

Implementation of synchronized space vector PWM for a Two-level Inverter using the digital I/O pins of the dSPACE hardware platform

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Abstract : This paper presents soft starting and speed control a 3-phase induction motor is obtained by (v/f) control. A voltage source inverter (VSI) is employed to impress a variable voltage, variable frequency supply to the motor. The VSI is controlled by dSPACE (an acronym digital signal processing and control engineering), hardware platform, which supports a hardware-in-loop feature. Simulink models can be converted into assembly language programs of the target DSP platform and can be downloaded into the target platform to run various real time applications. Six dedicated PWM lines are provided in dSPACE. Thus, two independent inverters can be simultaneously controlled. However these PWM lines can implement only asynchronous PWM not possible to ensure as it is an integral ratio of the carrier wave and modulating wave under all conditions. Consequently, it calls for the exploration of the capabilities of some other resources available with the dSPACE platform. It was found that one may configure the digital I/O lines provided by the dSPACE as PWM lines if the switching frequency is not high. In this paper the general purpose digital I/O lines are programmed as PWM lines to drive the VSI, which employs synchronous space vector modulation.

IndexTerms - dSPACE, soft starting, voltage source inverter (VSI), PWM, synchronous space vector modulation.

I. INTRODUCTION

An electric motor is a machine which converts electrical energy into mechanical energy. Its action is based on the principle that when a current carrying conductor is placed in a magnetic field, it experiences a mechanical force whose direction is given by Fleming's left hand rule. In D.C motors the electric power is conducted directly to the armature through brushes and commutator. But in Induction motors, the rotor does not receive power by conduction but by induction. That is three phase supply is given to the stator of the induction motor, this power is transferred to rotor by induction principle. Balanced polyphase currents in polyphase windings produce constant amplitude rotating mmf wave.

The stator produced mmf wave and rotor produced mmf wave both rotate in the air gap in the same direction at synchronous speed. These two mmf waves are thus stationary with respect to each other, consequently the development of steady state torque is possible. The stator and rotor mmf waves combines to give the resultant air gap flux wave of constant amplitude and rotating at synchronous speed.

Although it has been superseded open loop Volt/Hertz control or Scalar Control as it is known, is still widely used in applications where don't require precise speed control such as fans for Heating Ventilation and Air Condition (HVAC). This method is based on the torque speed curve for an induction motor. The shape of this curve depends on the voltage and frequency applied to the stator. By fixing the supply frequency and hence the motor speed, the torque can be varied as the square of the applied voltage. To maintain the air gap flux at its rated value the voltage and frequency should be varied in the same proportion i.e. if you double the frequency you need to double the supply voltage.

Providing the ratio between voltage and frequency remains constant maximum torque can be applied throughout the motors speed range. At low frequencies the supply voltage is also low so the voltage drop caused by the stator resistance cannot be neglected. To compensate for this the voltage below a certain frequency is maintained at a fixed value and the V/Hz relationship is abandoned. Similarly at high frequencies the voltage is fixed at a maximum value to avoid insulation breakdown.

This paper briefly discusses the theory and operation of Space Vector Pulse Width Modulation (SVPWM) and explains the implementation of SVPWM for a two level inverter topology [1]. Variable voltage and frequency supply to ac drives is invariably obtained from a three-phase voltage source inverter (VSI) [5]. A number of Pulse width- modulation (PWM) scheme is used to obtain variable voltage and frequency supply [4]. The most widely used PWM schemes for three-phase VSI are carrier-based sinusoidal PWM and space vector PWM (SVPWM) [2]. There is an increasing trend of using space vector PWM (SVPWM) because of their easier digital realization and better dc bus utilization [3].

II. PROBLEM FORMULATION

The eight vectors are called the basic space vectors and are denoted by $V_0(000)$, $V_1(100)$, $V_2(110)$, $V_3(010)$, $V_4(011)$, $V_5(001)$, $V_6(101)$, $V_7(111)$. The binary numbers indicate the switch state of inverter legs. Here 1 implies upper switch being on and 0 refers to the lower switch of the leg being on. The same transformation can be applied to the desired output voltage to get the desired reference voltage vector V_{ref} in the d-q plane. The objective of SVPWM technique is to approximate the reference voltage vector V_{ref} using the eight switching patterns.

One simple method of approximation is to generate the average output of the inverter in a small period, T to be the same as that of V_{ref} in the same period.

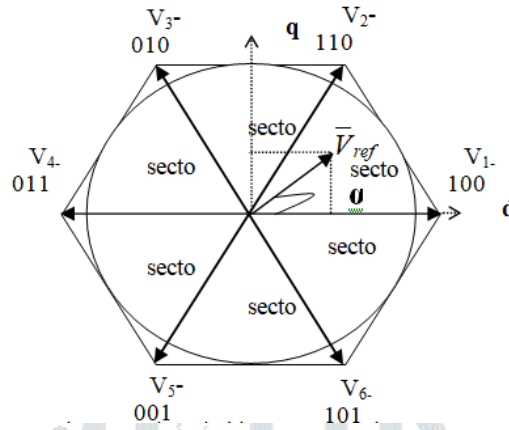


Fig 1. Basic switching vectors and sectors

Therefore, space vector PWM can be implemented by the following steps

2.1. Objective 1: Determination of V_d , V_q , V_{ref} , and angle (α)

$$\begin{aligned}
 V_d &= V_{an} - V_{bn} \cdot \cos 60 - V_{cn} \cdot \cos 60 \\
 &= V_{an} - \frac{1}{2} V_{bn} - \frac{1}{2} V_{cn} \\
 V_q &= 0 + V_{bn} \cdot \cos 30 - V_{cn} \cdot \cos 30 \\
 &= V_{an} + \frac{\sqrt{3}}{2} V_{bn} - \frac{\sqrt{3}}{2} V_{cn} \\
 \therefore \begin{bmatrix} V_d \\ V_q \end{bmatrix} &= \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \\
 \therefore |\bar{V}_{ref}| &= \sqrt{V_d^2 + V_q^2}
 \end{aligned}$$

$$\therefore \alpha = \tan^{-1} \left(\frac{V_q}{V_d} \right) = \omega t = 2\pi f t, \text{ where } f = \text{fundamental frequency.}$$

2.2. Objective 2: Determination of time duration T_1 , T_2 , T_0

Switching time duration can be calculated as follows:

Switching time duration at Sector 1

$$\begin{aligned}
 \int_0^{T_z} \bar{V}_{ref} dt &= \int_0^{T_1} \bar{V}_1 dt + \int_{T_1}^{T_1+T_2} \bar{V}_2 dt + \int_{T_1+T_2}^{T_z} \bar{V}_0 dt \\
 \therefore T_z \cdot \bar{V}_{ref} &= (T_1 \cdot \bar{V}_1 + T_2 \cdot \bar{V}_2) \\
 \Rightarrow T_z \cdot |\bar{V}_{ref}| \cdot \begin{bmatrix} \cos \alpha \\ \sin \alpha \end{bmatrix} &= T_1 \cdot \frac{2}{3} \cdot V_{dc} \cdot \begin{bmatrix} 1 \\ 0 \end{bmatrix} + T_2 \cdot \frac{2}{3} \cdot V_{dc} \cdot \begin{bmatrix} \cos(\pi/3) \\ \sin(\pi/3) \end{bmatrix}
 \end{aligned}$$

$$(where, 0 \leq \alpha \leq 60^\circ) \therefore T_0 = T_z - (T_1 + T_2) \quad \left(where \ T_z = \frac{1}{f_z} \text{ and } a = \frac{|\bar{V}_{ref}|}{\frac{2}{3}V_{dc}} \right)$$

2.3. Objective 3: Determination of the switching time of each switch (S₁ to S₆)

Sector number	Upper switches (s ₁ , s ₃ , s ₅)	Lower switches (s ₄ , s ₆ , s ₂)
1	S ₁ =T ₁ +T ₂ +T ₀ /2 S ₃ =T ₂ +T ₀ /2 S ₅ =T ₀ /2	S ₄ =T ₀ /2 S ₆ =T ₁ +T ₀ /2 S ₂ =T ₁ +T ₂ +T ₀ /2
2	S ₁ =T ₁ +T ₀ /2 S ₃ =T ₁ +T ₂ +T ₀ /2 S ₅ =T ₀ /2	S ₄ =T ₂ +T ₀ /2 S ₆ =T ₀ /2 S ₂ =T ₁ +T ₂ +T ₀ /2
3	S ₁ =T ₀ /2 S ₃ =T ₁ +T ₂ +T ₀ /2 S ₅ =T ₂ +T ₀ /2	S ₄ =T ₁ +T ₂ +T ₀ /2 S ₆ =T ₀ /2 S ₂ =T ₁ +T ₀ /2
4	S ₁ =T ₀ /2 S ₃ =T ₁ +T ₀ /2 S ₅ =T ₁ +T ₂ +T ₀ /2	S ₄ =T ₁ +T ₂ +T ₀ /2 S ₆ =T ₂ +T ₀ /2 S ₂ =T ₀ /2
5	S ₁ =T ₂ +T ₀ /2 S ₃ =T ₀ /2 S ₅ =T ₁ +T ₂ +T ₀ /2	S ₄ =T ₁ +T ₀ /2 S ₆ =T ₁ +T ₂ +T ₀ /2 S ₂ =T ₀ /2
6	S ₁ =T ₁ +T ₂ +T ₀ /2 S ₃ =T ₀ /2 S ₅ =T ₁ +T ₀ /2	S ₄ =T ₂ +T ₀ /2 S ₆ =T ₁ +T ₂ +T ₀ /2 S ₂ =T ₂ +T ₀ /2

Sector number	On-sequence	Off-sequence
1	0-1-2-7	7-2-1-0
2	0-3-2-7	7-2-3-0
3	0-3-4-7	7-4-3-0
4	0-5-4-7	7-4-5-0
5	0-5-6-7	7-6-5-0
6	0-1-6-7	7-6-1-0

Table 1. Switching Time Table at Each Sector & Switching Sequence Table

III. DC BUS UTILIZATION WITH SVPWM

The principal advantage of the SVPWM over SPWM is that it enhances the DC bus utilization by about 15% [6]. It is instructive to evaluate the sample-averaged pole voltage of a phase, V_{AO} for instance, to understand this fact.

$$T_1 = \frac{|\mathbf{v}_{sr}| T_s \sin(\pi/3 - \alpha)}{V_{dc} \sin(\pi/3)}$$

$$T_2 = \frac{|\mathbf{v}_{sr}| T_s \sin \alpha}{V_{dc} \sin(\pi/3)}$$

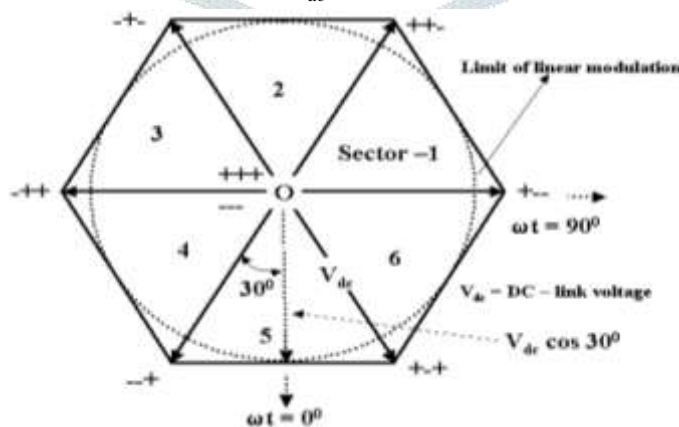


Fig 2. Determination of the sample-averaged pole voltage

Which are calculated already.

In |V_{sr}| denotes the amplitude of the reference vector and 'α' represents the position of the reference vector with respect to the beginning of the sector in which the tip of the reference vector is situated.

IV. RESULTS AND DISCUSSION

Soft starting minimizes the starting mechanical and thermal stress and shocks on the machine and the motor. It results in reduced maintenance cost, fewer breakdowns and hence longer operating life for both. Reduced starting current is an added advantage. A solid-state soft start is that an unbalanced power supply is transformed to a balanced source of supply automatically by suitably adjusting the firing angle of each SCR or IGBTs through their switching logistics.

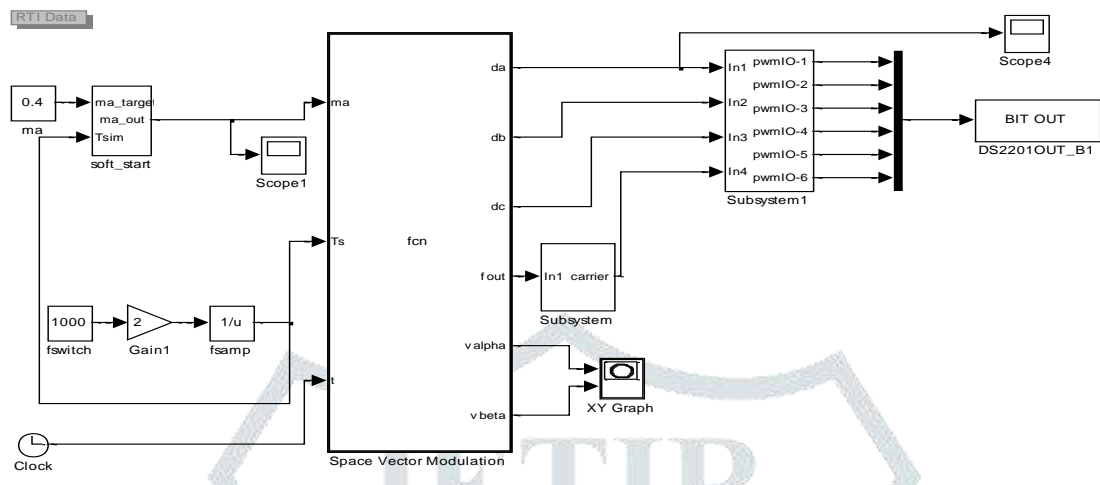


Fig 3. Simulink model for the soft start space vector modulation (SVM)

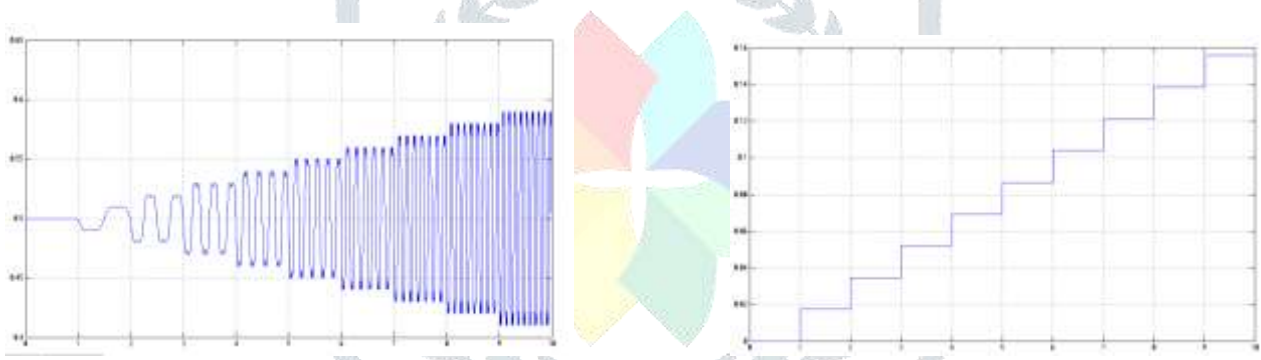


Fig 4. Simulation result from MALTAB for a modulation index of 0.4 of the SVM (T_{ga} wave form & m_a value increase from initial value to its final value)

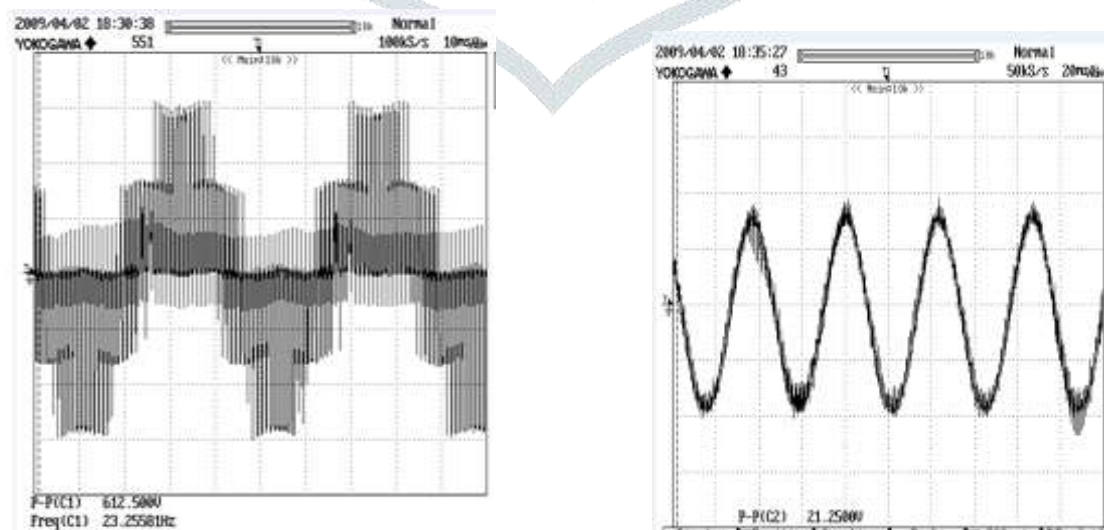


Fig 5. Experimental results with dSPACE control circuit for modulation index of 0.4 output voltage and current of the SVM

V. CONCLUSIONS

A voltage source inverter (VSI) is employed to impress a variable voltage, variable frequency supply to the motor. The VSI is controlled by dSPACE (an acronym digital signal processing and control engineering), hardware platform, which supports a hardware-in-loop feature. Six dedicated PWM lines are provided in dSPACE. Thus, two independent inverters can be simultaneously controlled. In this paper the general purpose digital I/O lines are programmed as PWM lines to drive the VSI, which employs synchronous space vector modulation. Consequently, it calls for the exploration of the capabilities of some other resources available with the dSPACE platform. It was found that one may configure the digital I/O lines provided by the dSPACE as PWM lines if the switching frequency is not high.

VI. ACKNOWLEDGEMENT

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