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Design and Simulation of Control Technique for Permanent Magnet Synchronous Motor Using Space Vector Pulse Width Modulation

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Abstract. After the rapid advancement in the field of power electronics devices and drives for last few decades, there are different kinds of Pulse Width Modulation techniques which have been brought to the market. The applications ranging from industrial appliances to military equipment including the home appliances. The vey common application for the PWM is three phase voltage source inverter, which is used to convert DC to AC in the homes to supply the power to the house in case electricity failure, usually named as Un-interrupted Power Supply. In this paper Space Vector Pulse Width Modulation techniques is discussed and analysed under the control technique named as Field Oriented Control. The working and implementation of this technique has been studied by implementing on the three phase bridge inverter. The technique is used to control the Permanente Magnet Synchronous Motor. The drive system is successfully implemented in MATLAB/Simulink using the mathematical equation and algorithm to achieve the satisfactory results. PI type of controller is used to tuned ers of the motothe parametr i.e. torque and current.

Introduction

These Permanent Magnet Synchronous Motors (PMSM), has been under a lot of research and has been considered as the backbone of modern engineering products [1]. Its applications range from robots, electric automobiles, and heavy industries to domestic products such as washing/drier machines, water pumps, vacuum cleaners, etc. Due to its improved characteristic regarding precise speed and position control, it is considered as one of the best options to be used in the portable devices. To achieve the maximum performance of the PMSM with the use of low cost enhanced essential materials, modern digital processors have made it possible to implement sophisticated control algorithms and techniques for the purpose. A number of control studies have been proposed by the researchers to improve the specific parameters of the motors such as current, speed and position depending upon its usage to achieve maximum efficiency.

A lot of research has been conducted to improve the controllability efficiency and dynamics of drives in the last two decades. Researchers proposed some new designs, in 1986, related to Interior PMSM (IPMSM) for the speed control, contrary to the AC drives present at the moment, resulting robust, efficient systems bearing dynamic speed regulation [2, 3]. Since PMSM is designed to work under

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FOC barring damping windings, so the equations of synchronous motor can be used to produced d-q model without considering the effects of the damper winding and the field currents. Two level inverter based detail explanation of SVPWM is described in [4, 5]. While the modelling, analysis, controlling and losses of PMSM have been discussed in different literatures [6-18].
In this research work, the SVPWM technique is simulated using MATLAB/ SIMULINK using the PI control for speed and current control. The technique is adopted using the three phase bridge inverter. The insight of the simulation is gained for the closed loop scenario, speed, and current plots are drawn against dynamic load and reference speed. The plots of the torque, speed and current of SVPWM technique show satisfactory results.

Analytical Model of PMSM

The PMSM has been extensively studied for the past two decades. In widely held methods used for PMSM, there is a set of equations dependent on rotor position. In this work, the motor equations are represented in rotor reference frame. As a result a set of equations is derived which is independent of the rotor position. The currents in the d-q axis are found using the two transformations. The Park transformation converts the three phase quantitates (*abc*) to the two phase (*αβ*). The second part transfers the quantities from the stationary frame to rotational frame.

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (2)$$

Where θ represents the rotor position. Keeping the rotor reference frame as a reference, the PMSM voltage equations are:

$$V_q = R_s i_q + \omega_r \lambda_d + \rho \lambda_q \quad (3)$$

$$V_d = R_s i_d - \omega_r \lambda_q + \rho \lambda_d \quad (4)$$

The equations (5) and (6) show the relationships for the flux linkages.

$$\lambda_q = L_q i_q \quad (5)$$

$$\lambda_d = L_d i_d + \lambda_f \quad (6)$$

Using the equations of flux linkages into the voltages' equations result in

$$V_q = R_s i_q + \omega_r (L_d i_d + \lambda_{f)} + \rho L_q i_q \quad (7)$$

$$V_d = R_s i_d - \omega_r L_q i_q + \rho L_d i_d + \lambda_f \quad (8)$$

Equation (7) and (8) can be written in the matrix form as:

$$\begin{bmatrix} V_q \\ V_d \end{bmatrix} = \begin{bmatrix} R_s + \rho L_q & \omega_r L_d \\ -\omega_r L_q & R_s + \rho L_d \end{bmatrix}\begin{bmatrix} i_q \\ i_d \end{bmatrix} + \begin{bmatrix} \omega_r \lambda_f \\ \lambda_f \end{bmatrix} \quad (9)$$

According to what was mentioned above, electromechanical behaviour of the PMSM is as follows:

$$T_e = \frac{P}{2}\lambda_m \begin{bmatrix} i_a & i_b & i_c \end{bmatrix}\begin{bmatrix} -\sin\theta_e \\ \frac{1}{2}sin\theta_e + \frac{\sqrt{3}}{2}cos\theta_e \\ \frac{1}{2}sin\theta_e - \frac{\sqrt{3}}{2}cos\theta_e \end{bmatrix} \quad (10)$$

Where the θ_e, is the rotor electrical position and θ_m, the rotor mechanical position.

Space Vector Pulse Width Modulation

In three Phase Bridge VSI, with the help of high frequency pulses given at the gate an output voltage of low frequency is generated. The generated voltages is controllable. In this VSI structure, a total of eight states, also known as vectors, are generated, $\mathbf{V_0}$ to $\mathbf{V_7}$. Out of these states, the non-zero active voltage states are from V1 to V6 while zero voltage vectors are $\mathbf{V_0}$ and $\mathbf{V_7}$. Figure 1 shows a diagram of the vectors. The eight states are described from the equation as below:

$$V_k = \begin{cases} \frac{2}{3} V_{dc} e^{j(k-1)\frac{\pi}{3}}, & k = 1,2,3,4,5,6 \\ 0 \end{cases} \quad (11)$$

For a preferred value of the fundamental components for the output phase voltages, a reference quantity, V_{ref}, is used which is voltage space vector. At equal intervals of the sampling time period, T_s, the reference voltage is sampled. Within this time period, the inverter produces different voltage vectors at different time durations. During the time period, the average vector and V_{ref}, are equal in magnitude and angle. The space vector pulse width modulation (SVPWM) for three phase VSI is based on transformation of the three phase vector quantities to a two dimensional (αβ) quantitates.
In the SVPWM technique, the inverter will switch, producing switching vectors ($\mathbf{V_0} - \mathbf{V_7}$) with the consideration of having angle (θ) of desirable voltage. The switching frequency for the inverter is variable, which is considered as a major drawback of the SVPWM method.

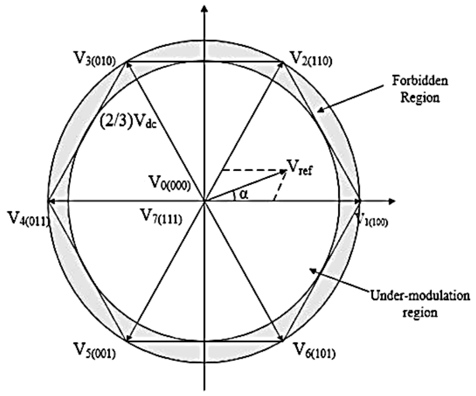


Figure 1. SVPWM Voltage Vector.

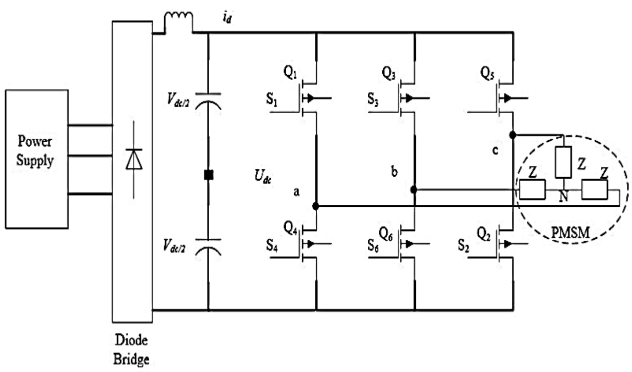


Figure 2. Three Phase Bridge Inverter.

Proposed Work

A classic two-level full bridge inverter is designed with the help of 6 switches that produce 3 phase voltage. A thorough illustration of a 3-phase inverter is presented in Figure 2.Once an upper switch gets turned on, the respective switch is swapped to the opposite state. S_0, S_1, S_3 and S_5 switches are govern to produce the voltage at the output by switching the upper switches. The transistors in a pair cannot be switched ON at the same time.
According to the SVPWM principle, binary codes are used to characterize the switching arrangements, the upper switches S_1, S_3 and S_5 as depicted in Figure 2. Every switching circuit produces three sovereign voltages values at pole V_{ao} ,V_{bo} and V_{co} , which represents the output voltages referenced to the midpoint of source. The pole voltages have two values i.e. $V_{dc} / 2$ and $V_{dc} / 2$. The eight inverter positions can be converted into eight equivalent space vectors. For every shape, '0' characterizes the negative voltage level while '1' characterizes the positive voltage level. Association among these vectors and equivalent switching situations is agreed in Table 1. Right-angle axis is used to characterize the under consideration inverter when it comes to phase illustration.
The block diagram of SVPWM control of PMSM drive is shown in Figure 3. The three phase currents are detected from the motor through the closed loop control and are then changed to 2 phase system using Clark transformation. The (αβ) system is then Park transformed into d-q system. The d-q currents are then compared to the reference current and fed to the controller, which is the Proportional Integral (PI) one. The result of which is the d-q referenced voltages which are Park transformed to the (αβ) referenced and fed to the SVPWM system. The three phase inverter then controls the PMSM through the switching pattern formed, which has been discussed above.

Table 1. Switching States of the Space Vectors.

Space Vector	Switching State	On-State Switch	Magnitude and Angle
$\vec{V_0}$	[000]	S_4, S_6, S_2	$\vec{V_0} = 0$
$\vec{V_1}$	[100]	S_1, S_6, S_2	$\vec{V_1} = \frac{2}{3}V_{dc}$
$\vec{V_2}$	[110]	S_1, S_3, S_2	$\vec{V_2} = \frac{2}{3}V_{dc}e^{j\pi/3}$
$\vec{V_3}$	[010]	S_4, S_3, S_2	$\vec{V_3} = \frac{2}{3}V_{dc}e^{j2\pi/3}$
$\vec{V_4}$	[011]	S_4, S_3, S_5	$\vec{V_4} = \frac{2}{3}V_{dc}e^{j\pi}$
$\vec{V_5}$	[001]	S_4, S_6, S_5	$\vec{V_5} = \frac{2}{3}V_{dc}e^{j4\pi/3}$
$\vec{V_6}$	[101]	S_1, S_6, S_5	$\vec{V_6} = \frac{2}{3}V_{dc}e^{j4\pi/3}$
$\vec{V_7}$	[111]	S_1, S_3, S_5	$\vec{V_7} = \frac{2}{3}V_{dc}$

Simulation and results

The paper discusses, the control of PMSM, which is achieved by means of the SVPWM. The controlling is achieved with aid of 3-phase bridge inverter. The d-q currents graph is shown in Figure 4. While the electrical torque and speed of the PMSM is plotted in Figure 5. The Figure 6 shows the three phase currents.

MATLAB/SIMULINK has been used to develop and simulate the whole drive system. The motor equations have been modelled in SIMULINK. The SVPWM signal generator, PI Controller, the bridge inverter and Park transformations models are also developed in SIMULINK. The simulation results depict satisfactory response for the developed model when the command speed was being tracked. The results of the simulation have demonstrated that the adopted SVPWM based control of PMSM drive has a satisfactory performance for the speed, torque and position control with being implemented on three phase bridge inverter. The results obtained also show that the SVPWM control strategy can be adopted effectively with low cost.

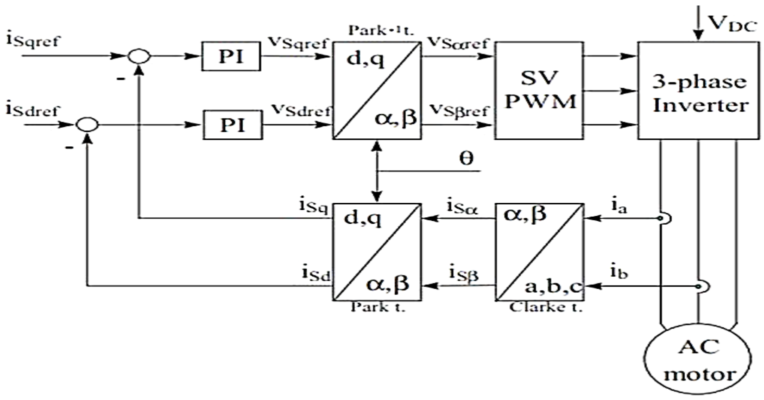


Figure 3. Block Diagram of the SVPWM control of PMSM.

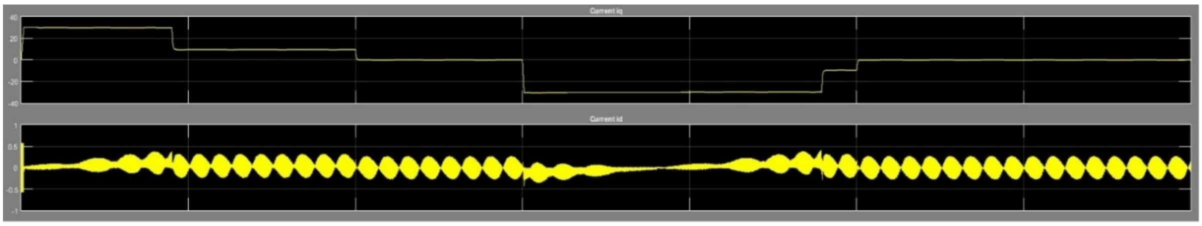
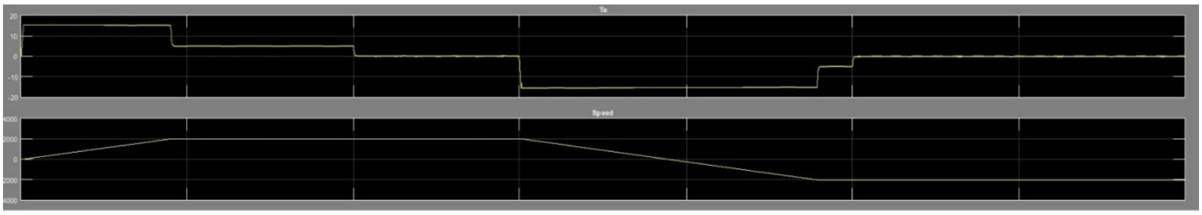


Figure 4. *d-q* Currents



. **Figure 5.** Torque and Speed Curve of PMSM

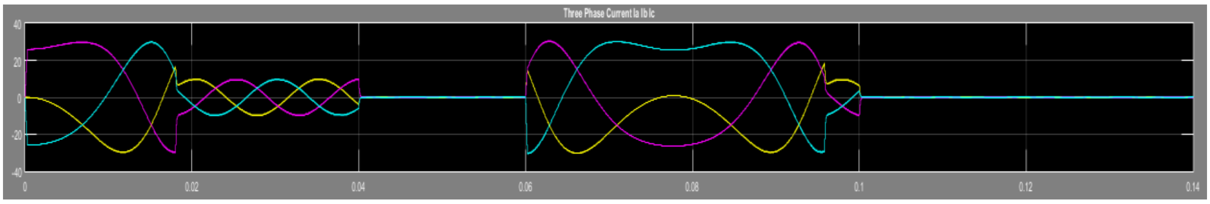


Figure 6. Three Phase Currents

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