Control Theory For Permanent Magnet Synchronous Motor – A Review

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***Abstract*—Permanent Magnet Synchronous Motor (PMSM) is well developing for a wide range of industrial drive and servo motor application. The two different speed control techniques for the Permanent Magnet Synchronous Motor. This paper represents this two techniques for PMSM. This paper also represents the Space Vector Modulation for PMSM.**

Keywords—Permanent Magnet Synchronous Motor;Scalar Control; Vector control; Space Vector Modulation.

I. INTRODUCTION

PMSM is recently use more popular in industrial application for their advantages over other motor, which include high efficiency, compactness and well develop drive. Another application of PMSM is electrical vehicle. These drives are best choice for the high performance application.

PMSM is a synchronous machine in the sense that the stator frequency is directly proportional to the rotor speed in the steady state. However it differs from a synchronous machine in that it has permanent magnet in place of the filed winding and otherwise has no rotor conductor.

Control techniques for motor can be divided into two main categories depending of what quantities they control. The techniques for PMSM are scalar control and vector control.

II. PERMANENT MAGNET SYNCHRONOUS MOTOR

PMSM has been used in many automation fields such as robot, metal cutting machines, precision machining because of its advantages.
The PMSM is a synchronous Ac motor, normally with a 3-phase stator winding similar to induction motor. However, the rotor is different in PMSM. PMSM provide a constant flux to magnetize the motor.
PMSM uses permanent magnet rotor to create a constant magnetic field. PMSM is normally controlled with a frequency converter that supplies the motor with the correct frequency and voltage value [1].

III. SCALAR CONTROL

The simplest method to control a PMSM is scalar control, where the relationship between voltage and current and frequency are kept constant through the motors speed range. Scalar Control controls only magnitudes. Scalar control, in which the V/f control is based on the open- and closed-loop control system of the motor. The variable voltage and frequency of motor in a closed-loop control system are always employed to control the speed and torque of drives. The V/f control strategy is applied to drives to develop the performance and dynamic response of the drives. The main principle of V/f control is to maintain the scalar voltage/frequency ratio constant, thereby maintaining the magnetic flux in the maximum air gap [2].

V/f control is more advantages in which simple structure, low cost, easy design, initial current requirement is low. By controlling the change of supply frequency, the acceleration and deceleration can be controlled.

A. Space Vector Modulation

Nowadays space vector PWM (SVM) method is more popular PWM method. SVM is the best method in the all PWM techniques for variable-frequency drive (VFD) application. Because of its better performance characteristics, it has been finding wide spread application in recent years.

Consider 120° apart three phase waveforms,

$$Va = Vm \sin\omega t$$
$$Vb = Vm \sin(\omega t - 120°)$$
$$Vc = Vm \sin(\omega t + 120°)$$

These three vectors Va, Vb, Vc can be represented by a one vector which is known as space vector.

Space vector is defined as,

$$Vs = Va + Vb\, e^{j2\pi\, 3} + Vc\, e^{-j2\pi\, 3}$$
$$V s = 3/2\, Vm\, [\sin\omega t - j\cos\omega t]$$

i.e, V s is vector having magnitude of 3/ 2 Vm and rotates in space at ω rad/sec.

By simply resolving abc in to dq axis, this vector can be represented in two dimensional space.

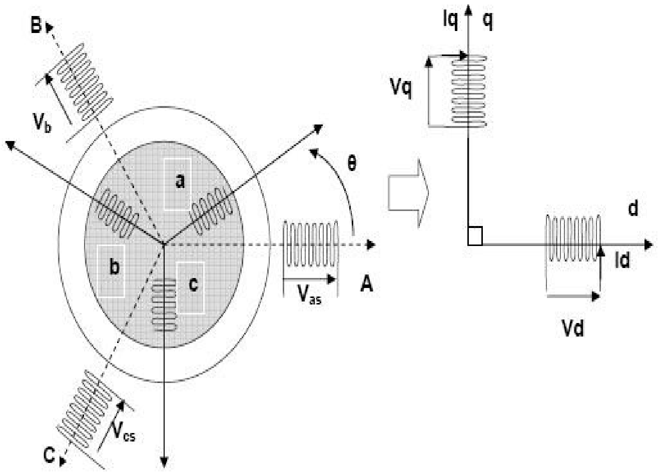

Figure 1: abc to dq transformation

Therefore space vector can also be written as

$$Vs = Vd + jVq$$
$$\theta = \tan^{-1} Vq / Vd$$

SVM direct generate a voltage vector that is close to the reference circle through the various switching modes of inverter. A typical two level three-phase voltage source PWM inverter is shown in Fig 2. S1 to S6 are the six power switches that shape the output, which are controlled by the switching variables a, a, b, b, c and c. When an upper transistor is switched on, i.e., when a, b or c is 1, the corresponding lower transistor is switched off, i.e., the corresponding a′, b′ or c is 0. To determine the output voltage, the on and off states of the upper transistors S1, S3 and S5 can be used.

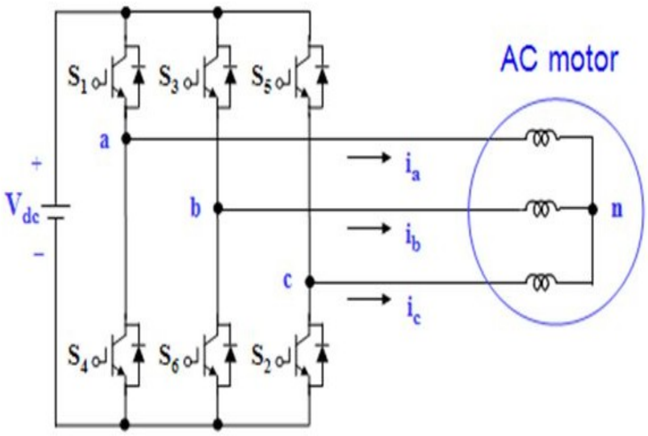

Figure 2: Three-phase voltage source PWM Inverter

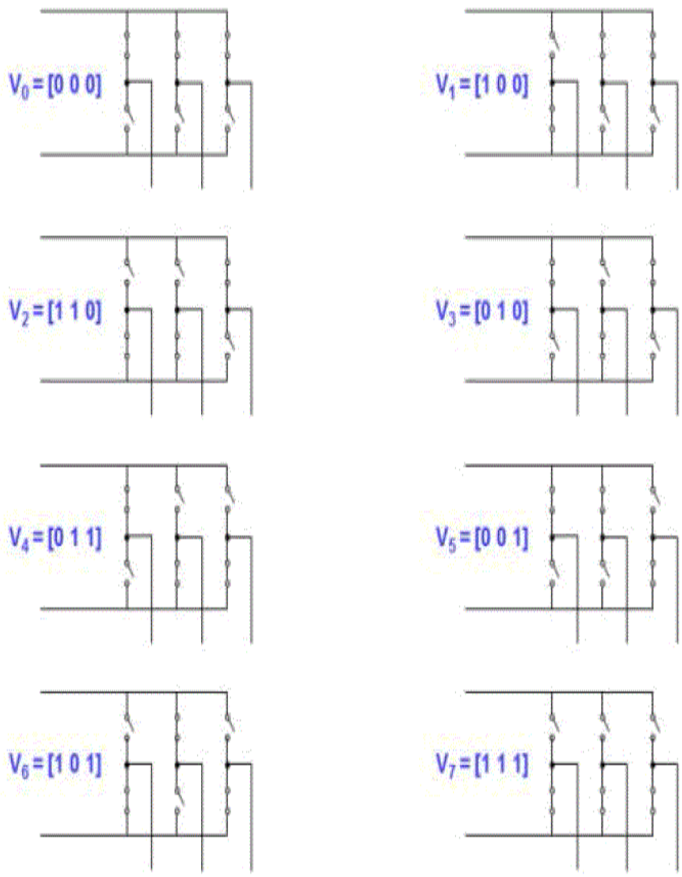

Figure 3: Eight possible voltage vector

Consider the switching states, (0,0,0) & (1,1,1)

Van = Vbn = Vcn =0;
Hence, Vd = Vq = 0
Therefore, Vs= 0∠0°

Now consider the switching state (1,0,0),

Va0 = Vdc 2, Vb0 = Vc0 = -Vdc 2
Van = ⅔ Vdc, Vbn = Vcn = -⅓ Vdc
Hence, Vd= 3/ 2Van = Vdc & Vq=0
Therefore, Vs= Vdc ∠0°

Since (0,1,1) is the complementary of (1,0,0);

For (0,1,1), Vs= Vdc ∠180°

For all possible switching states, similarly derive the magnitude and angle of space vector.

They are,

- For (0,0,0) : Vs= 0∠0° →V0
- For (1,0,0) : Vs= Vdc ∠0° →V1
- For (1,1,0) : Vs= Vdc ∠60° →V2

- For (0,1,0) : Vs= Vdc ∠120° →V3
- For (0,1,1) : Vs= Vdc ∠180° →V4
- For (0,0,1) : Vs= Vdc ∠240° →V5
- For (1,0,1) : Vs= Vdc ∠300° →V6
- For (1,1,1) : Vs= 0∠0° →V7

There are 6 non-zero vectors (V1 to V6) and 2 zero vectors (V0 & V7).

Table-1 Switching vectors, Phase voltages and Output Line to Line voltages

Voltage vectors	Switching vectors			Line to neutral voltage			Line to line voltage		
	A	B	C	V_{an}	V_{bn}	V_{cn}	V_{ab}	V_{bc}	V_0
V_0	0	0	0	0	0	0	0	0	0
V_1	1	0	0	2/3	-1/3	-1/3	1	0	-1
V_2	1	1	0	1/3	1/3	-2/3	0	1	-1
V_3	0	1	0	-1/3	2/3	-1/3	-1	1	0
V_4	0	1	1	-2/3	1/3	1/3	-1	0	1
V_5	0	0	1	-1/3	1/3	2/3	0	-1	1
V_6	1	0	1	1/3	-2/3	1/3	1	-1	0
V_7	1	1	1	0	0	0	0	0	0

While plotting 8 voltage vectors in complex plane, the non-zero vectors form the axes of a hexagon as shown in Figure 4. The angle between any two non-zero vectors is 60 electrical degrees. The zero vectors are at the origin and apply to the motor. If the phase voltages are sinusoidal, locus of the 'Vs' is circle.

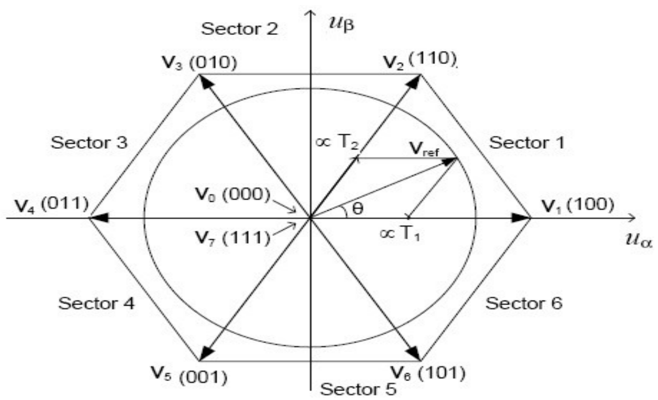

Figure 4: Basic switching vectors ans sectors

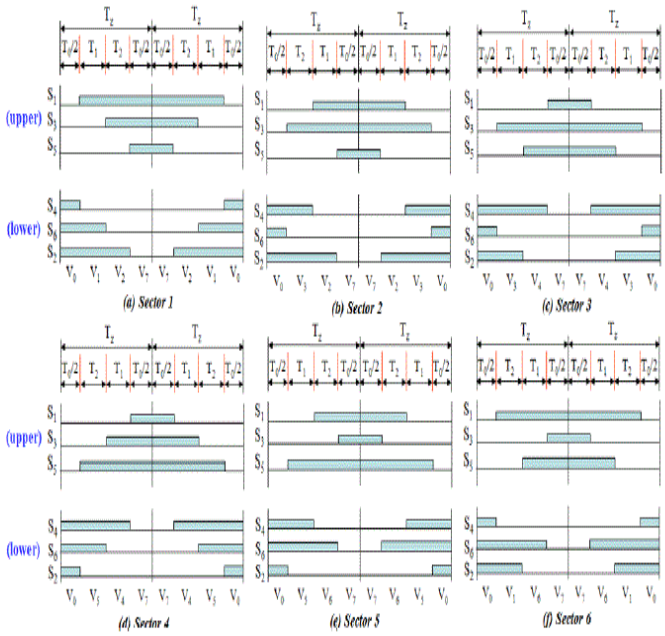

Figure 5: Space Vector PWM switching patterns at each sector.

IV. VECTOR CONTROL

Vector control is the most commonly used method in many applications because of its high performance for control. The principle of vector control is based on obtaining the magnitude and phase of voltages or currents to control drives. Thus, vector control is based on controlling the position of the flux, voltage, and current vectors of the drives.

To achieve higher dynamic performance of the drive system, control of both magnitude and the angle of the flux. Field Oriented Control and Direct Torque Control are two different types of technique for vector control. Depending on the Clarke and Park transformations, these techniques are performed.

A. FIELD ORIENTED CONTROL

The For better dynamic performance, complex control scheme needs to be applied to control the PM motor. Such decoupled torque and magnetization control is commonly called rotor flux oriented control (FOC). By using FOC, independent Control of Torque and Speed are achieved. Where two currents responsible for Torque and Field are separately resolved and Controlled (q axis current and d axis current). The vector control scheme allow the control of the PMSM as same as a separately excited DC motor operated with a current regulated armature supply, the torque is proportional to the product of armature current and the excitation flux. Similarly, by controlling the torque current component and flux current component independently, torque control of the PMSM is achieved.

A vector represents the control of stator current in field oriented control. This control is based on projections that transform a three phase time and speed dependent system into a two coordinate (d and q frame) time invariant system. These transformations and projections lead to a structure similar to that of a DC machine control. FOC machines require two constants as input references: one is torque component (aligned with the q coordinate) and another is flux component (aligned with d coordinate). The three-phase voltages, currents and fluxes of AC-motors can be analysed in terms of complex space vectors.

figure 6 shows that three PI controllers are used for controlling the speed of the PMSM. Two PI controllers control the inner d- and q-axis current loops which translate the current errors into voltages in the rotor reference frame. The outer PI controller control the speed of the PMSM, hence the speed error translates into the necessary q-axis current level, which is the reference for the inner q-axis PI controller.

The mechanical current loops are slower than the inner current loop they can be tuned independently. The q-axis current loop and speed loop configuration is a cascade system which utilizes the advantages of cascade control that improves the dynamic performance.

The inverter currents are firstly convert into the abc to dq component then dq component convert into the αβ component.

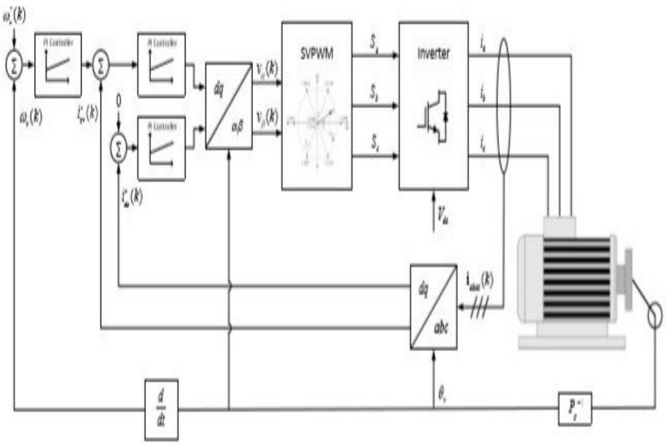

Figure 6: The structure of FOC of a PMSM drive system

A three phase machine can be described by a set of differential equations with time dependent coefficients. The complexities of machine calculations are reduce, by transforming the motor parameters.

According to the definitions the transforms give a third component, is call zero-sequence. The zero sequence can be ignored, where motor normally is a balanced load.

B. CLARK'S TRANSFORMATION

The Clarke transformation converts a stationary three phase system into stationary two phase system with orthogonal axes. The new two phase variables are denoted α and β, the original and transformed system can be seen in figure 7. The ABC parameters are transformed into αβ0 parameters by equation (1) and in reverse by equation (2).

$$f_{\alpha\beta0} = Tf_{ABC} \quad (1)$$
$$f_{ABC} = T-1f_{\alpha\beta0} \quad (2)$$

Where f is the motors armature parameters, and the transformation matrix T is.

$$T_{\alpha\beta0} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

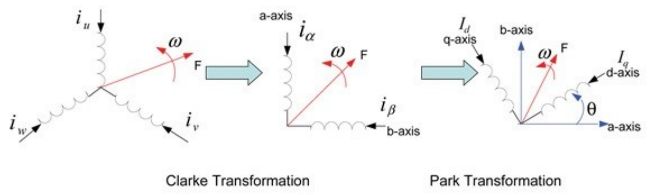

Figure 7: Clarke and Park transform

C. PARK'S TRANSFORMATION

Figure The Park transformation convert a three phase system in one stationary reference frame into a two phase system with orthogonal axes in a different rotating reference frame. The two new phase variables are denoted d and q, which are direct- and quadrature-axis respectively. The original and transformed system can be seen in figure 7. The ABC parameters are transformed into dq0 parameters by equation (3) and in reverse by equation (4).

$$f_{dq0} = T(\theta\ f_{ABC} \quad (3)$$
$$f_{ABC} = T(\theta)^{-1} f_{dq0} \quad (4)$$

Where f is the motors armature parameters and the transformation matrix T is.

$$T_{qd0s}(\theta) = \frac{2}{3}\begin{bmatrix} \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin(\theta) & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

By using the Park's transform, the stator parameters such as voltages, currents and flux linkages, are associated with fictitious stator windings that rotate with the rotor. The time varying parameters between stator and rotor are thus eliminated and all variables are expressed in the same orthogonal or mutually decoupled direct- and quadrature-axes. [5].

Acknowledgment (Heading 5)

The preferred spelling of the word "acknowledgment" in America is without an "e" after the "g." Avoid the stilted expression "one of us (R. B. G.) thanks ...". Instead, try "R. B. G. thanks...". Put sponsor acknowledgments in the unnumbered footnote on the first page.

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