

# An Induction Motor Control by Space Vector PWM Technique

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**Abstract** - This paper focuses on step by step development of space vector modulation for linear and over modulation region for controlling of induction motor. SVPWM increased voltage utilization factor up to 0.906 by adding the zero sequence voltage. It is possible to control the stator flux linkage and the electromagnetic torque by the optimum selection of inverter switching vectors using VSI. For that purpose constant V-Hz control used due to its simplicity and better response. In this paper simulation work is done on, control of induction motor using V-Hz principle by space vector modulation.

**Index Terms**— Electrical drive, SVPWM, Constant V/f control, Inverter, linear, Over-modulation

## I. INTRODUCTION

Most industrial process required some kind of control or adjustment for normal operation. Due to recent development in power electronic device it is easy to control high power and manage voltage, current and frequency as per requirement in process. In electrical variable speed drive (VSD) power converter control the flow of power to load supplied from source to control speed or torque.

Many PWM strategies developed over the years but SVPWM is considering as the best because of operate at constant switching frequency and gives better DC bus utilization. The control techniques for induction motor divided into two parts: scalar control and vector control. In this paper constant V/f scalar control is used because of simple to understand and implement.

In this paper design of VSI using space vector modulation is presented for controlling of induction motor. A simple constant V/f technique by open and closed loop used for control the machine speed. Analysis is done using matlab/Simulink.

## II. CONSTANT V/F PRINCIPLE

The relationship between rotor speed, synchronous speed, and slip is given by,

$$S = \frac{N_s - N_r}{N_s} \quad (1)$$

$$N_r = N_s(1 - S) \quad (2)$$

$$\text{Rotor speed } N_r = \frac{120f}{P}(1 - S) \quad (3)$$

Thus, speed of an induction motor can be varied by changing frequency (f), slip (S), or number of poles (P) for which the winding are wound.

The scalar control is based on changing any one parameter like frequency, slip or pole. The speed can be changed by increasing or decreasing in frequency but this result in change of impedance. This in turn is the reason for change in current drawn by the motor. Reduction in supply frequency increase the air gap flux which result in saturation of the core. To avoid these problems, it is necessary to vary the frequency and the voltage at the same time. According to induced voltage equation (4) constant V/HZ control gives constant flux in the stator.[1]

$$\frac{V_{rms}}{f} = 4.44N\phi\zeta \quad (4)$$

Where

$V_{rms}$ =induced voltage in the stator  
 f= frequency of the supplied voltage  
 N=number of turns  
 $\phi$ =flux linkage in stator  
 $\zeta$ =constant of coil

The torque-speed equation (5) of induction motors reveals the voltage-torque-frequency relation, given by,

$$T_{air-gap} = \frac{3}{2\omega_m} I_r^2 \frac{R_r}{S} \tag{5}$$

From equation (5) it reveals that frequency and torque is inversely proportional, while voltage is directly proportional to torque.

$$T \approx \frac{V^2}{2\pi f} \approx \frac{V}{f} \tag{6}$$

Torque developed by induction motor remains constant if V/f ratio is constant up to the base speed. Beyond base speed torque is decrease in inverse proportion to increase in frequency because voltage can't be higher than rated value of equipment.

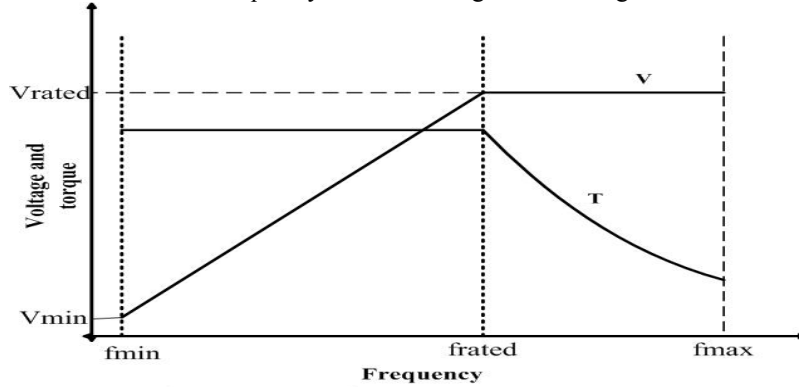


Fig. 1-Frequency-voltage-torque curve

Other than the variation in speed, the torque-speed characteristics of the V/F control reveal the following:[2][7]

- The starting current is low.
- The stable operating region of the motor is increased. Instead of simply running at its base/ rated speed (NB), the motor can be run typically from 5% of the synchronous speed (NS) up to the base speed. The torque generated by the motor can be kept constant throughout this region.
- Since almost constant rated torque is available over the entire operating range; the speed range of the motor becomes wider.

**A. Open loop speed control**

In open loop control there is feedback so response is slow, so it applicable where accuracy is not primary disquiet. As per shown in fig 2 frequencies is define from required speed and rough assumption is made that motor follow its synchronous speed. Required voltage is determined from V/f curve given by motor manufacturer.

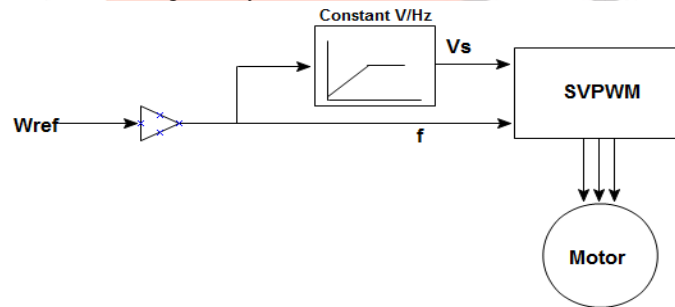


Fig. 2-diagram of open loop V/f control

Due to simplicity, low cost and immune from feedback system, open loop V/f control system is widely used in industry where precision is not great concern.

**B. Close loop speed control**

Major disadvantage in open loop control is that this technique doesn't control the torque so desired torque accessible only at nominal operating point. Torque control is provided by close loop and it gives more precious speed control.

As shown in block diagram of close loop control speed is sensed by tachometer and it's compared with reference speed which gives error signal. Error signal is fed to PID controller which tries to reduce error to zero and according to PID output frequency and voltage is define for SVPWM inverter.

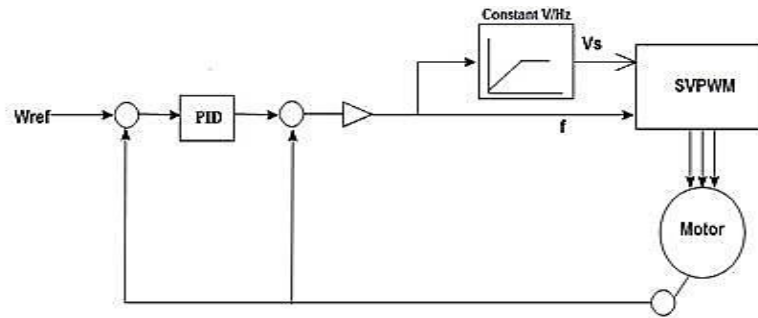


Fig. 3-diagram of close loop V/f control

**III. SPACE VECTOR MODULATION**

Variable voltage and frequency is obtained from VSI. Many PWM techniques developed over years but ideal modulation scheme looks for lower harmonics generation, linear modulation range and low switching losses. SVPWM fulfil all requirements and also operate at a constant switching frequency so it considers as best PWM techniques. SVPWM treats inverter as whole while traditional PWM techniques consider as N single phase inverter tied together.[4]

Three phase inverter have eight possible combinations; two of them are a null value because all terminals are connected to same potential either at ground or at Vcc. The remaining six combinations give non-zero voltage and all are represented as a state which form hexagon in plane spanning 60° each.

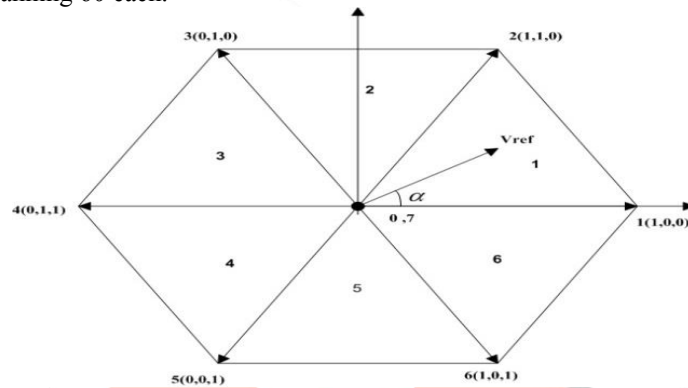


Fig. 4-Phase voltage representation

As shown in fig 4 each state is represented by three numbered coordinate system which is corresponding to the state of the inverter leg. 0 represent conduction of lower switch and 1 represent conduction of upper switch. There is a command vector which is rotate at same angular speed of desired frequency and position of vector gives instantaneous voltage output of the inverter. When vector lies between two state vectors, a vector sum is made in order to obtain desired voltage, given by

$$V = V_a + V_b + V_0 \tag{7}$$

Where  $V_a$  and  $V_b$  are the two nearby active state vector, and  $V_0$  is a null vector; which become necessary because it helps to control the magnitude of applied voltage by adding time on commutation sequence where energy is not applied to the load.[4]

According to the modulation index, PWM range is divided into linear and over-modulation range. The modulation index for PWM inverter is define by,[5]

$$MI = V^* / \left( \frac{2}{\pi} V_{dc} \right) \tag{8}$$

Where  $V^*$  is phase voltage reference and  $V_{dc}$  is input voltage to inverter.

*A. Linear modulation range*

In linear modulation range trajectory of reference voltage vector is inside the hexagon so it generates sinusoidal output voltages. To calculate the time of application of different vector, consider fig 5, depicting the position of different available space vectors and the reference vector in the first sector. From fig 5 times for application of active space vector is found as,[3]

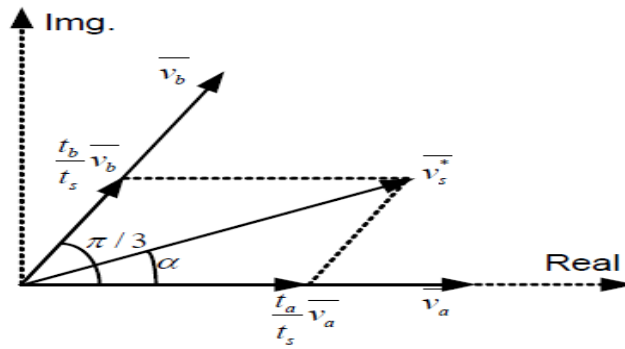


Fig. 5-time calculation for application of space vector

$$t_a = \frac{V \sin(\pi/3 - \alpha)}{V_a \sin(2\pi/3)} \tag{9}$$

$$t_b = \frac{V \sin(\alpha)}{V_b \sin(2\pi/3)} \tag{10}$$

$$t_0 = t_s - t_a - t_b \tag{11}$$

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

Similarly for other sector application time of active vector given by volt-time balance theory is as per,

$$T_a = T_s \frac{V \sin(n\pi/3 - \alpha)}{V_a \sin(2\pi/3)} \tag{12}$$

$$T_b = T_s \frac{V \sin(\alpha - (n-1)\pi/3)}{V_a \sin(2\pi/3)} \tag{13}$$

$$T_0 = T_s - (T_a + T_b) \tag{14}$$

To obtain optimum harmonics performance and for fixed switching frequency from SVPWM, each leg change its state only once in a single switching period. To achieve half wave symmetry switching period is divide into 7 parts and at starting zero vector is applied for 1/4<sup>th</sup> of the zero vector time. Then zero vectors followed by two active vectors in half cycle and next half cycle are mirror image of the first half.

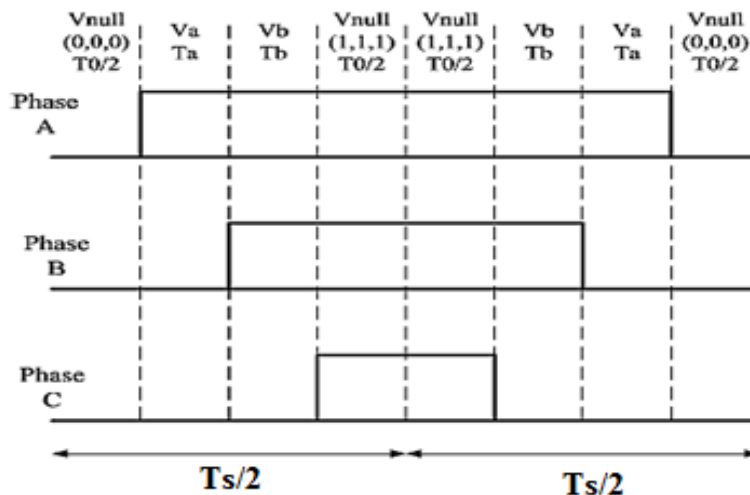


Fig. 6-space vector disposition for one switching period in sector 1

For sinusoidal reference space vector, maximum output voltage magnitude is largest circle that can be inscribed within the hexagon. This circle is tangential to mid points of lines joining the ends of the active space vector.

For sinusoidal reference space vector maximum fundamental output is given by,

$$V = \frac{2}{3} V_{dc} \cos(\pi/6) = \frac{1}{\sqrt{3}} V_{dc} \tag{15}$$

*B. Over-modulation range*

In general, a standard motor supplied from a PWM inverter is unable to operate at its rated voltage and power at rated speed. To obtain sufficient voltage, operating the inverter in the over modulation region is required.[6]

The transition from a PWM wave to a six-step in over-modulation range, trajectory of reference voltage is excursive the hexagon boundary; as a consequence, there is a loss of fundamental voltage in that region. So boundary of hexagon is limit for the reference voltage which is given by equation 15.

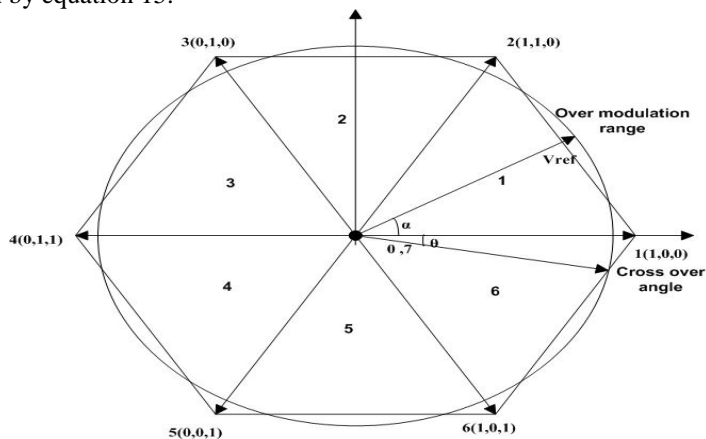


Fig. 7-over-modulation region

As shown in fig 7 that the command vector intersects the hexagon at an angle  $\theta$  which is known as the crossover angle. In over-modulation region inverter cannot generate output voltage as large as the reference since the maximum output is limited up to the side of the hexagon.[5] When command vector leaves the hexagon  $T_0$  vanishes. Then, the switching interval is given by,

$$T_{a1} = \frac{T_s}{2} \frac{T_a}{T_a + T_b} \tag{16}$$

$$T_{b1} = \frac{T_s}{2} \frac{T_b}{T_a + T_b} \tag{17}$$

IV. MATLAB/SIMULINK MODEL

For the analysis of V/f drive matlab/Simulink environment is used here because of its simplicity and user friendly environment. In fig 8 subsystem of space vector is shown in which first block generate three phase sinusoidal waveform according to given voltage and frequency reference. In second block three phase quantity is converted into two phases and according to them Vref and angle is calculated. As per reference application time for vector and switching time for inverter switch is calculated. According to switching time gate signal is generated.

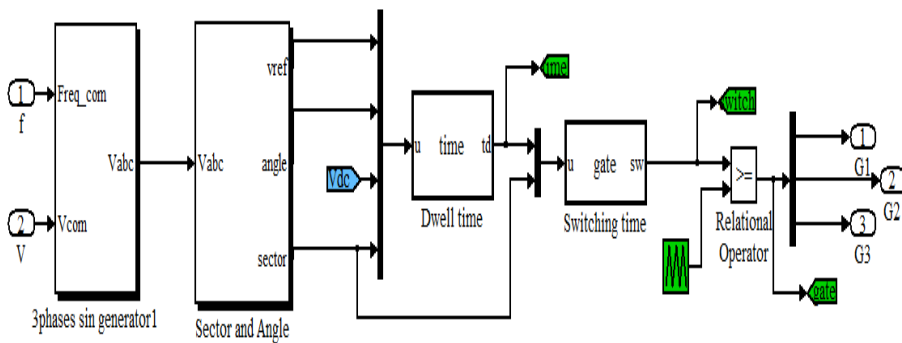


Fig. 8 Sub-system for SVPWM

In fig 9, waveform of angle and sector is shown according to them dwell time is calculated which convert to switching time. Waveform of dwell time and switching time is also shown in fig 10 ad11.

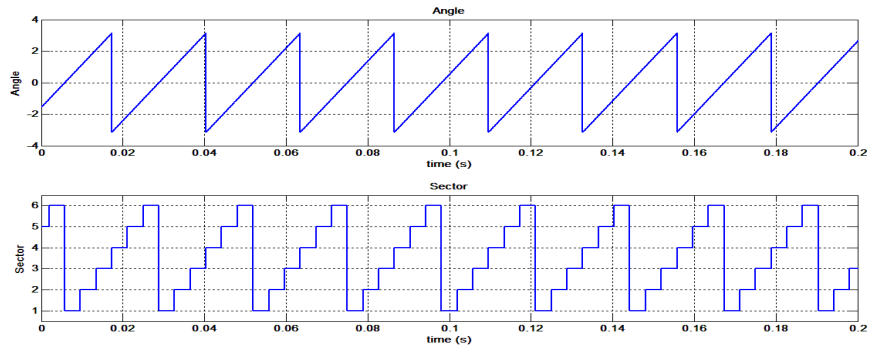


Fig. 9 angle and sector

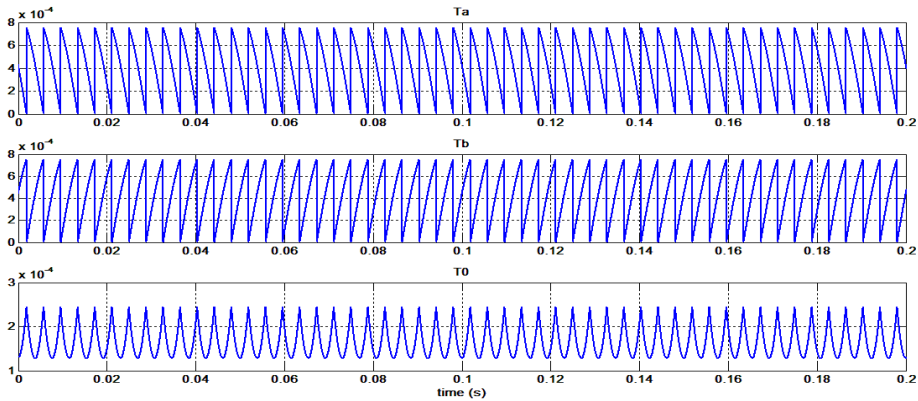


Fig. 10 dwell time

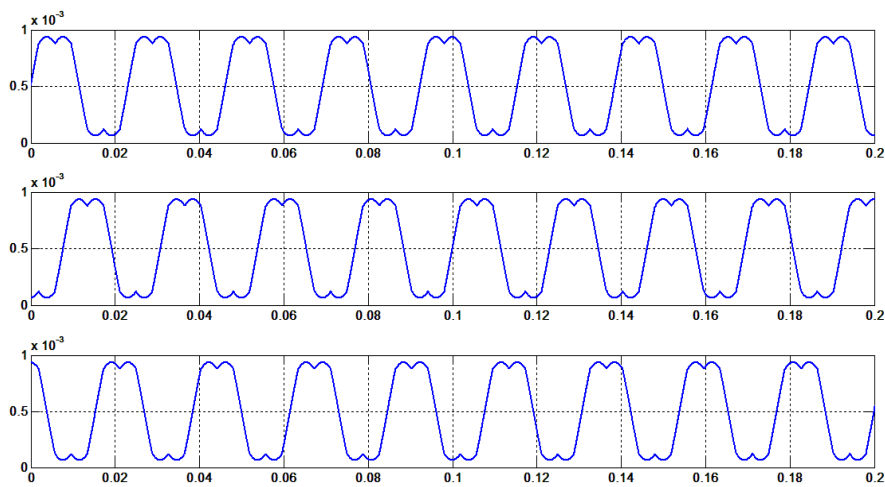


Fig. 11 application time for switch

In following fig Simulink model of V/f drive for both loops is shown. In open loop there is no feedback loop. In closed loop system motor speed is compared with reference to generate error signal. PID controller is used for minimize the error.

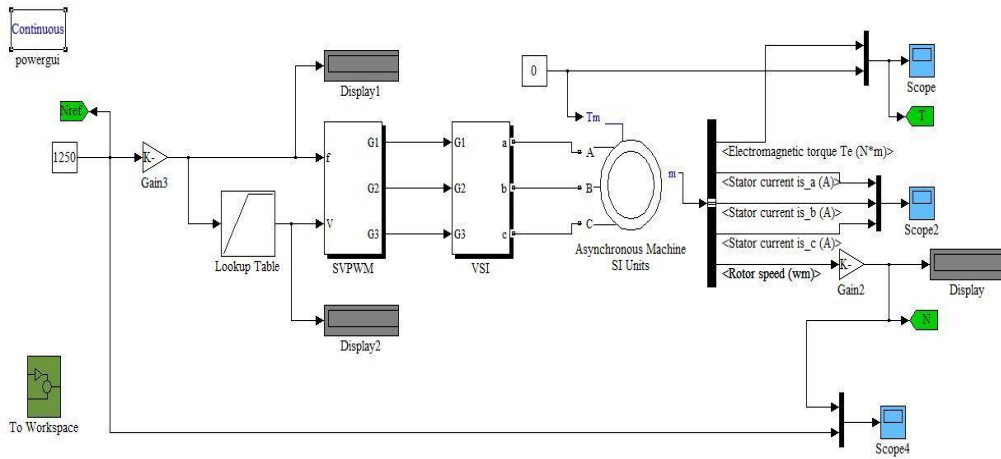


Fig. 12-simulink model of open loop V/F drive

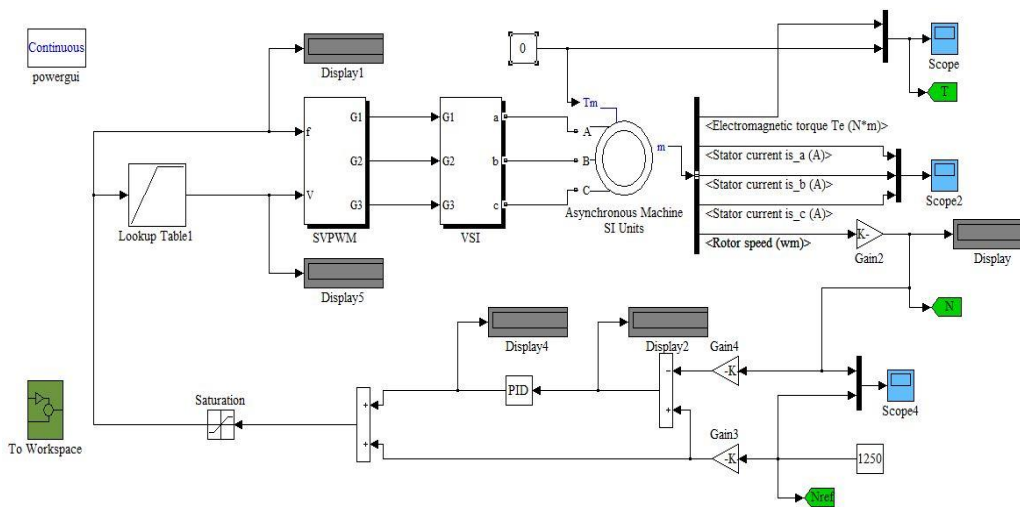


Fig. 13-Simulink model of closed loop V/f drive

For analysis purpose parameter is consider as per table 1 and table 2.

TABLE 1 SVPWM PARAMETER

Vdc	DC link voltage	400 V
f	fundamental frequency	50 Hz
t <sub>s</sub>	sampling time	0.001 s
f <sub>z</sub> = 1/t <sub>s</sub>	switching frequency	1 KHz

TABLE 2 MOTOR PARAMETER

V <sub>line</sub>	Line to line voltage	400 V
f	Frequency	50 Hz
P <sub>n</sub>	Nominal Power	5.4 HP
J	Inertia	0.0131 Kg <sup>m</sup> <sup>2</sup>
p	Pole pair	2

In fig (14-17) wave form of gate signal and phase voltage is shown.



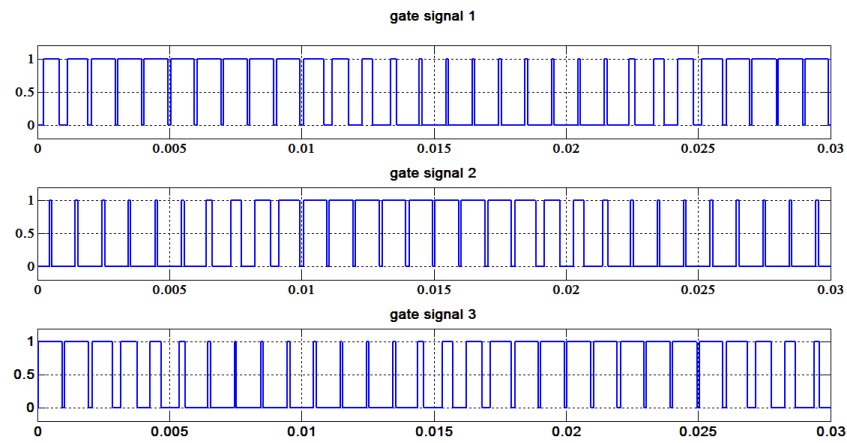


Fig. 14-gate signal for linear modulation

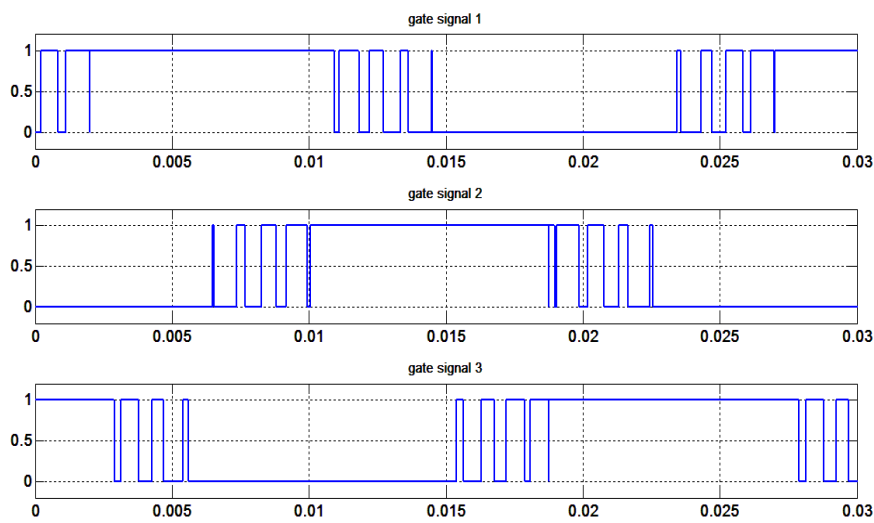


Fig. 15-gate signal for over modulation

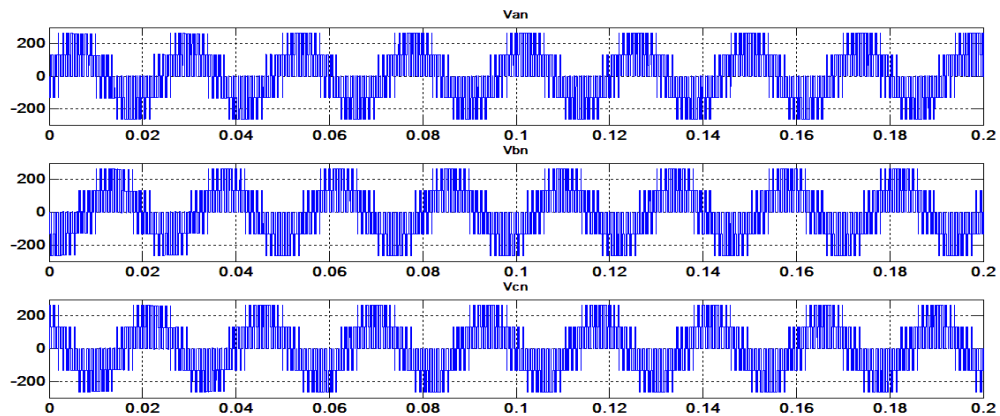


Fig. 16-phase voltage for linear modulation



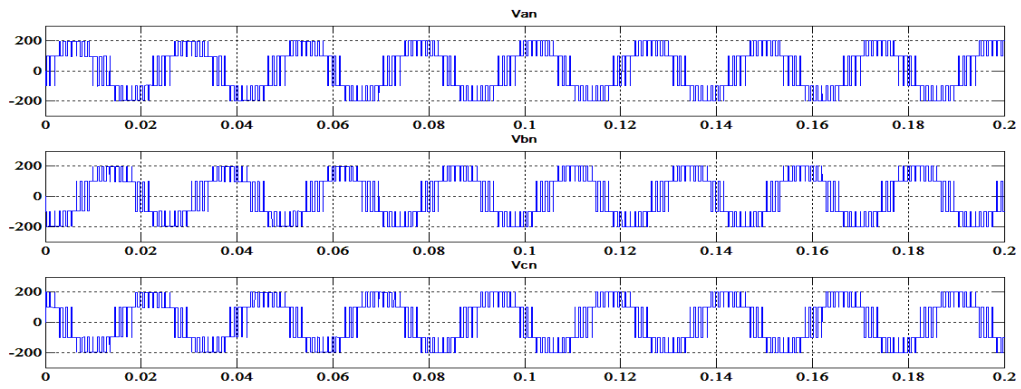
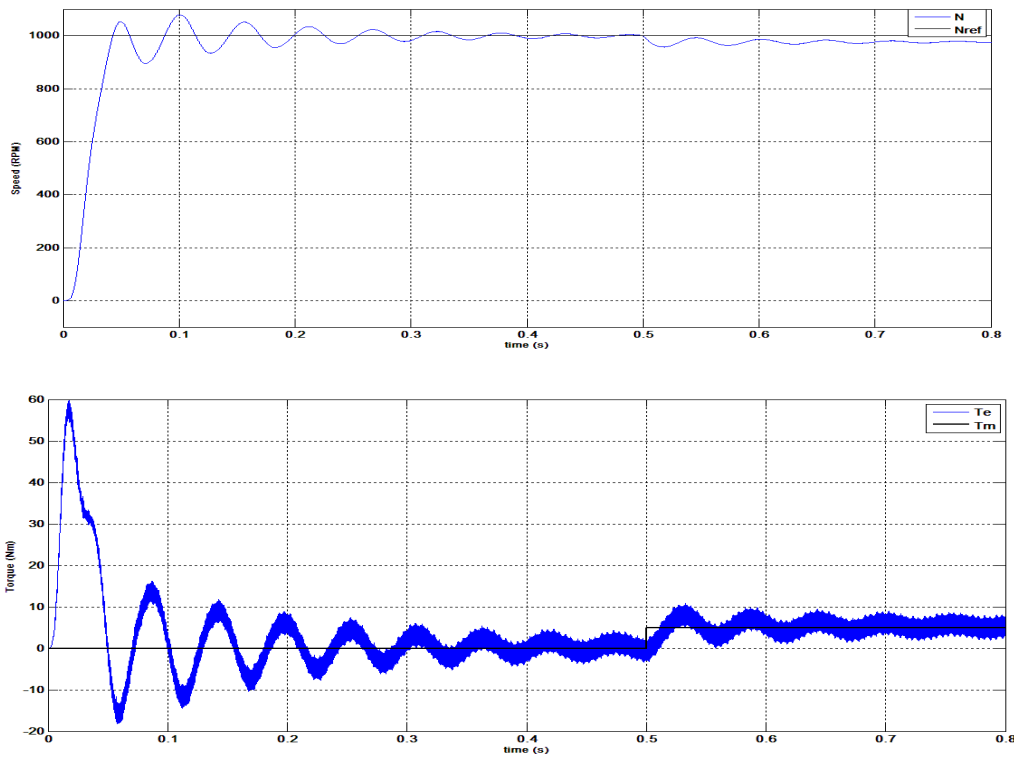


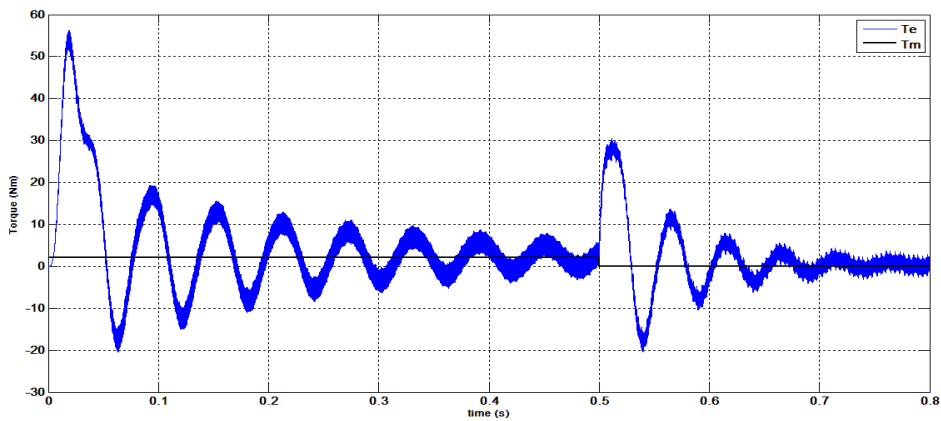
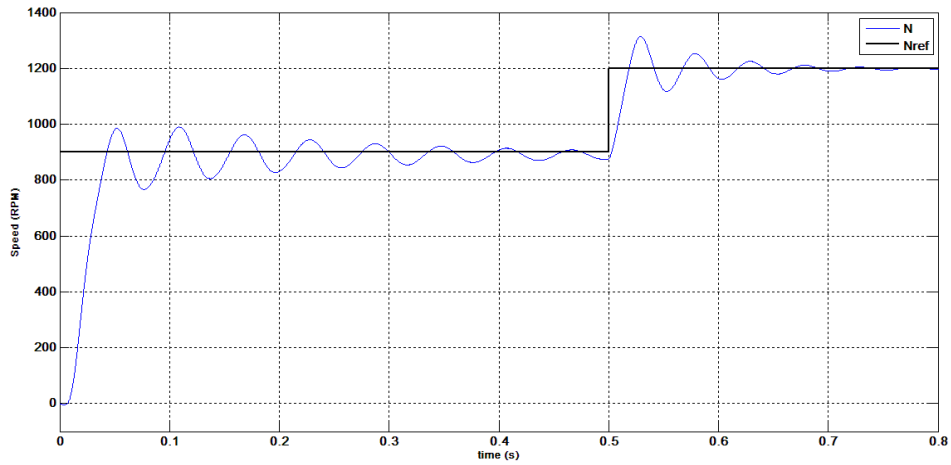
Fig. 17-phase voltage for over modulation

In following figure speed and torque response of motor for different set point is shown. In I.M. response 1<sup>st</sup> and 2<sup>nd</sup> are for open loop control and 3<sup>rd</sup> and 4<sup>th</sup> are for closed loop control.

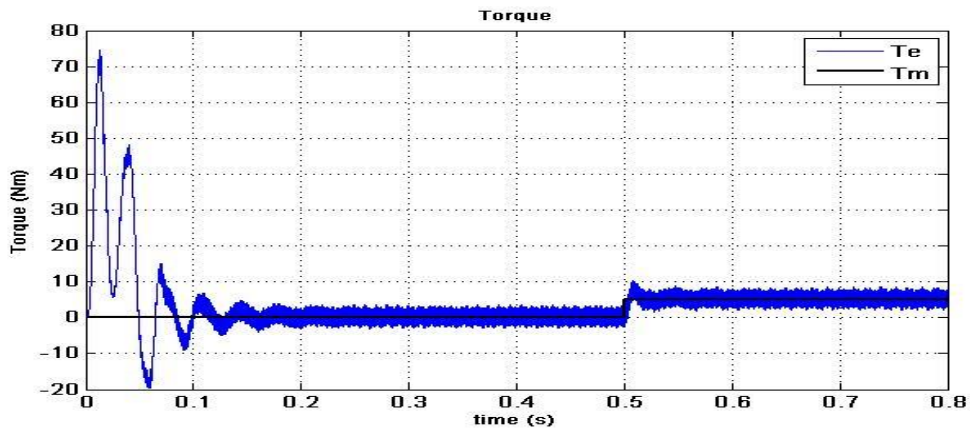
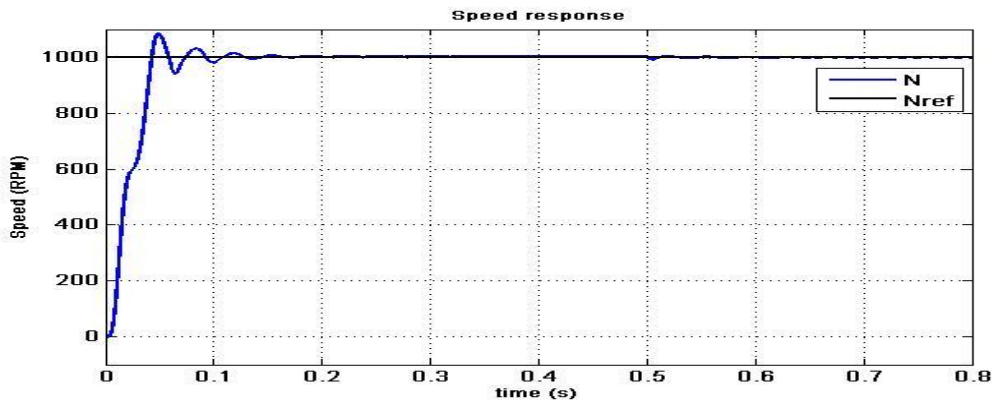
1. Speed=1000 RPM, Tm=0Nm till 0.5s and after that 5 Nm



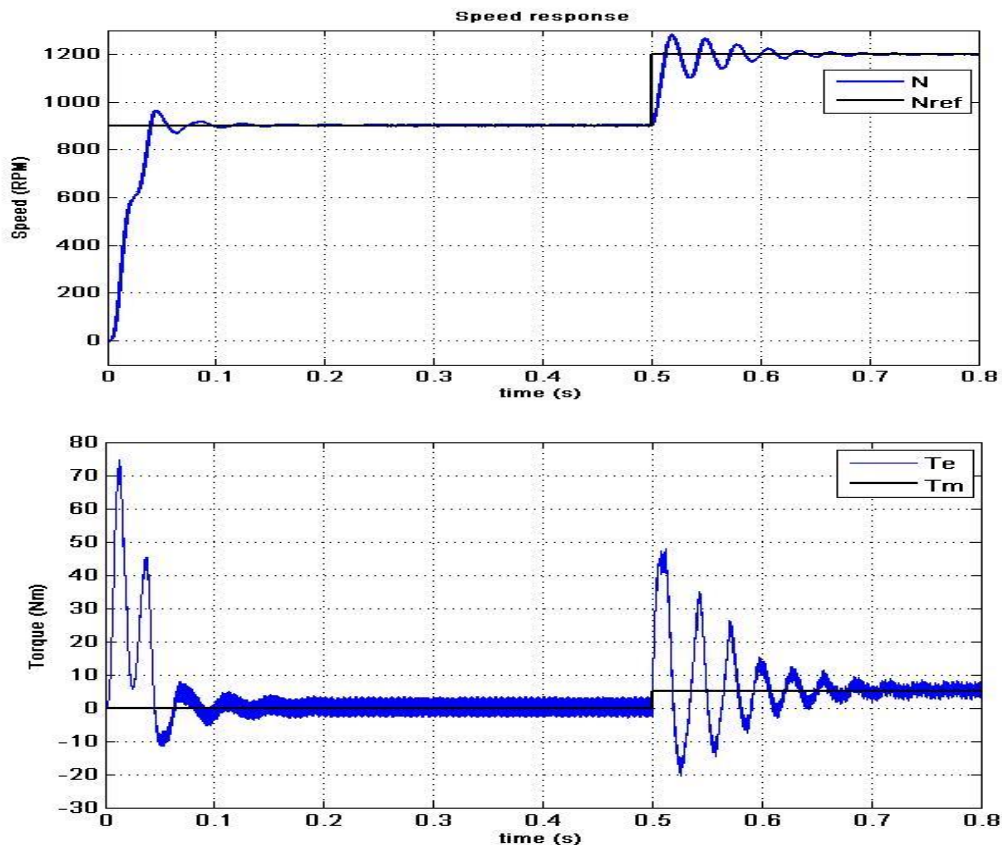
2. Speed=900 RPM till 0.5s after that 1200 RPM, Tm=0 Nm till 0.5s after that 5 Nm



3. Speed=1000 RPM,  $T_m=0$  Nm till 0.5s after that 5 Nm ( $K_p=8$ ,  $K_i=1$ ,  $K_d=0.0001$ )



4. Speed=900 RPM till 0.5s after that 1200 RPM,  $T_m=0$  Nm till 0.5s after that 5 Nm ( $K_p=8$ ,  $K_i=1$ ,  $K_d=0.0001$ )



## V. CONCLUSION

SVPWM for sinusoidal signal gives linear control of output voltage up to  $MI=0.906$  without loss of reference voltage. When  $MI$  exceeds 0.906, then it enters in over modulation region, where some part of fundamental voltage is lost. SVPWM gives smooth transition between linear and over modulation region. SVPWM gives effective control of induction motor in both linear and over modulation region. In over modulation region SVPWM gives full DC utilization with slightly higher harmonics. V/f control gives effective control of induction motor for higher speed, at low speed low speed response become low. Controlling of motor is done effectively using space vector PWM in both mode without exceeding current and torque limit.

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