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A Comparative Study of Sinusoidal PWM and Space Vector PWM of a Vector Controlled BLDC Motor

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Abstract*:* This paper focuses on the vector control of a BLDC motor with two different concepts of Pulse Width Modulation- the Sinusoidal PWM and the Space Vector Modulation strategy. The paper deals with the basics of a BLDC motor, its dynamic modeling and its speed control using two different strategies of Pulse Width Modulation. The vector control is one of the methods used in variable frequency drives or variable speed drives to control the torque (and thus the speed) of three-phase AC electric motors by controlling the current. The results prove that the Space Vector Modulation technique helps to improve the performance and thus the efficiency of the system.

Keywords*:* BLDC motor, Vector control, Space Vector PWM.

I. INTRODUCTION

The Brushless DC Motors are synchronous motors which are powered by DC electric source via an inverter or switching power supply which produces an AC electric signal to drive the motor. Its stator consists of ac winding which is either star or delta connected and the rotor consists of Permanent Magnets. BLDC motors are used in industries such as Appliances, Automotive, Aerospace, Consumer, Medical, Industrial Automation Equipment and Instrumentation. BLDC motors have many advantages over brushed DC motors and induction motors. A few of these are:

1. Higher torque to weight ratio
2. More torque per watts (increased efficiency)
3. Increased reliability
4. Reduced noise
5. Longer lifetime
6. Elimination of ionizing sparks from commutator
7. Reduced EMI
8. Easier cooling by conduction
9. Better power factor.

The speed of a motor can be controlled using open loop control. But accurate speed control is necessary in various applications, which can be achieved by closed- loop speed control only. Vector control is an important technology for motor systems, particularly those using Permanent Magnets (PM). It provides an efficient way to control a synchronous motor in adjustable speed drive applications that have quickly changing loads, and can improve the power efficiency of AC induction motor, especially at lower speeds. This does not mean that the vector control technique can solely be used for the power efficiency of induction motors. The Brushless DC motors are by themselves, very efficient (up to 96%), but by implementing vector control in BLDC motors, the torque ripple can be reduced to a great extent, resulting in an improved performance. In the past few years the field of controlled electrical drives has undergone rapid expansion due to the technological improvements in semiconductor devices. New electronic microprocessors and DSPs which provide amazing computational speeds have enabled the development of effective vector controlled AC drives with lower power dissipation and more accurate control.

II. DYNAMIC MODELLING OF BLDC MOTOR

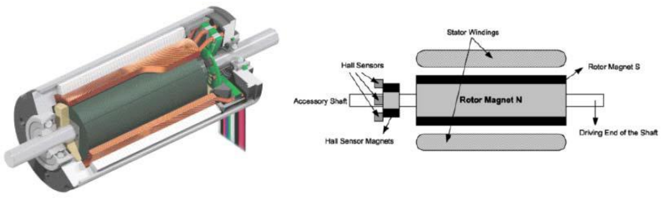

Figure 1. Brushless DC Motor

The modelling of BLDC motor is based on the assumption that the iron and stray losses and also the induced currents due to stator harmonic fields are neglected. The motor is considered to be a three phase motor.

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L_s & M & M \\ M & L_s & M \\ M & M & L_s \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

Where i_a, i_b and i_c are the stator currents per phase. The induced emfs are $e_{a,}$ $e_b$and e_c which are assumed to be trapezoidal with a peak value of $E_{p,}$ derived as

$$E_p = (Blv)N = N\,(Blrw_m)$$
$$= N\emptyset_a w_m$$

$$= \lambda_p \omega_m$$

Where N is the number of conductors in series per phase, v is the velocity, l is the length of the conductor, r is the radius of the rotor bore, ω_m is the angular velocity and B is the flux density of the field in which the conductors are placed.

The flux density B is solely due to the rotor magnets. The product (Blr), denoted as φ_a has the dimensions of flux and is directly proportional to the air gap flux φ_g.

$$\varphi_a = Blr = \frac{1}{\pi} B\pi lr = \frac{1}{\pi}\varphi_g$$

The product of flux and the number of conductors in in series has the dimension of flux linkages and is denoted by λ_p . Since it is proportional to the flux linkages by a factor of $\frac{1}{\pi}$, it is referred to as modified flux linkages.
By the Laplace Transform method, the voltage of each phase can be written as

$$V_{an}(s) = R_a I_a(s) + L_a s I_a(s) + K_e \omega(s)$$

From the above equation we obtain the per- phase current as

$$I_a(s) = \frac{V_{an}(s) - K_e \omega(s)}{R_a + sL_a}$$

Mechanical equation:

$$T_{em}(t) = \omega(t)B + J\frac{d\omega(t)}{dt} + T_L(t)$$

Where $T_{em}(t)$is the developed electromagnetic torque, $\omega(t)$is the rotor angular velocity, B is the viscous friction constant, J is the rotor Moment of Inertia and $T_L$is the load torque.
Also,

$$T_{em}(t) = K_t I_a(t)$$

$$T_{em}(s) = K_t I_a(s)$$

$$T_{em}(s) = sJ\omega(s) + B\omega(s) + T_L(s)$$

$$\omega(s) = \frac{T_{em}(s) - T_L(s)}{B + Js}$$

$$T_{em}(s) = K_t\left[\frac{V_{an}(s) - K_e\omega(s)}{R_a + sL_a}\right]$$

The back emfs can be written as

$$E_a = K_e\omega(m)f(\theta_e)$$

$$E_b = K_e\omega(m)f\left(\theta_e - 2\frac{\pi}{3}\right)$$

$$E_a = K_e\omega(m)f\left(\theta_e + 2\frac{\pi}{3}\right)$$

The torque can be written as

$$T_a = K_t I_a f(\theta_e)$$

$$T_b = K_t I_b f\left(\theta_e - 2\frac{\pi}{3}\right)$$
$$T_c = K_t I_c f\left(\theta_e + 2\frac{\pi}{3}\right)$$

$$T_e = T_a + T_b + T_c$$

$$= K_t[I_a f(\theta_e)] + I_b f\left(\theta_e - 2\frac{\pi}{3}\right) + I_c f\left(\theta_e + 2\frac{\pi}{3}\right)$$

$$T_e - T_L = J\frac{d^2\theta_m}{dt} + B\frac{d\theta_m}{dt}$$

$$\theta_c = \frac{P}{2}\theta_m$$

$$\omega_m = \frac{d\theta_m}{dt}$$

Phase induced emf

$$e_a = K_e f_a(\theta)\omega_r$$

The induced emfs are of a trapezoidal shape. It can be observed that the phase voltage equations are identical to the armature voltage equations of a dc machine. This is one of the reasons for naming this machine as Permanent Magnet Brushless DC Machine, even though it is an AC machine.

III. VECTOR CONTROL

The oscillations in the air gap flux linkages would result in oscillations in the electromagnetic torque, which would reflect as speed variations, which is undesirable. Separately excited dc drives are simpler in control as they independently control flux, which when maintained constant, contributes to an independently controlled torque. This control strategy can be applied in the case of ac drives also, known as Vector Control.

The motor controlled through a voltage source inverter. It is coupled to a dc tacho, the output of which is the actual rotor speedω_r.This is compared with the reference speed $\omega_r{}^*$. The error is amplified and limited to produce the q- axis reference current. This is compare with the actual q- axis current from the motor and the error is amplified and limited with a PI controller. Similarly the d-axis current reference, which is taken as zero is compared with the actual d- axis current and the error is again amplified and limited. These currents are transformed to the a-b-c reference frame and then provided as inputs to the Pulse Width Modulation circuit. The paper aims at a comparative study of the responses for the two different methods of Pulse Width Modulation, the Sinusoidal PWM and the Space Vector PWM when they are used in the Vector controlled BLDC motor.

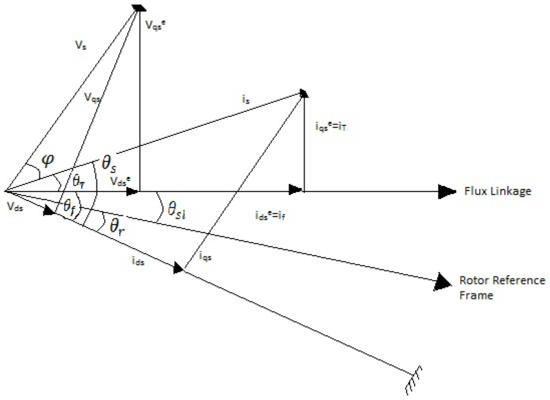

Figure 2:Vector diagram

IV. COMPARISON OF SINE PWM AND SPACE VECTOR PWM IN A VECTOR CONTROLLED BLDC MOTOR

A.Sinusoidal PWM

Pulse width modulation is the process of modifying the width of the pulses in a pulse train, in direct proportion to a small control signal; the greater the control voltage, the wider the pulses become. By using a sinusoid of the desired frequency as the control voltage for a PWM circuit, it is possible to produce a high power waveform whose average voltage rises sinusoidally in a manner suitable for driving ac motors.

B.Space Vector PWM

The main aim of any modulation technique is to obtain variable output having a maximum fundamental component with minimum harmonics. Space Vector PWM (SVPWM) method is an advanced; computation intensive PWM method and possibly the best techniques for variable frequency drive application. Because of the constraint that the input lines must never be shorted and the output current must always be continuous, a voltage source inverter can assume only eight distinct topologies. Six out of these eight topologies produce a non-zero output voltage and are known as non-zero switching states and the remaining two topologies produce a zero output voltage and are known as zero switching states.

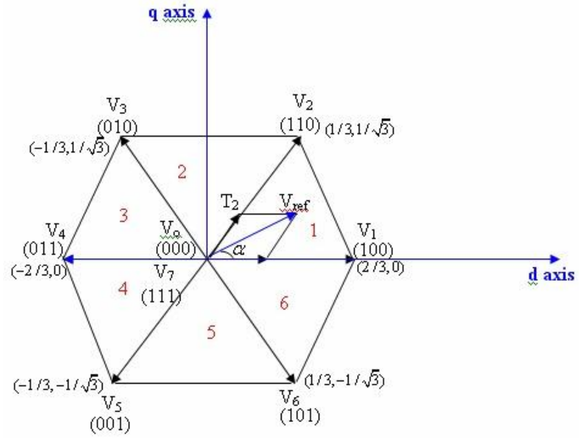

Figure 3:Sectors in SVPWM

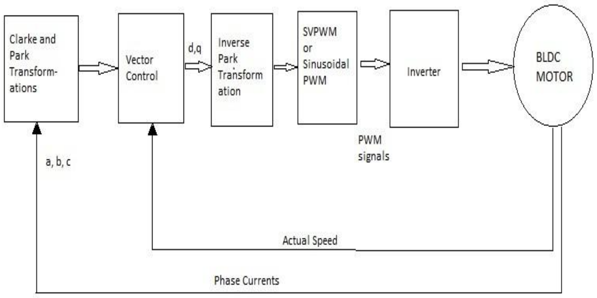

Figure 4:BLDC speed control block diagram with Vector Control Scheme

Figure 4 depicts the vector control block diagram of a BLDC motor implementing Space Vector PWM or Sinusoidal PWM. The actual speed of the motor is compared with the speed reference. The error is given to a PI controller and limited. The resulting signal is called the torque reference currenti_q^*. This is compared with the actual current i_q, obtained from the motor after Clarke and Park's transformations of currents i_a , i_b *and* i_c , the stator currents. The current i_d is compared with a zero reference current. The errors are again amplified and limited and the outputs are given to the PWM block.

The comparison between Sinusoidal PWM and Space Vector PWM clearly reveals that the torque and hence the speed fluctuations, the current waveforms are better for the Space Vector Modulation when implemented in a Vector Control circuit. Figures 5 and 6 show the speed waveforms of Sinusoidal PWM and SVPWM respectively. A reference speed of

1500 is given as input.The speed fluctuations are more in sinusoidal PWM. Similarly the current waveforms are shown from Figures 7 to 10. This also reveals that the current waveforms are better for SVPWM.

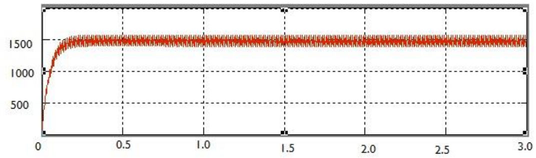

Figure 5:Speed response of a BLDC Motor when Sinusoidal PWM is used as the modulation strategy. Speed reference of 1500rpm is given as the input.

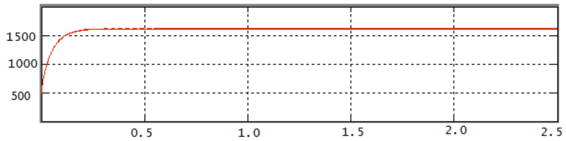

Figure 6:Speed response of a BLDC Motor when Space Vector PWM is used as the modulation strategy. Speed reference of 1500rpm is given as the input.

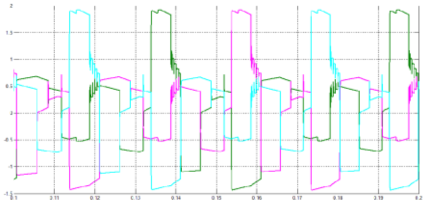

Figure 7:Three phase stator currents when sinusoidal PWM is employed in a vector controlled brushless motor.

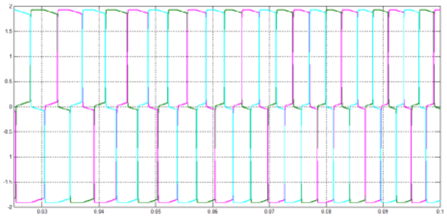

Figure 8:Three phase stator currents when Space Vector PWM is employed in a vector controlled brushless motor.

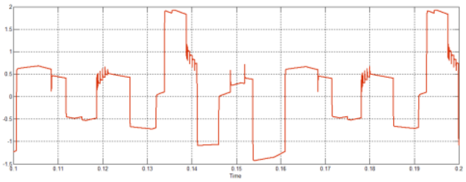

Figure 9:Single phase phase stator currents when sinusoidal PWM is employed in a vector controlled brushless motor.

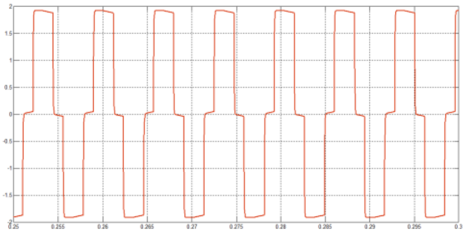

Figure 10:Single phase phase stator currents when Space Vector PWM is employed in a vector controlled brushless motor.

V. CONCLUSION

In this paper, the comparison of current and speed waveforms are done when Sinusoidal PWM and SVPWM are implemented in the Field Oriented Control of Brushless DC motor. The simulation results reveal that the fluctuation in speed and torque are less when the Space Vector Modulation strategy is implemented in the vector controlled motor. Thus it can be concluded that the overall performance of a motor drive system is improved when Space Vector Modulation technique is used in the system.

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