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# Study Of Total Harmonic Distortion Using Space Vector Modulation Technique In Permanent Magnet Synchronous Motor

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***Abstract:*** *This paper presents the study of total harmonic distortion in permanent magnet synchronous motor (PMSM) using space vector modulation (SVM) technique. SVM generates low Total Harmonic Distortion (THD) and it is well suitable for motor control. Harmonics is one of the major power quality issues occurring in most of the application. SVM holds the major advantage that only one switch is turned on at a time. The proposed model shows the effect of eliminating the lower order harmonics in SVM. MATLAB/Simulink is used develop the model.*

***Key Words:*** *PMSM, SVM, Total Harmonic Distortion.*

## 1. INTRODUCTION:

Permanent magnet synchronous motor drives (PMSM) offers many advantages over the induction motor, such as overall efficiency, effective use of reluctance torque, smaller losses and compact motor size. In recent years many studies have been developed to find out different solutions for the PMSM drive control having the features of quick and precise torque response, and the field oriented control has been recognized as viable and robust solution to achieve these requirements. In this paper total harmonic distortion studied using space vector modulation technique on permanent magnet synchronous machine.

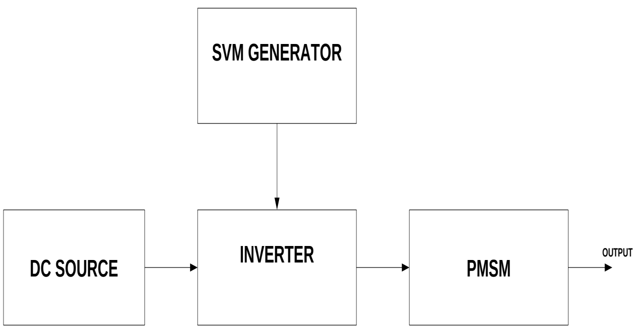


Fig 1. Block diagram of the system

Figure 1 gives the block diagram of operation technique using SVM to the load through inverter.

## 2. MATHEMATICAL MODEL OF PERMANENT MAGNET SYNCHRONOUS MOTOR:

The mathematical model is similar to that of the wound rotor synchronous motor. Since there is no external source connected to the rotor side and variation in the rotor flux with respect to time is negligible, there is no need to include the rotor voltage equations. Rotor reference frame is used to derive the model of the PMSM shown in figure 1 and 2.

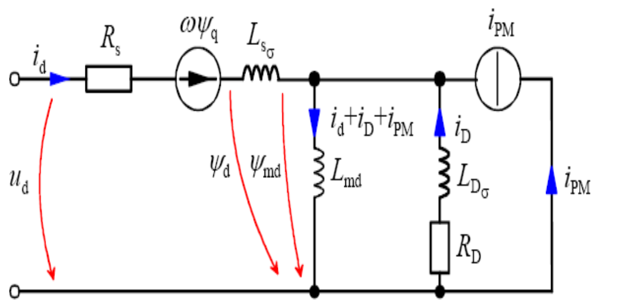

Fig 2. PM equivalent for d-axis

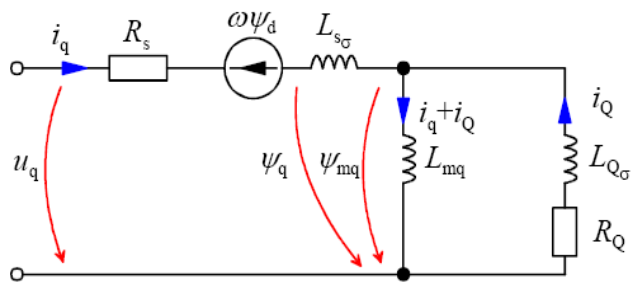

Fig 3. PM equivalent for q-axis

The electrical dynamic equation in terms of phase variables can be written as:

$v_a = R_a i_a + p\lambda_a$ ...(1)

$v_b = R_b i_b + p\lambda_b$ ...(2)

$v_c = R_c i_c + p\lambda_c$ ...(3)

While the flux linkage equations are:

$\lambda_a = L_{aa} i_a + L_{ab} i_b + L_{ac} i_c + \lambda_{ma}$ ...(4)

$\lambda_b = L_{ab} i_a + L_{bb} i_b + L_{bc} i_c + \lambda_{mb}$ ...(5)

$\lambda_c = L_{ac} i_a + L_{bc} i_b + L_{cc} i_c + \lambda_{mc}$ ...(6)

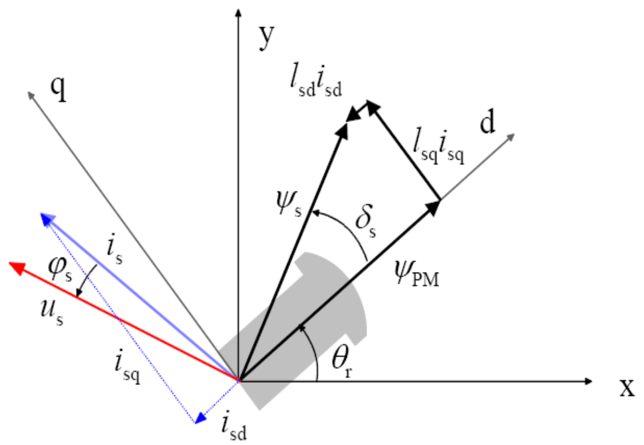


Fig 4. Stator reference axis X-Y axis & Rotor reference axis d-q axis

Considering symmetry of mutual inductances such as Lab = Lba, self inductances Laa = Lbb =Lcc and flux linkage λma = λmb = λmc = λm. Applying the transformations (1) and (3) to voltages, flux linkages equation (4)-(6), we get a set of simple transformed equations as:

$$v_q = ( R_s + L_q p)\, i_q + \omega_r L_d i_d + \omega_r \lambda_m \qquad ...(7)$$
$$v_d = ( R_s + L_d p) i_d - \omega_r L_q i_q \qquad ... (8)$$

Ld and Lq are called d and q-axis synchronous inductances, respectively. ωr is motor electrical speed. Each inductance is made up of self inductance (which includes leakage inductance) and contributions from other two phase currents.
The electromagnetic torque Te can be represented as:

$$T_e = (3/2)(P/2)( \lambda_m i_q + (L_d - L_q)\, i_d i_q) \qquad ...(9)$$

It is apparent from the above equation that the produced torque is composed of two distinct mechanisms. The first term corresponds to the mutual reaction torque occurring between iq and the permanent magnet, while the second term corresponds to the reluctance torque due to the differences in d axis and q-axis reluctance (or inductance). The equation for motor dynamics is:

$$T_e = Jp\omega_r + B\omega_r + T_l \qquad ... (10)$$

## 3. SPACE VECTOR MODULATION:

In SVM technique, the combined effect of three phases is considered as one vector. Firstly three phases are converted into two phases for simplicity. Here space vectors are expressed as any time varying quantities which always sum to zero and are separated by 120° are expressed as space vectors. Here three phase systems are defined as V1(t), V2(t), V3(t)) can be represented uniquely by a rotating vector,

$$V = V_A(t) + V_B(t)e^{j2\Pi/3} + V_C(t)e^{-j2\Pi/3} \qquad ... (11)$$

where,

$V_A(t) = V_m \sin\omega t$

$V_B(t) = V_m \sin(\omega t - 2\Pi/3)$

$V_C(t) = V_m \sin(\omega t + 2\Pi/3)$

Here three phase frames are converted into two phase frames using any transformation technique. Here Clarks transformation is used for three phase to two phase transformation.

$$\begin{bmatrix} V_x \\ V_y \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{a11} \\ V_{b11} \\ V_{c11} \end{bmatrix} \qquad ... (12)$$

In a three-phase system, the vectorial representation is achieved by the transformation given in figure1.

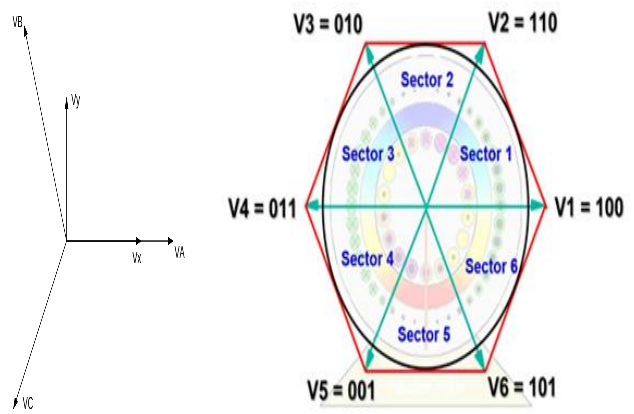


Fig 5. Relation between Stationary frames and xy frames

The orthogonal two phase system is given as (Vx, Vy),

Where,

$$V = V_x + jV_y \qquad ... (13)$$

The VSI configuration is shown in figure 6. Three phase normal inverters is used here and the inverter is connected at the voltage between +VDC/2 and -VDC/2.

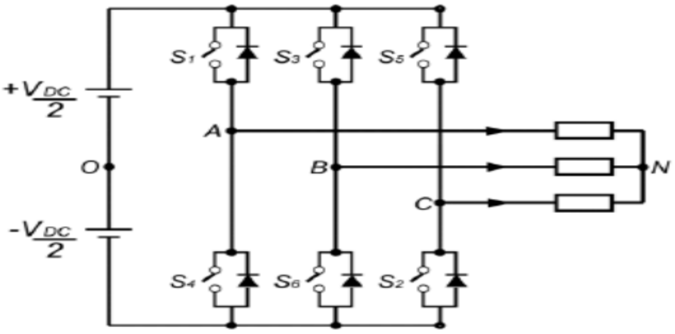


Fig 6. Three phase inverter configurations

As per the operation of SVM, there are only eight possible switching combinations for a three phase inverter and those patterns are shown in table 1.

| Voltage in Vectors | Switching Vectors | | | Line - Neutral Voltage | | | Line - 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 |

Table 1: switching vectors

As shown in Table1, the vector 0 is used to represent the negative phase voltage level and vector 1 represents the positive phase voltage level. The non-zero vector namely V1 to V6 shape the hexagon axis and the angle between two non-zero vectors +is 400. The null vectors V0 and V7 represent the short circuit on the output, where others are vectors in x-y plane. These eight vectors are called the space vectors.

## 4. SIMULATION & RESULTS:

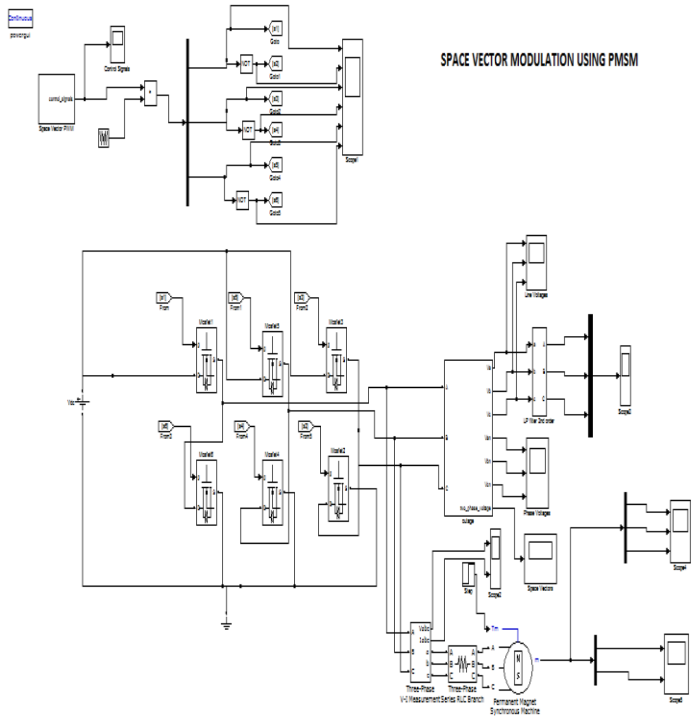


Fig 7. Simulation of three phase inverter with SVM technique using PMSM

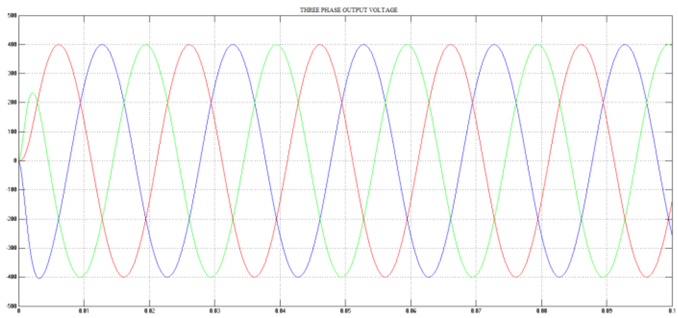


Fig 8. Three phase output voltage

Figure 8 shows the motor output voltage produced in the system.

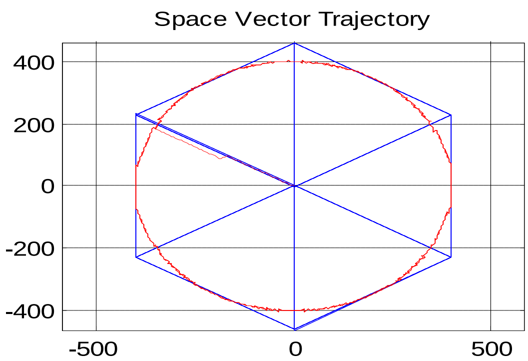


Fig 9. Space vector trajectory

Figure 9 shows the spacevector trajectory of the SVM model.

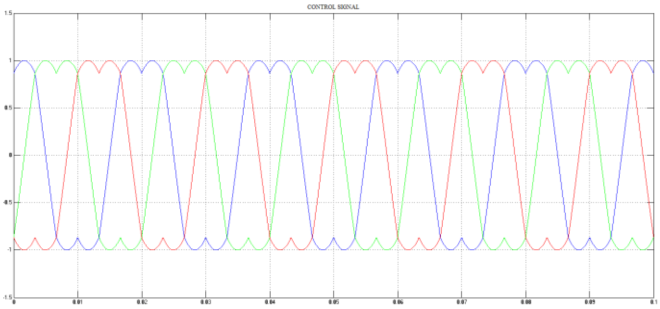


Fig 10. Space vector control signal

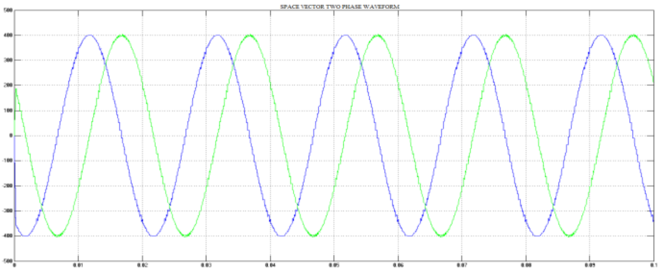


Fig 11. Space vector two phase waveform

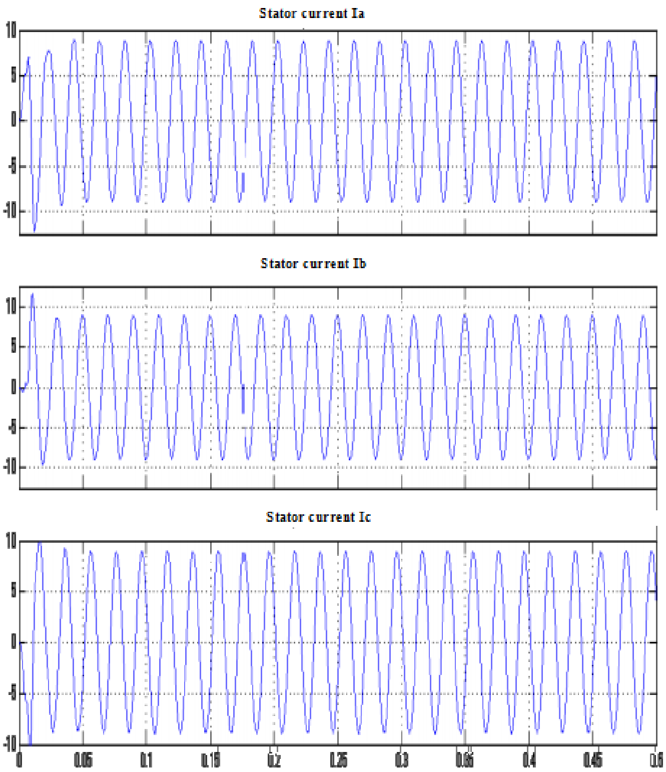


Fig 10. Motor Current results

Figure 10 shows the output current of the PMSM at load.

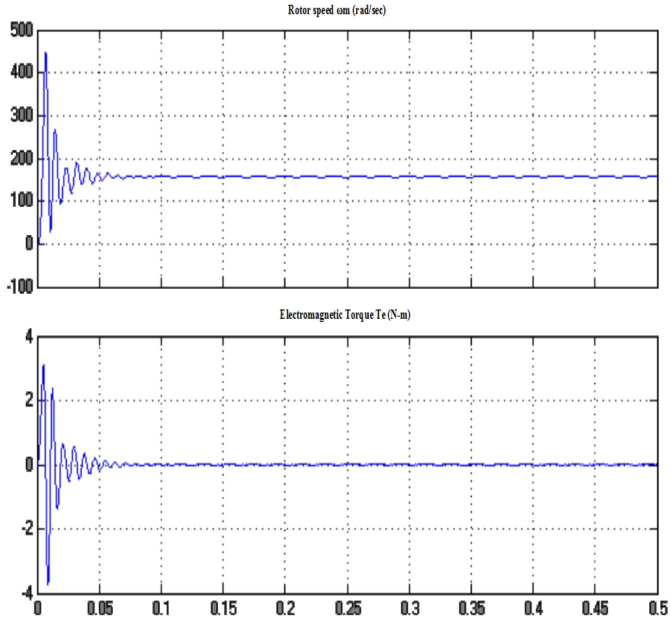


Fig 11. Motor speed and Torque

Figure 11 shows the speed of the rotor and the electromagnetic torque induced in the machine.

The THD values measured after the development of the system is tabulated to analyze the efficiency or result obtained. The THD is mainly concentrated on the stator phase output current. The harmonics present in the three phases are so found form the simulation done. The result obtained proves that the distortion in the system is less. The tabulation shows the values of the harmonics in the system.

| | Voltage in Volts | Frequency in Hertz | Modulation Index | THD of Stator Currents |
|---|---|---|---|---|
| Phase a | 400 | 50 | 0.8 | 0.49% |
| Phase b | 400 | 50 | 0.8 | 0.48% |
| Phase c | 400 | 50 | 0.8 | 0.47% |

Table 2. THD analysis of load currents

## V CONCLUSION

Here the mathematical model of a SVM based three phase inverter is formulated and simulations are done with MATLAB/Simulink. From the results it can be given that the total harmonic distortion can be reduced appreciably. This model can be applied to various motor applications and also to non-linear loads to get a less distortion results.

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