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V/F Speed Control of 3 phase Induction Motor using Space Vector Modulation

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Abstract:- **Speed control techniques are generally essential in adjustable speed drive system which requires variable voltage and frequency supply which is invariably obtained from a three-phase Voltage source inverter. A number of pulse width modulations scheme is used to obtain variable voltage and frequency supply from an inverter, but Space Vector Pulse Width Modulation has advantages such as easier digital realization, better dc bus utilization over the other methods of Pulse width modulations. In this paper v/f speed control of three phase induction motor using space vector modulation is demonstrated by using MATLAB/SIMULINK model.**

Keywords: Voltage source inverter (VSI), Pulse width modulations (PWM), Space Vector Pulse Width Modulation (SVPWM), Three phase induction motor (3 phase I.M)

I.INTRODUCTION

The speed control of three phase induction motor is essential because the motor control industry is a dominant sector. To remain competitive, new products must be developed having several design aspects such as, cost reduction, low power consumption & improved power factor. In order to meet these challenges, conventional methods need to modify with advanced control techniques which allow meeting the above requirements with high level of performance. In industrial sector, among all type of machines, the squirrel cage induction motor is the most commonly used, because of its advantages such as economical, rugged construction, less maintenance, its ability to operate in dirty or explosive conditions better performance, reliable and are easily available in the wide ranges of power. There are various methods which are used for the speed control of three phase induction motor such as stator voltage control, frequency control, rotor resistance control but v/f speed control is the most popular method which is used in adjustable speed drive system. In v/f speed control technique v/f ratio is to be kept constant so that flux remains constant. [1]

Speed control techniques are generally essential in adjustable speed drive system. This system requires variable voltage and frequency supply which is invariably obtained from a three-phase Voltage source inverter (VSI). A number of Pulse width modulations (PWM) scheme is used to obtain variable voltage and frequency supply from an inverter, such as Sine wave Pulse Width Modulation (SPWM), Third Harmonic Pulse Width Modulation (THPWM) and Space Vector Pulse Width Modulation (SVPWM).There is an increasing trend of using space vector PWM (SVPWM) because of their easier digital realization, better dc bus utilization and output voltage is more closed to sinusoidal wave. [4]

This paper aims at study of v/f speed control technique for Induction Motor using Space Vector Pulse Width Modulation technique with stepwise understanding of v/f speed control method for three phase induction motor and space vector modulation and its realization by using MATLAB/SIMULINK model for two level inverter.

II. V/F SPEED CONTROL FOR THREE PHASE INDUCTION MOTOR.

There are various methods which are used for the speed control of three phase induction motor such as stator voltage control, frequency control, rotor resistance control but v/f speed control is the most popular method which is used in adjustable speed drive system. In v/f speed control technique v/f ratio is to be kept constant so that flux remains constant. As we have the torque developed by the motor is directly proportional to the magnetic field produced by the stator. So, the voltage applied to the stator is directly proportional to the product of stator flux and angular velocity. This makes the flux produced by the stator proportional to the ratio of applied voltage and frequency of supply.

$$V \alpha \Phi * f$$

And hence

$$\Phi \alpha v/f$$

Therefore by varying the voltage and frequency by the same ratio, the torque can be kept constant throughout the speed range. This makes constant V/f is the most common speed control of an induction motor. [3]

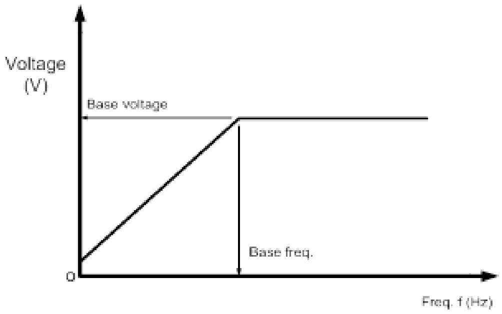

Fig.1.Voltage-frequency under constant V/f principle.

III.THREE-PHASE VOLTAGE SOURCE INVERTER AND SPACE VECTORS.

A mathematical model of three-phase is presented here based on space vector representation. The power circuit topology of a three-phase VSI is shown in Fig.2. Each switch in the inverter leg is composed of two back-to-back connected semiconductor devices. One of these two is a controllable device and other one is a diode for protection. Leg voltage waveforms is shown in Figure 3 for 180° conduction mode.

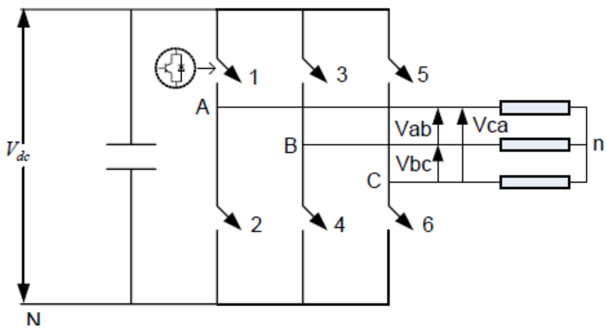

Fig.2.Power circuit of a three-phase Voltage Source Inverter.

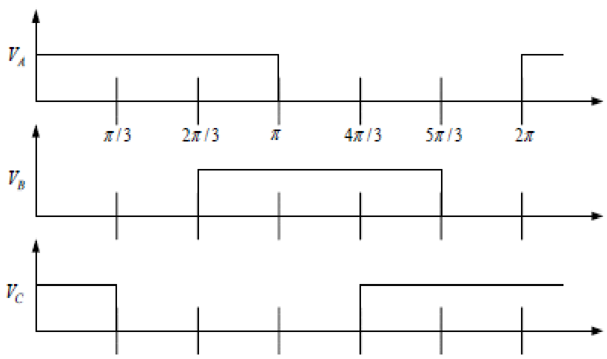

Fig.3.Leg voltage waveform of a three- phase VSI for 180° conduction.

It is observed from Fig.3 that one inverter leg's state changes after an interval of 60° and their state remains constant for 60° interval. Thus it follows that the leg voltages will have six distinct and discrete values in one cycle (360°).

Space vector representation of the three-phase inverter output voltages is introduced next. Space vector is defined as

$$V_s = (2/3)\,(V_a + a\,V_b + a^2\,V_c) \qquad (1)$$

Where,

A=exp (j 2π/3)

The space vector is a simultaneous representation of all the three-phase quantities. It is a complex variable and is function of time in contrast to the phasors.
Phase-to-neutral voltages of a star-connected load are most easily found by defining a voltage difference between the star point n of the load and the negative rail of the dc bus N. The following correlation then holds true,

$$V_A = V_a + V_{nN}$$
$$V_B = V_b + V_{nN} \qquad (2)$$
$$V_C = V_c + V_{nN}$$

Since the phase voltages in a start connected load sum to zero, summation of equation (2) yields

$$V_{nN} = (1/3)(V_A + V_B + V_C) \qquad (3)$$

Substitution of (3) into (2) yields phase-to-neutral voltages of the load in the following form:

$$V_a = (2/3)\,V_A - (1/3)(V_B + V_C)$$
$$V_b = (2/3)\,V_B - (1/3)(V_A + V_C)$$
$$V_c = (2/3)\,V_C - (1/3)(V_B + V_A)$$

Phase voltages are summarized in Table 1 and their corresponding space vectors are listed in Table2.

Table:1 Phase voltage values for different switching state

State	Switch ON	V_A	V_B	V_C
1	1,4,6	(2/3)Vdc	-(1/3) Vdc	-(1/3) Vdc
2	1,3,6	(1/3) Vdc	(1/3) Vdc	-(2/3)Vdc
3	2,3,6	-(1/3) Vdc	(2/3)Vdc	-(1/3) Vdc
4	2,3,5	-(2/3)Vdc	(1/3) Vdc	(1/3) Vdc
5	2,4,5	-(1/3) Vdc	-(1/3) Vdc	(2/3)Vdc
6	1,4,5	(1/3) Vdc	-(2/3)Vdc	(1/3) Vdc
7 &0	1,3,5 & 2,4,6	0	0	0

And we have space vectors corresponding to above Phase voltages are as follows.

Table 2 Phase voltage space vectors.

State	Phase voltage space vectors
1	(2/3)Vdc
2	(2/3)Vdc exp (j π/3)
3	(2/3)Vdc exp (j 2π/3)
4	(2/3)Vdc exp (j π)
5	(2/3)Vdc exp (j 4π/3)
6	(2/3)Vdc exp (j 5π/3)
7 & 0	0

The discrete phase voltage space vector positions are shown in Fig.4

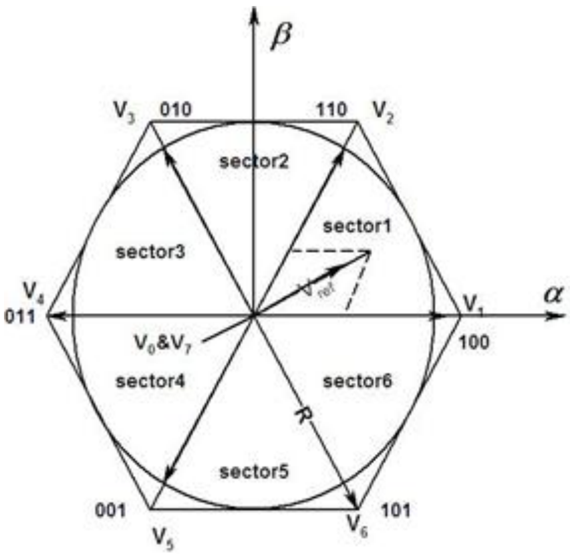

Fig.4. Phase voltage space vectors.

The binary numbers on the figure 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 most significant bit is for leg A, the least significant bit is related to leg C and the middle is for leg B..

IV.CONCEPT OF SPACE VECTOR PWM

This section briefly discusses the space vector PWM principle. This PWM method is frequently used in vector controlled and direct torque controlled drives. In vector controlled drive this technique is used for reference voltage generation when current control is exercised in rotating reference frame.

It is seen in the previous section that a three-phase VSI generates eight switching states which include six active and two zero states. These vectors form a hexagon in Fig.4which can be seen as consisting of six sectors spanning 60° each. The reference vector which represents three-phase sinusoidal voltage is generated using SVPWM by switching between two nearest active vectors and zero vectors. To calculate the time of application of different vectors, consider fig.5, depicting the position of different available space vectors and the reference vector in the first sector.

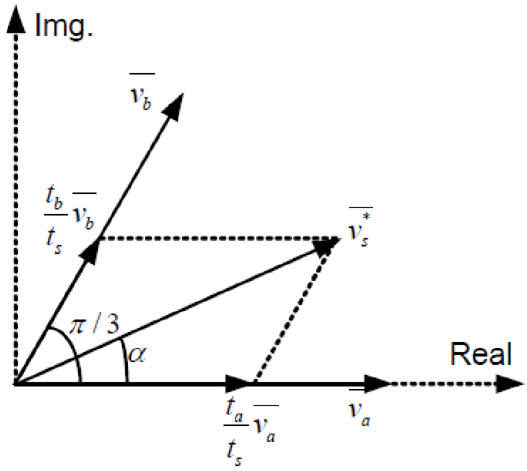

Fig.5. Principle of space vector time calculation.

The time of application of active space voltage vectors is found from fig.5 as follows.

$$t_a = \frac{|V_s^*| \sin(\pi/3 - \alpha)}{|V_a| \sin(2\pi/3)}$$

$$t_b = \frac{|V_s^*| \sin(\alpha)}{|V_b| \sin(2\pi/3)}$$

$$t_0 = t_s - t_a - t_b$$

Where,

$$|V_a| = |V_b| = (2/3)V_{dc}$$

In order to obtain fixed switching frequency and optimum harmonic performance from SVPWM, each leg should change its sate only once in one switching period. This is achieved by applying zero state vector followed by two adjacent active state vector in half switching period. The next half of the switching period is the mirror image of the first half. The total switching period is divided into 7 parts, the zero vector is applied for 1/4th of the total zero vector time first followed by the application of active vectors for half of their application time and then again zero vector is applied for 1/4th of the zero vector time. This is then repeated in the next half of the switching period. This is how symmetrical SVPWM is obtained. The leg voltage in one switching period is depicted in fig.6 for sector I.[6].

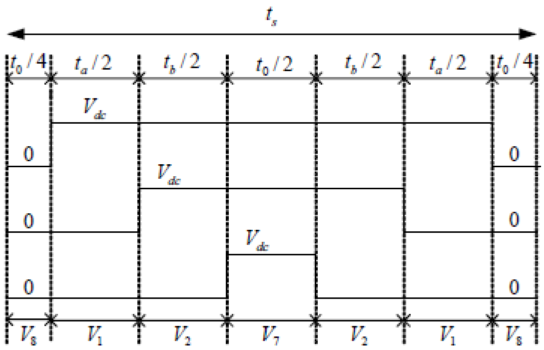

Fig.6.Leg voltages and space vector disposition for one switching period in sector I.

The sinusoidal reference space vector form a circular trajectory inside the hexagon. The largest output voltage magnitude that can be achieved using SVPWM is the radius of the largest circle that can be inscribed within the hexagon. This circle is tangential to the mid points of the lines joining the ends of the active space vector. Thus the maximum obtainable fundamental output voltage is

$$|V_s^*| = \frac{2}{3} V_{dc} \cos(\pi/6) = \frac{1}{\sqrt{3}} V_{dc}$$

V. D-Q TRANSFORMATION.

The space vector concept, which is derived from the rotating field of induction motor, is used for modulating the inverter output voltage. In this modulation technique the three phase quantities can be transformed to their equivalent two-phase quantity either in synchronously rotating frame (or) stationary frame. From these two-phase components, the reference vector magnitude can be found and used for modulating the inverter output. The process of obtaining the rotating space vector is explained in the following section, considering the stationary reference frame. Considering the stationary reference frame let the three-phase sinusoidal voltage component be,

Va = VmSinωt

Vb = VmSin(ωt-2π/3)

Vc = VmSin(ωt-4π/3)

When this three-phase voltage is applied to the AC machine it produces a rotating flux in the air gap of the AC machine. This rotating resultant flux can be represented as single rotating voltage vector. The magnitude and angle of the rotating vector can be found by means of Clark's Transformation as explained below in the stationary reference frame. To implement the space vector PWM, the voltage the stationary d-q reference frame that consists of the horizontal (d) and vertical (q) axes as depicted in figure 7. From this figure, the relation between these two reference frames is $f_{dq0} = K_s f_{abc}$

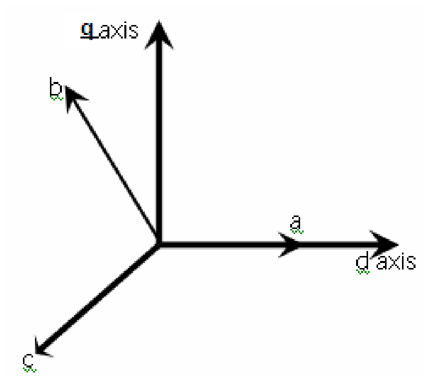

Fig.7.The relationship of abc reference frame and stationary d-q frame.

$$K_s = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & -\sqrt{3}/2 & -\sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix} . f_{dq0} = [f_d \quad f_q \quad f_0]^T . f_{abc}$$

$$K_s = [f_a \quad f_b \quad f_c]^T$$

Where,
f denotes either a voltage or a current variable.

As described in Fig.7 this transformation is equivalent to an orthogonal projection of [a b c]t onto the two-dimensional perpendicular to the vector [1 1 1]t (the equivalent d-q plane) in a three-dimensional coordinate system. As a result, six non-zero vectors and two zero vectors are possible. Six non-zero vectors (V1-V6) shape the axes of a hexagonal as depicted in Fig.8, and supplies power to the load. The angle between any adjacent two non-zero vectors is 60 degrees. Meanwhile, two zero vectors (V0 and V7) and are at the origin and apply zero voltage to the load. The eight vectors are called the basic space vectors and are denoted by (V0, V1, V2, V3, V4, V5, V6, V7). The same transformation can be applied to the desired output voltage to get the desired reference voltage vector Vref in the d-q plane. The objective of SVPWM technique is to approximate the reference voltage vector Vref 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 Vref in the same period

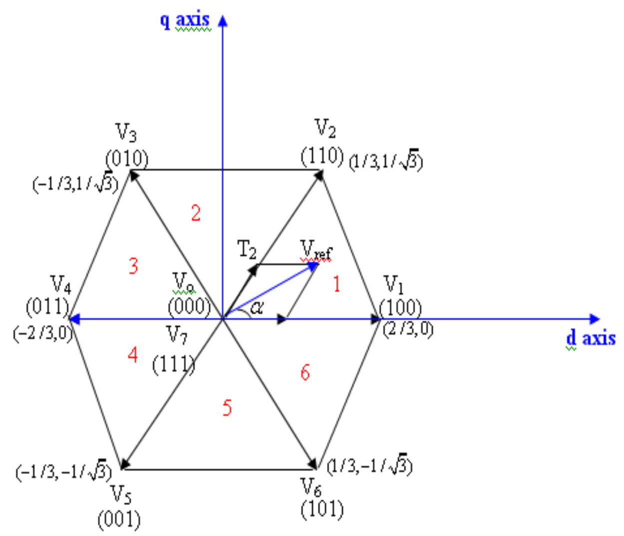

Fig.8 Basic switching, vectors and sectors.

Switching States:

Table 3: Switching patterns and output vectors.

Voltage	Switching Sectors			Line to neutral voltage			Line to line voltage		
	A	B	C	Van	Vbn	Vcn	Vab	Vbc	Vo
V0	0	0	0	0	0	0	0	0	0
V1	1	0	0	2/3	-1/3	-1/3	1	0	-1
V2	1	1	0	1/3	1/3	-2/3	0	1	-1
V3	0	1	0	-1/3	2/3	-1/3	-1	1	0
V4	0	1	1	-2/3	1/3	1/3	-1	0	1
V5	0	0	1	-1/3	1/3	2/3	0	-1	1
V6	1	0	1	1/3	-2/3	1/3	1	-1	0
V7	1	1	1	0	0	0	0	0	0

For 180° mode of operation, there exist six switching states and additionally two more states, which make all three switches of either upper arms or lower arms ON. To code these eight states in binary (one-zero representation), it is required to have three bits (23 = 8). And also, as always upper and lower switches are commutated in complementary fashion, it is enough to represent the status of either upper or lower arm switches. In the following discussion, status of the upper bridge switches will be represented and the lower switches will it's complementary. Let "1" denote the switch is ON and "0" denote the switch in OFF. Table3 gives the details of different phase and line voltages for the eight states.[5]

VI. MATLAB/SIMULINK MODEL

In proposed work, i.e., the V/f control of three phase induction motor using space vector modulation is done by MATLAB R2010A. The DC voltage source is directly connected to inverter. The inverter is consist of cascade connected inverters i.e. 2 level inverter, which feeds three phase induction motor. An open loop speed control based on constant V/f ratio technique is tried for a 15: 5.4 HP (4KW) 400 V 50Hz 1430 RPM asynchronous machine.

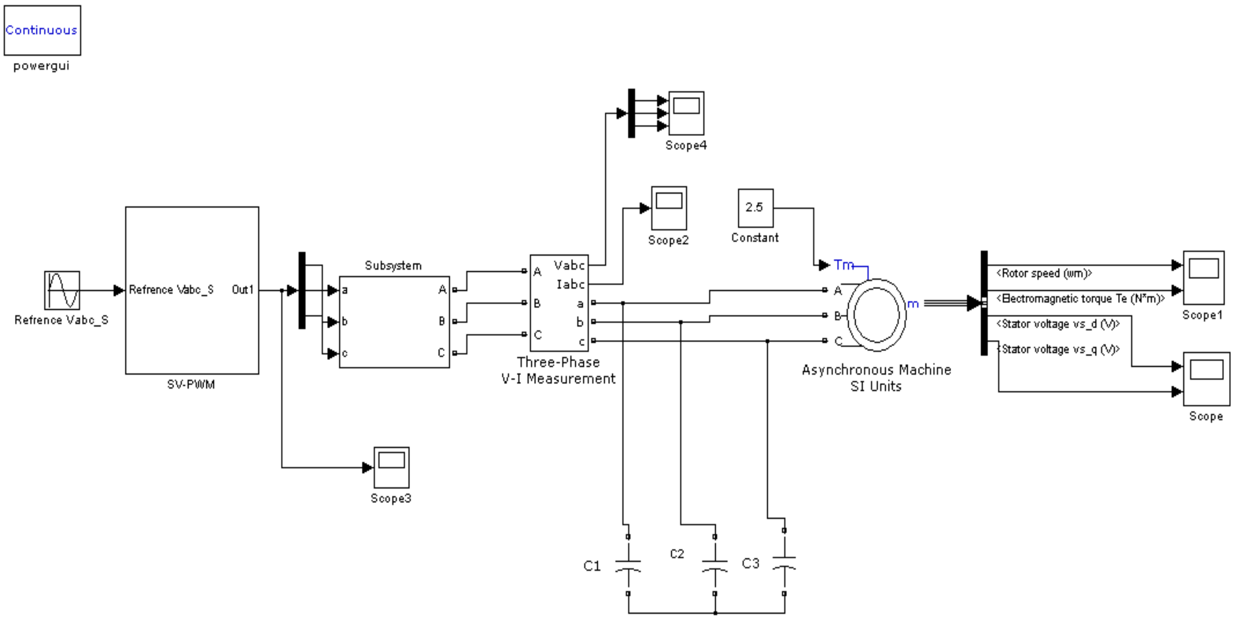

Fig.9.SIMULINK Model

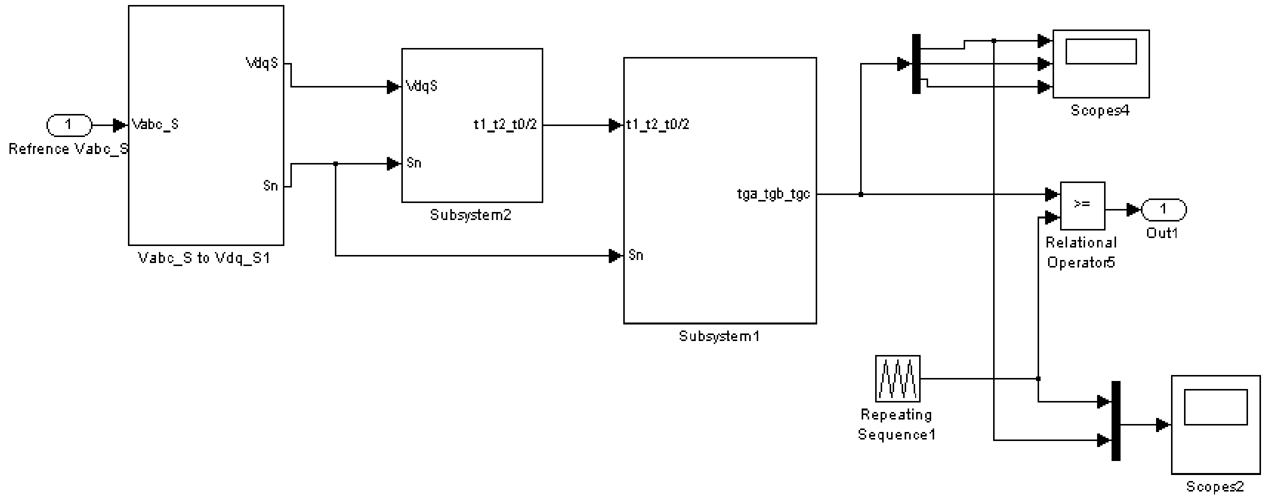

Fig.10.Space Vector Modulation based pulse generating block

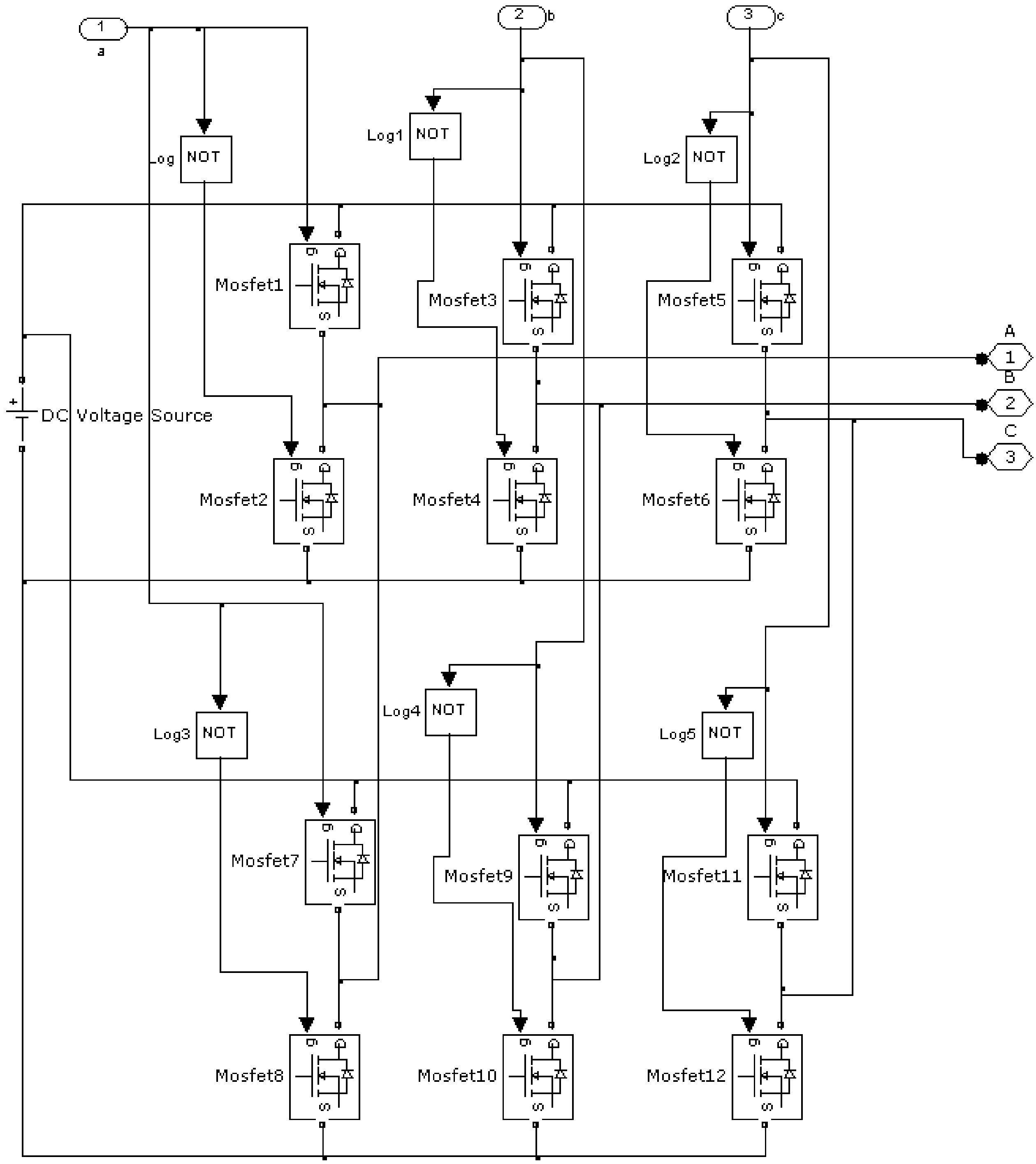

Fig.11.Three phase inverter block

VII. SIMULATION RESULT

Simulation of the proposed system, the space vector modulation technique is used to control the two level three phase inverter. An open loop speed control based on constant V/f ratio technique is tried for a 5.4HP, 400V, 50 Hz asynchronous machine. The torque applied to asynchronous machine is 2.5 and the speed was found to be settling from the initial value to the final value. The results are shown below.

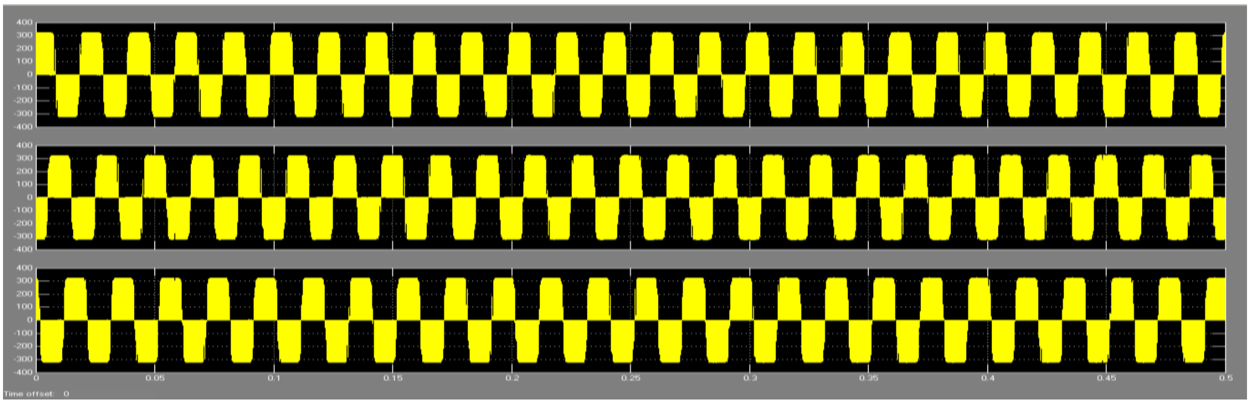

Fig.12.Inverter output voltage V_a,V_b,V_c

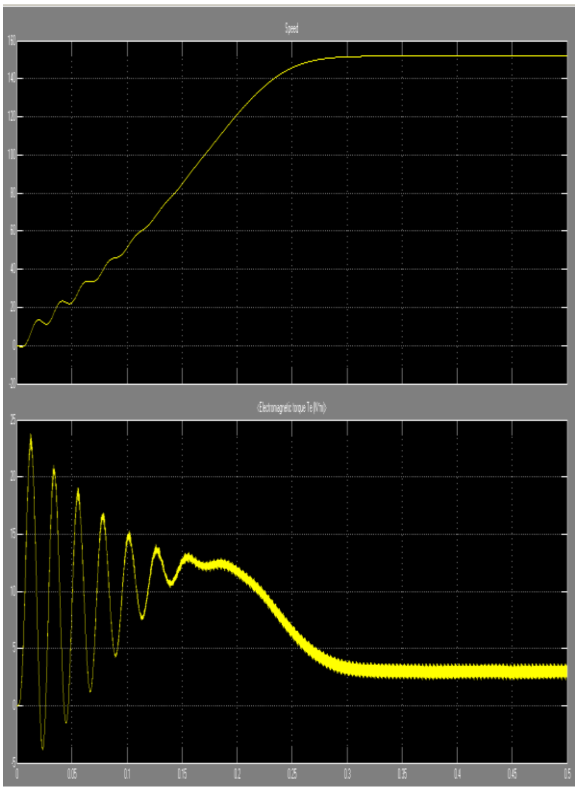

Fig.13.Speed and Torque

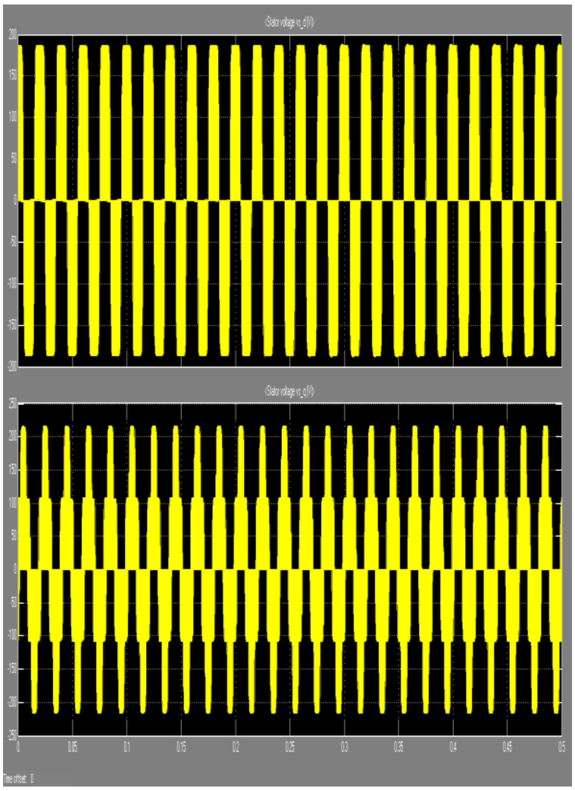

Fig.14.Stator Voltages Vd,Vq

VIII. CONCLUSION

This simulation work deals with V/f control of three phase induction motor through two level inverter using space vector modulation technique. The SVPWM techniques offers better harmonic reduction, fast switching frequency and better utilization of DC link.

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