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Open Loop Control of BLDC Motor Using SVPWM Inverter

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ABSTRACT: This paper presents a sensorless drive scheme for a brushless DC (BLDC) motor based on the BEMF method. In this the use of BLDC motor drive requires implementing of voltage source inverter supplied by DC voltage source and space vector PWM. In this paper a technique is implemented for a better control for sensorless BLDC motor of BEMF method. The proposed new estimation method solves the problem of the BLDC motor drives at low speed and zero speed in Matlab/Simulink environment. Through this method, the brushless DC motor can start from standstill smoothly. The voltage source inverter system is fed with SVPWM method to control the BLDC motor. The simulations are performed using MATLAB/SIMULINK software and the results are presented.

KEYWORDS*:* Pulse Width Modulation, Space Vector Pulse Width Modulation, Brushless DC motor, Voltage Source Inverter.

I. INTRODUCTION

Permanent magnet brushless DC Motor (PMBLDC motor) has a series of advantages such as simple structure, no commutation spark, good speed regulation performance, reliable operation, no excitation loss, maintenance convenience and energy efficiency. It has been widely used in the many fields[1]. A PMSM classified into two types based on the back electro-motive force (BEMF) waveform shape. One variety with sinusoidal BEMF is known as a brushless AC (BLAC) motor and the other with trapezoidal BEMF is a brushless DC (BLDC) motor[3]. A BLDC motor which is typically excited by a sinusoidal current requires continuous rotor position, thus a position sensor with high resolution such as an encoder or a resolver is used. One the other hand BLDC motor which is powered by a rectangular current requires only six discrete rotor position , thus low-cost hall sensors are usually used. There are several drawbacks when such types of position sensors are used. These sensors increase the cost of the motor and reduce simplicity and reliability of the system due to the extra components and wiring. Especially, hall sensors increase the size of the motor and they are temperature sensitive since they are mounted inside. So size become large.

The method of open-loop start has no special requirements on structure of the motor, therefore it has wider applicability. Hence, many researchers focus on improving the performance of open-loop start to make it closer and closer to the performance of position closed-loop start. Reference [15-21] adopts SVPWM to control six power transistors with two phases conducted once. It chooses the proper duration of voltage vectors to make the flux continuously move in circular trajectory, and adopts a two-point current comparator in order to ensure stable and reliable starting performance. However, distributing the duration of the two basic voltage vectors generated by conducting two certain phases in a control cycle is hard to realize and not necessary. Moreover, the current comparator jumps sharply and overshoots seriously, resulting in serious ripple of speed which reaches 27% and it does not make full use of the advantages of SVPWM method.

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II. BLOCK DIAGRAM OF PROPOSED SYSTEM

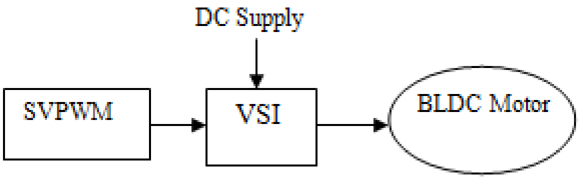

Fig 1:- Block Diagram of Proposed System

The above Fig-1 shows the proposed block diagram of Open loop control of BLDC Motor using SVPWM Inverter. In this space vector pulse width modulation is used to generate pulses for gate signals to the inverter and DC supply is given as input to the inverter. The output from the inverter is used to run the BLDC Motor.

III.SVPWM INVERTER

BLDC motor is usually operated under 120° switch-on mode by conducting any two phases at the same time. In order to start the motor, the rotating stator magnetic potential is required, which can also be generated by conducting any three phases simultaneously. A continuously rotating voltage vector can drag the rotor via composing two adjacent basic vectors of the inverter under 180° switch-on operating mode.

The conventional three-phase inverter is shown in Fig.2, which has eight different operating modes as shown in Fig. 3. Inverter is operated under complementary control. Define the state that upper arm is switch-on while lower arm is switch-off as “1”, otherwise “0”.

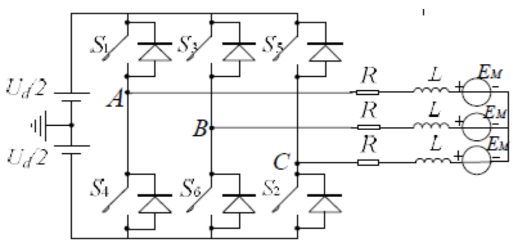

Fig-2:-Three Phase Inverter

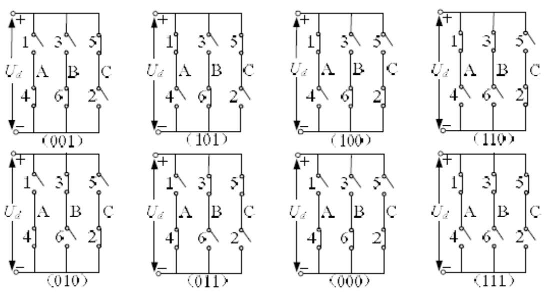

Fig-3:-Switching states of Three Phase Inverter

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Fundamental voltage space vectors can be expressed as follows:

$$U_r = \frac{2}{3}(u_A + e^{j\frac{2}{3}\pi}u_B + e^{j\frac{4}{3}\pi}u_C) \qquad (1)$$

By substituting corresponding terminal voltage potential under different operating states into (1), eight fundamental vectors can be got, including six non-zero vectors which are U1~6 and two zero vectors which are U0 and U7. The amplitude of six non-zero vectors is 2/3Ud and that of two zero vectors is zero.

A-B-C axis aligns with three-phase stator axis of BLDC motor and the region is divided into six sectors by non-zero voltage space vectors as shown in Fig. 4.

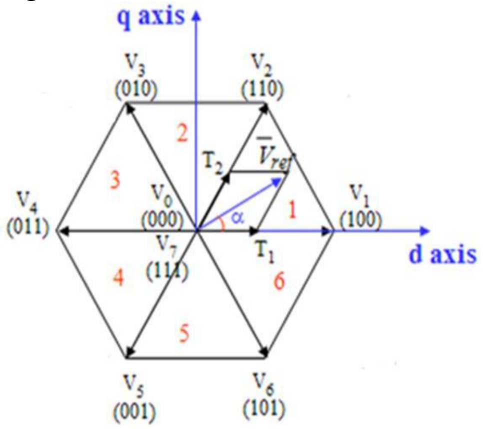

Fig-4:-Switching Vectors and Sectors

Switching Time Duration in any Sector,

$$T_a = \frac{\sqrt{3}.T_Z.V_{ref}}{V_{dc}}\left[\sin\frac{n}{3}\pi\cos\alpha - \cos\frac{n}{3}\pi\sin\alpha\right] \qquad (2)$$

$$T_b = \frac{\sqrt{3}\,T_z V_{ref}}{V_{dc}}\left[-\cos\alpha.\sin\frac{n-1}{3}\pi + \sin\alpha.\cos\frac{n-1}{3}\pi\right] \qquad (3)$$

$$T_o = T_z - T_a - T_b \qquad (4)$$

Table 1:- Times T_a, T_b and T_0 for all sectors

Sector	T_a	T_b	T_o
I	$T_z.a.\sin(\frac{\pi}{3} - \alpha)$	$T_z.a.\sin(\alpha)$	$T_z - T_a - T_b$
II	$T_z.a.\sin(\frac{2\pi}{3} - \alpha)$	$T_z.a.\sin(\alpha - \frac{\pi}{3})$	$T_z - T_a - T_b$
III	$T_z.a.\sin(\pi - \alpha)$	$T_z.a.\sin(\alpha - \frac{2\pi}{3})$	$T_z - T_a - T_b$
IV	$T_z.a.\sin(\frac{4\pi}{3} - \alpha)$	$T_z.a.\sin(\alpha - \pi)$	$T_z - T_a - T_b$
V	$T_z.a.\sin(\frac{5\pi}{3} - \alpha)$	$T_z.a.\sin(\alpha - \frac{4\pi}{3})$	$T_z - T_a - T_b$
VI	$T_z.a.\sin(2\pi - \alpha)$	$T_z.a.\sin(\alpha - \frac{5\pi}{3})$	$T_z - T_a - T_b$

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The SVPWM is realized based on the following steps:

Step1. Determine Vd, Vq, Vref, and angle (α).

Step2. Determine time duration Ta, Tb, T0.

Step3. Determine the switching time of each Switch (S1 to S6).

Table 2:- Switching sequence table for each switch in each leg

Sector	Upper Switches:S1,S3,S5	Lower Switches:S4,S6,S2
1	S_1=T_a+T_b+T_o/2 S_3=T_b+T_o/2 S_5=T_o/2	S_4=T_o/2 S_6=T_a+T_o/2 S_2=T_a+T_b+T_o/2
2	S_1=T_a+T_o/2 S_3= T_a +T_b+T_o/2 S_5=T_o/2	S_4= T_b+T_o/2 S_6=T_o/2 S_2=T_a+T_b+T_o/2
3	S_1=T_o/2 S_3= T_a +T_b+T_o/2 S_5= T_b +T_o/2	S_4= T_a+T_b+T_o/2 S_6=T_o/2 S_2=T_a+T_o/2
4	S_1= T_o/2 S_3= T_a +T_o/2 S_5= T_a +T_b+T_o/2	S_4= T_a+T_b+T_o/2 S_6= T_b+T_o/2 S_2=T_o/2
5	S_1=T_b+T_o/2 S_3=T_o/2 S_5= T_a +T_b+T_o/2	S_4= T_a+T_o/2 S_6= T_a+T_b+T_o/2 S_2=T_o/2
6	S_1=T_a+T_b+T_o/2 S_3=T_o/2 S_5= T_a +T_o/2	S_4=T_o/2 S_6= T_a+T_b+T_o/2 S_2=T_b+T_o/2

IV. MODELING OF BLDC MOTOR

A general BLDC motor has three phase stator windings and is driven by an inverter which constitutes of six switches. Fig. 1 shows the equivalent circuit of a Y connection BLDC motor and the inverter topology. Assuming that the stator resistance and inductance of all the windings are equal, the voltage equation of a BLDC motor can be expressed as

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = R \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + L \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} + \begin{bmatrix} V_n \\ V_n \\ V_n \end{bmatrix} \quad (5)$$

where , V_x, i_x, and e_x(x=a, b, c) denote the terminal voltage, the phase current, and the phase BEMF respectively. R is a stator resistance and L is a stator inductance. V_n is the neutral voltage of a Y connection motor.

The electromagnetic torque equation is given by,

$$T_e = \frac{e_a i_a + e_b i_b + e_c i_c}{w_m} \quad (6)$$

where T_e denotes the torque and ω_m is the rotor speed. The equation of motor is

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$$\frac{dwr}{dt} = \frac{1}{J}(Te - Tl - Bwr) \qquad (7)$$

where B is the damping constant, J is the moment of inertia and Tl is the load torque.

In a three phase BLDC motor back emf is related to as a function of rotor position. Rotor position function is a unit function generator which has a maximum value of +1 or -1. The back emf has a phase difference of 120° between each phase. The instantaneous value of induced emf can be represented by the following equations.

$$e_a = \sin\theta rkbwm \qquad (8)$$

$$e_b = \sin\left(\theta r - \frac{2\pi}{3}\right) kbwm \qquad (9)$$

$$e_c = \sin(\theta r + \frac{2\pi}{4}) kbwm \qquad (10)$$

wm is the rotor mechanical speed and θr is the rotor electrical position.

Back emf is generated as a function of rotor position by above equations. Table 3 shows the function of rotor position of three phases for different sectors of angles from 0- 360°.

Table 3:-Functions of rotor position based on angle

Theta-elect Θ(°)	$F_a(\theta)$	$F_b(\theta)$	$F_c(\theta)$
0-60	1	-1	$1-\frac{6}{\pi}\Theta$
60-120	1	$-3+\frac{6}{\pi}\Theta$	-1
120-180	$5-\frac{6}{\pi}\Theta$	1	-1
180-240	-1	1	$-7+\frac{6}{\pi}\Theta$
240-300	-1	$9-\frac{6}{\pi}\Theta$	1
300-360	$-11+\frac{6}{\pi}\Theta$	-1	1

Table 4:- Machine specifications

MOTOR DATA	VALUE
Rated Speed	3000rpm
Rated Torque	2.5Nm
Rated Power	1HP
Stator Inductance/Phase	4.35mH
Stator Resistance/Phase	1.75Ω
Moment of inertia, J	$0.0689kgm^2$
Friction coefficient, B	$0.05Nmsrad^{-1}$
Back emf constant	$0.051V/rads^{-1}$

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V. SIMULATION DIAGRAMS & RESULTS

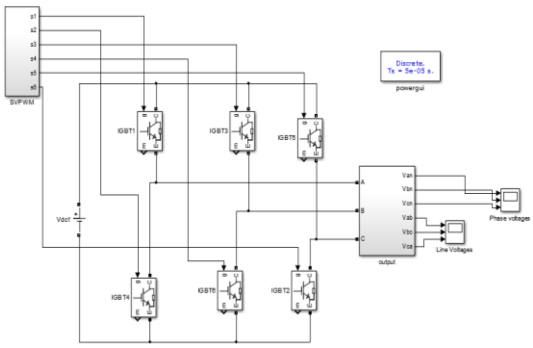

Fig 4:- Simulation diagram of SVPWM

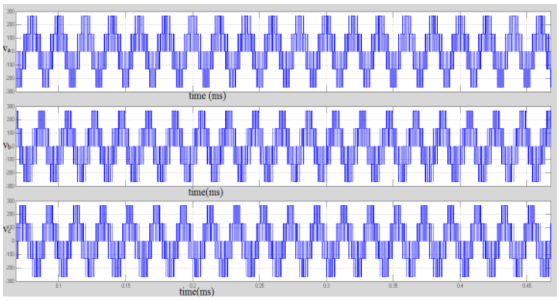

Fig 5:-Inverter Phase Voltage

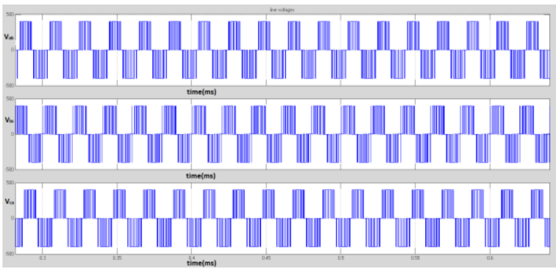

Fig 6:-Inverter Line Voltage

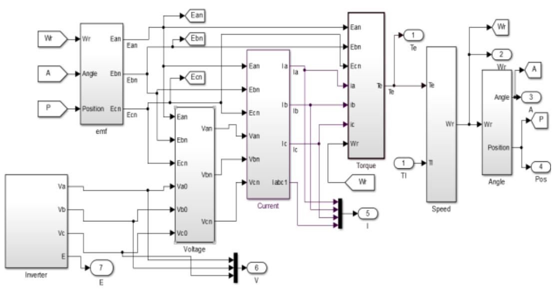

Fig 7:-Modeling circuit of BLDC Motor

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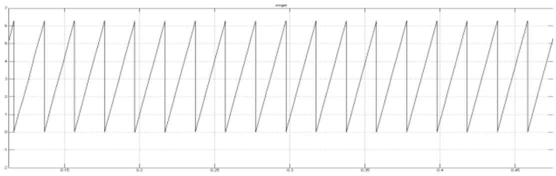

Fig 8:- Angle

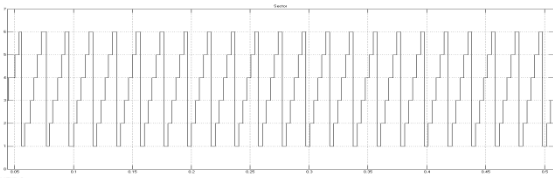

Fig 9:- Sector

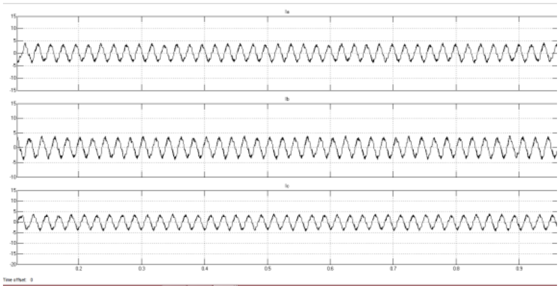

Fig 10:-Rotor current waveform

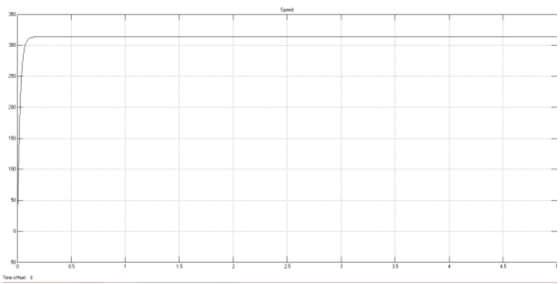

Fig 11:-Speed waveform of BLDC Motor

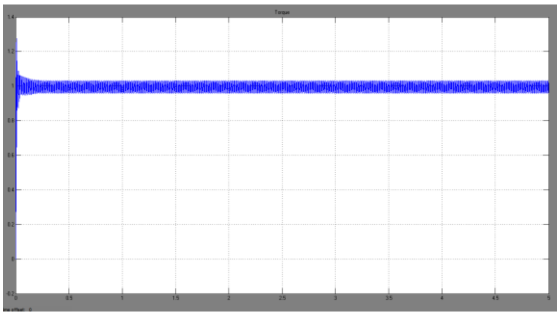

Fig 12:-Torque waveform of BLDC Motor

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VI. CONCLUSION

The simulation of voltage source inverter fed BLDC motor was carried out using space vector pulse width modulation. The performance of the inverter with SVPWM and BLDC motor has been done using MATLAB/SIMULINK.

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