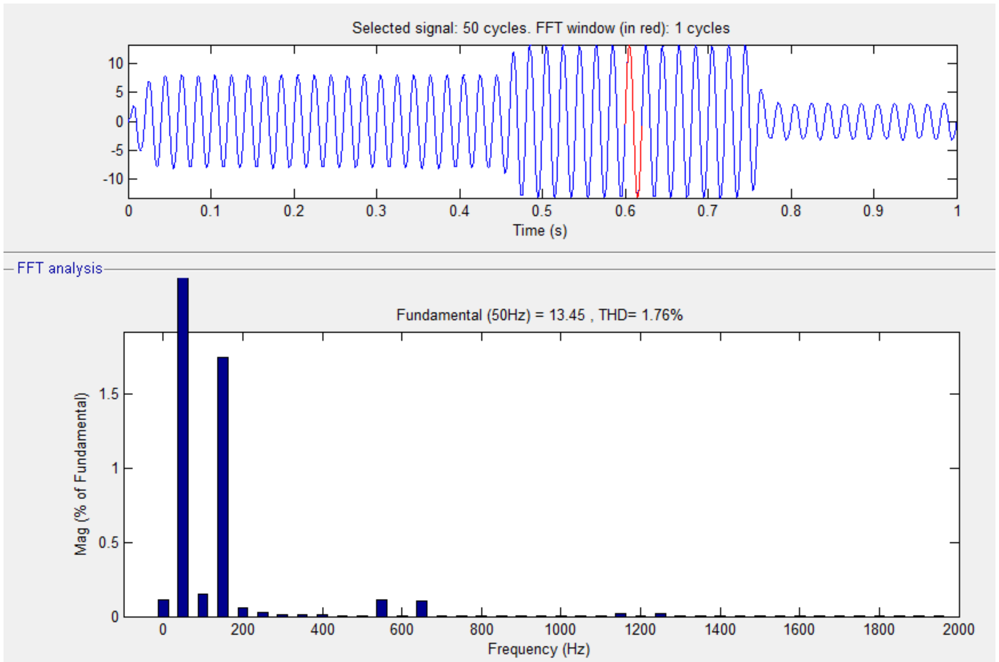

Fig-4: FFT Analysis at Iss for AC Voltage 270V

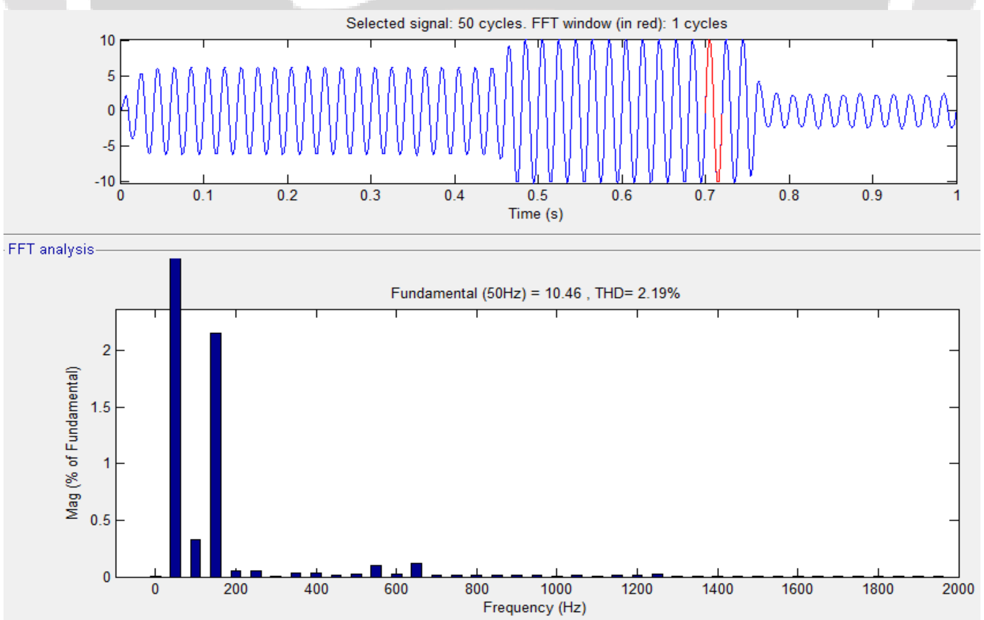

Fig-5: FFT Analysis at Iss for AC Voltage 210V

Vac (volts)	**Speed (rpm)**	**THD %**	**PF**	**Is (amps)**	**Load%**
270	1500	1.76	0.9999	0.975	0.2(Nm)
240	1200	2.20	0.9991	1.22	0.5(Nm)
200	1000	2.64	0.9983	1.84	1.5(Nm)
150	800	3.34	0.9984	2.21	2(Nm)
100	600	5.0	0.9977	2.96	4(Nm)
80	300	12.9	0.9974	3.84	5(Nm)

Table-I: Variation of PQ parameters with input AC Voltage (Vs) between 1500-300 RPM

6. CONCLUSION

A new speed control scheme for a PMBLDCMD using PID CONTROLLER in the control circuit has been simulated for an air-conditioner using a Cuk PFC converter. THD is reduced compared to conventional method. The PFC Cuk converter gives near unity power factor in a wide range of the speed and the input ac voltage. Various power quality problems like poor power factor, inrush current, and speed control may be can be resolved by the proposed voltage-controlled PFC Cuk converter-based PMBLDCMD. 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.

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