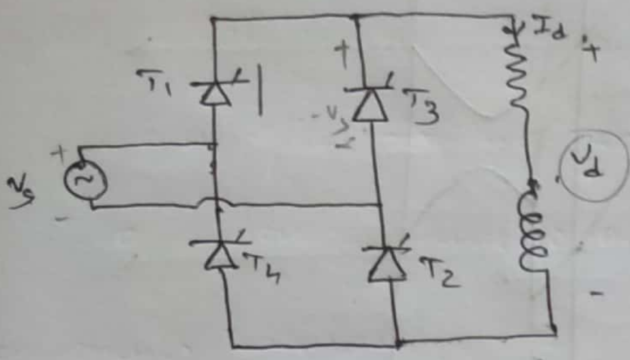
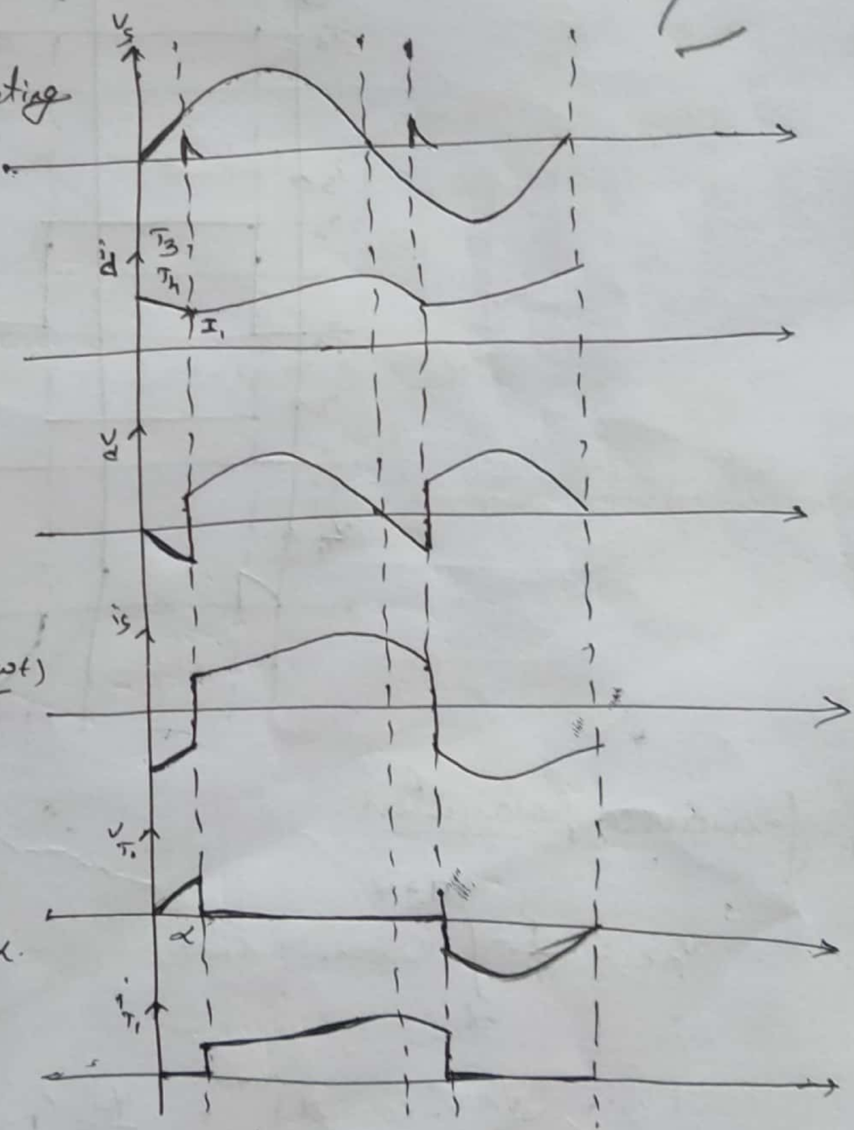
* For RL load

② continuous conduction mode:





$\omega t < \alpha$, T_3 & T_4 are conducting

At $\omega t = \alpha$, $i_d = I_1 \ (\neq 0)$

$v_d = -v_s$

$I_s = -I_d$

$v_{T_1} = v_s$

$\omega t > \alpha$, T_3 & T_4 are line commutated

$(\alpha \to \pi + \alpha)$

T_1 & T_2 are ON

$$v_d = v_s = R i_d(\omega t) + L \frac{d i_d(\omega t)}{dt}$$

$$\sqrt{2} V_s \sin \omega t = R i_d + L \frac{d i_d}{dt}$$

at $\omega t = \alpha$, $i_d = +I_1$

$$R I_1 + L \left. \frac{d i_d}{dt} \right|_{\omega t = \alpha} = \sqrt{2} V_s \sin \alpha$$

$$i_s = i_d$$

$$i_d = \frac{V_m}{Z} \sin(\omega t - \theta) + A e^{-t/\tau}$$

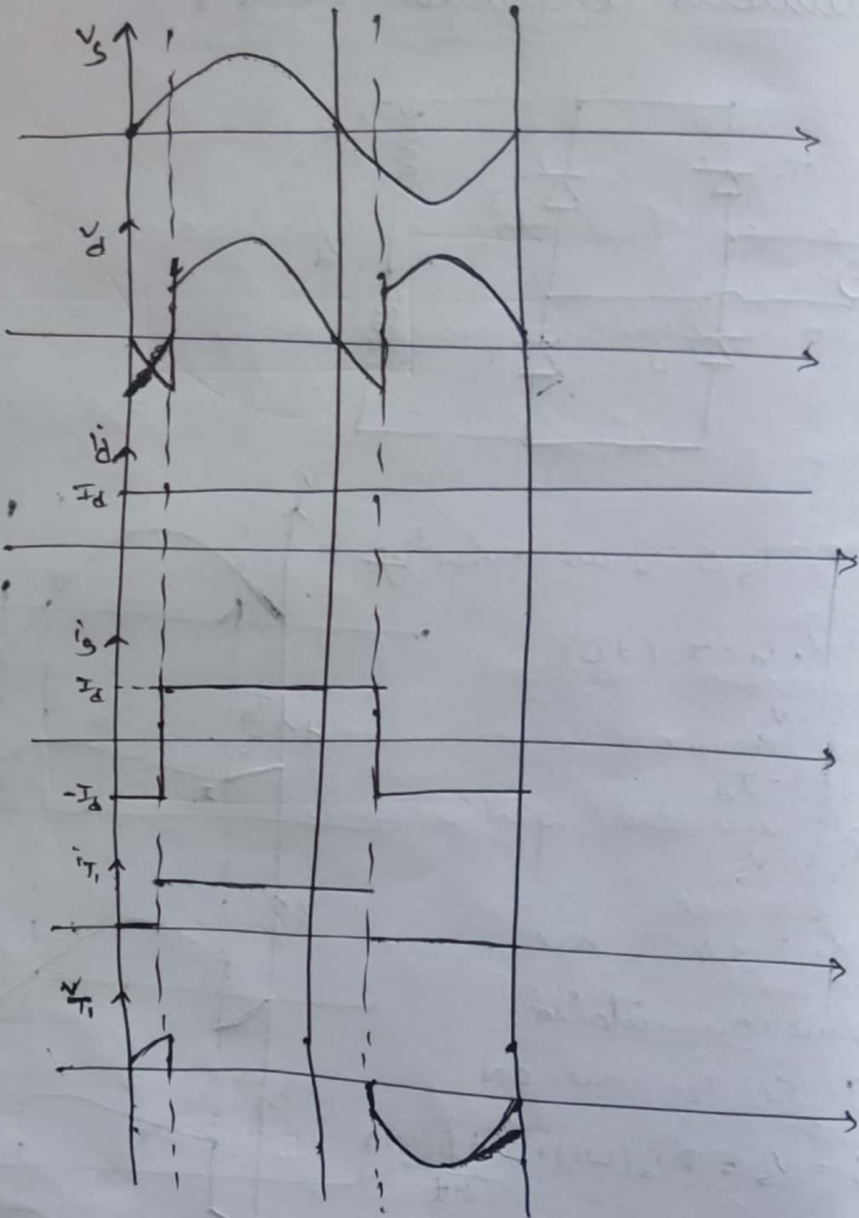
at $\omega t = \alpha$, $i_d = I_1$

$$A_1 = \left(I_1 - \frac{V_m}{Z} \sin(\alpha - \theta)\right) e^{t/\tau}$$

$$i_d = \frac{V_m}{Z} \sin(\omega t - \theta) + \left(I_1 - \frac{V_m}{Z} \sin(\alpha - \theta)\right) e^{\frac{\alpha}{\omega \tau}}$$

③ load current is constant

load inductance is very high



performance parameters:

$$v_{dc} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t \, d\omega t$$

$$v_{dc} = \frac{V_m}{\pi}\left(-\cos\omega t\right)_{\alpha}^{\pi+\alpha} = \cancel{\frac{V_m}{\pi}(1-\cos\alpha)} - \frac{V_m}{\pi}\left(\cos(\pi+\alpha) - \cos\alpha\right)$$

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

$$\boxed{I_{dc} = \frac{2V_m}{\pi R}(\cos\alpha)}$$

$(\cos\alpha = 1)$

$I_d = \frac{2V_m}{\pi R}$

$$v_{d\,rms} = \left[\frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m^2 \sin^2\omega t \, d\omega t\right]^{1/2}$$

$$= \frac{V_m}{\sqrt{2}} = V_s$$

Average power = $V_{davg} I_d = \frac{2 V_m I_d}{\pi} \cos\alpha$

Ripple frequency of o/p voltage = 2 times supply frequency

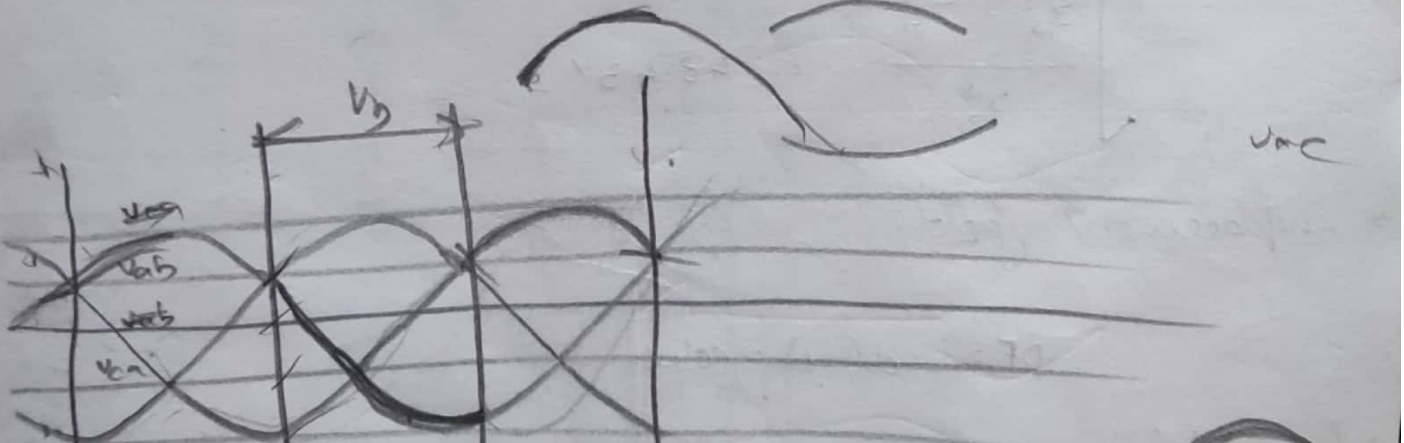
$$\text{voltage RF} = \sqrt{\frac{V_{RMS}^2 - V_{davg}^2}{V_{RMS}^2}}$$

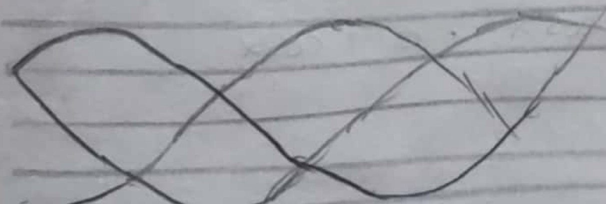
$$i_s(t) = a_0 + \sum_{n=1,2,3}^{\infty} a_n \cos n\omega t + b_n \sin n\omega t$$

$$a_0 = a_n = 0$$

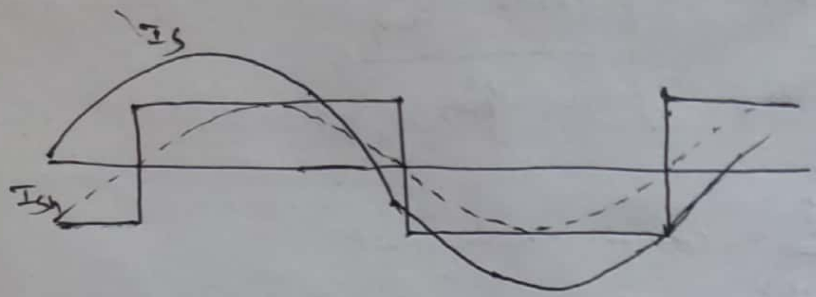
$$b_n = \frac{2}{2\pi}\left[\int_{\alpha}^{\pi+\alpha} I_d \sin\omega t \sin n\omega t - \int_{\pi+\alpha}^{2\pi+\alpha} I_d \sin\omega t \sin n\omega t\right]$$

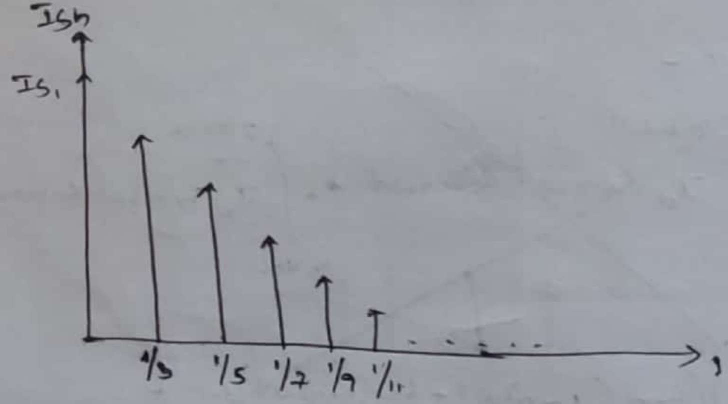
$$b_n = \frac{I_d}{2\pi}\left[\int_{\alpha}^{\pi+\alpha}(\sin(1-n)\omega t + \sin(1+n)\omega t)\,d\omega t - \int_{\pi+\alpha}^{2\pi+\alpha}(\sin(1-n)\omega t + \sin(1+n)\omega t)\,d\omega t\right]$$





$$I_{sh} = \begin{cases} 0 & \text{for even } h \\ \frac{I_{s_1}}{h} & \text{for odd } h \end{cases}$$





* Total harmonic distortion: (THD)

$$\sqrt{\frac{I_s^2 - I_{s_1}^2}{I_{s_1}^2}} = 48.43\%$$

* Displacement factor:

$$DF = \cos(-\alpha) = \cos\alpha$$

* power factor:

$$pf = \frac{V_s I_{s_1} \cos\phi}{V_s I_s} = \frac{2\sqrt{2}}{\pi}\cos\alpha = 0.9\cos\alpha$$

* power at source side:

Total apparent power = $V_s I_s$

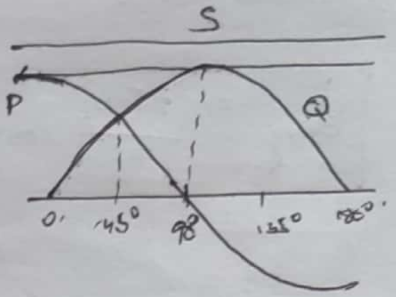
Active power $P = V_s I_{s_1} \cos\phi$

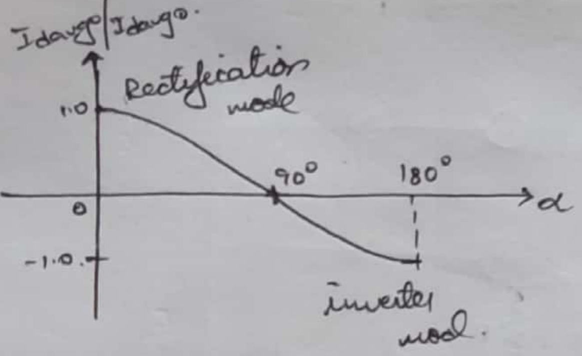
* fundamental frequency current results in fundamental reactive power

$$Q_1 = V_s I_{s1} \sin\phi_1 = V_s I_{s1} \sin\alpha$$

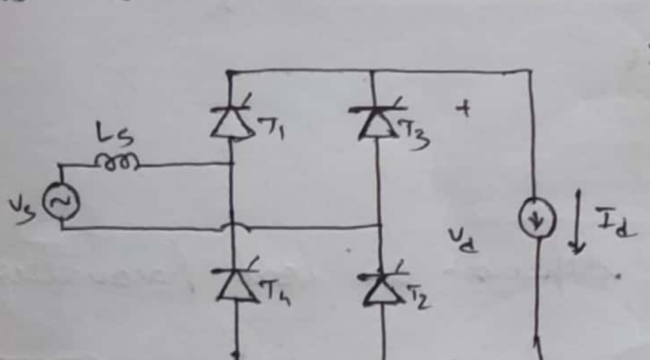
* fundamental frequency apparent power:

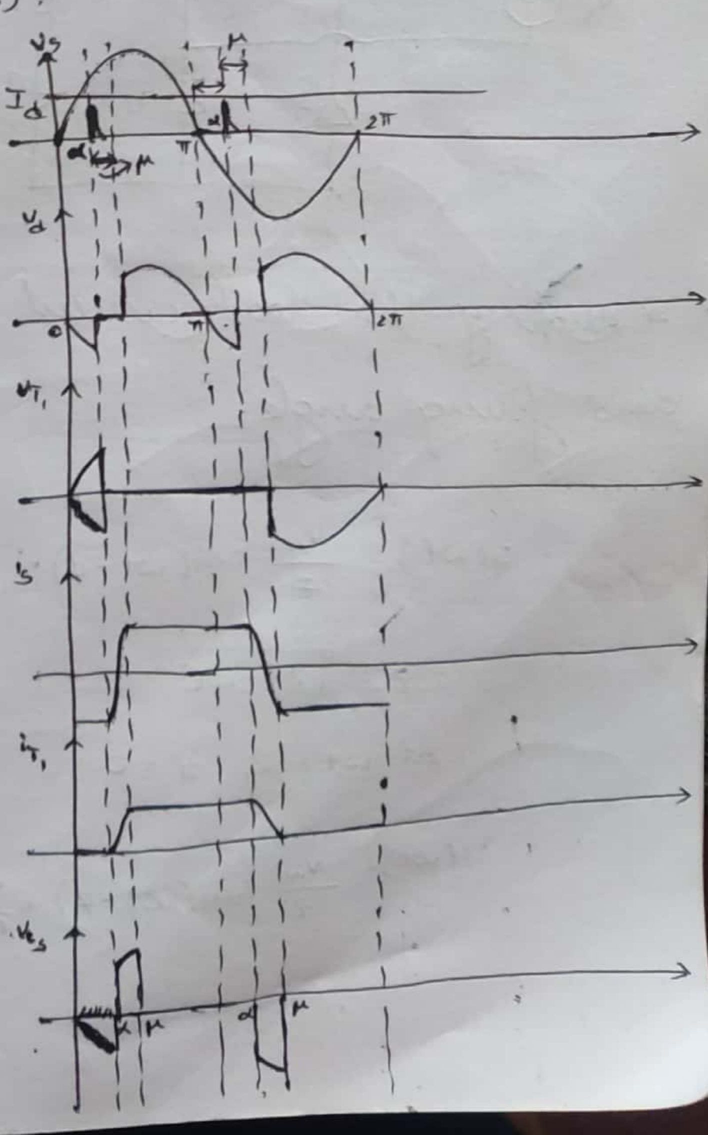
$$S_1 = V_s I_{s1} = \sqrt{P^2 + Q_1^2}$$





* Effect of source inductance (L_s):





$\alpha \rightarrow \mu$

$$V_s = V_{Ls}$$

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

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

$$\int_{\alpha}^{\alpha+\mu} \sin\omega t \, d\omega t = \int_{-I_d}^{I_d} \frac{\omega L_s \, di_s}{V_m}$$

$$\left[-\cos\omega t\right]_{\alpha}^{\alpha+\mu} = \frac{2 I_d \omega L_s}{V_m}$$

$$\cos\alpha - \cos(\alpha+\mu) = \frac{2 I_d \omega L_s}{V_m}$$

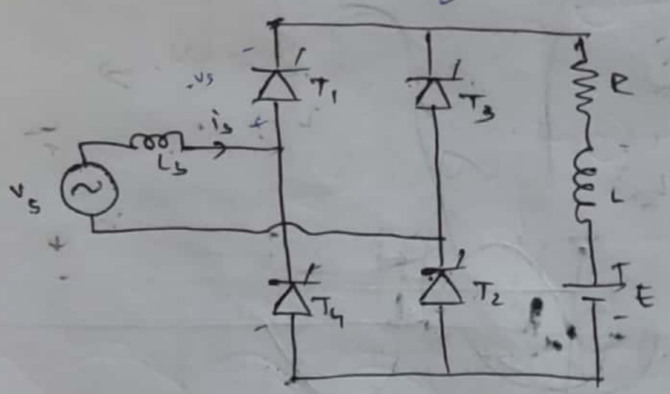
$$\boxed{\cos(\alpha+\mu) = \cos\alpha - \frac{2 I_d \omega L_s}{V_m}}$$

* $$V_{davg} = \frac{1}{\pi}\int_{\alpha+\mu}^{\pi+\alpha} V_m \sin\omega t \, d\omega t$$

$$= \frac{V_m}{\pi}\left[\cos(\alpha+\mu) - \cos(\pi+\alpha)\right].$$

$$\boxed{V_{davg} = \frac{2\sqrt{2}V_s}{\pi}\cos\alpha - \frac{2\omega L_s I_d}{\pi}}$$

* practical thyristor converters:



* shape of the load current depends on load parameters and firing angle.

$$i_d(\omega t) = \frac{V_m}{Z}\sin(\omega t - \phi) - \frac{E}{R} + ke^{-\frac{R}{L}t}$$

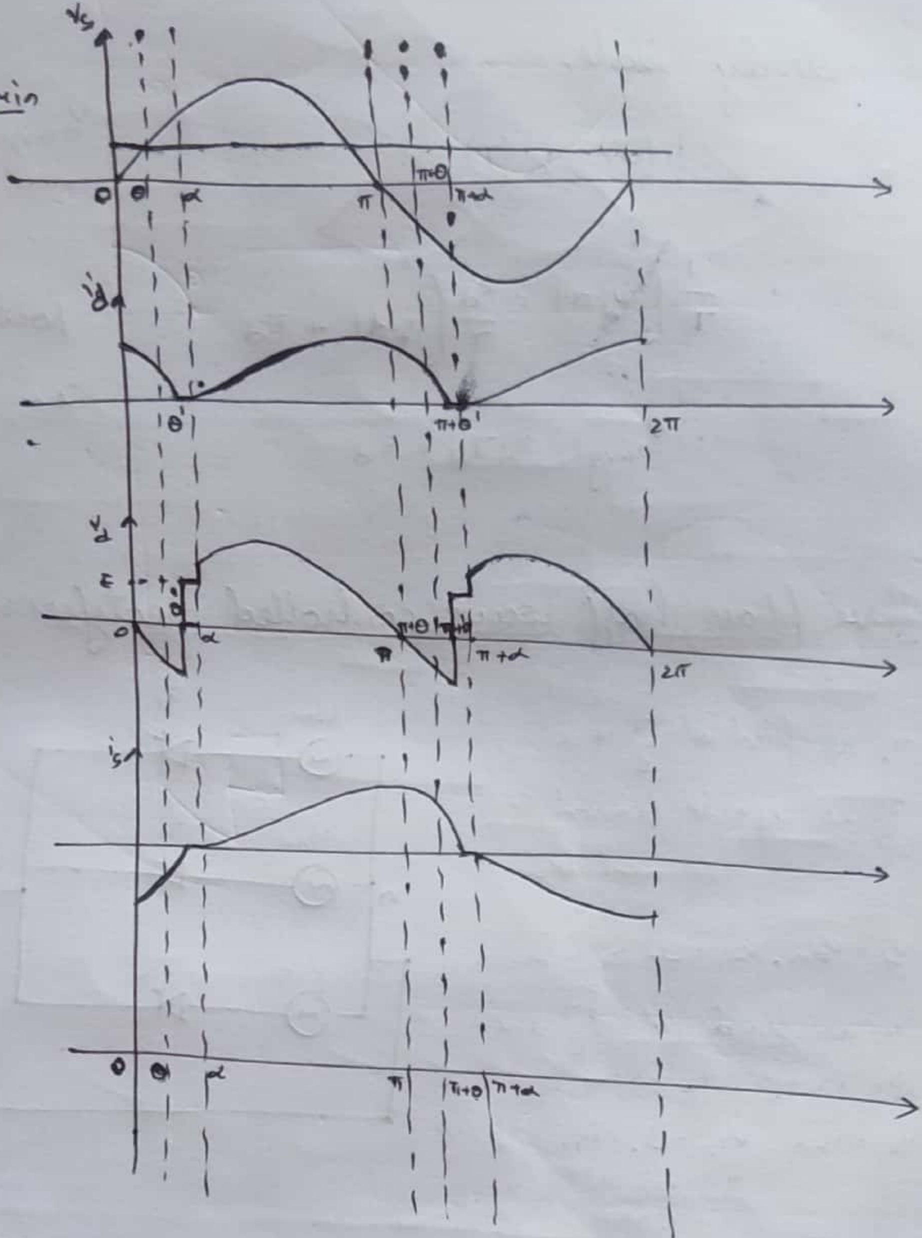
$$Z = \sqrt{R^2 + \omega L^2}$$

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

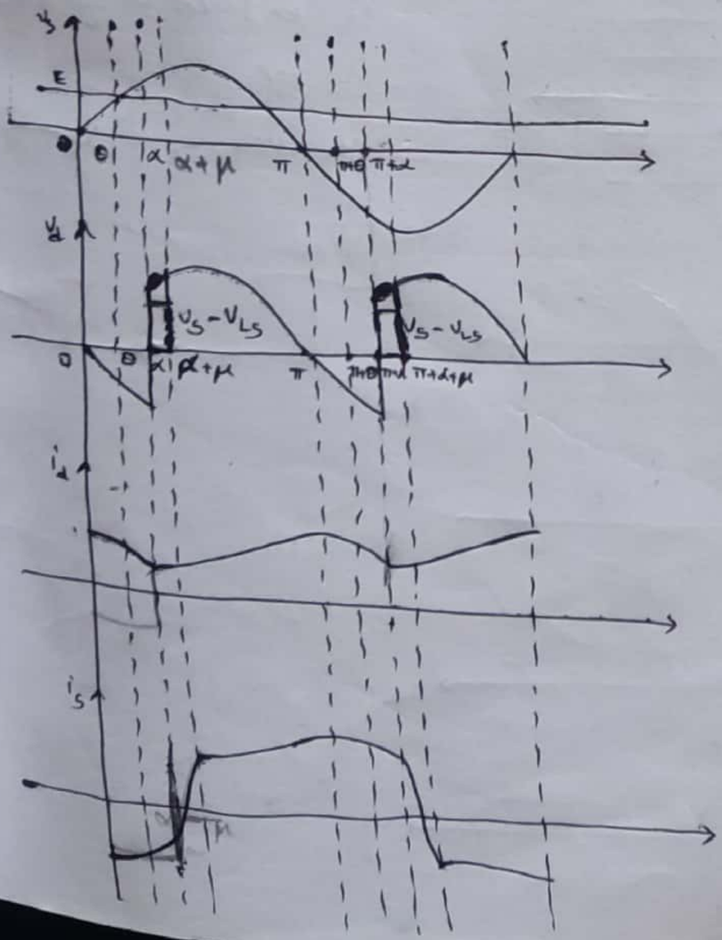
$$i_d(\omega t) = \frac{V_m}{Z}\sin(\omega t - \phi) - \frac{E}{R} + \left[\frac{E}{R} - \frac{V_m}{Z}\sin(\omega t - \phi)\right]e^{\frac{R\alpha}{\omega L}}e^{-\frac{R}{L}t}$$

→ Discontinuous mode:

$$V_{avg} = \frac{2\sqrt{2}\,V_s}{\pi}\cos\alpha - \frac{2\omega L_s i_{dmin}}{\pi}$$



→ continuous mode:



* Back emf is low or Torque is very high then the current will be continuous
* armature inductance is large

$$V_{davg} = \frac{2V_m}{\pi}\cos\alpha - \frac{2\omega L_s i_{dmin}}{\pi}$$

i_{dmin} is at $\omega t = \alpha$

$$v_d = r_d i_d + L_d \frac{di_d}{dt} + E_d$$

$$\frac{1}{T}\int_0^T v_d\,dt = \frac{r_d}{T}\int_0^T i_d\,dt + \frac{L_d}{T}\int_0^T di_d + E_d$$

In steady state,

$$i_d(0) = i_d(T)$$

$$\therefore \frac{1}{T}\int_0^T v_d\,dt = \frac{r_d}{T}\int_0^T i_d\,dt + E_d$$

$$\therefore v_{d\,avg} = r_d I_d + E_d$$

$v_{d\,avg}$ can be controlled by 'α'

$\therefore$ power delivered to load can be controlled by 'α'.

* <u>Three phase half wave controlled rectifier</u>:

T_1 is fired at $\frac{\pi}{6}+\alpha$

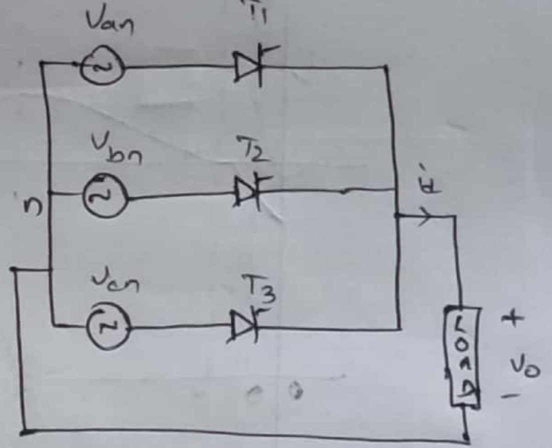
T_3 is reverse biased & turned off

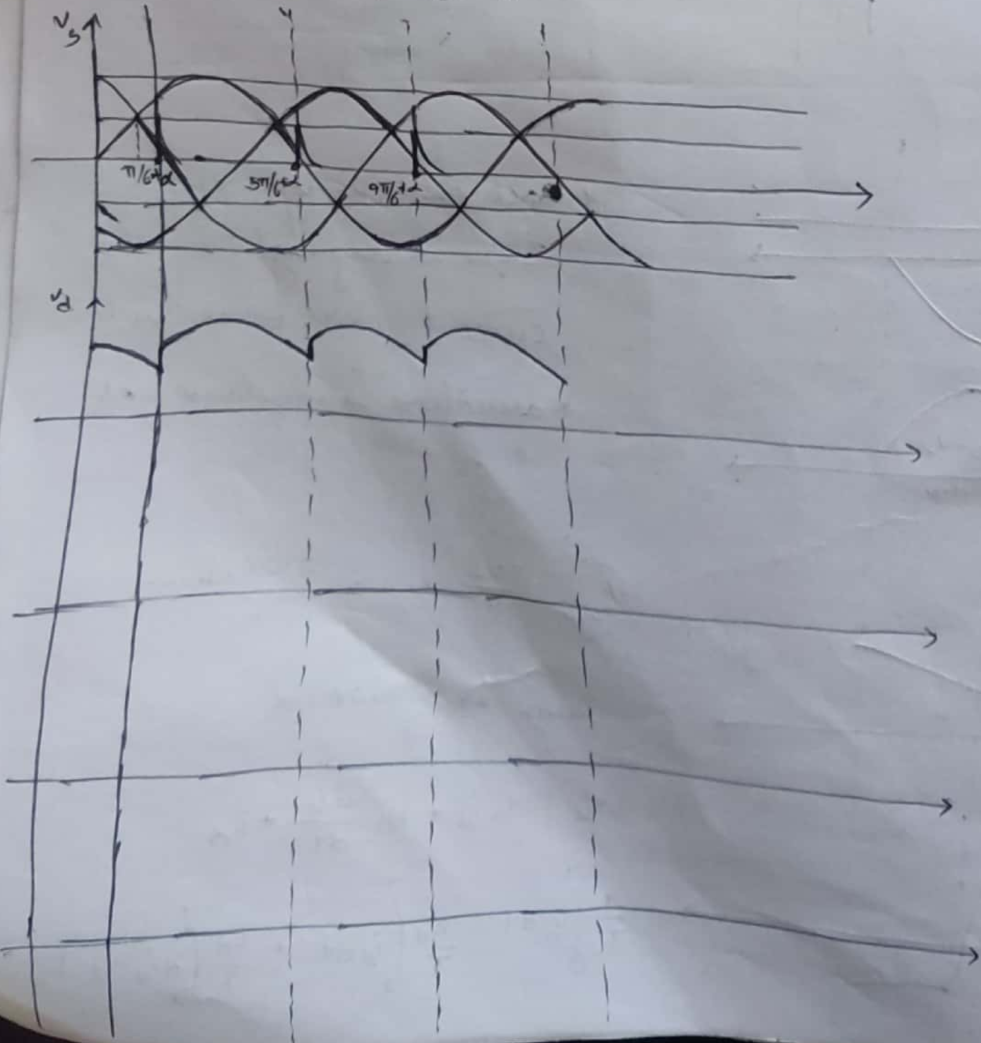
$v_d = v_{an}$, $v_{T_1} = 0$, $i_{T_1} = i_d$

T_2 is fired at $\frac{5\pi}{6}+\alpha$

T_1 is off, T_2 is ON

$v_d = v_{bn}$, $v_{T_2} = 0$, $i_{T_2} = i_d$





T_3 is fired at $\frac{9\pi}{6}+\alpha$

T_2 off, T_3 'ON'

$v_d = v_{cn}$, $v_{T_3} = 0$, $i_{T_3} = i_d$

For continuous current:

$$V_{d\,avg} = \frac{3}{2\pi}\int_{\pi/6+\alpha}^{\frac{5\pi}{6}+\alpha} V_m \sin\omega t \, d\omega t = \frac{3V_m}{2\pi}\left[\cos\left(\frac{\pi}{6}+\alpha\right) - \cos\left(\frac{5\pi}{6}+\alpha\right)\right]$$

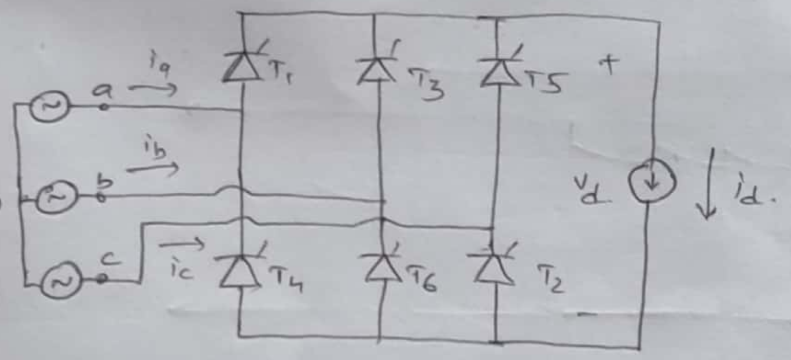
$$= \frac{3V_m}{2\pi}\left[\cos\left(\frac{\pi}{6}+\alpha\right) - \cos\left(\pi-\frac{\pi}{6}+\alpha\right)\right]$$

$$= \frac{3V_m}{2\pi}\left[2\cos\left(\frac{\pi}{6}+\alpha\right)\right]$$

$$= \frac{3V_m}{\pi}\left[\cos\left(\frac{\pi}{6}+\alpha\right)\right]$$

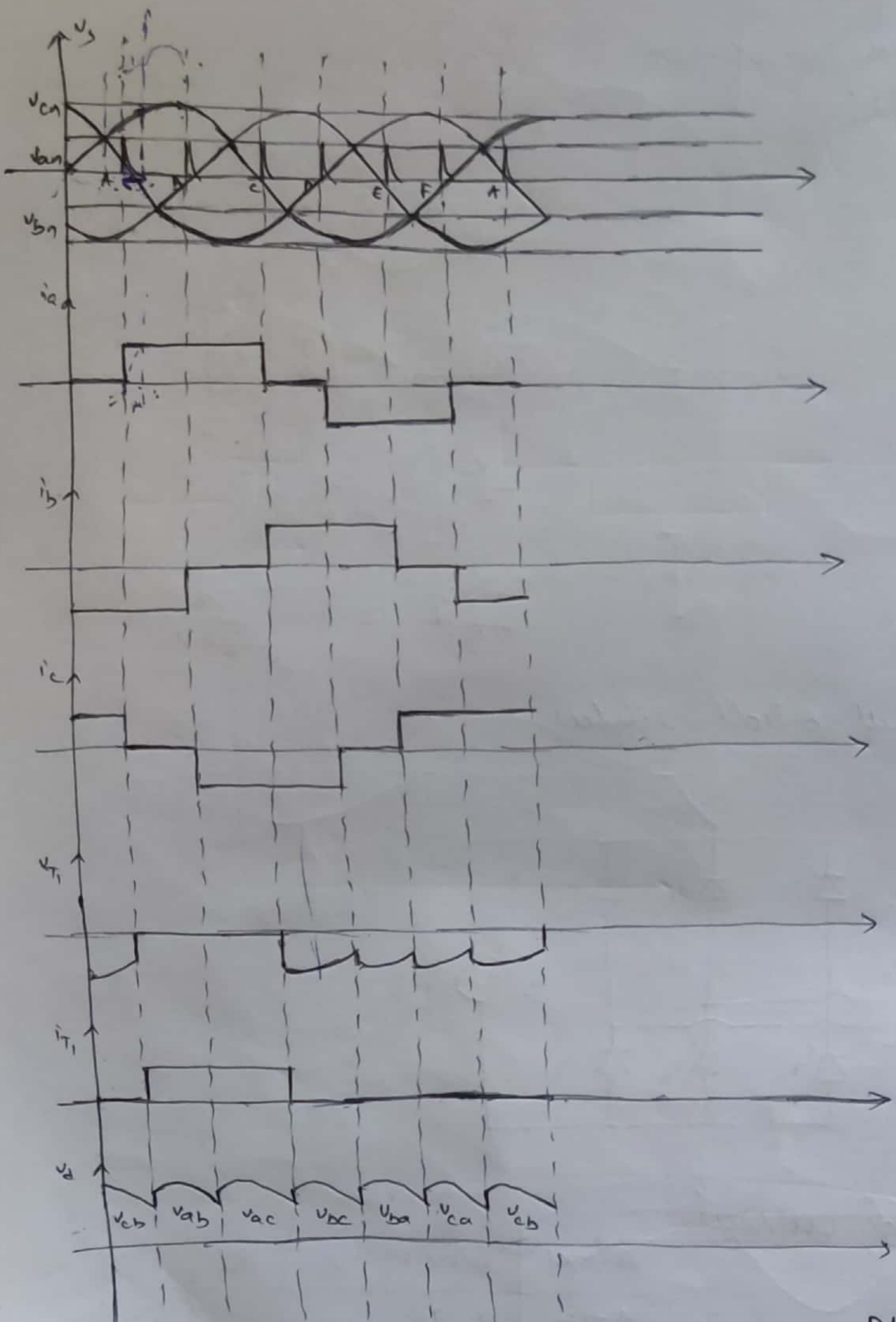
$$= \frac{3\sqrt{3}V_s}{\sqrt{2}\pi}\cos\alpha = \frac{3V_{LL}}{\sqrt{2}\pi}\cos\alpha$$

* Three phase full controll rectifier



* Constant load current:

Interval	Devices	V_d	i_a	i_b	i_c
A → B	T_1, T_6	V_{ab}	$+I_d$	$-I_d$	0
B → C	T_1, T_2	V_{ac}	$+I_d$	0	$-I_d$
C → D	T_2, T_3	V_{bc}	0	$+I_d$	$-I_d$
D → E	T_3, T_4	V_{ba}	$-I_d$	$+I_d$	0
E → F	T_4, T_5	V_{ca}	$-I_d$	0	$+I_d$
F → A	T_5, T_6	V_{cb}	0	$-I_d$	$+I_d$



PIV $= \sqrt{3}V_m$

$$v_{davg} = \frac{3}{\pi}\int_{\pi/6+\alpha}^{\pi/2+\alpha} V_m \sin\omega t \, d\omega t - \int_{\pi/6+\alpha}^{\pi/2+\alpha} V_m \sin(\omega t - 120)\, d\omega t$$

$$= \frac{3V_m}{\pi}\left[\left[\cos\left(\frac{\pi}{6}+\alpha\right) - \cos\left(\frac{\pi}{2}+\alpha\right)\right] - \left[\cos\left(\frac{\pi}{6}+\alpha-120\right) - \cos\left(\frac{\pi}{2}+\alpha-120\right)\right]\right]$$

$$= \frac{3V_m}{\pi}\left[\left[\cos\left(\frac{\pi}{6}+\alpha\right) + \sin\alpha\right] - \left[\cos(\alpha-90) - \cos(\alpha-30)\right]\right]$$

$$= \frac{3V_m}{\pi}\left[\left[\cos\frac{\pi}{6}\cos\alpha - \sin\frac{\pi}{6}\sin\alpha + \sin\alpha\right] - \left[\cos(90-\alpha) - \cos(30-\alpha)\right]\right] = \frac{3V_m}{\pi}\left[\left[\frac{\sqrt{3}\cos\alpha}{2} + \frac{\sin\alpha}{2}\right] - \sin\alpha + \cos(30-\alpha)\right]$$

$= \frac{3\sqrt{6}\,V_s}{\pi}\cos\alpha = 1.35\,V_{LL}\cos\alpha$

* **Average output power:**

$$P_{avg} = V_{d\,avg} \times I_{d\,avg} = 1.35\,V_{LL} \times I_d \cos\alpha$$

* **AC side current i_a:**

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

$$i_{a_1} = a_1 \cos\omega t + b_1 \sin\omega t$$

$$a_1 = \frac{1}{\pi}\left[\int_{\pi/6+\alpha}^{\frac{5\pi}{6}+\alpha} I_d \cos\omega t\, d\omega t - \int_{7\pi/6+\alpha}^{11\pi/6+\alpha} I_d \cos\omega t\, d\omega t\right]$$

$$a_1 = \frac{I_d}{\pi}\left[\sin\left(\frac{5\pi}{6}+\alpha\right) - \sin\left(\frac{\pi}{6}+\alpha\right) - \sin\left(\frac{11\pi}{6}+\alpha\right) + \sin\left(\frac{7\pi}{6}+\alpha\right)\right]$$

$$a_1 = \frac{I_d}{\pi}\left[\sin\left(\pi-\frac{\pi}{6}+\alpha\right) - \sin\left(\frac{\pi}{6}+\alpha\right) - \sin\left(2\pi-\frac{\pi}{6}+\alpha\right) + \sin\left(\pi+\frac{\pi}{6}+\alpha\right)\right]$$

$$a_1 = \frac{-2\sqrt{3}\,I_d}{\pi}\sin\alpha$$

$$b_1 = \frac{1}{\pi}\left[\int_{\pi/6+\alpha}^{\frac{5\pi}{6}+\alpha} I_d \sin\omega t\, d\omega t - \int_{7\pi/6+\alpha}^{11\pi/6+\alpha} I_d \sin\omega t\, d\omega t\right]$$

$$b_1 = \frac{I_d}{\pi}\left[\cos\left(\frac{\pi}{6}+\alpha\right) - \cos\left(\frac{5\pi}{6}+\alpha\right) - \cos\left(\frac{7\pi}{6}+\alpha\right) + \cos\left(\frac{11\pi}{6}+\alpha\right)\right]$$

$$b_1 = \frac{I_d}{\pi}\left[\cos\left(\frac{\pi}{6}+\alpha\right) - \cos\left(\pi-\frac{\pi}{6}+\alpha\right) - \cos\left(\pi+\frac{\pi}{6}+\alpha\right) + \cos\left(2\pi-\frac{\pi}{6}+\alpha\right)\right]$$

$$b_1 = 0$$

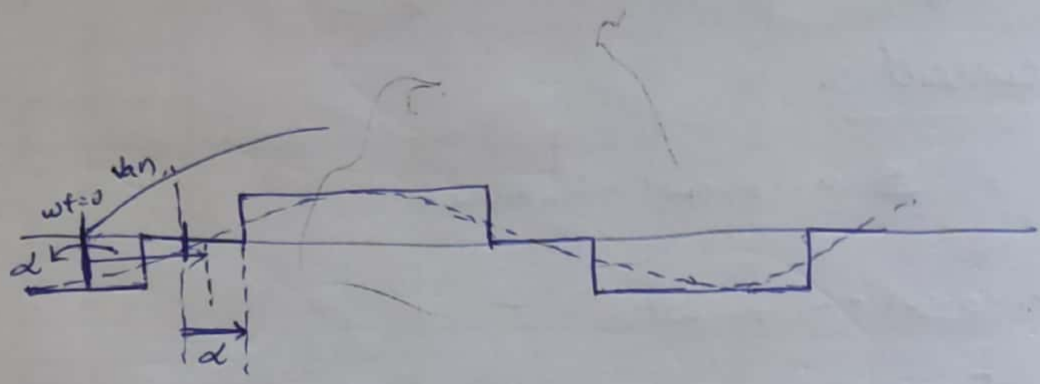
$$i_{a_1} = \frac{2\sqrt{3}\,I_d}{\pi}\sin(\omega t - \alpha)$$

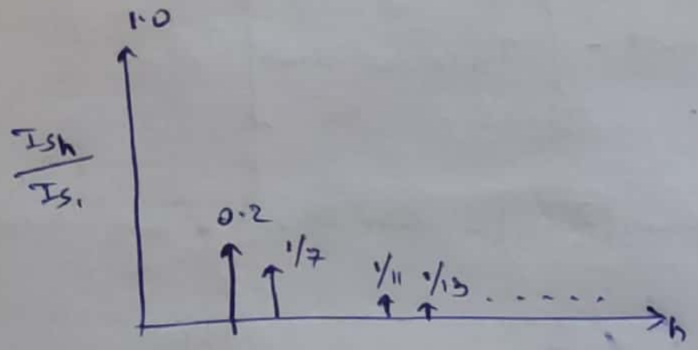
* RMS value of fundamental component is

$$i_{a_1(rms)} = \frac{2\sqrt{3}\,I_d}{\pi\sqrt{2}} = \frac{\sqrt{6}\,I_d}{\pi} = 0.78\,I_d$$

* RMS value of harmonic components $I_{ah} = \frac{I_{a_1}}{h}$

$$h = 6n \pm 1, \quad (n = 1, 2, 3, \cdots)$$





* Total RMS value of phase current I_a :

$$\sqrt{\frac{2}{3}}\, I_d = 0.816\, I_d$$

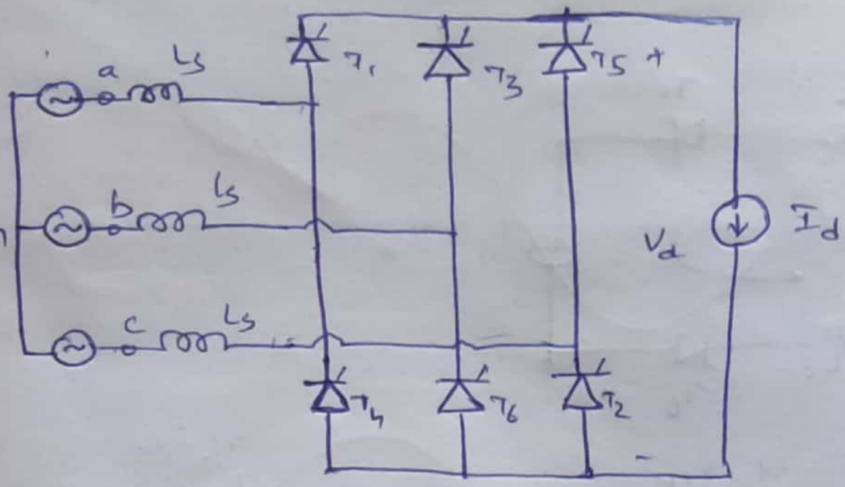
* $THD = \sqrt{\frac{I_s^2 - I_{s_1}^2}{I_{s_1}^2}} = \sqrt{\frac{(0.816)^2 I_d^2 - (0.78)^2 I_d^2}{(0.78)^2 I_d^2}}$

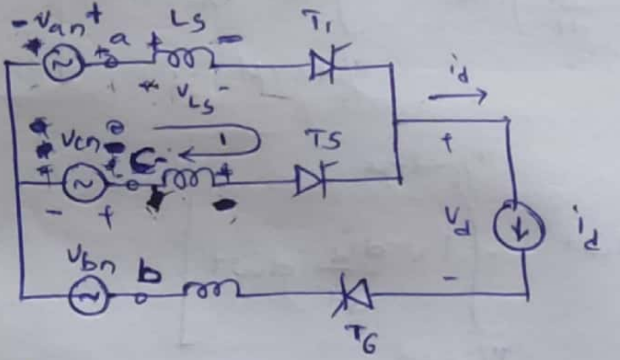
$$= 31.08\%$$

* $DPF = \cos\phi_1 = \cos\alpha$

* power factor $= \frac{V_s I_{s_1} \cos\phi}{V_s I_s} = \frac{I_{a_1} \cos\phi}{I_a} = \frac{3}{\pi}\cos\alpha = 0.96\cos\alpha$

* Effect of source inductance:





$\pi/6 + \alpha \longrightarrow \pi/6 + \alpha + \mu$

T_1, T_5, T_6 conducts

KVL LOOP1:

$V_{an} - V_{Ls} - V_{Ls} - V_{cn} = 0$

$V_{ac} - 2V_{Ls} = 0$

$+V_{an} - V_{Ls_a} - V_{Ls_c} - V_{cn} = 0$

$V_{ac} = \sqrt{2}V_s \sin(\omega t) - \sqrt{2}V_s \sin(\omega t + 120)$

$V_{ac} - L_s \frac{di_a}{dt} - L_s \frac{di_c}{dt} = 0$

$\sqrt{2}V_s \sin\omega t - \sqrt{2}V_s \sin(\omega t + 120) = 2L_s \frac{di_d}{dt}$

$V_{ac} - 2L_s \frac{di_a}{dt} = 0$

$\sqrt{2}V_s \sin\omega t - \sqrt{2}V_s \sin(\omega t + 120) = 2\omega L_s \frac{di_d}{d\omega t}$

$V_{ac} = 2L_s \frac{di_a}{dt}$

$$\int_{\pi/6+\alpha}^{\pi/6+\alpha+\mu} \sqrt{2}V_s \sin\omega t - \sqrt{2}V_s \sin(\omega t + 120)\, d\omega t = 2\omega L_s \int_0^{I_d} di_d$$

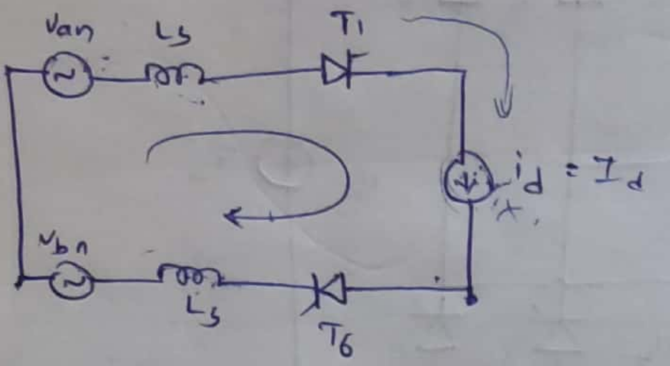
$$\frac{\sqrt{2}V_s}{2\omega L_s}\left[\cos\left(\frac{\pi}{6}+\alpha\right) - \cos\left(\frac{\pi}{6}+\alpha+\mu\right) + \cos\left(\frac{\pi}{6}+\alpha+\mu+120\right) - \cos\left(\frac{\pi}{6}+\alpha+120\right)\right]$$

$= I_d$

$$I_d = \frac{\sqrt{6}V_s}{2\omega L_s}\left(\cos\alpha - \cos(\mu+\alpha)\right)$$

$$\cos(\alpha+\mu) = \cos\alpha - \frac{\sqrt{2}\omega L_s I_d}{V_{LL}}$$

* $\frac{\pi}{6}+\alpha+\mu \longrightarrow \frac{\pi}{2}+\alpha$



$$V_{avg} = \frac{3}{\pi}\left[\int_{\pi/6+\alpha}^{\pi/6+\alpha+\mu}\left(v_{an}-v_{bn}-L_s\frac{di_d}{dt}\right)d\omega t + \int_{\pi/6+\alpha+\mu}^{\pi/2+\alpha}(v_{an}-V_{bn})\,d\omega t\right]$$

$$V_{avg} = \frac{3}{\pi}\left[\int_{\pi/6+\alpha}^{\pi/2+\alpha}(v_{an}-v_{bn})\,d\omega t - \int_{\pi/6+\alpha}^{\pi/6+\alpha+\mu} L_s\frac{di_d}{dt}\,d\omega t\right]$$

$$V_{avg} = \left[\frac{3V_m}{\pi}\left[\cos\left(\frac{\pi}{6}+\alpha\right)-\cos\left(\frac{\pi}{2}+\alpha\right)+\cos\left(\frac{\pi}{2}+\alpha-120\right)-\cos\left(\frac{\pi}{6}+\alpha-120\right)\right.\right.$$

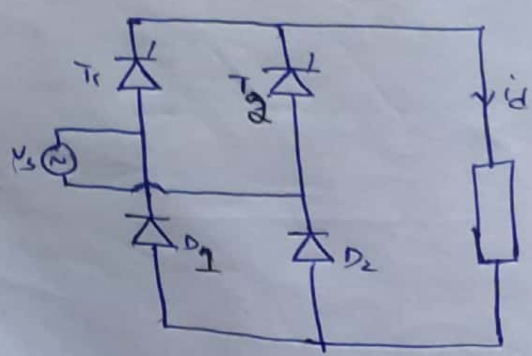
$$\left. - \omega L_s\int_0^{I_d} di_d\right]$$

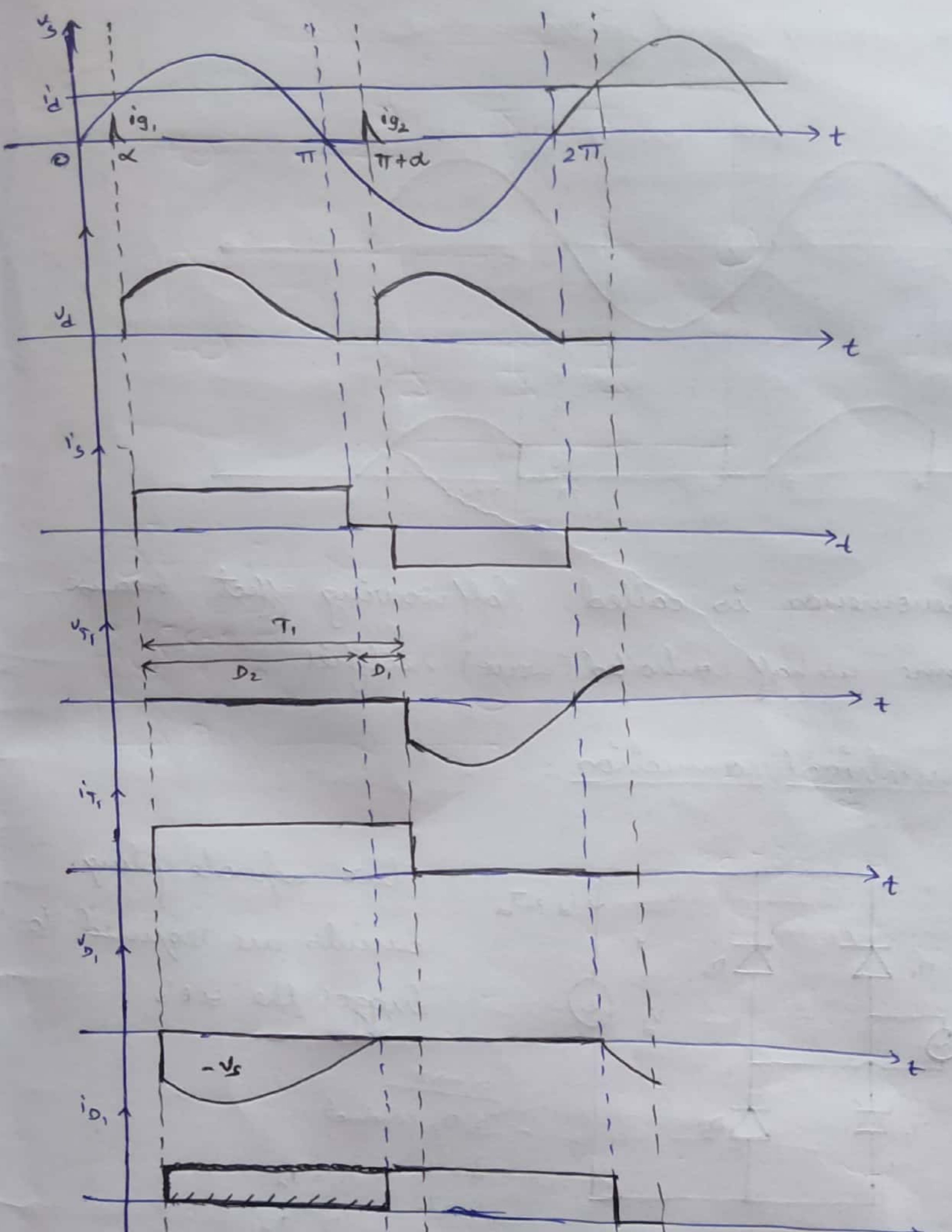
$$V_{avg} = \left[1.35V_{LL}\cos\alpha - \frac{3\omega L_s}{\pi}I_d\right]$$

* Single quadrant converters - Half controlled converters

① Symmetrical connection:

load current is constant 'I_d'





$\alpha \to \pi$

T_1, D_2 conduct

$v_d = v_s$

$i_s = +i_d$

$i_{T_1} = i_d,\ i_{T_2} = 0, i_{D_1} = 0$

$i_{D_2} = i_d$

$\pi \to \pi + \alpha$

T_1, D_1 conduct

$v_d = 0$

$i_s = 0$

$v_{T_1} = 0$

$i_{T_1} = i_D$

$v_{D_1} = 0$

$i_{D_1} = i_D$

$\pi + \alpha \to 2\pi$

T_2, D_1 conduct

$v_d = -v_s$

$i_s = -i_d$

$v_{T_1} = v_s$

$i_{T_1} = 0$

$v_{D_1} = 0$

$i_{D_1} = i_D$

$2\pi \to 2\pi + \alpha$

T_2, D_2 conduct

$v_d = 0$

$i_s = 0$

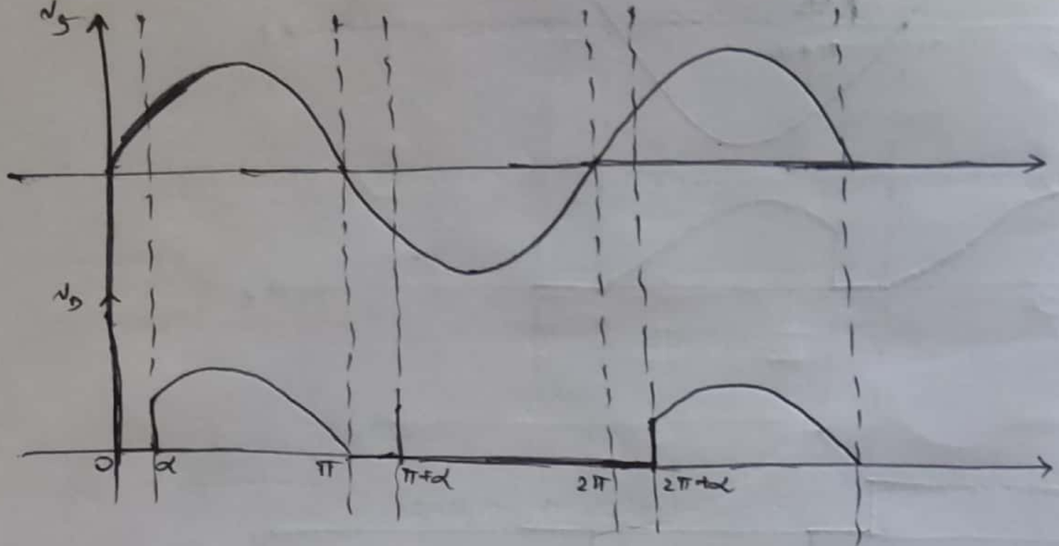
$v_{T_1} = v_s$

$i_{T_1} = 0$

$v_{D_1} = v_s$

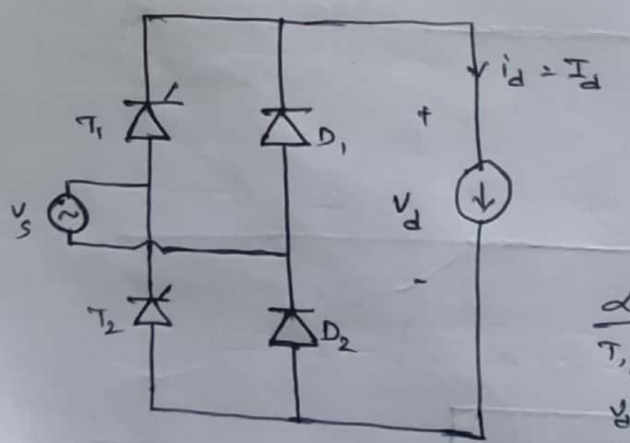
$i_{D_1} = 0$

* If i_{g_2} is missing or not given



This phenomenon is called Half waving effect, because it is same as half controlled (wave) rectifier

② <u>Assymmetrical</u> <u>connection</u> :



two seperate gating circuits are required to trigger the SCR's

<u>$\alpha \rightarrow \pi$</u>

T_1, D_2 conduct

$v_d = v_s$

$i_s = I_d$

$i_{T_1} = I_d$

$i_{D_2} = I_d$

<u>$\pi \rightarrow \pi + \alpha$</u>

D_1, D_2 conduct

$v_d = 0$

$i_s = 0$

$i_{T_1} = 0$

<u>$\pi + \alpha \rightarrow 2\pi$</u>

T_2, D_1 conduct

$v_d = -v_s$

$i_s = -I_d$

$i_{T_1} = 0$

$i_{D_2} = 0$

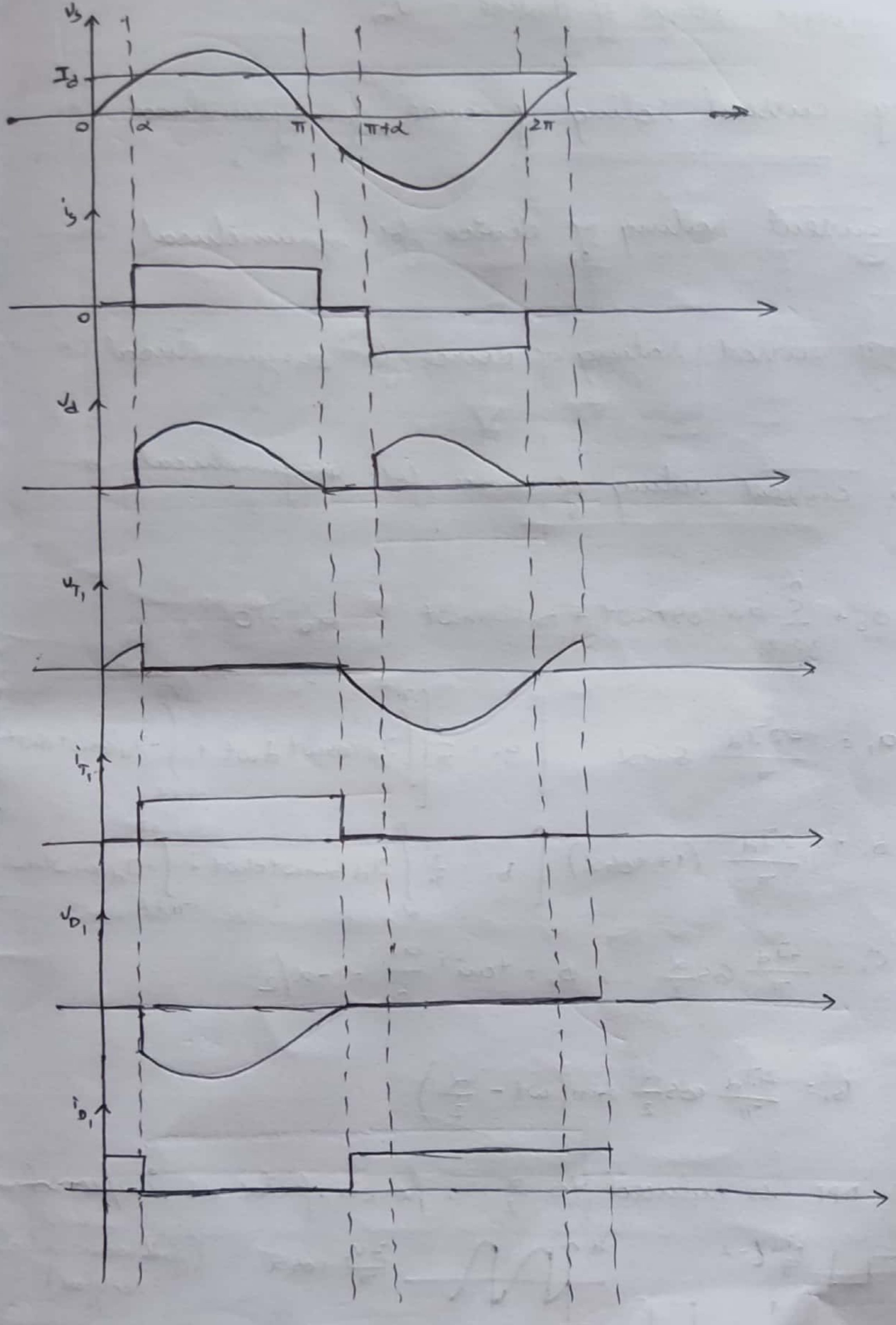
<u>$2\pi \rightarrow 2\pi + \alpha$</u>

D_1, D_2 conduct

$v_d = 0$

$i_s = 0$

$i_{T_1} = 0$



*DC side:

* Average load voltage, $V_{davg} = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \, d\omega t$

$$= \frac{\sqrt{2}V_s}{\pi}\left[1 + \cos\alpha\right]$$

* Average power through the converter

$$P = V_{davg} I_d = \frac{\sqrt{2}V_s I_d}{\pi}\left[1 + \cos\alpha\right]$$

* peak inverse voltage of device = V_m

* Average current rating of device for symmetrical con =

* RMS current rating of device for symmetrical con =

* Average current rating of device for assymmetrical con =

* RMS current rating of device for assymmetrical con =

* $i_s(t) = a_0 + \sum_{1,2,3,\dots}^{n} a_n \cos n\omega t + b_n \sin n\omega t \quad , \quad a_0 = 0$

$$a_1 = \frac{-2I_d}{\pi}\sin\alpha \qquad \left[a_1 = \frac{1}{\pi}\left[\int_{\alpha}^{\pi} I_d \cos\omega t \, d\omega t + \int_{\pi+\alpha}^{2\pi} -I_d \cos\omega t \, d\omega t\right]\right]$$

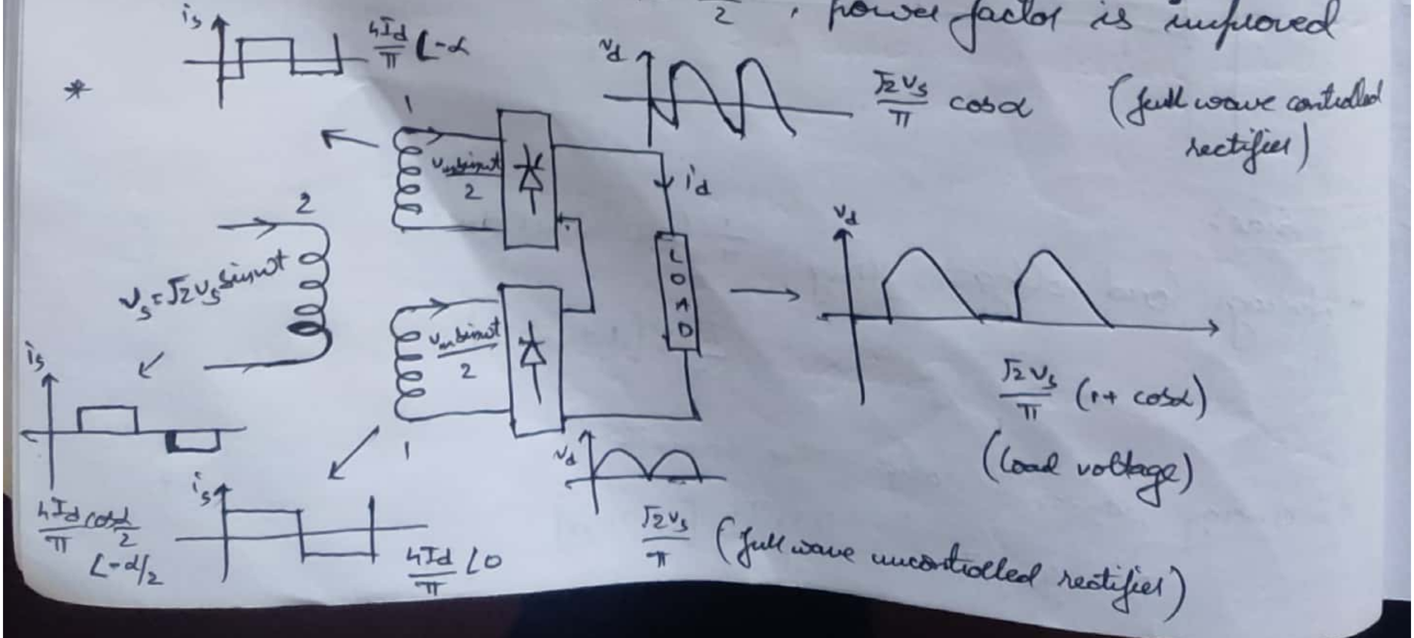
$$b_1 = \frac{2I_d}{\pi}(1+\cos\alpha) \qquad \left[b_1 = \frac{1}{\pi}\int_{\alpha}^{\pi} I_d \sin\omega t \, d\omega t + \int_{\pi+\alpha}^{2\pi} -I_d \sin\omega t \, d\omega t\right]$$

$$C_1 = \frac{4I_d}{\pi}\cos\frac{\alpha}{2} \quad , \quad \phi_1 = \tan^{-1}\frac{a_1}{b_1} = -\alpha/2$$

$$i_{s_1} = \frac{4I_d}{\pi}\cos\frac{\alpha}{2}\sin\left(\omega t - \frac{\alpha}{2}\right)$$

As DPF is reduced to $\frac{\alpha}{2}$, power factor is improved

*



* If full wave controlled rectifier & full wave uncontrolled rectifier are connected in series so o/p voltage will be sum of both

* $$i_s = \frac{4I_d}{\pi}(\cos\alpha - j\sin\alpha) + \frac{4I_d}{\pi}\cos 0$$

$$i_s = \frac{4I_d}{\pi}(\cos\alpha + \cos 0) - j\frac{4I_d}{\pi}\sin\alpha$$

$$\cancel{i_s = \frac{4I_d}{\pi}\left(2\cos\frac{\alpha}{2}\cos\frac{\alpha}{2}\right) - j\frac{4I_d}{\pi}\sin\alpha}$$

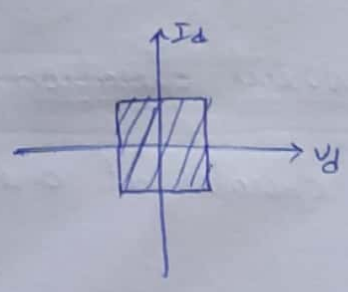
$$i_s = \frac{4I_d}{\pi}\cos\frac{\alpha}{2}\angle -\alpha/2$$

* Uncontrolled & Half controlled $\longrightarrow$ (1^{st} quadrant)
* Controlled rectifiers (1^{st} & 4^{th} quadrant)

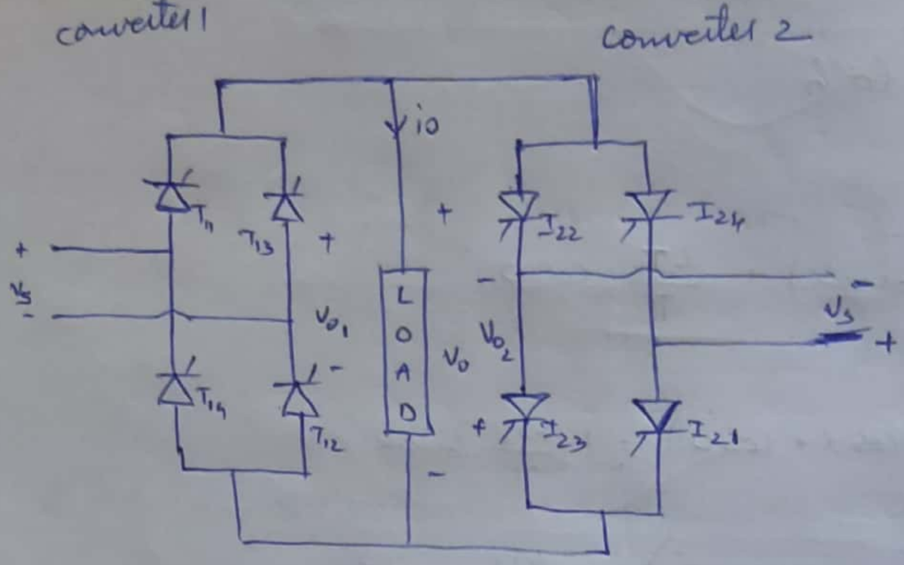
* Four Quadrant Converters:

Two converters are connected back - back (full controlled)

– Dual converters



* Single phase Dual converters:



* when triggering angle, $\alpha_1 < 90$, v_{01} is +ve, v_0 is positive

$\alpha_1 > 90$, v_{01} is -ve, v_0 is negative

$\alpha_2 < 90$, v_{02} is +ve, v_0 is negative

$\alpha_2 > 90$, v_{02} is -ve, v_0 is positive

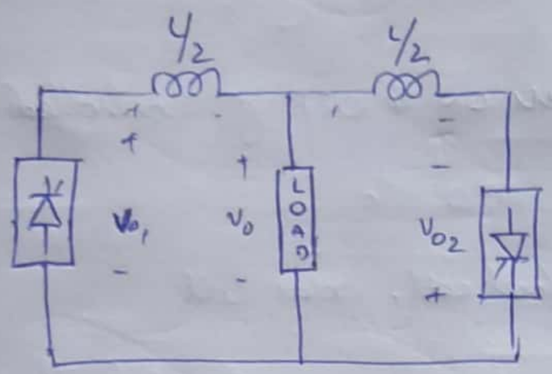
* Each converter has the ability to conduct current in one direction only
* So load current is bidirectional

① Non-circulating current operation:

* Only one converter operates at one time and carries entire load current
* +ve current → converter 1 is ON
* -ve current → converter 2 is ON
* No current limiting reactor is required because only one converter is ON at a time
* slow & sluggish

② Circulating current operation:

* Average voltages of both converters are equal.
* All the devices are ON (can give gate pulse to any device)



* Instantaneous voltages are different
* This leads to circulating current between the 2 converters
* A reactor is inserted in between the converters to limit this current within limits.

→ Average o/p voltages:

$$V_{o1} = V_{om}\cos\alpha_1 = \frac{2\sqrt{2}V_s}{\pi}\cos\alpha_1$$

$$V_{o2} = V_{om}\cos\alpha_2 = \frac{2\sqrt{2}V_s}{\pi}\cos\alpha_2$$

$$V_{o1} = -V_{o2} = V_o$$

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

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

* At any instant one converter operates as rectifier while the other one operates as inverter
* To reverse the current, roles of converter are interchanged
* Response is very fast

Drawbacks:

* A reactor is needed
* losses are more, less efficiency, low power factor.
* Devices are rated for high value to accomodate circulating currents