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Field Oriented Control of PMSM with Carrier Based Space Vector Pulse Width Modulation Technique

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***Abstract*—This paper consists of field oriented control of Permanent Magnet Synchronous Motor (PMSM) with Carrier based space vector pulse width modulation (CBSVPWM). Field oriented control enables independent control of flux and torque which results in a high performance motor drive. Fast acceleration, deceleration and smooth rotation over the entire speed range are achieved by this control technique. Carrier based space vector pulse width modulation (CBSVPWM) technique is used for generating pulses for the inverter operation. This method is based on the equivalence of SVPWM and sine triangle comparison approach. The simulation of field oriented control is realized in MATLAB.**

Keywords*— *Field oriented control, PMSM, four quadrant operation, CBSVPWM, PI controller, dynamic braking

I. INTRODUCTION

Permanent Magnet Synchronous motor (PMSM) has advantages like high efficiency, high power factor, high power density and maintenance free operation. Since there is no commutator and brushes, PMSM is more reliable than the DC motor. PMSM produce the rotor magnetic flux with permanent magnets, so it has superior advantage of higher efficiency compared to Induction motor. Moreover, the availability of low-cost power electronic devices and the improvement of PM characteristics enable the use of PMSM in high performance and high efficiency applications.

Fast acceleration and deceleration and smooth rotation over the entire speed range will enhance the motor control performance. By using Field oriented control technique in PMSM, high performance and superior dynamic response can be achieve because of independent control of torque and flux. The field oriented control algorithm is implemented by controlling the magnetic field and torque components of stator currents in the dq rotating reference frame. This enables a dc machine like control which simplifies the control of a permanent magnet synchronous motor.

II. FIELD ORIENTED CONTROL OF PMSM

Motor currents (I_a, I_b, I_c) are transformed into d-axis and q-axis currents based on projections. The q-axis component of stator current is used to control the torque and the d-axis component of stator current is used to control the rotor flux. In PMSM motor since the rotor is a permanent magnet, the d-axis component of the stator current can be kept 0 unlike Induction motor. PI controllers are used to control the speed, torque and flux of the motor. Integral anti windup is used to prevent integration wind-up when the PI controllers saturates. Corresponding d and q components of voltages from the controller are transformed to Va, Vb, Vc. These signals are used as the reference voltage for generating pulse width modulated signals for the inverter operation based on Carrier Based Space Vector Modulation Technique (CBSVPWM).

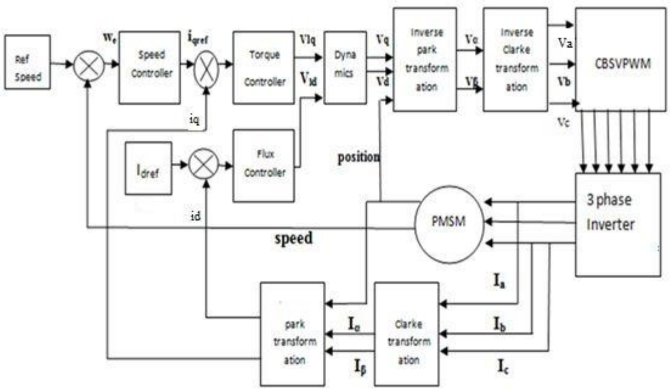

Fig.1 Block diagram of field oriented control of PMSM

III. MATHEMATICAL MODELLING OF PMSM

The PMSM motor has been modeled in d-q reference frame. The rotor reference frame is chosen because the rotor position determines the instantaneous induced emf and subsequently the stator currents and torque developed in the machine [5]. The stator voltage equation in d-q reference frame is given by

$$\frac{di_d}{dt} = \frac{v_d - r_s i_d + w_r L_q i_q}{L_d} \tag{1}$$

$$\frac{di_q}{dt} = \frac{v_q - r_s i_q - w_r(L_d i_d + \varphi_{PM})}{L_q} \quad (2)$$

$$T_e = \frac{3}{2}\, p\, [\varphi_{PM}\, i_q + (L_d - L_q) i_d i_q] \quad (3)$$

$$\frac{dw_m}{dt} = \frac{T_e - T_L - Bw_m}{J} \quad (4)$$

$$w_r = w_m * p \quad (5)$$

Where, (v_d, v_q), (i_d, i_q) are the stator voltage and current components. r_s is the stator resistance, L_d, L_q are the dq inductances, ω_m is the mechanical rotor speed, φ_{PM} is the PM flux, T_e is the electromagnetic torque, T_L is the load torque, J is the motor inertia, B is the viscous friction coefficient [4].

TABLE I

PARAMETERS	SYMBOL	VALUES
Stator leakage resistance in ohm	r_s	0.45
Stator d-axis equivalent inductance in H	L_d	0.26E-3
stator q-axis equivalent inductance in H	L_q	0.26E-3
Amplitude of the flux induced by the PMSM	φ_{PM}	0.1119
Inertia of the rotor and load kg-m^2	J	0.0010127
Friction coefficient of the rotor and load in Nm.s	B	0.0002024
Number of pole pairs of the machine	p	4
Rated electrical power of the machine in watt	P	10000

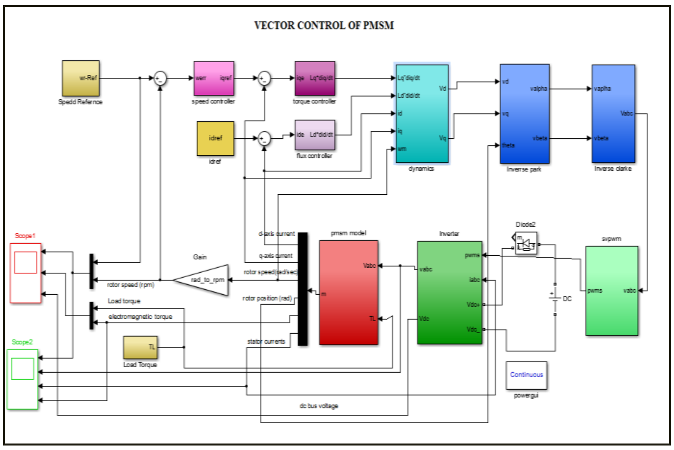

Fig.2 Field oriented control of PMSM in Matlab Simulink

IV. CARRIER BASED SPACE VECTOR MODULATION

Carrier based Space Vector Pulse Width Modulation (CBSVPWM) allows fast and efficient implementation of SVPWM without sector determination. The technique is based on the duty ratio profiles that SVPWM exhibits. By comparing the duty ratio profile with a higher frequency triangular carrier the pulses can be generated based on the same arguments as the sinusoidal pulse width modulation. In this paper, common mode voltage Injection Method is used to generate CBSVPWM [9].

To obtain the maximum possible peak amplitude of the fundamental phase voltage in linear modulation, a common mode voltage, V_{cm}, is added to the reference phase voltages where the magnitude of V_{cm} is given by,

$$V_{cm} = -(V_{max}+V_{min})/2 \quad (6)$$

Where, V_{max} = Maximum magnitude of the three sampled reference phase voltages in a sampling interval.

$$V_{max} = \max(V_{an}, V_{bn}, V_{cn}) \quad (7)$$

V_{min} = Minimum magnitude of the three sampled reference phase voltages in a sampling interval.

$$V_{min} = \min(V_{an}, V_{bn}, V_{cn}) \quad (8)$$

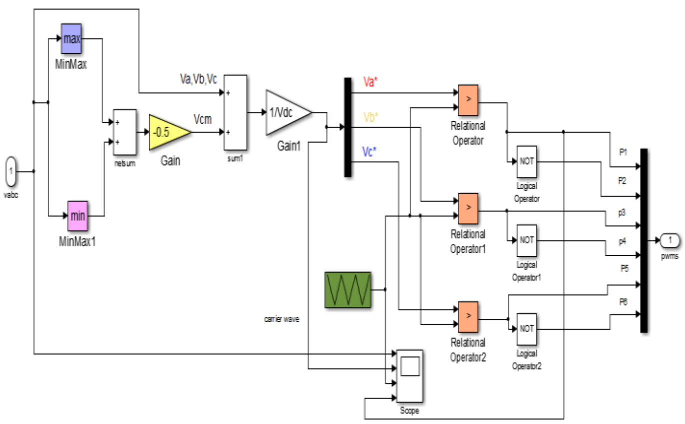

Fig.3 Carrier based Space Vector modulation

The addition of the common mode voltage, V_{cm} results in the active inverter switching vectors being centered in a sampling interval, making the SPWM technique equivalent to the SVPWM technique. Eqn (7) is based on the fact that, in a sampling interval, the reference phase which has lowest magnitude (termed the min phase) crosses the triangular carrier first and causes the first transition in the inverter switching state. While the reference phase, which has the maximum magnitude (termed the max-phase), crosses the carrier last and causes the last switching transition in the inverter switching states in a two level SVPWM scheme.

SIMULATION RESULTS

The matlab simulations of field oriented control of PMSM are shown below. The common mode voltage is added to reference voltage in order to obtain the equivalent modulating signal. This signal is in turn compared with the triangular carrier for generating the pulses for the inverter switches.

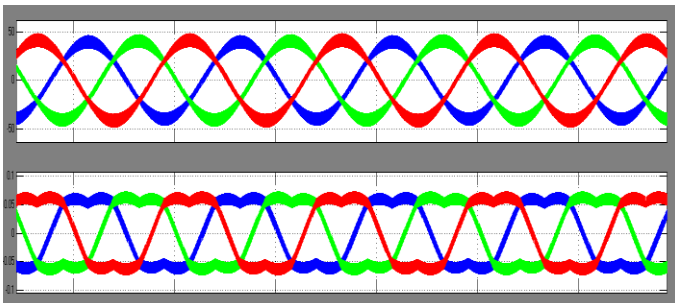

Fig.4 CBSVPWM waveforms a) Reference voltage b) Equivalent modulating voltage

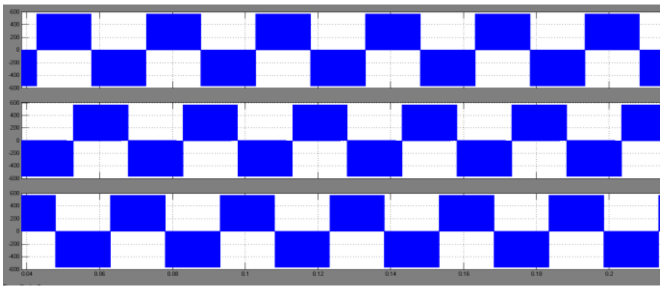

Fig.5 Inverter line to line output voltages a) v_{ab} b)v_{bc} c)v_{ca}

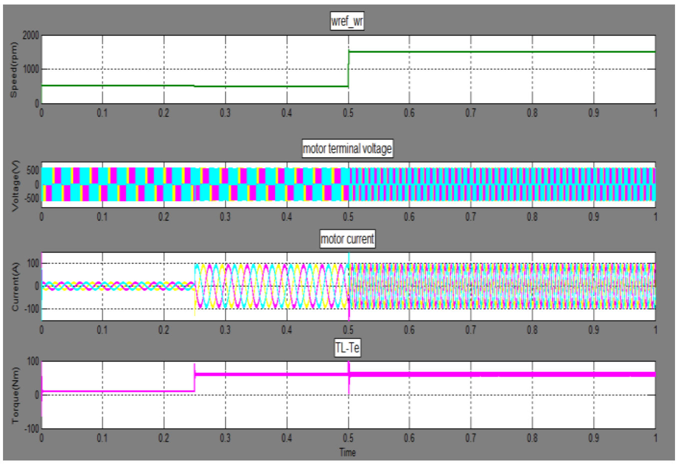

Fig.6 Speed, voltage, current and torque waveforms
Speed changed from 500 t0 1500 at 0.5s and
TL changed from 10 to 60 at 0.25s

As the speed of the motor increases, the frequency of motor terminal voltage and motor current increases and viceversa. (n_s=120*f/p). As per the motor torque, the magnitude of motor current changes. (T∞ I).

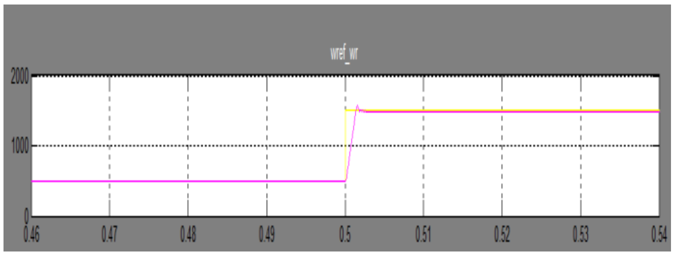

Fig.9 Speed response

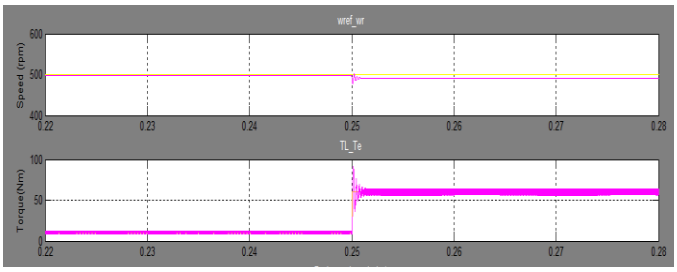

Fig.7 Dynamic Response in Transient Conditions

The motor curret and voltage waveforms for the four quadrant operation of the PMSM is shown in Fig. 11

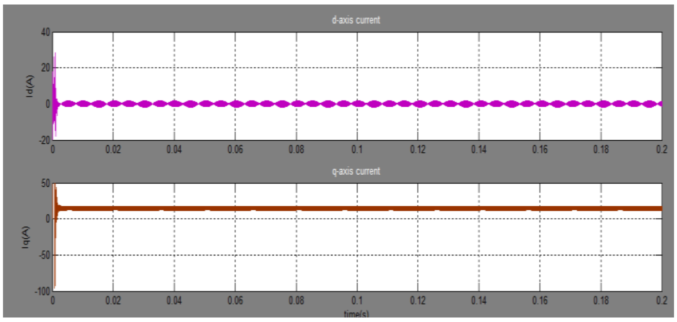

Fig.12 d-axis and q-axis current

V. CONCLUSION

Field oriented control of PMSM with Carrier based space vector modulation (CBSVPWM) was realized in MATLAB. CBSVPWM which is based on the equivalence of Sine PWM and SVPWM was used for generating the required voltage levels from the inverter. The PI controller is so designed that the motor speed tracks the reference speed accurately.

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