INVERTERS

Fixed dc ⟶ Variable AC (V_0, f_0)

***Classification of Inverters→**

(1.) Voltage source inverter (VSI) → — sq. wave inverter / PWM inverter.

- * 1ϕ Half bridge Inverter.
- * 1ϕ Full bridge inverter.
- * 3ϕ VSI

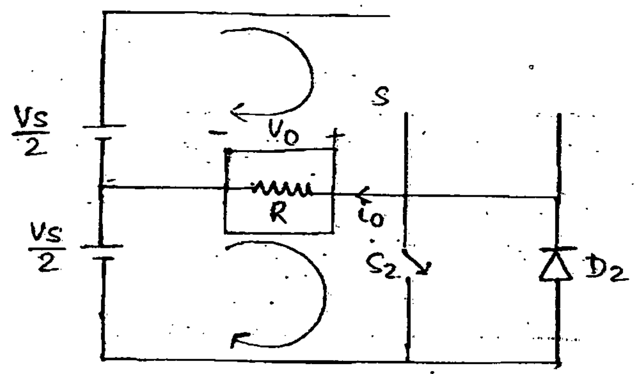
(2.) Current source inverter (CSI) —

(3.) Series inverter

(4.) Parallel inverter.

(1.) Voltage source inverter (VSI) →

(a.) 1-ϕ half bridge inverter →



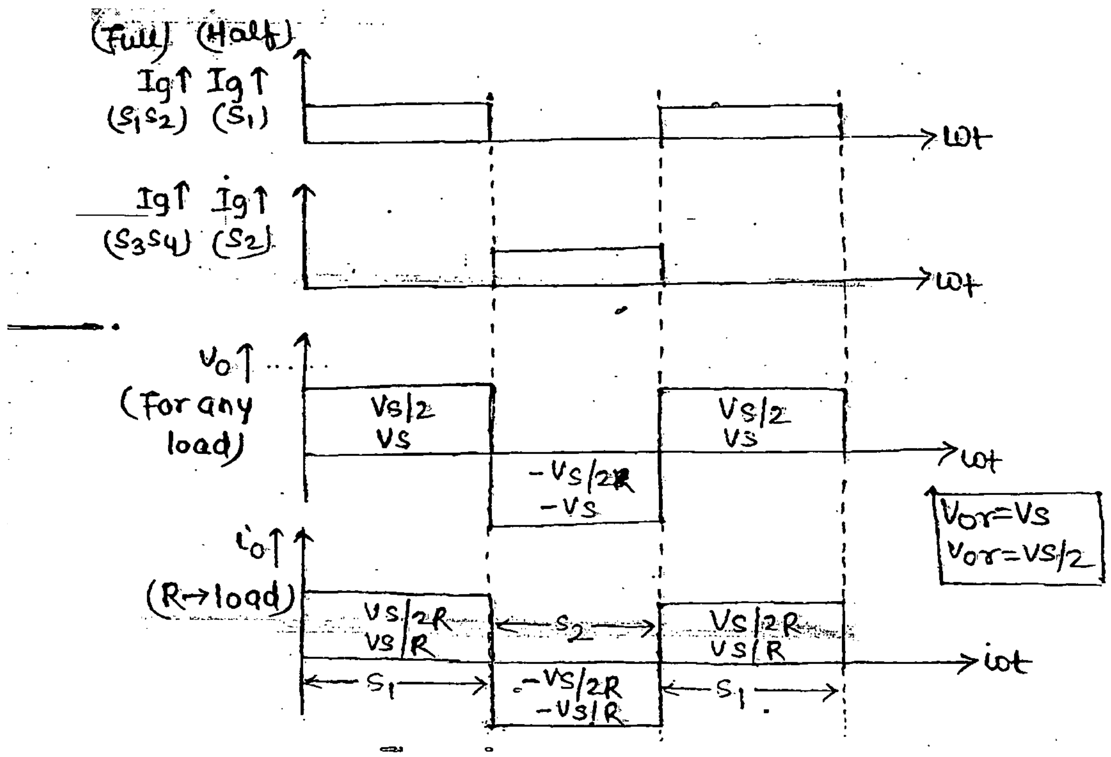
By the use of Fourier Series

$$V_0 = \sum_{n=1,3,5\ldots}^{\infty} \frac{2V_s}{n\pi} \sin \omega t$$

$$V_{0n} = \frac{2V_s}{n\pi} \sin n\omega t$$

$$V_{0n} = \frac{\sqrt{2}V_s}{n\pi}$$

$$\boxed{V_{01} = \frac{\sqrt{2}V_s}{\pi}}$$



$$g = \frac{V_{01}}{V_{or}} = \frac{\frac{\sqrt{2}V_s}{\pi}}{V_s/2}$$

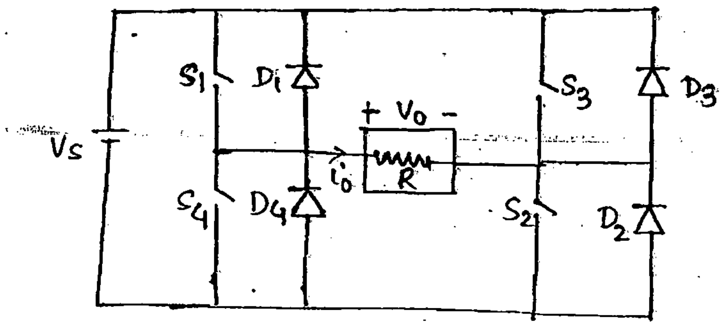
$$\boxed{g = \frac{2\sqrt{2}}{\pi}}$$

$$THD = \left(\frac{1}{g^2} - 1\right)^{1/2}$$

$$\boxed{THD = 48.34\%}$$

* For the +ve power, only R is presents & Hence F/b diode will not conducts. They will conduct only in case of -ve power
* which is found only in reactive elements (L & C)
* The shape of the V_o is not depands on the load, but the current waveform is depand on load.

(ii) 1-ϕ Full bridge inverter →



$S_1 S_2 \rightarrow ON$
$V_0 \rightarrow V_S$
$i_0 \rightarrow V_S/R$

$S_3 S_4 \rightarrow ON$
$V_0 \rightarrow -V_S$
$i_0 \rightarrow -V_S/R$

$$V_0 = \sum_{n=1,3,5\ldots}^{\infty} \frac{4V_S}{n\pi} \sin n\omega t$$

$$V_{on} = \frac{4V_S}{n\pi} \sin n\omega t$$

$$V_{on} = \frac{2\sqrt{2}V_S}{n\pi}$$

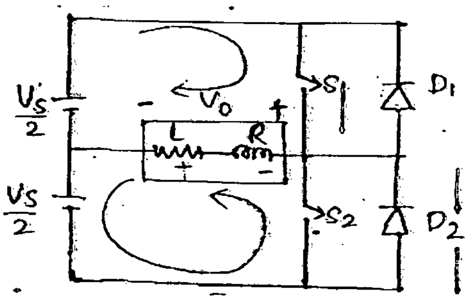
$$\boxed{V_{o1} = \frac{2\sqrt{2}V_S}{\pi}}$$

$$g = \frac{V_{o1}}{V_{or}} = \frac{\frac{2\sqrt{2}\cancel{V_S}}{\pi}}{\cancel{V_S}}$$

$$\boxed{g = \frac{2\sqrt{2}}{\pi}}$$

$$\boxed{THD = 48.34\%}$$

1-ϕ Half bridge inverter (Other load) →



mode (1) :- $S_1 \rightarrow ON$

$V_0 = \frac{V_S}{2}$, V_0+, i_0+, (P+)

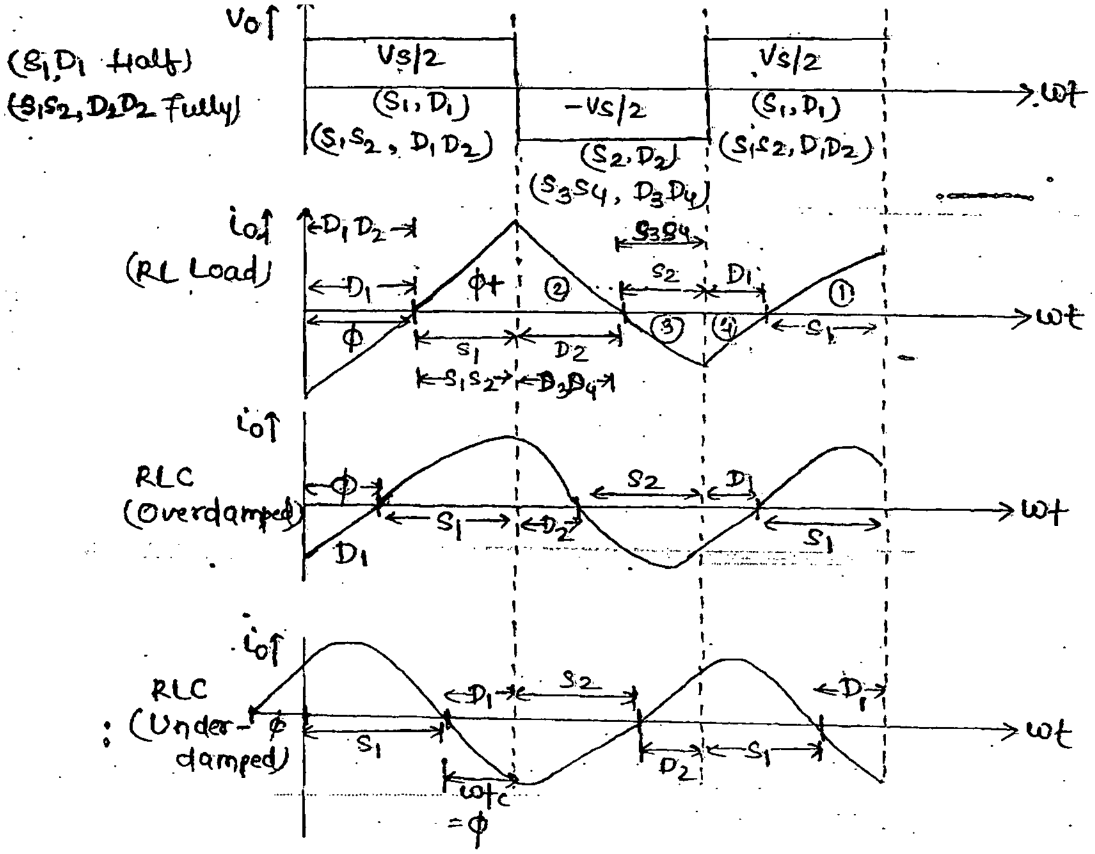
Source $\xrightarrow{P}$ load
$(I^2R, \frac{1}{2}Li^2)$

L → stores energy

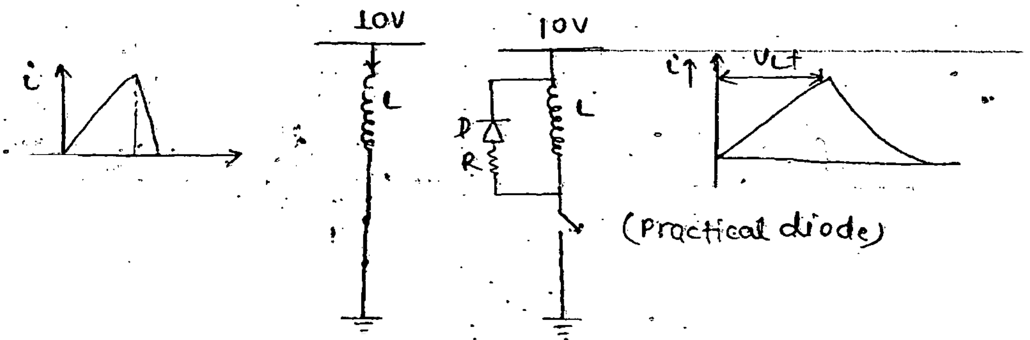
mode (2) → $D_2 \rightarrow ON$

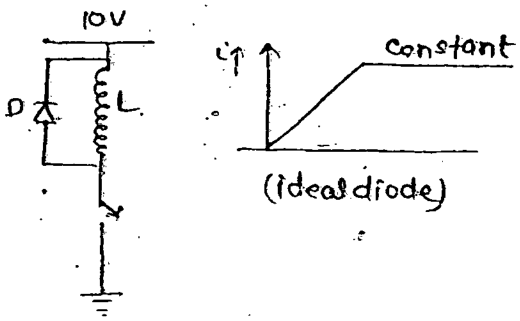
$\frac{1}{2}Li^2 \rightarrow$ Sourc & i^2R

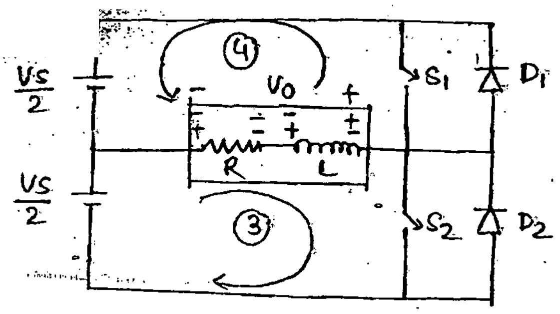
L → releasing energy



(1) RL Load → After reaching steady state, i_o lags by $\boxed{\phi = \tan^{-1}\left(\frac{\omega L}{R}\right)}$







mode ③ → $S_2 \rightarrow ON$

$V_0 = -\frac{V_S}{2}$, V_0-, i_0- (P+)

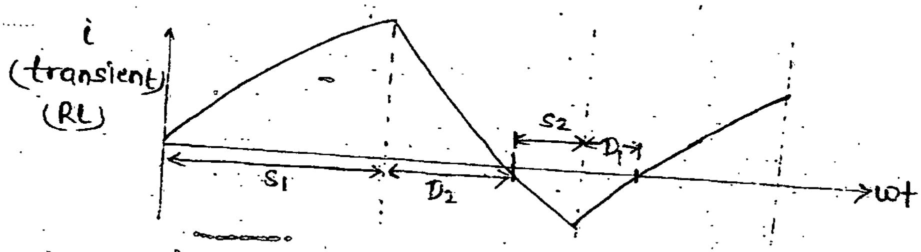
source $\xrightarrow{P}$ load (i^2R & $1/2 Li^2$)

L → stores energy

mode ④ → $D_1 \rightarrow ON$

$\frac{1}{2}Li^2 \longrightarrow$ source & i^2R

L → releasing energy



* Inductive load will draw dc componant at the begining.

V_0	I_0	P	device
+	+	+	S_1
+	-	-	D_1
-	-	+	S_2
-	+	-	D_2

$\boxed{\text{lagging load} \rightarrow \text{diode}}$

$\boxed{\text{leading load} \rightarrow \text{switch}}$

2. RLC (Overdamped) → $(X_L > X_C)$

i_o lags v_o by $\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$

$$\boxed{\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)}$$

~~Forced~~ Comm. is required.

(3.) RLC (Underdamped) →

$X_C > X_L$

i_o lags v_o by $\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$

i_o leads ~~v_o~~ by $\boxed{\phi = \tan^{-1}\left(\frac{X_C - X_L}{R}\right)}$

Load Comm. is required

** $\boxed{\omega t_c = \phi}$

$$t_c = \frac{\phi}{\omega} = \frac{\tan^{-1}(X_C - X_L)}{R\omega}$$

If $t_c > t_q$; load Comm. is successful

$t_c < t_q$; load Comm. is fails

∴ We require forced Comm.

$$V_{on} = \frac{2V_s}{n\pi} \cdot \sin\omega t \quad \text{(Any load)}$$

Let us consider RLC load;

$$i_{on} = \frac{V_{on}}{Z_n}$$

where $Z_n = R_n + j(X_{Ln} - X_{Cn})$

$$= \frac{V_{on}}{|Z_n| \angle \phi_n}$$

$Z_n = |Z_n| \angle \phi_n$

$|Z_n| = \sqrt{R^2 + (X_{Ln} - X_{Cn})^2}$

$$= \frac{V_{on} \angle -\phi_n}{|Z_n|}$$

$\phi_n = \tan^{-1}\left(\frac{X_{Ln} - X_{Cn}}{R}\right)$

$$\boxed{i_{on} = \frac{2V_s}{n\pi |Z_n|} \cdot \sin(n\omega t - \phi_n)}$$

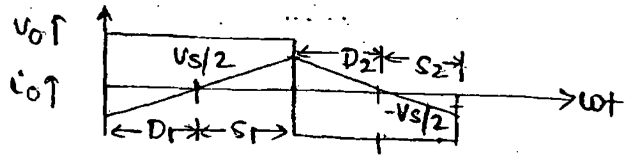
For pure inductive load

$$|Z_n| = X_{Ln} = n\omega L$$

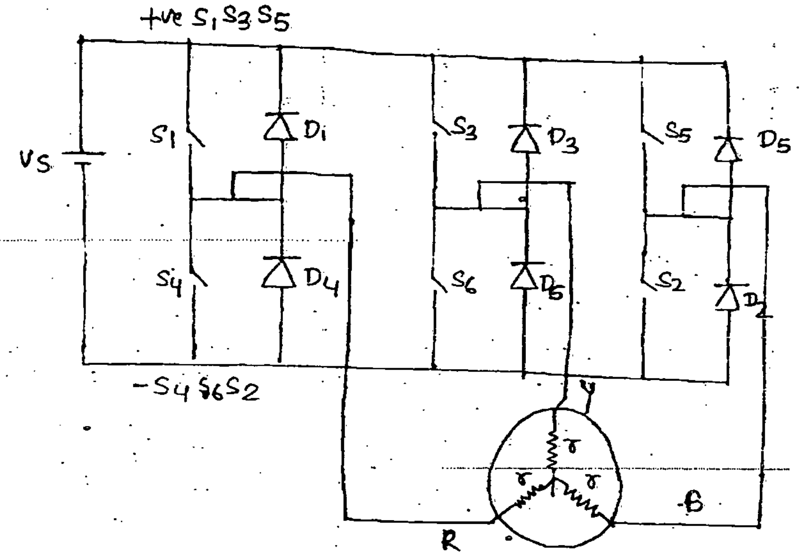
$$\phi_n = 90^\circ$$

$$i_{on} = \frac{2V_s}{n\pi(n\omega L)} \cdot \sin(n\omega t - 90^\circ)$$

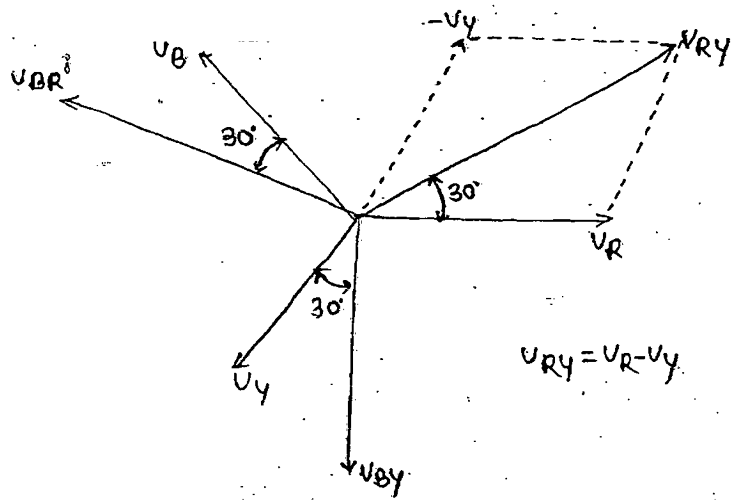
$$i_{on} \propto \frac{1}{n^2}$$

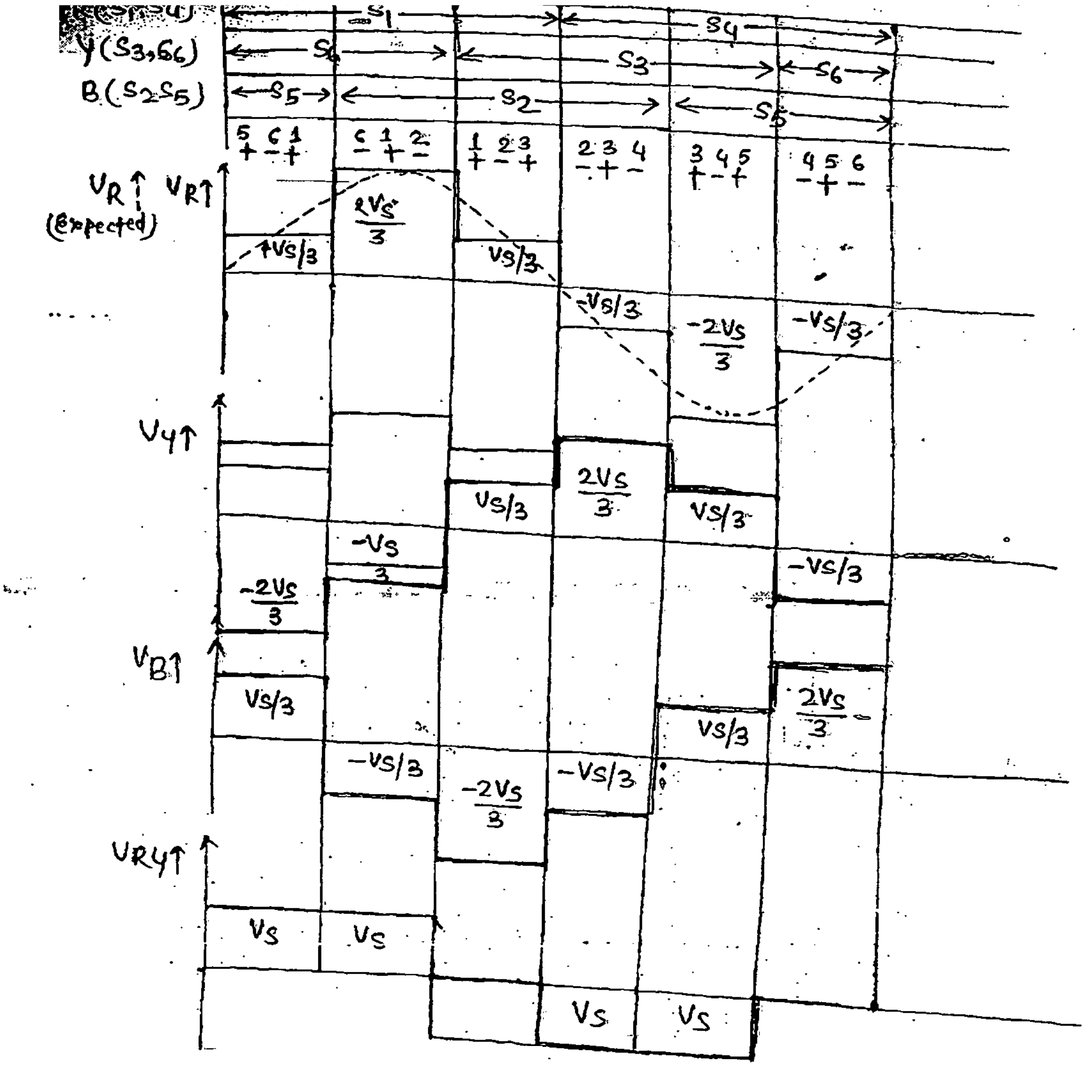


(iii) 3-φ VSI →



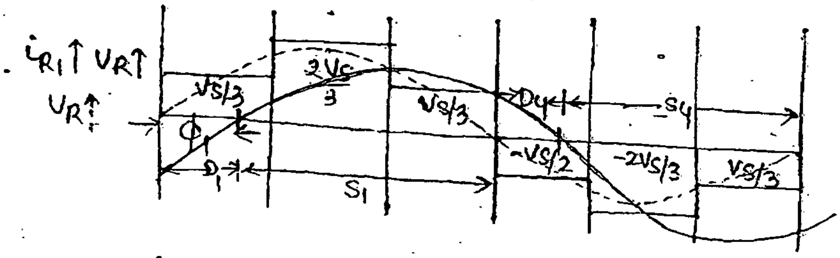
* In 180° VSI the conduction angle of switch & its antiparallel diode is 180°.



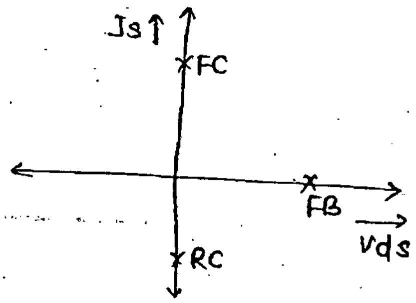


$$(V_{RY})_{Rms} = V_s\left(\frac{\frac{2\pi}{3}}{\pi}\right)^{1/2}$$

$$\boxed{V_L = \sqrt{\frac{2}{3}}\,V_s}$$

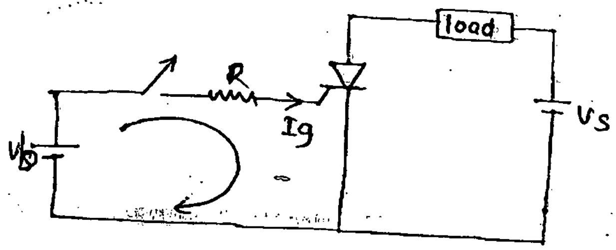


Question



ans(b)

(2.)



$V_b = 12 \pm 4V$ $\quad I_{g\,min} = 10mA$

$I_{g\,min} \le I_g \le I_{g\,max}$

For worst $cond^n$

min^m gate current

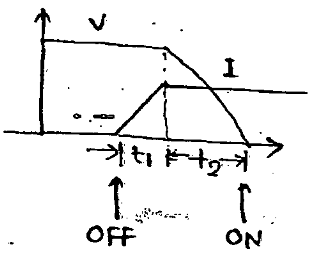
$= \frac{(V_b)_{min}}{R}$

$= \frac{12-4}{R} = \frac{8}{R} \ge I_{g\,min}$

$\therefore R \le \frac{8}{I_{g\,min}}$

$R \le \frac{8}{(10)\times 10^{-3}}$, $\boxed{R \le 800\Omega}$

(3.)



Turn on process

$E_{t1} = \int_0^{t_1} V \cdot \frac{I}{t_1} t \, dt = \frac{1}{2} V I t_1$

$E_{t1} = V(It)_{area} = I \cdot \frac{V}{2} \cdot t_2$

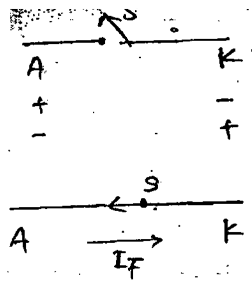
$E_{t2} = I(Vt)_{area}$

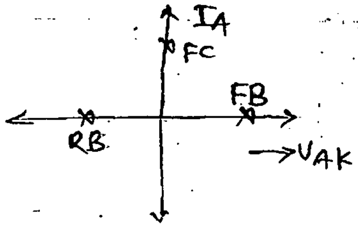
$= I \cdot (\frac{1}{2}) V t_2$

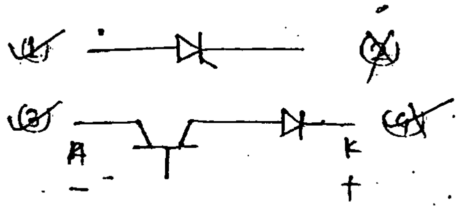
$= \frac{1}{2} V I t_2$

$\boxed{\text{Total } E = \frac{1}{2} V I (t_1 + t_2)}$

ans.(a)



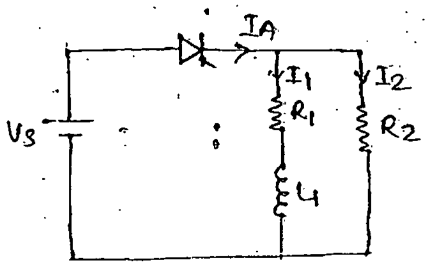




Ans(C)

(5.) $C = \frac{SF \cdot t_q}{R \ln 2} = \frac{2(50\times10^{-6})}{50\ln 2}$ $\boxed{C = 2.88\,\mu F}$

(6.)



$I_A = I_1 + I_2$

$I_1 = \frac{V_S}{R_1}(1 - e^{-t/T_1}) = \frac{100}{20}(1 - e^{-40t})$

$I_1 = 5(1 - e^{-40t})$

$I_2 = \frac{V_S}{R_2} = \frac{100}{5\times10^3} = 20\times10^{-3}$

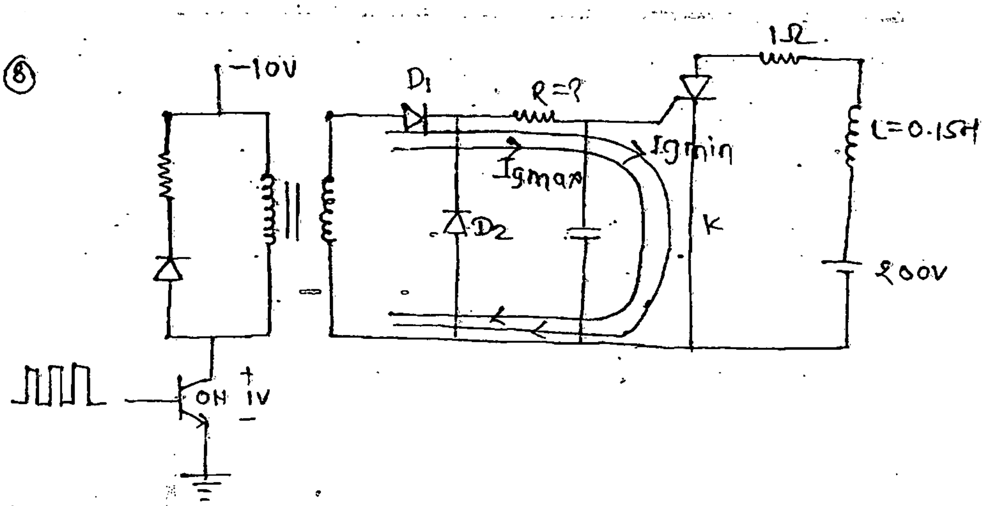
$T_1 = \frac{L_1}{R_1} = \frac{1}{40}$

$I_A = I_1 + I_2$

$I_L = 5(1 - e^{-40t}) + 20\times10^{-3}$

$\boxed{t_{min} = 150\,\mu s}$

7 & 8



$$9V = 1V + (I_{g max} R) + 1V$$

$$\boxed{R \geq 46.67\Omega}$$

$$9V = 1V + (I_{g min} R) + 1V$$

$$\boxed{R \leq 70\Omega}$$

If we consider both then $46.6 \leq R \leq 70\Omega$

Ans. (c) 47Ω

(8.) Volt sec rating of pulse Xmer $= 10 \times t_{gpw}$

$t_{gpw} > t_{min}$

gpw = Gate Pulse width

$$I_A = \frac{V_S}{R}(1 - e^{-t/T})$$

$$\downarrow$$

$$I_L = \frac{200}{1}(1 - e^{-t_{min}/0.15})$$

$$\boxed{t_{min} = 187\mu s}$$

$$= 10 \times t_{gpw}$$

$$\doteq 10 \times t_{min} = 10 \times 187 \mu Vs$$

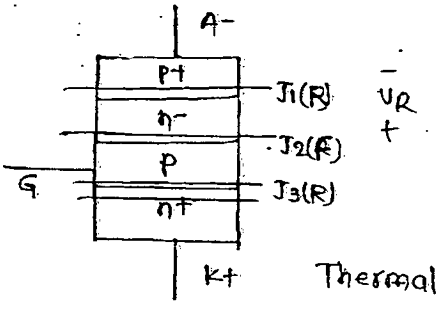
Volt sec rating of pulse Xmer $> 1870\ \mu Vs$

i.e. $2000\ \mu Vs$

(9.) (c) (10) MOSFET (11.) (a.) (12.) (a.) (13.) (c) (14) $I_g \uparrow$ OR $\frac{d}{dt} I_g \uparrow$ (d)

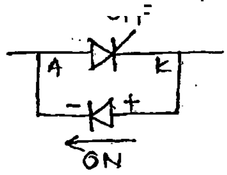
(15.) (c.) (16) (c.) (17.) (d.)

(17.)



$P \uparrow, T \uparrow, I_L \uparrow$

Thermal Runway

(18.) 

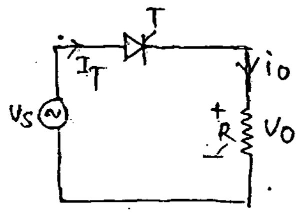
$V_R\uparrow,\ t_q\downarrow,\ \therefore P\uparrow$

$V_R\downarrow,\ t_q\uparrow,\ \therefore P\downarrow$

ans (b)

(19.) $I_{S/2} = \sqrt{2} I_{S1} \Rightarrow 3000 = \sqrt{2} I_{S1}$, $I_{S1} = 2121.3A$

(20.) $(I_T)_{avg}$. Rating $= \dfrac{(I_T)_{Rms}\ \text{Rating}}{FF}$



$$FF = \frac{I_{T(rms)}}{(I_T)_{(avg)}} = \frac{I_{or}}{I_o}$$

$$= \frac{V_{or}/R}{V_o/R}$$

$$= \frac{V_{or}}{V_o} = \frac{\frac{\cancel{V_m}}{\sqrt{2\cdot 2\pi}}\left[(\pi-\alpha) + \frac{1}{2}\sin 2\alpha\right]^{1/2}}{\frac{\cancel{V_m}}{2\pi}\cos\alpha}$$

$$= 3.98$$

$$(I_T)_{avg}\ \text{Rating} = \frac{35}{3.98}$$

$$= 8.8A$$

(21) more than 20A (22) (B.) (23.) (b.)

Conventional Q. (1) (b.)

Heat sink

J . C . S A

$T_j = 125°C$; $T_{S1} = 70°C$

$$P_{AV1} = \frac{T_J - T_{S1}}{\theta_{jc} + \theta_{cs}} = \frac{125-70}{0.16+0.08} = 229.16W$$

$\downarrow T_{S2} = 60°C$ (cool down)

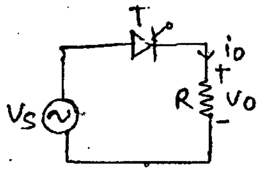
$$\therefore P_{AV2} = \frac{125-60}{0.16+0.08} = 270.8W$$

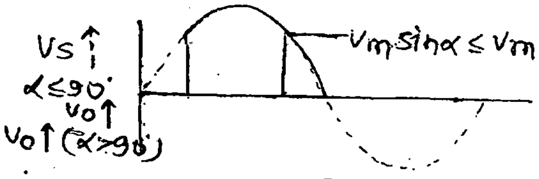
% increase in Rating $= \dfrac{\sqrt{P_{aV2}} - \sqrt{P_{aV1}}}{\sqrt{P_{aV1}}} \times 100 = 8.79\%$

Chap.(2.)

(2.) (b.) (3.) $PIV = 2V_m = 2(50)\sqrt{2} = 100\sqrt{2}$

(4.)





If $\alpha \geq 90^\circ$, $\left[V_o(\omega t)\right]_{peak} = V_m$

~~If α>~~ 90°, $\left[V_o(\omega t)\right]_{peak} = V_m \sin\alpha = 230V$

$230\sqrt{2}\sin\alpha = 230$

$\cancel{230}(\sqrt{2})\sin\alpha = \cancel{230}$

$\sin\alpha = \frac{1}{\sqrt{2}}$

$\alpha = 135^\circ$

(5.) $\alpha = 60^\circ$

$FDF = \cos\alpha$

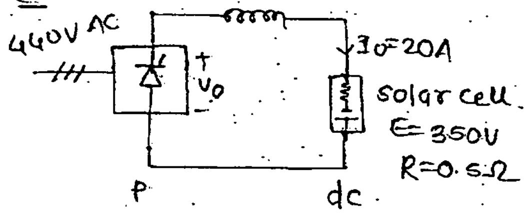
$= \cos 60^\circ = 0.5$

115

$PF = g\cos\alpha = 0.478$

[Ans. (c)]

(6.)



AC ← DC
INV ($\alpha > 90^\circ$) (V_o^-)

$V_o = -E + I_oR$

$\frac{3V_{mL}}{\pi}\cos\alpha = -E + I_oR$

$\frac{3(440\sqrt{2})}{\pi}\cos\alpha = -350 + (20 \times 0.5)$

$\alpha = 125^\circ$

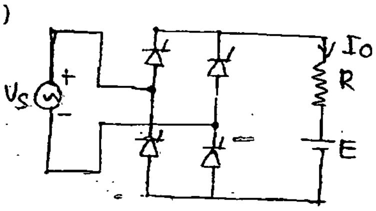
$\alpha \geq 60^\circ$

$\alpha + \omega t_c = \pi$

$\omega t_c = \pi - \alpha = 180^\circ - 125^\circ$

$\boxed{\omega t_c = 55^\circ}$

(7.)



(α to θ_2)

$\theta_1 = \sin^{-1}\frac{E}{V_m} = 38^\circ$

$\theta_2 = \pi - \theta_1 = 142$

$I_o = \frac{1}{2\pi R}\left[V_m(\cos\alpha - \cos\theta_2) - E(\theta_2 - \alpha)\right]$

$= \frac{1}{2\pi R}\left[V_m(\cos\theta_1 - \cos\theta_2) - E(\theta_2 - \theta_1)\right]$

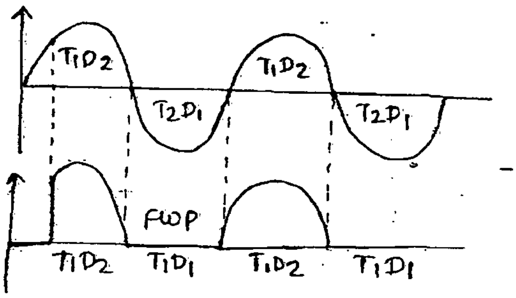
$- E(142 - 38)\frac{\pi}{180}$

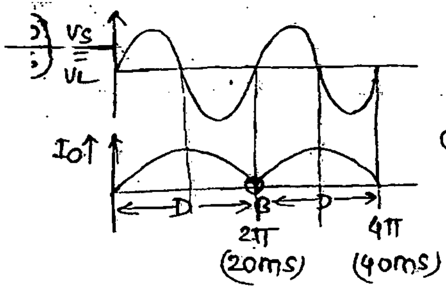
$\boxed{I_o = 11.9A}$

(8.) $\alpha = 25^\circ$, $\mu = 10^\circ$

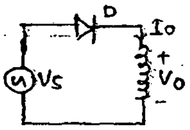
$FDF = \cos\left(\alpha + \frac{\mu}{2}\right) = 0.866$

(9.)





$f = 50Hz$
$T = 20ms$



(14/46) $V_s = 100\sqrt{2}\sin(100\pi t)$

$I_s = \underbrace{10\sqrt{2}\sin(100\pi t - \overset{\phi_1}{\frac{\pi}{3}})}_{I_{S1}} + \underbrace{5\sqrt{2}\sin(300\pi t + \frac{\pi}{4})}_{I_{S3}}$

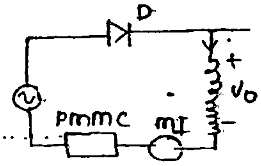
$+ \underbrace{2\sqrt{2}\sin(500\pi t - \frac{\pi}{6})}_{I_{S5}}$

$P = V_{sr} \cdot I_{sr}\cos\alpha = 100(2)\cos(\pi/3) = 500$

(15/46) $PF = g \cdot FDF$ $\quad g = \frac{I_{S1}}{I_{Sr}} = \frac{10}{\sqrt{10^2+5^2+2^2}}$

$PF = \frac{10}{\sqrt{129}}\cos 60° = 0.44$

*



$I_0 = \frac{V_m}{\omega L}(1-\cos\omega t)$

$= \frac{V_m}{\omega L} - \frac{V_m}{\omega L}\cos\omega t$

$(I_0)_{avg} = \frac{V_m}{\omega L}$, $I_{0r} = 1.225\frac{V_m}{\omega L}$

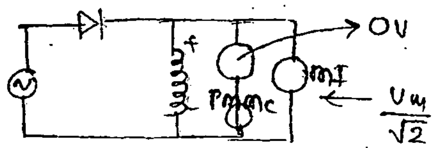
$I_{0r} = \sqrt{\left(\frac{V_m}{\omega L}\right)^2 + \left(\frac{V_m}{\sqrt{2}\omega L}\right)^2} = 1.225\frac{V_m}{\omega L}$

(18/47) $V_0 = \frac{V_m}{\pi}(1+\cos\alpha)$; $(V_0)_{max} = \frac{2V_m}{\pi}$

$= I_F(100+R_S)$

$\frac{2 \cdot 100\sqrt{2}}{\pi} = (1\times10^{-3})(100+R_S)$, $\boxed{R_S = 89.9k}$

*

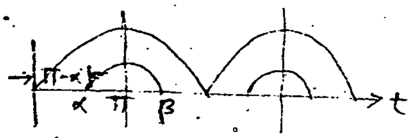


(19/47) RLE load 2pulse, $\alpha = 110$, $\mu = ?$

$\Delta V_{d0} = \frac{V_{d0}}{2}[\cos\alpha - \cos(\mu+\alpha)] = 4fL_sI_0$

$V_{d0} = \frac{2V_m}{\pi}$; $V_0 = -E_g + I_0R_a$ ---(i) [Because of $\alpha > 90°$ INV]

(16/6)



$\beta = \pi + (\pi - \alpha) = 2\pi - \alpha = 360 - 120 = 240°$

$V_0 = V_0\cos\alpha - 4fL_sI_0$ ----(ii)

$\boxed{I_0 = 35.7A}$ $\quad \boxed{\mu = 8.35°}$

(17/6) AC $\xleftarrow[\text{INV }(\alpha>90°)\ (V_0)]{}$ DC

$V_0 = -E + I_0R$ $\quad I_0 = \frac{V_0+E}{R}$

$V_0 = \frac{3V_{mL}}{\pi}\cos\alpha$; $\alpha = 90.001 = 90+$

$V_0 = (0^-)$ (Because INV is not possible at 90°)

$I_0 = \frac{0+400}{10} = \boxed{40A}$

KVA rating of $Tr = \sqrt{3}V_{sr} \cdot I_{sr}$

$I_{sr} = \sqrt{\frac{2}{3}}I_0$

$Tr = \sqrt{3} \cdot 400 \times \sqrt{\frac{2}{3}}I_0$

$\boxed{Tr = 22.6kVA}$

Conventional que (2) →

3pulse : $V_{d0} = \frac{3V_{mL}}{2\pi}$

$\alpha_{max} = 180° - [\omega t_q + \mu_0]$ $\quad \mu_0 =$ overlap angle at $\alpha =$

$\Delta V_{d0} = \frac{V_{d0}}{2}[\cos\alpha - \cos(\alpha+\mu)] = 3fL_sI_0$

$\frac{V_{d0}}{2}[1 - \cos\mu_0] = 3fL_sI_0$

Because at $\alpha = 0$ (Rec.mode)

$V_0 = E_b + I_0R_a$ ....(1)

$V_0 = V_{d0}\cos\alpha - 3fL_sI_0$ ...(2)

$I_0 = 14.74$, $\boxed{\mu_0 = 17°}$

$\omega t_q = 2\pi f t_q = 2\pi \cdot 50 \cdot 250\times10^{-6}\times\frac{180}{\pi} = 4.5$

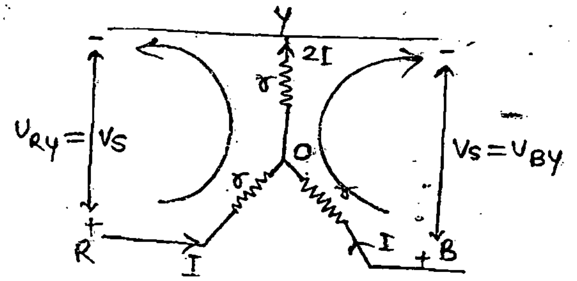
$\alpha_{max} = 180 - [\omega t_q + \mu_0] = 180 - [4.5 + 17]$

$\boxed{\alpha_{max} = 158.5}$

(I) 0 to $\pi/3 \rightarrow$ $S_5 S_6 S_1 \rightarrow ON$

$$\begin{matrix} + & - & + \end{matrix}$$

$S_1 S_6$ ($+$ $-$, R Y) $\quad$ $S_5 S_6$ ($+$ $-$, B Y)



By using KVL $\rightarrow$

$$V_S = Ir + 2Ir$$

$$V_S = 3Ir$$

$$Ir = \frac{V_S}{3}$$

$$V_R = +Ir = +\frac{V_S}{3}$$

$$V_Y = -2Ir = \frac{-2V_S}{3}$$

$$V_B = +Ir = +\frac{V_S}{3}$$

$$(V_R)_{Rms} = \left[\frac{1}{\pi}\left\{\left(\frac{V_S}{3}\right)^2 \times \frac{\pi}{3} + \left(\frac{2V_S}{3}\right)^2\frac{\pi}{3} + \left(\frac{V_S}{3}\right)^2\frac{\pi}{3}\right\}\right]^{1/2}$$

$$\boxed{V_{ph} = \frac{\sqrt{2}V_S}{3}}$$

$$\boxed{I_L = I_{ph} = \frac{V_{ph}}{r} = \frac{\sqrt{2}V_S}{3r}\,A}$$

$$(I_S)_{rms} = \left[\left\{\frac{1}{2\pi}\left(\left(\frac{V_S}{3r}\right)^2\frac{\pi}{3} + \left(\frac{2V_S}{3r}\right)^2\frac{\pi}{3} + \left(\frac{V_S}{3r}\right)^2\frac{\pi}{3}\right)\right\}\right]^{1/2}$$

$(I_S) \rightarrow$ switch

$$= \frac{V_S}{3r}$$

$$\boxed{(I_S)_{rms} = \frac{V_S}{3r}}$$

(1.) $V_{ph} = \frac{\sqrt{2}V_S}{3}$

(2.) $I_{ph} = \frac{V_{ph}}{r}$

(3.) $(I_S)_{rms} = \frac{I_{ph}}{\sqrt{2}}$

(4.) $V_L = \sqrt{3}V_{ph}$

(5.) $P = 3I_{ph}^2 r$

$$\boxed{P = \frac{3V_{ph}^2}{r}}$$

The Fourier Series of $V_R = \sum_{n=6k\pm1}^{\infty} \frac{2V_s}{n\pi} \sin n\omega t$

$n = 1, 5, 7, 11, 13, 17, 19 \ldots$

<u>Note:-</u> Even & tripple harmonics are not present.

$g = \frac{3}{\pi}$, THD $= 31\%$

$V_{Rn} = \frac{2V_s}{n\pi} \sin n\omega t \rightarrow$ Any load

Let us consider RLC load in each phase & let $(X_L > X_C)$

$$i_{Rn} = \frac{V_{Rn}}{Z_n} = \frac{V_{Rn}}{|Z_n| \angle \phi_n} = \frac{V_{Rn} \angle -\phi_n}{|Z_n|}$$

$$\boxed{i_{Rn} = \frac{2V_s}{n\pi|Z_n|} \cdot \sin(\omega t - \phi_n)}$$

$$\boxed{i_{R1} = \frac{2V_s}{\pi|Z_1|} \sin(\omega t - \phi_1)}$$

* Condn angle of each diode $\quad D \rightarrow \phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$

* Condn angle of each switch $\quad S = (\pi - \phi)$

Fourier Series for line voltages:-

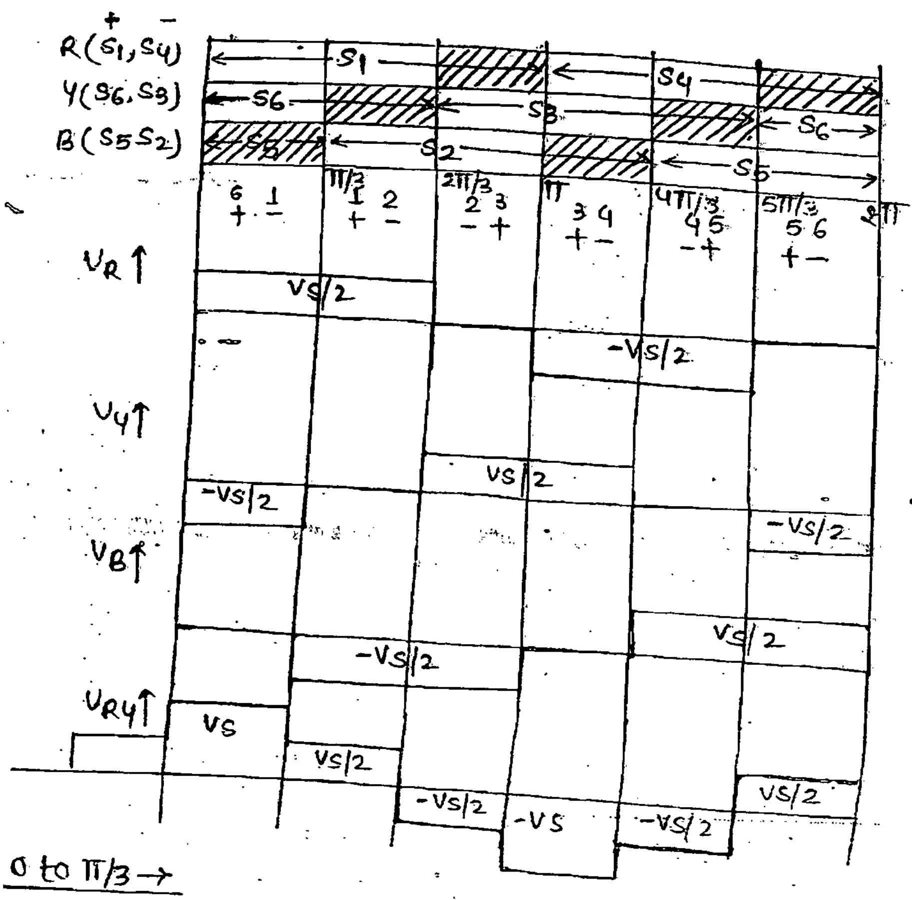
$$\boxed{V_{RY} = \sum_{\substack{n=1,3,5\ldots \\ n=6k\pm1}}^{\infty} \frac{4V_s}{n\pi} \sin\frac{n\pi}{3} \cdot \sin(\omega t + \pi/6)}$$

<u>Note:-</u> Even & ~~odd~~ tripple harmonics are not present.

$$\boxed{g = \frac{3}{\pi}, \text{THD} = 31\%}$$

<u>Drawback</u> $\rightarrow$ There is a possibility of SC across the supply when the incoming switch is start conducting before the outgoing switch belonging to the same phase stops conducting.

120° VSI → In this case a condⁿ angle of 120° is alloted for each switch & the last 60° is allotted for Commutation.



0 to π/3 →

$S_1\ S_6 \rightarrow ON$

$\underset{R}{+}\ \underset{Y}{-}$

$$V_R = \frac{V_S}{2},\quad V_Y = -\frac{V_S}{2},\quad V_B = 0$$

$$* \quad (V_R)_{rms} = \frac{V_S}{2}\left[\frac{2\pi/3}{\pi}\right]^{1/2}$$

$$\boxed{(V_R)_{rms} = \frac{V_S}{\sqrt{6}}}$$

$$* \quad I_{ph} = \frac{V_{ph}}{r} \qquad * \quad V_L = \sqrt{3}\, V_{ph}$$

$$* \quad (I_S)_{rms} = \frac{I_{ph}}{\sqrt{2}} \qquad * \quad P = 3 I_{ph}^2 r = \frac{3V_{ph}^2}{r}$$

$$V_R = \sum_{\substack{n=1,3\\ n=6k\pm1}}^{\infty} \frac{2V_S}{n\pi} \cdot \sin\frac{n\pi}{3} \cdot \sin\left(\omega t + \frac{\pi}{8}\right)$$

Note:- even & tripple harmonic are not present

$g = \frac{3}{\pi}$, THD = 31%

$$\boxed{V_{RY} = \sum_{n=1,3,5}^{\infty} \frac{3V_S}{n\pi} \sin n\omega t}$$

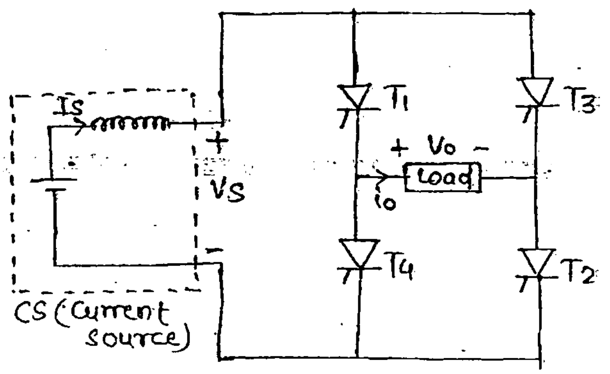
$n = 6K \pm 1$

$n = 1, 5, 7, 11, 13, 17$

Note → even & tripple harmonic are not present.

$g = \frac{3}{\pi}$, THD = 31%

Current Source Inverter → (CSI)

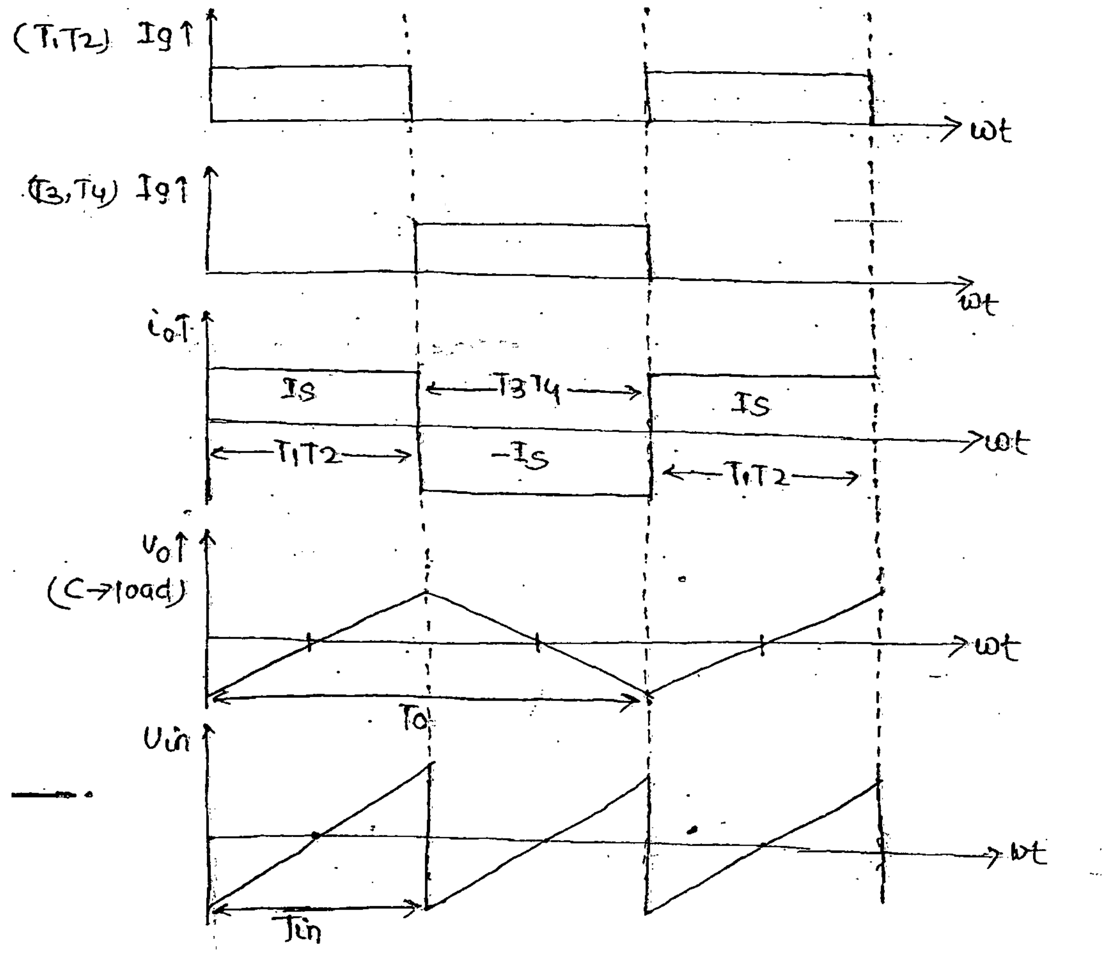


$T_1T_2 \rightarrow ON$

$i_o = I_S$

$T_3T_4 \rightarrow ON$

$i_o = -I_S$



$$i_s = \sum_{n=1,3,\ldots}^{\infty} \frac{4I_s}{n\pi} \sin n\omega t$$

$$g = \frac{2\sqrt{2}}{\pi}, \quad THD = 48.34\%$$

$$\boxed{i_{on} = \frac{4I_s}{n\pi} \sin n\omega t}$$

Let us consider RLC Load.

$$V_{on} = i_{on} Z_{on} = i_{on} |Z_n| \angle \phi_n$$

$$\boxed{V_{on} = \frac{4I_s}{n\pi} |Z_n| \sin(n\omega t + \phi_n)}$$

Eg:- For pure capacitive load;(load comm.)

$$|Z_n| = X_{cn} = \frac{1}{n\omega C}$$

$$\phi_n = -90^\circ$$

$$V_{on} = \frac{4I_s}{n\pi} \cdot \frac{1}{n\omega C} \sin(\omega t - 90^\circ)$$

$$\boxed{V_{on} \propto \frac{1}{n^2}}$$

$T_o = 2T_{in}$

$f_{in} \rightarrow dc$, $2f_o \rightarrow 4c$

$f_o = 2f_s$

Advantage of CSI →

(1.) Feedback diodes are not req. in CSI.

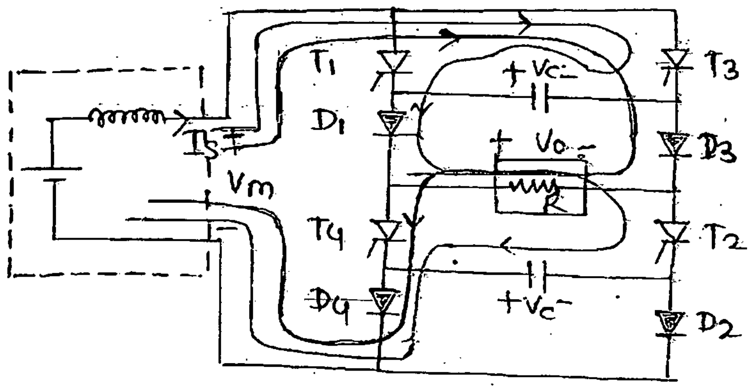
(2.) Comm. is very simple.

(3.) For capacitive load there is a possibility of load comm.

(4.) Inherently there is SC protection for the supply when the incoming thy. are switched on before the outgoing thy. becomes off.

Disadvantage → * During Comm. process the commutating capacitor(load) applies high rev. vol. across the device therefore the devices having low rev. vol. blocking capability such as GTO's, IGBT's & other transistors are generaly not prefered in CSI.

* If the ~~capa~~ comm. capacitor is connected directly across the load then it will be contineouly discharging through the load.
To avoid this prob we must connect blocking diode b/n the load & commutating capacitor as shown in fig. given below.



It is also called as ASCI (Auto seqential commutated inverter)

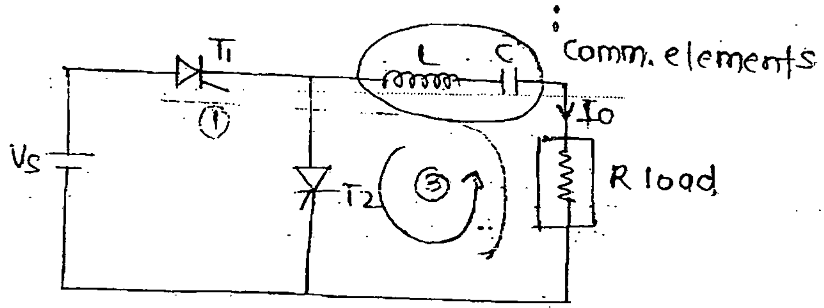
mode(1) → $\longrightarrow$ mode(2) $\rightleftarrows$

mode(3) → $\longleftarrow$ (at the end of mode 2 ⟶ becomes 0)

*(3.) The commutating capacitance limits the max^m freq. of inverter

$$\boxed{f_{max} = \frac{1}{4RC}}$$

* Series Inverter →



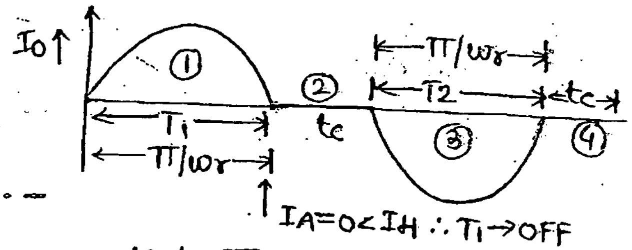
* Here RLC should satisfy underdamped cond^n

* Here the commutating device in series Hence called series inverter

$$\boxed{I = \frac{V_s}{\omega_r L} e^{-\delta t} \sin \omega_r t}$$

$$\omega_r = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}} \qquad \delta = \frac{R}{2L} \qquad (\delta = \text{damping factor})$$

mode ② In this mode we have to provide comm. time for the outgoing thy. T1 before the incoming thy. T2 is switched.
($t_c > t_q$)



$\omega_r t = \pi$

$t = \pi/\omega_r$

$T = 2\left(\frac{\pi}{\omega_r} + t_c\right)$

$f = \frac{1}{2\left(\frac{\pi}{\omega_r} + t_c\right)}$

$$\boxed{f_{max} = \frac{1}{2\left(\frac{\pi}{\omega_r} + t_c\right)}}$$

For ideal thy $t_q = 0$

$$\boxed{f_{max} = \frac{\omega_r}{2\pi}}$$

& $\boxed{f_{max} < \omega_r}$

* At low freq. harmonic distortion is higher. Therefore series inverter is ***not benificial at low freq.***

Resonant Converters (63I Bhimra) → * In this con^r comm. takes place at current 0 (or) voltage 0.

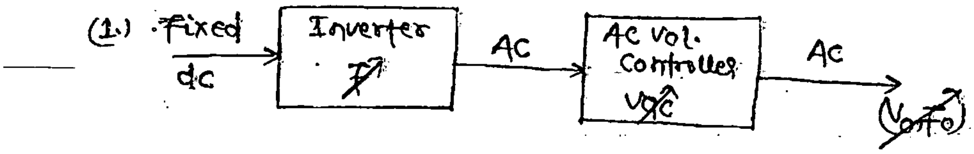
* This reduce the switching power loss even at high freq.
* If comm. takes place at current 0 then it is known as 0 current switching (ZCS)
* If comm. takes place at vol. 0 then it is known as 0 vol. switching (ZVS)
* In this con^r we must use LC elements for getting current 0 (or) voltage 0.

Advantage of series inverter → In series inverter comm. takes place at current 0 & this minimise the switching power loss even at high freq.

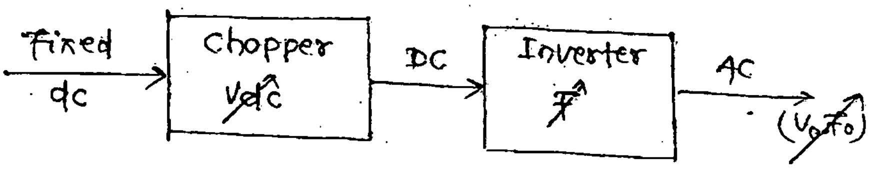
Voltage Control of inverters →

(1.) External Control →

(1.)



(2.)



Drawback → (1) As the no. of stages increases there is a increase in additional power loss along with the size & weight of the equipment.

(2) The filtering requirement becomes costlier due to the increased in harmonics as the no. of stages increased.

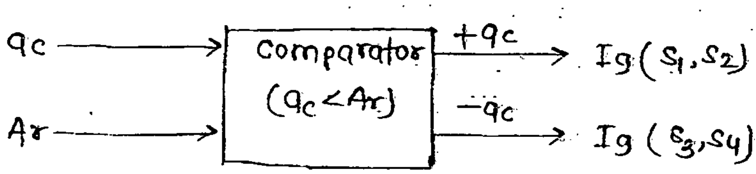
*

(2.) Internal vol. Control using PWM methods →

Advantage → (1.) We can control the vol. within the inverter itself.

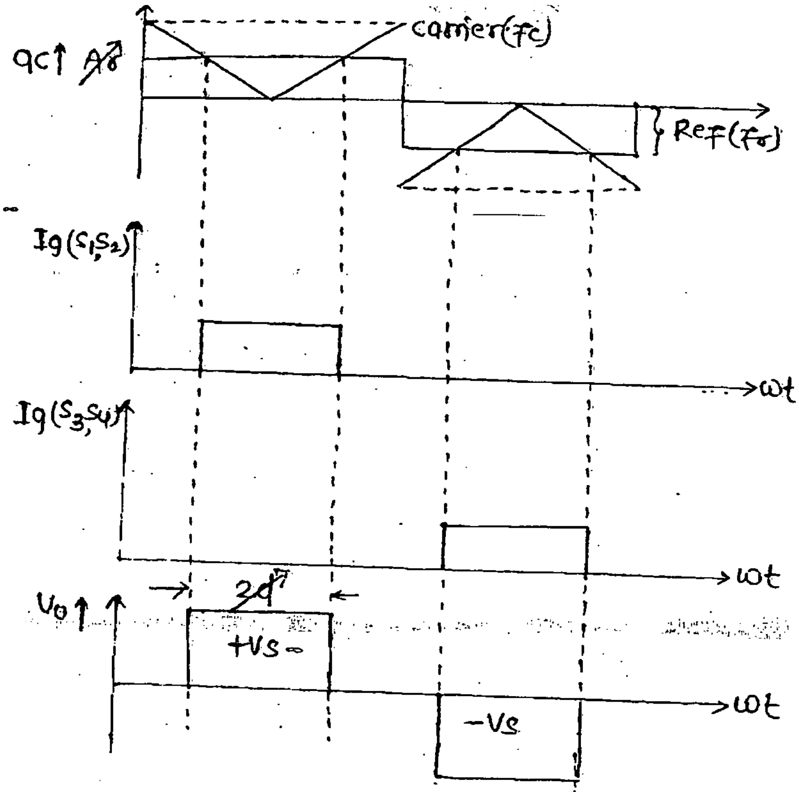
(2.) We can eliminate some of the lower order harmonics & this improves the quality of o/p waveform.

(a.) Single pulse width modn tech. → Let us realize this PWM tech. for 1φ full bridge inverter.



$$\boxed{V_{or} = V_s\left(\frac{2d}{\pi}\right)^{1/2}}$$

2d → total pulse width in each ½ cycle



$$V_o = \sum_{n=1,3,5\ldots}^{\infty} \frac{4V_s}{n\pi} \sin\frac{n\pi}{2} . \sin nd . \sin n\omega t$$

$$V_{on} = \frac{4V_s}{n\pi} . \sin\frac{n\pi}{2} . \sin nd . \sin n\omega t$$

$V_{on} = 0$, if $nd = \pi, 2\pi, 3\pi, .$

$$d = \frac{\pi}{n}, \frac{2\pi}{n}, \frac{3\pi}{n}$$

$$\boxed{2d = \frac{2\pi}{n}, \frac{4\pi}{n}, \frac{6\pi}{n}, \ldots}$$

Valid only if $2d \le \pi$ **
condⁿ to eliminate the harmonic

Que→ What is the pulse width req. to eliminate the 3rd harmonic?

Ans.→ * To eliminate the 3rd harmonic...

$$2d = \frac{2\pi}{3}, \frac{4\pi}{3}, \frac{6\pi}{3}$$

$$2d = \frac{360}{3}$$

$$2d = 120^\circ$$

* To eliminate the 5th harmonic.

$$2d = \frac{2\pi}{5}, \frac{4\pi}{5}, \cancel{\frac{6\pi}{5}}$$

$$2d = \frac{2\pi}{5}, \frac{4\pi}{5}$$

There are only 2 option to eliminate the 5th harmonics

$$2d = 72^\circ, 144^\circ$$

* Here we can eliminate the selected harmonics depanding upon the width of the pulse.
* For eliminating the low order harmonics (3^{rd}) there is only one option.
* so there is many option to eliminate the higher order harmonics.

$$\boxed{V_{on} = \frac{2\sqrt{2}}{n\pi} V_s \sin nd}$$

$$\boxed{V_{01} = \frac{2\sqrt{2}}{\pi} V_s \sin d}$$

$$g = \frac{V_{01}}{V_{or}} = \frac{\frac{2\sqrt{2}}{\pi} \cancel{V_s} \sin d}{\cancel{V_s}\left(\frac{2d}{\pi}\right)^{1/2}}$$

$$\boxed{g = \frac{2\sqrt{2}.\sin d}{\sqrt{(2d).\pi}}}$$

Radians

$$THD = \sqrt{\left(\frac{1}{g^2} - 1\right)}$$

eg:- Let $2d = \frac{2\pi}{3}$ rad $= 120^\circ$

$$g = \frac{2\sqrt{2}.\sin d}{\sqrt{(2d).\pi}} = \frac{2\sqrt{2}.\sin 60^\circ}{\sqrt{\left(\frac{2\pi}{3}\right).\pi}} = \frac{3}{\pi}$$

$$THD = 31\%$$

whenever the even & 3^{rd} order harmonics is not present then always

$$\boxed{g = \frac{3}{\pi} \quad THD = 31\%}$$

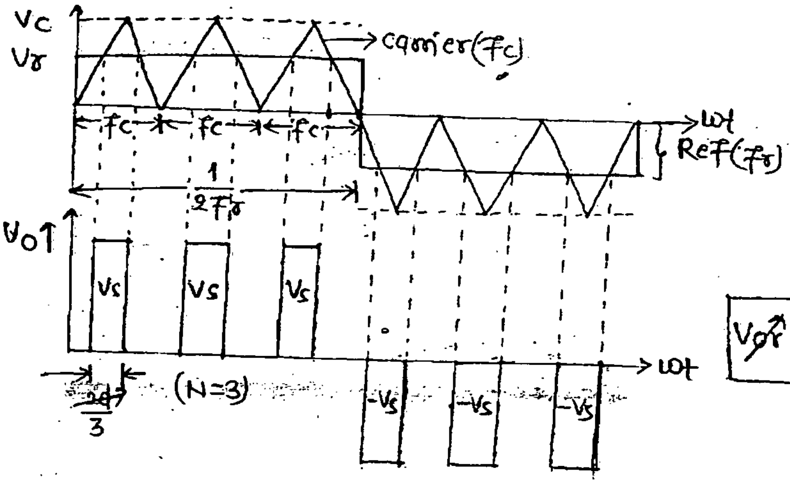
so by using pwm in 1ϕ VSI THD = 31%

$2d = 120°$

* we are using V-shape carrier, but if we use inverted V then the result is same.

V-shape carrier [carrier is high]

(2.) multiple PWM tech. → 3 pulse.



$V_{or} = V_s\left(\frac{2d}{\pi}\right)^{1/2}$

$$\frac{3}{f_c} = \frac{1}{2f_r} \qquad \therefore 3 = \frac{f_c}{2f_r}$$

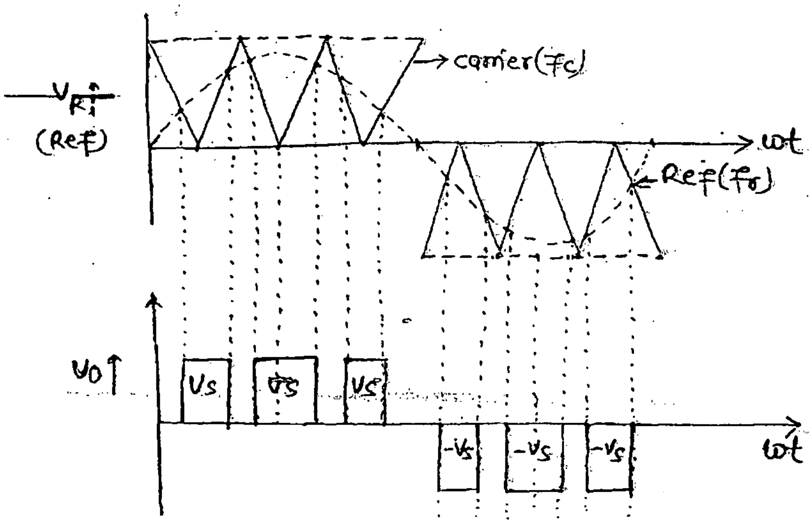
$$\boxed{N = \frac{f_c}{2f_r}}$$

$$\text{Pulse width} = \frac{2d}{N} = \left(1 - \frac{V_r}{V_c}\right)\frac{\pi}{N}$$

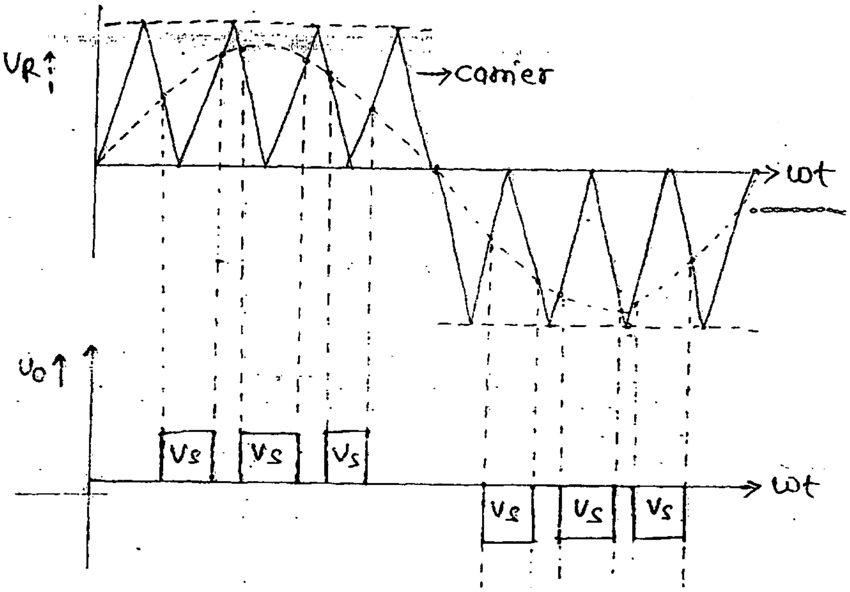
$$\boxed{PW = \left(1 - \frac{V_r}{V_c}\right)\frac{\pi}{N}}$$

3.) Sinusoidal PWM tech. →

(I.) Peak carrier coincident with zero of ref :-



<u>(II) Zero of carrier, coincident with zero of ref:-</u>



$$\boxed{N = \frac{f_c}{2f_r} - 1}$$

<u>Note:-</u> Dominant Harmonics $\rightarrow 2N \pm 1$

If $N=3$, $2(3)\pm1 = 5,7$

If $N=9$, $2(9)\pm1 = 17,19$

modulation index $(m_I) = \frac{V_r}{V_c}$

the domination is shown by lower order it is diff. to filter them.

* We can easily filter the higher order dominant harmonics.

* Therefore in sinusoidal PWM tech. we increase the no. of pulses in each half cycle & increase the order of dominant harmonics. So that they can be filtered very easily.

1 PWM	Multi PWM	Sinusoidal PWM
* $V_{or} = V_s\left(\frac{2d}{\pi}\right)^{1/2}$	* $N = \frac{f_c}{2f_r}$	* $N = \frac{f_c}{2f_r} - 1$
* $V_o = \frac{4V_s}{n\pi} \sin\frac{n\pi}{2} (\sin nd) (\sin n\omega t)$	* $PW = \left(1 - \frac{V_a}{V_c}\right)\frac{\pi}{N}$	* Dominant Harmonic $= 2N \pm 1$

* $V_{on} = \frac{4V_s}{n\pi} \sin\frac{n\pi}{2} (\sin nd)(\sin n\omega t)$

* $V_{on} = 0$, $nd = \pi, 2\pi, 3\pi$

$$d = \frac{\pi}{n}, \frac{2\pi}{n}, \frac{3\pi}{n} \ldots$$

$$2d = \frac{2\pi}{n}, \frac{4\pi}{n}, \frac{6\pi}{n} \ldots$$

If $n = 3$, $2d = 120^\circ$

$n = 5$, $2d = 72, 144^\circ$

* $V_{o1} = \frac{4V_s}{\pi\sqrt{2}} \sin d$

$$V_{o1} = \frac{2\sqrt{2}V_s \sin d}{\pi}$$

* $g = \frac{V_{o1}}{V_{or}} = \frac{2\sqrt{2}\cancel{V_s}\sin d/\pi}{\cancel{V_s}\left(\frac{2d}{\pi}\right)^{1/2}}$

$$g = \frac{2\sqrt{2}\sin d}{\sqrt{2d\pi}}$$

* $g = \frac{3}{\pi}$, THD $= 31\%$