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EE6031D - Power Electronic Circuits :-

Q1

Given dc link voltage = 800V

reference vector = 500 V.

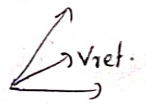
f = 50 HZ.

Switching frequency = 3000 HZ

$V_d \cos\theta + j V_d \sin\theta$

$V_d \cos 12.59 + j V_d \sin(60-12.59)$

$V_d (0.9759) + j(0.736))$



$V_d = 800V$

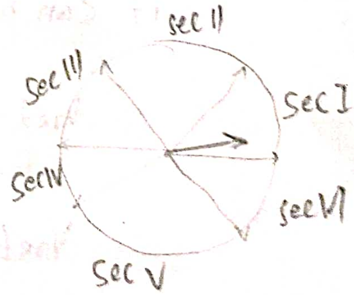
$\boxed{V_{ref_{max}} = 977.89}$

1a given $t_1 = 0.04008$ sec.

$\theta = \omega t_1 = 2\pi f t_1$

$\theta = 2 \cdot \pi \cdot 50 \cdot 0.04008 = 12.59^\circ$.

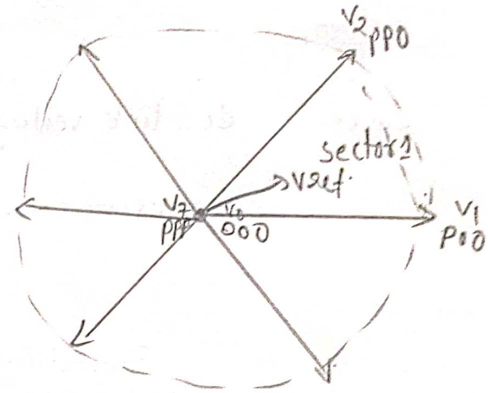
$\therefore$ it is in Sector 1



1(b)

7 - segment switching sequence.

		time period
000	$\vec{V_0}$	$T_0/4$
P00	$\vec{V_1}$	$T_1/2$
PP0	$\vec{V_2}$	$T_2/2$
PPP	$\vec{V_7}$	$T_0/2$
PP0	$\vec{V_2}$	$T_2/2$
P00	$\vec{V_1}$	$T_1/2$
000	$\vec{V_0}$	$T_0/4$



where $T_s = T_0 + T_1 + T_2$

In Above we have taken in Sector 1:

⇒ volt-sec balanced equation

$$\vec{V}_{ref}\ T_s = \vec{V_1}\, T_1 + \vec{V_2}\, T_2 + \vec{V_0}\, T_0.$$

it can be represent in real and imaginary

$$V_{ref}\ T_s \cos\theta = \frac{2}{3}\vec{V_d}\, T_1 \cos 0 + \frac{2}{3} V_d T_2 \cos\frac{\pi}{3} + \frac{2}{3} V_d T_0 \cos\frac{\pi}{2}$$

$$V_{ref}\ T_s \cos\theta = \frac{2}{3} V_d T_1 + \frac{1}{3} V_d T_2.$$

let written as.
$$V_{ref}\ T_s \cos\theta \times \frac{\sqrt{3}}{2} = \frac{1}{\sqrt{3}} V_d T_1 + \frac{1}{2\sqrt{3}} V_d T_2 \quad \text{—(1)}$$

and
$$V_{ref}\ T_s \sin\theta = \frac{2}{3} V_d T_2 \sin\frac{\pi}{3}$$

$$V_{ref}\ T_s \sin\theta \times \frac{1}{2} = \frac{1}{3} V_d T_2 \sin\frac{\pi}{3} = \frac{1}{2\sqrt{3}} V_d T_2 \quad \text{—(2)}$$

① + ②

$$V_{ref}\, T_s \left[\cos\theta \times \frac{\sqrt{3}}{2} + \sin\theta\, \frac{1}{2} \right] = \frac{1}{\sqrt{3}} V_d T_1$$

$$V_{ref}\, T_s \sin\left(\frac{\pi}{3} - \theta\right) = \frac{1}{\sqrt{3}} V_d T_1.$$

$$T_1 = \sqrt{3}\, \frac{V_{ref}}{V_d} \cdot T_s \sin\left(\frac{\pi}{3} - \theta\right) \quad \text{--- (3)}$$

from eq (2)

$$T_2 = \sqrt{3} \times \frac{V_{ref}}{V_d} T_s \sin\theta \quad \text{--- (4)}$$

$$T_s = T_1 + T_2 + T_0 \implies T_0 = T_s - T_1 - T_2.$$

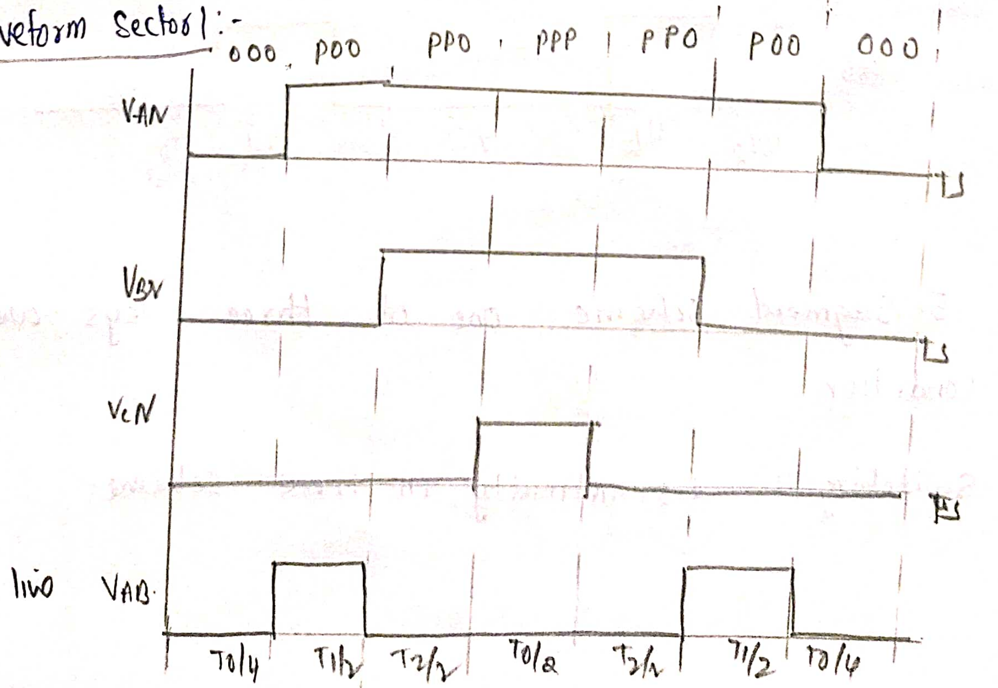
By generating

$$T_1 = \sqrt{3} \cdot \frac{V_{ref}}{V_d} \cdot T_s \cdot \sin\left(\frac{n\pi}{3} - \theta\right)$$

$$T_2 = \sqrt{3} \cdot \frac{V_{ref}}{V_d}\, T_s \sin\left(\theta - \frac{(n-1)\pi}{3}\right)$$

n = Sector number.

waveform Sector 1 :-



5-segment switching sequence:-

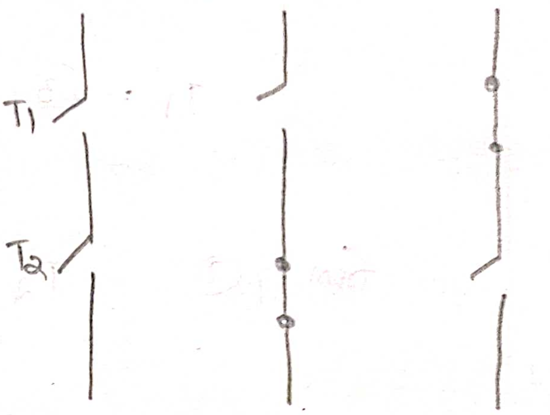
In sector I :

Switching sequence.

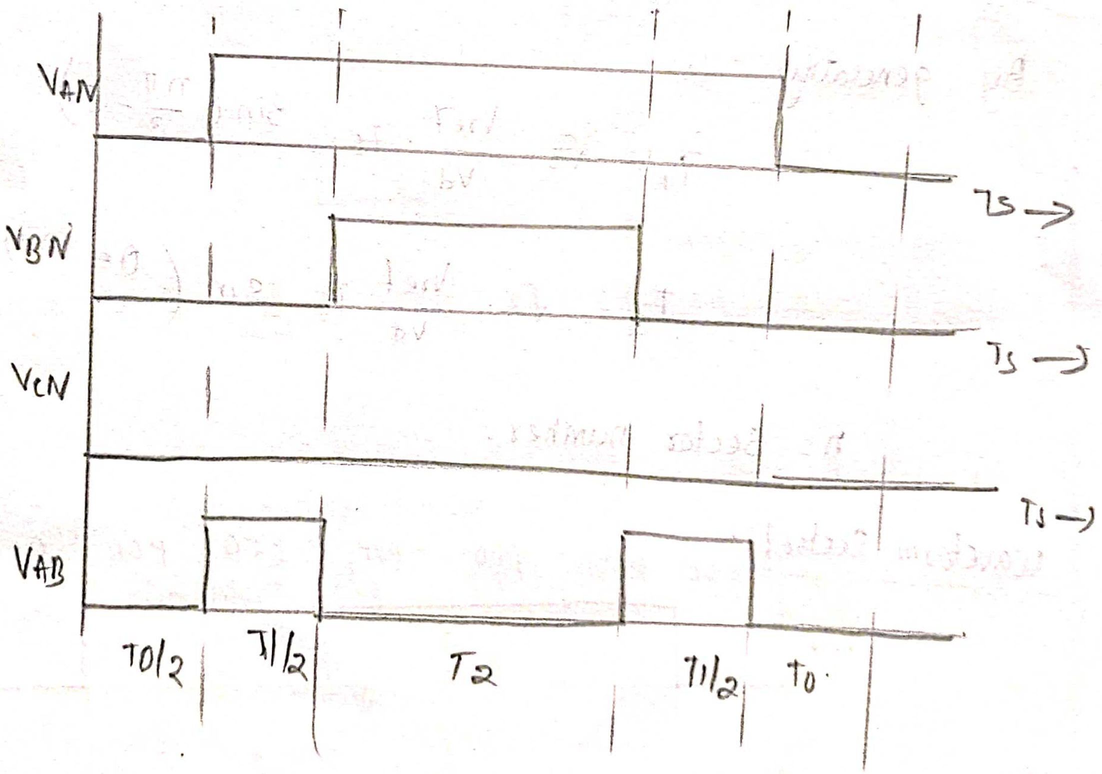
	time periods	
0 0 0	$T_0/2$	$\vec{V_0}$
P 0 0	$T_1/2$	$\vec{V_1}$
P P 0	T_2.	$\vec{V_2}$
P 0 0	$T_1/2$	$\vec{V_1}$
0 0 0	$T_0/2$.	$\vec{V_0}$

T_1 = open, T_2 = close → 0

T_1 = close, T_2 = open → 1



waveform:-



- In 5-Segment scheme one of three legs are OFF condition.

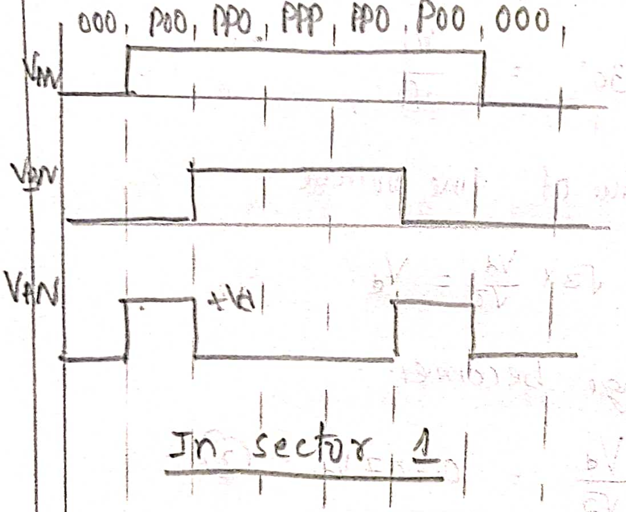
→ Switching is discontinuity. in these scheme.

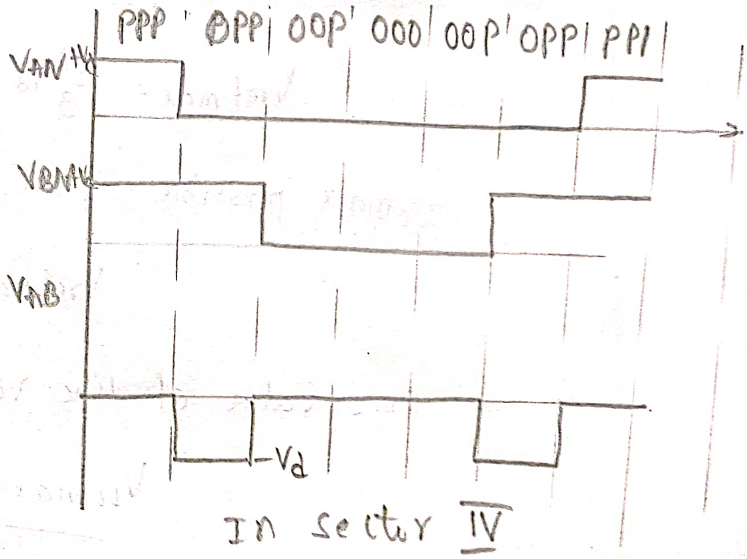
(1d) V_{AB} is not half wave symmetric, $\therefore$ even harmonics are present.

→ To eliminate even order harmonics, we make the line-line voltages are symmetrical.

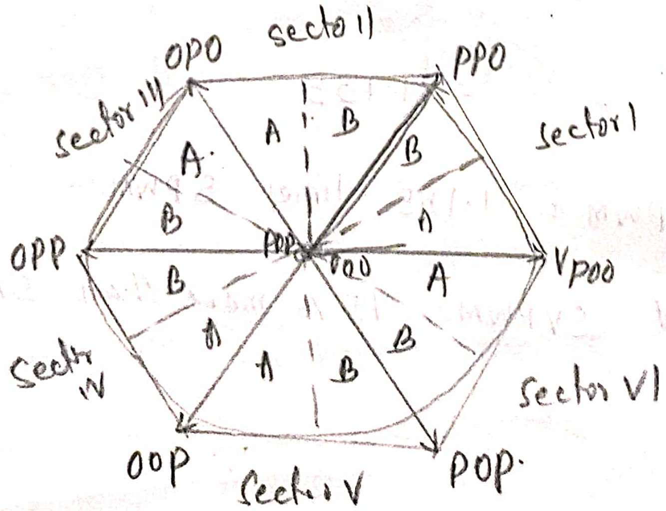
→ eliminate by using Type A and Type B sequence.

Type A Switching sequence: Type B switching





→ By using Switching sequece A & B alternatively in each sector we eliminate the even order harmonic.



1(e)

In Sinusoidal pulse width Modulation S PWM

Rms value. line - line voltage of fundamental component

$$V_{LL} = \frac{\sqrt{3}}{\sqrt{2}} ma \frac{V_d}{2}.$$

$V_{LL} = 0.612\ ma\ V_d$. for max $ma = 1$

$V_{LL\ max} = 0.612\ V_d$. — (1)

In space vector Pulse width modulation SVPWM

$$V_{ref\ max} = \frac{2}{3} V_d \cos 30^\circ = \frac{V_d}{\sqrt{3}}.$$

.max possible peak value of line voltage

$$V_{ref\ max} = \sqrt{3} \times \frac{V_d}{\sqrt{3}} = V_d.$$

Rms value of line voltage becomes.

$$V_{LL\ max} = \frac{V_d}{\sqrt{2}} = 0.707\ V_d. \quad (2)$$

$\frac{(2)}{(1)} \Rightarrow \frac{\text{SVPWM}}{\text{SPWM}}$ of Rms value $= \frac{0.707\ V_d}{0.612\ V_d}$

$= 1.155$

SV PWM = 1.155 times SPWM.

Nothing But SVPWM = 15% more than SPWM.

(a) torque and flux depends on current.

∴ "current Mode control scheme"

(b) Advantages of current Mode control scheme :

i) ripples currents are reduced

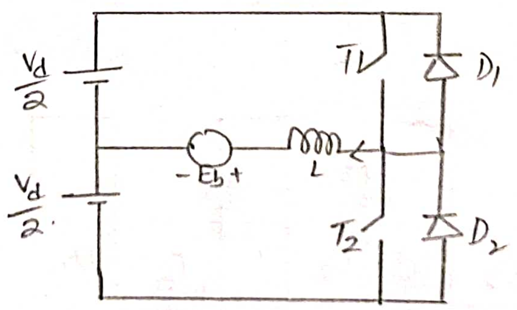
ii) Reduces the peak current values of devices.

iii) Minimize the cost.

iv) Avoid the more heating and torque ripples in drive output.

v) Sinusoidal waveform is generated

(c)



T_1 is turn ON at positive wave of current. when T_1 is turned off T_2 is turn ON.. During the positive load current flows through the D_2. and T_1 conduction takes place.

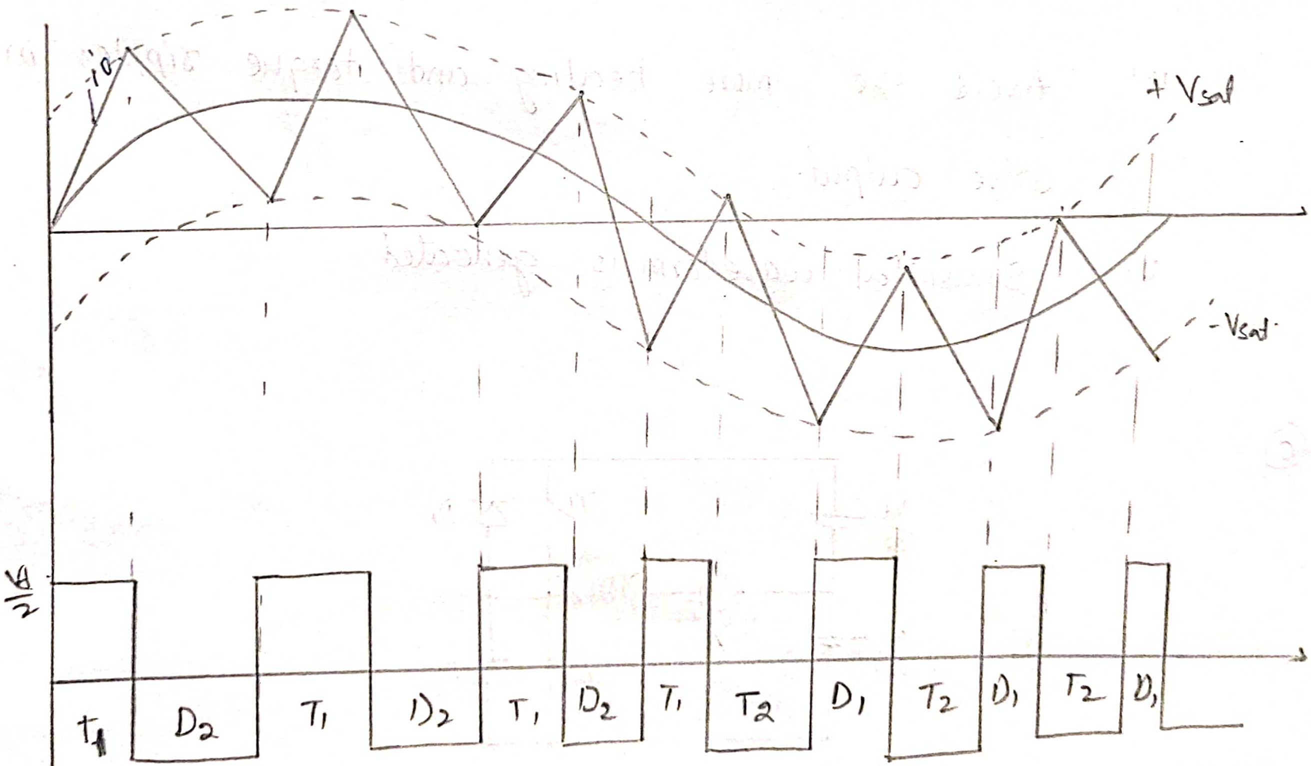
- Here we implemented the hysteresis band PWM

Because when $I_L > I_{ref}$ T_2 Turn ON

$I_L < I_{ref}$ T_1 turn ON.

maximum operating frequency can be obtained in it.

where maximum frequency leads to more losses in the inverter. To Avoid these we go for hysteresis band PWM



i) During positive half cycle of load current io, T_1 is conducts and io rises. when the current exceeds a lower hysteresis band then T_1 is turn-OFF and lower Switch is turn ON. Then D_2 conduction takes place.

ii) when current crosses the lower band of hysteresis T_2, D_2 - Then OFF And T_1 turn ON Takes place.

During positive half cycle $i_0 \geq i_H$ T_1 is then OFF

$i_0 \leq i_L$ D_2 is then OFF

During Negative half cycle $i_0 > i_H$ D_1 is then OFF

$i_0 < i_L$ T_2 is then OFF

⇒ when T_1 is ON :- current rises :-

$$\frac{V_d}{2} - L\frac{di_0}{dt} - E_b = 0$$

$$\frac{di_0}{dt} = \frac{\frac{V_d}{2} - E_b}{L} = \frac{\Delta I}{t_{on}}$$

$$t_{on} = \frac{L\Delta I}{\frac{V_d}{2} - E_b}$$

⇒ When D_2 is ON, T_1 is OFF :

then

$$-\frac{V_d}{2} - E_b + L\frac{di_0}{dt} = 0$$

$$\frac{di_0}{dt} = \frac{\frac{V_d}{2} + E_b}{L} = \frac{\Delta I}{t_{OFF}}$$

$$t_{OFF} = \frac{L\Delta I}{\frac{V_d}{2} + E_b}$$

⇒ Total time period $t = t_{on} + t_{OFF} = L\Delta I\left[\frac{2\cdot\frac{V_d}{2}}{\left(\frac{V_d}{2}\right)^2 - (E_b)^2}\right]$

$$T_s = \frac{L\Delta I}{\frac{V_d}{4}} \times \frac{1}{1-\left(\frac{E_b}{\frac{V_d}{2}}\right)^2}$$

$$f_s = \frac{1}{T_s} = \frac{V_d/4}{L\Delta I}\left(1-\left(\frac{E_b}{V_d/2}\right)^2\right]$$

at $E_b = 0$ $\quad f_s = \text{max}$

$$f_{s\,max} = \frac{V_d}{4L\Delta I}$$

$$\therefore \quad f_s = f_{max}\left[1-\left(\frac{E_b}{V_d/2}\right)^2\right]$$

when $E_b = E_m \sin\omega t$ then.

$$f_s = f_{max}\left[1-\frac{E_m^2 \sin^2\omega t}{\left(\frac{V_d}{2}\right)^2}\right]$$

$$f_s = f_{max}\left[1-\frac{E_m^2}{\left(\frac{V_d}{2}\right)^2}\left[\frac{1-\cos 2\omega t}{2}\right]\right]$$

$$f_s = f_{max}\left[1-\frac{E_m^2}{\left(\frac{V_d}{\sqrt{2}}\right)^2}\left[1-\cos 2\omega t\right]\right]$$

$$f_s = f_{max}\left[1-\left(\frac{E_m}{V_d/\sqrt{2}}\right)^2+\left(\frac{E_m}{V_d/\sqrt{2}}\right)^2\cos 2\omega t\right]$$

$$\because \; f_{max} = \frac{V_d}{4L\Delta I}.$$

it is Switching frequency.

(d) factors Affect the switching frequency is

i) Ripple current (ΔI)

ii) DC bus voltage (V_d)

iii) Induced emf ($E_b = E_m \sin\omega t$)

Q(3) no.

given fundamental voltag = 80 %. of input voltage.

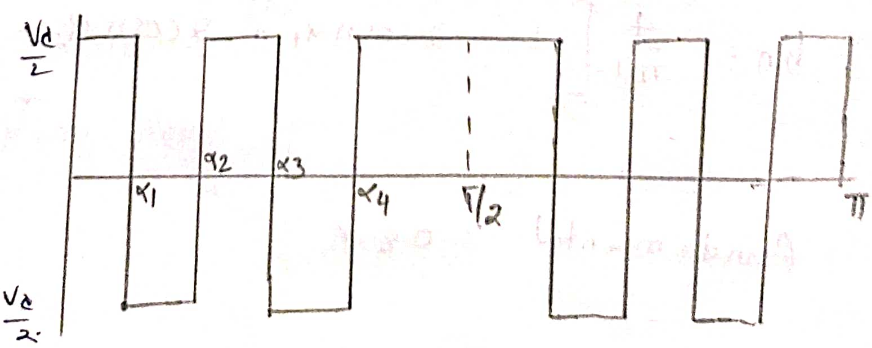
Lower order harmonics of square wave can be eliminated by using the Selected harmonic elimination PWM.

→ In these method notches are created on the square wave as predetermined angles

→ If we need to eliminate 'n' no. of harmonics, 'n+1' number of notches be created in the square wave.

→ from given we need to eliminate 3^{rd}, 5^{th} and 9^{th} '3' harmonics we need to eliminate 4 notches are created.

→ let us take $\alpha_1, \alpha_2, \alpha, \alpha_3$ are the notches. controlled to eliminate three significant harmonic components.



Voltage waveform

- Fourier series of the wave

$$V(t) = \sum_{n=1}^{\infty} a_n \cos n\omega t + b_n \sin n\omega t$$

Sine wave half-wave symmetry $a_n = 0$.

& quarter wave symmetry.

only odd harmonics are present

$$\therefore V(t) = \sum_{n=1}^{\infty} b_n \sin n\omega t$$

$$\therefore b_n = \frac{8}{2\pi} \int_0^{\pi/2} V(t) \sin n\omega t \, d(\omega t)$$

$$b_n = \frac{4}{\pi} \left[\int_0^{\alpha_1} V_m \sin n\omega t + \int_{\alpha_1}^{\alpha_2} -V_m \sin n\omega t + \int_{\alpha_2}^{\alpha_3} +V_m \sin n\omega t + \int_{\alpha_3}^{\alpha_4} -V_m \sin n\omega t + \int_{\alpha_4}^{\pi/2} V_m \sin n\omega t \right]$$

let us take unit Amplitute $V_m = 1$.

$$\therefore b_n = \frac{4}{n\pi} \quad -\cos n\omega t \Big|_0^{\alpha_1} + \cos n\omega t \Big|_{\alpha_1}^{\alpha_2} - \cos n\omega t \Big|_{\alpha_2}^{\alpha_3} + \cos n\omega t \Big|_{\alpha_3}^{\alpha_4} - \cos n\omega t \Big|_{\alpha_4}^{\pi/2}.$$

$$b_n = \frac{4}{n\pi} \left[1 - 2\cos n\alpha_1 + 2\cos n\alpha_2 - 2\cos n\alpha_3 + 2\cos n\alpha_4 \right].$$

Given fundamental $= 0.8$.

If $n=1$

$$b_1 = \frac{4}{\pi}\left[1 - 2\cos\alpha_1 + 2\cos\alpha_2 - 2\cos\alpha_3 + 2\cos\alpha_4\right] = 0.8$$

3rd harmonic

$$b_3 = \frac{4}{3\pi}\left[1 - 2\cos 3\alpha_1 + 2\cos 3\alpha_2 - 2\cos 3\alpha_3 + 2\cos 3\alpha_4\right]$$

5th harmonic

$$b_5 = \frac{4}{5\pi}\left[1 - 2\cos 5\alpha_1 + 2\cos 5\alpha_2 - 2\cos 5\alpha_3 + 2\cos 5\alpha_4\right]$$

7th harmonic

$$b_7 = \frac{4}{7\pi}\left[1 - 2\cos 7\alpha_1 + 2\cos 7\alpha_2 - 2\cos 7\alpha_3 + 2\cos 7\alpha_4\right]$$

to eliminate 3rd, 5th, 7th.

$$b_3 = b_5 = b_7 = 0.$$

Solving $b_1 = 0.8$, $b_3 = 0$, $b_5 = 0$, $b_7 = 0$.

$$\frac{4}{\pi}\left[1 - 2\cos\alpha_1 + 2\cos\alpha_2 - 2\cos\alpha_3 + 2\cos\alpha_4\right] = 0.8$$

$$1 - 2\cos 3\alpha_1 + 2\cos 3\alpha_2 - 2\cos 3\alpha_3 + 2\cos 3\alpha_4 = 0$$

$$1 - 2\cos 5\alpha_1 + 2\cos 5\alpha_2 - 2\cos 5\alpha_3 + 2\cos 5\alpha_4 = 0$$

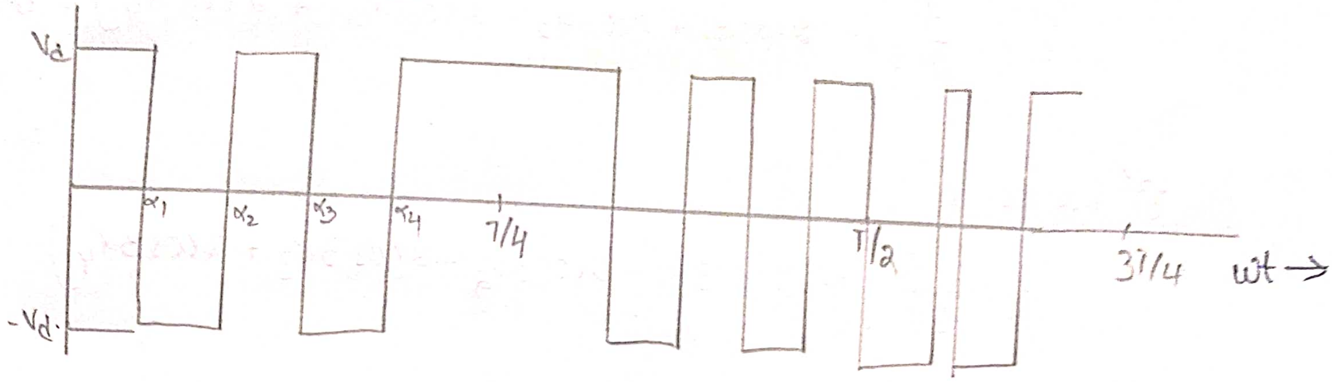
$$1 - 2\cos 7\alpha_1 + 2\cos 7\alpha_2 - 2\cos 7\alpha_3 + 2\cos 7\alpha_4 = 0$$

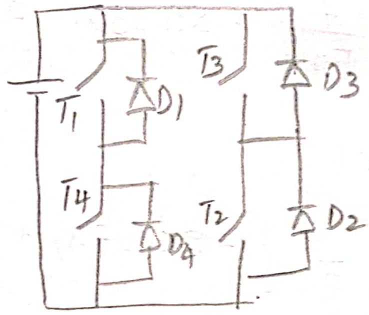
By solving Above we get

α_1, α_2, α_3 α_4 Angles.

output voltage wave form

$\Rightarrow$ V_0





$\Rightarrow$ During the intervals.

$(0 \ \alpha_1) \rightarrow$ T_1 and T_2 conduct $V_0 = +V_d$.

$(\alpha_1 \ \alpha_2) \rightarrow$ T_3 and T_4 conduct $V_0 = -V_d$

$(\alpha_2 \ \alpha_3) \rightarrow$ T_1 and T_2 conduct $V_0 = +V_d$

$(\alpha_3 \ \alpha_4) \rightarrow$ T_3 and T_4 conduct $V_0 = -V_d$.