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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]

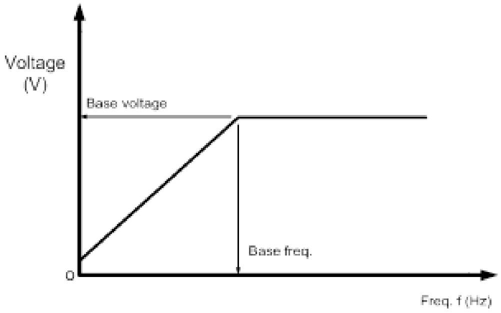

Fig. 1 Voltage-Frequency under constant V/f principle.

III. THREE-PHASE VOLTAGE SOURCE INVERTER AND SPACE VECTORS

The topology of a three-leg voltage source inverter is shown in Fig. 2. Because of the constraint that the input lines must never be shorted and the output current must always be continuous a voltage source inverter can assume only eight distinct topologies. These topologies are shown on Fig. 3. Six out of these eight topologies produce a nonzero output voltage and are known as non-zero switching states and the remaining two topologies produce zero output voltage and are known as zero switching states.

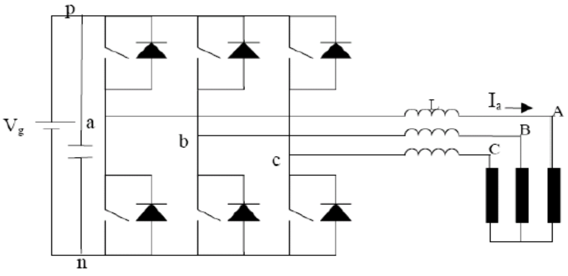

Fig. 2 The topology of a three-leg voltage source inverter

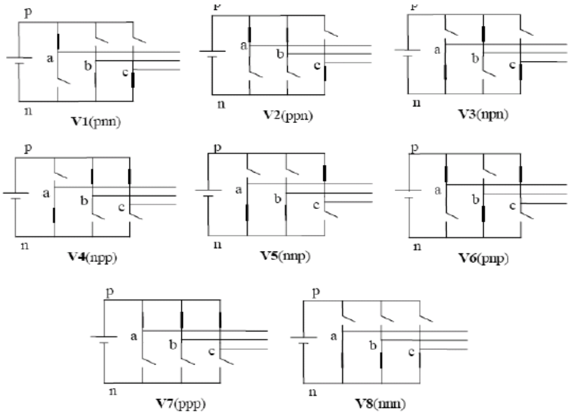
V1(pnn) V2(ppn) V3(npn) V4(npp) V5(nnp) V6(pnp) V7(ppp) V8(nnn)

Fig. 3 Eight switching state topologies of a voltage source inverter.

IV. VOLTAGE SPACE VECTORS

Space Vector Modulation (SVM) for three-leg VSI is based on the representation of the three phase quantities as vectors in a two-dimensional αβ plane. This is illustrated here for the sake of completeness. Considering topology 1 of Fig. 3, which is repeated in Fig. 4(a) we see that the line voltages V_{ab}, V_{bc}, and V_{ca} are given by

$$V_{ab} = Vg$$
$$V_{bc} = 0$$
$$V_{ca} = -Vg$$

This can be represented in the αβ, plane as shown in Fig. 4(b), where voltages V_{ab}, V_{bc}, and V_{ca} are three line voltage vectors displaced 120 in space. The effective voltage vector generated by this topology is represented as V1(pnn) in Fig. 4(b). Here the notation “pnn” refers to the three legs/phases a,b,c being either connected to the positive dc rail (p) or to the negative dc rail (n). Thus “pnn” corresponds to phase a being connected to the positive dc rail and phases b and c being connected to the negative dc rail.

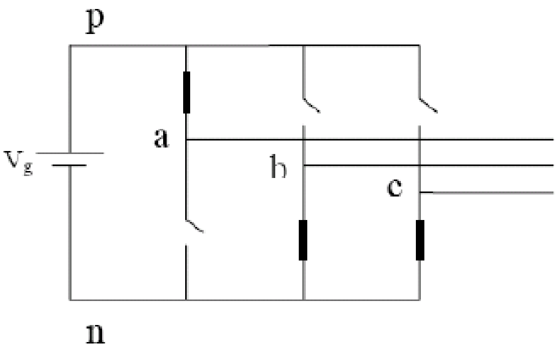

Fig. 4 (a) Topology 1-V1 (pnn) of a voltage source inverter.

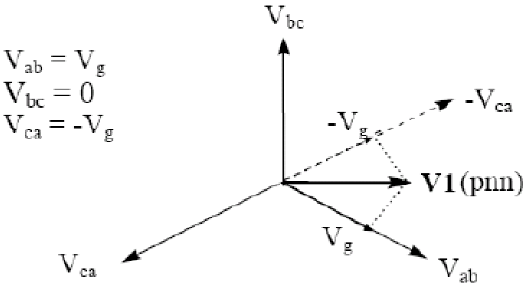

Fig. 4(b) Representation of topology 1 in the αβ plane.

Proceeding on similar lines the six non-zero voltage vectors (V1 - V6) can be shown to assume the positions shown in Fig.5. The tips of these vectors form a regular hexagon (dotted line in Fig. 5). We define the area enclosed by two adjacent vectors, within the hexagon, as a sector. Thus there are six sectors numbered 1 - 6 in Fig. 5.

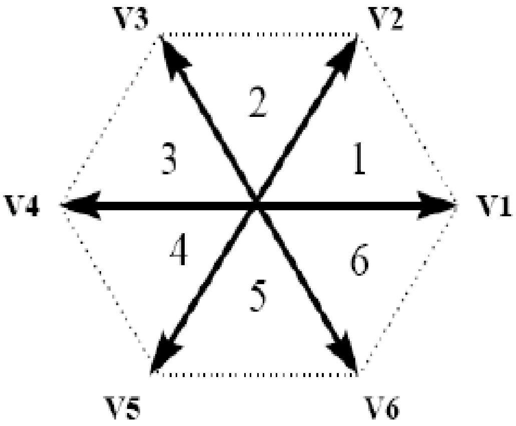

Fig. 5 Non-zero voltage vectors in the αβ plane

Considering the last two topologies of Fig. 4 which are repeated in Fig. 6(a) for the sake of convenience we see that the output line voltages generated by this topology are given by

$$V_{ab} = 0$$
$$V_{bc} = 0$$
$$V_{ca} = 0$$

These are represented as vectors which have zero magnitude and hence are referred to as zero-switching state vectors or zero voltage vectors. They assume the position at origin in the αβ, plane as shown in Fig. 6(b). The vectors V1-V8 are called the switching state vectors (SSVs).

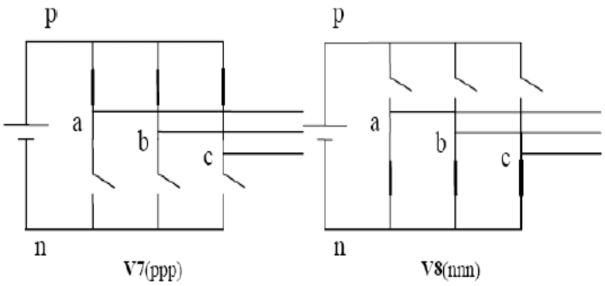

Fig. 6(a): Zero output voltage topologies

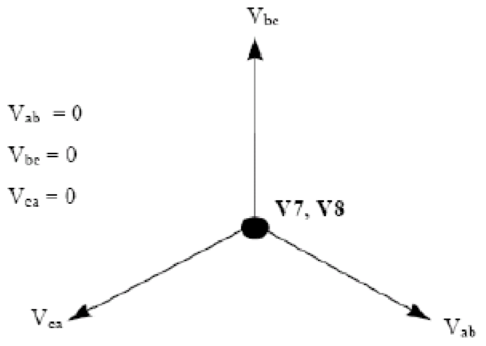

Fig. 6(b): Representation of the zero voltage vectors in the αβ plane

V. SPACE VECTOR MODULATION

Consider the 3-phase inverter shown below (Fig. 7)

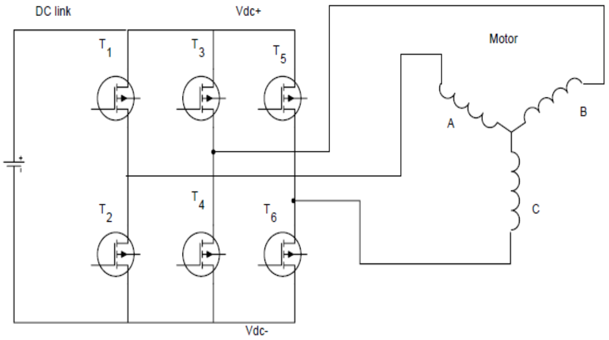

Fig. 7 Typical Inverter Bridge Configuration

The six-switch combination in the inverter has eight permissible switching states. Table 1 summaries these states along with the corresponding line to neutral voltage applied to the motor.

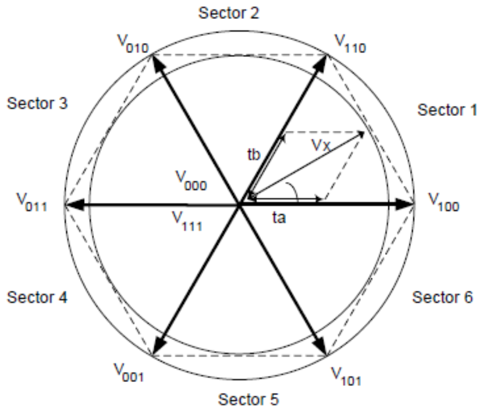

Fig. 8 Space Vector Diagram – Line to Neutral Voltages

State	On Devices	V_{an}	V_{bn}	V_{cn}	Space Voltage Vector
0	T2,T4,T6	0	0	0	V_0(000)
1	T1,T4,T6	$2/3V_{dc}$	$-1/3V_{dc}$	$-2/3V_{dc}$	V_1 (100)
2	T1,T3,T6	$1/3V_{dc}$	$1/3V_{dc}$	$-1/3V_{dc}$	V_2 (110)
3	T3,T2,T6	$-1/3V_{dc}$	$2/3V_{dc}$	$-1/3V_{dc}$	V_3 (010)
4	T1,T4,T6	$-2/3V_{dc}$	$1/3V_{dc}$	$1/3V_{dc}$	V_4 (011)
5	T1,T4,T6	$-1/3V_{dc}$	$-1/3V_{dc}$	$2/3V_{dc}$	V_5 (001)
6	T1,T4,T6	$1/3V_{dc}$	$-2/3V_{dc}$	$1/3V_{dc}$	V_6 (101)
7	T1,T4,T6	0	0	0	V_7 (111)

Table 1 Inverter Switching States

VI. REFERENCE VECTOR

The inverter has six states when a voltage is applied to the motor and two states (0 and 7) when the motor is shorted through the upper or lower transistors resulting in zero volts being applied to the motor. The six vectors including the zero voltage vectors can be expressed geometrically as shown in Fig. 9. SVPWM seeks to average out the adjacent vectors for each sector. Using the appropriate PWM signals a vector is produced that transitions smoothly between sectors and thus provide sinusoidal line to line voltages to the motor. In order to generate the PWM signals that produce the rotating vector, formulae must be derived to determine the PWM time intervals for each sector.

The reference vector is represented in a αβ-plane. This is a two dimensional plane transformed from a three-dimensional plane containing the vectors of the three phases. The switches being ON or OFF are determined by the location of the reference vector on this αβ-plane.

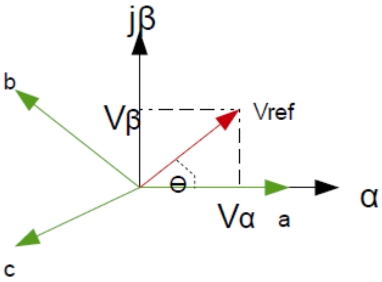

Fig. 9 The reference vector in the two and three dimensional plane

It is assumed that the three-phase system is balanced:

$$V_{a0} + V_{b0} + V_{c0} = 0$$

These are the instantaneous phase voltages:

$$V_a = V\sin(\theta)$$

$$V_b = V\sin(\theta + \frac{2\pi}{3})$$

$$V_c = V\sin(\theta + \frac{4\pi}{3})$$

When the three phase voltages are applied to a AC machine a rotating flux is created. This flux is represented as one rotating voltage vector. The magnitude and angle of this vector can be calculated with Clark's Transformation:

$$V_{ref} = V_\alpha + jV_\beta = \frac{2}{3}\,(V_a + aV_b + a^2V_c)$$

a is given by

$$a = e^{j\frac{2\pi}{3}}$$

The magnitude and angle (determining in which sector the reference vector is in) of the reference vector is:

$$|V_{ref}| = \sqrt{{V_\alpha}^2 + {V_\beta}^2}$$

$$\theta = \tan^{-1}(\frac{V_\alpha}{V_\beta})$$

The reference voltage can then be expresses as:

$$V_\alpha + jV_\beta = \frac{2}{3}\,(V_a + e^{j\frac{2\pi}{3}}V_b + e^{-j\frac{2\pi}{3}}V_c)$$

Inserting the phase shifted values for Va, Vb and Vc gives:

$$\begin{aligned} V_\alpha + jV_\beta = \frac{2}{3}\,&(V_a + \cos(\frac{2\pi}{3})V_b + \cos(\frac{2\pi}{3})V_c) \\ &+ j\frac{2}{3}\,(\sin(\frac{2\pi}{3})V_b - \sin(\frac{2\pi}{3})V_c) \end{aligned}$$

Comparing both sides,

$$V_\alpha = \frac{2}{3}\,(V_a + \cos(\frac{2\pi}{3})V_b + \cos(\frac{2\pi}{3})V_c)$$

$$V_\beta = \frac{2}{3}\,(\sin(\frac{2\pi}{3})V_b - \sin(\frac{2\pi}{3})V_c)$$

The voltage vectors on the alpha and beta axis can then be described as:

$$\begin{pmatrix} V_\alpha \\ V_\beta \end{pmatrix} = \frac{2}{3}\begin{pmatrix} 1 & \cos\left(\frac{2\pi}{3}\right) & \cos\left(\frac{2\pi}{3}\right) \\ 0 & \sin\left(\frac{2\pi}{3}\right) & -\sin\left(\frac{2\pi}{3}\right) \end{pmatrix}\begin{pmatrix} V_a \\ V_b \\ V_c \end{pmatrix}$$

$$= \frac{2}{3}\begin{pmatrix} 1 & -\frac{1}{2} & \frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix}\begin{pmatrix} V_a \\ V_b \\ V_c \end{pmatrix}$$

$$V_\alpha = \frac{2}{3}\left(V_a - \frac{1}{2}V_b + \frac{1}{2}V_c\right)$$

$$V_\beta = \frac{2}{3}\left(\frac{\sqrt{3}}{2}V_b - \frac{\sqrt{3}}{2}V_c\right)$$

Having calculated Vα, Vβ, Vref and the reference angle, the first step is taken. The next step is to calculate the duration time for each vector V1-V6.

VII. SWITCHING TIME

Duty Cycle: For each sector there are 7 switching states for each cycle. It always starts and ends with a zero vector. This also means that there is no extra switching state needed when changing the sector. The uneven numbers travel counter clockwise in each sector and the even sectors travel clockwise. Duty cycle for sector 1 for sector 1 it goes through these switching states: 000-100-110-111-110-100-000, one round and then back again. This is during the time Tc and it has to be divided amongst the 7 switching states, three of them being zero vectors:

$$T_c = \frac{T_0}{4} + \frac{T_1}{2} + \frac{T_0}{2} + \frac{T_2}{2} + \frac{T_1}{2} + \frac{T_0}{4}$$

VIII. 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 R2014A. The DC voltage source is directly connected to inverter. The inverter feeds the supply to three phase induction motor. An open loop speed control based on constant V/f ratio technique is applied for a 5.4 HP (4 KW) 400 V 50Hz 1430 RPM asynchronous machine. Simulink model and space vector modulation based generating block are shown in Fig. 10 and Fig. 11 respectively.

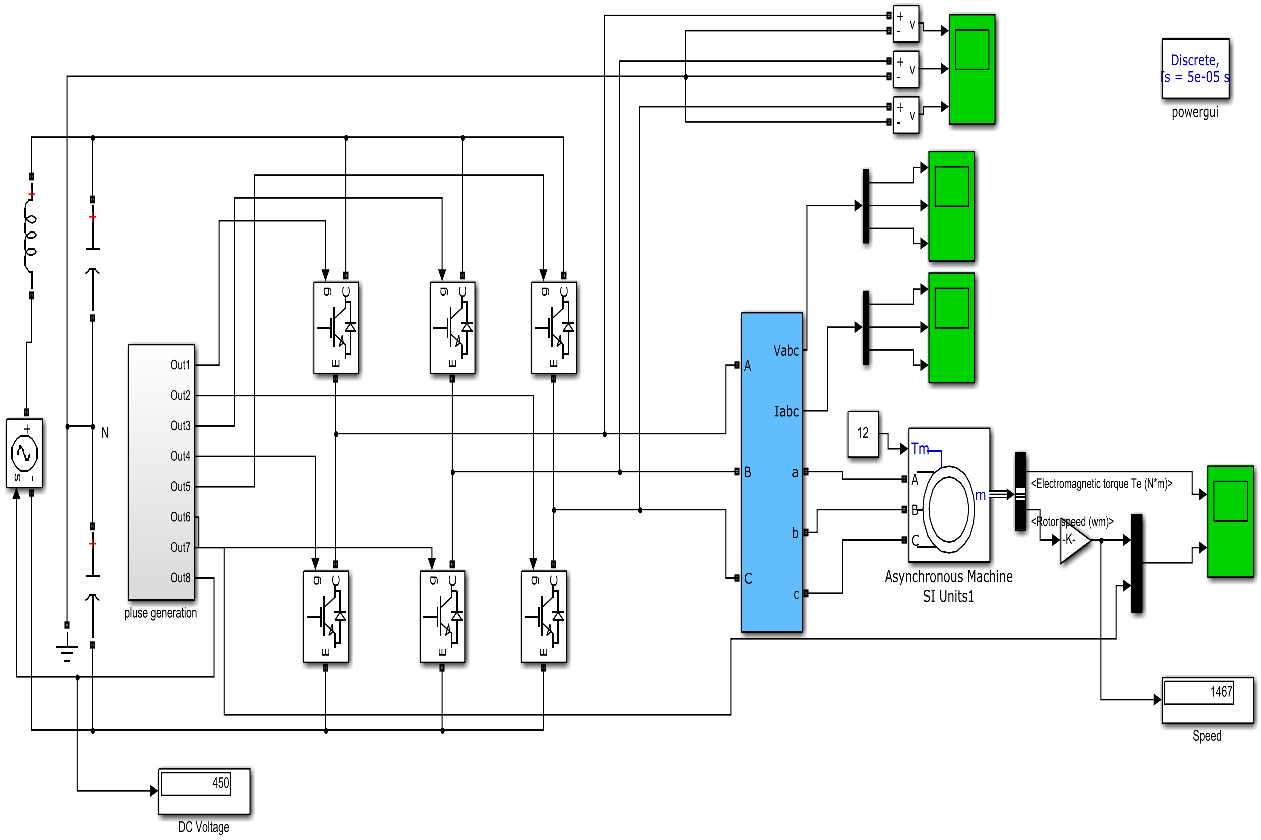

Fig. 10 SIMULINK Model

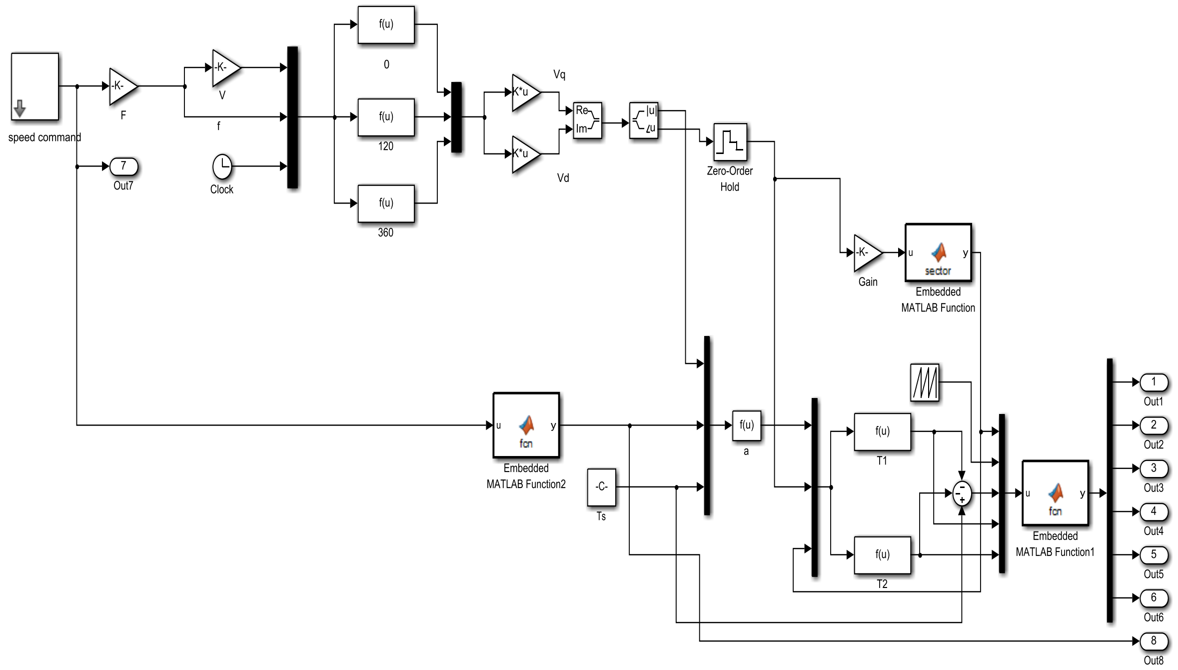

Fig. 11 Space Vector Modulation based pulse generating block

IX. SIMULATION RESULTS

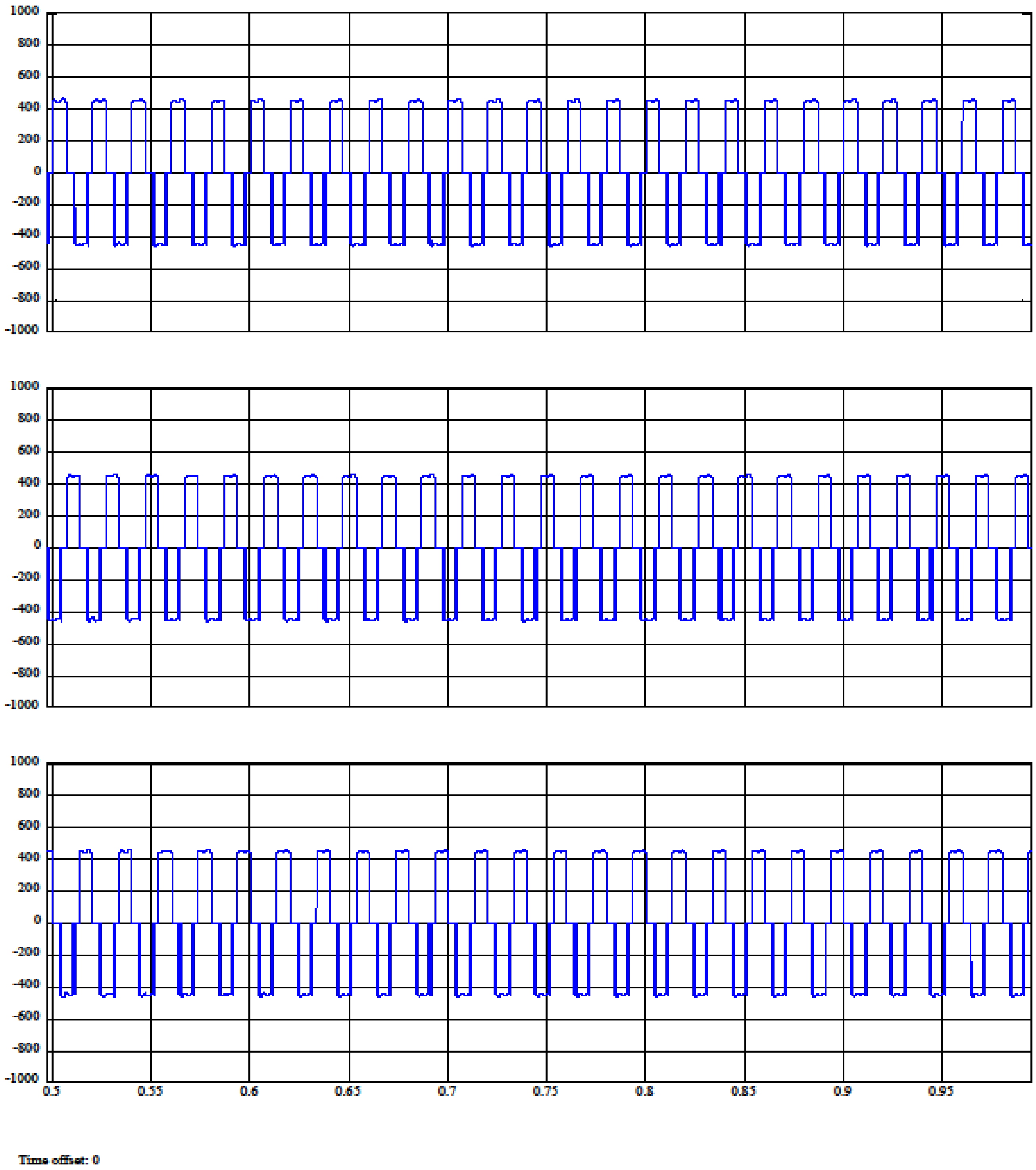

Fig. 12 Stator Line Voltages

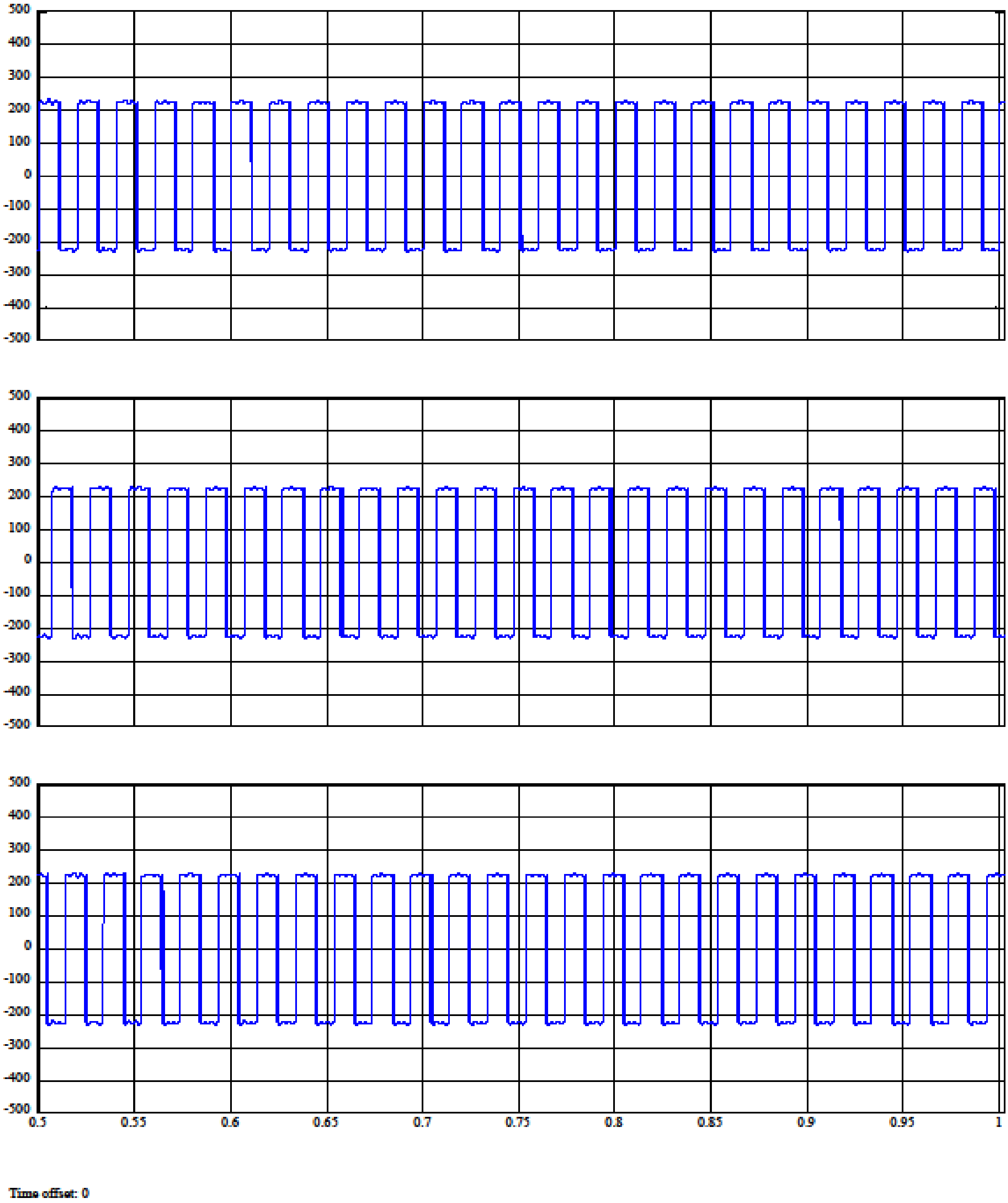

Fig. 13 Stator Phase Voltages

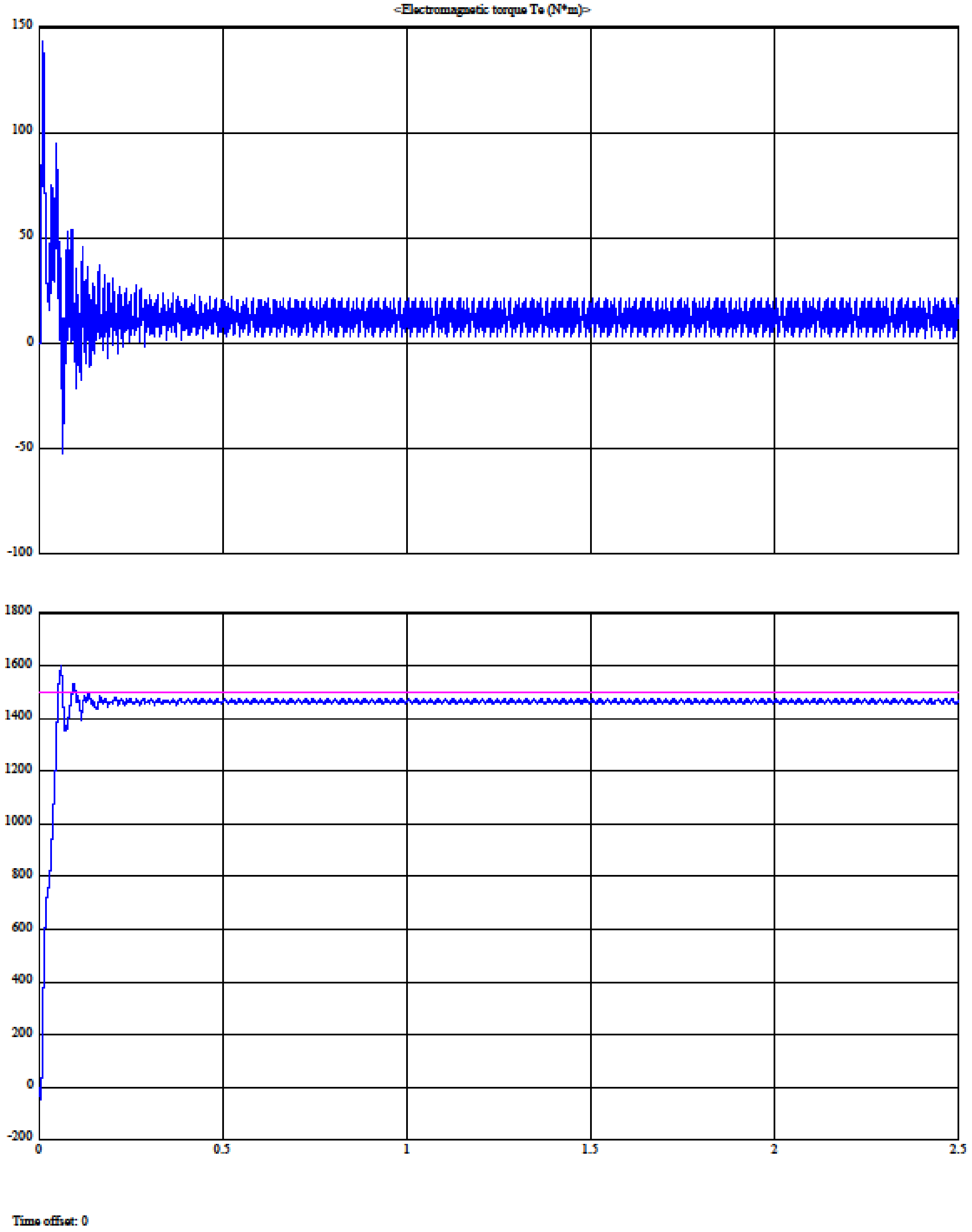

Fig. 14 Electromagnetic Torque and Speed

X. CONCLUSION:

This paper is presented for employing the inverter using space vector pulse width modulation (SVPWM) to drive three phase induction motor and controlling the speed of induction motor. Speed control of three phase induction motor using space vector pulse width modulation technique (SVPWM) is simulated by MATLAB. As we observe that controlling the speed of three phase induction motor by using space vector pulse width modulation is easy to operate. As three phase voltage decreases which is applied to the stator of induction motor then the frequency also decreases in same manner to maintain constant V/f ratio. The motor speed varies as voltage and frequency varies but V/f ratio remains constant.

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