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Minal A Bodkhe
Department of Electrical Engineering, Priyadarshini College of Engineering, Nagpur, India, m.bodkhe@gmail.com

Vaishali Nandanwar
Department of Electrical Engineering, Priyadarshini College of Engineering, Nagpur,India, vaishali.nandanwar@gmail.com

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Design and Implementation of Single Stage PFC Microcontroller Based Drive For Permanent Magnet Brushless DC Motor

Minal A Bodkhe & Vaishali Nandanwar

Department of Electrical Engineering, Priyadarshini College of Engineering, Nagpur, India
E-mail : m.bodkhe@gmail.com, vaishali.nandanwar@gmail.com

***Abstract* -** In this paper ,a new approach is presented aim at improving the power factor of three phase bridge inverter that equip with permanent Magnet Brushless DC motor(PMBLDCM)drive through microcontroller. Power factor correction converter is used for feeding a three phase bridge inverter based PMBLDC motor drive. The front end of PFC converter is a diode bridge rectifier fed from a step down transformer. In this three phase bridge inverter is operated as electronic commutator of the PMBLDCM .Nearly sinusoidal input current is achieved using. The proposed PMBLDCM drive with PFC converter is designed to run the motor to desired speed. This scheme improves an efficiency of proposed drive system with PFC feature in wide range of the speed and an input AC voltage.

***Keywords* -** *PFC,PMBLDC Motor,Microcontroller,three phase bridge inverter.*

I. INTRODUCTION

In recent years, a number of home appliances and low power electrical derives equipped with DC or universal AC motors are being redesigned in order to comply with new standards on electric power quality that heavily limit line current harmonics and distortions.

Permanent magnet brushless DC motors (PMBLDCMs) are most preferred motors in many applications due to advantages of high efficiency, wide speed range and low maintenance requirements. It is a kind of three-phase synchronous motor with permanent magnets (PMs) on the rotor and trapezoidal back EMF waveform. It operates on electronic commutation accomplished by solid state switches of a three-phase voltage bridge inverter. Brushless Direct Current PMBLDC motors are one of the motor types rapidly gaining popularity. PMBLDC motors are used in industries such as Appliances, Automotive, Aerospace, Consumer, Medical, Industrial Automation Equipment and Instrumentation. As the name implies, PMBLDC 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. With relatively simple converter and control requirements, the PMBLDC motor is gaining high attention in the drive industry. The conventional PMBLDC drive usually includes a simple diode rectifier with a filter capacitor. Although this structure is simple, it draws a pulsating ac line current, resulting in a low power factor and high harmonic line current. With the increasing demand for better power quality, this approach is no longer suitable for high performance PMBLDC drives.

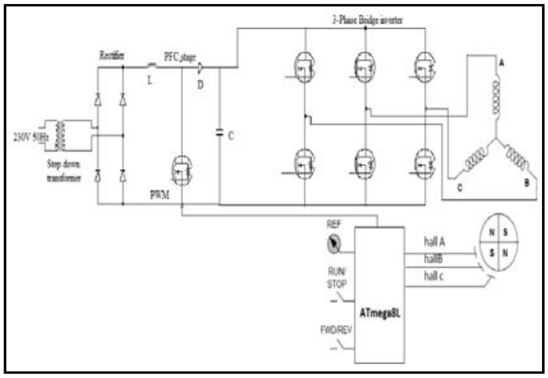
In order to achieve sinusoidal input currents and to improve the low power factor in PMBLDCM drive system, several approaches are introduced [2]-[5].The proposed approach in reference [2] consists of the cascaded power stages of a boost and a buck eliminating PWM control in the machine side converter while delivering sinusoidal ac input current. This converter topology has high power factor and improved input current waveform. However, this approach is not a suitable choice in practical applications, because of complexity and high cost due to the cascaded power stages. The described SRM driver employing a halfwave ZCS quasi-resonant boost converter [3] obtained better performances and higher power densities using high quality rectifier with capacitive energy storage. Line current pollution generated by electric drives, was reduced by addition of both passive input filters and active input current shapers. However, adding an active switch has disadvantages since it increases cost and switching loss. An SRM drive system using SPC-PFC was investigated in reference [4], this approach is sufficient to improve the power factor and to reduce the harmonics. However, because this SRM drive system consists of two power stages, double energy conversion is needed; therefore, overall efficiency may be decreased. And also, a complexity and a cost problem are still not solved. To solve the complexity problem with a high power factor, a simple SRM drive converter in which PWM switches can be used to draw near sinusoidal current is proposed in reference [5]. The power electronics component s used are kept low, but control complexity is increased. Since the operation of phase is not completely independent, at least two phases are required. Most of all, this method of improving the power factor of the SR drive is suitable only for a limited range of output power

The PMBLDCM drive is fed from the single-phase AC mains through a diode bridge rectifier (DBR) with a capacitor at DC link, draws a pulsed current with a peak higher than the amplitude of the fundamental input current at AC mains due to an uncontrolled charging of the DC link capacitor. This results in many power quality (PQ) problems such as poor power factor (PF), increased total harmonic distortion (THD) of AC mains current and its high crest factor (CF). Moreover, the PQ standards for low power equipments such as IEC 61000-3-2 [5], emphasize on low harmonic contents and near unity power factor current to be drawn from AC mains by these motors. Therefore, the use of a power factor correction (PFC) converter amongst various available converter topologies [6-8] is almost inevitable for a PMBLDCM drive. In this paper, a novel single-stage power factor corrected PMBLDCM drive system is presented to drive with an unity power factor and to improve the input current waveforms. The proposed PMBLDCM drive is simple compared with the conventional approaches employing a power factor correction circuitry.

II. PROPOSED SPEED CONTROL SCHEME OF PMBLDC MOTOR

The proposed speed control scheme (as shown in Fig. 1) controls reference voltage at DC link as an equivalent reference speed, thereby eliminates the conventional speed control loop and various sensors (voltage and current) in this loop. However, the rotor position signals are used in an electronic commutator, only to generate the switching sequence for the inverter feeding the PMBLDC motor. Therefore, rotor-position is sensed using Hall effect sensors only at the commutation points, i.e. every 60°electrical in the three-phases .

Fig. 1.3: Phase bridge inverter fed PMBLDCM drive



The PFC controls the DC link voltage by its duty ratio (D) at a switching frequency (fs). For a fast and effective control with reduced size of magnetics and filters, a high switching frequency is used; however, its value depends on various factors such as the switching device, switching losses and operating power level. Metal oxide field effect transistor (MOSFET) is used as the switching device for high switching frequency in the proposed PFC converter. However, MOSFETs are used in bridge inverter feeding PMBLDCM, to reduce the switching stress, because of its operation at lower frequency compared to PFC converter switch.

III. DESIGN OF PFC BASED PMBLDCM DRIVE

The proposed PFC is designed for a PMBLDCM drive with main considerations on PQ constraints at AC mains and allowable ripple in DC link voltage. The DC link voltage of the PFC converter is given as,

$$V_{dc} = (N_2/N_1)\ V_{in}\ D \text{ with } D(1+N_3)/\ N_1<1 \quad (1)$$

Where N1, N2, N3 are number of turns in primary, secondary and tertiary windings of the high frequency (HF) isolation transformer, respectively. The tertiary winding is used to return stored energy back to DC source, during turnoff time, for resetting the flux in the high frequency transformer core. Vin is the average output of the DBR for a given AC input voltage (Vs) related as,

$$V_{in} = 2\sqrt{2}V_s/\pi \quad (2)$$

The high frequency AC voltage from the transformer is rectified using rectifier that provides improved efficiency due to voltage drop of only one diode in the forward converter. A ripple filter is designed to reduce the ripples introduced in the output voltage due to high switching frequency of the PFC. The inductance (Lo) of the ripple filter restricts the inductor peak to peak ripple current (ΔI_{Lo}) within specified value for the given switching frequency (fs), whereas, the capacitance (Cd) is calculated for a specified ripple in the output voltage (ΔV_{Cd}). The output filter inductor and capacitor are given as,

$$L_o = (1-D)V_{dc}/\{f_s(\Delta I_{Lo})\} \quad (3)$$

$$C_d = I_o/(2\omega\Delta V_{Cd}) \quad (4)$$

IV. MODELING OF THE PROPOSED PFC BASED PMBLDCM DRIVE

The main components of the proposed PMBLDCM drive are the PFC and PMBLDCM drive, which are modeled by mathematical equations and the complete drive is represented as a combination of these models.

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) Reference Current Generator : The reference current at the input of the buck forward is denoted by idc* and given as,

$$i_{dc}^* = I_c\ (k)\ u_{Vs} \quad (5)$$

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

$$u_{Vs} = v_d/V_{sm};\ v_d = |v_s|;\ v_s = V_{sm} \sin \omega t \quad (6)$$

where V_{sm} is the amplitude of the voltage and ω is frequency in rad/sec at input AC mains.

2) PWM Controller : The reference input current of the buck forward converter (idc*) is compared with its sensed current (idc) to generate the current error $\Delta i_{dc} = (i_{dc}^* - i_{dc})$.This current error is amplified by gain k_{dc} and compared with fixed frequency (fs) saw-tooth carrier waveform md(t) to get the switching signal for the MOSFET of the PFC forward buck as,

$$\text{If } k_{dc}\ \Delta i_{dc} > m_d\ (t) \text{ then } S = 1 \text{ else } S = 0 \quad (7)$$

Where S denotes MOSFET of the inverter and its values ‘1’ and ‘0’ represent ‘on’ and‘off’ condition.

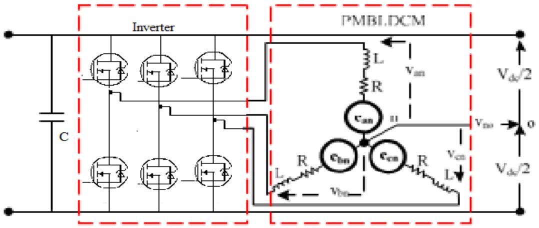


Fig. 2 : Equivalent circuit of a three phase bridge inverter fed PMBLDCM drive

TABLE-I

3PHASE BRIDGE INVERTER SWITCHING SEQUENCE BASED ON THE HALL EFFECT SENSOR SIGNALS

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

B. PMBLDCM Drive

The PMBLDCM drive consists of an electronic commutator, a three phase bridge inverter and a PMBLDC motor.

1) Electronic Commutator: The electronic commutator uses signals from Hall effect position sensors to generate the switching sequence for the inverter based on the logic given in Table I.

2) Three phase bridge Inverter: Fig. 2 shows an equivalent circuit of a inverter fed PMBLDCM. The output of inverter to be fed to phase ‘a’ of the PMBLDC motor is given as,

$$v_{ao} = (V_{dc}/2) \quad \text{for } S_1 = 1 \quad (8)$$

$$v_{ao} = (-V_{dc}/2) \quad \text{for } S_2 = 1 \quad (9)$$

$$v_{ao} = 0 \quad \text{for } S_1 = 0, \text{ and } S_2 = 0 \quad (10)$$

$$v_{an} = v_{ao} - v_{no} \quad (11)$$

where v_{ao}, v_{bo}, v_{co}, and vno are voltages of the three-phases and neutral point (n) with respect to virtual mid-point of the DC link voltage shown as ‘o’ in Fig. 2. The voltages van, vbn, vcn are voltages of three-phases with respect to neutral point (n) and Vdc is the DC link voltage. The values 1 and 0 for S1 or S2 represent ‘on’ and ‘off’ condition of respective MOSFETs of the inverter. Similarly, the switching of other MOSFETs of the inverter i.e. S3- S6 is considered .

The voltages for other two phases of the VS feeding PMBLDC motor i. e v_{bo}, v_{co}, v_{bn}, v_{cn} are generated using similar logic.

3) PMBLDC Motor: The PMBLDCM is modeled in the form of a set of differential equations [16] given as,

$$V_{an} = Ri_a + p\lambda_a + e_{an} \quad (12)$$

$$v_{bn} = Ri_b + p\lambda_b + e_{bn} \quad (13)$$

$$v_{cn} = Ri_c + p\lambda_c + e_{cn} \quad (14)$$

In these equations, p represents differential operator(d/dt), i_a, i_b, i_c are currents, λ_a, λ_b, λ_c are flux linkages and e_{an}, e_{bn}, e_{cn} are phase to neutral back emfs of PMBLDCM, in respective phases, R is resistance of motor windings/phase. Moreover, the flux linkages can be represented as,

$$\lambda_a = L_s i_a - M\,(i_b + i_c) \quad (15)$$

$$\lambda_b = L_s i_b - M\,(i_a + i_c) \quad (16)$$

$$\lambda_c = L_s i_c - M\,(i_b + i_a) \quad (17)$$

where Ls is self-inductance/phase, M is mutual inductance of PMBLDCM winding/phase.

The developed electromagnetic torque Te in the PMBLDCM is given as,

$$T_e = (e_{an}\, i_a + e_{bn}\, i_b + e_{cn}\, i_c)/\,\omega_r \quad (18)$$

Where ω_r is motor speed in rad/sec.

Since the PMBLDCM has no neutral connection, therefore,

$$i_a + i_b + i_c = 0 \quad (19)$$

From eqs. (10-17, 19) the voltage (v_{no}) between neutral point (n) and mid-point of the DC link (o) is given as,

$$v_{no} = \{v_{ao} + v_{bo} + v_{co} - (e_{an} + e_{bn} + e_{cn})\}/\,3 \quad (20)$$

From Eqs. (15-17, 19), the flux linkages are given as,

$$\lambda_a = (L_s+M)\, i_a,\ \lambda_b = (L_s+M)\, i_b,\quad \lambda_c = (L_s+M)\, i_c, \quad (21)$$

From Eqs. (12-14 and 21), the current derivatives in generalized state space form are given as,

$$pi_x = (v_{xn} - i_x\, R - e_{xn})/(L_s+M) \quad (22)$$

Where x represents phase a, b or c.

The back emfs may be expressed as a function of rotor position (θ) as,

$$e_{xn} = K_b\, f_x(\theta)\, \omega_r \quad (23)$$

Here x can be phase a, b or c and accordingly $f_x(\theta)$ represents function of rotor position with a maximum value±1 identical to trapezoidal induced emf given as,

$$f_a(\theta) = 1 \qquad \text{for } 0 < \theta < 2\pi/3 \quad (24)$$

$$f_a(\theta) = \{(6/\pi)(\pi - \theta)\}-1 \qquad \text{for } 2\pi/3 < \theta < \pi \quad (25)$$

$$f_a(\theta) = -1 \qquad \text{for } \pi < \theta < 5\pi/3 \quad (26)$$

$$f_a(\theta) = \{(6/\pi)(\theta - 2\pi)\}+1 \qquad \text{for } 5\pi/3 < \theta < 2\pi \quad (27)$$

The functions $f_b(\theta)$ and $f_c(\theta)$ are similar to $f_a(\theta)$ with a phase difference of 120° and 240° respectively.

Therefore, the electromagnetic torque expressed as,

$$T_e = K_b\{f_a(\theta)\, i_a + f_b(\theta)\, i_b + f_c(\theta)\, i_c\} \quad (28)$$

The mechanical equation of motion in speed derivative form is given as,

$$p\omega_r = (P/2)\,(T_e - T_l - B\omega_r)/(J) \quad (29)$$

The derivative of rotor position is given as,

$$p\theta = \omega_r \quad (30)$$

Where P is number of poles, T_l is load torque in Nm, J is moment of inertia in kg-m2 and B is friction coefficient in Nms/Rad. These equations (11-29) represent the dynamic model of the PMBLDC motor.

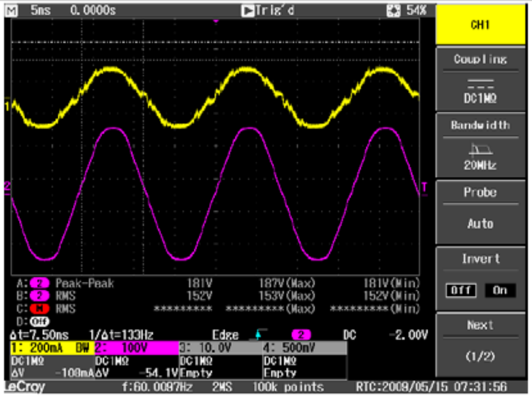


Fig. 3 : Waveform IAC AND VAC AT 175W

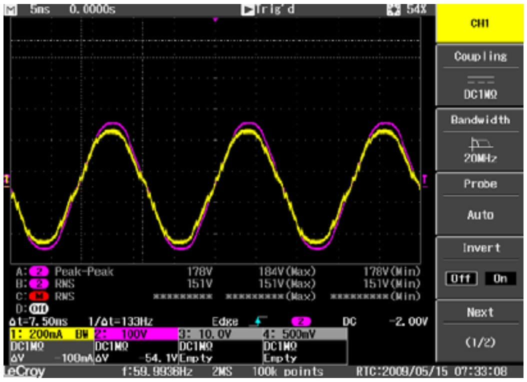


Fig. 4 : Waveform of IAC AND VAC AT 350W

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