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PMSM Speed Control using SVPWM Technique

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Abstract

A simulation analysis of a voltage source inverter using Space Vector Pulse Width Modulation (SVPWM) to control the speed of a Permanent Magnet Synchronous Motor (PMSM) has been presented in this research. PMSM is an AC drive that widely helps in high power propulsion systems. SVPWM is one of the best PWM techniques. The SVPWM is powered by a voltage source inverter connected to the PMSM. Space vector modulation is responsible for developing pulses to control the switches of the inverter. This research introduces an SVPWM-fed three-phase voltage source inverter for controlling the speed of PMSM drives using MATLAB/Simulink.

Keywords: Space Vector Pulse Width Modulation, Voltage Source Inverter, Permanent Magnet Synchronous Motor.

1. Introduction

In the present days, there is a lot of improvement in the controlling of drives by using power electronics. These drives have various applications, and are controlled by using a variable supply. To produce the variable supply, power electronic devices use pulse modulating methods which are mainly known as Pulse Width Modulation (PWM) techniques. These pulse modulating methods are used in the operation of inverters by providing switching patterns to it. These switching controlled inverters are used in various applications such as controlling the speed of drives, etc.

There are various types of motors which are employed in drives. Among the various AC drives, the Permanent Magnet Synchronous Motor (PMSM) has been highly preferred due to their high quality and better performance. This motor is highly preferable when high efficiency is needed and there is roughness in the place of operation. The PMSM has a special

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place among all drives. In order to control the drive, PMSM is fed with the inverter which is a voltage source type. This Voltage Source Inverter (VSI) controls or gets the gating signals by a Pulse Width Modulation method. There are different pulse controlling techniques which are known as PWM techniques. Among these techniques, a Space Vector Pulse Width Modulation (SVPWM) technique which is fed with the PMSM is used to get control over VSI. The block diagram for PMSM which is controlled by Space Vector PWM technique is shown below in fig.1.

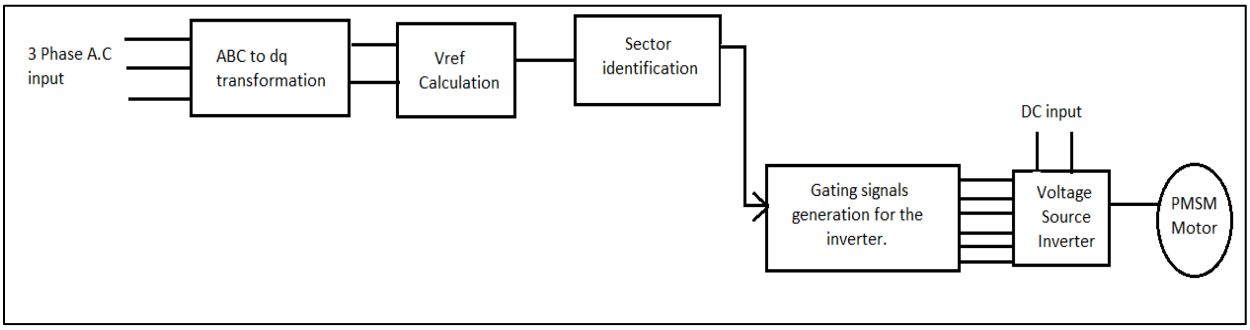

Figure 1. Block Diagram

2. Permanent Magnet Synchronous Motor

Permanent magnet synchronous motor is a type of AC motor. Its function is same as to the synchronous motor; while in synchronous motor the field excited is from a strong electromagnetic field but in this permanent magnet synchronous motor, the field excited is from permanent magnets. The motor construction is same as an AC motor such as induction motor synchronous motor, etc. The motor contains both stator and rotor, and these produce stationary and rotating magnetic fields. It uses a permanent magnet in the rotor to create a rotating magnetic field. By using these magnets, the use of field winding on rotor can be eliminated. From these, higher performance can be achieved and the efficiency can be increased. The representation of PMSM is shown in fig. 2. This motor is highly efficient, brushless, and a safe motor. It has a very smooth operation and is mainly used for high-speed applications like robotics. The PMSM is a 3-phase AC synchronous motor; with the help of AC source, it rotates with synchronous speed.

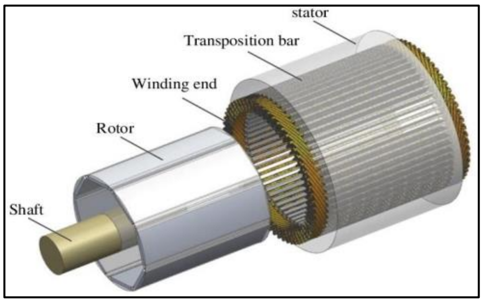

Figure 2. PMSM

3. Voltage Source Inverter

A DC input is converted into a three-phase AC output by using a three-phase bridge inverter. Like a single-phase converter, it collects DC power from the battery or a source. Generally, the simple three-phase converter is also called as six-level bridge inverter. The number of thyristors used are 6 switches. In inverter standards, the step is represented as the difference of firing from one thyristor to the another, in correct order. Each step is 60° apart to get a 360° cycle. This means that the thyristors are driven in the correct sequence at regular intervals of 60°, and a 3-phase AC output voltage is synthesized in the output legs, the filter of the output and the load of the 3-phase. Every branch contains two power transistors along with anti-parallel diodes connected in series.

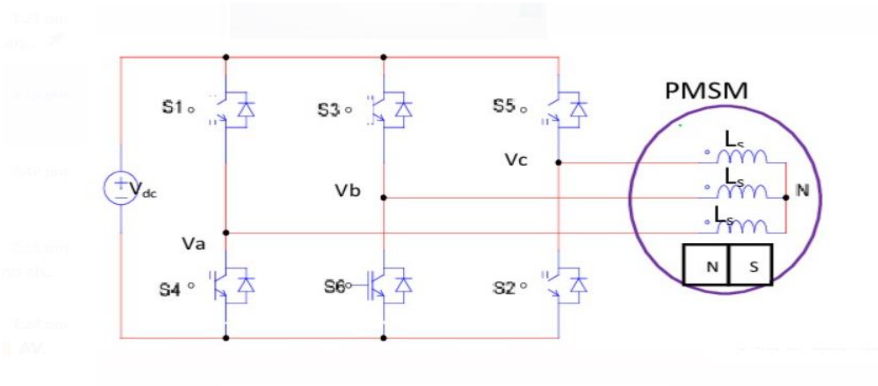

Figure 3. PWM Inverter with Three-Phase Voltage Source

The electric circuit for a three-phase bridge inverter is a side-by-side arrangement of three half-bridge inverters. It is assumed that the load connected to the inverter is three-phase and output points a, b, and c are STAR-connected. For the schematic, thyristors are numbered in an order in which they are triggered to give voltages vab, vbc, and vca at the output points a, b, and c.

There are two designs for driving a thyristor. Each thyristor has a 180° conducting pattern along with a 120° conducting pattern. However, in these two patterns, the control signal is employed and also removed at the 60° period in output voltage graph. For both these two models, a 6-mode bridge inverter is required. Inverters can output sine waves of variable frequency and variable amplitude, allowing the size of the input and output filters to be reduced by power transistors when they operate at high frequencies.

Figure 3 shows three-phase two-stage Voltage Source Inverters applied to AC motor drivers, PV systems, and wind turbines. However, VSI applications always have a large current ripple, so a larger capacitor is required. Additionally, the shoot-through that occurs in the two power transistors of the same branch, was prohibited. To address these issues, a basic topology of CSI with higher reliability and inherent overcurrent protection is proposed. Multi-stage techniques are also introduced in the CSI to decrease the harmonic content of the output current and total harmonic distortion.

4. Modulation of Space Vector Pulse Width

PWM mainly helps to control inverters to obtain variable power. The main principle of PWM is chopping a DC signal using a switching device. There are many switching devices in power electronics and these devices mainly use power electronics switches. By controlling the duty cycle of the switch, amplitude of output voltage and its harmonic content, etc. can be controlled. Space vector modulation technique is one of several modulation techniques. Compared to another PWM methods, Space Vector PWM topology has proven as the superior technique. The elements of a three-phase sinusoidal voltage are explained in the steady-state body as,

$$V_a = V_m \sin(wt) \qquad \text{-------------------(1)}$$

$$V_b = V_m \sin(wt-120) \qquad \text{-------------------(2)}$$

$$V_c = V_m \sin(wt-240) \qquad \text{-------------------(3)}$$

A three-phase VSI has six switches driven by space vector pulse width modulation. The converter has an upper switch and a lower switch which convertes the AC to DC. There are a total of 8 ON/OFF switches on the top. The on/off state of the bottom power switch is the opposite of the on/off state of the top switch. Figure 4 shows the converter voltage vector (V0 to V7).

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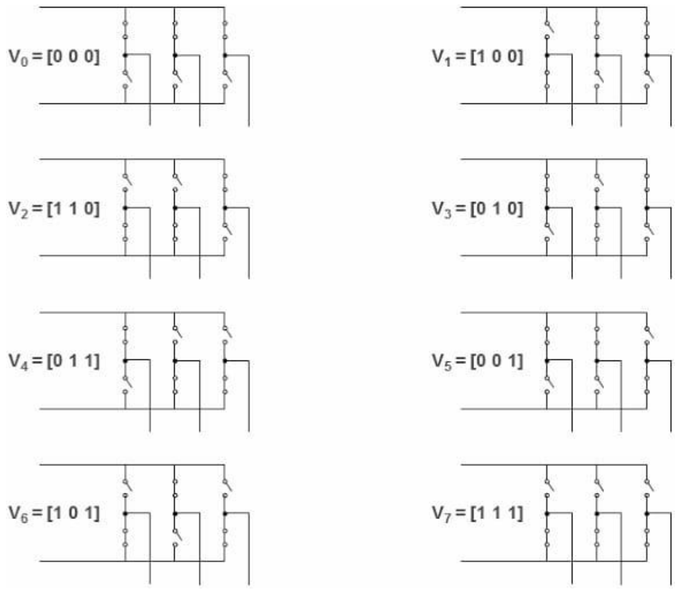

Figure 4. Voltage Vectors (V0 to V7) of Inverter

The alternating three phase voltages shown in equations (1),(2) and (3), rotates in a stationary reference frame. These three phase voltages are converted into the two phases by using Clarks Transformation. This two-phase component rotates in a dq stationary frame which is shown in equation (4).

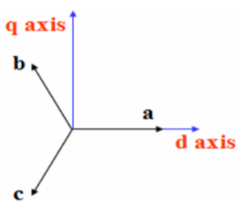

Figure 5. Relation between abc Stationary Frame and dq Frame

$$\therefore \begin{bmatrix} Vd \\ Vq \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \qquad \text{------------(4)}$$

Converting the three-dimensional projection (a,b,c) to a two-dimensional (d-q) projection, develops a six possible nonzero vectors and two zero vectors. The nonzero vectors (V1-V6) form a hexagonal axis as shown in Figure 6, and the angle between any two sides of nonzero vectors is 60°. The zero vector (V0, V7) is the origin. A nonzero vector applies electrical energy to the load and a zero vector applies zero voltage to the load. These vectors are called basis space vectors and are represented by V0 to V7. Figure 7 shows the switching patterns of each thyristor in an inverter.

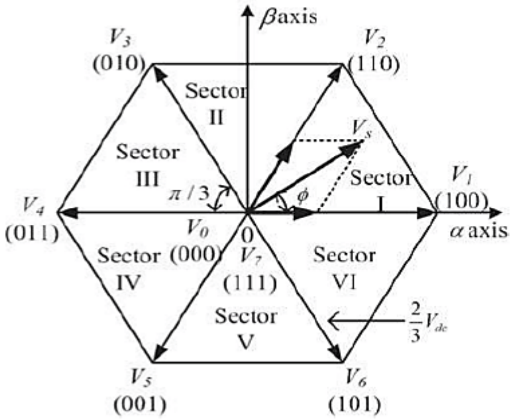

Figure 6. Switching Vectors along with Sectors for Inverter

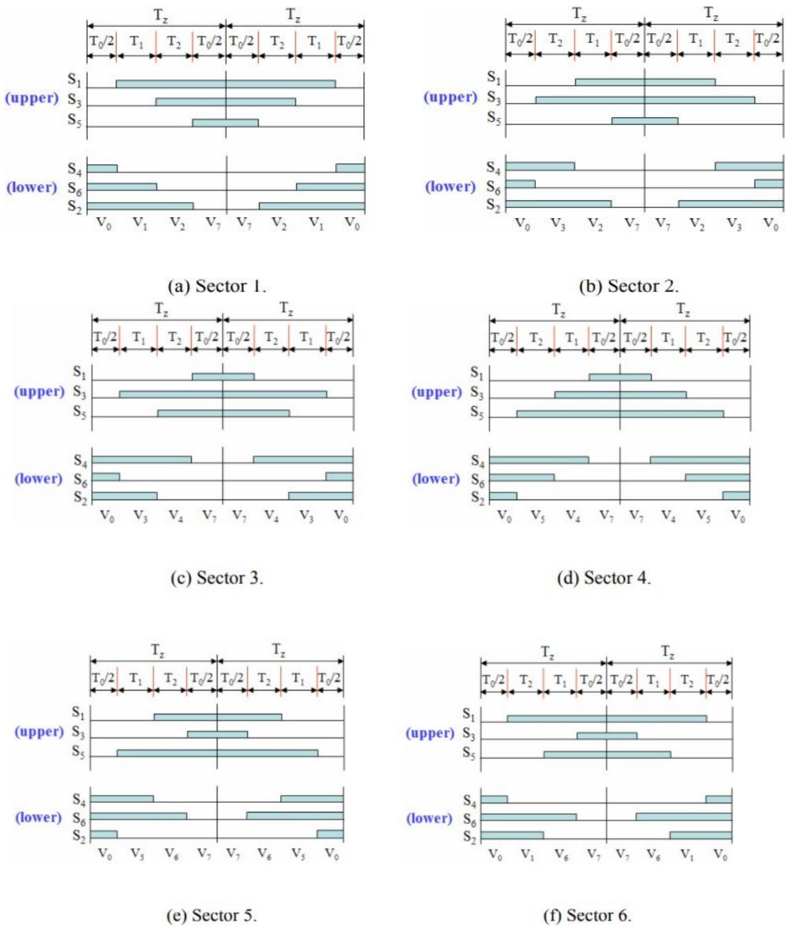

Figure 7. Vector pwm in Space Switching Characteristics in Every Sector

5. Simulation and Results

A simulation of PMSM drive speed control using SVPWM was performed in the MATLAB/SIMULINK environment. The simulation of the proposed model is presented in Figure 8. This reference space vector generates the six switching or control pulses that feed the inverter's six switches to control the inverter's output voltage. The previously discussed PMSM model is fed from a voltage source inverter whose control pulses are provided by space vector modulation techniques. Clarke transformation is performed to obtain stationary and rotating 2D reference frames. The simulation tracks the target value to the actual value of the motor. Figures 9 and 10 show the Simulink model of the SVPWM method for generating gate pulses and three-phase inverters, respectively.

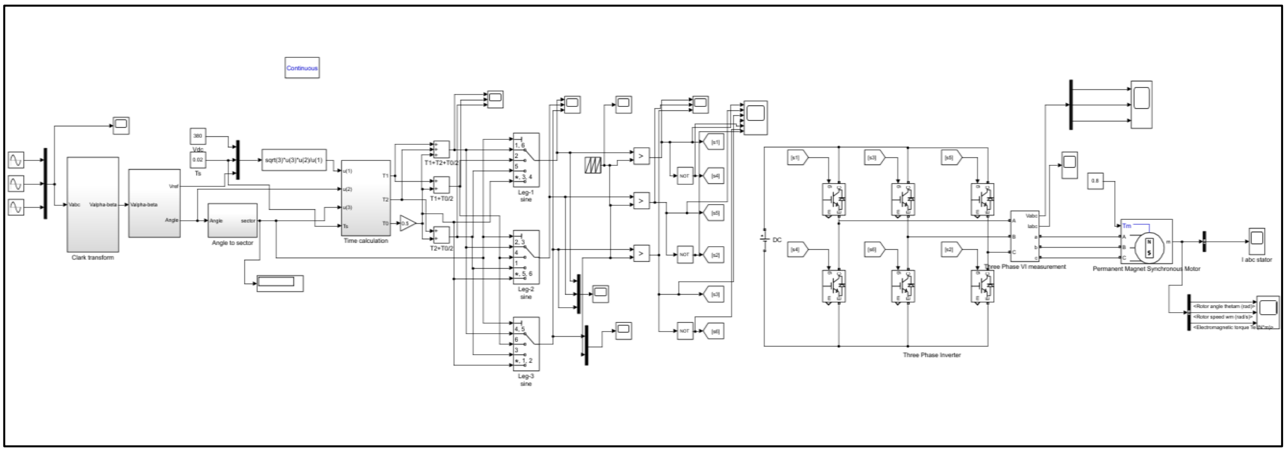

Figure 8. Simulation Block

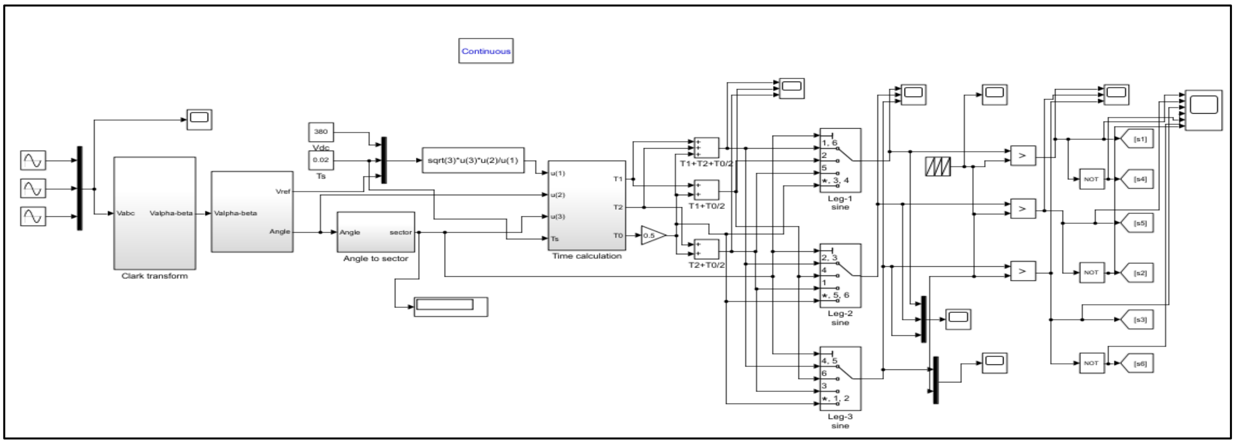

Figure 9. SVPWM Technique

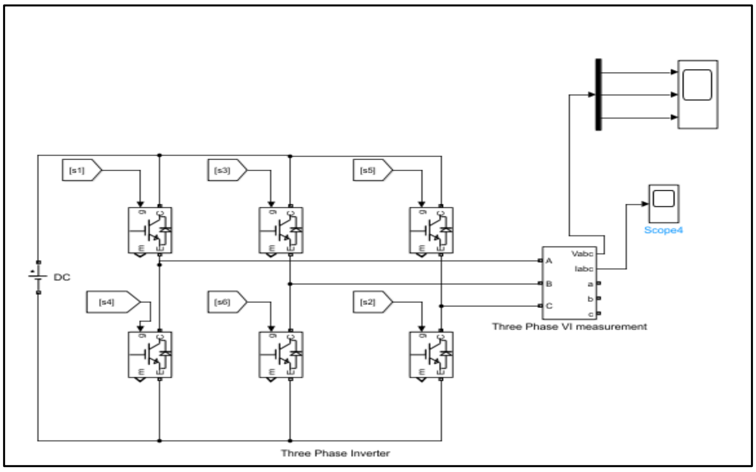

Figure 10. Simulation of Inverter

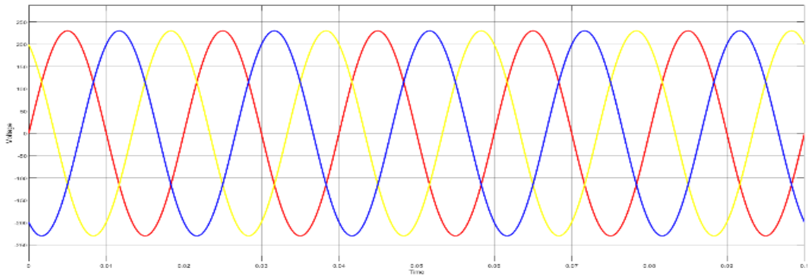

Figure 11. Input Three Phase Sine Wave

Figure 11 shows the three phase input sine wave. The three phases are labelled as R, Y, and B with 120-degree displacement. This sine wave shows the alternating quantity with a frequency of 50HZ.

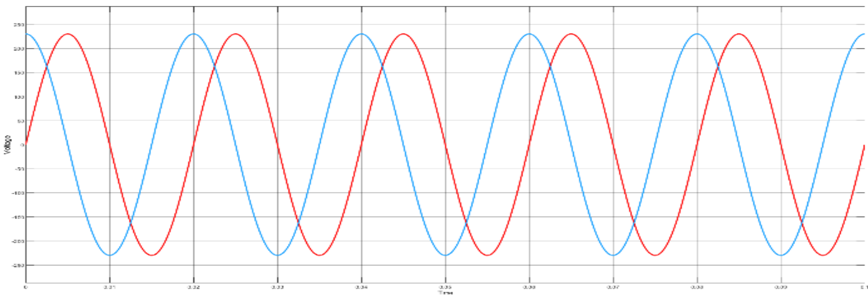

Figure 12. Clarks Transformation Output

Figure 12 depicts the Clarks transformation output wave form. Generally, Clarks Transformation is a method which converts the three phase input sine wave shown in figure 11 into two-phase.

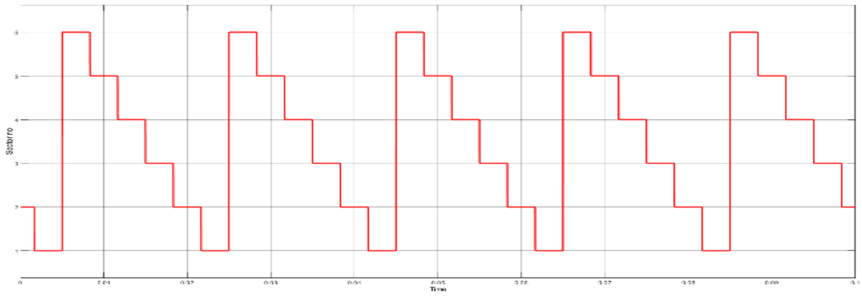

Figure 13. Sectors

Figure 13 shows the sector waveform. Corresponding sectors are identified according to the size and angle. Since there are 3 levels of VSI, there are a total of 6 sectors varying from 1 to 6 as represented in Figure 13.

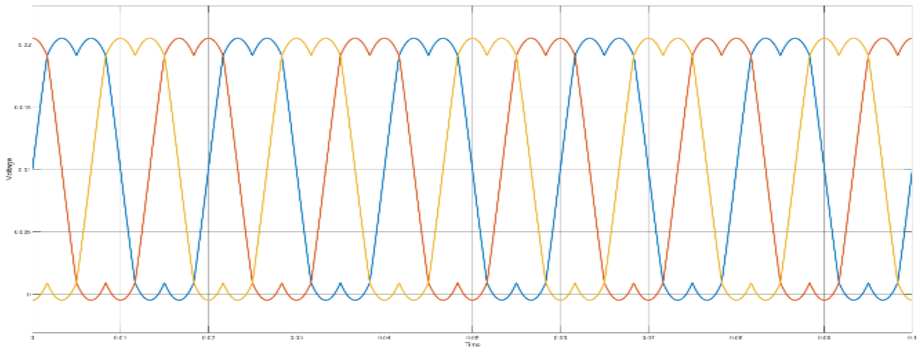

Figure 14. Output of SVPWM

Figure 14 shows the Three Phase Output of Space Vector Pulse Width Modulation, which helps in the application of switches. This output is compared with the reference signal and generates gating pulse, which are used for the switching of the inverter switches.

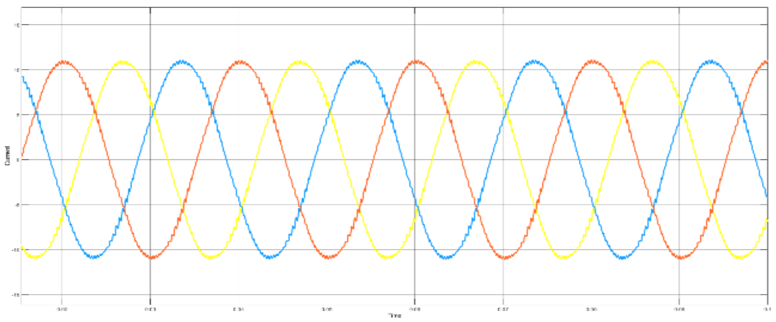

Figure 15. Results of Inverter Output Current Simulations (iA, iB, iC)

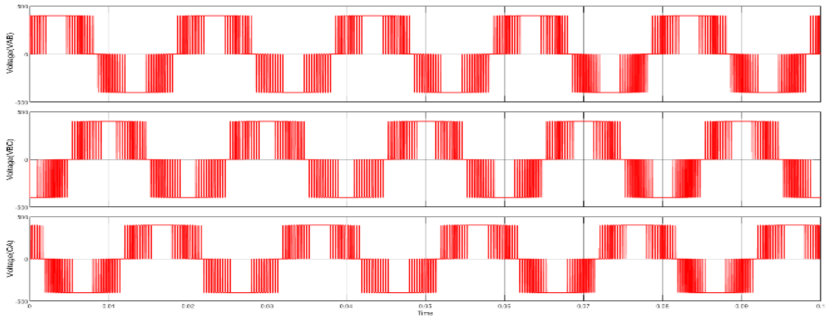

Figure 16. Line to Line Ouput Waveform Of The Inverter *i (ViAB, ViBC, ViCA)*

Figures 16 and 15 show the VSI output voltage and current supplied as input power to the stator of the modelled PMSM respectively. A PMSM system is modelled as one 4-pole machine, operating at a mains frequency of 50 Hz and having a nominal speed of 1500 rpm.

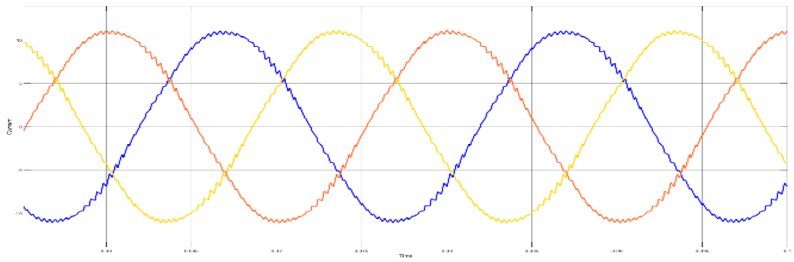

Figure 17. Simulation Results of PMSM Stator Currents

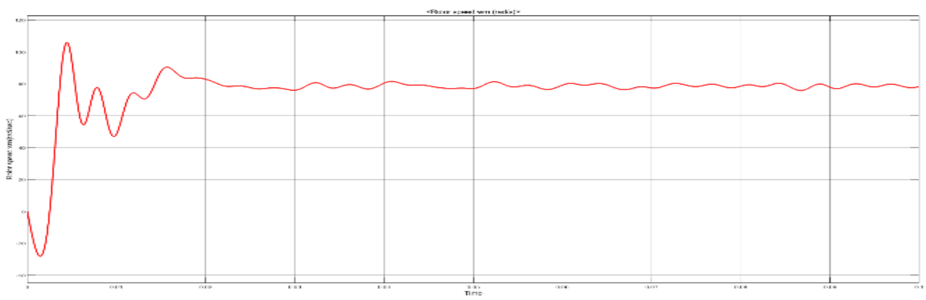

Figure 18. Speed of the PMSM (765 rpm) at the 400V DC link

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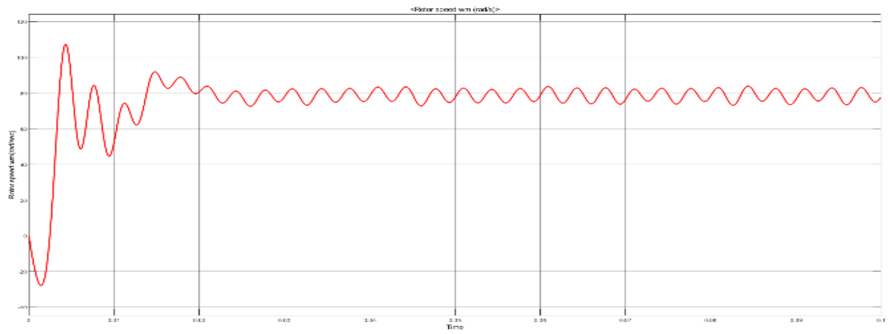

Figure 19. Speed of the PMSM (792 rpm) at the 350V DC link

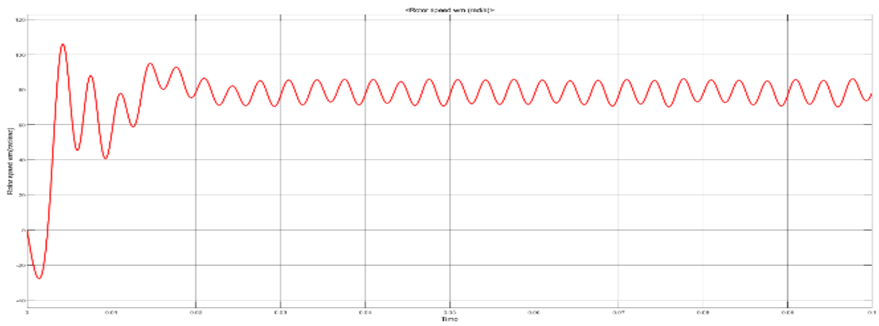

Figure 20. Speed of the PMSM (812 rpm) at the 300V DC link

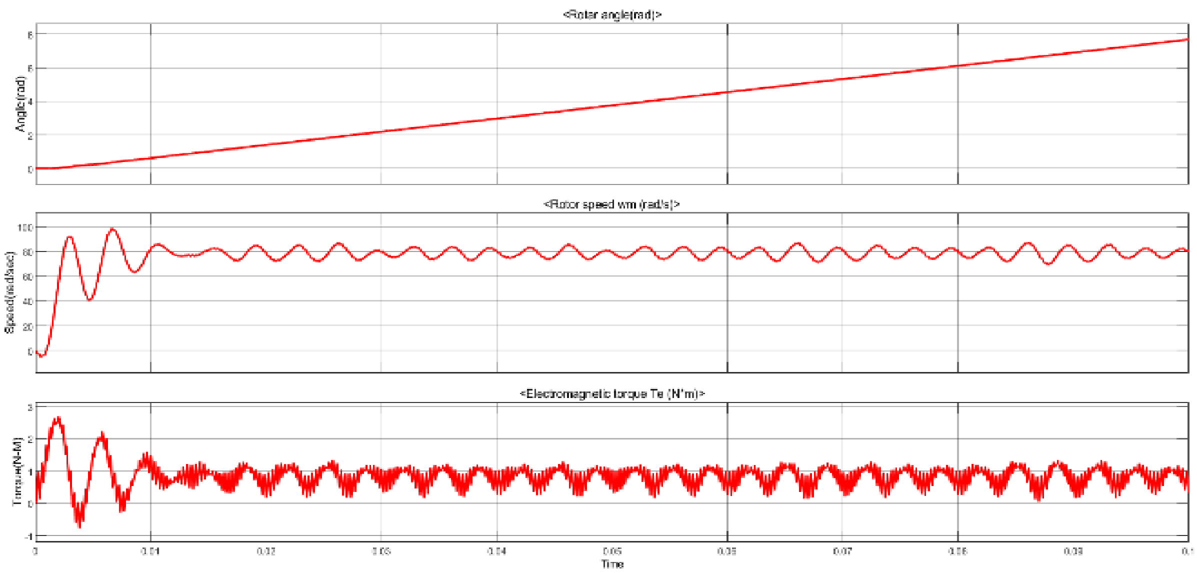

Figure 21. Simulation Results of PMSM Rotor Angle, Rotor Speed and Electromagnetic Speed

The figures 17 and 21 depict the stator currents and rotor angle, rotor speed, and electromagnetic speed of four pole 50Hz 1500rpm Permanent Magnet Synchronous Motor.

These stator currents are developed by the output of three phase inverter which is connected to the PMSM. The switching of the inverter switches is controlled by SVPWM technique.

6. Conclusion

Space vector modulation technology is the most advanced technology among various PWM technologies. SVPWM technique, a digital modulation technique has been used in this research based on the presented reduction calculation method. In this SVPWM technique, the inverter gating signal is derived from the sector. The SVPWM scheme drives the inverter with eight switching states. This switching state can be produced by the two-axis space state vector forming a six-sector hexagon. The time interval for switching the state vector of each sector is calculated at the sampled time T to implement the desired modulation procedure. Nominal speed regulation of PMSM at 1500 rpm is achieved by adjusting SVPWM with DC link variations at 765 rpm, 792 rpm and 812 rpm. Speed control of PMSM is achieved using both V and V/F control methods. In the voltage regulation method, variable speed of the motor is obtained by varying the intermediate circuit voltage. The V/F control scheme provides variable speed with constant motor flux.

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