A Review on Design and control of Permanent Magnet Synchronous Motor

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Abstract

The PMSMs are particularly used in high-performance drive systems such as the submarine propulsion. The permanent magnet synchronous motor eliminates the use of slip rings for field excitation, resulting in low maintenance and low losses in the rotor 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. Permanent magnet synchronous motors (PMSMs) have been widely used in many industrial applications. Due to their compactness and high torque density. This paper represents this two techniques for PMSM and design aspects. This paper also represents the Space Vector Modulation for PMSM.

Index Terms—*PMSM, MATLAB, SVPWM,VECTROL CONTROL*

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1 INTRODUCTION

The power density of permanent magnet synchronous motor is higher than induction motor with the same ratings due to the no stator power dedicated to the magnetic field production. Nowadays, permanent magnet synchronous motor is designed not only to be more powerful but also with lower mass and lower moment of inertia This Permanent magnet synchronous motors finds applications in several areas such as traction, automobiles, robotics and aero space technology..

PMSM is a synchronous machine in the sense that the stator frequency is directly proportional to the rotor speed in the steady state.. 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. 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

2 CONSTRUCTION DETAILS

The construction details of Permanent Magnet Synchronous Motor are discussed below.

2.1 Air Gap Flux Density

For designing the stator geometry, methods can be utilizedthatarewellestablishedfrome.g.asynchronousmotordesign. This has therefore not been studied in the present work. Furthermore a slotted stator is assumed Generally, the flux density is lower in high efficiency machines and higher in machines designed for maxi- mumtorquedensity.Thepeakair-gapfluxdensityliestypically in the range 0.7–1.1Tesla. It should be noted that this is the total flux density, i.e. the sum of rotor and stator fluxes. This means that the rotor flux can be chosen higher if the armature reaction is smaller implying higher alignment torque. To achieve a great reluctance torque contribution however, the stator reaction must be large. The machine parameters give that alarge$m$ andsmall inductances$L$, are requiredtoobtain mainly alignment torque. This is usually desirable for operation below base speed ashigh inductanceslower the power factor cos (Ø).

2.2 Permanent Magnet Materials

There are many devices in which magnets play a significant role so it is very important to improve properties of these materials. Currently attention is focused on materials based on rare earth metals and transition metals. These materials allow to obtain permanent magnets with high magnetic properties. Depending on the technology magnets are characterized by different magnetic and mechanical properties and show different corrosion resistance.

Neodymium Iron Boron ($Nd_2Fe_{14}B$) and Samarium Cobalt (Sm_1Co_5 and Sm_2Co_{17}) magnets are the most advanced commercialized permanent magnet materials available today.

Some important properties used to compare permanent mag- nets are: remanence (M_r), which measures the strength of the magnetic field; coercivity (H_{ci}), the material's resistance to be- coming demagnetized; energy product (BH_{max}), the density of magnetic energy;andCurie temperature(T_C),. The table below *compares the* magnetic performance ofneoTable2 Simulation Parameters of PMSM

Designation	Unit	Value
Speed	Rpm	1500
Frequency	Hz	50
No.ofpoles	-	4
Stack length	Mm	51.4
Internaldiameter	Mm	90
External diameter	Mm	146
No.ofslots	-	36

3 PMSM DESIGN PROCEDURE

The PMSM Design is being carried out by using MATLAB. Following equations are used to calculate the copper losses, back e.m.f., iron losses and self and mutual inductance.

The pole pitch can be calculated by the formula,

$$\tau_p = 2\pi R_a / 2p$$

Dymium magnets with other types of permanent magnets.

2.3 Parameters of PMSM

For the design of the Permanent Magnet Synchronous Motor (PMSM), the permanent magnet rotor is constructed based on the stator frame of a three-phase induction motor without changing the geometry of stator and the winding. The specification and geometry are shown in Table 2.Totalfluxcanbecalculatedbythe total flux calculated using thisformula,

$$\varphi = \frac{2}{3} * B_g \tau_p L_z pN * phase$$

BackEMFcanbecalculatedbytheformula,

$$E = {}^{\partial\varphi}/_{\partial t}$$

Theequationtocalculatecopper lossesisgivenbelow

$$P_j = 3R_S I^2$$

Statorresistancecanbecalculatedbytheformula,

$$R_s = \rho * L / S$$

Totallengthofcopperperphasecanbecalculatedas,

$$L_{end} = \frac{\frac{\pi}{2} 2\pi \left(R_a + {}^{h_{enc}}/_{2} \right)}{2p}$$

$$L_{total} = 2(L_z + L_{end})$$

The inductance L can be defined as the ration of the flux link- ages to the current I generating the flux, this has the units of henrys (H), equal to a weber per ampere. Inductors are devices used to store energy in the magnetic field, analogous to the storage of energy in the electric field by capacitors. Inductors most generally consist of loops of wire, often wrapped around a ferrite or ferro magnetic core, and their value of inductance isa function only of the physical configuration of theconductor along withthe permeability of thematerial through which the flux passes.

It is found that the design with NdFeB as ac PM rotor material the flux produced in the air gap is improved, leading to the reduction in internal radius of stator to 26.50 mm as compare to31.11mm as incase of the SmCo PM rotor material. Also the effective copper losses in the NdFeB are reduced by 8.124% as seen in the results.

For the SmCo as a permanent magnet material the flux is found to be equal to 637.17 mWb which will be a sinusoidal varying quantity as shown in the following figure.

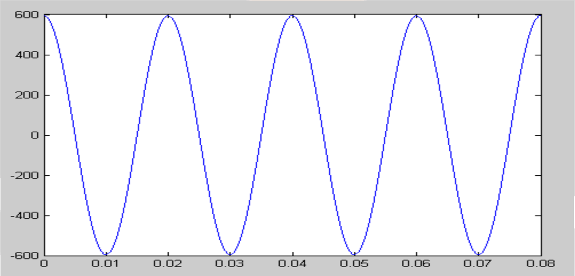


Figure1: Flux wave forms for PM material SmCo

For the NdFeB as a permanent magnet material the flux is found to be equal to 633.31 mWb which will be a sinusoidal varying quantity as shown in the following figure.

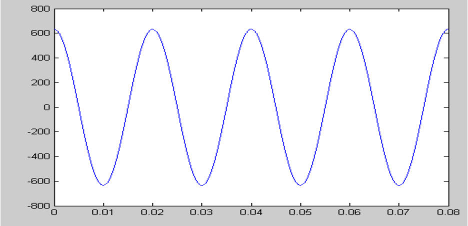


Figure2: Flux waveforms for PM material NdFeB

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 [4].

4 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 [5]. 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 accelerationand deceleration can be controlled.

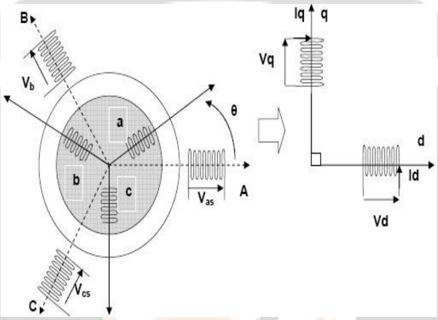


Fig 3: abc to dq transformation

Figure4:Three-phase voltage source PWM Inverter

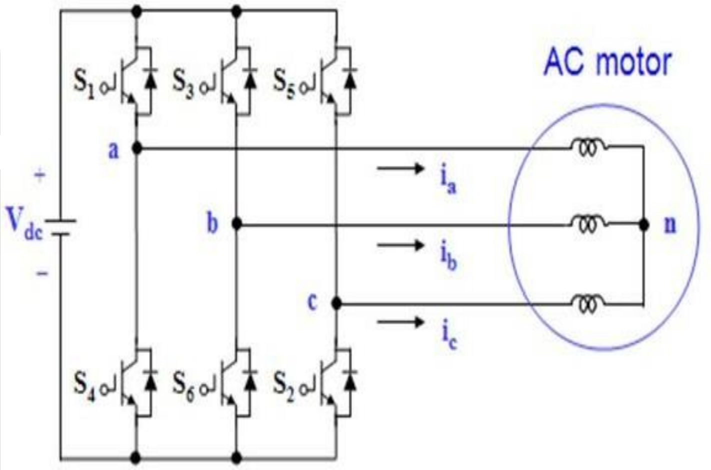
A. Space Vector Modulation

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.

Therefore space vector can also be written as
$Vs=Vd+jVq$
$=\tan^{-1}/$

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 4.S1to 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 transistorisswitchedoff,i.e.,thecorrespondinga′,b′orcis0. To determine the output voltage, the on and off states of the upper transistors S1, S3 and S5 can be used.



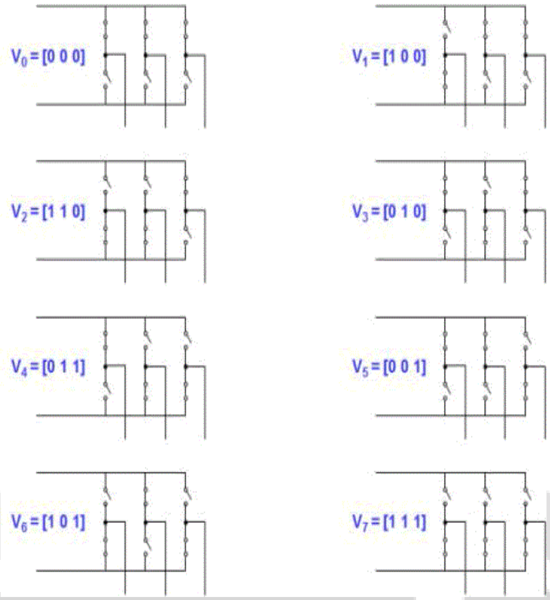


Figure5: Eight possible voltage vector Consider the switching

states, (0,0,0) & (1,1,1)

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

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

Va0 =Vdc 2,Vb0 =Vc0 =-Vdc 2 Van=⅔Vdc, Vbn=Vcn=-⅓Vdc

Hence, Vd=3/2Van=Vdc&Vq=0

Therefore, Vs=Vdc∠0°

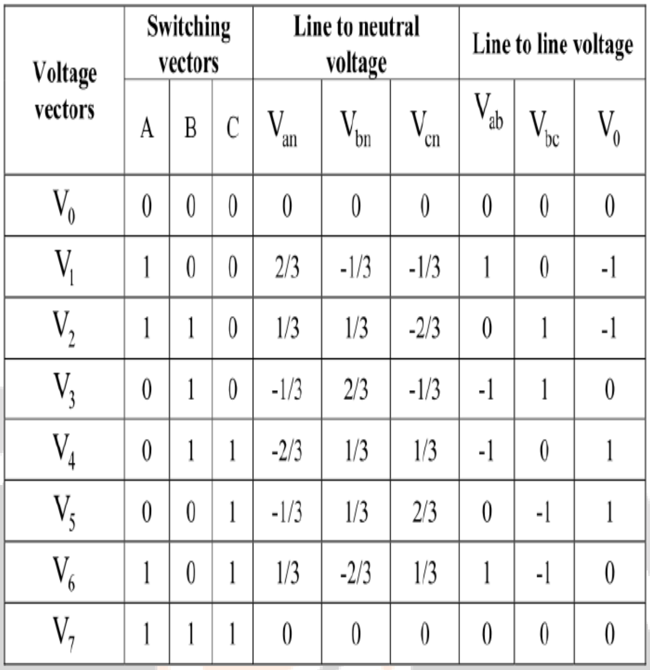
Since(0,1,1) is the complementary of (1,0,0); For (0,1,1), Vs= Vdc ∠180°

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

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

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

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.

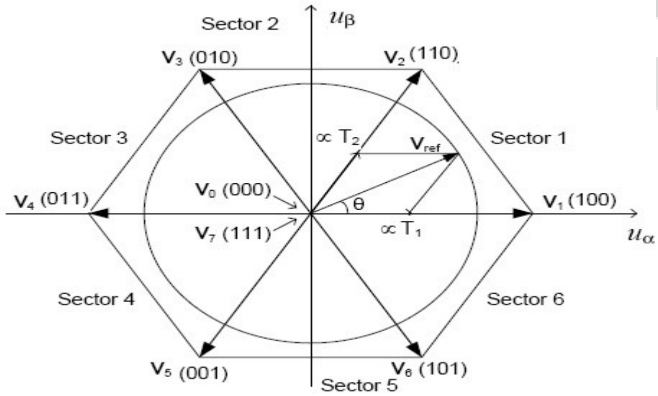
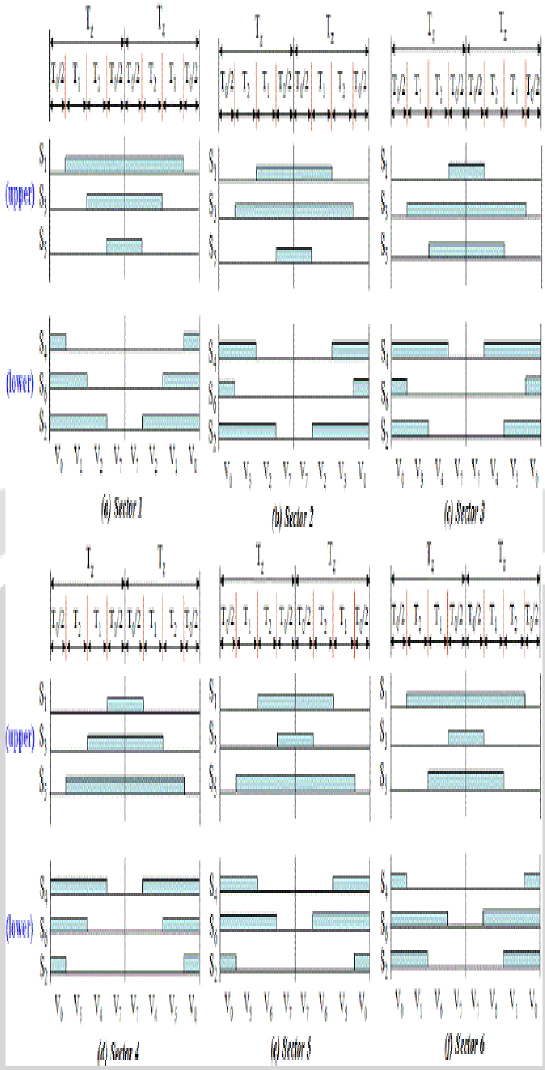


Figure7: Basic switching vectors and sectors



(a) Sector 1 (b) Sector 2 (c) Sector 3

(d) Sector 4 (e) Sector 5 (f) Sector 6

Figure6: Space Vector PWM switching patterns at each sector.

5 VECTORCONTROL

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 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 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 converting to the αβ component.

CONCLUSION

Permanent magnet synchronous motors (PMSMs) have been playing an important role in high performance drive systems. However, most of the PMSMs used in the industries have been imported. That is, the squirrel cage rotor is replaced by a newly designed permanent magnet rotor.

A MATLAB based programme is developed which gives the design parameters for the PMSM motor including the self and mutual inductances, Torque produced, Copper losses for two different permanent magnet rotor materials. These parameters are evaluated to determine the performance of the PMSM motor for the water pumping application.

By converting into Park;s and clarke’s transformation we can easily represent and operate the PMSM motor effectively with better performance. Vector control of PMSM is more accurate than scalar type control. There is scope of better performance of PMSM motor with logarithm

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