Analysis of PWM Techniques for Power Quality Improvement in PMSM Drives

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Abstract

Inverter fed adjustable speed drives are very much needed in today motion Industry. The switching of inverter plays a vital role in the operation of a drive. This paper presents a comparison of two different pulse width modulation techniques and its performance characteristics are analyzed for PMSM drives. The analysis is carried out for the different Modulation Index (MI). The SVPWM inverter allows to nourish the motor with a greater voltage and less harmonic distortions than the conventional sinusoidal PWM inverter. The SVPWM technique is better than previous switching methodologies and comparison of both SPWM and SVPWM using MATLAB is given with respect to its RMS voltage, THD and other power quality terms.

Keywords: PMSM, SPWM, SVPWM, THD

1. Introduction

Pulse-Width Modulation (PWM) is a modulation procedure which is based on the pulse duration width. This pulse varies with respect to the type of Modulating Signal. Even though this PWM method can be used for signal communication or information transfer, its key purpose is to supply a controlled power for major electrical devices particularly to motors. Out of all the available methodologies this PWM technique precedes with the advantages of requiring little effort in its implementation and control, no deviation in temperature and no variation or changes in power due to senescence¹. There are several approaches of obtaining a pulse or a control signal for an Inverter fed drives with the help of Modulation Techniques like Trapezoidal, Sinusoidal, Harmonic Injection, SVPWM and Random PWM²³. Each methodology has special features Space Vector Pulse Width Modulation method foregoes with features like Low switching losses, very less harmonics in voltage and current²³.

In Today motion Industry Permanent Magnet Synchronous Machines (PMSMs) are enticing cumulative attention for an extensive range of applications and it is also used in various home appliances and industries. Now days due to the exhaust of non-renewable energy sources we are in a position to focus on energy conservation and so there is an increasing need for energy efficient, high performance and consistent electrical drives. Considering all the above facts PMSMs are the perfect suited reliable machines due to their high efficacy, high output power per mass and volume and exceptional dynamic performance². PMSM also has some demerits such as demagnetizing of permanent magnets due to age and high price of the machine. This paper analyses the performance of SVPWM and SPWM technique based inverter fed Permanent Magnet Synchronous Machine for various modulation Index. The entire block diagram for analyzing the PWM Techniques is shown in the Figure 1.

2. Mathematical Modelling

The modeling of the machine is done with the following assumptions neglecting the losses and damper winding in the rotor³.
The reference signal $V_{ref}$ is generated with a sampling frequency of $f_s$ ($T_s = 1/f_s$) from three separate phase references using the transformations. The generation of the reference signal and synthesis voltage vector and switching time is derived as follows.

### 3.3 Calculation of Sector Number

The sector number of the reference signal is obtained from these $\alpha\beta$ coordinates.

$$R_1 = V_\beta$$

$$R_2 = \sqrt{3}V_a - V_\beta$$

$$R_3 = -\sqrt{3}V_a - V_\beta$$

The sector number is obtained from (5)

$$N = \text{sign } (R_1) + 2 \text{ sign } (R_2) + 4 \text{ sign } (R_3)$$

The relationship between the Sector Number and the Section to be selected is given in the Table 1. After calculating this Sector number the voltage vectors are identified and the conducting time of inverter switch is estimated.

### 3.4 Estimation of Action Time

The estimation of action time is shown in Table 2.

$$A = \sqrt{3}V_\beta T_s/V_{DC}$$

$$B = 3V_a - \sqrt{3}V_\beta/2V_{DC}$$

$$C = -3V_a - \sqrt{3}V_\beta/2V_{DC}$$

(6)
3.5 Switch Time Sequence Generation

In different sections, X, Y, Z three phase switch time $T_{s1}$, $T_{s2}$, $T_{s3}$, evaluation is done according to Table 3.

The three different switching sequences are evaluated from the Equation (7).

$$
T_X = (T_3 - S_1 - S_2)/4
$$

$$
T_Y = T_X + S_1/2
$$

$$
T_Z = T_Y + S_2/2
$$

(7)

$T_X$, $T_Y$, $T_Z$ are the switching time of 3 Phases.

4. Simulation

The Simulation model built using MATLAB environment proves the validity and feasibility of SVPWM fed Permanent Magnet Synchronous Machine.

The parameters of PMSM machine is as follows: Back emf – Sinusoidal, Stator resistance $R_s = 0.2 \, \Omega$; Flux of permanent magnet $\phi_f = 0.175 \, \text{Wb}$, revolving speed = 1500 rpm. $L_d = L_q = 8.5 \times 10^{-3}$, Inertia = 0.089 kgm$^2$, Friction = 0.005 Nm s, No of Pole pairs = 4 and mechanical input as Torque.

4.1 Filter Design

The rectified DC needs a filter for obtaining a constant DC source at the input of the Inverter.

The ripple factor $R.F = \frac{V_{rms}}{V_o}$

Where $V_{rms} = V_p / \sqrt{2}$ and $V_p = \text{Peak value of Ripple voltage}$ $V_o = \text{Average value of Rectifier}$

The capacitor was fixed to a value of 260 $\mu$F the Inductance value was varied till the desired Ripple factor such that the ripple is around 3%.

4.2 Switching of Inverter

The Switching of Inverter was generated using a MATLAB Simulink system. The same was also executed and verified with the help of the Discrete 3 phase PWM generator with the following Carrier frequency $= 18 \times 60 = 1080 \, \text{Hz}$ Trapezoidal.

The switching of Inverter using Space Vector pulse width modulation was generated using a Simulink sub system. It was also executed with a 2 pulse SVPWM generator block in Sim power systems.

4.3 Modulation Index (M)

The Modulation Index is given by $\text{Modulation Index} = \frac{V_r}{V_c}$.

Where,

$V_r$ = reference voltage
$V_c$ = carrier voltage.

The Modulation index is always proportional to the fundamental component of its output voltage. But MI can never be more than unity. Thus the output voltage is controlled by varying MI.

The rms line voltage shall be obtained using the formula given in equation (8).

$$
V_{\text{rms}} = \frac{m}{2} \times \frac{\sqrt{3}}{\sqrt{2}} \times V_{dc}
$$

(8)

Where, $m$ – modulation Index.

5. Simulation Results

The overall simulation was performed with the following simulation Parameters,

Solver type – ode23tb,
Relative tolerance – $1e^{-4}$,
Absolute tolerance – Auto,
Step Time = 1s.

Figures 4 to 9 shows the Stat or current, Electro magnetic Torque and Speed performance of the SPWM and SVPWM fed Permanent magnet synchronous motor.
The overall simulation diagram is shown in Figure 3. The characteristics shows better performance for SVPWM Technique.

Figures 4 and 5 shows the stator current performance characteristics of SVPWM and SPWM. The dynamic response of SVPWM shows that the response is better in 0.1s than that of SPWM in 0.2s.

Figures 6 and 7 show the response of speed for sinusoidal and space vector PWM. The response to space vector obtains its steady state in 0.2 seconds and a speed of 1500 RPM. Whereas the speed of SPWM based system is controlled at 1500 RPM in 0.3 seconds. This shows a better output response when comparing sinusoidal pulse width modulation.

Figures 8 and 9 show the response of electromagnetic torque for sinusoidal and space vector PWM. The response for space vector obtains its steady state in 0.2 seconds and a torque of 10 Nm whereas the Torque is controlled at 10 Nm in 0.3 seconds in SPWM. This shows the better output response when comparing sinusoidal pulse width modulation.

The waveforms were discretised and analysed through FFT Analysis with the following parameters Sample time of $10^{-6}$s and fixed step.

**Figure 3.** Simulation of SPWM & SVPWM fed PMSM.

**Figure 4.** Stator current for SVPWM.

**Figure 5.** Stator current for SPWM.

**Figure 6.** Speed for SVPWM.

**Figure 7.** Speed for SPWM.
The values obtained in the Tables 4 and 5 shows that the SVPWM has better line voltage and lower Harmonic Distortion.

**Table 4.** Line voltage for different Modulation Index

<table>
<thead>
<tr>
<th>Modulation Index</th>
<th>SPWM</th>
<th>SVPWM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>231.1</td>
<td>254.2</td>
</tr>
<tr>
<td>0.5</td>
<td>271.5</td>
<td>302.4</td>
</tr>
<tr>
<td>0.6</td>
<td>316.4</td>
<td>360.1</td>
</tr>
<tr>
<td>0.7</td>
<td>366.2</td>
<td>425</td>
</tr>
<tr>
<td>0.8</td>
<td>422.5</td>
<td>495.6</td>
</tr>
<tr>
<td>0.9</td>
<td>487</td>
<td>590.2</td>
</tr>
</tbody>
</table>

**Table 5.** % THD for different Modulation Index

<table>
<thead>
<tr>
<th>Modulation Index</th>
<th>SPWM</th>
<th>SVPWM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>25.8</td>
<td>22.9</td>
</tr>
<tr>
<td>0.5</td>
<td>21.2</td>
<td>20.4</td>
</tr>
<tr>
<td>0.6</td>
<td>20.8</td>
<td>18.3</td>
</tr>
<tr>
<td>0.7</td>
<td>18.1</td>
<td>15.7</td>
</tr>
<tr>
<td>0.8</td>
<td>16.6</td>
<td>14.4</td>
</tr>
<tr>
<td>0.9</td>
<td>15.4</td>
<td>12.6</td>
</tr>
</tbody>
</table>

6. **Conclusion**

The analysis for different Modulation Index (MI) shows that SVPWM has good performance. The comparison of both SPWM and SVPWM using MATLAB shows that SVPWM is better than previous switching methodologies. The Performance factors like VRMS, %THD have been estimated and analyzed. It is found that the SVPWM inverter is better with low harmonic distortions than the conventional sinusoidal PWM inverter.

7. **References**