

## **Implementation Of Various PWM Techniques To Control The Speed Of PMSBLDC Drive**

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### **Abstract**

This paper uses PI controller to control the speed of BLDC motor fed by a SVPWM inverter. Brushless DC (BLDC) motors have a wide range of applications because of their higher effectiveness and simple control procedures. In BLDC motor just two phases are supplied and the third phase is kept off. These two stages are to be supplied, which is resolved on the basis of the rotor position. Taking into account the position of the rotor, switching devices in the inverter are commutated for each 60 degree. Rotor position sensors are utilized to sense the position of the rotor at each moment of time. For controlling the output voltage and frequency of the inverter, Pulse Width Modulation (PWM) techniques are utilized. Sinusoidal PWM and Space Vector PWM (SVPWM) are the most recently utilized techniques. Sinusoidal PWM is the least complex and most utilized PWM methods, yet it has some drawbacks. The recently invented Space Vector PWM technique overcomes these setbacks, for example, it lessen switching loses, harmonic content in the output, better usage of accessible dc-transport voltages.

**Keywords** – BLDC Motor, Pulse width modulation, Space Vector Pulse Width Modulation

### **INTRODUCTION:**

Brushless DC motors (BLDC) are variable frequency permanent magnet synchronous motors having very much alike torque-speed characteristics to that of DC motors that is the reason the name Brushless DC came into effect [1]. It requires an electronic circuit for commutation rather than brushes. Today the use of BLDC motor have enhanced and it's competing with induction motor and DC motors. BLDC motor

require an inverter to feed power. Inverters are utilized to change over AC power into DC power we can control the output voltage and output frequency of the inverter according to our requirement. The output waveform of the inverter depends on upon the switching state of the inverter. Studies are done to reduce harmonic content in the output, switching frequency of the inverter and better consumption of the available dc voltage. One of the most well-known methods utilized for inverter switching is Pulse Width Modulation (PWM) Techniques[1]-[2]. In this paper we control the output voltage by changing the on-off time of the switching components in the inverter. The most prominent PWM procedures utilized today are Sinusoidal PWM (SPWM) and Space Vector PWM (SVPWM). With the increase of the use of microcontroller, SVPWM get to be most important PWM techniques for inverters. In SVPWM we figure the on-off time for every switch.

#### **Review on brushless dc motor:**

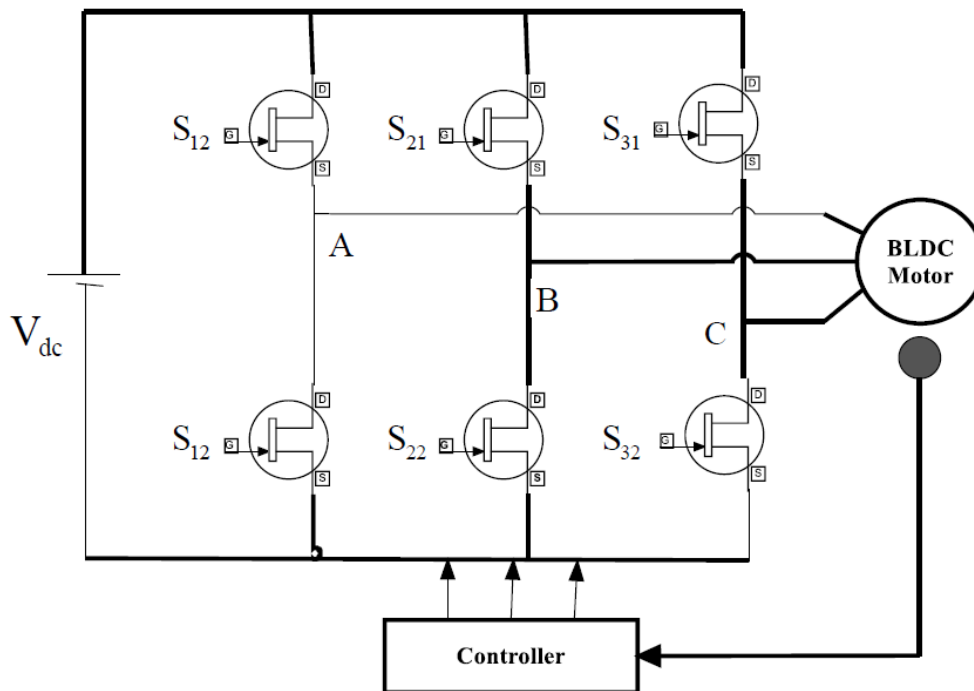
With the on-going research on permanent magnet motors, in the same way as brushless dc motor (BLDC) shows many advantages over the induction motor. The BLDC motor has trapezoidal back-emf characteristics and requires steady stator current at the middle to phase voltage waveform to produce a constant torque. The torque speed characteristics of BLDC motor is like that of a dc motor. Permanent magnet synchronous motor (PMSM) shows sinusoidal back-emf and to deliver steady torque it required a sinusoidal shaped current. PMSM is like the synchronous machine with a permanent magnet rotor rather than field winding.[3] Consequently the d-q axis modelling of the PMSM can be obtained. Then again in BLDC motor the back- emf is trapezoidal so the change in d-q axis is not suitable as it can't explain inductance of the a-b-c edge into d-q outline. Thus a-b-c model of BLDC motor is utilized rather than d-q model.

#### **Operation of BLDC motor with Inverter:**

A trapezoidal PM machine gives execution more like a dc motor. For this its known as a brushless dc motor (BLDC). It is an electronic motor and requires a three-level inverter to the driving side for feeding power into the machine, as demonstrated in figure 3. The machine is represented to by its identical circuit, which comprises of stator resistance  $R_s$ , self inductance  $L_s$ , and a back-emf.[4] The inverter functions as an electronic commutation which performs the switching as per the output from the position sensors. The inverter works in the following two modes

$2\pi/3$  edge switch-on mode

Voltage and current switch PWM mode



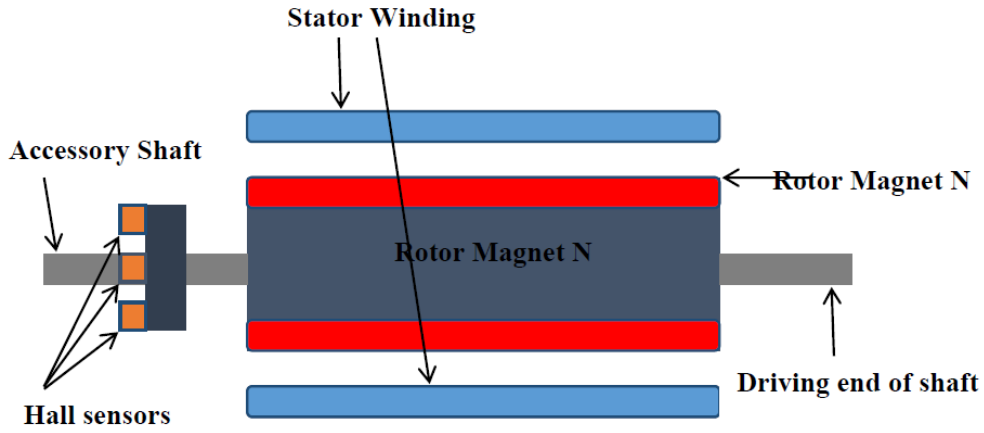
**Fig.1 BLDC Motor Drive**

### **$2\pi/3$ angle switch-on mode:**

In this mode of operation all inverter switching devices (T1 to T6) are switch on-off in such a way that the current input  $I_s$  is similarly for the  $2\pi/3$  angle at the centre of each induced back-emf voltage waveform. At a moment just two switches are on, one from the positive group also one from the negative group. For instance, from moment  $t_1$ , T1 and T6 are leading then the supply voltage  $V_s$  and input dc current  $I_s$  are connected over the AB period of the inverter such that positive  $I_s$  will flow in phase A and negative  $I_s$  will flow in phase B. At that point, after  $\pi/3$  interval T6 is turn OFF and T2 is turn ON, T1 proceeds with conduction for full  $2\pi/3$  angle. The conduction example changes each  $\pi/3$  degree, with each switch has a conduction time of  $2\pi/3$  degree. The switching arrangement depends on upon the output of the position sensors.

### **Voltage and current switch PWM mode:**

In the past mode every switch of the inverter are switched ON-OFF for  $2\pi/3$  degree point to generate the commutation function only. It is possible to control the voltages and currents continuously at the machine terminal by controlling the switches in PWM mode. There are basically two modes for the current and voltage control operations of the inverter. These two modes are feedback (FB) mode and freewheeling mode.[6] In both these modes switching devices are turned on and off for timing basis to control the machine currents  $I_{av}$  and the machine average voltages  $V_{av}$ .



**Fig.2 Transverse view of BLDC indicating Hall Sensors**

The BLDC motor has three stator winding and a permanent magnet rotor. Because of turn of rotor emf is incited in the stator windings. Consequently the circuit mathematical statements of the three windings are

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1)$$

Where we undertake the stator resistance of all the windings are equivalent. The back-emf has trapezoidal shapes. Expecting that there is no change in the motors inductance with the turn of motor.

$$L_{aa}=L_{bb}=L_{cc}=L \quad (1.1)$$

$$L_{ab}=L_{ba}=L_{ac}=L_{ca}=L_{bc}=L_{cb}=M \quad (1.2)$$

Hence the above equation takes the shape:

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (2)$$

Where

$$V_{as}=V_{ao}-V_{no} \quad (2.1)$$

$$V_{bs}=V_{bo}-V_{no} \quad (2.2)$$

$$V_{cs}=V_{co}-V_{no} \quad (2.3)$$

For an balanced load the stator current is given by

$$I_a+I_b+I_c=0 \quad (2.4)$$

Along these lines in state space model the comparisons are arranged as

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (3)$$

The Back-emf has Trapezoidal shape and is represented as

$$\begin{bmatrix} ea \\ eb \\ ec \end{bmatrix} = \omega_m \lambda_m \begin{bmatrix} fas(\theta_r) \\ fbs(\theta_r) \\ fcs(\theta_r) \end{bmatrix} \quad (4)$$

Where, the angular speed of the rotor in radians per second, is the flux linkage, is the rotor position and the functions have same shape as. The induced emf is of trapezoidal nature.

The Electromagnetic Torque is defined as follows

$$T_e = [e_a i_a + e_b i_b + e_c i_c] / \omega_m \quad (5)$$

The moment of inertia is described as

$$J = J_m + J_i. \quad (6)$$

The equation of motion is

$$J d\omega_m / dt + B\omega_m = (T_e - T_i) \quad (7)$$

The relation between rotor speed and position is given by

$$d\theta_r / dt = p / 2 \omega_m \quad (8)$$

The damping coefficient B is generally small and often neglected thus the system. The above equation is the rotor position and it repeats every  $2\pi$  degree. The ground to neutral voltage is required to be considered in order to avoid inequality in the applied voltages.

This is obtained by substituting equation (3) in the volt-ampere equation and adding then give as

$$V_{ao} + V_{bo} + V_{co} - 3V_{no} = R_s(i_a + i_b + i_c) + (L - M)(p i_a + p i_b + p i_c) + (e_a + e_b + e_c) \quad (9)$$

Substituting equation 2.2 in equation 8 we get,

$$V_{ao} + V_{bo} + V_{co} - 3V_{no} = (e_a + e_b + e_c) \quad (10)$$

$$\text{Thus, } V_{no} = ((V_{ao} + V_{bo} + V_{co}) - (e_a + e_b + e_c)) / 3 \quad (11)$$

Combining all the equations the state space form would be

$$X = Ax + Bu + Ce \quad (12)$$

Where

$$x = [i_a \ i_b \ i_c \ \omega_m \ \theta_r]^t \quad (13)$$

$$A = \begin{bmatrix} -R_s / (L - M) & 0 & 0 & -\lambda m f a s(\theta_r) / j & 0 \\ 0 & -R_s / (L - M) & 0 & -\lambda m f b s(\theta_r) / j & 0 \\ 0 & 0 & -R_s / (L - M) & -\lambda m f c s(\theta_r) / j & 0 \\ \lambda m f a s(\theta_r) / j & \lambda m f b s(\theta_r) / j & \lambda m f c s(\theta_r) / j & B / J & 0 \\ 0 & 0 & 0 & P / 2 & 0 \end{bmatrix} \quad (13.1)$$

$$B = \begin{bmatrix} 1 / (L - M) & 0 & 0 \\ 0 & 1 / (L - M) & 0 \\ 0 & 0 & 1 / L - M \\ 0 & 0 & 0 & 1 / L - M \end{bmatrix} \quad (13.2)$$

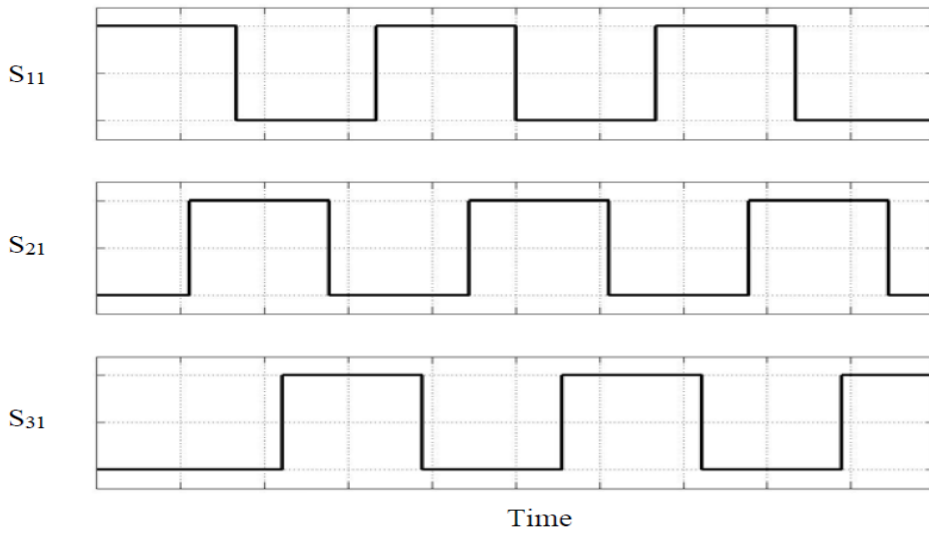
$$C = \begin{bmatrix} -1/(L-M) & 0 & 0 \\ 0 & -1/(L-M) & 0 \\ 0 & 0 & -1/(L-M) \end{bmatrix} \tag{13.3}$$

$$u = [V_{as} \ V_{bs} \ V_{cs} \ T_i]^t \tag{13.4}$$

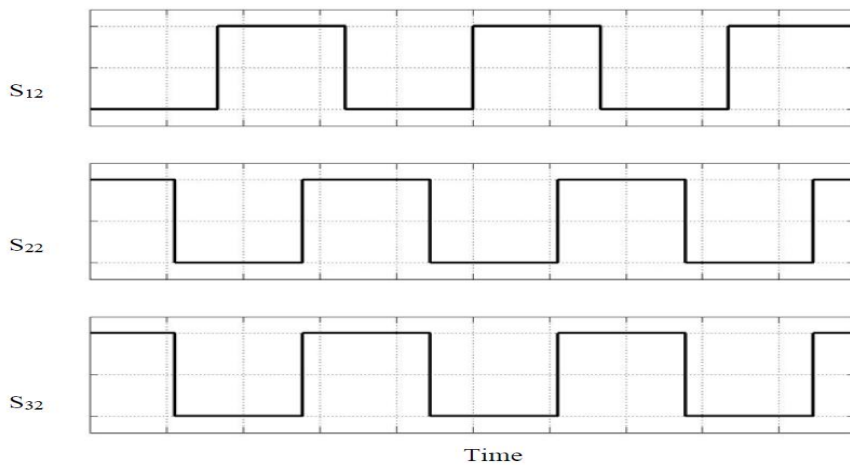
$$e = [e_a \ e_b \ e_c]^t \tag{13.5}$$

**Six-Step VSI Inverter:**

BLDC motor drives are generally utilized three-phase bridge inverters for supplying power to it. The circuit diagram of a six-stage VSI is as demonstrated in Figure 1, it embodies three half-bridges, and these three are shifted by 120 degree to deliver the three stage voltages.



**Fig.3 Switching signals for upper devices**



**Fig.4 Switching signals for upper devices**

With the utilization of Fourier analysis the stage voltages regarding the dc centre tap is expressed as,

$$V_{an}=2V_{dc}/\pi[\cos\omega t-1/3\cos3\omega t+1/5\cos5\omega t-\dots] \quad (14.1)$$

$$V_{bn}=2V_{dc}/\pi[\cos(\omega t-2\pi/3)-1/3\cos3(\omega t-2\pi/3)+1/5\cos5(\omega t-2\pi/3)-\dots] \quad (14.2)$$

$$V_{cn}=2V_{dc}/\pi[\cos(\omega t+2\pi/3)-1/3\cos3(\omega t+2\pi/3)+1/5\cos5(\omega t+2\pi/3)-\dots] \quad (14.3)$$

The line voltages can accordingly be gotten from the stage voltages as

$$V_{ab}=V_{an}-V_{bn} \quad (14.4)$$

$$V_{ab}=2\sqrt{3}V_{dc}/\pi[\cos(\omega t+\pi/6)-1/5\cos5(\omega t+\pi/6)-1/7\cos7(\omega t+\pi/6)+\dots] \quad (14.5)$$

$$V_{bc}=V_{bn}-V_{cn} \quad (14.6)$$

$$V_{bc}=2\sqrt{3}V_{dc}/\pi[\cos(\omega t-\pi/2)-1/5\cos5(\omega t-\pi/2)-1/7\cos7(\omega t-\pi/2)+\dots] \quad (14.7)$$

$$V_{ca}=V_{cn}-V_{an} \quad (14.8)$$

$$V_{ca}=2\sqrt{3}V_{dc}/\pi[\cos(\omega t+5\pi/6)-1/5\cos5(\omega t+5\pi/6)-1/7\cos7(\omega t+5\pi/6)+\dots] \quad (14.9)$$

The fundamental value of the line voltages is  $\sqrt{3}$  times to the phase voltage. The line voltage waveforms have a state of six separate steps in this way the inverter is called six-step inverter.

### PWM Techniques:

Pulse Width Modulation is a procedure in which the ON-OFF time of switches is controlled by reference wave. In this the convergence between a reference wave and a carrier wave delivers the pulses as per which the switches are switched ON and OFF.

There are diverse PWM methods utilized for motor control application. We utilize the subsequent procedures:

Sinusoidal PWM

Space Vector PWM

### Sinusoidal PWM:

The principle of SPWM is, a low frequency sinusoidal reference signal is contrasted and a high-frequency carrier signal. The carrier signal has triangular shape. The switching output pulses changes when the reference signal converges with the triangular signal. The convergence positions decides the switching time. [6] Frequency of output voltage depends on upon the frequency of the reference and switching frequency depends on upon carrier frequency.

In a SPWM, we think about the sinusoidal control signals ( $V_a, V_b$  and  $V_c$ ), which are 120 degree separated with one another with a triangular voltage signal ( $V_t$ ). Convergence of triangular signal with every period of the sinusoidal control signal produces switching signal for every periods of the inverter. At the point when the carrier signal is not exactly the sinusoidal signal, the upper devices are directing and the lower devices are OFF. Essentially, when the triangular signal is not exactly the sinusoidal signal, the upper devices is OFF and the lower devices are ON. The switches in every leg of the inverter are controlled together and the control signal is as under:

$S_{11}$  is ON when  $V_a > V_T$   $S_{12}$  is ON when  $V_a < V_T$

$S_{21}$  is ON when  $V_b > V_T$   $S_{22}$  is ON when  $V_b < V_T$

$S_{31}$  is ON when  $V_c > V_T$   $S_{32}$  is ON when  $V_c < V_T$

$V_a, V_b, V_c$  are amplitude of reference and  $V_T$  is amplitude of carrier.

The inverter line-to-line is achieved from the pole voltages as:

$$V_{ab} = V_{ao} - V_{bo} \quad (15.1)$$

$$V_{bc} = V_{bo} - V_{co} \quad (15.2)$$

$$V_{ca} = V_{co} - V_{ao} \quad (15.3)$$

### Space Vector PWM:

The Space Vector PWM (SVPWM) is the most generally utilized inverter switching component for three-stage inverter utilized for BLDC motors. It accomplishes the voltage vector control by changing the timing and duty ratio of the eight switching conditions of the three-stage inverter.[7]-[9] Assuming that stator coils in the three phases are identical, each switching state of the three-phase inverter corresponds to a voltage vector in the three-phase stator coil frame. Therefore corresponds to eight switching state there are eight voltage vector ( $V_0$  to  $V_7$ ) as indicated in figure 4, and their comparing switch states are demonstrated in table 1.  $V_1$  and  $V_0$  are zero vectors having zero size  $V_1$  to  $V_6$  are six dynamic vectors with fixed magnitude and  $60^\circ$  separated from one another. For any reference voltage vector which falls in the three-phase outline, we can resolve this vector utilizing the combination of the eight voltage vectors.

**Table 1 Eight dynamic vectors as per the switching states**

Voltage Vectors	Switching state			Phase Voltage( $\times V_{dc}$ )			Line voltage( $\times V_{dc}$ )		
	a	b	c	$V_{an}$	$V_{bn}$	$V_{cn}$	$V_{ab}$	$V_{bc}$	$V_{ca}$
$v_0$	0	0	0	0	0	0	0	0	0
$v_1$	1	0	0	2/3	-1/3	-1/3	1	0	-1
$v_2$	1	1	0	1/3	1/3	-2/3	0	1	-1
$v_3$	0	1	0	-1/3	2/3	-1/3	-1	1	0
$v_4$	0	1	1	-2/3	1/3	1/3	-1	0	1
$v_5$	0	0	1	-1/3	-1/3	2/3	0	-1	1
$v_6$	1	0	1	1/3	-2/3	1/3	1	-1	0
$v_7$	1	1	1	0	0	0	0	0	0

Where  $d_1$  and  $d_2$  is the term for which vector  $V_1$  and  $V_2$  is connected separately and  $d_3$  is the length of time for which zero vectors ( $V_0$  and  $V_7$ ) are connected. Any voltage vector placed in the six divisions can be communicated as

$$V^r = d_1 V_k^r + d_2 V_{k+1}^r + 1/2 d_3 V_0^r + 1/2 d_3 V_7^r \tag{16}$$

Where

$$d_1 = V/V_k \sin[\pi/3 - (\delta - k\pi/3)] / [\sin(\pi/3)] \tag{16.1}$$

$$d_2 = V/V_{k+1} \sin[\pi/3 - (\delta - k\pi/3)] / [\sin(\pi/3)] \tag{16.2}$$

where  $k = 1, 2, \dots, 6$ , ON OFF time of the switches is calculated as

$$T_a = d_1 T_s \tag{17.1}$$

$$T_b = d_2 T_s \tag{17.2}$$

$$T_c = d_3 T_s \tag{17.3}$$

Where  $T_s$  is the Time period of carrier signal, i.e.  $T_s = 1/f_s$ ,  $f_s$  is the frequency of PWM signal  $T_a$ ,  $T_b$  and  $T_c$  are the time period for which two dynamic vector and zero vector has been connected. The switching time for every switch in every segment is demonstrated in the table.

**Table 2 switches on-off timing in every part**

Sector	Upper Devices( $S_{11}, S_{21}, S_{31}$ ); Lower Devices ( $S_{12}, S_{22}, S_{32}$ )
1	$S_1 = T_a + T_b + T_0/2, S_2 = T_b + T_0/2, S_3 = T_0/2$
2	$S_1 = T_a + T_0/2, S_2 = T_a + T_b + T_0/2, S_3 = T_0/2$
3	$S_1 = T_0/2, S_2 = T_a + T_b + T_0/2, S_3 = T_b + T_0/2$
4	$S_1 = T_0/2, S_2 = T_a + T_0/2, S_3 = T_a + T_b + T_0/2$
5	$S_1 = T_a + T_0/2, S_2 = T_0/2, S_3 = T_a + T_b + T_0/2$
6	$S_1 = T_a + T_b + T_0/2, S_2 = T_0/2, S_3 = T_a + T_0/2$

**Controller Design for BLDC motor:**

**Commutation Strategies:**

For driving the BLDC motor, we need an electronic commutation circuit. For this we use a position based commutation for producing maximum torque in the motor. There are many commutation methods are used for BLDC motor mainly are sinusoidal commutation, trapezoidal commutation and field oriented control.[9]In this we use trapezoidal commutation. Each of these methods has their advantages and

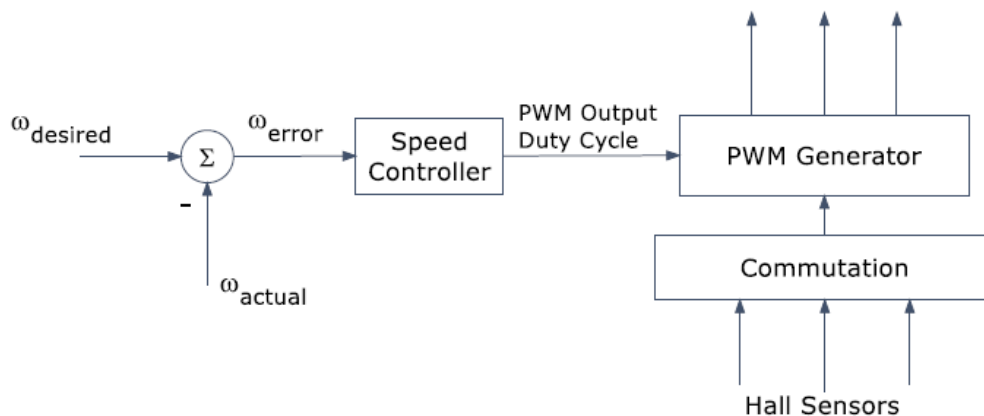
implemented in different ways.

In trapezoidal commutation only two switching devices are kept ON, one on the upper half and one from lower half. [10] This is one of the most popular methods used today because it is very easy to implement. It uses a predefined sequence according to the output of the hall sensors.

For rotor position sensing hall-effect sensors are used because they are cheapest of all and provide a better accuracy these hall sensors are placed at 120 degree apart in the motor and changes its state with every 60 degree rotation of rotor. [11] The electronic commutation circuit decides which to phases has to be supplied for proper operation of the motor. According to the rotor position electronic commutation circuit decides to supply the stator so that the motor rotates in the same direction.

### SPEED CONTROLLER STRUCTURE:

Electronic commutation circuit guarantee proper rotation of BLDC motor, but the speed of the motor depends on the amplitude of the voltage fed to the motor. PWM techniques are used to control the magnitude of voltage fed to the motor thus control the speed of the BLDC motor. A speed controller is required to control the required speed. Many speed controllers are available for this we use a PI control scheme. [13] PI controller is the most commonly used controller for industrial use because it is easy to implement. The input to the controller is the error between reference speed and actual speed of the motor. Based on the error signal the PI controller produces a control signal for the PWM block which changes the ON-OFF time of the switching devices in the inverter thus control the voltage fed to the motor. Figure 5 shows a schematic diagram of speed controller



**Fig.5 Schematic diagram of speed controller**

The structure of speed controller is defined by the following equations:

$$u(t) = K_c(e(t) + 1/T_i \int_0^t e(\tau) d\tau) \quad (18)$$

$e(t)$  = reference speed – actual speed

### PI Controller Design for BLDC Motor Speed Control

The speed of the BLDC motor depends on the stator current value for controlling the speed of motor we have to control the stator current feed into the motor. We can control the value of stator current by controlling the average output voltage of the three-phase inverter which further depends on the on/off time of the six switches. Since the speed of BLDC motor is directly proportional to the inverter output voltage by varying the on/off time of the six switches.

The Speed to voltage transfer function of BLDC motor is given as follows:

$$G(s) = \omega_m/V_s = (1/K_e)/(\tau_m\tau_e s^2 + \tau_m s + 1) \quad (19)$$

$\omega_m$  = speed of the motor

$V_s$  = Applied Voltage to the motor

$K_e$  = back emf constant

$\tau_m = 3RJ/k_e k_t$  = mechanical time constant

$\tau_e = L/3R$  = Electrical time constant

$k_t$  = Torque constant

$L$  = Inductance per phase

$R$  = Resistance per phase

$J$  = Inertia of the motor

Based on the step response of the open loop bode angle, a PI controller is designed on the basis of the Ziegler-Nichols, Method.

### Ziegler-Nichols method for controller tuning

Based on the Step response of the system, Ziegler-Nichols proposed set of procedures to determine the proportional gain, integral gain and derivative gain.

Ziegler-Nichols method is used when the step response of the plant is an S-shaped curve

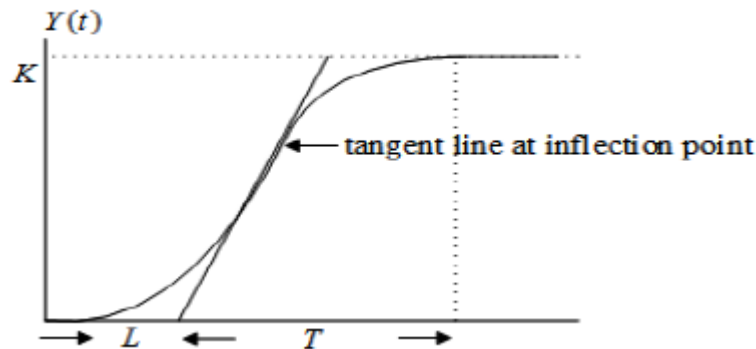


Fig.6.S-shaped curve

As shown in the figure 6. By drawing a tangent line at the point of reflection of the curve and determine the intersections point of the time axis and line  $Y(t) = K$  with the tangent drawn, as shown in figure 5 we can define the two characteristics of the curve that are time constant  $T$  and delay time  $L$ . Then the transfer function of the

system may be approximated by first-order system with a transport lag as follows:

$$G(s) = Ke^{-Ls}/(Ts+1) \quad (20)$$

Ziegler and Nichols suggested setting the value of  $K_p$  and  $T_i$  will be

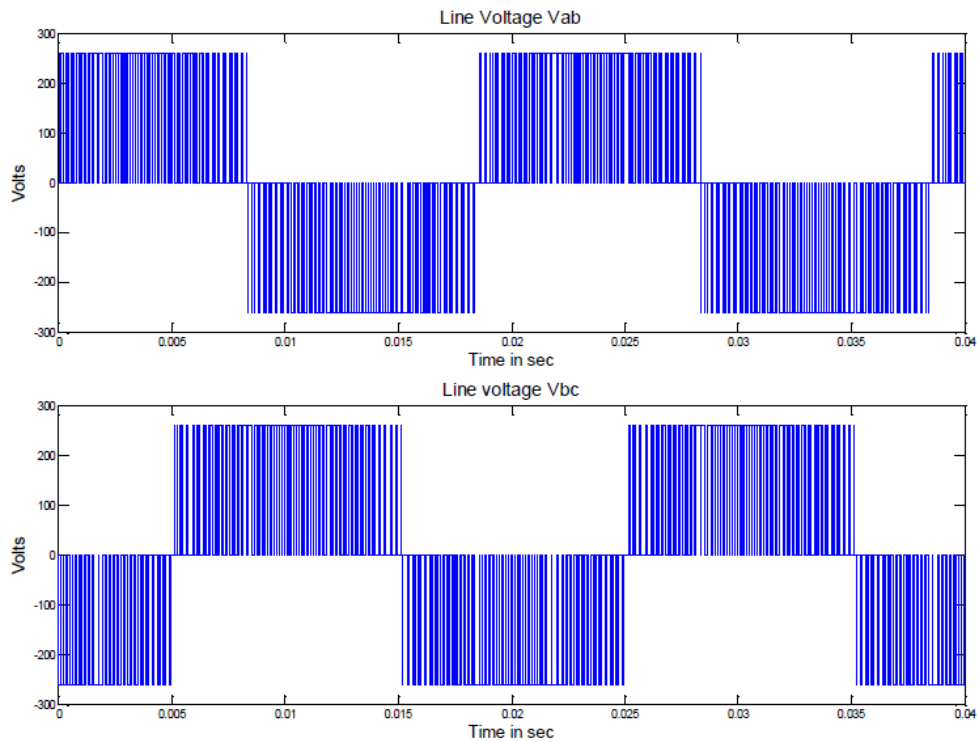
$$K_p = T/L \quad (21)$$

$$K_i = 0.9 T/L \quad (22)$$

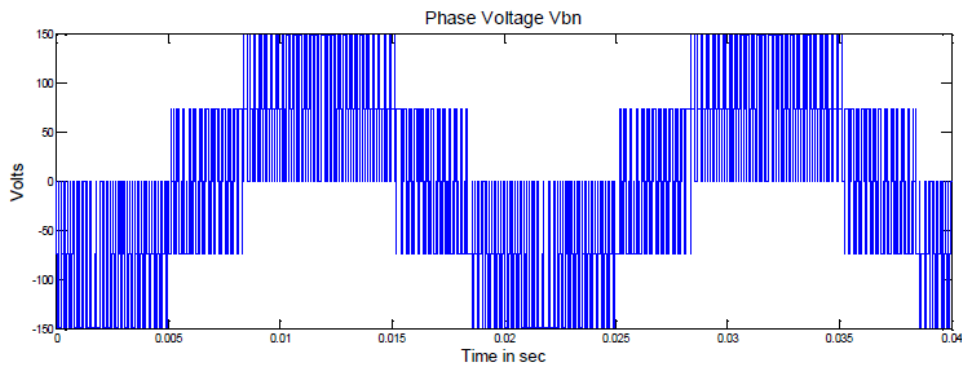
## RESULTS AND WAVEFORMS:

### Simulation results of PWM Technique:

$V_{dc} = 230V$ , Inverter Frequency = 50Hz, Switching Frequency = 5000Hz



**Fig.7.1 Line to Line Voltage output**



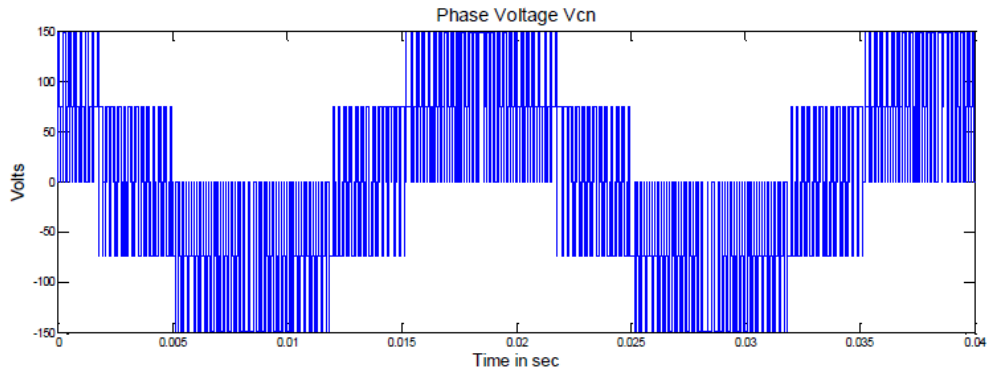


Fig.7.2 Phase voltage output

**Simulation results of SVPWM Technique**

$V_{dc} = 300V$  Inverter frequency = 50Hz Switching frequency = 4000Hz

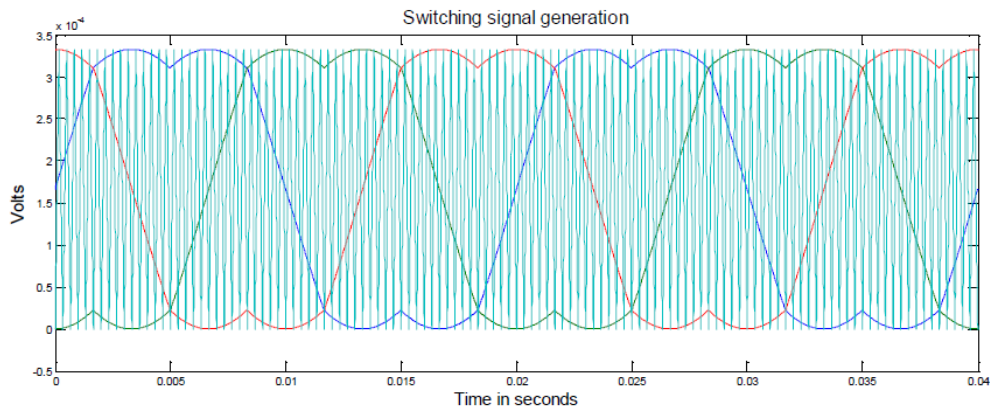
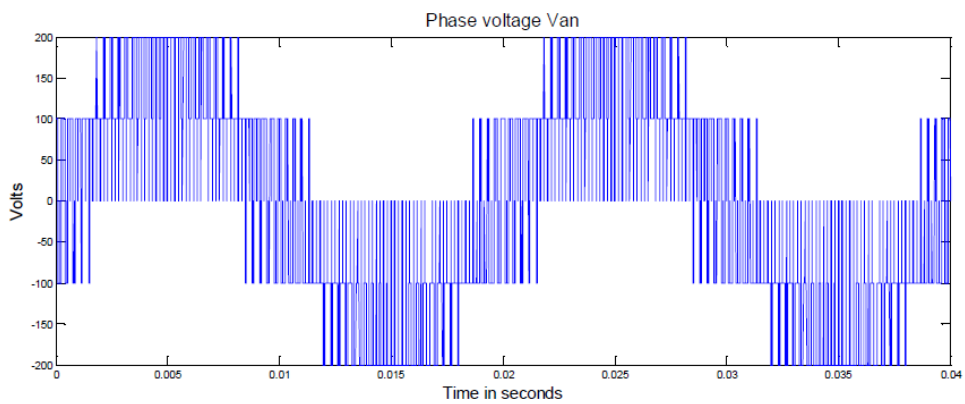
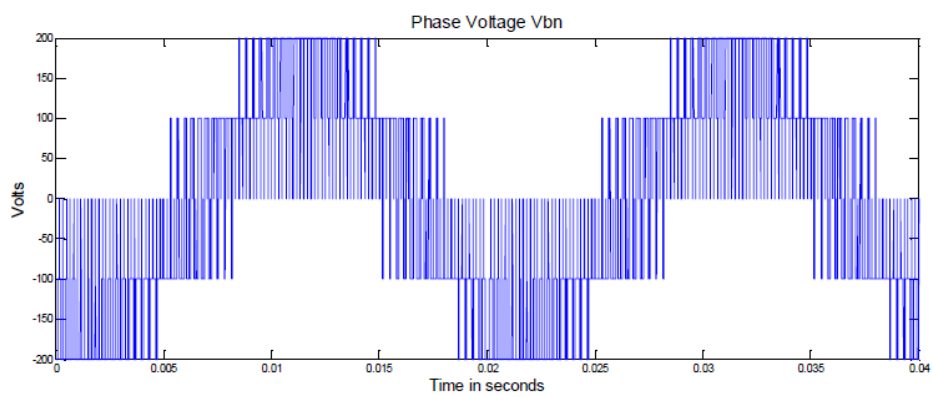
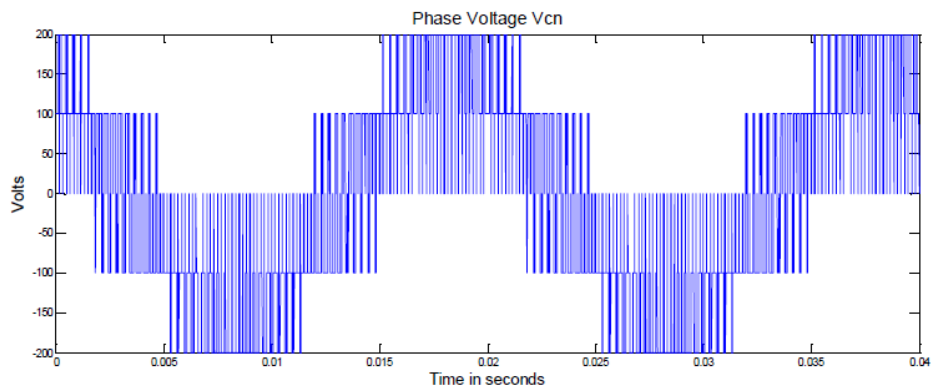
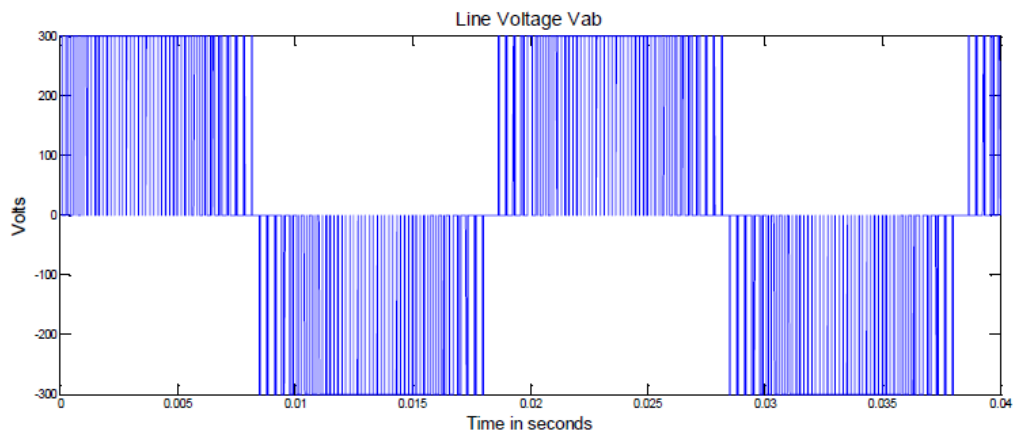


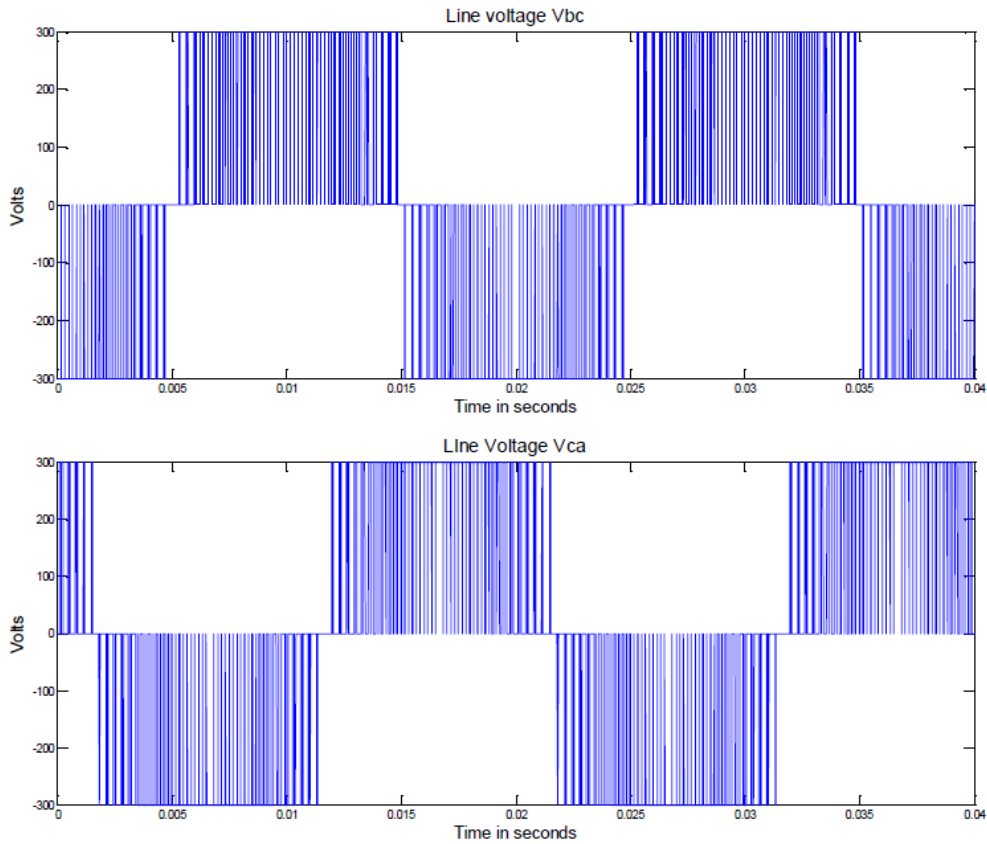
Fig.7.3 Comparison of time signals with triangular carrier signal





**Fig.7.4 Phase-to-Neutral Voltages of Phases A,B,C**



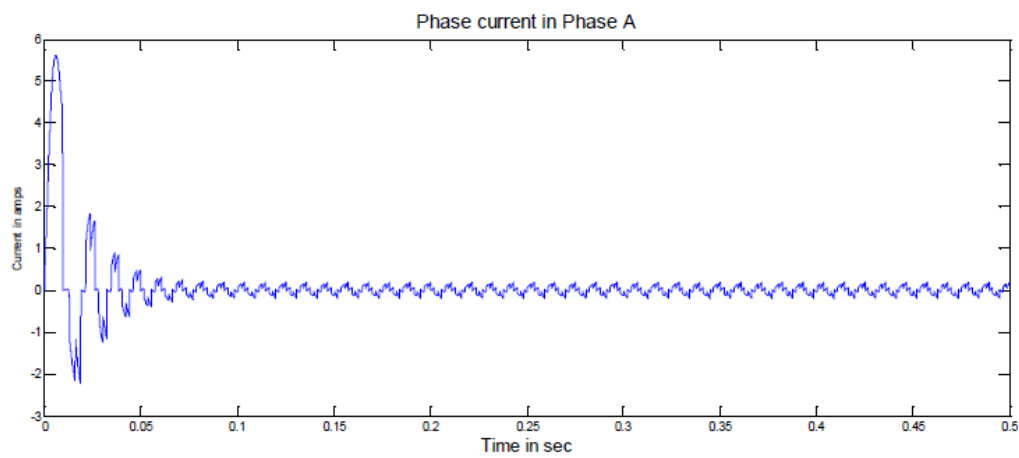
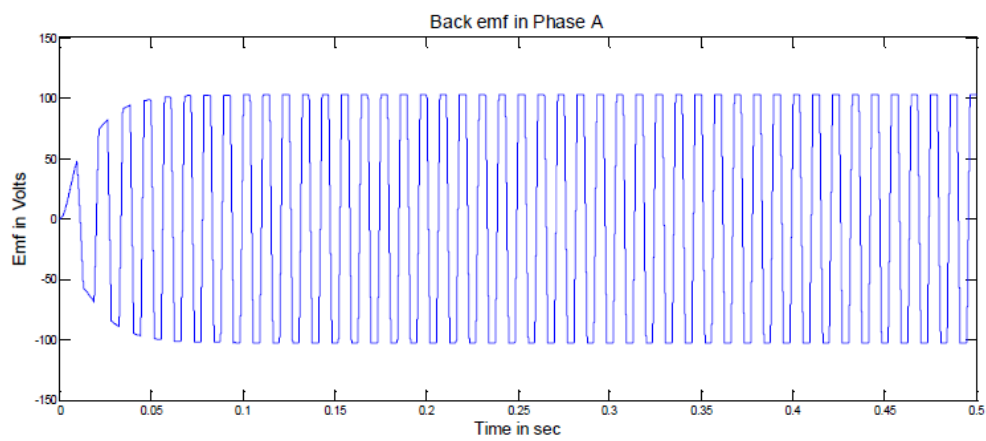
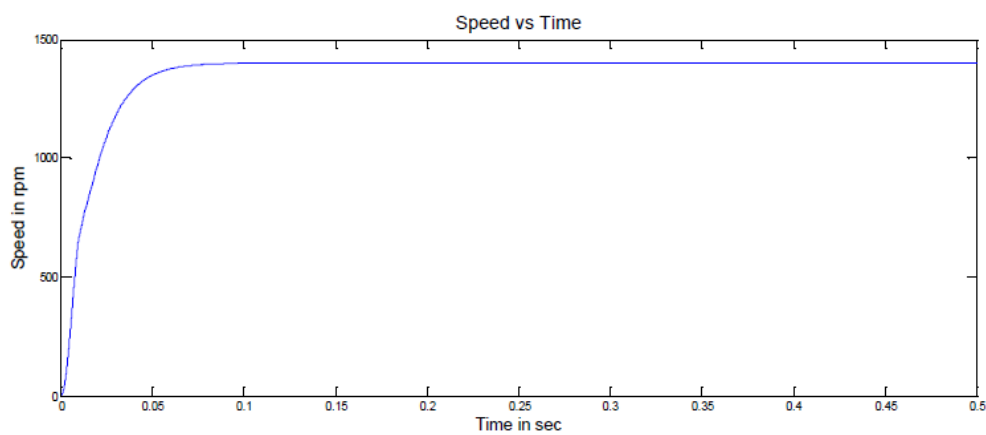


**Fig.7.4 Line-to-line voltages**

This Inverter is made to work in  $2\pi/3$  angle mode. Each switch is in conduction for 120 degrees. The output results are shown as below

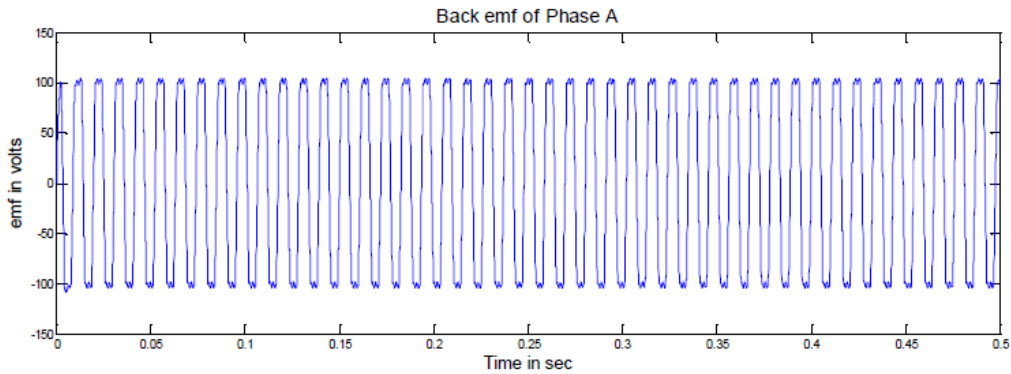
Specification	Value
Resistance	2.875Ω
Inductance	8.5mH
Friction constant	0.01
Rotor Inertia	0.0008Kgm <sup>2</sup>

**Fig.7.5 Motor Specifications**

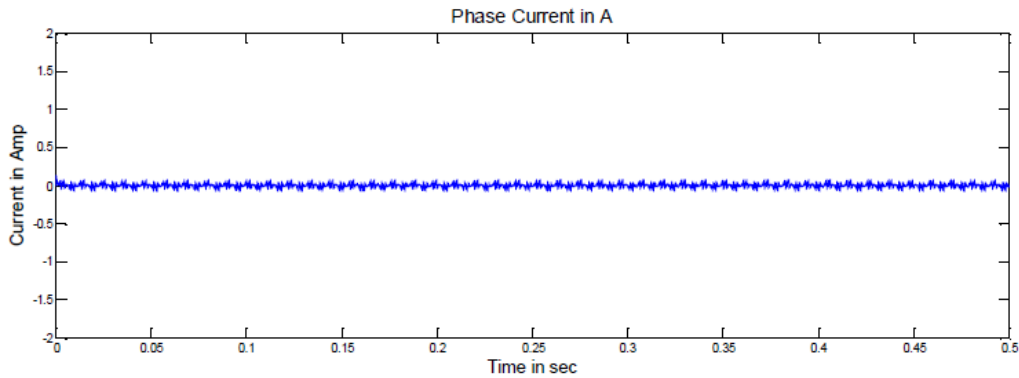
**Fig.7.6 Stator phase current of motor****Fig.7.7 EMF induced in the stator****Fig.7.8 Speed response in rpm vs time**

**SIIMULATION RESULTS WITH SVPWM**

SVPWM technique in used to control the duty ratio of switches of the three phase inverter. A PI controller is used to control the speed of BLDC motor drive. The value of proportional and integral gain is 0.015 and 12 respectively. The simulation results are shown.



**Fig.7.9 EMF induced in the stator**



**Fig.7.10 Stator Current of Phase A**

**CONCLUSION**

SVPWM provides a superior result with the inverter when matched with the ordinary SPWM system for inverter. There is 15.5% increment in the line voltage of the inverter. SVPWM better used the available DC link power. BLDC motor with SVPWM inverter and PI control scheme for speed control shows better results over 120 degrees switch on mode. With SVPWM we achieve a superior control over voltage and current supplied to the BLDC motor.

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