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An Improved Technique for Power Factor Correction in PMBLDC Motor Drive using SEPI Converter for Variable Speed Applications

Sk. Azhar
M.Tech Student,
Dept of Electrical and Electronics Engineering,
Madanapalle Institute of Technology and Science,
Madanapalle.

M. Lokesh
Asst. Professor,
Dept of Electrical and Electronics Engineering,
Madanapalle Institute of Technology and Science,
Madanapalle.

Abstract:

In this exposition a permanent magnet brushless DC motor (PMBLDCM) drive is adopted to work for variable speed applications and activated at rated torque and changeable speed to reach energy conservation. A single-phase single-switch power factor correction (PFC) based Single Ended Primary Inductor Converter (SEPIC) is used here to organize DC bus voltage of voltage source inverter (VSI) to run PMBLDCM. The calculation, design and performance evaluation of the SEPI converter is done to drive variable speed application system. The entire model is to be designed in Mat lab/ Simulink. The whole process is carried out to improve power factor in a huge range of speed and input voltage.

Keywords:

Power Factor Correction converter, Single Ended Primary Inductor converter, PMBLDC motor, power quality (PQ). Continuous Conduction Mode (CCM)

I. INTRODUCTION:

Variable speed applications consist of huge quantity of load in AC distribution system [1]. Most of the existing variable speed application systems are not energy efficient and in that way, present a scope for energy conservation. These variable speed applications in household sector are normally designed with a single-phase induction motor operating at steady rated torque along with on and off control. A PMBLDC motor is a better drive for variable speed applications for its very high efficiency, low noise, compressed size, good reliability, simple controlling and low maintenance.

A PMBLDC motor is a type of 3 synchronous motor containing permanent magnets on the rotor side [2-5]. Typically PMBLDC motor in small variable speed applicant is power-driven by 1- AC mains by a DBR and VSI [3-6]. Because of uncontrolled charging of DC link capacitor, the AC supply current waveform is a pulsed one, providing maximum out value greater than the amplitude of the basic input current. Many power quality problems generally happen at input of the supply which counts very low Power Factor, amplified total harmonic distortion (THD) and huge crest factor (CF) etc. These PQ harms as assessed in IEC 61000-3-2 [7] particularly in low power appliances.

Because of having the intrinsic power factor the PMBLDCM is chosen to work in the paper. As we see before in Power Factor Correction converter a DC to DC converter is used frequently and the best of all other methods [8-12]. Some of DC-DC topologies are boost, buck-boost, cuk etc... with different methods of energy transfer. By using this method we can improve the performance which includes current harmonics, acoustic noise and also decreasing the number of components.
A single ended primary inductor converter (SEPIC) gives continuous input and lowers in ripple current introduced as a PFC converter is proposed for PMBLDC motor to drive the variable speed applications [13-15]. This thesis, deals with complete design and in-depth working evaluation of the SEPIC converter.

II. OPERATION AND CONTROL OF SEPIC FED PMBLDC Motor:

Fig:1 presents the schematic diagram of SEPI Converter. A proportional-integral (PI) is utilized to control the speed of the PMBLDC Motor.

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The speed signals are converted from the rotor which is located in PMBLDCM which are sensed by using Hall- effect sensors and comparison with the reference speed of the motor. The error speed is given to the speed controller to gain the torque and then it is changed to the current signal. This signal is multiplied with the back emf of the motor in order to get reference current.

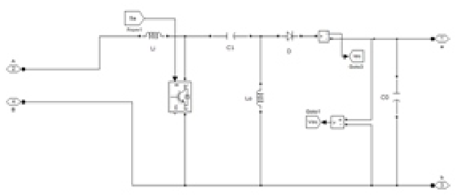

Fig. 1: Control Schematic based SEPIC Converter fed PMBLDCM Drive

Again these currents are compared with motor currents which are sensed from motor and thus give current error..

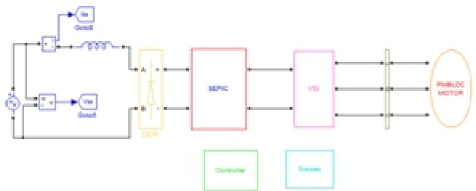

Figure: 2 Schematic diagram of the system.

The system had a Diode Bridge Rectifier (DBR) which is fed from1- AC input and connected to the SEPIC which is DC-DC converter and fallowed by Voltage Source Inverter all together feed PMBLDC motor. The DBR gives an uncontrolled output to the SEPI converter. Then SEPI converter converts the uncontrolled dc signal into controlled dc signal along with power factor correction at high switching of frequency. The duty cycle of the proposed converter is controlled by the inputs and outputs. The switching frequency is to be determined by the devices which are used in the VSI. Usually IGBT's are used as the switching devices in Power Factor Correction design and as well as in VSI design too. It is because IGBT's have the ability to operate in different switching frequencies. Current control scheme along with current multiplier method is used I this project. The SEPI converter is used in CCM in order to drive PMBLDC motor. The voltage control loop starts along with the detection of DC link voltage and is examined along with the reference DC link voltage.

Now the error voltage is passes all the way through PI controller in order to give modified current signal. Then after it is multiplied with input voltage. The result is compared with the DC current which is the output of DBR in order to present current error. Finally the current error is improved and is given as input to converter in order to generate the switching pulse signals.

III. DESIGNING OF SEPI CONVERTER :

Fig. 2 shows the total design of SEPIC converter fed PMBLDC motor. As the SEPI converter gains high power density and fast transient response when it is operated at high switching frequencies.

Basically it is designed for constant current in the intermediary inductor (Lo) as it works on the rule of inductive energy transfer [16], the boost inductor (L1)and capacitors (C1,Co) are designed in order to pass maximum current & voltage ripple at the time of transient conditions of the PMBLDC motor. The modeling equations of the components present in the SEPI converter are as fallows

Output voltage $V_{dc} = DV_{in} / (1\text{-}D)$ (1)

Boost inductor $L_i = DV_{in} / \{f_s(\Delta I_{Li})\}$ (2)

Intermediate capacitor

$$C_1 = D / \{(R f_s) (\Delta V_{c1} / V_o)\} \quad (3)$$

Output filter capacitor

$$L_o = (1\text{-}D)\, V_{dc} / \{f_s(\Delta I_{Lo})\} \quad (4)$$

Output filter capacitor

$$C_o = I_{av} / (2\omega\Delta V_{dc}) \quad (5)$$

IV. DESIGN OF PROPOSED CONVERTER FED PMBLDC MOTOR:

Design of the proposed SEPI converter fed PMBLDC motor includes molding of a SEPI converter and PMBLDC motor. The design consists of a Diode Bridge Rectifier at front end which is supplied from 1- AC mains, a SEPIC converter, Voltage Source Inverter, PMBLDC motor. There is a Power Factor Controlling Scheme which consists of reference current generator, PWM controller, voltage controller. Along with this there are some other components namely current sensors, speed controller and Hall Effect sensors. All these mechanism are designed by mathematical equations and whole modeling is done with the combinations of the obtained equations.

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A. Power Factor Correction Converter :

Designing of a Power Factor Correction converter includes the designing of voltage controller, reference current generator and a PWM controller as explained below.

1. Voltage Controller :

The voltage controller plays a major role in PFC converter because this voltage controller affects the performances. A proportional integral (PI) is introduced in order to organize voltage of DC link.
At Pth interval of time,
V*dc(p) is a ref DC link voltage (6),
Vdc(p) is a DC link voltage which is sensed (7)
Then the voltage error is calculated as,
Ve(p) = V*dc(p)-Vdc(p) (8)
When this error signal is disposed to the PI controller the preferred control signal is obtained. The result of the controller at the Tth interval of time is shown below
Ic(t) = Ic (t-1) + Ppv {Ve(t) –Ve (t-1)} + PivVe(t) (10)
Where 'Ppv' is proportional gain of voltage controller and 'Piv' is integral gain of voltage controller.

2. Ref. Current Generator:

The reference inductor current of SEPI converter is shown as
Idc*= Ic (k) uvs (11)
Here 'uvs' is component pattern of voltage at input and is considered as shown below
uvs= vd/Vsm
vd=vs
vs= Vsm sin ωt (12)
Where "ω" is frequency in rad/sec at input and 't' is the time.

3. PWM Controller :

The ref inductor current of the SEPI converter (Idc*) is compared along with the sensed current (Idc) to create Current error Δidc = (Idc*- Idc) (13). This error is improved by gain 'kdc' and compared along with the 'fs' and 'md (t)' in order to obtain switching signals for the IGBT's of the power factor correction scheme.
Kdc Δidc > md (t) then S=1 (14)
Kdc Δidc <= md (t) then S=0 (15)

Where 'fs' is fundamental frequency, md (t) is saw tooth carrier waveform and S is a switch which represents
S=1 is ON position
S=0 is OFF position

B. PMBLDCM DRIVE:

The designing of the speed controller of PMBLDC motor is a challenge and the complete system's performance is depended on this control scheme only. At tth interval of time the speed error is defined as below
ωe(t) = ω*r(t) - ωr(t) (16)
Where ω*r(k) is reference speed, ωr(k) is rotor speed and ωe(k) is the speed error. This ωe(k) is given to speed controller in order to obtain preferred control signal.

1. Speed Controller :

Pi controller is the controller which is used to organize the speed of the PMBLDC motor and it controls whole drive's performance. If at pth interval of time
T(p) = T(p-1) + Kpω { ωe(p) - ωe(p-1)} +Kiω ωe(p) (17)
Here Kpω is proportional gain of speed controller and Kiω is integral gains of speed controller.

2. Reference Winding Currents :

The amplitude of stator winding current is calculated as
I* = T(k) / (2Kb) (18)
Where Kb is the back emf constant of the PMBLDC motor.
The ref 3- currents of the motor windings are represented by Ia* ib*and ic* for phase a, b and c given as
Ia*= I*, ib*= - I*, ic* = 0 for 00≤θ≤600 (19)
Ia*= I*, ib*= 0 , ic* = - I* for 600≤θ≤1200 (20)
Ia*= 0, ib*= I*, ic* = - I* for 1200≤θ≤1800 (21)
Ia*= -I*, ib*= I*, ic* = 0 for 1800≤θ≤2400 (22)
Ia*= -I*, ib*= 0, ic* = I* for 2400≤θ≤3000 (23)
Ia*= 0 , ib*= - I*, ic* = I* for 1200≤θ≤1800 (24)

Where "θ" is the rotor position angle in radian/sec.

These ref currents are to be compared along with the sensed phase c currents to produce the current errors for 3phasesof motor

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Δia = (Ia* - ia) (25),
Δib = (ib* - ib) (26),
Δic = (ic*- ic) (27)
These errors are amplified along with gain "k" before giving input to Pulse Width Modulation current controller.

3. Pulse Width Modulation Current Controller:

The PWM current controller distinguishes the improved current errors of each and every phase along with carrier waveform w(t) of a fundamental frequency and produce the switching sequence for the VSI according to the synthesis given for phase "a" as
K1 Δia > w (t) then Sa=1 (28)
K1 Δia <= w (t) then Sa=0 (29)
The sequences sb and sc are obtained using the same logic as the two phases of the system.

4. Voltage Source Inverter:

Figure: 3 show a corresponding circuit of a VSI. The output of VSI is connected to phase "a" of the PMBLDC motor is given as
Vao=(Vdc/2) for Sa1=1, Sa2=0 (30)
Vao=(-Vdc/2) for Sa1=0, Sa2=1 (31)
Vao=0 for Ia=0 (32)
Van= Vao -Vno (33)
Fallowing the same technique vbo, vco, vbn, vcn are formed from other two phases of the Voltage Source Inverter.
Where vao, vbo, vco, vno are voltages of 3-phases and "o" is the virtual mid-point of the capacitor neutral with respect to effective midpoint of the capacitor is presented as 'o' in Fig. 2.

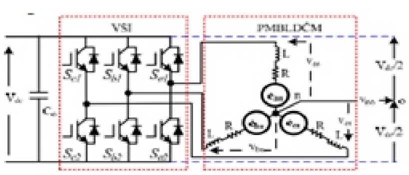

Figure:3 Presents the Circuit of a Voltage Source Inverter fed PMBLDC Motor.

5. Permanent Magnet Brush Less DC MOTOR:

The set of equations which define the modeling of PMBLDC motor is as below

$V_{xn}=Ri_x+p\lambda_x+e_{xn},\quad \lambda_a = Li_a - M(i_b+i_c);$

$\lambda_b = Li_b - M(i_a+i_c);\ \lambda_c = Li_c - M(i_b+i_a);$

$i_a+ i_b+i_c= 0;\quad V_{an}= V_{ao} -V_{no}$

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

$\lambda_a=(L+M)\ i_a,\ \lambda_b=(L+M)\ i_b,\ \lambda_c=(L+M)\ i_c,$

$Pi_x = v_{xn} - i_{xR} - e_{xn})/(L+M)$

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

$E_{xn} = K_b\, f_x(\theta)\ \omega$

$f_a(\theta) = 1$ for $0< \theta<2\pi/3$

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

$f_a(\theta) = -1$ for $\pi < \theta<5\pi/3$

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

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

$p\omega = (P/2)(T_e - T_L\text{-}B\omega)/(J)$

Various symbols that are used in the above equations are ref currents for phases a, b and c are ia*, ib*, ic*. Current error of phase "a" is Δia, Error gain k1 and carrier waveform for the PWM current controller m(t). with respect to virtual mid-point of the DC link voltage 'o', vao, vbo, vco, and vno are the voltages of 3-phases with respect to neutral point (n) van, vbn, vcn and the DC link voltage vdc . Resistance, self-inductance and mutual inductance of the motor per phases are R, L and M .

6. Hall-Effect sensor:

Hall-Effect sensors generate the hall-effect signals. According to hall-effect signals generated the switches are to be controlled. The switching signals of the IGBT's are as fallows in table:1

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

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Table: 1 Table for hall signals and regarding switching signals.

V. PERFORMANCE EVALUTION:

The total performance of system is done in Matlab-Simulink atmosphere. An important assumption is to be reminded throughout the operation is we are designing all this system for variable speed applications. In this process we assume some constant values in order to gain good result and good power factor along with the healthy performance of the complete system. They are
Constant vrms = 220 v
Constant DC link voltage = 400 v
Constant fundamental frequency = 50 Hz
As the SEPI converter is considered for the operation the components used in this are to chosen on the bases of power quality requirements at AC input and the system is checked under different speed variations at different conditions as discussed below.

1. EVALUATION AT STARTING TIME

Figure:4 shows the system in the very starting time where the drive id given 220 rrms as AC input at the rated speed of 1200 rpm. Here we limit the upper limit torque and stator current for the period of transient condition in order to twice the rated value. Here we notice that the rated speed achieves the reference speed in only 0.1 sec. This is shown in graph form for easy analysis.

2. EVALUATION AT VARIABLE SPEEDS

Probably we consider the rated speed as 100%, now we divide the speed into four partitions. When the drive is activated speed is full of rated speed that is at 1200 rpm and now we decrease the speed to 80% of the rated speed that is 960rpm. After that we again boost the speed to full speed and see the performance in graphical view as shown in figure:5 . Now again we retest the drive by keeping the starting speed at 960rpm and we decrease the speed to 50% of the rated speed that is 600rpm and the performance is checked. The graphical representation of the changes took place in the performance is shown in figure: 6, and finally the motor speed is even decreased into 25% of the rated speed that is 300rpm and the performance of the drive is checked. The performance is monitored in Matlab-Simulink and graphs are as shown in figure: 7.

3. EVALUATION BY VARYING INPUT VOLTAGE:

Till now we have seen the performance of the drive under the speed variations and now we also check the same performance by changing different input AC voltage values. We vary the AC input voltage values from 140v to 280v by keeping the DC link voltage value at constant at 400v and the motor is driving at the rated speed of 1200 rpm constantly. The whole details are tabulated below in table:2. Here we have noticed a drastic change in the values of total harmonic distortion and got less than 5% every time when tested, and also observed that PF is received almost near to unity when a huge range of input AC voltage is given as input to the system. The THD at input AC mains in examined conditions for all time reached the standards of IEC 61000-3-2 [7] and PF remain almost at unity..

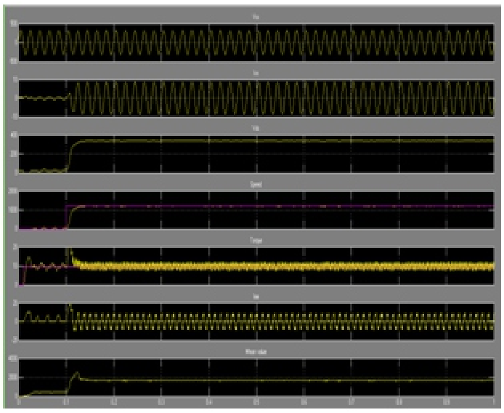

Figure: 4 Presents the valuation of the designed system at rated speed of 1200 rpm when 220vrms AC is given at input and DC link voltage is reserved constant at 400v.

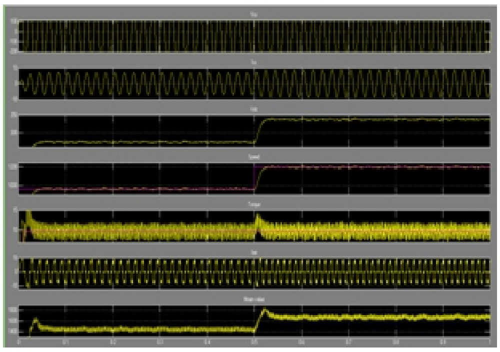

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Figure: 5 Presents the valuation of the designed system when the speed is increased from 80% to 100% of rated speed.

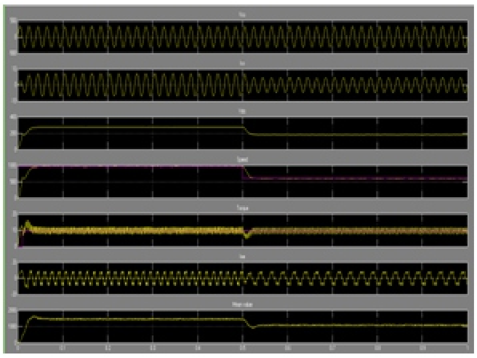

Figure: 6 Presents the valuation of the designed system when the speed is decreased from 80% to 50% of the rated speed.

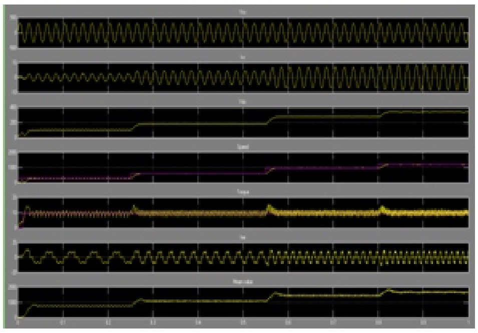

Figure: 7 Shows the evaluation of the proposed system when the variations of speed is done at given input AC voltage.

Vs	THDi (%)	PF	Eff of drive
140	3.02	0.9991	91
150	2.57	0.9994	91.1
160	2.2	0.9996	91.1
170	2.05	0.9997	91.1
180	1.8	0.9998	91.2
190	1.7	0.9998	91.3
200	1.55	0.9998	91.3
210	1.3	0.9999	91.4
220	1.14	0.9999	91.4
230	1.01	1	91.5
240	0.92	0.9999	91.4
250	0.84	0.9999	91.4
260	0.76	0.9999	91.3
270	0.7	0.9999	91.3
280	0.65	0.9999	91.3

Table: 2 this table shows the Power Quality parameters gained at wide range if input AC voltage at rated speed 1200rpm and 400v as DC link voltage.

VI. CONCLUSION :

Therefore designing of SEPI converter which is based on the power factor correction for driving PMBLDC motor is done successfully. The SEPI converter has gained a very high power factor almost very near to unity even when the system is operated at huge range of speed and as well as input AC voltage. The examined results which are achieved shows the broad improvement in PQ, less in torque ripple and smoother speed control of PMBLDC motor. THD of the system at AC mains is always below 5% when examined every time and satisfy the international standards [7]. The evaluation of the proposed device is excellent in huge range of input AC and speeds. So it is strongly concluded that this converter is quit proper for speed control at torque load variable speed application systems.

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