Performance Enhancement of PMBL DC Motor Drive by Multi-Carrier Modulation Technique

G. Joga Rao, D.V.N. Ananth, P.Kiran Kumar, P.RamReddy

Abstract: ***Vital importance of this work is to enhance the performance of the Permanent magnet brushless DC motors (PMBLDC or simply BLDC) with help of Multicarrier modulation technique on multilevel inverter. BLDC Motors are extensively used in electrical drives as they are more high efficiency, responds dynamically, reliable and free maintenance. This scheme is an efficient replacement for the orthodox method. The modelling of this planned drive system is designed and simulated by using the MATLAB/ Simulink software. This software based results portray an effective control in the motor, and an enhanced drive performance.***

Keywords: PMBLDC Motor, Multicarrier modulation, Multilevel Inverter, Electromagnetic torque, MATLAB/Simulink

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I. INTRODUCTION

Recently, applications of inverters like controllable AC sources, renewable energy sources, and drive systems, etc been widely implemented in various industries using multi-level inverter topologies [1-4]. The use of Permanent Magnet Brushless DC motor (PMBLDCM) is becoming popular for the last decade due to low cost, easy in maintenance and better controllability [5-8]. Certain disadvantages like cost, demagnetising effect, field flux controlling, and more maintenance of permanent magnet synchronous motor has led to alternate machine called PMBLDC motors [5]. This PMBLDC or simply BLDC motors have better speed-torque characteristics, availability from low power to large ratings, better controllability, cheaper, lesser maintenance are advantages of BLDC [6-10]. In the literature, there are numerous replication models presented for BLDC motor drives [6-7].

A new current control technique is developed to [7] decrease torque ripple for a high speed BLDCM using synchronous d-q reference frame. The improved back EMF with better speed and torque control under variable load applications is described [8]. The effectiveness of this BLDC motor can be further improved with the help of multilevel inverter (MLI) [8]. In this paper, a six step inverter with electronic commutator is used instead of a conventional inverter.

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The BLDCM are observed to have quite lesser noise and decreased vibrations and torque pulsations when multi-level inverters or better pulse techniques like space vector current control method [9-10]. Consequently, the reduction or exclusion of noise disturbance and quivering is severe issue in BLDC motor drive. Also, with MLI based PMBLD motors, the reliability, efficiency, better maintenance and silent operation, and also wide range of applications like attachments for computers, aerospace, medical equipment, household products, and value addition in Air Conditioner are possible [11].

To reduce the aforementioned problem, this study emphasizes to develop the operation and performance by using inverter as an electronic commutator fed to a PMBLDC motor.

II. MODELLING OF BLDC MOTOR

In general, the rotor of BLDC motor is constructed in such a way that it has windings on the alternate permanent magnets [12]. They can be differentiated, depending on the Permanent magnet mounting and the back electro motive force shape. The back electro motive force (BEMF) shape can either be trapezoidal or sinusoidal. In the BLDC motor, the BEMF has a trapezoidal shape persuaded in the stator windings, and supply to the phase is a quasi-square current for torque ripple-less operation. Later, it needs a high resolution position sensor for optimal operation. Mechanism's which use sensors like mechanical position hall-effect sensor which is a shaft encoder is used to obtain rotor position in degrees [13-14]. The current point of the rotor is obligatory to regulate the following commutation time period. A constant inverted voltage is the input to a BLDC motor to generate trapezoidal back EMF.

The magnitude of BEMF is directly proportional to the angular position and velocity given by the equation $E = \frac{d\lambda r}{dt}$. With the variation in the source voltage forces the current to rise abruptly from its steady-state value, and develops torque with ripples. However, a better control strategy helps to mitigate these ripples considerably. The time constant (L/R) of the motor is high enough that rise or fall in the current parameter, however produces more current ripples. The current ripple normally produces large commutation phase currents will influence the torque ripples considerably [15-16].

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Using high frequency semiconductor switches like IGBTs with electronic commutation technique leads to deficiency in stator and its associated controller. Hence, the motor input power supply results in larger harmonics [17]. The motor control and operation is enhanced when current or torque ripples are mitigated effectively. The assumptions like iron losses and saturation of motor are neglected. Ideal semiconductor devices are considered for the analysis. Windings resistance of stator and mutual inductance on all the phases are same.

The closed loop simulation design of PBLDC system is given in the Fig.1. The total system is a closed loop control scheme with rotor position is constant typically 60 degrees electrically for a six-step commutation. The proposed BLDC drive topology consists of BLDCM, multilevel inverter, PWM pulse generator circuit, and rotor angle sensor which detects its position in degrees. The rotor position or angle is measured using a Hall Effect sensor and its corresponding back emf generation is described in Table I. It contains an electronic commutator, so that the power input waveform to the winding is in sequence with the proper rotor position. The logic and switching are achieved using electronics for commutation to convert the information about the rotor position to the correct excitation for the stator phases. The relating norm among the BLDC drive and the hall-effect position sensor is evocative of the miniaturized magnetic position encoder, which are developed on 3-ph hall position sensor. A permanent magnet is placed at corner of the revolving shaft and magnetic sensor underneath it. This forms a parallel magnetic field is created by the magnet to the surface of the sensor. Magnetic sensor gives sensitive directions to the surface. Using closed loop mechanism motor performance is improved, where three signals are required with a phase shift of 120o as it has three signals. The 3-ph winding of BLDCM uses in each phase one Hall position sensor providing three overlapping angles with 60° phase position. Depending on decoded signal, the desired firing pulses are produced by a PWM which are given to the inverter. This voltage source inverter provides excitation the stator winding making the motor to run at desired speed and torque.

Table 1. Hall Effect sensor signals and corresponding BEMF signals [13]

h_a	h_b	h_c	e_a	e_b	e_c
0	0	0	0	0	0
0	0	1	0	-1	+1
0	1	0	-1	+1	0
0	1	1	-1	0	+1
1	0	0	+1	0	-1
1	0	1	+1	-1	0
1	1	0	0	+1	-1
1	1	1	0	0	0

The PMBLDC motor produces trapezoidal flux in the d-q rotor reference frame however this flux is sinusoidal in permanent magnet synchronous motor. The PMBLDC motor doesn't have damper winding, so the inverter control design needs damping mechanism. In this inverter topology, at a time only one phase or two phases is operated. The BLDC motor three phase voltages are represented in terms of phase currents and back EMF give by the equation (1),

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1)$$

where

ea, eb, and ec are three phases trapezoidal back EMF.

R is the phase resistance

L and M are the self and mutual inductance

v_a, v_b and v_c are three input inverter voltages/phase

ia, ib, ic are phase currents.

The electromagnetic torque, rotor speed and the rotor position are shown in equations (2) to (5)

$$T_e = T_L + J\frac{d\omega_r}{dt} + B\omega_r \quad (2)$$

$$\omega_r = \frac{1}{J}\int (T_e - T_L)\, dt = J\int [(T_a + T_b + T_c) - T_L]dt \quad (3)$$

$$T_e = \frac{e_a i_a + e_b i_b + e_c i_c}{\omega_r} \quad (4)$$

$$\frac{d\theta}{dt} = \frac{P}{2}\omega_r \quad (5)$$

here, ω_r and θr is the mechanical rotor speed and rotor position.

Te and TL are electromagnetic torque and load torque.

B and J are damping constant and moment of inertia of motor rotor shaft.

The Back EMF is directly proportional to the rotor speed and hence the Back EMF can be written as

$$E = K_e\omega_r \quad (6)$$

where, Ke is the back EMF constant.

Depending on the rotor position, back emf produced in all the three phases is given by

$$e_a = \begin{cases} \frac{6E}{\pi}\phi_r & = \quad 0 < \phi_r < \frac{\pi}{6} \\ E & = \quad \frac{\pi}{6} < \phi_r < \frac{5\pi}{6} \\ \frac{-6E}{\pi}\phi_r + 6E & = \quad \frac{5\pi}{6} < \phi_r < \frac{7\pi}{6} \\ -E & = \quad \frac{7\pi}{6} < \phi_r < \frac{11\pi}{6} \\ \frac{6E}{\pi}\phi_r - 12E & = \quad \frac{11\pi}{6} < \phi_r < 2\pi \end{cases} \quad (7)$$

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$$e_b = \begin{cases} -E & = 0 < \emptyset_r < \frac{\pi}{2} \\ \frac{6E}{\pi}\emptyset_r - 4E & = \frac{\pi}{2} < \emptyset_r < \frac{5\pi}{6} \\ E & = \frac{5\pi}{6} < \emptyset_r < \frac{9\pi}{6} \\ \frac{-6E}{\pi}\emptyset_r + 10E & = \frac{9\pi}{6} < \emptyset_r < \frac{11\pi}{6} \\ E & = \frac{11\pi}{6} < \emptyset_r < 2\pi \end{cases} \quad (8)$$

$$e_c = \begin{cases} E & = 0 < \emptyset_r < \frac{\pi}{6} \\ \frac{-6E}{\pi}\emptyset_r + 2E & = \frac{\pi}{6} < \emptyset_r < \frac{\pi}{2} \\ -E & = \frac{\pi}{2} < \emptyset_r < \frac{7\pi}{6} \\ \frac{6E}{\pi}\emptyset_r - 8E & = \frac{7\pi}{6} < \emptyset_r < \frac{9\pi}{6} \\ E & = \frac{9\pi}{6} < \emptyset_r < 2\pi \end{cases} \quad (9)$$

The phase current flowing through each winding can be expressed as follows

$$I_a = \frac{1}{Ls-M} J \int (V_a - E_a - R_{ia})dt \quad (10)$$

$$Ib = \frac{1}{Ls-M} J \int (V_b - E_b - R_{ib})dt \quad (11)$$

$$Ic = \frac{1}{Ls-M} J \int (V_c - E_c - R_{ic})dt \quad (12)$$

where, Ls is self inductance of winding,M is mutual inductance of winding,R is resistance of the winding.

The MATLAB based Simulink model for locked loop organized PMBLDC motor drive has been designed and developed using equation (1) to (9) and the same is shown in Fig.1.

With the help of designed circuit parameters using the MATLAB simulation and results are analysed. The stator three individual phase current waveforms are depicted in Fig. 2a to 2c with 120° displacement the waveform is shaped quasi- sinusoidal. The back electromotive force waveforms are depicted in Fig. 3. From this figure it can be observed that the three phase voltages are displaced each by 120° apart electrically. For a 360O of the inverter having three phases with six pulses, the rotor position commutation 60° electrically. Therefore, a reasonably normal controller is needed for commutation and for current control. Hence, the torque is kept constant by controlling stator current in a PMBLDC motor.

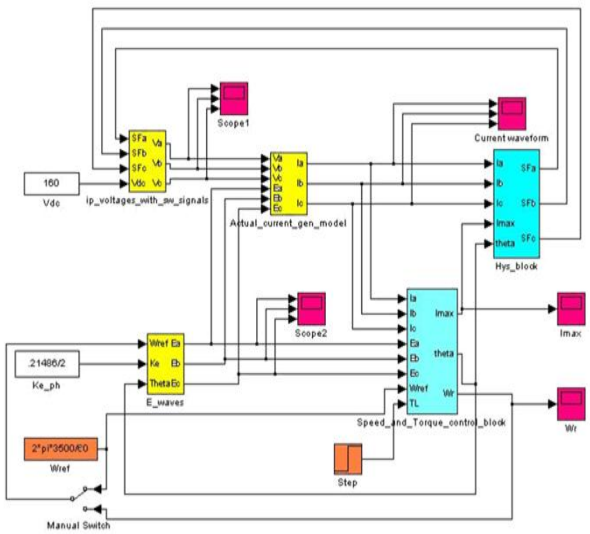

Fig.1. MATLAB based model design of PBLDC Drive

III. SIMULATION RESULTS AND ANLAYSIS

The MATLAB/ Simulink model is shown in Fig.1 consists of three sub-systems, v_a, v_b and v_c and ea, eb, and ec are input three phase inverted voltages and generated back EMF of the motor and the outputs of these giving controlled current inputs to the motor. Based on the controlled current value and back EMF, the motor speed and torque is developed. Inputs for the MATLAB function are hall signals, positive and negative pulses. Accordingly, coding is written to suitably select the pulses depending on the hall signal.

To revolve the BLDC motor, a sequence must be followed in energizing the stator windings. The position of the rotor is sensed using the hall sensor attached to stator to attained high or low signal. For every rotation, the rotor magnetic pole crosses hall sensors, which signify either North or South Pole. A precise commutation sequence is obtained by using combination of Hall Effect position sensor signals and rotor angular position signals. Using this decoded signal, respective firing pulses to the inverter switches are developed. This energizes the stator winding, and induces the current. Due to the interaction of the stator and rotor fluxes, electromagnetic torque is produced. Electromagnetic torque (EMT) pulsations are reduced, in which the EMT is predicted by multiplying the current and instantaneous back-EMF. It has a comparatively lesser torque ripple because of the proportionality between the torque and current. The EMF is proportional to the rotor speed.

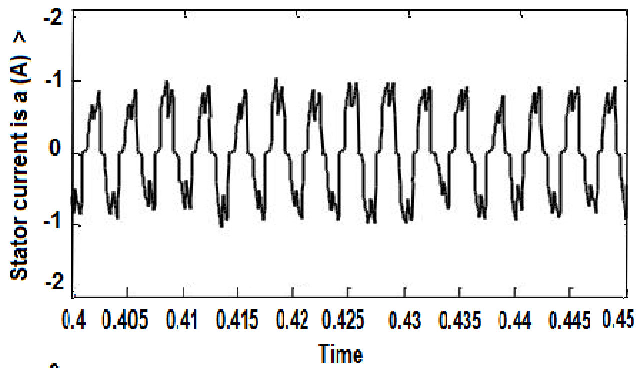

Fig.2a. Generated phase-A current waveform

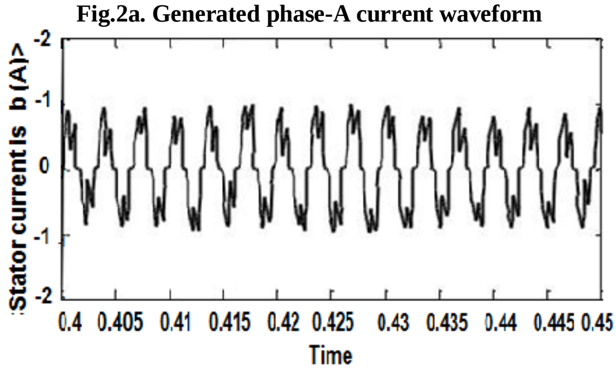

Fig.2b. Generated phase-B current waveform

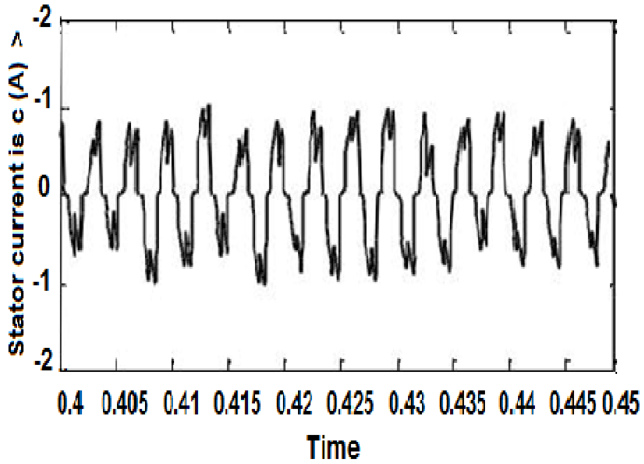

Fig.2c. Generated phase-C current waveform

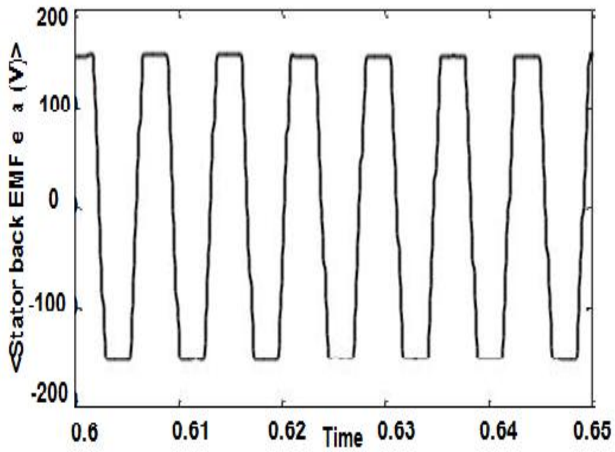

Fig.3a. Generated phase-A voltage waveform

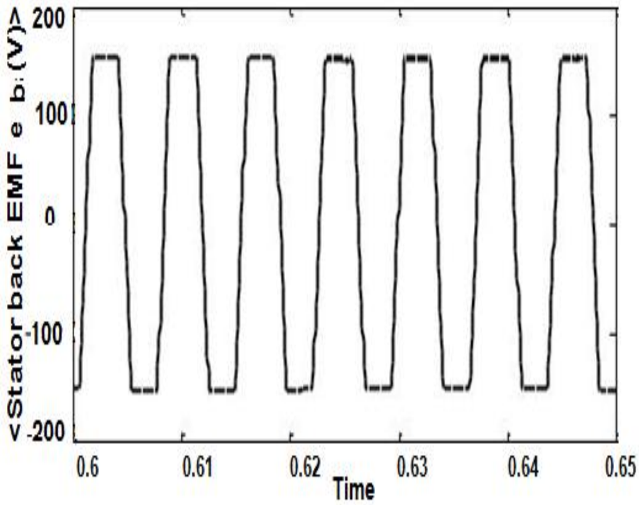

Fig.3b. Generated phase-B voltage waveform

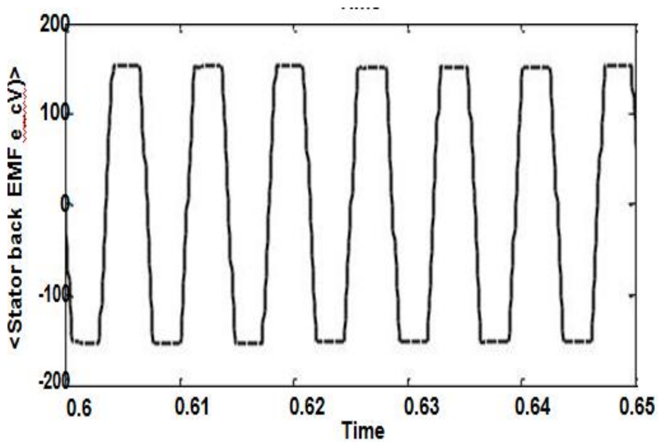

Fig.3c. Generated phase-C voltage waveform

The stator current and BEMF voltages in the stator winding of the motor are shown in fig. 2a,2b,2c and 3a,3b,3c respectively. The waveform of motor electromagnetic-torque with ripples is shown in fig.4.

This result shows a better dynamic performance with reduced torque ripples in the PMBLDC. The dynamic operation of the PMBLDC motor fed by various inverter topologies have been obtained from the dynamic simulation study.

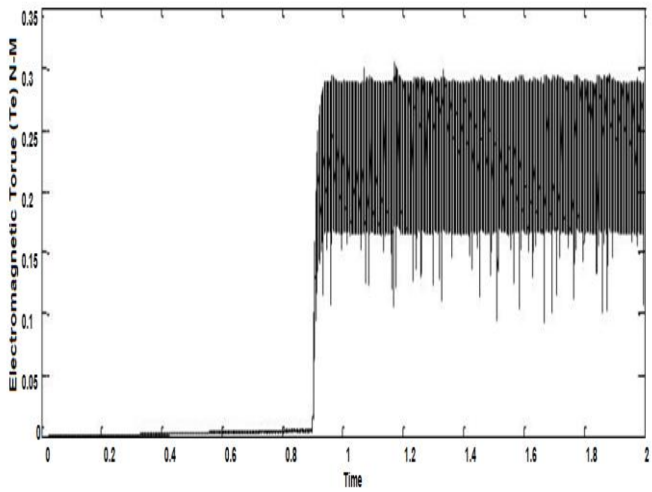

Fig.4. Electromagnetic torque with ripple waveform

IV. CONCLUSION

This paper dealt with PMBLDC motor drives fed from inverters. These drives have been compared to regulate the optimal arrangement and control pattern for enhancing the performance parameters. The dynamic performance and feasibilities of the PMLBDC motor drive have been studied. This work is primarily an engineering design study and is meant to lead the way for it to be practically implemented. Subsequent works may be included in the future as an extension with different control techniques.

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