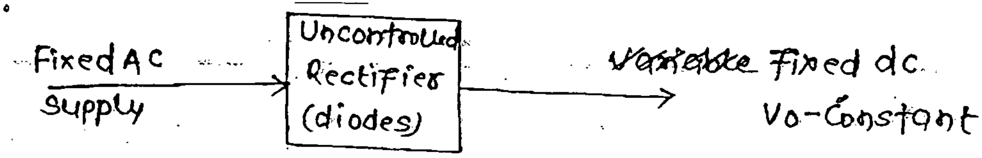
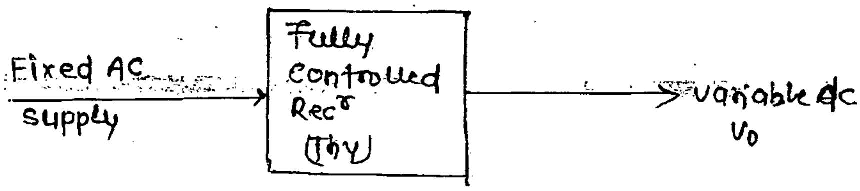
Phase Controlled Rectifier

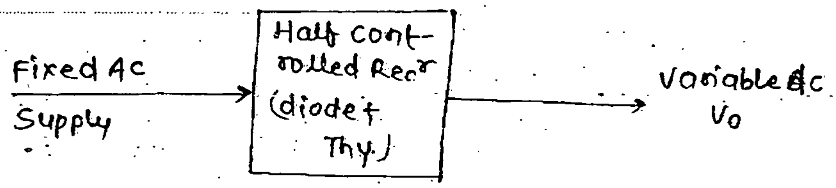
* Uncontrolled Rectifier →



Fully controlled Rectifier → (Full converter)
2 quadrant operations



Half controlled Rectifier → (semiconverter)
one quadrant operation.

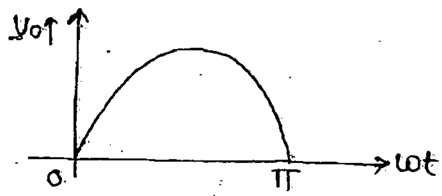


Classification of Converter based on pulse no. of the converter →

Pulse no. 'm' → Pulse no. gives the no. of the o/p pulse for 1 cycle AC source voltage.

(1) One pulse con^r →

1-ϕ half wave rec^r.

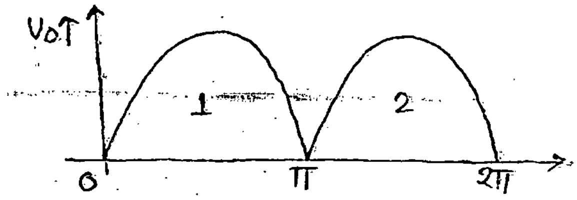


$$T_0 = \frac{2\pi}{m} = \frac{2\pi}{1} \Rightarrow T_0 = 2\pi \text{ rad.}$$

$$f_0 = f_s$$

(2) Two pulse con^r →

1-ϕ full wave rec^r



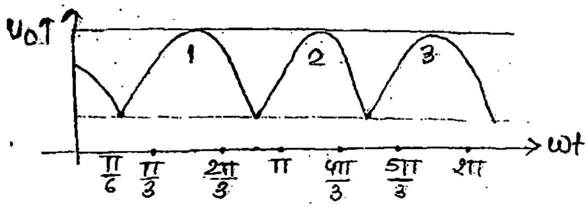
$T_0 = \frac{2\pi}{2} = \pi$ rad.

$f_0 = 2f_s$

T_0 = Time period pulse in rad $= \frac{2\pi}{m}$ (rad)

(3) 3 pulse con^r →

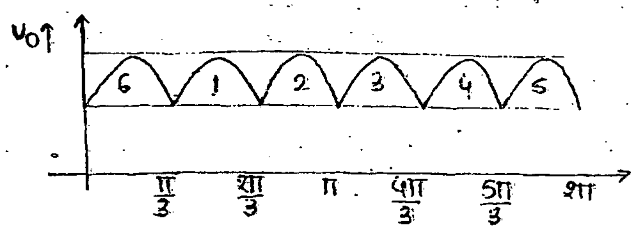
3-ϕ half wave rectifier



$T_0 = \frac{2\pi}{3} = \underline{120^\circ}$

$f_0 = 3f_s$

(4) 6 pulse con^r →



$T_0 = \frac{2\pi}{6} = \frac{\pi}{3}$ rad.

$f_0 = 6f_s$

$f_0 = mf_s$

where f_0 = o/p ripple freq.

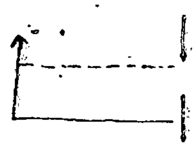
f_s = supply freq.

$m\uparrow$, $T_0\downarrow$, $f_0\uparrow$, ripple vol. $\downarrow$ $\therefore$ Harmonics$\downarrow$

SMPS →

$\underset{50Hz}{AC} \xrightarrow{(1)} DC \xrightarrow[(MOSFET)]{(2)} AC \longrightarrow$ pure DC

$f\uparrow$ (50KHz to 100KHz)



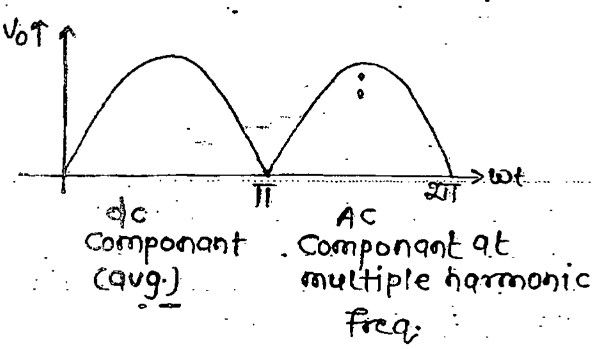
* Effect of harmonics on the performance of dc motor →

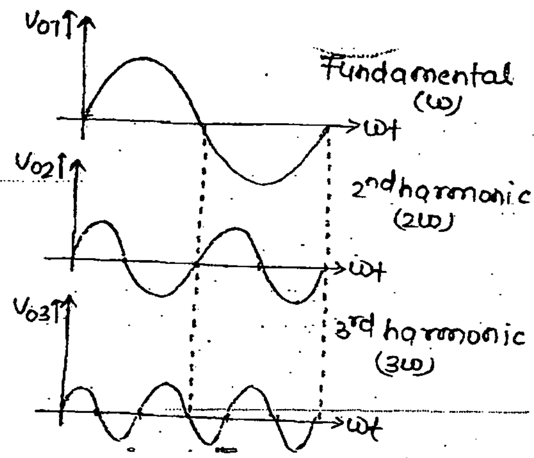
* Harmonics overheat the m/c wdg. & Hence we can't use (utilise) the m/c to its full capacity.

  Therefore we must derate the m/c when fed to conʳ.
* Harmonics produce pulsating torque in rotor & hence smooth rotation may not be possible if it is used for power motors.
* The rotor inertia will damp ~~for~~
* This pulsating torque produced by harmonics & hence smooth rotation is possible for bigger m/c.

Harmonics Analysis on the dc side of the converter →

Let us consider a 2 pulse converter





* Mathematical Formula For Fourier analysis →

$$V_o = \underset{(avg)}{a_0} + \sum_{n=1}^{\infty} (a_n \cos\omega t + b_n \sin\omega t)$$

$$V_0 = a_0 + \sum_{n=1}^{\infty} C_n \sin(n\omega t + \phi_n) \quad \text{where } C_n = \sqrt{a_n^2 + b_n^2}$$

ϕ_n = n^{th} harmonic displacement angle.

O/P Rms voltage

$$V_{or} = \sqrt{V_0^2 + V_{01}^2 + V_{02}^2 + V_{03}^2 + \cdots}$$

For all the dc loads avg. value is responsible to deliver the useful power.

$$V_{or}^2 = V_o^2 + V_{o1}^2 + V_{o2}^2 + \cdots$$

$$V_{or}^2 - V_o^2 = V_{o1}^2 + V_{o2}^2 + \cdots$$

$$\sqrt{V_{or}^2 - V_o^2} = \sqrt{V_{o1}^2 + V_{o2}^2 + \cdots} = V_{oH}$$

<u>Voltage Ripple factor (VRF) →</u> It is a measure of harmonics on the dc side of converter.

$$VRF = \frac{\sqrt{V_{or}^2 - V_o^2}}{V_o}$$

$$\boxed{VRF = \sqrt{\left(\frac{V_{or}}{V_o}\right)^2 - 1}}$$

<u>Form factor →</u>

$$FF = \frac{V_{or}}{V_o}$$

$$\boxed{VRF = \sqrt{FF^2 - 1}}$$

<u>perfact dc →</u> (1.) No ripple

(2.) $V_{or} = V_o$

(3.) $FF = 1$

(4.) $VRF = 0$ (No harmonics)

<u>Significance of FF:-</u>

(1.) Without harmonics $FF = 1$

(2.) With harmonics $FF > 1$

(3.) As the FF decreases & reaches to unity then smoothness of wave form is improved towards dc.

(4.) FF gives the information on shape of waveform on dc side of converter.

Harmonics analysis of the ac side of converter →

Let us consider an inverter

* The o/p vol. waveform of the inverter may not be pure sinusoidal, it may contains harmonics.

* For all the ac loads fundamental component is responsible to deliver usefull power.

$$V_{or} = \sqrt{V_0^2 + V_{01}^2 + V_{02}^2 + \cdots}$$

$$\sqrt{V_{or}^2 - V_{01}^2} = \sqrt{V_0^2 + V_{02}^2 + \cdots}$$

Total harmonic distortion (THD) → It is measure of harmonics on Ac side of the con^r.

$$THD = \frac{\sqrt{V_{or}^2 - V_{01}^2}}{V_{01}}$$

$$\boxed{THD = \sqrt{\left(\frac{V_{or}}{V_{01}}\right)^2 - 1}}$$

Distortion Factor 'g' → It gives the information of waveform on Ac sides.

$$\boxed{g = \frac{V_{01}}{V_{or}}} \qquad \boxed{THD = \sqrt{\frac{1}{g^2} - 1}}$$

Perfact AC →

(1.) $V_{or} = V_{01}$

(2.) $g = 1$

(3.) THD = 0 (No harmonics)

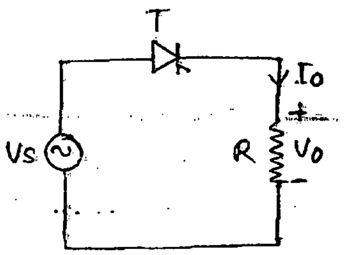
Significance of distortion factor →

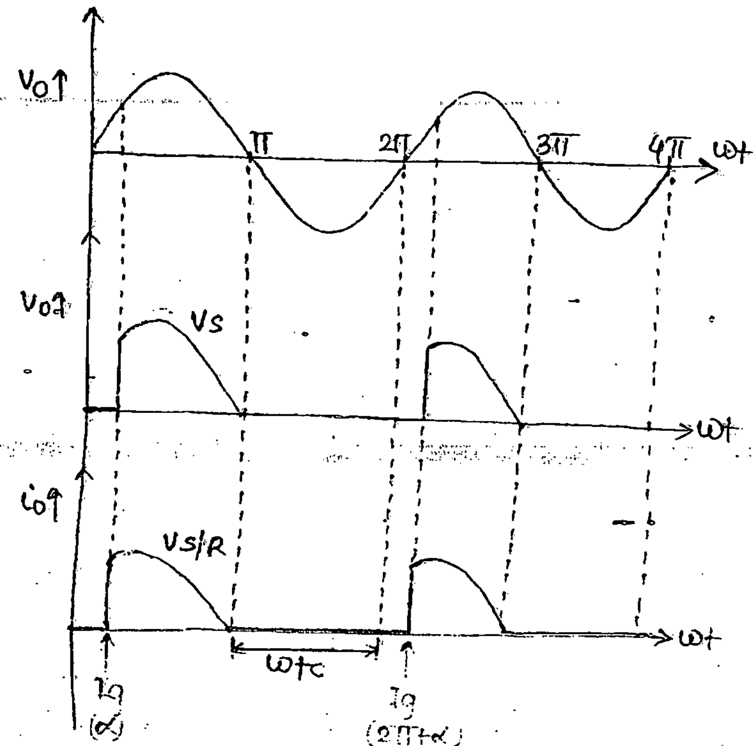
(1.) Without harmonics $g = 1$

(2.) With harmonics $g < 1$

(3.) As g value is ~~increased~~ & approches unity then smoothness of waveform is improved towards sinusoidal.

(1.1) 1-ϕ Half wave Rectifier (one pulse converter) →





$i_s = i_o$

$\omega t_c = \pi \text{ rad}$

$t_c = \frac{\pi}{\omega} \text{ sec}$

$$V_o = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \, d(\omega t)$$

$$= \frac{V_m}{2\pi}(-\cos\omega t)_{\alpha}^{\pi}$$

$$V_o = \frac{V_m}{2\pi}\left[-\cos\pi + \cos\alpha\right]$$

$$\boxed{V_o = \frac{V_m}{2\pi}(1+\cos\alpha)}$$

$$I_o = \frac{V_o}{R} = \frac{V_m}{2\pi R}(1+\cos\alpha)$$

$$\boxed{I_o = \frac{V_m}{2\pi R}(1+\cos\alpha) = (I_s)_{avg.}}$$

Drawback → The source current contains dc componants & saturates the supply T/F core.

Therefore HWR is generaly not prefered for applications.

$$V_{or} = \left[\frac{1}{2\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

$$V_{or} = \left[\frac{V_m^2}{2\pi}\left\{(\omega t)_{\alpha}^{\pi} - \frac{1}{2}(\sin 2\omega t)_{\alpha}^{\pi}\right\}\right]^{1/2}$$

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

$$\boxed{V_{or} = \frac{V_m}{\sqrt{2T_0}}\left[(U-U) + \frac{1}{2}(\sin 2L - \sin 2U)\right]^{1/2}}$$

$P_{in} = V_{sr} \cdot I_{sr} \, PF$ ------- (i)

$V_s = V_m \sin\omega t$; $V_{sr} = \frac{V_m}{\sqrt{2}}$

$I_{sr} = I_{or} = \frac{V_{or}}{R}$

$P_{in} = V_{sR} \, I_{sr} \cos\phi_1$ ------ (ii)

$P_o = V_o I_o$ ✗

i.e. For resistive load take Rms values ... i.e.,

$P_o = V_{or} \cdot I_{or}$

Assuming no losses in the thy.

$V_{sr} \cdot \cancel{I_{sr}} \cdot PF = V_{or} \cdot \cancel{I_{or}}$

53 $\boxed{PF = \frac{V_{or}}{V_{sr}}}$ For R load

$$PF = \frac{1}{\sqrt{2\pi}}\left[(\pi - \alpha) + \frac{1}{2}\sin 2\alpha\right]^{1/2}$$

(1) The supply current contains harmonics on Ac side of the converter. In general (other then resistive load) fundamental source current is responcible to deliver useful power on Ac side of the conr.

Fundamental displacement factor (FDF) $= \cos\phi_1$

$\cancel{V_{sr}} \cdot I_{sr} \cdot PF = \cancel{V_{sr}} \cdot I_{s1} \cos\phi_1$

$PF = \frac{I_{s1}}{I_{sr}} \cdot \cos\phi_1$

$PF = g \cdot \cos\phi_1$

$\boxed{PF = g \cdot FDF}$

(1.) PF depands on Firing angle α. As α increases PF is decreases.

(2.) PF depands on the shape of supply current waveform, i.e. it depands on Harmonics on the Ac side of conr

$$\boxed{PF = g \cdot FDF}$$

(3.) PF also depands on type of the conr & type of load.

Drawback of PE conr →

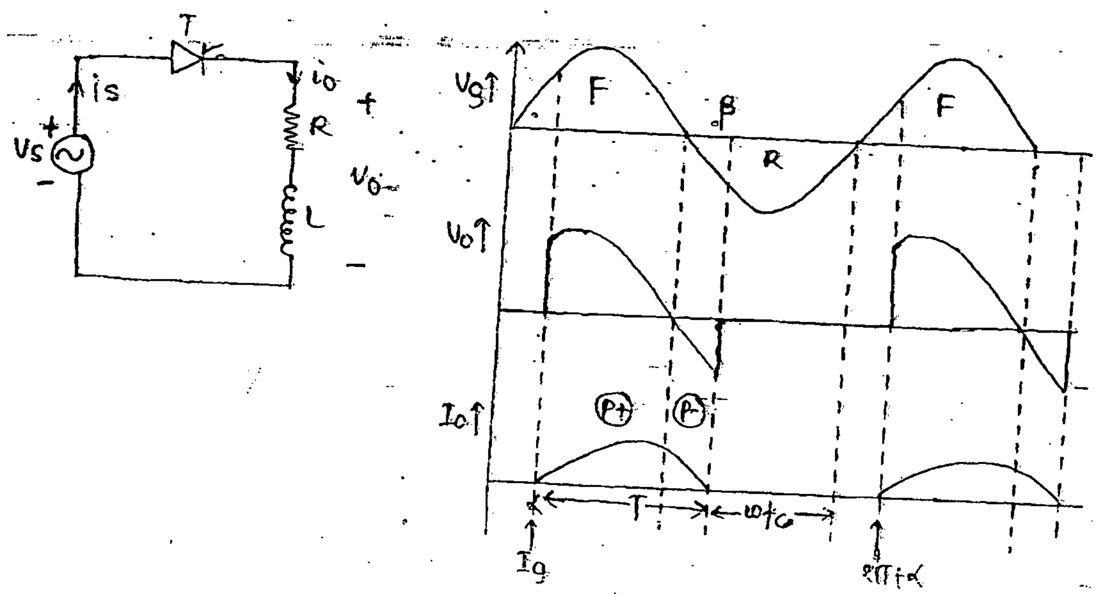
(1.) The conr injects harmonics into the supply & reduce its power quality.

To rectify this problem we must use Ac Filter on Ac side of the conr.

(2.) At high values of firing angle α, the PF is very low. Therefore it draws very high lagging reactive power from the supply.

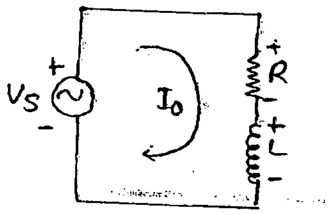
* To rectify this problem we must connect a reactive power source on Ac side of conr to compensate the required reactive power for the conr operation.

(2.) 1-ϕ HWR (RL load) →



Mode(1) → (α to π)

$V_0 = V_s$



* Power flows from source to the load
So power is +ve i.e. (P+)

Apply KVL;

$$V_s = V_m \sin\omega t = Ri_0 + L\frac{di_0}{dt}.$$

$$i_0 = \underset{(PI)}{I_{steady}} + \underset{(CF)}{I_{transient}}$$

$$i_0 = \frac{V_m}{|Z|}\sin(\omega t - \phi) + Ke^{-t/T}$$

at $\omega t = \alpha$, $i_0 = 0$

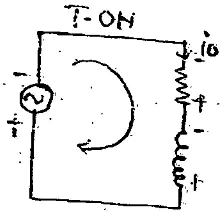
$$K = \frac{V_m}{|Z|}(e^{t/T}) \times \sin(\alpha - \phi)$$

$$\boxed{K = \frac{-V_m}{|Z|}\sin(\alpha-\phi)\, e^{\frac{-R\alpha}{\omega L}}}$$

Mode(2) → (π to β)

$\frac{1}{2}Li^2 \longrightarrow$ Source & I^2R

L is releasing energy



* Here the inductance energy makes the thy. to conduct even in the -ve cycle until it releases its complete energy at $\omega t = \beta$

$$\downarrow PF = \frac{P_0 \downarrow}{V_{sr}\, I_{sr}}$$

$\omega t_c = 2\pi - \beta$

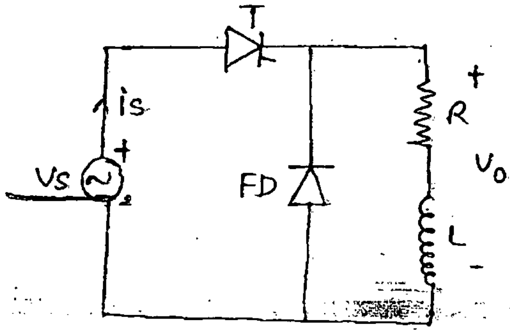
$$\boxed{t_c = \frac{2\pi - \beta}{\omega} \text{ sec}}$$

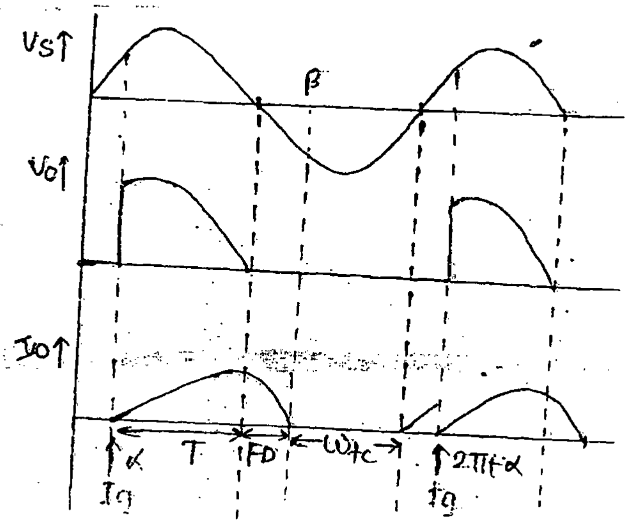
$$V_0 = \frac{1}{2\pi}\int_{\alpha}^{\beta} V_m \sin\omega t\, (d\omega t)$$

$$\boxed{V_0 = \frac{V_m}{2\pi}(\cos\alpha - \cos\beta)}$$

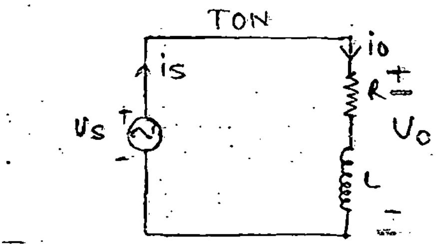
$$V_{or} = \frac{V_m}{2\sqrt{\pi}}\left[(\beta-\alpha) + \frac{1}{2}(\sin 2\alpha - \sin 2\beta)\right]^{1/2}$$

3) 1-ϕ HWR RL load with FD →



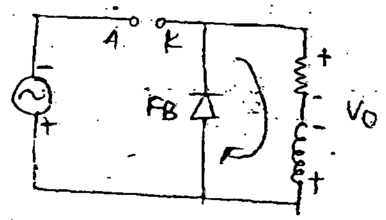


mode(1) →



ource (P) → load

mode(2) →



$\frac{1}{2}Li^2 \rightarrow I^2R$

PF improved, $PF = \frac{P_o}{V_{sr} I_{sr}}$

$$V_o = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \, (d\omega t)$$

$$\boxed{V_o = \frac{V_m}{2\pi}(1+\cos\alpha)}$$

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

$\omega t_c = \pi \text{ rad}$

$$\boxed{t_c = \frac{\pi}{\omega}}$$

* −Ve power is removed i.e. avg. Po is increased; so PF is increased.

$$\uparrow PF = \frac{Po\uparrow}{V_{sr} I_{sr}}$$

Advantage of FD →

(1.) The PF is improved on AC side of the conr.

(2.) −Ve voltage spikes in the o/p voltage waveform is removed; thus increased o/p voltage, active power & PF.

(3.) The shape of the o/p current waveform is improved.

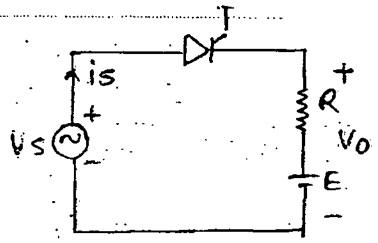
Hence the performance of the converter is improved with a FD.

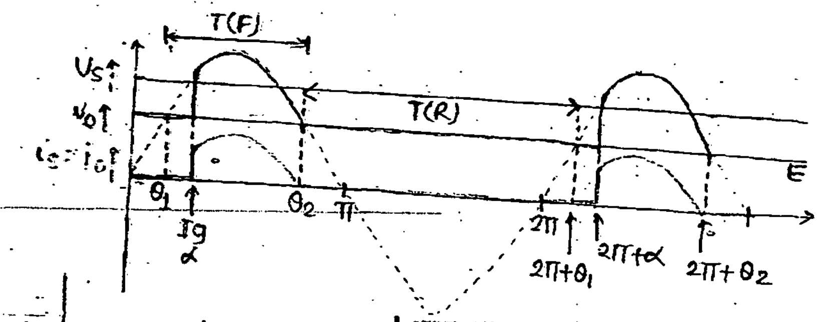
* The PF of the semiconvr is better than full convr due to its freewheeling action.

Therefore the performance of the semiconr is superior to full conr.

Application →

1-φ HWR charging a battery (RE load) →





+Vs > E, T(F)

At $\omega t = \theta_1$; $V_s = E$

$$V_m \sin\theta_1 = E$$

$$\theta_1 = \sin^{-1}\left(\frac{E}{V_m}\right)$$

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

$$\theta_1 \le \alpha \le \theta_2$$

T(ON)

$V_0 = V_s$

$V_s = R i_0 + E$

$$i_0 = \frac{V_s - E}{R}$$

$$i_0 = \frac{V_m \sin\omega t - E}{R}$$

T → (OFF)

$i_0 = 0$; $V_0 = E$

$\omega t = 2\pi + \theta_1 - \theta_2$

$= 2\pi + \theta_1 - \pi + \theta_1$

$\omega t_c = \pi + 2\theta_1$ rad.

$$\boxed{t_c = \frac{\pi + 2\theta_1}{\omega}\ \text{sec}}$$

* PIV of thyristor $= V_m + E$

$$V_{o(avg)} = \frac{1}{2\pi}\left[\int_{\alpha}^{\theta_2} V_m \sin\omega t \, d(\omega t) + \int_{\theta_2}^{2\pi+\alpha} E \, d(\omega t)\right]$$

$$V_{o(avg)} = \frac{1}{2\pi}\left[V_m(\cos\alpha - \cos\theta_2) + E\,\frac{(2\pi+\alpha-\theta_2)}{Rad.}\right]$$

Charging current of Battery

$$I_o = \frac{1}{2\pi}\int_{\alpha}^{\theta_2}\left(\frac{V_m \sin\omega t - E}{R}\right) d(\omega t)$$

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

** when the diode rectifier is charging a battery substitute $\alpha = \theta_1$ in the above eqn to find the V_o & I_o

$$P_{in} = V_{sr} I_{sr} PF$$

$$P_o = I_{or}^2 R + E I_o$$

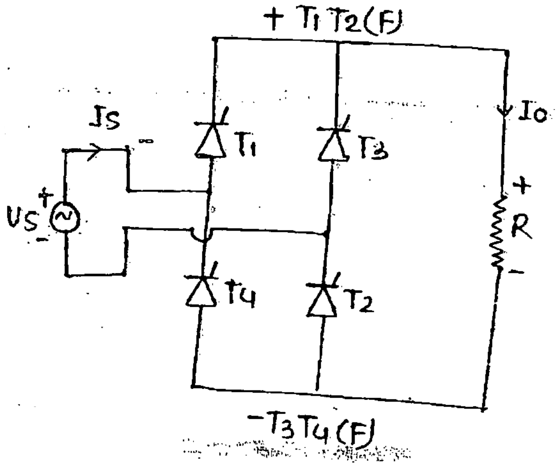
Assuming no losses in thy. i.e. we get;

$$\boxed{PF = \frac{I_{or}^2 R + E I_o}{V_{sr} I_{sr}}}$$

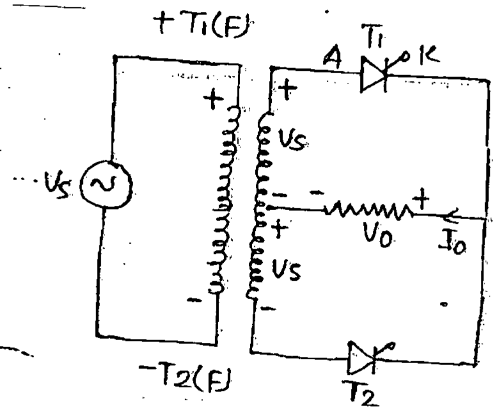
$$I_{or} = \left[\frac{1}{2\pi}\int_{\alpha}^{\theta_2}\left(\frac{V_m \sin\omega t - E}{R}\right)^2\right]^{1/2}$$

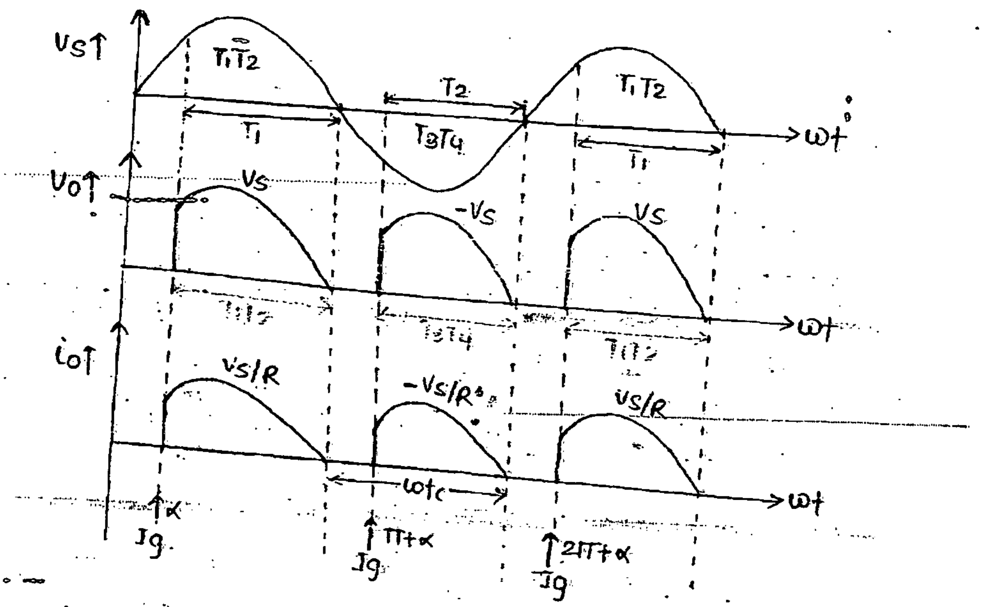
1-ϕ Full Wave Rectifier → (2-pulse converter)

* Bridge Rectifier



* Mid point rectifier





$T_1T_2 \longrightarrow$ ON

i.e. $V_o = V_s$

$i_o = \dfrac{V_s}{R}$

$T_3T_4 \longrightarrow$ ON

i.e. $V_o = -V_s$

$i_o = \dfrac{-V_s}{R}$

$T_1 \longrightarrow$ ON

i.e. $V_o = V_s$

$i_o = \dfrac{V_s}{R}$

$T_2 \longrightarrow$ ON

$V_o = -V_s$

$i_o = \dfrac{-V_s}{R}$

$$\omega t_c = \pi$$

$$\boxed{t_c = \frac{\pi}{\omega}}$$

$$V_o = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \, d(\omega t)$$

$$\boxed{V_o = \frac{V_m}{\pi}(1+\cos\alpha)}$$

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

For Resistive load; $PF = \frac{V_{or}}{V_{sr}}$

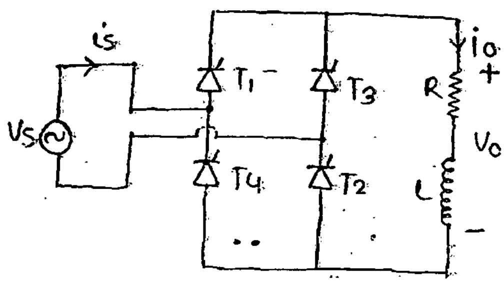
$$= \frac{1}{\sqrt{\pi}}\left[(\pi-\alpha)+\frac{1}{2}\sin 2\alpha\right]^{1/2}$$

* For mid point rectifier PIV $= 2V_m$
* For bridge rectifier PIV $= V_m$.
* In mid point rectifier V_m is the peak value of upper 2° voltage.

<u>Advantage of bridge rectifier →</u>

* The PIV of the thy. in bridge rectifier half of that when compared to mid point rectifier.
* If same thy. are used in both the conv^r then the avg. o/p vol. & power handled by bridge rectifier is double that of mid point rectifier.

<u>Bridge Rectifier with RL load →</u> (1φ fully controlled rectifier)



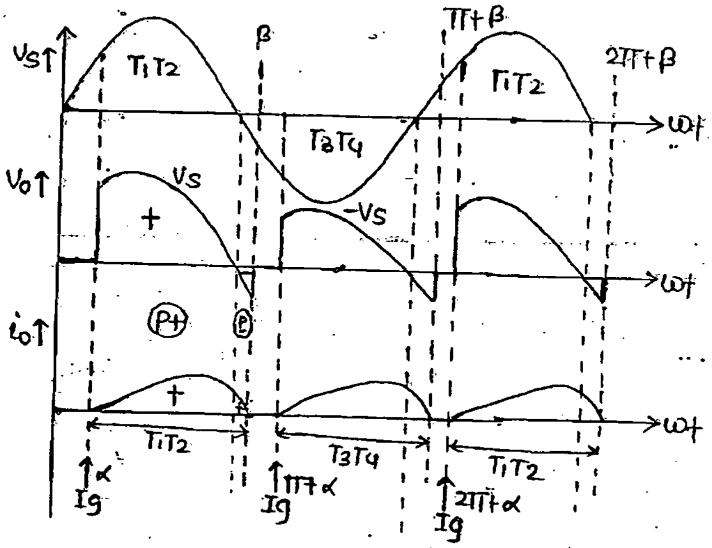
$$\omega t_c = 2\pi - \beta$$

$$\boxed{t_c = \frac{2\pi-\beta}{\omega}}$$

$$V_0 = \frac{1}{\pi}\int_{\alpha}^{\beta} V_m \sin\omega t \, d(\omega t)$$

$$V_0 = \frac{V_m}{\pi}(\cos\alpha - \cos\beta)$$

$$\boxed{V_0 = \frac{V_m}{\pi}(\cos\alpha - \cos\beta)}$$



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

We get discontineous condn $\beta < (\pi+\alpha)$

Reasons → (1.) $L\downarrow\ T\downarrow$ i.e. $\beta\downarrow$

$$\because \downarrow T = \frac{L\downarrow}{R\uparrow}$$

(2.) $\alpha\uparrow\ \beta\downarrow$

(3.) If avg o/p current is less the β is also less. ($I_o\downarrow\ \beta\downarrow$)

RL Load with Contineous conduction →

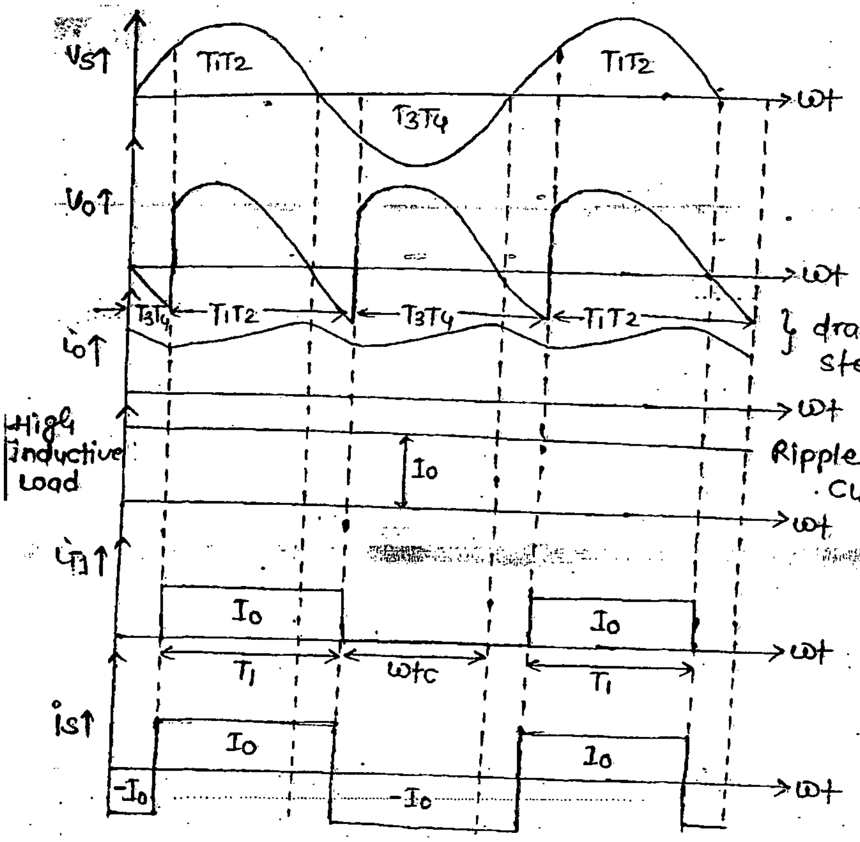
We get contineous condn when $\beta \geq (\pi+\alpha)$

Reasons → (1.) $L\uparrow\ T\uparrow$ i.e. $\beta\uparrow$

$$\uparrow T = \frac{L\uparrow}{R\downarrow}$$

(2.) $\alpha\downarrow\ \beta\uparrow$

(3.) $I_o\uparrow\ \beta\uparrow$



} drawn after load attains steady state

Ripple free load current

* T_1T_2 ON
i.e. $i_s = i_0 = I_0$

* T_3T_4 ON
i.e. $i_s = -i_0 = -I_0$

$\omega t_c = 2\pi - (\pi+\alpha)$
$= \pi + \alpha$

$$\boxed{t_c = \frac{\pi-\alpha}{\omega}}$$

$$V_0 = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t \, d(\omega t)$$

$$\boxed{V_0 = \frac{2V_m}{\pi}\cos\alpha}$$

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

$$V_{or} = \frac{V_m}{\sqrt{2}} = V_{sr}$$

$$\boxed{I_{sr} = I_0}$$

Assume high inductive load →

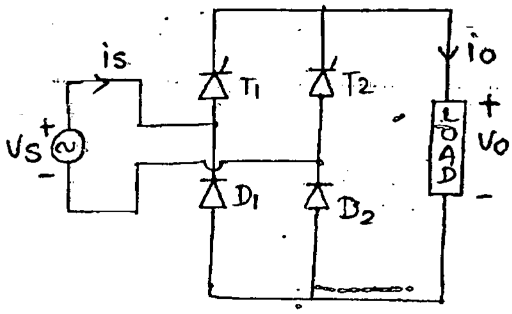
(1) Conduction angle of each thy. $= \pi$ rad for every cycle. $\{(\pi+\alpha)-\alpha\}$

(2) Avg. thy. current $(I_T)_{avg} = \frac{I_0\pi}{2\pi} = \frac{I_0}{2}$

$$(I_T)_{RMS} = I_0\left(\frac{\pi}{2\pi}\right)^{1/2} = \frac{I_0}{\sqrt{2}}$$

1-ϕ Half Controlled Rectifier →

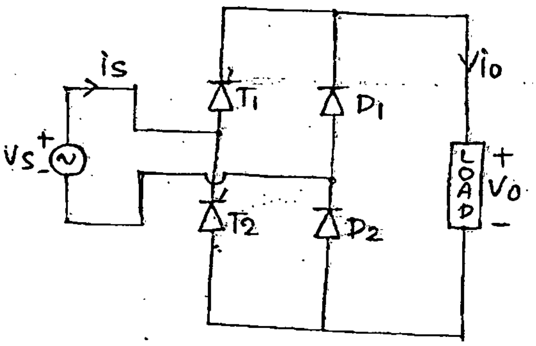
Symmetrical Connection



$+ T_1 D_2 (F)$

$- T_2 D_1 (F)$

Asymmetrical Connection

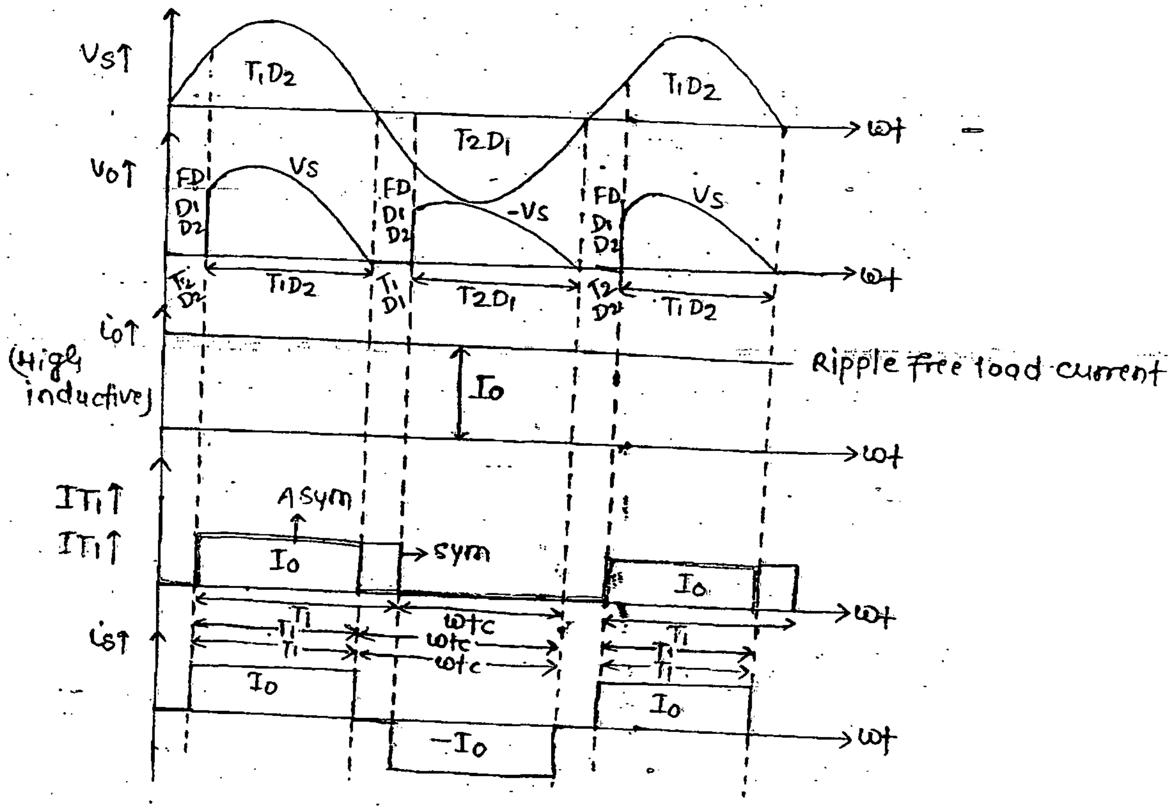


$+ T_1 D_2 (F)$

$- T_2 D_1 (F)$

* During FD period the -ve spikes are removed & the source current also becomes zero.
* For resistive load waveforms are same in full conv & semiconv.

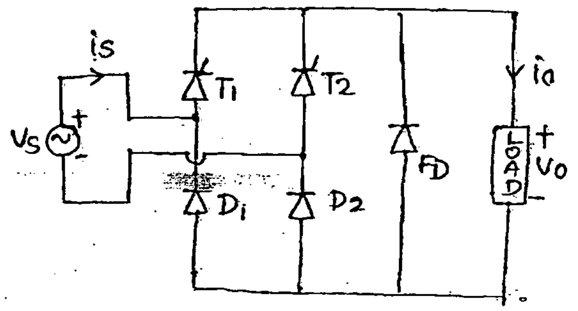
** Let us assume high inductive load.



Que → what is the problem with sym. connection?

Ans → * At α, $\pi+\alpha$, $2\pi+\alpha$ ------- There is a possibility of short circuit across the supply when incoming thy stats conducting before the o/p (outgoing) thy stops conducting.

* To rectify this problem we must connect a seprate FD across the load as shown in the fig. given below:-



$$\boxed{V_o = \frac{V_m}{\pi}(1+\cos\alpha)}$$

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

* In the semiconverter :-

(1.) Cond^n angle of each thy. $= \pi-\alpha$ (for every 2π rad)

(2.) Avg. thy. current $(I_T)_{avg} = I_0\left(\frac{\pi-\alpha}{2\pi}\right)$

$$(I_T)_{Rms} = I_0\left(\frac{\pi-\alpha}{2\pi}\right)^{1/2}$$

(3.) Cond^n angle of FD is α rad. (for every π rad)

(4.) Avg. FD current $(I_{FD})_{avg.} = I_0\left(\frac{\alpha}{\pi}\right)$

$$(I_{FD})_{Rms} = I_0\left(\frac{\alpha}{\pi}\right)^{1/2}$$

$$I_{sr} = I_0\left(\frac{\pi-\alpha}{\alpha}\right)^{1/2}$$ {If you have any symm. -ve wave form we cal. for π rads)

Ratings of Thyristor →

(1.) Thyristor Rms Rating $(I_T)_{Rms}$ →

* It gives the Rms value Rating of ON state current of thy.
* $(I_T)_{Rms}$ value in conr should be less than thy. Rms Rating.

(2.) Average thy. Rating $(I_T)_{avg}$ →

* It gives the avg. rating of ON state current of a thy.

$$\boxed{(I_T)_{avg} = \frac{(I_T)_{Rms} \text{ Rating}}{FF}}$$

FF → It is a FF of thy. current waveform in a conr.

Avg. Rating of thy. depends on :-

(1.) Condn angle of thy. ↑ FF ↓ ⇒ $(I_T)_{avg}$ ↑

(2.) Avg. Rating depends on type of the load.

Eg. → L↑ $\frac{di}{dt}$↓ smoothness↑ ∴ FF↓ ⇒ $(I_T)_{avg}$ ↑

(3.) I^2t Rating → * This Rating is provided for the thy. to select a proper fuse for over current protection.

* I^2t rating of thy. should always greater than fuse.

(4.) Surge Current Rating → Surge Current Rating is specified for short duration of time.

n cycle surge current Rating (I_{sn}) → It is the surge current that the SCR can with stand for n cycle.

$$I_{sn}^2\left(\frac{nT}{2}\right) = I^2t \text{ Rating of thy.}$$

From above we can find I_{sn}

One cycle surge current Rating (I_{s1}) → It is the surge current that the SCR can withstand for 1 cycle.

$$I_{S1}^2 \left(\frac{T}{2}\right) = I_{Sn}^2 \cdot n \cdot \frac{T}{2}$$

$$\boxed{I_{S1} = \sqrt{n}\, I_{Sn}}$$

Sub cycle current Rating $(I_{S/n}) \rightarrow$ It is the surge current that the SCR can with stand for $\frac{1}{n}$th period of a cycle.

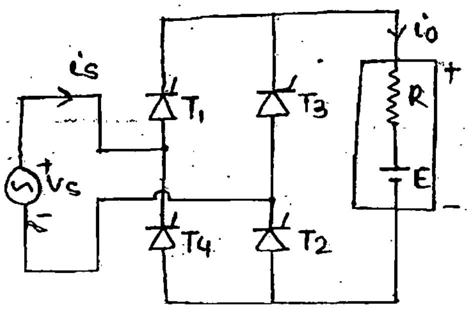
$$(I_{S/n})^2 \cdot \left(\frac{1}{n}\right) \frac{T}{2} = (I_{S1})^2 \frac{T}{2}$$

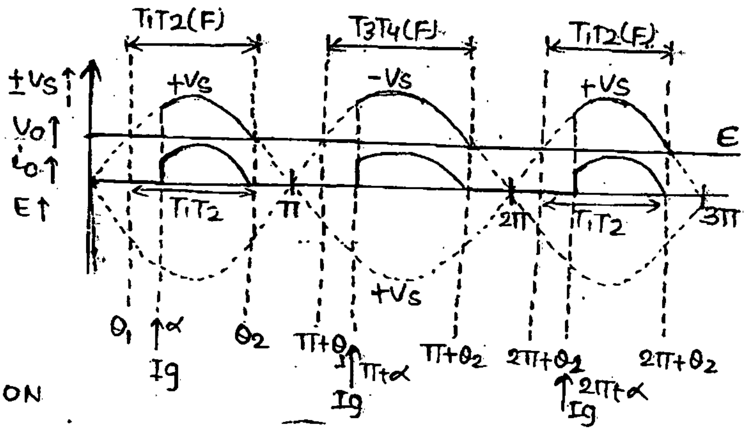
$$\boxed{(I_{S/n}) = \sqrt{n}\, I_{S1}}$$

Half cycle surge current Rating

$$(I_{S/2}) = \sqrt{2}\, I_{S1}$$

(ii) 1ϕ Full converter – Charging Battery →





+ve, $+V_s > E$, $T_1T_2(F)$

−ve, $-V_s > E$, $T_3T_4(F)$

$\theta_1 = \sin^{-1}\left(\frac{E}{V_m}\right)$, $\theta_2 = \pi - \theta_1$

$\theta_1 \le \alpha \le \theta_2$

$T_1T_2 \rightarrow ON$

$V_o = V_s$

$i_o = \frac{V_s - E}{R}$

$i_o = \frac{V_m \sin\omega t - E}{R}$

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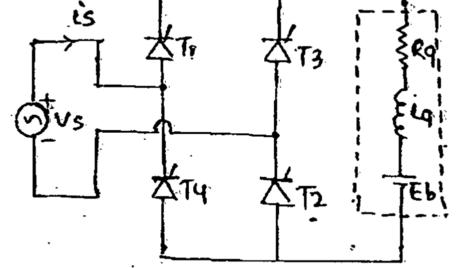
$$V_o = \frac{1}{\pi}\left[\int_{\alpha}^{\theta_2} V_m \sin\omega t \, d(\omega t) + \int_{\theta_2}^{\pi+\alpha} E \, d(\omega t)\right]$$

$$\boxed{V_o = \frac{1}{\pi}\left[V_m(\cos\alpha - \cos\theta_2) + E(\pi + \alpha - \theta_2)\right]}$$

$$I_o = \frac{1}{\pi}\left[\int_{\alpha}^{\theta_2} \frac{V_m \sin\omega t - E}{R} \, d(\omega t)\right]$$

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

1ϕ Full converter – DC motor (RLE load) →



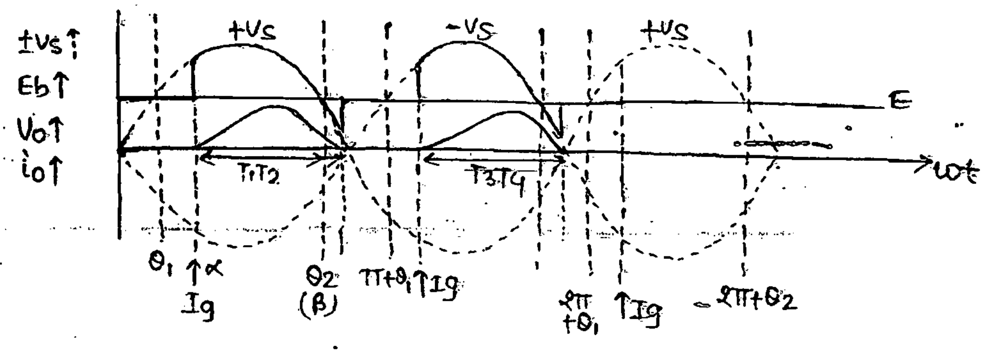
(1.) Discontineous Conduction

$\theta_2 < \beta < (\pi + \alpha)$

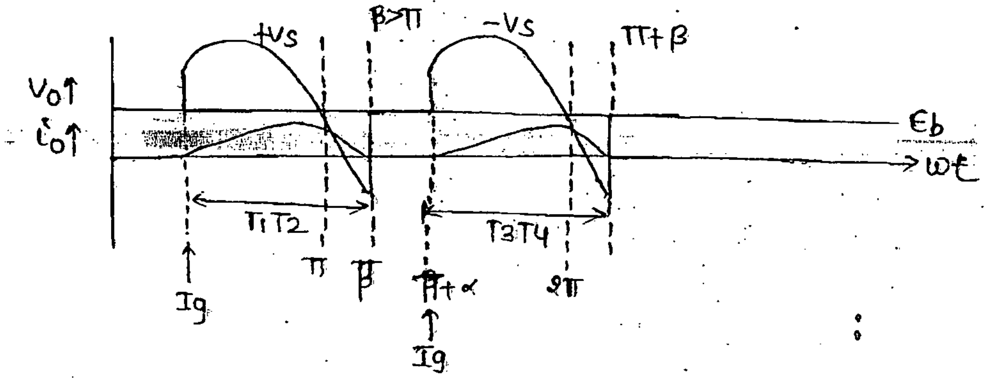
(a) $\beta < \pi$

(b) $\beta > \pi$

(i) $\beta < \pi$



(ii) $\beta > \pi$



$$t_c = \frac{2\pi + \theta_1 - \beta}{\omega}$$

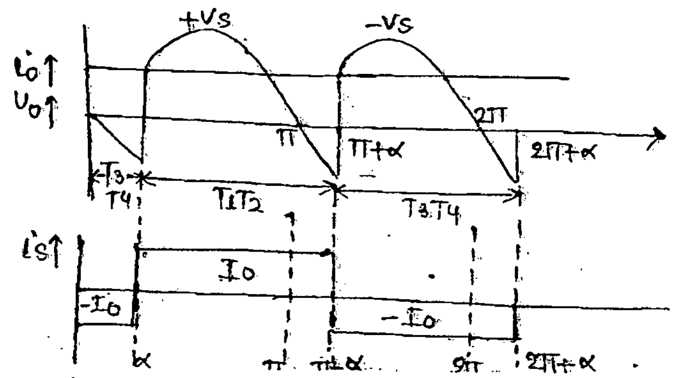
$$V_o = \frac{1}{\pi}\left[\int_{\alpha}^{\beta} V_m \sin\omega t \, d(\omega t) + \int_{\beta}^{\pi+\alpha} E_b \, d(\omega t)\right]$$

$$\boxed{V_o = \frac{1}{\pi}\left[V_m(\cos\alpha - \cos\beta) + E_b(\pi + \alpha - \beta)\right]}$$

(2) Contineous Conduction →

$$\beta > (\pi + \alpha)$$

* For contineous condn there is no effect of back emf in the o/p vol. waveform therefore the o/p vol. waveform will remain same for RL & RLE load.



$$\boxed{V_0 = \frac{2V_m}{\pi}\cos\alpha \qquad I_{sr} = I_0} \rightarrow RL, RLE$$

$$I_{sr} = I_0\left(\frac{\pi + \cancel{\alpha} - \cancel{\alpha}}{\pi}\right)^{1/2}$$

$$I_{sr} = I_0$$

Harmonic analysis on AC side of converter →

The Fourier series for supply waveform is

$$i_s = \sum_{n=1,3,5\ldots}^{\infty} \frac{4I_0}{n\pi}\sin(n\omega t + \phi_n)$$

where $\phi_n = -n\alpha$, $\phi_1 = -\alpha$

$$i_{sn} = \frac{4I_0}{n\pi}\sin(n\omega t + \phi_n)$$

i = instantaneous
I = RMS

$$I_{sn} = \frac{2\sqrt{2}}{n\pi} I_0$$

$$\boxed{I_{s1} = \frac{2\sqrt{2}}{\pi} I_0} \text{ -------- (i)}$$

$$FDF = \cos\phi_1$$

$$\boxed{FDF = \cos\alpha} \text{ ------ (ii)}$$

$$g = \frac{I_{s1}}{I_{sr}}$$

$$= \frac{\frac{2\sqrt{2}}{\pi} I_0}{I_0}$$

$$\boxed{g = \frac{2\sqrt{2}}{\pi}} \text{ -------- (iii)}$$

$$PF = g \cdot FDF$$

$$\boxed{PF = \frac{2\sqrt{2}}{\pi}\cos\alpha} \text{ -------- (iv)}$$

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

$$= \left(\frac{\pi^2}{8} - 1\right)^{1/2}$$

$$= 0.4834$$

$$\boxed{THD = 48.34\%} \text{ -------- (v)}$$

Active power (useful power) $P = V_{sr} \cdot I_{s1} \cos\alpha$

$$P = \frac{V_m}{\cancel{\sqrt{2}}} \cdot \frac{2\cancel{\sqrt{2}}}{\pi} I_o \cos\alpha$$

$$P = \frac{2V_m}{\pi} I_o \cos\alpha$$

$$\boxed{P = V_o I_o} \quad \text{----(vi)} \quad \text{where; } V_o = \frac{2V_m}{\pi} \cos\alpha$$

Reactive power

$$Q = V_{sr} \cdot I_{s1} \sin\alpha \quad (\text{lag}) \rightarrow \boxed{\sin(-\alpha) = -\sin\alpha}$$

$$= V_{sr} \cdot I_{s1} \cos\alpha \frac{\sin\alpha}{\cos\alpha}$$

$$Q = P \tan\alpha$$

$$\boxed{Q = P\tan\alpha = V_o I_o \tan\alpha} \quad \text{-----(vii)}$$

Harmonics analysis on dc side of converter →

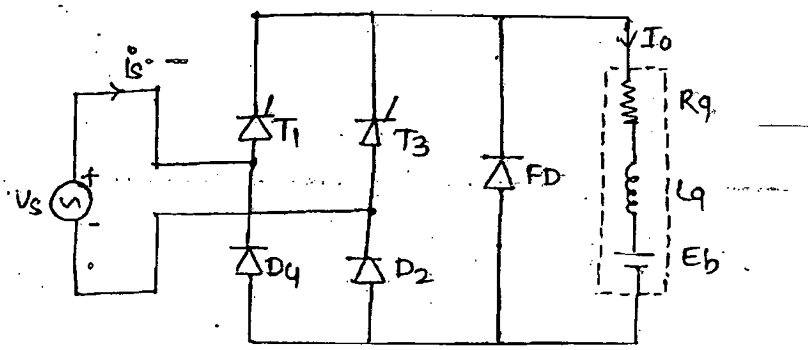
$$FF = \frac{V_{or}}{V_o} = \frac{\cancel{V_m}/\sqrt{2}}{\frac{2\cancel{V_m}}{\pi}\cos\alpha}$$

$$\boxed{FF = \frac{\pi}{2\sqrt{2}\cos\alpha}}$$

$$VRF = \sqrt{FF^2 - 1}$$

$$\boxed{VRF = \sqrt{\frac{\pi^2}{8\cos^2\alpha} - 1}}$$

1ϕ semi Converter →



(i) Discontineous Conduction :-

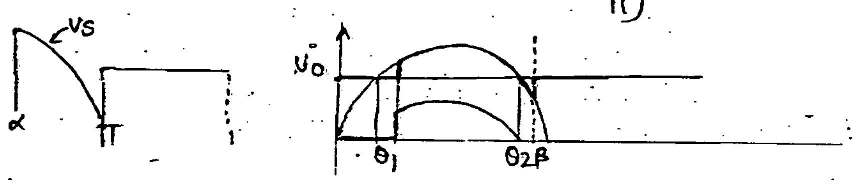
$\theta_2 < \beta < (\pi+\alpha)$

(a) $\beta < \pi$

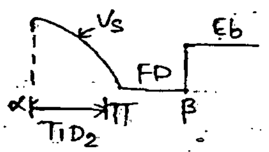
(b) $\beta > \pi$

(a) $\beta<\pi$ → * In this condition FD will not conduct (Because FD conduct after π rad. i.e. due to ind^r the -ve spikes come after π)

$$\boxed{V_0 = \frac{1}{\pi}\left[V_m(\cos\alpha - \cos\beta) + E_b(\pi+\alpha-\beta)\right]}$$



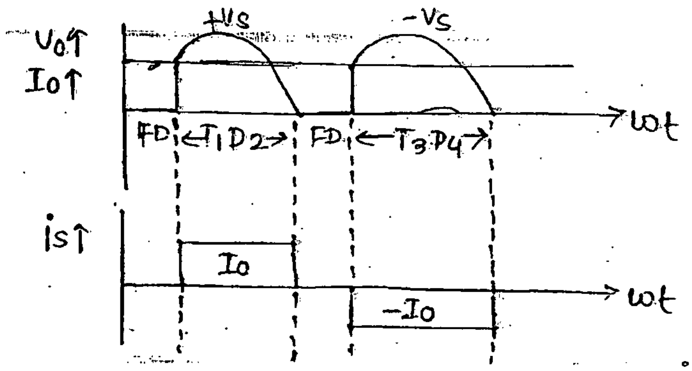
(b) $\beta>\pi$ → * In this cond^n FD will conduct from π to β



$$V_0 = \frac{1}{\pi}\left[\int_\alpha^\pi V_m \sin\omega t\, d(\omega t) + \underbrace{\int_\pi^\beta 0\, d\omega t}_{FWR} + \underbrace{\int_\beta^{\pi+\alpha} E_b\, d(\omega t)}_{\text{discontineous}}\right]$$

$$\boxed{V_0 = \frac{1}{\pi}\left[V_m(1+\cos\alpha) + E_b(\pi+\alpha-\beta)\right]}$$

Contineous Conduction → For this condⁿ there is no effect of back
$(\beta > (\pi+\alpha))$ emf for o/p vol. waveform. Therefore
the o/p vol. waveform will remain same for RL & RLE load.



$$\boxed{\begin{aligned} V_0 &= \frac{V_m}{\pi}(1+\cos\alpha) \\ I_{sr} &= I_0\left(\frac{\pi-\alpha}{\pi}\right)^{1/2} \end{aligned}}$$

Harmonic analysis on AC side of Conʳ →

The fourier series for the supply current

$$i_s = \sum_{n=1,3,5\ldots}^{\infty} \frac{4I_0}{n\pi}\cos\frac{n\alpha}{2}\sin(n\omega t+\phi_n)$$

where $\phi_n = -\frac{n\alpha}{2}$, $\phi_1 = -\frac{\alpha}{2}$

$$i_{sn} = \frac{4I_0\cos\frac{n\alpha}{2}}{n\pi}\sin(n\omega t+\phi_n)$$

$$I_{sn} = \frac{2\sqrt{2}}{n\pi}I_0\cos\frac{n\alpha}{2}$$

$$\boxed{I_{s1} = \frac{2\sqrt{2}}{\pi}I_0\cos\frac{\alpha}{2}} \quad \text{------(i)}$$

$$\boxed{FDF = \cos\frac{\alpha}{2}} \quad \text{------(ii)}$$

$$g = \frac{I_{s1}}{I_{sr}} = \frac{\frac{2\sqrt{2}}{\pi}\cancel{I_0}\cos\frac{\alpha}{2}}{\cancel{I_0}\left(\frac{\pi-\alpha}{\pi}\right)^{1/2}}$$

$$\boxed{g = \frac{2\sqrt{2}\cos\alpha/2}{\sqrt{\pi(\pi-\alpha)}}} \quad \text{-------(iii)}$$

$$PF = g \cdot \underline{PDF}$$

$$= \frac{2\sqrt{2}\cos\alpha/2}{\sqrt{\pi(\pi-\alpha)}}\cos\alpha/2$$

$$= \frac{2\sqrt{2}\cos^2\alpha/2}{\sqrt{\pi(\pi-\alpha)}}$$

$$\boxed{PF = \frac{2\sqrt{2}(1+\cos\alpha)}{\sqrt{\pi(\pi-\alpha)}}} \quad \text{------(iv)}$$

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

$$\boxed{THD = \left[\frac{\pi(\pi-\alpha)}{8\cos^2\alpha/2}-1\right]^{1/2}} \quad \text{-----(v)}$$

Active Power

$$P = V_{sr} \cdot I_{s1}\cos\alpha/2$$

$$= \frac{V_m}{\cancel{\sqrt{2}}} \cdot \frac{2\cancel{\sqrt{2}}}{\pi} I_o \cos\frac{\alpha}{2} \cdot \cos\frac{\alpha}{2}$$

$$= \frac{V_m}{\pi}(1+\cos\alpha) \cdot I_o$$

$$= V_o I_o$$

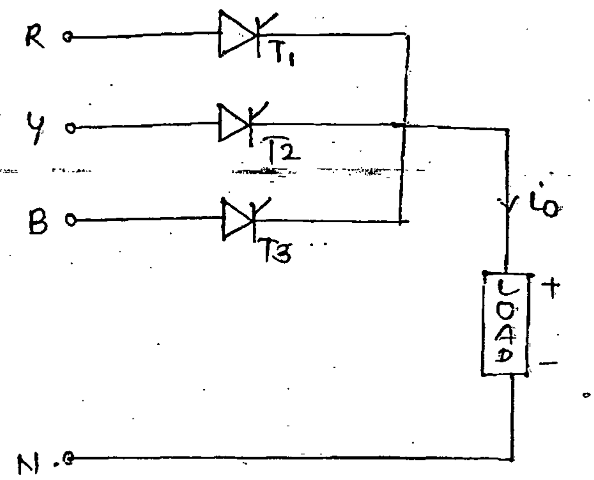
$$\boxed{P = V_{sr} \cdot I_{s1}\cos\alpha/2 = V_o I_o} \quad \text{-------(vi)}$$

Reactive Power

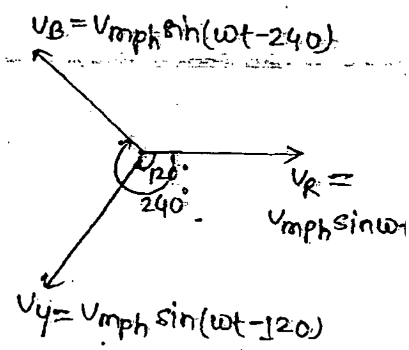
$$Q = V_{sr} \cdot I_{s1} \cdot \sin\alpha/2$$

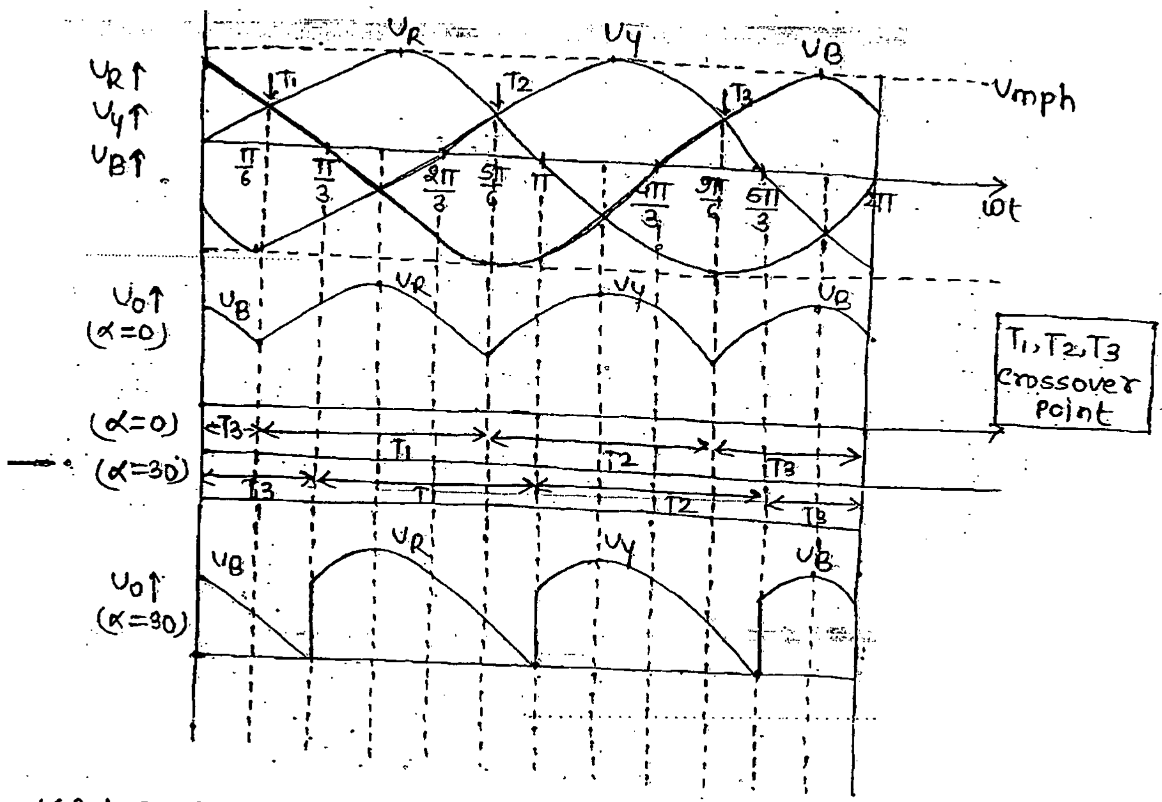
$$\boxed{Q = P\tan\alpha/2} \quad \text{-------(vii)}$$

3φ HWR → 3 pulse converter



Phase seq. → RYB





(1.) $\alpha \le 30°$ Contineous Condⁿ for R load →

$$V_o = \frac{1}{2\pi/3} \int_{\pi/6+\alpha}^{5\pi/6+\alpha} V_{mph} \sin\omega t \, d(\omega t)$$

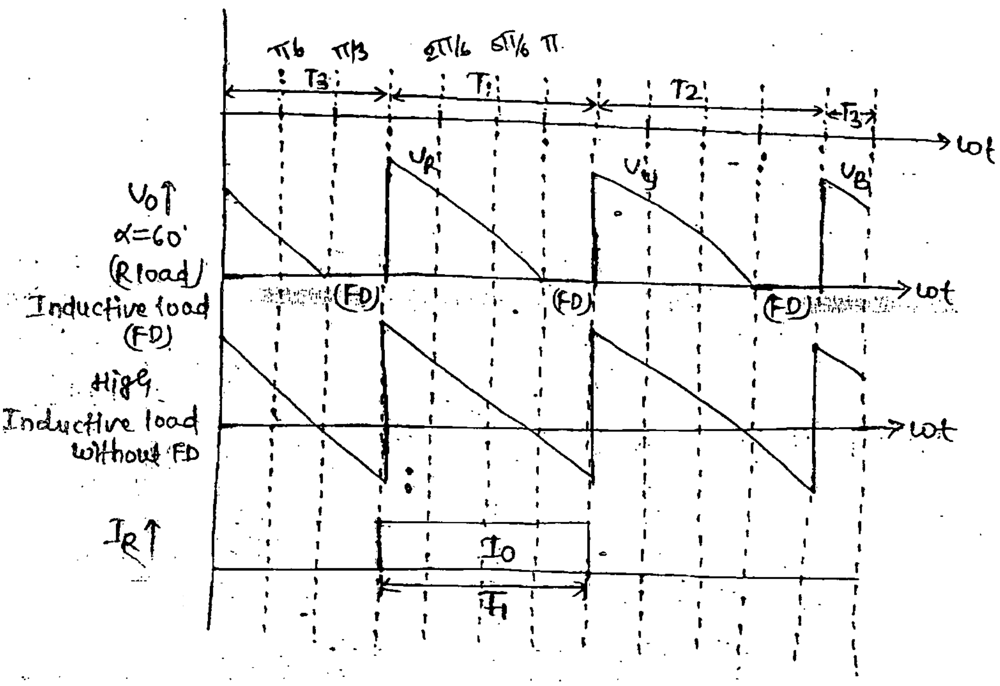
$$\boxed{V_o = \frac{3\sqrt{3}}{2\pi} V_{mph} \cdot \cos\alpha}$$

$$\boxed{V_o = \frac{3 V_{mL}}{2\pi} \cos\alpha}$$

R ($\alpha \le 30°$)   R & RLE (any α) (contineous)

$$V_{or} = \left[\frac{1}{(2\pi/3)} \int_{\pi/6+\alpha}^{\cancel{5\pi/6+\alpha}} V_{mph}^2 \sin^2\omega t \, d(\omega t) \right]^{1/2}$$

$$\boxed{V_{or} = V_{mL} \left[\frac{1}{6} + \frac{\sqrt{3}}{8\pi} \cos 2\alpha \right]^{1/2}}$$



(2) α>30° : discontineous conduction for R load :-

$$V_o = \frac{1}{(2\pi/3)} \int_{\pi/6+\alpha}^{\pi} V_{mph} \sin\omega t \, d(\omega t)$$

$$\boxed{V_o = \frac{3V_{mph}}{2\pi} \left[1 + \cos\left(\frac{\pi}{6} + \alpha\right) \right]}$$ R (α>30°)
RL, RLE (with FD α>30°)

$$V_{or} = \left[\frac{1}{(2\pi/3)} \int_{\pi/6+\alpha}^{\pi} V_{mph}^2 \sin^2\omega t \, d(\omega t) \right]^{1/2}$$

$$\boxed{V_{or} = \frac{V_{mL}}{2\sqrt{\pi}} \left[\left(\frac{5\pi}{6} - \alpha\right) + \frac{1}{2} \sin\left(\frac{\pi}{3} + 2\alpha\right) \right]^{1/2}}$$

Assume high inductive load with FD:-

(1.) $\alpha \le 30$:- FD will not conduct

Conduction angle of each thy. is $\frac{2\pi}{3}$ rad [For every 2π rad]

$$(I_T = I_{ph} = I_L)_{avg} = I_0 \left[\frac{2\pi/3}{2\pi}\right]$$

$$= \frac{I_0}{3}$$

$$(I_T = I_{ph} = I_L)_{rms} = \frac{I_0}{\sqrt{3}}$$

(2.) $\alpha > 30$ →

Conduction angle of FD $= \left(\alpha - \frac{\pi}{6}\right)$ [For every $\frac{2\pi}{3}$ rad]

Conduction angle of each thy. is $\left(\frac{5\pi}{6} - \alpha\right)$ [For every 2π rad]

$$(I_T = I_{ph} = I_L)_{avg} = \frac{I_0\left[\frac{5\pi}{6} - \alpha\right]}{2\pi}$$

$$(I_T = I_{ph} = I_L)_{rms} = I_0 \left[\frac{\frac{5\pi}{6} - \alpha}{2\pi}\right]^{1/2}$$

$$\boxed{(I_{FD})_{Avg} = I_0\left(\frac{\alpha - \pi/6}{2\pi/3}\right)} \qquad \boxed{(I_{FD})_{rms} = I_0\left(\frac{\alpha - \pi/6}{2\pi/3}\right)^{1/2}}$$

Assume high inductive load without FD:-

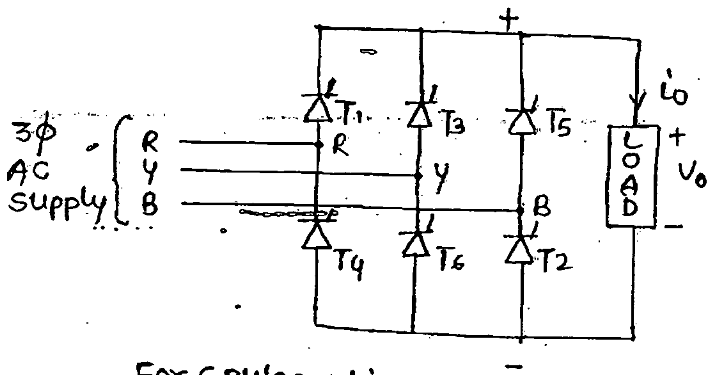
For any value of α

Conduction angle of each thy $= \frac{2\pi}{3}$ rad [For every 2π rad]

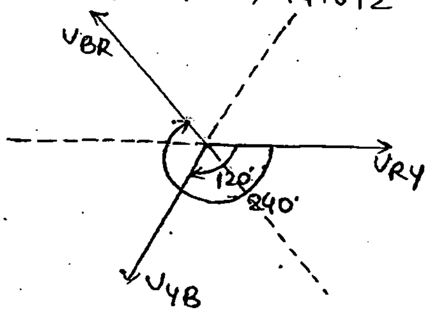
$$(I_T = I_{ph} = I_L)_{avg} = I_0\left(\frac{2\pi/3}{2\pi}\right) = \frac{I_0}{3}$$

Drawback → The source current contains dc component & saturates the supply Xmer core.

3φ Fully Controlled Rectifier :- (6 pulse converter) →



+ve group thy $T_1 T_3 T_5$
−ve group thy $T_4 T_6 T_2$



For 6 pulse → Line vol.
3 pulse → Phase vol.

(1.) $\alpha \le 60°$:- Contineous conduction for R load →

$$V_o = \frac{1}{\pi/3}\int_{\frac{\pi}{3}+\alpha}^{\frac{2\pi}{3}+\alpha} V_{mL}\sin\omega t\, d(\omega t)$$

$$\boxed{V_o = \frac{3V_{mL}}{\pi}\cos\alpha}$$

→ R ($\alpha \le 60$)
→ RL, RLE (Any α) (Contineous)

$$V_{or} = \left[\frac{1}{\pi/3}\int_{\pi/3+\alpha}^{2\pi/3+\alpha} V_{mL}^2\sin^2\omega t\, d(\omega t)\right]^{1/2}$$

$$V_{or} = \frac{V_{mL}}{\sqrt{\frac{2\pi}{3}}}\left[\frac{\pi}{3}+\frac{1}{2}\left\{\sin\left(\frac{2\pi}{3}+2\alpha\right)-\sin\left(\frac{4\pi}{3}+2\alpha\right)\right\}\right]^{1/2}$$

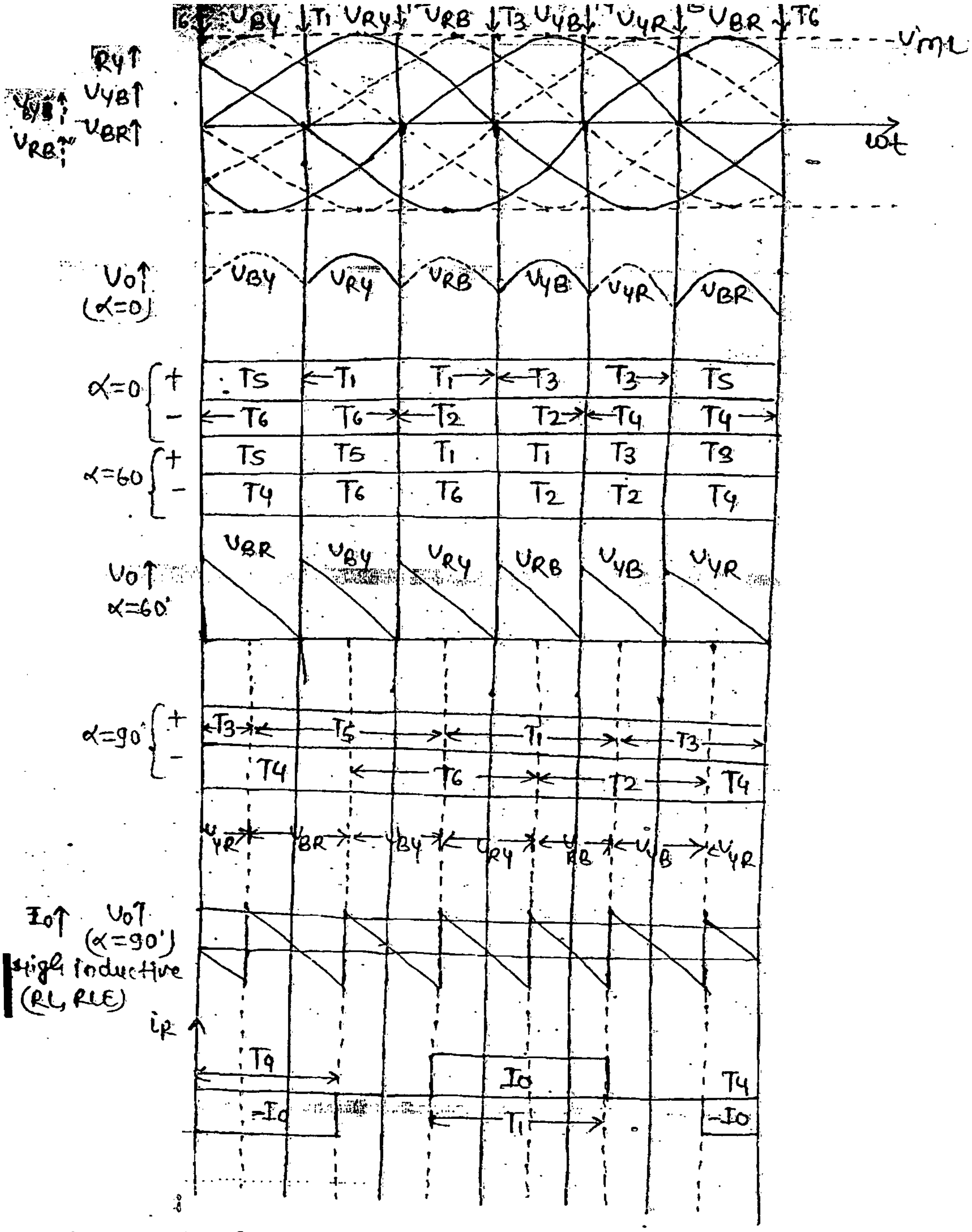
(2.) $\alpha > 60°$:- Discontineous conduction for R load →

$$V_o = \frac{1}{\pi/3}\int_{\pi/3+\alpha}^{\pi} V_{mL}\sin\omega t\, d(\omega t)\ ; \quad \boxed{V_o = \frac{3V_{mL}}{\pi}\left[1+\cos\left(\frac{\pi}{3}+\alpha\right)\right]}$$

R ($\alpha > 60°$).

$$V_{or} = \left[\frac{1}{\pi/3}\int_{\frac{\pi}{3}+\alpha}^{\pi} V_{mL}^2\sin^2\omega t\, d(\omega t)\right]^{1/2}$$

$$\boxed{V_{or} = \sqrt{\frac{3}{2\pi}}\, V_{mL}\left[\left(\frac{2\pi}{3}-\alpha\right)+\frac{1}{2}\sin\left(\frac{2\pi}{3}+2\alpha\right)\right]^{1/2}}$$



Assume High inductive load →

Conduction of angle of each thy. $= \frac{2\pi}{3}$ rad. (For every 2π rad)

$$(I_T)_{Avg} = I_0\left(\frac{2\pi/3}{2\pi}\right) = \frac{I_0}{3}$$

$$(I_T)_{rms} = \frac{I_0}{\sqrt{3}}$$

$$I_{sr} = I_0\left(\frac{2\pi/3}{\pi}\right)^{1/2} = \sqrt{\frac{2}{3}}\, I_0$$

Harmonic analysis on AC side of Converter →

$$i_s = \sum_{n=1,3,5\ldots}^{\infty} \frac{4I_0}{n\pi} \sin\frac{n\pi}{3} \cdot \sin(n\omega t + \phi_n)$$

$$\boxed{\phi_n = -n\alpha,\ \phi_1 = -\alpha}$$

$n = 6k \pm 1$

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

Note:- Even & tripple harmonics are not present in the waveform

$$i_{sn} = \frac{4I_0}{n\pi} \sin\frac{n\pi}{3} \cdot \sin(n\omega t + \phi_n)$$

$$I_{sn} = \frac{4I_0}{n\pi\sqrt{2}} I_0 \sin\frac{n\pi}{3} = \frac{2\sqrt{2}}{n\pi} I_0 \sin\frac{n\pi}{3}$$

$$I_{s1} = \frac{2\sqrt{2}}{\pi} \cdot I_0 \sin\frac{\pi}{3}$$

$$\boxed{I_{s1} = \frac{\sqrt{6}}{\pi} I_0} \text{ ------(i)}$$

$$\boxed{FDF = \cos\alpha} \text{ ------(ii)}$$

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

$$g = \frac{I_{s1}}{I_{sr}} = \frac{\frac{\sqrt{6}}{\pi} \cancel{I_0}}{\sqrt{\frac{2}{3}} \cancel{I_0}}$$

$$\boxed{g = \frac{3}{\pi}} \text{ -------(iii)}$$

$$PF = g \cdot FDF$$

$$= \frac{3}{\pi} \cos\alpha$$

$$\boxed{PF = \frac{3}{\pi} \cos\alpha} \text{ -----(iv)}$$

$$THD = \left(\frac{1}{g^2} - 1\right)^{1/2} = \left(\frac{\pi^2}{9} - 1\right)^{1/2}$$

$$\boxed{THD = 0.31}$$

$$\boxed{THD = 31\%} \text{ ------(v)}$$

$$\boxed{\begin{array}{l} m\uparrow,\ g\uparrow,\ THD\downarrow \\ m\uparrow,\ g\uparrow,\ PF\downarrow \end{array}}$$

Active power →

$$P = \sqrt{3}\, V_{sr} . I_{s1} \cos\alpha$$

$$= \sqrt{3} \times \frac{V_{ml}}{\sqrt{2}} \times \frac{\sqrt{6}}{\pi} I_0 \cos\alpha$$

$$= \sqrt{3} \times \frac{V_{ml}}{\sqrt{2}} \times \frac{\sqrt{2}\sqrt{3}}{\pi} I_0 \cos\alpha$$

$$= \frac{3V_{ml}}{\pi} \cos\alpha . I_0$$

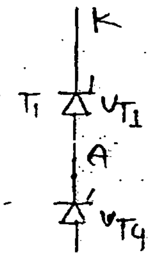
$$\boxed{P = \frac{3V_{ml}}{\pi} \cos\alpha . I_0 = V_0 I_0} \text{ ------ (vi)}$$

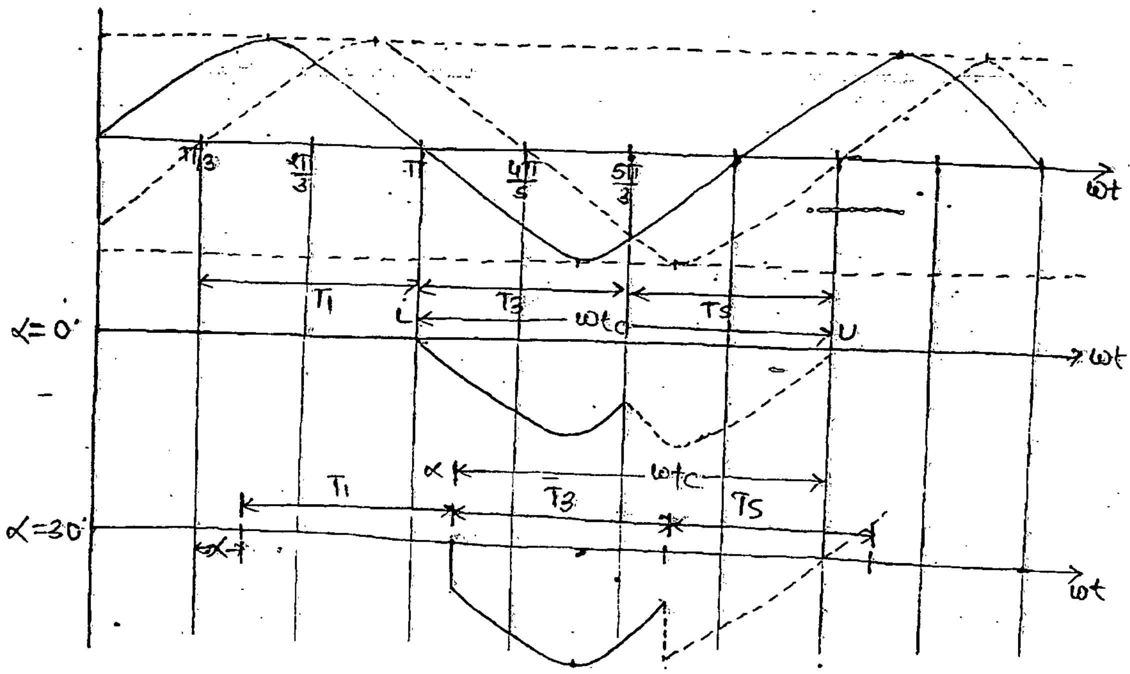
Reactive power →

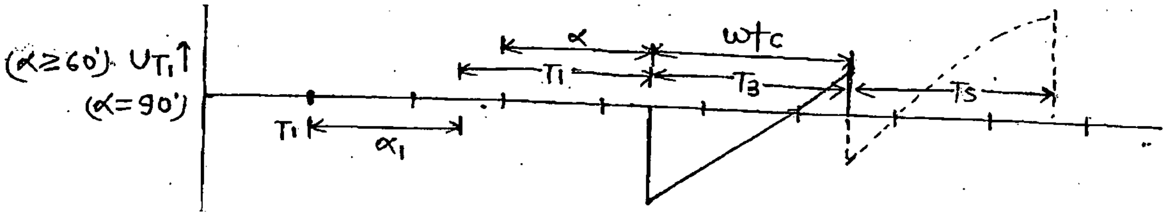
$$Q = \sqrt{3}\, V_{sr} . I_{s1} \sin\alpha$$

$$\boxed{Q = P \tan\alpha} \text{ ------ (vii)}$$

$V_{AK} \rightarrow (V_{T_1})$
$T_1 \rightarrow ON, \quad V_{T_1} = 0$
$T_3 \rightarrow ON, \quad V_{T_1} = V_{RY}$
$T_5 \rightarrow ON, \quad V_{T_1} = V_{RB}$







$\underline{\alpha = 0^\circ}$

$$\omega t_c = \frac{4\pi}{3}$$

$$t_c = \frac{4\pi}{3\omega} \text{ sec}$$

$$\boxed{PIV = V_{ml}}$$

$\underline{\alpha < 60^\circ}$

$$\alpha + \omega t_c = \frac{4\pi}{3}$$

$$\omega t_c = \frac{4\pi}{3} - \alpha$$

$$\boxed{t_c = \frac{\frac{4\pi}{3} - \alpha}{\omega}}$$

$\alpha > 60^\circ$

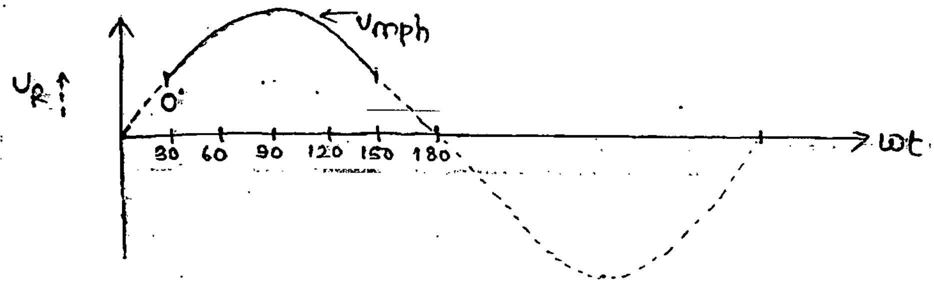
$$\alpha + \omega t_c = \frac{3\pi}{3}$$

$$\alpha + \omega t_c = \pi$$

$$\omega t_c = \pi - \alpha$$

$$\boxed{t_c = \frac{\pi - \alpha}{\omega}}$$

nagination method For 3 pulse Converter →



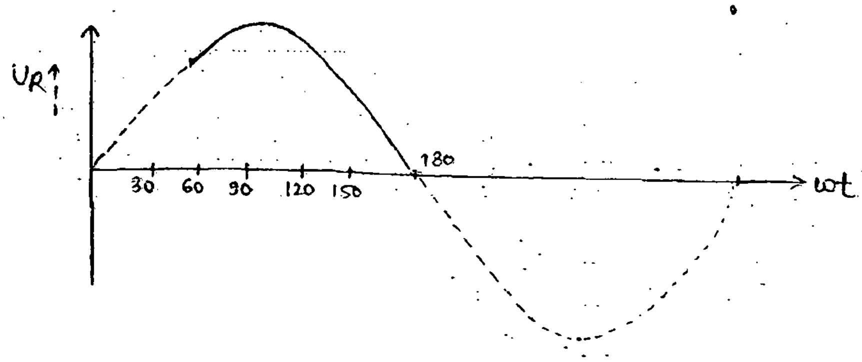
$\alpha = \omega t - 30°$

Pulse Length $= \frac{2\pi}{3}$ rad $= 120°$

$0 \le \alpha \le 150° \longrightarrow$ R Load

$0 \le \alpha \le 180° \longrightarrow$ Inductiven load.

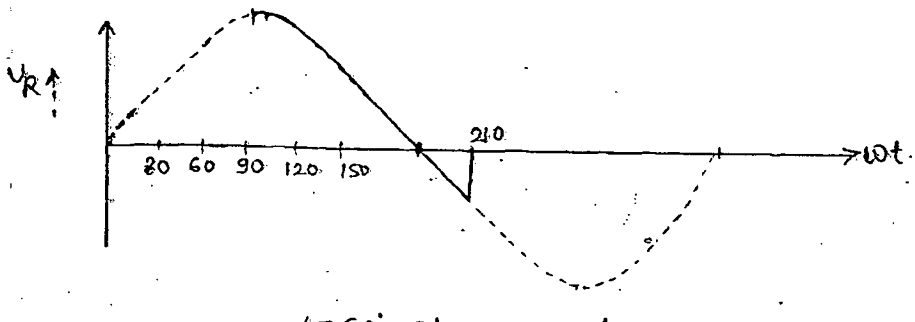
For $\alpha = 0°$, $\omega t = 30°$ (Fig (i))



$\alpha = \omega t - 30°$

Pulse length $= 120°$

For $\alpha = 30°$, $\omega t = 60°$ & $60 + 120 = 180°$



$\alpha = 60°$, $\omega t = 90°$, end $90 + 120 = 210°$

[redacted] converter →

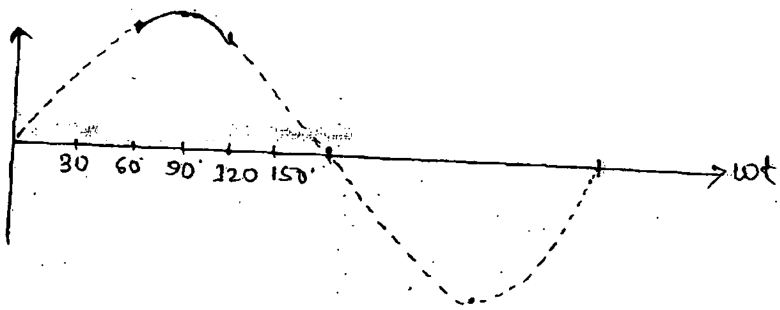
$$\alpha = \omega t - 60^\circ$$

$$\text{Pulse length} = \frac{2\pi}{6}\,\text{rad} = \frac{\pi}{3}\,\text{rad}$$

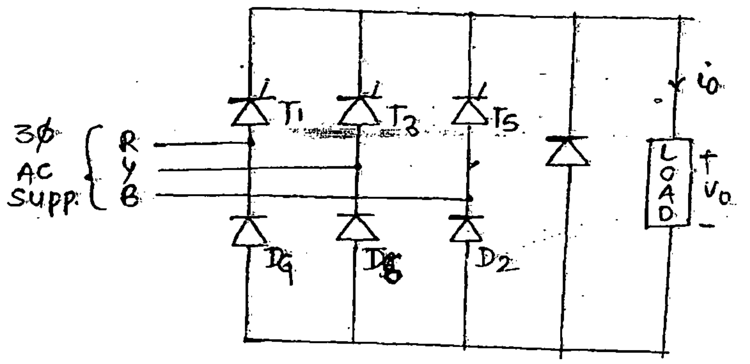
$$= 60^\circ$$

$$\boxed{\begin{array}{ll} 0 \le \alpha \le 120^\circ & R\ \text{load} \\ 0 \le \alpha \le 180^\circ & L\ \text{load} \end{array}}$$

$\alpha = 0^\circ$, $\omega t = 60^\circ$ & $60 + 60 = \underline{120}^\circ$



* 3ϕ semi conv^r / 3ϕ Half controlled Rectifier →



Assume High inductive load →

(1) $\alpha \le 60°$ → * FD will not conduct.

* Conduction angle of each thy. $= \frac{2\pi}{3}$ rad {For every 2π rad}

$$(I_T)_{avg.} = I_0\left(\frac{2\pi/3}{2\pi}\right) = \frac{I_0}{3}$$

$$(I_T)_{rms} = \frac{I_0}{\sqrt{3}}$$

$$\boxed{I_{sr} = I_0\left(\frac{2\pi/3}{\pi}\right)^{1/2} = \sqrt{\frac{2}{3}}\, I_0}$$

(2) $\alpha > 60°$ → * conduction angle of FD $= (\alpha - \frac{\pi}{3})$ {For every $\frac{2\pi}{3}$ rad}

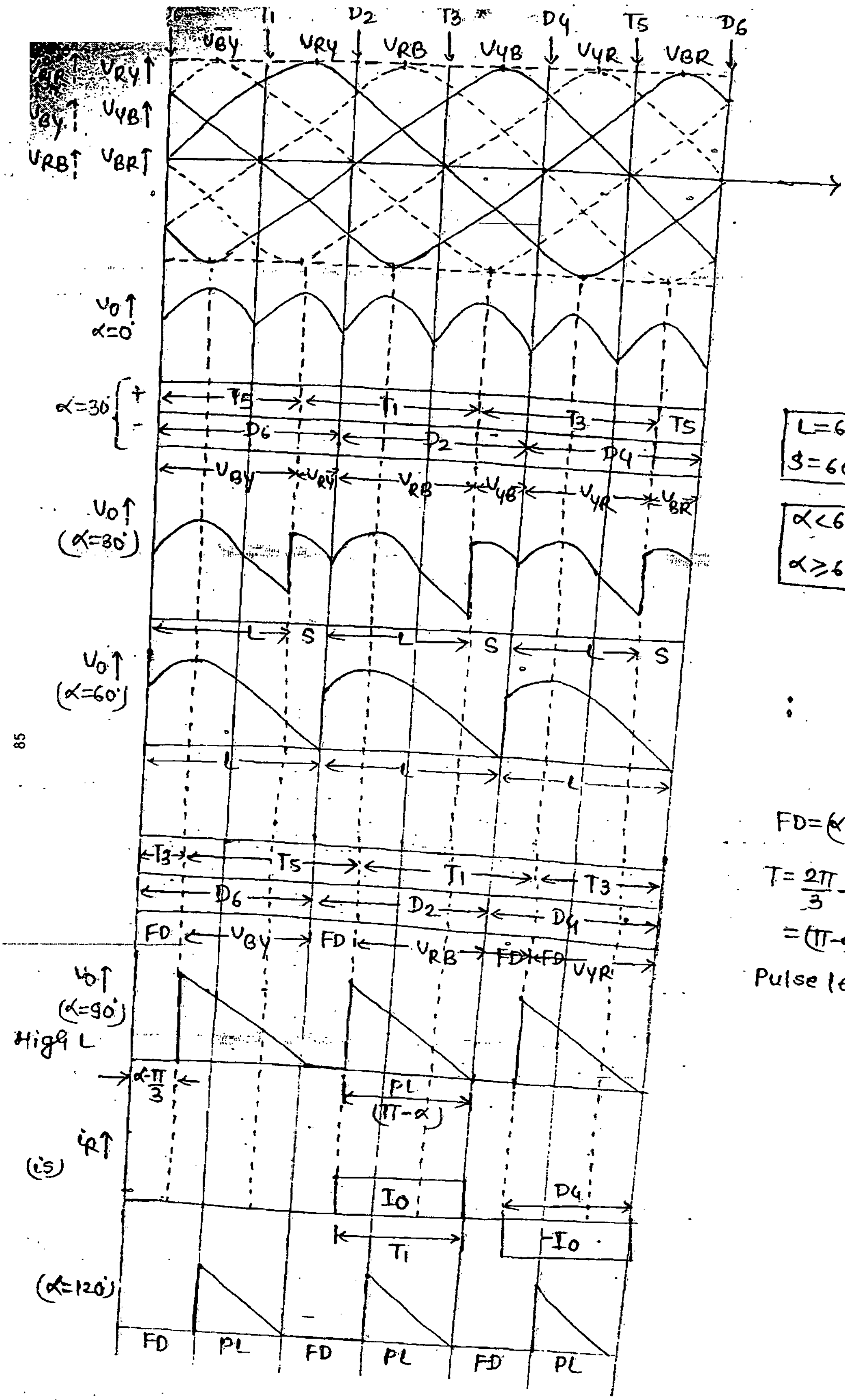
* Conduction angle of each thy. $= (\pi - \alpha)$ [For every $2\pi/3$ rad]

$$(I_T)_{avg.} = I_0\left(\frac{\pi-\alpha}{2\pi}\right) \qquad (I_T)_{rms} = I_0\left(\frac{\pi-\alpha}{2\pi}\right)^{1/2}$$

$$\boxed{I_{sr} = I_0\left(\frac{\pi-\alpha}{\pi}\right)^{1/2}}$$

$$\boxed{(I_{FD})_{avg.} = I_0\left(\frac{\alpha - \pi/3}{2\pi/3}\right)} \qquad \boxed{(I_{FD})_{rms} = I_0\left[\frac{\alpha-\pi/3}{2\pi/3}\right]^{1/2}}$$

$$\boxed{V_0 = \frac{3V_{mL}}{2\pi}(1+\cos\alpha)}$$



$\boxed{\begin{array}{l} L = 60 + \alpha \\ S = 60 - \alpha \end{array}}$

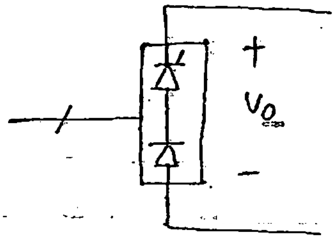
$\boxed{\begin{array}{l} \alpha < 60 \Rightarrow 6\text{pulse} \\ \alpha \geq 60 \Rightarrow 3\text{pulse} \end{array}}$

$FD = (\alpha - \pi/3)$

$$T = \frac{2\pi}{3} - \left(\alpha - \frac{\pi}{3}\right) = (\pi - \alpha)$$

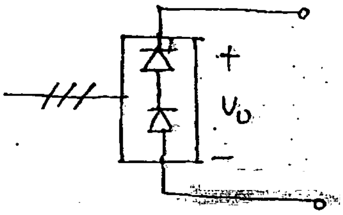
Pulse length $= T$

1φ semiconverter →



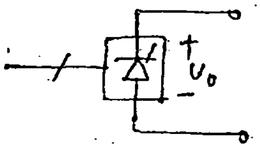
$$\boxed{V_0 = \frac{V_m}{\pi}(1+\cos\alpha)}$$

3φ semi converter →



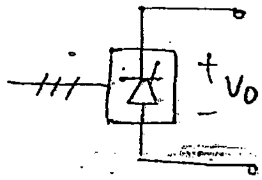
$$\boxed{V_0 = \frac{V_{mL}}{2\pi/3}(1+\cos\alpha)}$$

1φ Full Cond^r →



$$\boxed{V_0 = \frac{2V_m}{\pi}\cos\alpha}$$

3φ Full Conv^r →

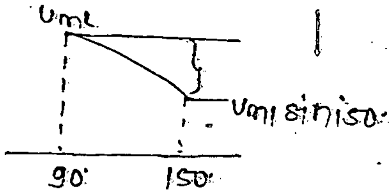


$$\boxed{V_0 = \frac{3V_{ml}}{\pi}\cos\alpha}$$

$\frac{1}{44}$

$\alpha = 30^\circ$

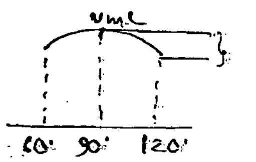
$$\frac{\text{Peak to peak ripple voltage}}{\text{Peak o/p dc voltage}}$$



$$\frac{V_{ml} - V_{ml}\sin 150^\circ}{V_{ml}} = 0.5$$

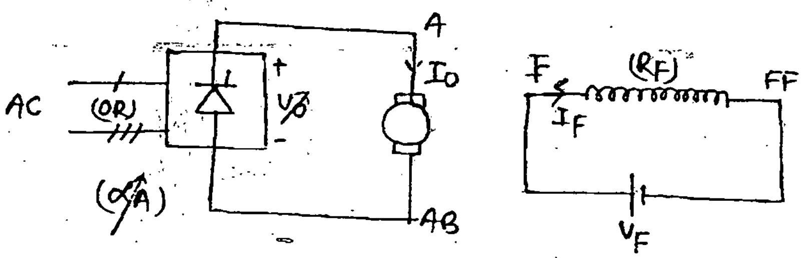
$\alpha = 0^\circ$

$$\frac{V_{ml} - V_{ml}\sin 120^\circ}{V_{ml}} = 1 - \frac{\sqrt{3}}{2}$$



DC drives →

(1) Armature voltage Control method → ($\omega < \omega_r$)



(ϕ-Constant)

$$\boxed{\begin{array}{l} 1\phi,\ V_0 = \dfrac{2V_m}{\pi}\cos\alpha_A \\ 3\phi,\ V_0 = \dfrac{3V_{mL}}{\pi}\cos\alpha_A \end{array}}$$

We know that; $E_b \propto \phi N$

$E_b \propto N$ ($\because \phi \to$ const)

$\boxed{E_b = kN}$ → emf const (OR) motor Const $= \dfrac{V}{rpm}$

$\boxed{E_b = k\omega}$ → emf const (OR) motor const $\left(\dfrac{V.sec}{rad}\right)$

SI → ω rad/sec

$\omega = \dfrac{2\pi N}{60}$

We know that;

$T_q \propto \phi I_a$

$T_q \propto I_a$

$\boxed{T_q = k I_a}$ → motor Const. (OR) Torque const. $\left(\dfrac{Nm}{A}\right)$

$\dfrac{Nm}{A} = \dfrac{V.sec}{rad}$

$I_0 = \frac{T_a}{K}$; For motoring mode

$V_0 = E_b + I_0 R_a$

$V_0 = K\omega + I_0 R_a$

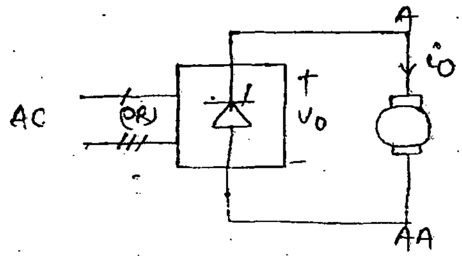
$\cancel{\omega = \frac{V_0}{K} - \frac{R_a}{K^2} T_a}$

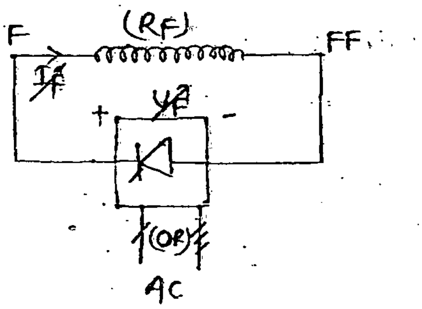
$\omega = \frac{V_0}{K} - \frac{I_0 R_a}{K}$

$\boxed{\omega = \frac{V_0}{K} - \frac{R_a}{K^2} T_a}$ speed-torque eqn

$\alpha_A \uparrow, V_0 \downarrow \therefore \omega \downarrow \; (\omega < \omega_r)$

(2) Field Control method →





$$\boxed{\begin{aligned} V_F &= \frac{2V_m}{\pi}\cos\alpha_F \rightarrow 1\phi \\ V_F &= \frac{3V_{mL}}{\pi}\cos\alpha_F \rightarrow 3\phi \end{aligned}}$$

$I_F = \frac{V_F}{R_F}$

$\phi \propto I_F$

$\boxed{\phi = K_F I_F}$ $(K_F \rightarrow$ Field constant$)$

$E_b \propto \phi N$

$E_b = K_1 \phi N$

$E_b = K_1 K_F N I_F$

$\boxed{E_b = K I_F N}$ → emf const (OR) motor const $\left(\frac{V}{rpm A}\right)$

$\boxed{\cancel{E_b = K I_F \omega}}$ → ~~EMF const (OR) motor const $\left(\frac{V \cdot sec}{rad\,A}\right)$~~

$T_a \propto \phi I_a$

$T_a = K_1 \phi I_a$

$T_a = K_1 (K_F I_F) I_0$

$\boxed{T_a = K I_F I_0}$ → Torque const. (OR) motor const $\frac{Nm}{A^2} = \frac{V\,sec}{rad.A}$

$I_0 = \frac{T_a}{K I_F}$; For motoring mode;

$V_0 = E_b + I_0 R_a$

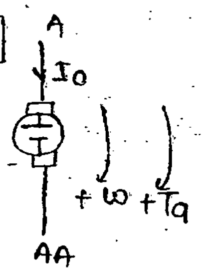
$V_0 = K I_F \omega + I_0 R_a$

$\omega = \frac{V_0}{K I_F} - \frac{I_0 R_a}{K I_F}$

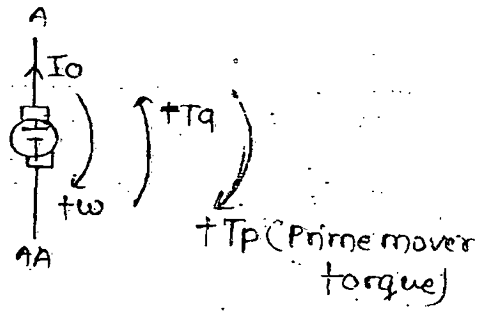
$$\boxed{\omega = \frac{V_0}{K I_F} - \frac{R_a}{(K I_F)^2} T_a}$$

$\alpha_F \uparrow,\ V_F \downarrow,\ I_F \downarrow \ \therefore \omega \uparrow \ (\omega > \omega_r)$

motoring action



Generating action



Electrical Braking →

Brake energy $(\frac{1}{2} J \omega^2)$ → Electrical Form

this energy is dessipated in external resestannce

(1.) Dynamic Braking (slow)

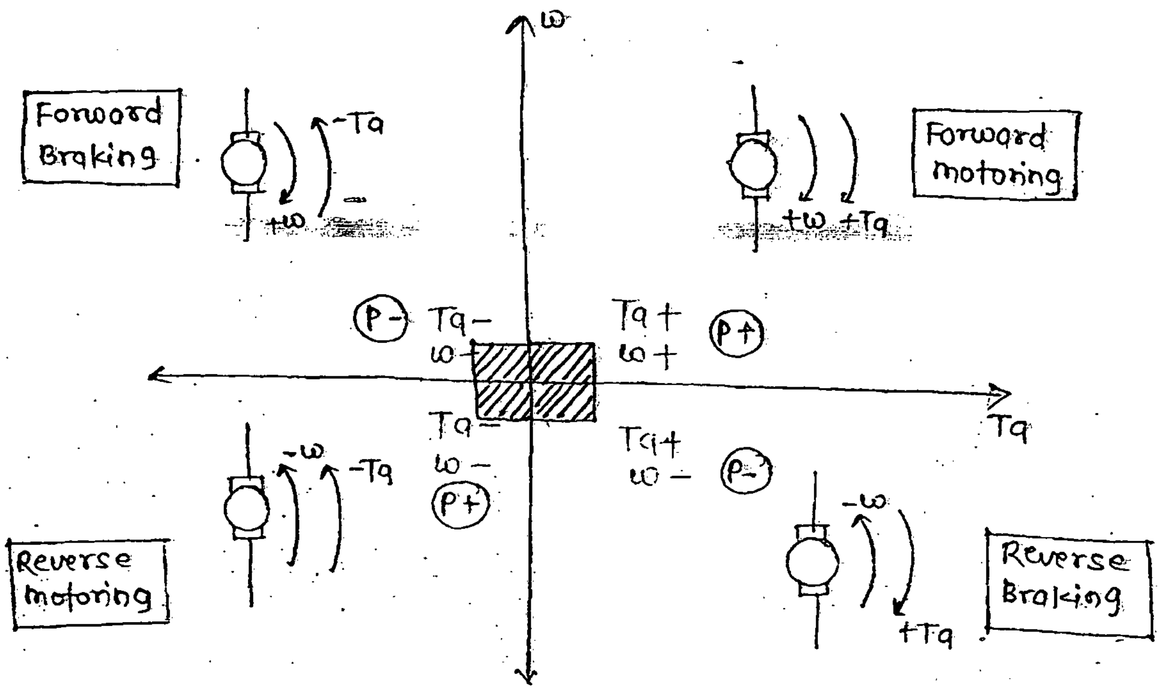
(2.) Plugging (Fast)

Source

(3) Regenerative Braking

* During braking the m/c behaves as generator & the brake energy available in the rotor inertia is converted into ele. form.
* If this energy is given back to the supply then it is known as regenerative braking.

* We can utilize a dc m/c in 4 modes:-



Quadrant operation of Full Converter → (Two quadrant)

1ϕ Full conv^r

$V_0 = \frac{2V_m}{\pi} \cos\alpha$

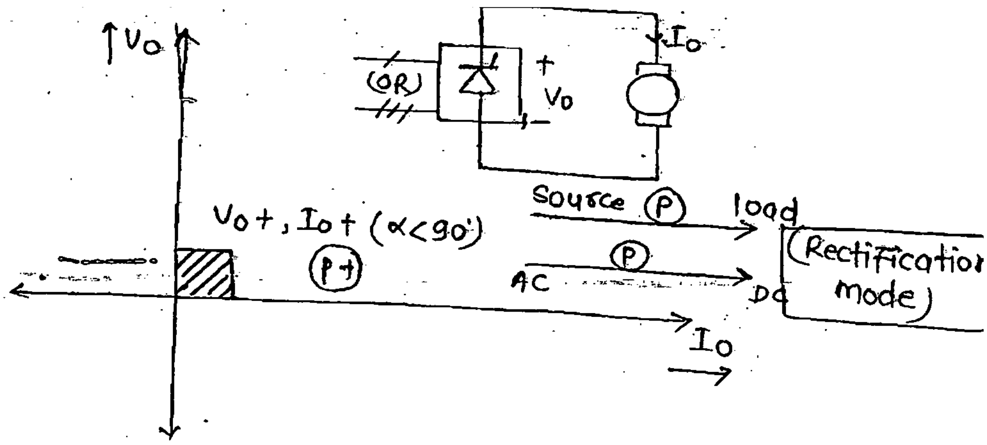
3ϕ Full conv^r

$V_0 = \frac{3V_{mL}}{\pi} \cdot \cos\alpha$

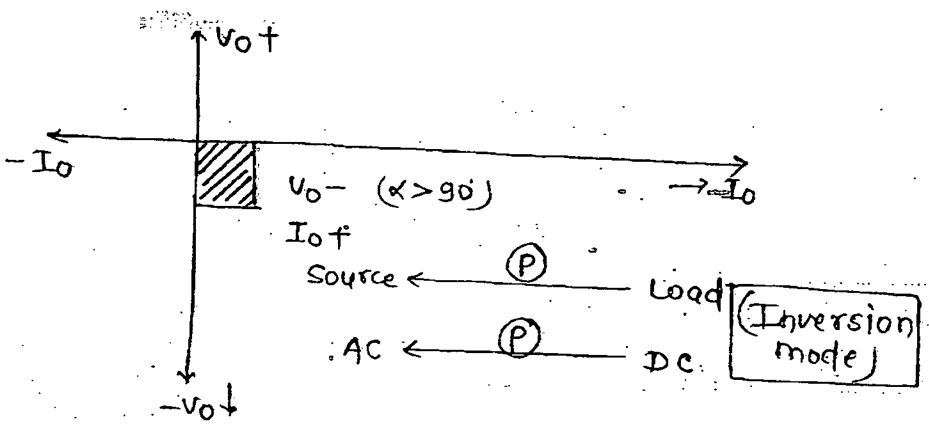
$\alpha < 90°$, $V_0 +$

$\alpha > 90°$, $V_0 -$

I_0 (always) +

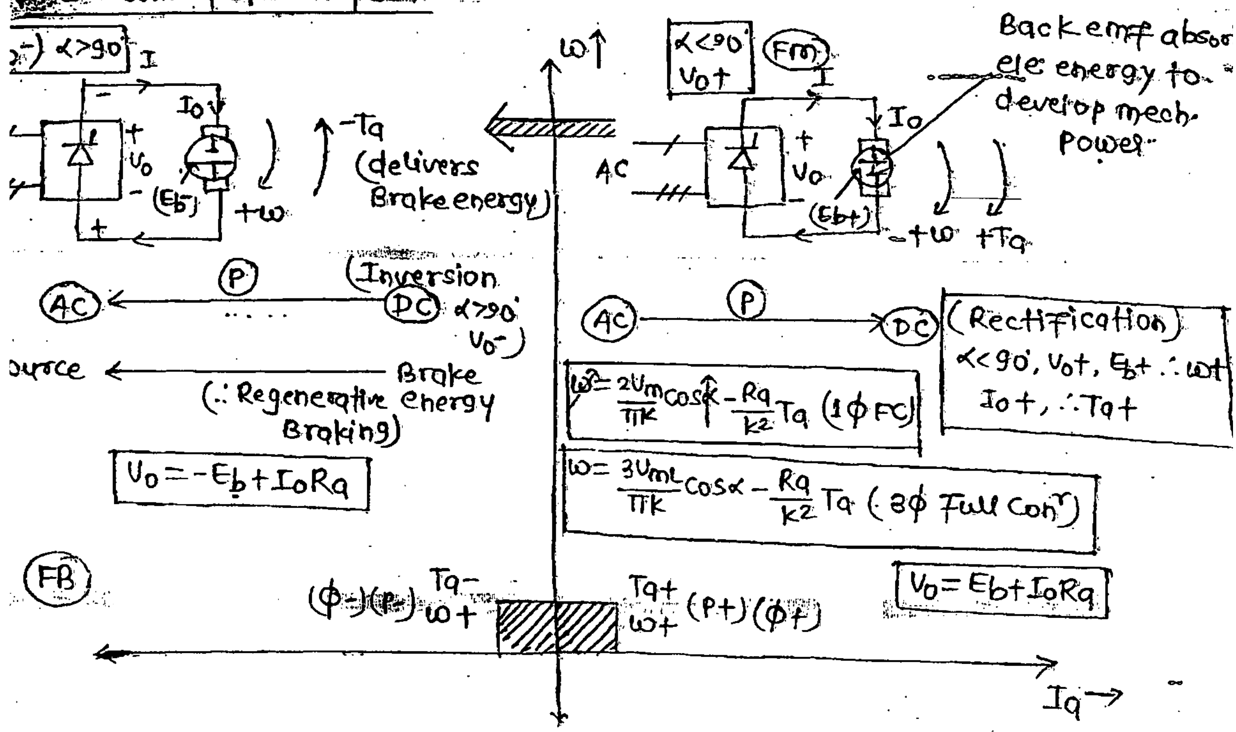


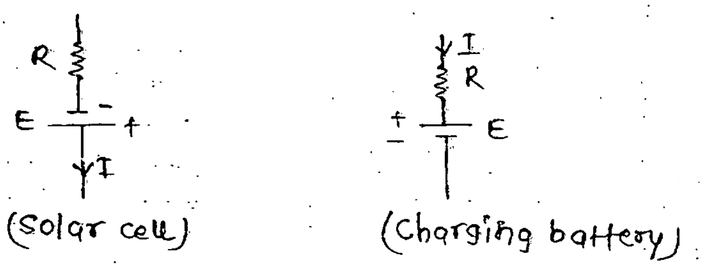
* Rectification mode can be used for motoring mode of a dc m/c & charging battery.



* Inversion mode can be used for regenerative braking of a dc m/c.
* Inversion mode is also used for solar sell.
  (The solar energy stored in the form of dc is given to the AC side of con^r when con^r is supporting the inversion mode)

Full Conv^r Fed DC m/c →





Quadrant Operation of semi converter →

1φ semi con^r

$$V_0 = \frac{V_m}{\pi}(1+\cos\alpha)$$

3φ semi con^r

$$V_0 = \frac{3V_{mL}}{\pi}(1+\cos\alpha)$$

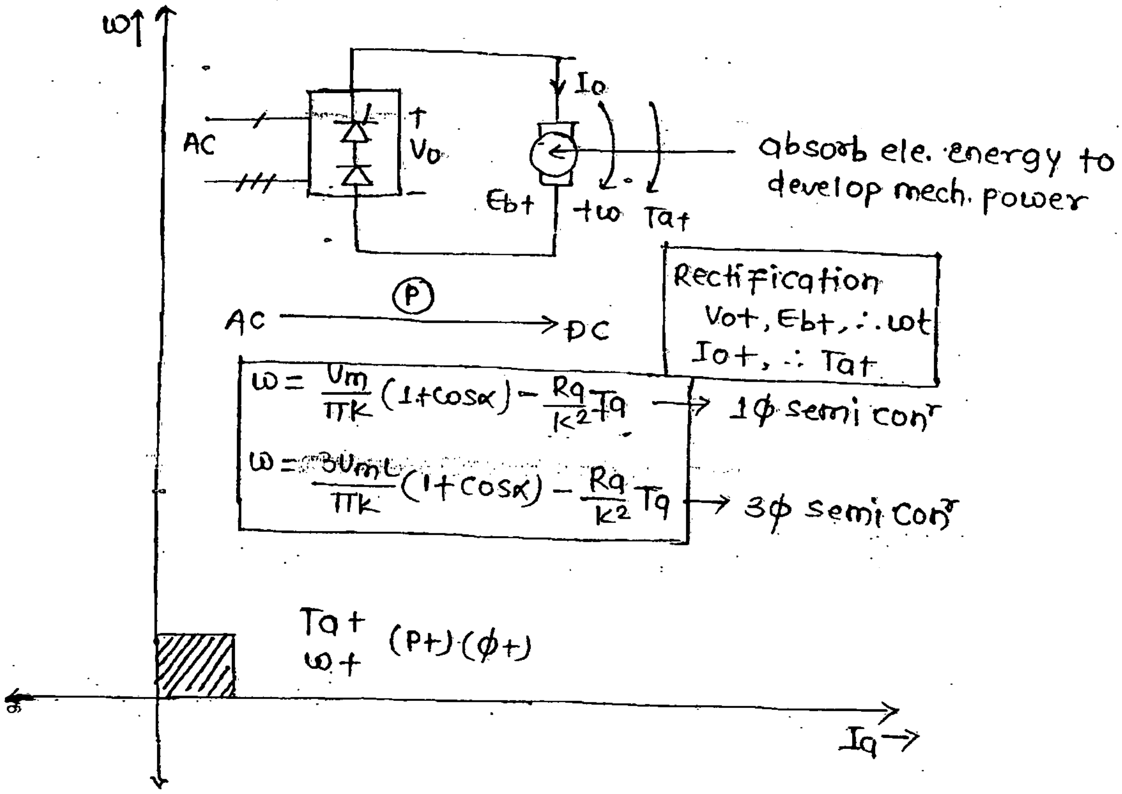
$$V_0 \xrightarrow{\text{always}} +ve$$

$$I_0 \xrightarrow{\text{always}} +ve$$

* Semiconverter gives only one quadrant operation.
* Inversion of semiconverter is not accepted i.e only charging batter

application is possible with semiconvr.

* solar cell application is not possible with semiconverter.



$$\omega = \frac{V_m}{\pi K}(1+\cos\alpha) - \frac{R_a}{K^2}T_a \rightarrow 1\phi \text{ semi con}^r$$

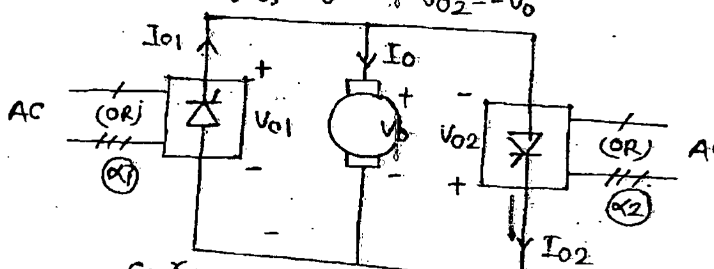
$$\omega = \frac{3V_{mL}}{\pi K}(1+\cos\alpha) - \frac{R_a}{K^2}T_a \rightarrow 3\phi \text{ semi con}^r$$

* **Dual Con^r** → * It gives 4 quadrant operation.

(1.) Non-circulating current type :– * In this dual con^r if one con^r is in the ON state then other con^r remains in the off state.

Advantage:– There is no circulating current b/w 2 con^r.

$V_{01} = V_0$; $V_{02} = -V_0$



Con^r(1.)

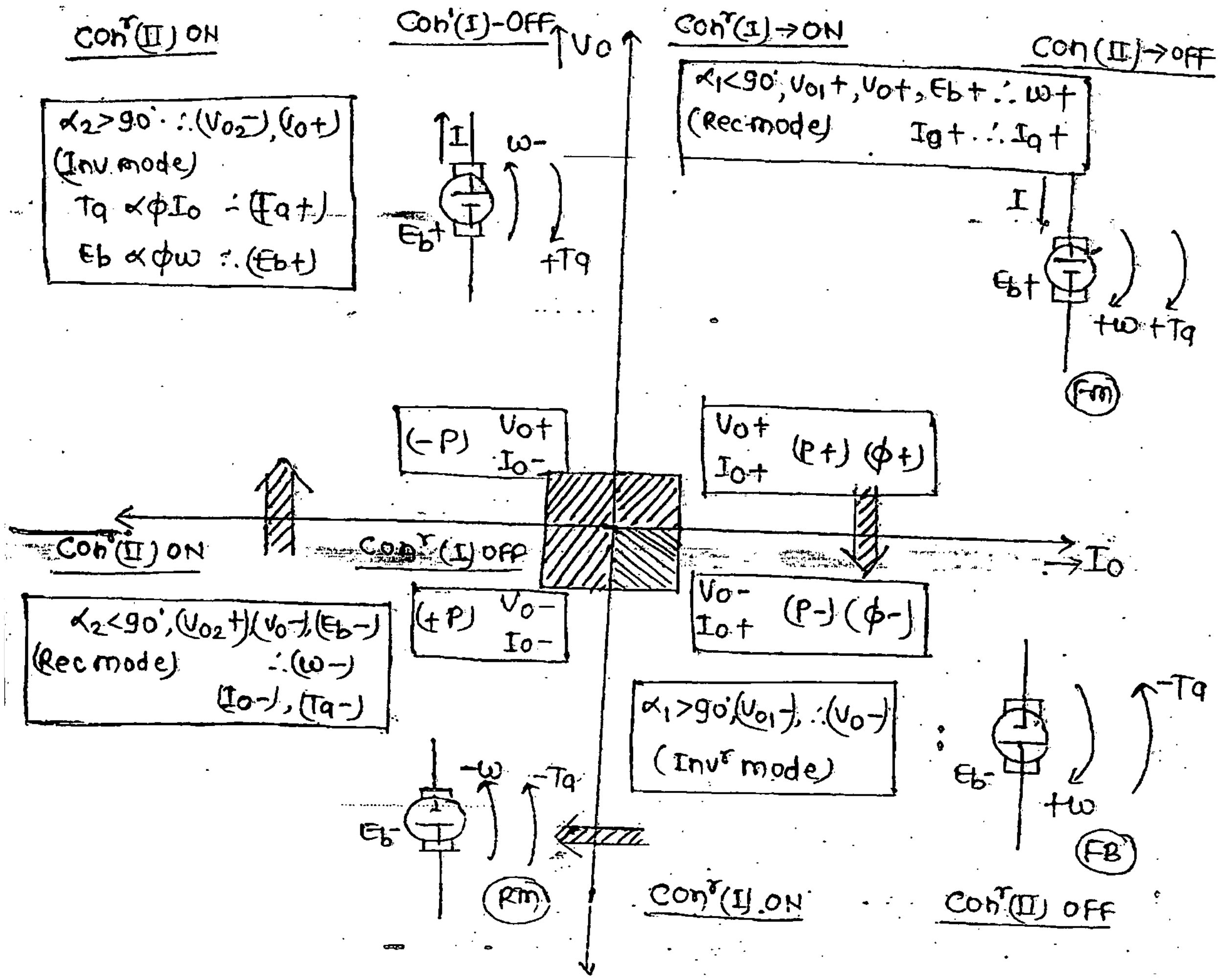
$$V_{01} = \frac{2V_m}{\pi}\cos\alpha_1$$

$$V_{01} = \frac{3V_{mL}}{\pi}\cos\alpha_1$$

Con^r(2.)

$$V_{02} = \frac{2V_m}{\pi}\cos\alpha_2$$

$$V_{02} = \frac{3V_{mL}}{\pi}\cos\alpha_2$$



* **Disadvantage:-** It gives slow speed responce & the reversal of arm current is not smooth during switching operation of the conʳ.

* **Reason of slow speed responce:-** Here we must provide comm. delay time for outgoing conʳ before the incoming conʳ is switched on. to avoid high circulating current

* This comm. delay time is responsible for slow speed responce.

(2) Circulating current type → * In this dual conʳ both the conʳ are simultaneously in the on state.

Disadvantage:- There will be circulating current b/w 2 conʳ & hence power loss is responsible.

* we can reduce the circulating current if $V_{01} = -V_{02}$

$$V_{01} = -V_{02}$$

$$\frac{2V_m}{\pi}\cos\alpha_1 = -\frac{2V_m}{\pi}\cos\alpha_2$$

$$\cos\alpha_1 + \cos\alpha_2 = 0$$

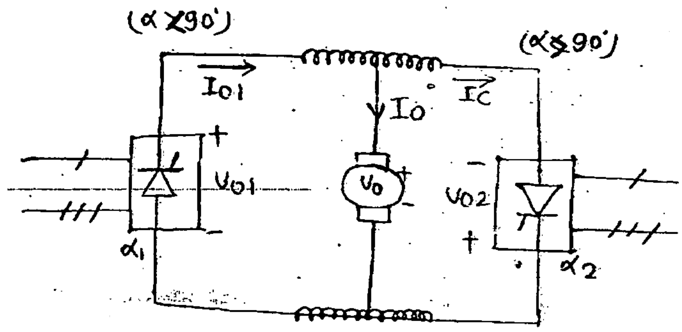
$$\cos\alpha_1 + \cos(180 - \alpha_1) = 0 \qquad (\alpha_2 = 180 - \alpha_1)$$

$$0 = 0$$

Hence $\alpha_2 = 180 - \alpha_1$

$$\boxed{\alpha_1 + \alpha_2 = 180^\circ}$$

* Even after satisfying the condn $\alpha_1 + \alpha_2 = 180^\circ$ still there is some circulating current due to the instantaneous vol. diff. between the 2 conr.
* To reduce this circulating current we must connect a reactor b/w the 2 conr as shown in fig. given below.

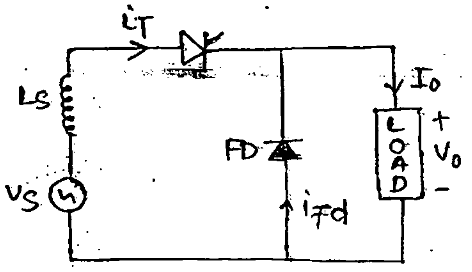


$I_{01} = I_0 + I_C$

Advantage → It gives high speed responce & reversal of arm. current is smooth during switching operation of conr.

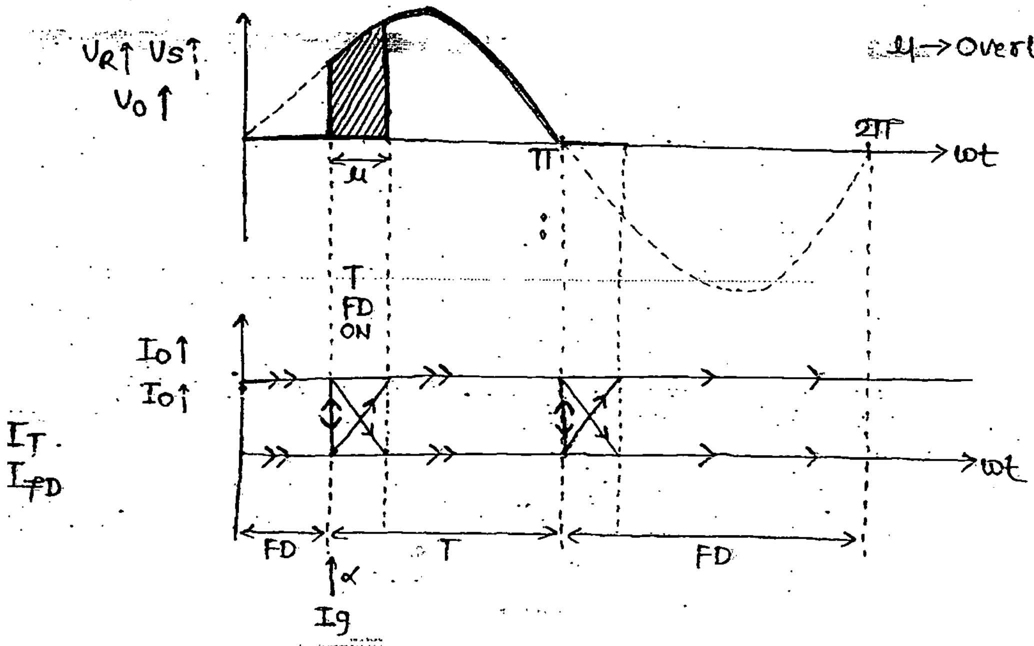
Effect of source inductance → Let Lsp the source inductance

One pulse converter →



Let us assume high inductive Load.

without Ls (ideal source) →
with Ls (Non-ideal source) →



μ → Overlap angle

→ Reduction in V_0 due to Ls.

With Ls →

During μ, T & FD → ON state ∴ $V_0 = 0$

$\uparrow i_T + i_{FD} \downarrow = I_0$ (During μ)

The value of load current constant & value of thy. current suddenly increases. Hence $I_{FD} \downarrow$.

& $V_S = L_S \frac{di_s}{dt}$

$V_m \sin\omega t \, dt = L_s \, di_s$

Multiplying ω by the both sides of eq^n

$$V_m \sin\omega t \, dt(\omega) = L_s \omega \, di_s$$

$$V_m \sin\omega t \, d(\omega t) = L_s \omega \, di_s$$

Integrating both sides

$$\int_{\alpha}^{\alpha+\mu} V_m \sin\omega t \, d(\omega t) = \omega L_s \int_{0}^{I_0} di_s$$

$$V_m \left[\cos\alpha - \cos(\mu+\alpha)\right] = \omega L_s I_0$$

Deviding both side by 2π; then we will get average reduction in area

$$\frac{V_m}{2\pi}\left[\cos\alpha - \cos(\mu+\alpha)\right] = \frac{\omega L_s I_0}{2\pi}$$

$$\frac{V_m}{\cancel{2\pi}}\left[\cos\alpha - \cos(\mu+\alpha)\right] = f L_s I_0$$

$$\boxed{\Delta V_{do} = \frac{V_m}{2\pi}\left[\cos\alpha - \cos(\mu+\alpha)\right] = f L_s I_0} \quad \text{------ (i)}$$

Where; ΔV_{do} = average reduction in dc o/p voltage due to L_s

$$V_o = \frac{V_m}{2\pi}(1+\cos\alpha) - \Delta V_{do}$$

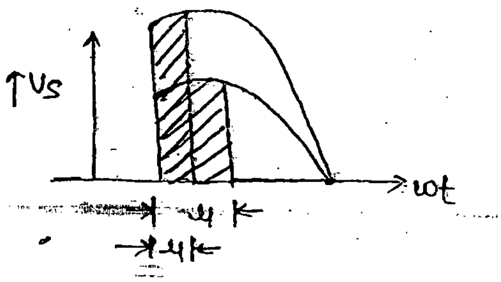
$$V_o = \frac{V_m}{2\pi}(1+\cos\alpha) - f L_s I_0 \quad \text{------ (ii)}$$

$$V_o = \frac{V_m}{2\pi}\left[1+\cos(\alpha+\mu)\right] \quad \text{------ (iii)}$$

ΔV_{do} does not depand on μ; it depands on $f L_s I_0$ but μ depand on the ΔV_{do}.

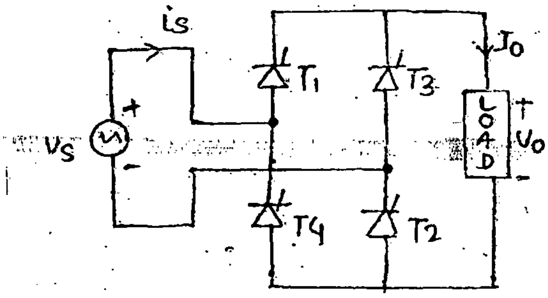
* <u>ΔV_{do}</u> depands only on <u>f, L_s, I_0</u>
* <u>μ</u> depands on <u>ΔV_{do}</u> & hence <u>f, L_s, I_0, V_s, α</u>
* If $f\uparrow$ (or) $L_s\uparrow$ (or) $I_0\uparrow$, without changing the ~~overlap angle~~ V_s & α then $\mu\uparrow$

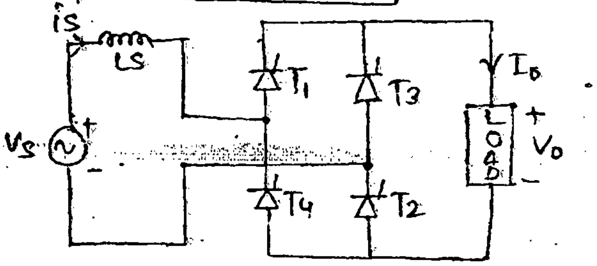
If $V_s\uparrow$, without changing $F, L_s; I_o, \alpha$ then $\mu\downarrow$ to remains the area constant.

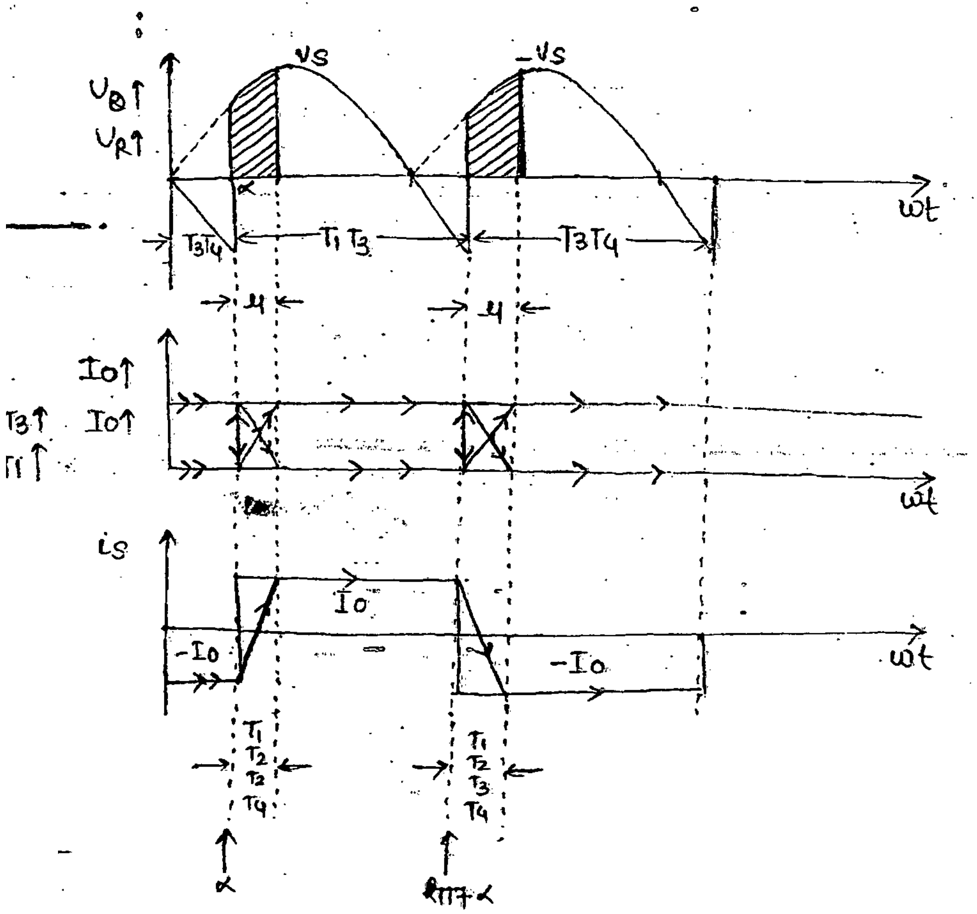


(2) Two pulse converter→

without Ls (Ideal)
with Ls (Non-ideal)

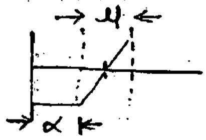






[redacted] displacement Factor

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

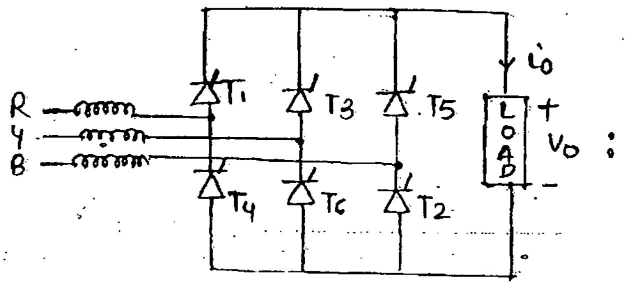


(iv) $g\uparrow$, THD$\downarrow$ $\therefore$ Harmonic on AC side$\downarrow$
(advantage)

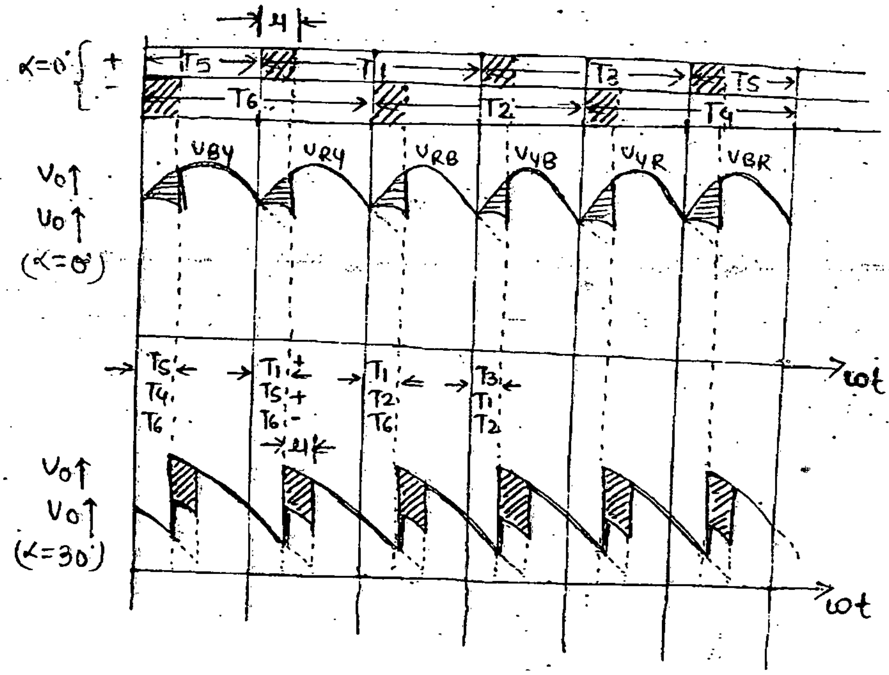
(v) $PF = g\uparrow FDF\downarrow$ (can't say)

Here the increase in g value is more than decrease in FDF
∴ the PF is slightly increased.

(3.) 6 pulse converter →

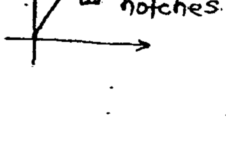


without Ls
with Ls



$\overset{+}{T_5}\overset{-}{T_6}$ & $\overset{+}{T_1}\overset{-}{T_6}$

$\frac{V_{BY} + V_{RY}}{2}$ (mean value)



Que → If α increases without changing other parameters then what happen to overlap angle?

Ans → Case(1) $0 \le \alpha \le 90^\circ$ ($\alpha\uparrow, \mu\downarrow$)

If $\alpha\uparrow$, without changing $\underbrace{f, L_s, I_o}_{\text{Const}}$ & V_s, then $\mu\downarrow$

$\Delta V_{do} \rightarrow$ constant

$\alpha\uparrow$ ripple vol $\uparrow$, height of reduction $\uparrow$ $\therefore \mu\downarrow$ to maintain same area of ΔV_{do}.

Overlap angle is max^m at $\alpha = 0^\circ$ & min^m at $\alpha = 90^\circ$

Case② $\alpha > 90^\circ$ ($\alpha\uparrow, \mu\uparrow$)

$\alpha\uparrow$ Ripple$\downarrow$, height$\downarrow$, $\therefore \mu\uparrow$

Conventional Question →

Que. $\frac{3}{48}$ at $\alpha = 0$, $\mu_0 = 30^\circ$

then μ_0 at $\alpha = 30^\circ, 60^\circ, 90^\circ, 120^\circ$

$$\frac{I_o}{I_p} = \cos\alpha - \cos(\mu + \alpha)$$

For $\alpha = 0^\circ$,
$$\frac{I_o}{I_p} = \cos 0^\circ - \cos(30 + 0^\circ)$$

$$\frac{I_o}{I_p} = 0.133$$

α	μ	
0	30°	→ max^m
30°	~~8.46~~ 12.85	$\alpha\uparrow, \mu\downarrow$
60°	~~7.61~~ 8.46	
90°	7.61	→ min^m
120°	9.21	$\alpha\uparrow, \mu\uparrow$

Let $V_{do} \rightarrow (V_0)_{max}$

$$V_{do} = \frac{2V_m}{\pi} \quad (2\text{pulse})$$

$$V_{do} = \frac{3V_{mL}}{2\pi} \quad (3\text{pulse})$$

$$V_{do} = \frac{3V_{mL}}{\pi} \quad (6\text{pulse})$$

With L_s →

During μ, T_1T_2 & $T_3T_4 \rightarrow$ ON $\therefore V_0 = 0$

$$V_m \sin\omega t = L_s \frac{di_s}{dt}$$

$$V_m \sin\omega t \, dt = L_s \, di_s$$

$$V_m \sin\omega t \, d(\omega t) = \omega L_s \, di_s$$

$$\int_{\alpha}^{\alpha+\mu} V_m \sin\omega t \, d(\omega t) = \omega L_s \int_{-I_0}^{I_0} di_s$$

[Source current change from I_0 to $-I_0$]

$$V_m\left[\cos\alpha - \cos(\alpha+\mu)\right] = 2\omega L_s I_0$$

$$\frac{V_m}{\pi}\left[\cos\alpha - \cos(\alpha+\mu)\right] = \frac{2\omega L_s I_0}{\pi}$$

$$\boxed{\Delta V_{do} = \frac{V_m}{\pi}\left[\cos\alpha - \cos(\alpha+\mu)\right] = \frac{2\omega L_s I_0}{\pi}} \quad \text{------ (i)}$$

$$\boxed{\Delta V_{do} = \frac{V_{do}}{2}\left[\cos\alpha - \cos(\alpha+\mu)\right]}$$

$m = 2, 3, 6$

***

m	ΔV_{do}
1	fL_sI_0
2	$4fL_sI_0$
3	$3fL_sI_0$
6	$6fL_sI_0$

$$V_0 = V_{do}\cos\alpha - \Delta V_{do} \quad \text{------ (ii)}$$

$$\boxed{V_0 = \frac{V_{do}}{2}\left[\cos\alpha + \cos(\alpha+\mu)\right]} \quad \text{---- (iii)}$$

$$-\frac{V_m}{\pi}\left[\cos\alpha - \cos(\alpha+\mu)\right] = \frac{2\omega L_s I_0}{\pi}$$

$$I_0 = \frac{V_m}{2\omega L_s}\left[\cos\alpha - \cos(\alpha+\mu)\right]$$

$$I_0 = I_P\left[\cos\alpha - \cos(\alpha+\mu)\right]$$

$$\boxed{\frac{I_0}{I_P} = \cos\alpha - \cos(\alpha+\mu)} \qquad \text{where } I_P = \frac{V_m}{2\omega L_s}$$

Que.→ What is meant by inductive vol. regulation?

Ans.→ It is a measure of reduction is o/p vol. due to source inductance.

It is taken as a ratio of $= \frac{\Delta V_{do}}{V_{do}}$

$$= \frac{\frac{\cancel{V_{do}}}{2}\left[\cos\alpha - \cos(\mu+\alpha)\right]}{\cancel{V_{do}}}$$

$$VR^n = \left[\frac{\cos\alpha - \cos(\alpha+\mu)}{2}\right]$$

$$= \frac{1-\cos\mu_0}{2}$$

μ_0 = Overlap angle at $\alpha = 0°$

Que.→ What is the effect of source inductance of the performance of conʳ?

Ans.→ (i) It reduce the avg. o/p vol. of conʳ.

(ii) It limits the max^m range of firing angle.

$$\boxed{\alpha_{max} = 180° - \left[\omega t_q + \mu_0°\right]}$$

Ideal vol. source, ideal thy. $\alpha_{max} = 180°$

Ideal vol. source, practical thy. $\alpha_{max} = 180 - \omega t_q$

practical vol. source, practical thy. $\alpha_{max} = 180° - \omega t_q - \mu$