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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 senescence[1]. 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 PWM[3,4]. Each methodology has special features Space Vector Pulse Width Modulation method foregoes with features like Low switching losses, very less harmonics in voltage and current[1,3].

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 performance[2]. 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 rotor[3].

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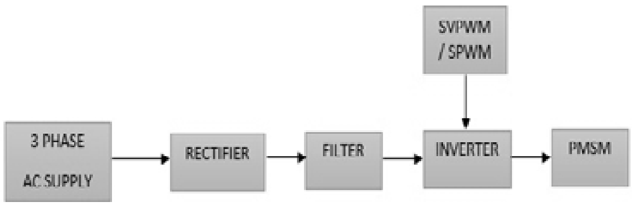

Figure 1. Overall block diagram.

$$V_a = R_S i_a + L_S\, di_a/dt - \omega_r \phi_f \sin\theta$$
$$V_b = R_S i_b + L_S\, di_b/dt + \omega_r \phi_f \cos\theta \qquad (1)$$

$$\phi_\alpha = \int (V_a - R_S i_a)dt$$
$$\phi_\beta = \int (V_b - R_S i_b)dt \qquad (2)$$

$$T = 1.5\, Np\, (\phi_a i_b - \phi_b i_a) \qquad (3)$$

Where, $V_{a,}$ V_b are the Stator Voltages, $i_{a,}$ i_b - Stator Currents, R_S - Stator Resistance, $L_{S\,-}$ Stator Inductance, ϕ_f the flux of Permanent Magnet, ϕ_a the direct axis flux, ϕ_b Quadrature axis flux, θ the rotating Angular Speed, Np pole Pairs, T motor Torque and ω_r Rotor Speed of the Machine.

3. PWM Techniques

3.1 Sinusoidal PWM

In this Modulation the modulating signal is a sinusoidal wave and the carrier wave is a triangular wave. The switching pulse is produced by comparing these two signals. The carrier wave frequency is 1080 Hz. The switching pulse is provided as the switching pulse to the respective inverter switches. The number of voltage pulses per half-cycle (N) was chosen as 9, since 2N = fc/fs. Where fc is carrier frequency and fs is the modulating signal.

3.2 Space Vector Pulse Width Modulation (SVPWM)

SVPWM technique is a radically distinctive modulation type, it helps the inverter to get a perfect three phase sinusoidal voltage. The target of this technique is to obtain a circular magnetic field for the machine. The switching is based on the selection of space vectors. The space vectors has six non zero vectors or active vectors which are displaced by 60 degrees and 2 zero voltage vectors which is shown in the Figure 2.

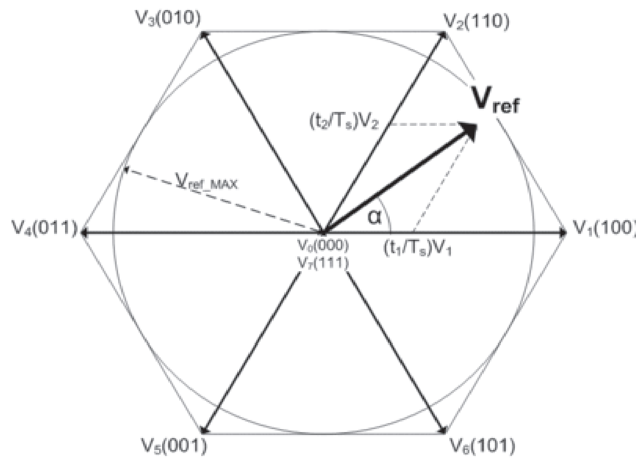

Figure 2. Space Vectors in SVPWM.

The reference signal V_{ref} is generated with a sampling frequency of fs (Ts = 1/fs) 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 αβ coordinates.

$$R_1 = V_\beta$$
$$R_2 = \sqrt{3}V_\alpha - V_\beta$$
$$R_3 = -\sqrt{3}V_\alpha - V_\beta \qquad (4)$$

The sector number is obtained from (5)

$$N = \text{sign}(R_1) + 2\,\text{sign}(R_2) + 4\,\text{sign}(R_3) \qquad (5)$$

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.

$$A = \sqrt{3}V_\beta T_S/V_{DC}$$
$$B = 3V_\alpha - \sqrt{3}V_\beta\,/2V_{DC}$$
$$C = -3V_\alpha - \sqrt{3}V_\beta\,/2V_{DC} \qquad (6)$$

Table 1. Relationship of section and sector number

Sector Number	1	2	3	4	5	6
Section	2	6	1	4	3	5

Table 2. Conducting time for different voltage vectors

N	1	2	3	4	5	6
S_1	C	B	–C	–A	A	–B
S_2	B	–A	A	C	–B	–C

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).

$$T_X = (T_S - S_1 - S_2)/4$$
$$T_Y = T_X + S_1/2$$
$$T_Z = T_Y + S_2/2 \quad (7)$$

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 $\phi_f = 0.175$ Wb, revolving speed = 1500 rpm. Ld = Lq = 8.5 e^{-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 $R.F = \frac{Vrms}{V_o}$

Where Vrms $= Vp/\sqrt{2}$ and

Vp = Peak value of Ripple voltage

Vo = Average value of Rectifier

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

Table 3. Switch time evaluation table

N	1	2	3	4	5	6
T_{S1}	T_X	T_Y	T_Z	T_Z	T_Y	T_X
T_{S2}	T_Y	T_X	T_X	T_Y	T_Z	T_Z
T_{S3}	T_Z	T_Z	T_Y	T_X	T_X	T_Y

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 x 60 = 1080 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 Modulation Index = Vr/Vc.

Where,

Vr= reference voltage

VC=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).

$$V_{ll(rms)} = \frac{m}{2} \times \frac{\sqrt{3}}{\sqrt{2}} \times Vdc \quad (8)$$

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 $10e^{-6}$s and fixed step.

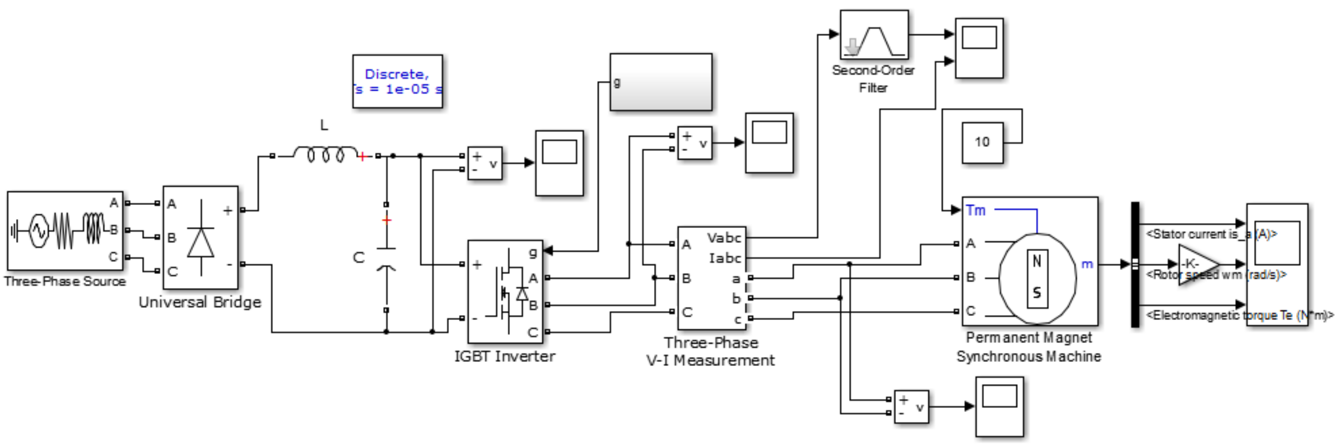

Figure 3. Simulation of SPWM & SVPWM fed PMSM.

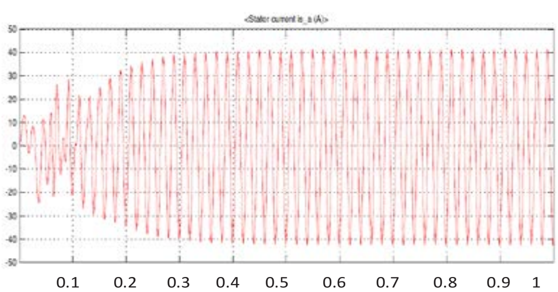

Figure 4. Stator current for SVPWM.

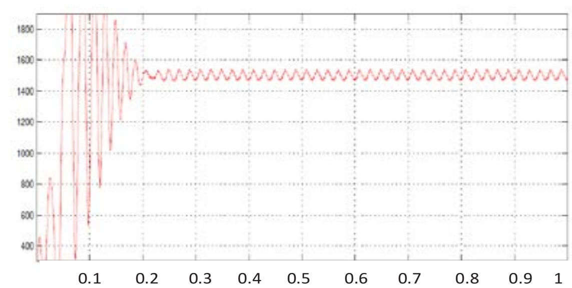

Figure 6. Speed for SVPWM.

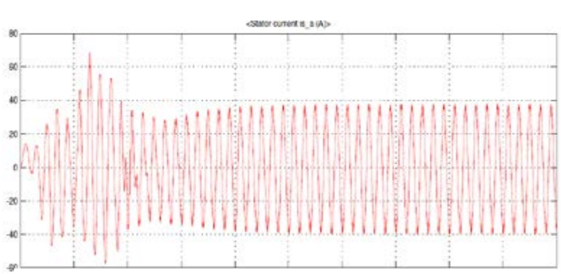

Figure 5. Stator current for SPWM.

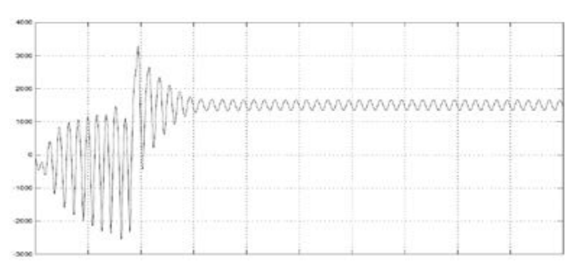

Figure 7. Speed for SPWM.

The values obtained in the Tables 4 and 5 shows that the SVPWM has better line voltage and lower Harmonic Distortion.

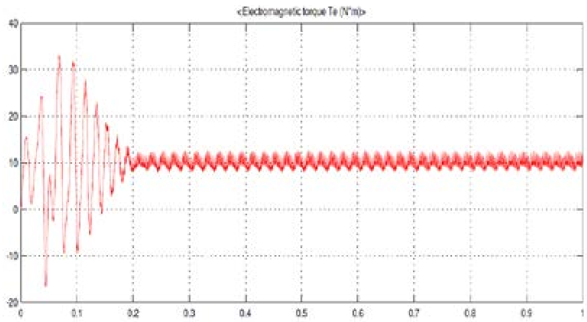

Figure 8. Electromagnetic Torque for SVPWM.

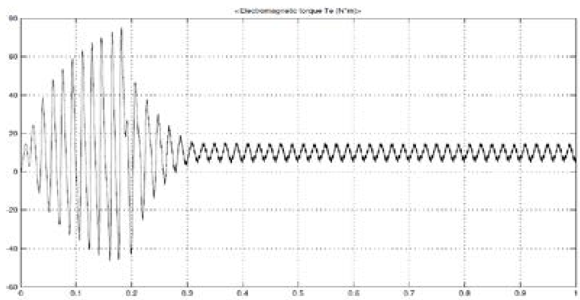

Figure 9. Electromagnetic Torque for SPWM.

Table 4. Line voltage for different Modulation Index

Modulation Index	Line Voltage in volts	
	SPWM	SVPWM
0.4	231.1	254.2
0.5	271.5	302.4
0.6	316.4	360.1
0.7	366.2	425
0.8	422.5	495.6
0.9	487	590.2

Table 5. % THD for different Modulation Index

Modulation Index	% of THD	
	SPWM	SVPWM
0.4	25.8	22.9
0.5	21.2	20.4
0.6	20.8	18.3
0.7	18.1	15.7
0.8	16.6	14.4
0.9	15.4	12.6

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

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