Modeling and Simulation of Field Oriented Control PMSM Drive System using SVPWM Technique

Pradeep Kumar\(^1\), Deepak Lakra\(^2\), Ruchi Makin\(^3\)

\(^1\)Assistant professor Department of Electrical Engineering, DPGITM Gurgaon, India
\(^2\)Assistant professor Department of Electrical and Electronics Engineering, DTC Bahadurgarh, India
\(^3\)Assistant professor Department of Electrical Engineering, DPGITM Gurgaon, India

Abstract— In this paper performance analysis of permanent magnet synchronous motor (PMSM) using space vector pulse width modulation (SVPWM) technique has been done. PMSM is an ac synchronous motor whose field excitation is provided by permanent magnets and has a back sinusoidal back emf waveform. With the help of these permanent magnets it can generate torque at zero speed. PMSM has various advantages over induction motor in the field of variable AC speed drives. SVPWM technique is applied to the PMSM and obtained speed, current responses when load is changes. Assuming that the current in the electric motor is symmetrical three phase sinusoidal current and the system model of FOC vector control has been established. The whole control system has been performed in the MATLAB/SIMULINK software. The result obtained after simulation shows that the speed of rotor is controlled with high precision and response of the whole system is fast.

Index Terms— PMSM, Field oriented control, Space vector pulse width modulation.

I. INTRODUCTION

In recent years permanent magnet synchronous motor because of large properties such as high efficiency, high torque, high power, small volume and accurate speed control has become more attention in the various countries. The vector control separates the torque component of current and flux channels in the motor through its stator excitation. The vector control of the PM synchronous motor is derived from its dynamic model [1-10].

II. PERMANENT MAGNET SYNCHRONOUS MOTOR CONFIGURATIONS

In PM motors, the magnets can be placed in two different ways on the rotor. Depending on the placement they are called either as surface permanent magnet motor or interior permanent magnet motor.

Surface mounted PM motors have a surface mounted permanent magnet rotor. Each of the PM is mounted on the surface of the rotor, making it easy to build, and specially skewed poles are easily magnetized on this surface mounted type to minimize cogging torque. These motors are considered to have small saliency, thus having practically equal inductances in both axes [2]. The permeability of the permanent magnet is almost that of the air, thus the magnetic material becoming an extension of the air gap. For a surface permanent magnet motor \(L_q = L_d\).

The rotor has an iron core that may be solid or may be made of punched laminations for simplicity in manufacturing. Thin permanent magnets are mounted on the surface of this core using adhesives. Alternating magnets of the opposite magnetization direction produce radially directed flux density across the air gap. This flux density then reacts with currents in windings placed in slots on the inner surface of the stator to produce torque. Figure 2 shows the placement of the magnet [6].

![Surface permanent magnet motor](http://www.ijettjournal.org)

Figure 2 - Surface permanent magnet motor

Interior PM motors have interior mounted permanent magnet rotor as shown in figure 3 [6]. Each permanent magnet is mounted inside the rotor. It is not as common as the surface-mounted type but it is,
a good candidate for high-speed operation. There is inductance variation for this type of rotor because the permanent magnet part is equivalent to air in the magnetic circuit calculation. These motors are considered to have saliency with q axis inductance greater than the d axis inductance ($L_q > L_d$).

$\begin{align*}
i_b &= I_m \sin(\omega t + \alpha - \frac{2\pi}{3}) \\
i_c &= I_m \sin(\omega t + \alpha + \frac{2\pi}{3})
\end{align*}$

Writing equations 3.3 to 3.5 in the matrix form:

$$\begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} = \begin{pmatrix} \cos(\omega t + \alpha) \\ \cos(\omega t + \alpha - \frac{2\pi}{3}) \\ \cos(\omega t + \alpha + \frac{2\pi}{3}) \end{pmatrix} \begin{pmatrix} I_m \end{pmatrix}$$

Where $\alpha$ is the angle between the rotor field and stator current phasor, $\omega$ is the electrical rotor speed.

The previous currents obtained are the stator currents that must be transformed to the rotor reference frame with the rotor speed $\omega_r$, using Park’s transformation. The q and d axis currents are constants in the rotor reference frames since $\alpha$ is a constant for a given load torque. As these constants, they are similar to the armature and field currents in the separately excited dc machine. The q axis current is distinctly equivalent to the armature current of the dc machine; the d axis current is field current, but not in its entirety. It is only a partial field current; the other part is contributed by the equivalent current source representing the permanent magnet field. For this reason the q axis current is called the torque producing component of the stator current and the d axis current is called the flux producing component of the stator current.

$$\begin{pmatrix} i_q \\ i_d \end{pmatrix} = I_m \begin{pmatrix} \sin \alpha \\ \cos \alpha \end{pmatrix}$$

the electromagnetic torque equation is obtained as given below.

$$T_e = \frac{3}{2} \frac{P}{g} \left[ \frac{1}{2} (L_d - L_q) I_m^2 \sin 2\alpha + \lambda_f I_m \sin \alpha \right]$$

### III. FIELD ORIENTED CONTROL OF PMSM

The objective of field oriented control (FOC) of PMSM is to control the torque variation demand, rotor speed and to regulate phase currents. The goal of FOC (also known as vector control) in synchronous machine is to separately control the torque and magnetizing flux producing components. FOC promotes us to decouple the torque and magnetizing components of stator current [12]. With this decoupling, the torque producing components of the stator flux now can be thought of as an independent torque control. For decoupling these components, it is necessary to engage several mathematical transforms.

In general the FOC consist of controlling the stator current represented by a vector. This control is based on several mathematical transforms in which a three phase time and speed dependent system is converted into a two co-ordinate time variant system. FOC makes the control accurate in every walking operations (steady state or transient) and independent of the limited band with mathematical model [13].

The PMSM control is equivalent to that of the dc motor by a decoupling control known as field oriented control or vector control. The vector control separates the torque component of current and flux channels in the motor through its stator excitation. The vector control of the PM synchronous motor is derived from its dynamic model. Considering the currents as inputs, the three currents are:

$$i_a = I_m \sin(\omega t + \alpha)$$

$$i_b = I_m \sin(\omega t + \alpha - \frac{2\pi}{3})$$

$$i_c = I_m \sin(\omega t + \alpha + \frac{2\pi}{3})$$

Detailed modeling of PM motor drive system is required for proper simulation of the system. The d-q model has been developed on rotor reference frame as shown in figure 4. At any time t, the rotating rotor...
d-axis makes and angle $\theta_f$ with the fixed stator phase axis and rotating stator mmf makes an angle $\alpha$ with the rotor d-axis. Stator mmf rotates at the same speed as that of the rotor.

The model of PMSM without damper winding has been developed on rotor reference frame using the following assumptions:
1) Saturation is neglected.
2) The induced EMF is sinusoidal.
3) Eddy currents and hysteresis losses are negligible.
4) There are no field current dynamics.

The stator current equations of the PMSM is in the rotating d-q reference frame are as follows-

$$\frac{d}{dt} i_d = \frac{1}{L_d} (\omega - R_s i_d + \frac{L_m}{L_r} \omega_r i_q)$$  \hspace{1cm} (7)$$

$$\frac{d}{dt} i_q = \frac{1}{L_q} (\omega - R_s i_q + \frac{L_m}{L_r} \omega_r i_d - \frac{\psi_f}{L_r} \omega_r)$$  \hspace{1cm} (8)$$

$$T_e = 1.5P \left[ \psi_d i_q - (L_d - L_r) i_d i_q \right]$$  \hspace{1cm} (9)$$

$$\frac{d}{dt} \omega_r = \frac{1}{J} (T_e - B \omega_r - T_i)$$  \hspace{1cm} (10)$$

$$\omega_r = p \omega_m$$  \hspace{1cm} (11)$$

Equations (7-9) are electrical equation, while equation (10) is mechanical equation.

Where

- $\psi_f$ = rotor magnetic flux
- $L_d =$ d-axis stator inductance
- $L_q =$ q-axis stator inductance
- $R_s =$ stator resistance

$T_e =$ electromagnetic torque
$T_i =$ load torque
$\omega_r =$ mechanical speed
$\omega_e =$ angular speed
$J =$ moment of inertia
$B =$ coefficient of friction
$p =$ no. of poles

IV. SPACE VECTOR PULSE WIDTH MODULATION

Space vector control is the process to generate a PWM modulation signal for PMSM voltage signal. In this technique the inverse Clarke transform has been folded into the SVM routine which simplifies the equation. Each of the three output of inverter can be in one of the two states which allows for $2^3 = 8$ possible states of output as shown in Table (I). SVPWM is accomplished by rotating a reference vector around the state diagram, which is composed of six basic non-zero vectors forming a hexagon. A circle can be inscribed inside the state map and corresponds to sinusoidal operation. The area inside the inscribed circle is called the linear modulation region or under-modulation region. As seen in Figure 6, the area between the inside circle and outside circle of the hexagon is called the nonlinear modulation region or over-modulation region.

SVPWM subjects to generate a voltage vector which is close to a reference circle through different switching modes of inverter [11-13]. Figure (5) shows the basic diagram of three phase VSI model.

![Figure 5. Basic Voltage Source Inverter](image-url)

The space vector of output voltage of inverter can be given as [14]:

$$V_A(S_A, S_B, S_C) = 2V_{dc}(S_A + aS_B + a^2S_C)/3$$  \hspace{1cm} (12)$$

Where $V_{dc}$ is DC bus voltage of inverter and $a$ is $e^{j2\pi}$. If the state of upper and lower arm switches is considered 1 and 0 respectively, then the on-off state will have eight possible
Combination voltage space vectors as shown in Figure 6.

T-refers to the operation time of two non-zero voltage vectors in the same zone. \( V_0(000) \) and \( V_7(111) \) are called zero voltage space vector, while remaining six vectors are known as effective vectors with magnitude of \( 2V_{dc}/3 \).

<table>
<thead>
<tr>
<th>Table (I)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inverter states</strong></td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
</tbody>
</table>

The entire space is divided into six equal-size sectors of 60°. Each sector is bounded by two active vectors. \( V_0 \) and \( V_7 \) are two voltage vectors with zero amplitude located at the origin of the hexagon. The eight active and non-active state vectors are geometrically drawn in figure 6. when the reference voltage vector rotates through revolution in space, the inverter output varies one electrical cycle over time. The inverter output frequency coincides with the rotating speed of the reference voltage vector. The zero vectors \( (V_0 \text{ and } V_7) \) and active vectors \( (V_1 \text{ to } V_6) \) do not move in space. They are referred to as stationary vectors. Figure 6 shows the reference vector \( V_{ref} \) in the first vector.

**VI. RESULTS**

Matlab/Simulink based computer simulation is performed for the verification of the proposed speed control strategy. The real speed is compared with the reference input speed. Reference speed is considered as 1500 rpm.

Figure 7 shows that the motor is started at no load and there is a change in the load after 0.2 sec from no load to 1Nm. The time of simulation is kept 0.4 Sec. Figure 8 shows stator current of PMSM.
VII. CONCLUSION

In this Paper the analysis of FOC method with space vector pulse width modulation technique has been performed. Speed of PMSM has been controlled using field oriented control method.

The results based on Matlab/Simulink shows that the real speed of rotor has been controlled with the help of space vector pulse width modulation. The real speed will follow the reference speed after a very short duration of time i.e. 0.05 sec.

REFERENCES