Unit - II.

PHASE CONTROLLED RECTIFIERS.

CONVERTER:-

It is a circuit which converts the nature of energy namely from ac to dc (or) from dc to ac.

It has two modes.

(i) Rectifier:- It is a circuit which converts ac to dc.

(ii) Inverter:- It is a circuit which converts dc to ac.

Rectifiers are classified as:-

a) Uncontrolled Rectifier

b) Fully controlled Rectifier.

c) Half controlled rectifier

i) Uncontrolled rectifier:-

* Uses only diodes. Diodes cannot be controlled.
* amplitude of output voltage cannot be varied and it is fixed by the amplitude of supply voltage.

) Fully controlled rectifier:-

* Uses only SCRs.
* Output voltage is dependant on supply voltage and firing angle. SCRs can be controlled easily.

) Half controlled rectifier.

* Uses combination of diodes and SCRs.
* Only limited control over output voltage.

Phase control:-

The method of controlling the turning "ON" of an SCR by varying its firing angle is called as phase control.

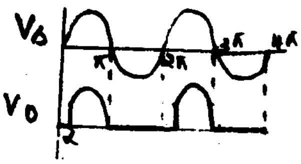
Firing angle (α):-

It is the angle at which the SCR is turned ON.

classification:-

Phase controlled Rectifiers.

- Single-phase.
  - Half wave
  - Full wave.
    - Semi-controlled (or) Half controlled.
    - Fully controlled
- Three-phase.
  - Half wave
  - Full wave.
    - Semi-controlled (or) Half controlled
    - Fully controlled.

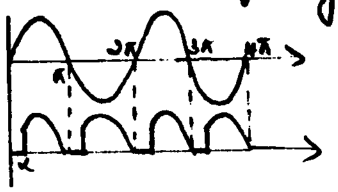


Half wave rectifier:-

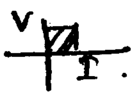
* when positive half cycle of supply voltage alone is applied to the load, it is called as half-wave converter.

Full wave rectifier:-

* when both half cycles are applied to load after rectifying

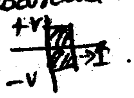


Half controlled (or) Semicontrolled rectifier:-



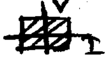
* circuit has combination of SCRs and diodes.
* due to presence of diode control is effected only for positive o/p vge. o/p vge ∴ cannot be negative. Can be operated only in first quadrant.

Fully controlled rectifier:- * Uses only SCRS. * o/p current is always +ve.
* o/p vge can be positive or negative. Operated in I and IV quadrant



ual converter (or) Four quadrant converter:-

* operates on all 4 quadrants * o/p vge and crnt can be either +ve or -ve



Principle of phase control:-

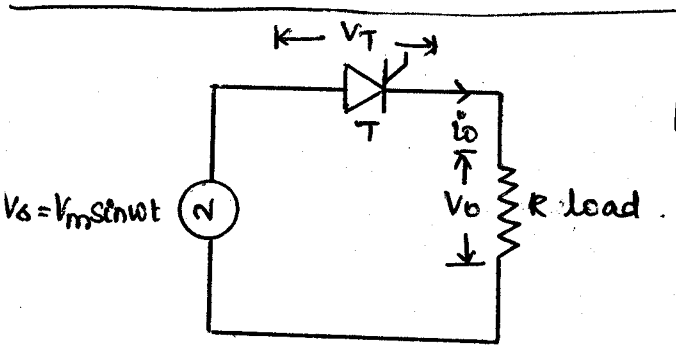
The principle of phase control can be explained by means of a 1ϕ Half wave rectifier.

In phase control the SCRs are turned OFF by line or natural commutation. ∴ they do not need external commutation circuits.

NOTE:-
In this discussion, SCRs and diodes are assumed as ideal switches.

* No vge drop across them.
* No reverse current under reverse bias condition.
* Holding current is zero.

1ϕ HALF WAVE RECTIFIER (HWR) WITH RESISTIVE (R) LOAD:-



[NOTE:-
* SCR is forward biased when anode of SCR is +ve w.r.t cathode.
* SCR can be triggered only when it is in forward biased condition.
* when SCR is turned ON, Vge across SCR = 0 and current = ↑ing.
* when SCR is turned OFF, Vge across SCR = supply vge and current = 0.]

The SCR T is supplied with an ac voltage given by

$V_s = V_m \sin \omega t$.

i_0 = load current; V_0 = load Vge.

V_T = Vge across SCR.

In the positive half cycle:-

* Anode of SCR is +ve w.r.t. cathode
* SCR T is forward biased.
* SCR is triggered or turned ON at $\omega t = \alpha$.

∴ from 0 to α

SCR T is OFF

∴ $V_T = V_s$

$i_T = 0$

* At α SCR T is ON

∴ $V_T = 0$ [when SCR is ON vge across it is zero)

$i_0 = i_T = \uparrow$

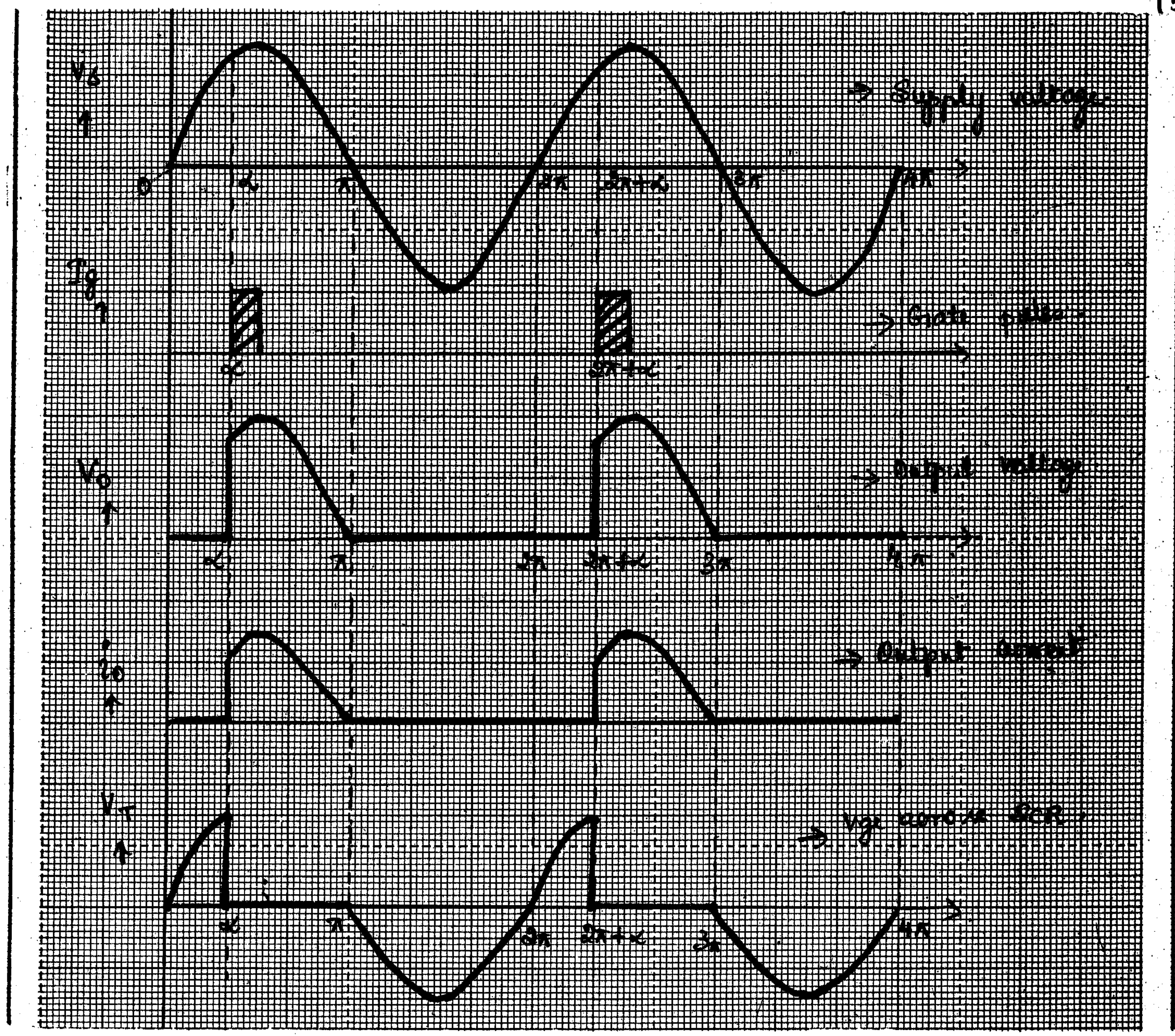
* In the negative half cycle:

* At $\omega t = \pi$; anode of SCR is -ve w.r.t. cathode.
* ∴ SCR T is reverse biased and turned OFF (by line commutation)

∴ $V_0 = 0$; $i_0 = 0$; $V_T = V_s$.

In this SCR conducts only in +ve half cycle.

Period	V_0	i_0	i_T	V_T
0 to α	0	0	0	V_s
α to π	follows V_s	+ve current	+ve curnt	0
π to $\pi+\alpha$	0	0	0	V_s
$\pi+\alpha$ to 2π	follows V_s	+ve	+ve.	0



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

$$= \frac{V_m}{2\pi}\left[-\cos\omega t\right]_{\alpha}^{\pi}$$

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

$$= \frac{-V_m}{2\pi}\left[-1 - \cos\alpha\right]$$

$$\boxed{V_o(avg) = \frac{V_m}{2\pi}\left[1+\cos\alpha\right]}$$

$$V_{o(rms)} = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \cdot d\omega t}$$

$$= \sqrt{\frac{V_m^2}{2\pi}\int_{\alpha}^{\pi} \sin^2\omega t \cdot d\omega t}$$

$$= \sqrt{\frac{V_m^2}{2\pi}\int_{\alpha}^{\pi} \frac{(1-\cos 2\omega t)}{2}\, d\omega t}$$

$$= \sqrt{\frac{V_m^2}{4\pi}\left\{\left[\omega t\right]_{\alpha}^{\pi} - \left[\frac{\sin 2\omega t}{2}\right]_{\alpha}^{\pi}\right\}}$$

$$= \sqrt{\frac{V_m^2}{4\pi}\left\{\left[\pi - \alpha\right] - \frac{1}{2}\left[\sin 2\pi - \sin 2\alpha\right]\right\}}$$

$\sin 2\pi = 0$

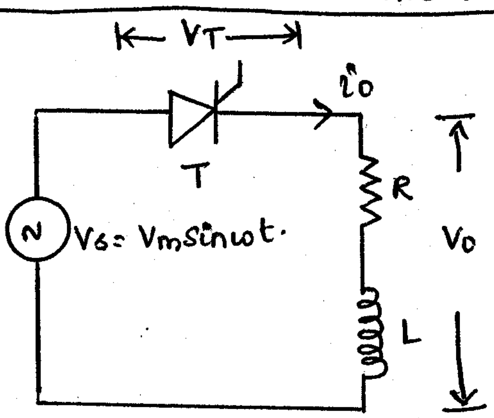
$$\boxed{V_{o(rms)} = \frac{V_m}{2\sqrt{\pi}}\sqrt{(\pi-\alpha) + \frac{1}{2}\sin 2\alpha}}$$

$$I_{o(avg)} = \frac{V_{o(avg)}}{R} = \frac{V_m}{2\pi R}\left[1+\cos\alpha\right]$$

$$I_{o(rms)} = \frac{V_m}{2R\sqrt{\pi}}\sqrt{(\pi-\alpha) + \frac{1}{2}\sin 2\alpha}$$

$$\text{Power} = P = V_{orms} * I_{orms}$$

1φ HALF WAVE CIRCUIT WITH RL load :-



During positive half cycle.

* The SCR T is forward biased.
* At $\omega t = \alpha$; triggering pulse is given to SCR T.

* From 0 to α; SCR T is forward biased.

∴ Vge across SCR $V_T = V_s$.

* current $i_T = i_0 = 0$.
* Vge across load $V_o = 0$.

At $\omega t = \alpha$ when SCR T is ON

* $V_T = 0$

  $V_o = V_s$

  i_o = ↑ing slowly due to inductance L.

But because the load has an inductance L the current increases very slowly and reaches its maximum at $\omega t = \pi$.

∴ At $\omega t = \pi$; $V_o = 0$; $i_o = i_{max}$.

During -ve half cycle:-

* during -ve half cycle at $\omega t = \pi$, though load voltage is zero and though the SCR T is reverse biased, it will not turn OFF because i_o is not less than holding current.

* i_o takes some time (β) to reduce to zero.

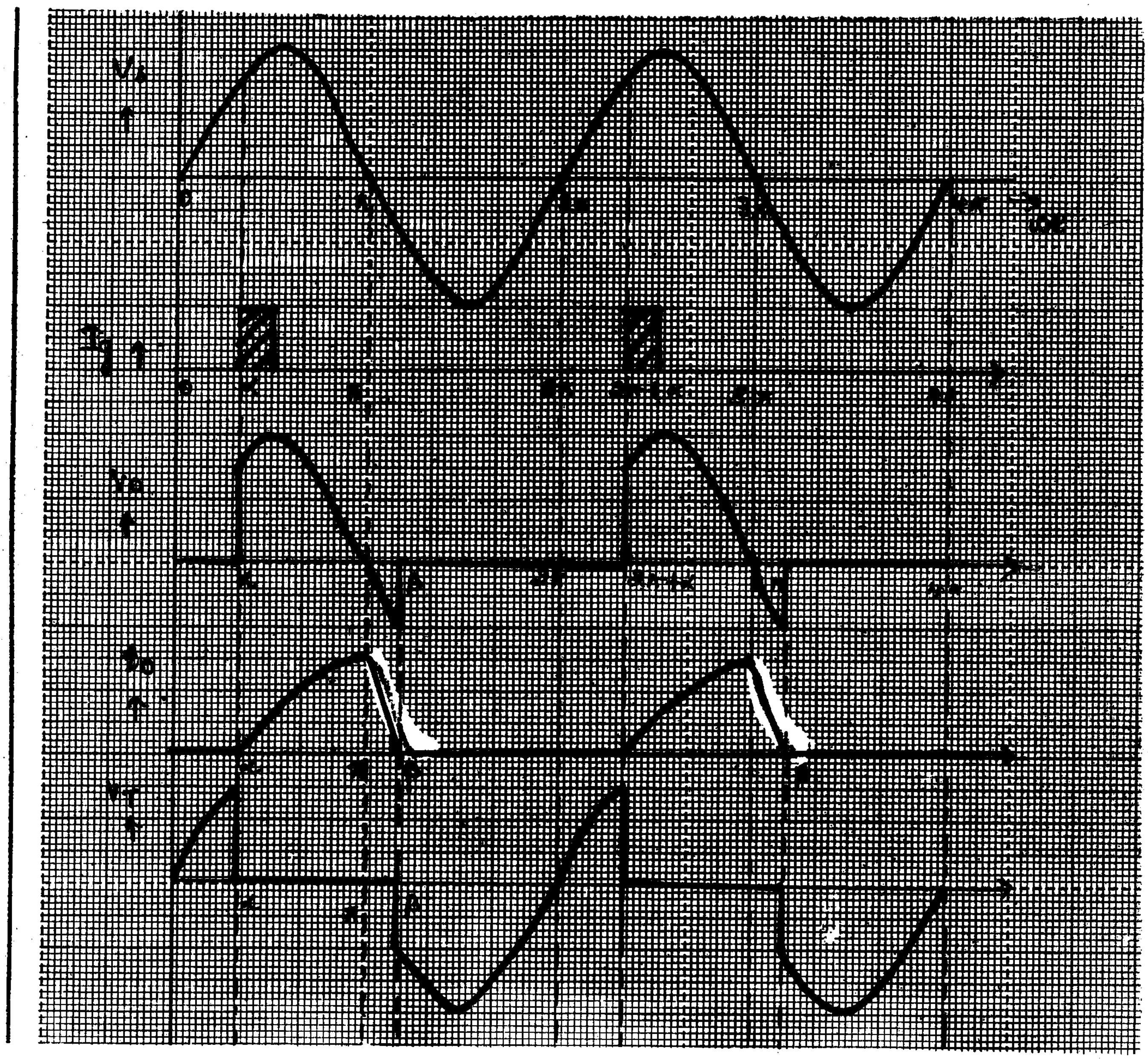
∴ at $\omega t = \beta$; $V_o = 0$, $i_o = 0$.

* From π to $\pi + \beta$ the Vge across SCR will be -ve like the supply vge. (∵ it is reverse biased).

* Again at $\omega t = 2\pi + \alpha$, SCR T is turned ON. and the same process at above is repeated.

* α is called firing angle.
* β is called extinction angle.
* $(\beta - \alpha) = \gamma$ is called conduction angle.

Period	V_0	i_0	V_T
0 to α	0	0	V_s
α to π	V_s	increase slowly	0
π to β	$-V_s$	decreases to zero	0
β to 2π	0	0	$-V_s$



Average value of load voltage $V_{o(avg)} = \frac{1}{2\pi}\int_{\alpha}^{\beta} V_m \sin\omega t \cdot d\omega t$.

$$V_{o(avg)} = \frac{V_m}{2\pi}\int_{\alpha}^{\beta} \sin\omega t \cdot d\omega t$$

$$= \frac{V_m}{2\pi}\left[-\cos\omega t\right]_{\alpha}^{\beta} = \frac{-V_m}{2\pi}\left[\cos\beta - \cos\alpha\right]$$

$$\boxed{V_{o(avg)} = \frac{V_m}{2\pi}\left[\cos\alpha - \cos\beta\right]}$$

$$I_{o(avg)} = \frac{V_{o(avg)}}{R} = \boxed{\frac{V_m}{2\pi R}\left[\cos\alpha - \cos\beta\right]}$$

Rms value :- $V_{o(rms)} = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\beta} V_m^2 \sin^2\omega t \cdot d\omega t}$.

$$= \sqrt{\frac{V_m^2}{2\pi}\int_{\alpha}^{\beta}\left[\left(\frac{1-\cos 2\omega t}{2}\right)\right] d\omega t}$$

$$= \sqrt{\frac{V_m^2}{4\pi}\left\{\left[\omega t\right]_{\alpha}^{\beta} - \left[\frac{\sin 2\omega t}{2}\right]_{\alpha}^{\beta}\right\}}$$

$$\boxed{V_{orms} = \frac{V_m}{2\sqrt{\pi}}\sqrt{\left[\beta-\alpha\right] - \frac{1}{2}\left[\sin 2\beta - \sin 2\alpha\right]}}$$

$$I_{o(rms)} = \frac{V_{orms}}{R} = \frac{V_m}{2R\sqrt{\pi}}\sqrt{\left[\beta-\alpha\right] - \frac{1}{2}\left[\sin 2\beta - \sin 2\alpha\right]}.$$

$$\boxed{P = V_{orms} * I_{orms}}$$

1φ HALF WAVE RECTIFIER WITH RL LOAD & FREEWHEELING DIODE.

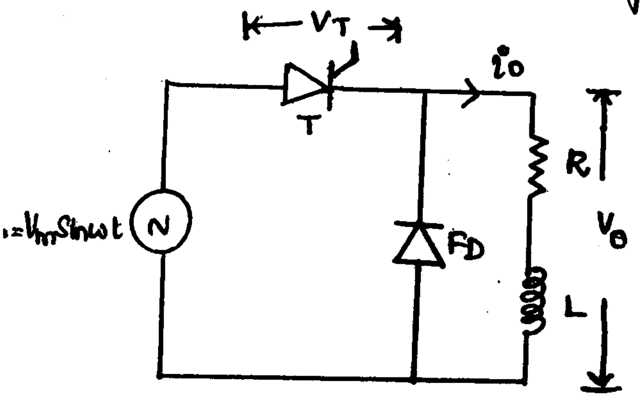
* The waveform of load current i_0 is improved by connecting a freewheeling diode (F_D). across the load.

* FD is also called as flywheel diode or commutating diode.

* It is used to prevent the reversal of load voltage.

Advantages of freewheeling diode:-

* Improves input power factor angle.
* Improves load current waveform.
* Better load performance.



In the positive half cycle.

* SCR T is forward biased.
* freewheeling diode is reverse biased.

$\therefore V_T = V_s$; V_{FD} = vge across FD = $-V_s$.

* At $\omega t = \alpha$; SCR T_1 is ON.

$\therefore V_{T_1} = 0$, i_{T_1} = slowly increases towards max value.

$V_0 = V_s$. , $i_0 = i_{T_1}$ = ↑es slowly.

In the negative half cycle:-

Supply vge $V_s = 0$.

At $\omega t = \pi$; freewheeling diode is forward biased.

SCRT is reverse biased and turns OFF.

The load current i_0 decays through diode FD.

* The freewheeling diode conducts till the SCR is turned ON again at $(2\pi+\alpha)$

The operation can be explained in two modes.

(i) Conduction mode (from α to π, $2\pi+\alpha$ to 3π]

In this mode the SCR conducts (ON) and the freewheeling diode is reverse biased.

$\therefore$ $V_T = 0$; $V_{FD} = -V_s$. $i_0 = \uparrow^{es}$ slowly.

(ii) Freewheeling mode:- [from π to $2\pi+\alpha$; 3π to $4\pi+\alpha$]

In this mode SCR is reverse biased from π to 2π ; 3π to 4π and diode (FD) conducts (Forward biased) from π to $2\pi+\alpha$ and 3π to $4\pi+\alpha$.

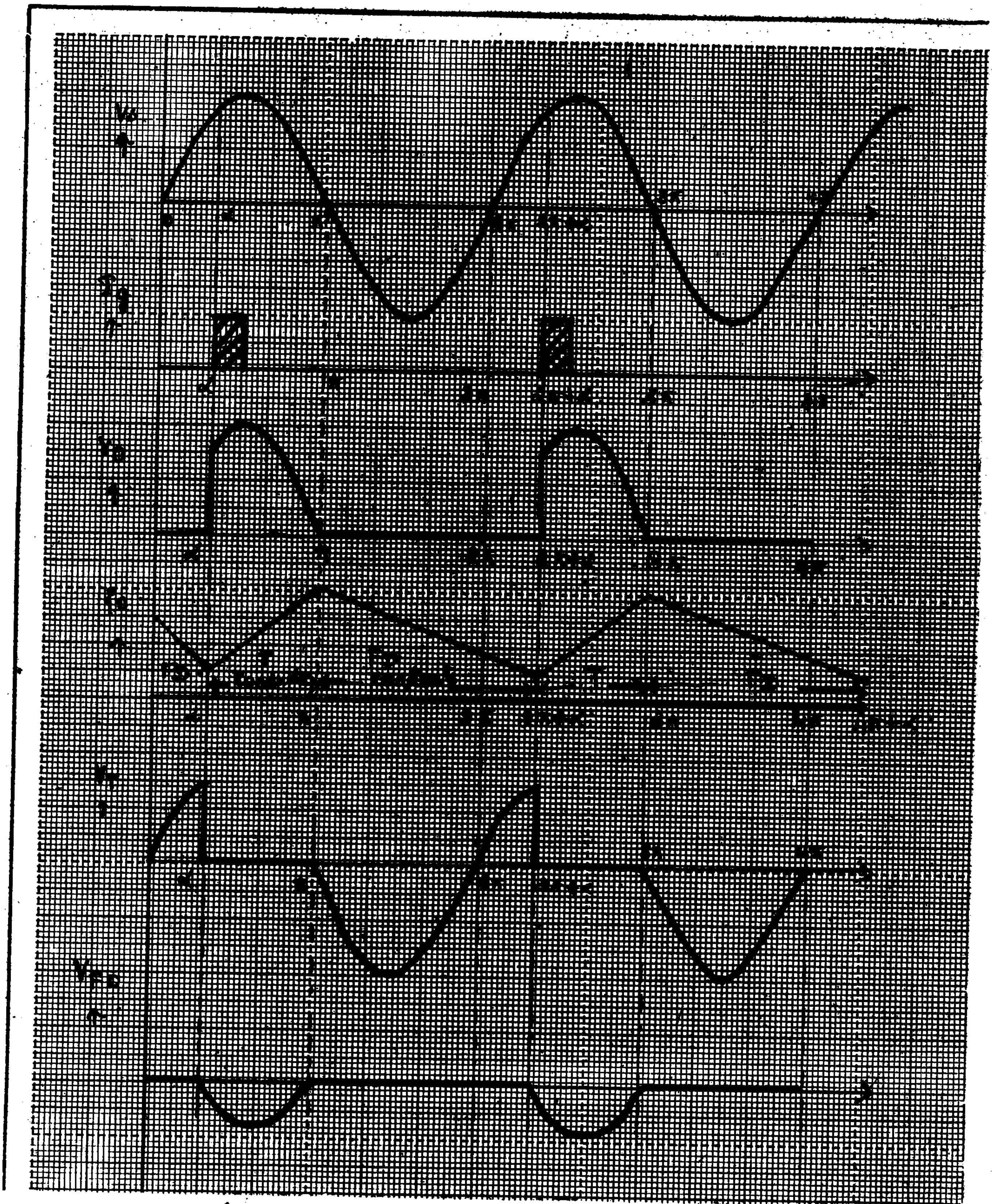
$V_T = -V_s$ (from π to 2π) ; $V_T = V_s$ (2π to $2\pi+\alpha$)

$V_{FD} = 0$ (3π to 4π) ; $V_{FD} = 0$ (2π to $2\pi+\alpha$)

$V_0 = 0$; $V_0 = 0$.

Freewheeling diode will be ON till, the SCR is turned ON again.

Period.	V_0	i_0	V_T	V_{FD}.
0 to α	0	0	V_s	$-$ve Vge
α to π	+ve Vge	increasing	0	$-$ve.
π to 2π	0	decreasing	$-V_s$	0
to $2\pi+\alpha$	0	decreasing	$+V_s$	0
$2\pi+\alpha$ to 3π	+ve	increasing	0	$-$ve.



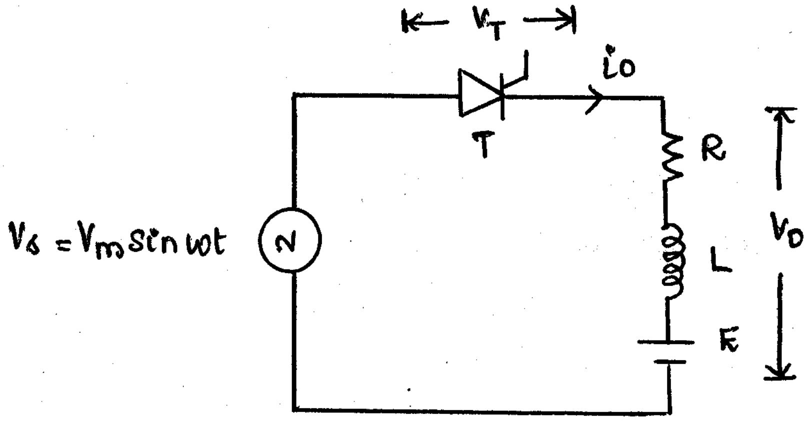
$v_0(avg) = \frac{1}{2\pi}\int_{\alpha}^{\pi} v_m \sin\omega t \, d\omega t = \frac{V_m}{2\pi}(1+\cos\alpha)$ [already derived]

$I_0 = \frac{V_0(avg)}{R} = \frac{V_m}{2\pi R}[1+\cos\alpha]$

$V_0(rms) = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \, d\omega t} = \frac{V_m}{2\sqrt{\pi}}\sqrt{\left[\pi-\alpha+\frac{1}{2}\sin 2\alpha\right]}$

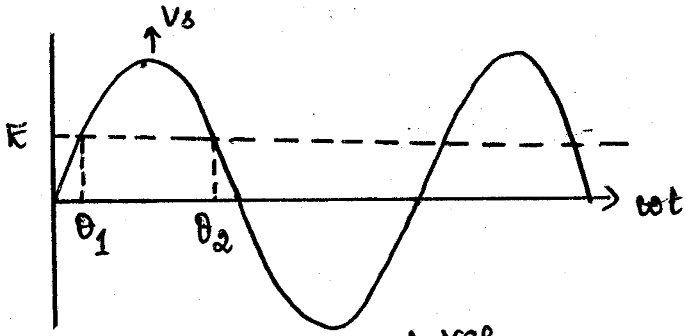
$I_0(rms) = \frac{V_m}{} \sqrt{[\pi-\alpha]+\frac{1}{2}\sin 2\alpha}$.

1ϕ HALF WAVE CIRCUIT WITH RLE LOAD:-



* $V_s = V_m \sin \omega t$ = supply vge.
* E = emf of load (motor) connected.
* ∴ Vge across SCR = V_T.

$$\boxed{V_T = V_s - E}$$



* Till $\omega t = \theta_1$; V_s is less than E
  when $V_s < E$
  $V_T = V_s - E = -$ve value.

* when a −ve value of vge is applied across an SCR, it is reverse biased and cannot be turned ON.
* SCR can be triggered only after θ_1 ie $\alpha > \theta_1$. Because only after θ_1; V_s is $> E$ and so $V_T = V_s - E$ is +ve value and SCR will be forward biased.

$$\theta_1 = \sin^{-1}\left[\frac{E}{V_m}\right]$$

* Also after an angle θ_2, V_s is $< E$ and so $V_T = V_s - E = -$ve value
So SCR cannot be triggered after θ_2. $[\theta_2 = \pi - \theta_1]$

$$\therefore \theta_1 < \alpha < \theta_2.$$

<u>During +ve half cycle:</u>

* SCR T is triggered at an angle "α": α is $> \theta_1$.
* from $\omega t = 0$ to α; SCR is OFF.
  $i_o = 0$ (load current).
  Vge across SCR = V_T.

till θ_1 ; V_S is $< E$ $\therefore$ V_T = $-$ve value

After θ_1 ; V_S is $> E$ $\therefore$ V_T = +ve value.

$$V_0 = i_0 R + E.$$

i_0 starts flowing only after SCR is ON.

$\therefore$ till $\omega t = \alpha$; $i_0 = 0$.

$\therefore$ From 0 to α.

$$V_0 = i_0 R + E = E \quad (\because i_0 = 0 \text{ till } \alpha).$$

$\therefore$ $V_0 = E$ (from 0 to α).

At α when SCR is turned ON, i_0 starts increasing.

$\therefore$ $V_0 = i_0 R + E$. [from α to π]

i_0 = increasing.

Vge across SCR = $V_T = 0$.

At $\omega t = \pi$ i_0 is maximum.

<u>In $-$ve half cycle:-</u>

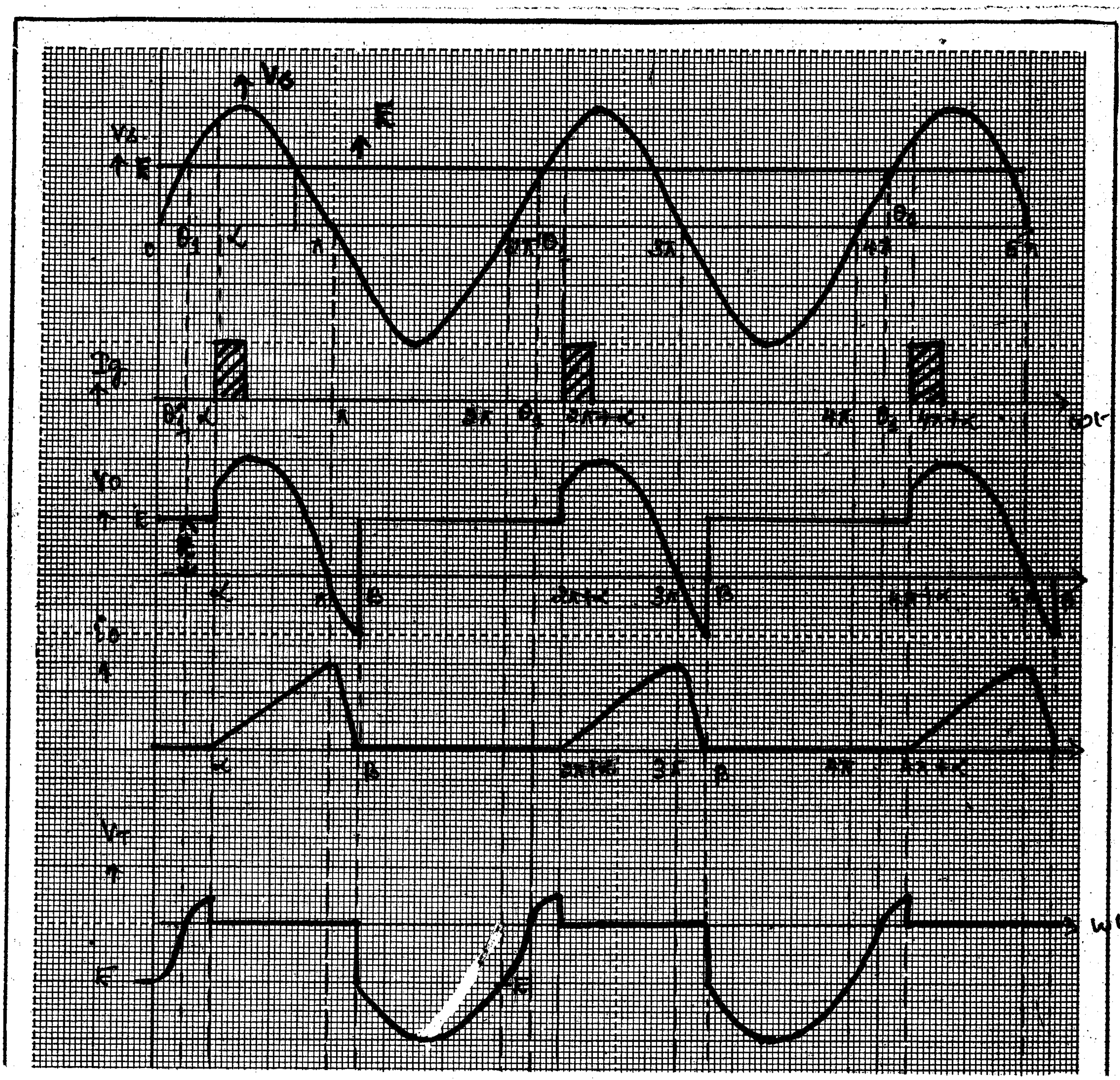
At $\omega t = \pi$; i_0 is maximum.

But the SCR 'T' is reverse biased, but it is not turned OFF because i_0 is $>$ than holding current.

$\therefore$ $V_0 = -V_S$ (Reverse vge).

i_0 decreases and reaches zero at $\omega t = \beta$. $\therefore$ SCR turns OFF at β.

$\therefore$ At $\omega t = \beta$; $V_0 = E$; $i_0 = 0$, $V_{T_1} = -V_S$.



$$V_0 = i_0 R + E$$

$$i_0 = \frac{V_0 - E}{R}$$

$$\therefore I_0 = \frac{1}{2\pi R}\int_{\alpha}^{\beta} (V_m \sin\omega t - E)\, d\omega t.$$

$$I_0 = \frac{1}{2\pi R}\left\{ \left[- V_m \cos\omega t \right]_{\alpha}^{\beta} - \left[E\omega t \right]_{\alpha}^{\beta} \right\}$$

$$= \frac{-V_m}{2\pi R}\left[\cos\beta - \cos\alpha\right] - \frac{E}{2\pi R}\left[\beta - \alpha\right]$$

$$I_o = \frac{V_m}{2\pi R}\left[\cos\alpha - \cos\beta\right] - \frac{E}{2\pi R}\left[\beta - \alpha\right]$$

$$\gamma = \beta - \alpha \; ; \; \therefore \beta = \alpha + \gamma$$

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

W.K.T $\cos x - \cos y = 2\sin\frac{x+y}{2} \cdot \sin\frac{y-x}{2}$

$$I_o = \frac{1}{2\pi R}\left[V_m\left(2\sin\frac{(2\alpha+\gamma)}{2} \cdot \sin\frac{\gamma}{2}\right) - E.\gamma\right]$$

$$\boxed{I_o = \frac{1}{2\pi R}\left[2V_m \sin\left(\alpha+\frac{\gamma}{2}\right).\sin\frac{\gamma}{2} - E.\gamma\right]}$$

$$V_o = I_o R + E = \frac{1}{2\pi R} \times R \left[2V_m \sin\left(\alpha+\frac{\gamma}{2}\right).\sin\frac{\gamma}{2} - E.\gamma\right] + E$$

$$= \frac{2V_m}{2\pi} \sin\left(\alpha+\frac{\gamma}{2}\right).\sin\frac{\gamma}{2} - \frac{E.\gamma}{2\pi} + E$$

$$\boxed{V_o = V_m \sin\left(\alpha+\frac{\gamma}{2}\right).\sin\frac{\gamma}{2} + E\left(1 - \frac{\gamma}{2\pi}\right)}$$

1ϕ FULL WAVE RECTIFIER:-

They are classified as

a) Fully controlled full wave rectifier.

b) Half controlled full wave rectifier (or) Semiconverter.

a) Fully controlled full wave rectifier.

There are two type of Full wave rectifiers.

(i) Centre tapped (or) Midpoint type.

(ii) Bridge type.

Note:- (X)

* The centre-tap rectifier uses 2 SCRs while the bridge type uses 4 SCRs.

* Their output eqn and waveforms are the same.

* Only the no of SCRs conducting will change.

* During +ve half cycle.

In centre tap rectifier T_1 conducts

In bridge rectifier T_1, T_2 will conduct.

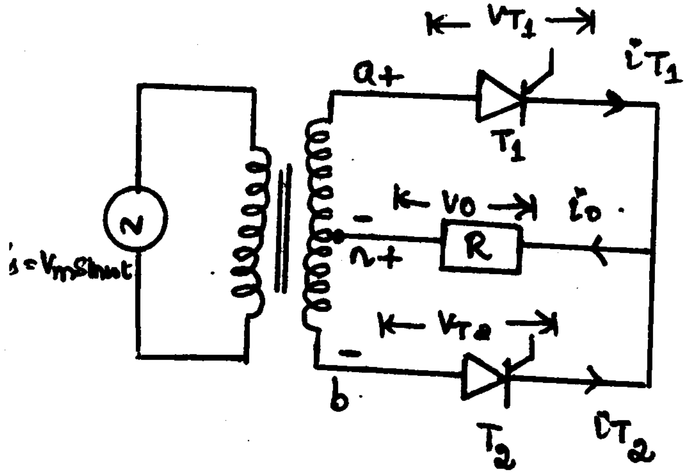
* During -ve half cycle.

In centre tap rectifier T_2 conducts

In bridge rectifier T_3, T_4 will conduct.

Since their eqns and waveforms are same they are explained on comparison.

<u>Centre-tap full wave rectifier with R load:-</u>
(or)
Midpoint



* $V_s = V_m \sin\omega t$ = input supply voltage.
* Centre tap transformer is used.
* n is the midpoint of centre tap transformer.
* In +ve half cycle terminal 'a' is +ve w.r.t n and terminal 'b' is −ve w.r.t n.

$\therefore V_{an} = V_{nb}$ $\qquad V_{nb} = -V_{bn}$.

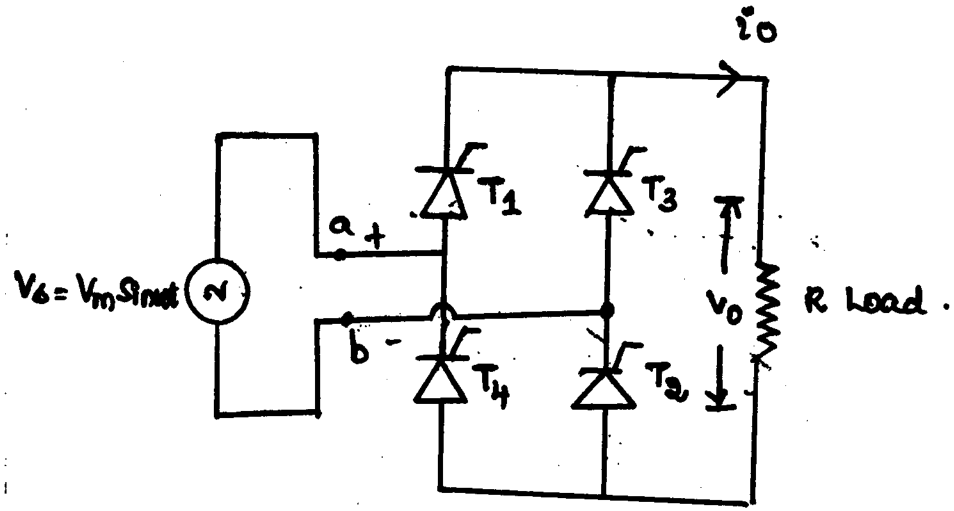
(or)

$V_{an} = -V_{bn}$.

V_{an} supplies SCR T_1

V_{bn} supplies SCR T_2.

<u>Full wave bridge rectifier with R load:-</u>



* $V_s = V_m \sin\omega t$ = Supply voltage.
* Four SCRs T_1, T_2, T_3, T_4 are used.
* In +ve half cycle terminal 'a' is +ve w.r.t. terminal 'b'.

ie, $V_{ab} = +V_m \sin\omega t$ $\qquad V_{ba} = -V_{ab}$

$V_{ba} = -V_m \sin\omega t$.

* V_{ab} supplies SCRs T_1, T_2.
* V_{ba} supplies SCRs T_3, T_4.

Centre-tap rectifier:-

Working :-

Positive half cycle:-

* In +ve half cycle terminal 'a' is +ve w.r.t to terminal 'b'
* terminal a is +ve.
* terminal b is -ve.
* $V_{an} = +V_m \sin \omega t$.
* $V_{bn} = -V_m \sin \omega t$.
* V_{an} gives supply to SCR T_1. ∴ SCR T_1 is forward biased by vge V_{an}.
* V_{bn} gives supply to SCR T_2. ∴ SCR T_2 is reverse biased by -ve vge V_{bn}.
* Only the forward biased SCR can be turned ON. ∴ SCR T_1 is turned ON at $\omega t = \alpha$.

From $\omega t = 0$ to α

SCR T_1 is forward biased	T_2 is reverse biased.
∴ vge across $T_1 = V_{T_1} = V_{an}$ $i_{T_1} = 0$ (∵ not conducting)	vge across $T_2 = V_{T_2} = V_{bn}$. $i_{T_2} = 0$ (not conducting)

$$\therefore i_0 = i_{T_1} + i_{T_2} = 0$$

$$\therefore V_0 = i_0 R = 0$$

Full wave bridge rectifier:-

Working :-

Positive half cycle:-

* In +ve half cycle terminal 'a' is +ve w.r.t 'b'
* a is +ve ; b is -ve.
* $V_{ab} = +V_m \sin \omega t$.
* $V_{ba} = -V_m \sin \omega t$.
* V_{ab} supplies SCR T_1 and T_2

So SCR T_1 & T_2 are forward biased in +ve cycle

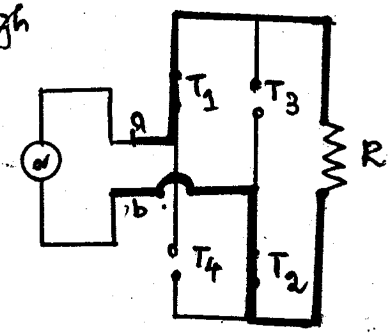
* V_{ba} supplies SCR T_3 & T_4.

∴ SCR T_3 and T_4 are reverse biased in +ve cycle.

SCR T_1, T_2 are turned ON at $\omega t = \alpha$.

∴ load current flows through

$$a - T_1 - R - T_2 - b$$



From $\omega t = 0$ to α.

T_1, T_2 are forward biased.

∴ $V_{T_1} = V_{T_2} = V_{ab}$

$i_{T_1} = i_{T_2} = 0$

T_3, T_4 are reverse biased

∴ $V_{T_3} = V_{T_4} = V_{ba}$

$i_{T_3} = i_4 = 0$

∴ $i_0 = V_0 = 0$

At $\omega t = \alpha$ SCR T_1 is turned ON.

$\therefore$ From $\omega t = \alpha$ to π

SCR T_1 remains ON.

$\therefore$ Vge across SCR $T_1 = V_{T_1} = 0$

current through $T_1 = i_{T_1} = \uparrow$ ing

T_2 is OFF

$\therefore V_{T_2} = V_{bn}$.

$i_{T_2} = 0$

$\therefore i_0 = i_{T_1} + i_{T_2} = i_{T_1}$

$\therefore V_0 = i_0 R = i_{T_1} * R$.

During -ve half cycle.

In -ve half cycle terminal a is -ve w.r.t. terminal b; ie $a = -ve$; $b = +ve$

$\therefore V_{an} = -V_m \sin \omega t$; $V_{bn} = +V_m \sin \omega t$.

$\because V_{an}$ is -ve at π, SCR T_1 is reverse biased due to -ve Vge V_{an} and is turned OFF at $\omega t = \pi$.

* But SCR T_2 is forward biased due to +ve Vge V_{bn}.

* SCR T_2 is triggered at an angle $\omega t = \pi + \alpha$.

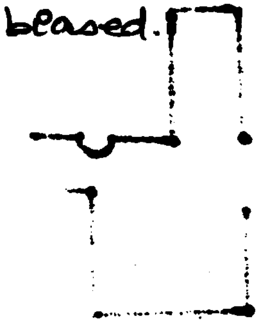
Full wave

At $\omega t = \alpha$; SCRs, T_1, T_2 are turned ON.

$\therefore$ From $\omega t = \alpha$ to π.

T_1, T_2 are ON

T_3, T_4 are OFF and reverse biased.



$\therefore V_{T_1} = V_{T_2} = 0$

$i_{T_1} = i_{T_2} = i_0 = \uparrow$ ing.

$V_0 = V_{ab} = i_0 R$.

$V_{T_3} = V_{T_4} = V_{ba}$.

$i_{T_3} = i_{T_4} = 0$.

During -ve half cycle:-

* In -ve half cycle terminal a is -ve w.r.t. b; $a = -ve$; $b = +ve$.

* $V_{ab} = -V_m \sin \omega t$; $V_{ba} = +V_m \sin \omega t$.

$\because V_{ab} = -ve$ at $\omega t = \pi$; SCR T_1, T_2 are turned OFF at $\omega t = \pi$ due to -ve vge.

$\therefore$ But since V_{ba} is +ve; SCR T_3, T_4 are forward biased.

* SCR T_3, T_4 are turned ON at $\omega t = \pi + \alpha$.

centre tap rectifier.

from $\omega t = \pi$ to $\pi + \alpha$.

T_1 is OFF at $\omega t = \pi$

$\therefore \quad V_{T_1} = V_{an}$

$i_{T_1} = 0.$

T_2 is forward biased at $\omega t = \pi$

$\therefore \quad V_{T_2} = V_{bn}.$

$i_{T_2} = 0$

$\therefore \quad i_0 = i_{T_1} + i_{T_2} = 0$

$V_0 = i_0 R = 0$

From $\omega t = \pi + \alpha$ to 2π.

at $\pi + \alpha$, SCR T_2 is turned ON

$\therefore \quad V_{T_2} = 0.$

$i_{T_2} =$ increasing $\uparrow$

T_1 is OFF, $\therefore \quad V_{T_1} = V_{an}$

$i_{T_1} = 0$

$\therefore \quad i_0 = i_{T_1} + i_{T_2} = i_{T_2}.$

$V_0 = i_0 R = i_{T_2} * R.$

full wave bridge ...

from $\omega t = \pi$ to $\pi + \alpha$

T_1, T_2 are turned OFF at $\omega t = \pi$

$\therefore \quad V_{T_1} = V_{T_2} = V_{ab}$

$i_{T_1} = i_{T_2} = 0$

T_3, T_4 are forward biased at $\omega t = \pi$

$\therefore \quad V_{T_3} = V_{T_4} = V_{ba}.$

$i_{T_3} = i_{T_4} = 0$

$i_0 = 0$

$V_0 = 0.$

From $\omega t = \pi + \alpha$ to 2π.

at $\pi + \alpha$, SCR T_3, T_4 is turned ON.

$\therefore V_{T_3} = V_{T_4} = 0.$ $\quad$ $T_1, T_2 = $ OFF

$\quad$ $V_{T_1} = V_{T_2} = V_{ab}$

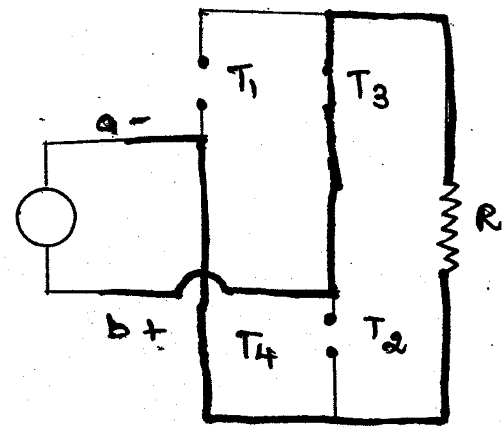
$i_{T_3} = i_{T_4} = \uparrow$ $\quad$ $i_{T_1} = i_{T_2} = 0.$

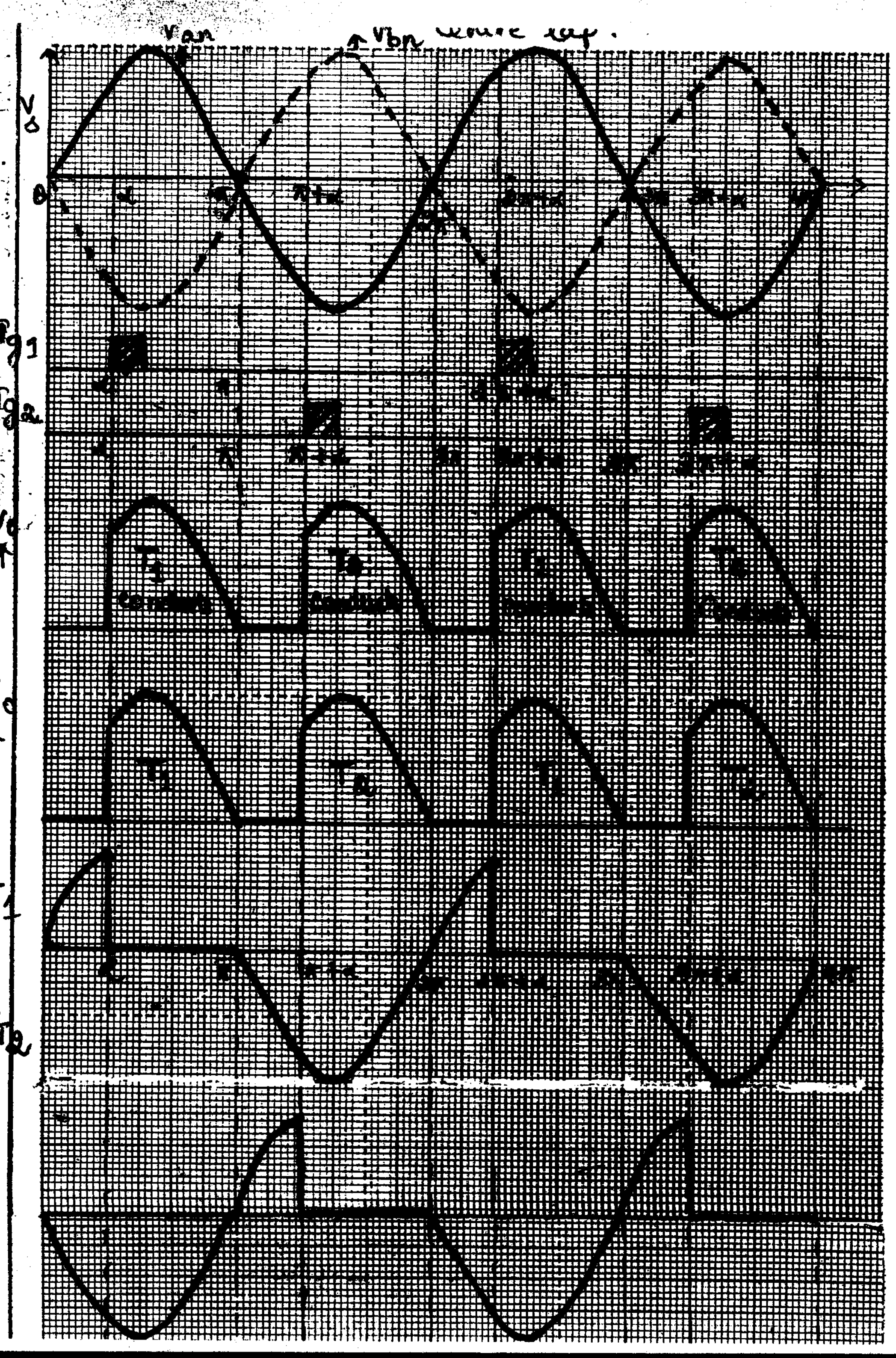
$\therefore \; i_0$ is $\uparrow$

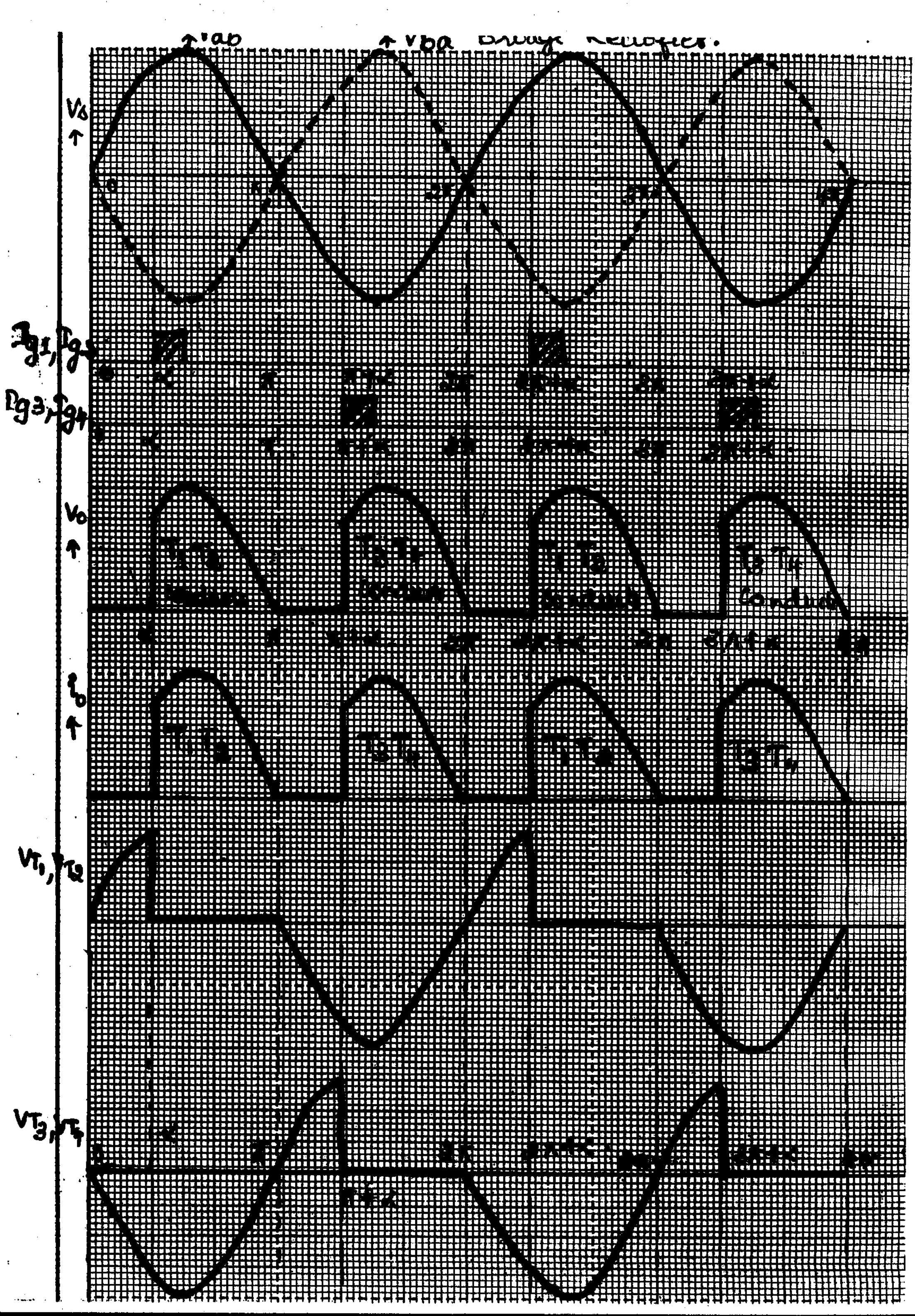
$V_0 = V_{ba}$

i_0 flows through

$b - T_3 - R - T_4 - a.$




Van
Vbn centre tap.
Vo
Ig1
Ig2
Vo
io
VT1
VT2


Vab
Vba bridge rectifier.
Vo
Ig1, Ig2
Ig3, Ig4
Vo
io
VT1, VT2
VT3, VT4

Centre tap

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

$$= \frac{V_m}{\pi}\left[-\cos\omega t\right]_\alpha^\pi = -\frac{V_m}{\pi}\left[\cos\pi - \cos\alpha\right]$$

$$= -\frac{V_m}{\pi}\left[-1 - \cos\alpha\right] = \frac{V_m}{\pi}\left[1 + \cos\alpha\right]$$

$$\therefore V_o(avg) = \frac{V_m}{\pi}\left[1 + \cos\alpha\right]$$

$$I_o(avg) = \frac{V_o(avg)}{R} = \frac{V_m}{\pi R}\left[1 + \cos\alpha\right]$$

$$V_{orms} = \sqrt{\frac{1}{\pi}\int_\alpha^\pi V_m^2 \sin^2\omega t \cdot d\omega t}$$

$$= \sqrt{\frac{V_m^2}{\pi}\int_\alpha^\pi \left(\frac{1 - \cos 2\omega t}{2}\right) d\omega t}$$

$$= \sqrt{\frac{V_m^2}{2\pi}\left\{\left[\omega t\right]_\alpha^\pi - \left[\frac{\sin 2\omega t}{2}\right]_\alpha^\pi\right\}}$$

$\sin 2\pi = 0$

$$= \sqrt{\frac{V_m^2}{2\pi}\left\{\left[\pi - \alpha\right] - \frac{1}{2}\left[\sin 2\pi - \sin 2\alpha\right]\right\}}$$

$$V_{orms} = \frac{V_m}{\sqrt{2\pi}}\sqrt{\pi - \alpha + \frac{1}{2}\sin 2\alpha}$$

$$I_{orms} = V_{orms}/R$$

Bridge rectifier

Average value of voltage:-

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

$$V_o(avg) = \frac{V_m}{\pi}\left[1 + \cos\alpha\right].$$

$$I_o(avg) = \frac{V_o(avg)}{R} = \frac{V_m}{\pi R}\left[1 + \cos\alpha\right]$$

← [derivation done in centre tap]

$$V_{orms} = \sqrt{\frac{1}{\pi}\int_\alpha^\pi V_m^2 \sin^2\omega t \cdot d\omega t}$$

$$V_{orms} = \frac{V_m}{\sqrt{2\pi}}\sqrt{\left[\pi - \alpha + \frac{1}{2}\sin 2\alpha\right]}$$

$$I_{orms} = \frac{V_{orms}}{R} = \frac{V_m}{R\sqrt{2\pi}}\sqrt{\pi - \alpha + \frac{1}{2}\sin 2\alpha}$$

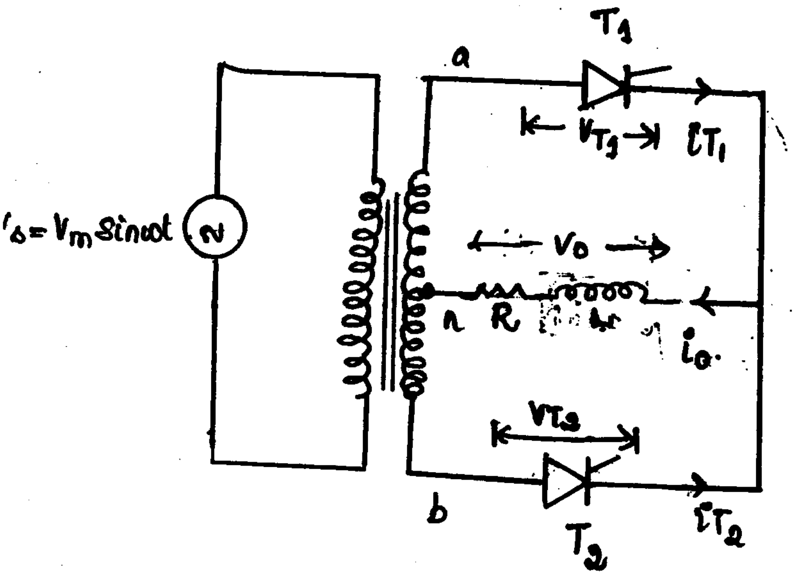
$$P = V_{orms} * I_{orms}$$

[From all above it's seen that the waveforms, eqns and working for centre tap and Bridge rectifier are same. Only the no of SCRs conducting vary]

* **NOTE:-**

Similarly even for bridge rectifier with RL, RLE load and midpoint or centre tap rectifier the eqns and waveforms will remain the same.

MIDPOINT OR CENTRE TAPPED RECTIFIER WITH RL load:-



* In +ve half cycle terminal a is +ve w.r.t. terminal b.

$\therefore V_{an} = +V_m \sin\omega t$.

$V_{bn} = -V_m \sin\omega t$.

V_{an} supplies T_1

V_{bn} supplies T_2.

$\therefore$ SCR T_1 is forward biased in +ve half cycle.

$\therefore$ SCR T_2 is reverse biased in +ve half cycle.

At $\omega t = \alpha$ SCR T_1 is turned ON.

From $\omega t = 0$ to α, SCR T_1 is Forward biased [FB], T_2 is reverse biased [RB].

Vge across SCR T_1 = $V_{T_1} = V_{an}$

" " " T_2 = $V_{T_2} = V_{bn}$.

$i_{T_1} = 0$,

$i_{T_2} = 0$

$\therefore i_0 = 0$; $V_0 = 0$.

At $\omega t = \alpha$ SCR T_1 is ON.

From $\omega t = \alpha$ to π;

SCR T_1 is ON; T_2 is Reverse biased. (RB)

$\therefore$ Vge across SCR T_1 = $V_{T_1} = 0$.

Due to Inductive load current thro' SCR T_1 increases very slowly, so load cunt $i_0 = i_{T_1} \uparrow$.

$\therefore$ i_0 $\uparrow$ very slowly and reaches maximum value at $\omega t = \pi$.

$i_{T_2} = 0$

$V_{T_2} = V_{bn}$.

At $\omega t = \pi$ [During −ve half cycle]

* At $\omega t = \pi$; Vge across SCR T_1 is Reverse biased.

[$\because$ a is −ve; b is +ve; $V_{an} = -V_m \sin\omega t$; $V_{bn} = +V_m \sin\omega t$]

* SCR T_2 is forward biased.

But,

* SCR T_1 does not turn OFF due to the reverse voltage at $\omega t = \pi$; the current i_0 has not dropped below holding current.

* It takes some time to drop to zero. The time taken by the current to fall to zero is "β". It is also called as extinction angle.

Based on the value of β we can divide the operation into two modes.

a) discontinuous mode. $(\alpha > \beta)$ (or) $\beta < \alpha$

b) continuous mode. $(\alpha = \beta)$

a) discontinuous mode :- $\alpha > \beta$

* when β is less than α, the current reaches to zero before the ~~turning~~ ON of the next SCR at α.

b) continuous mode : $\alpha = \beta$.

* when $\alpha = \beta$ the current reaches to zero at the time when the next SCR is turned ON.

$\therefore$ From π to β.

i_0 gradually reduces and falls to zero and so SCR T_1 is turned OFF at $\omega t = \beta$.

$V_{T1} = 0$ till β

$V_{T1} = V_{an}$ at β

$V_{T2} = V_{bn}$

$i_0 = 0$ at β.

$V_0 = V_{an}$ till β.

From β to $\pi + \alpha$:-

$V_0 = 0$

$i_0 = 0$

$V_{T1} = V_{an}$

$V_{T2} = V_{bn}$

At $\pi + \alpha$,

At $\omega t = \pi + \alpha$, SCR T_2 is ON. SCR T_1 is RB.

$\therefore$ $V_{T2} = 0$

$V_{T1} = V_{an}$.

$i_{T1} = 0$

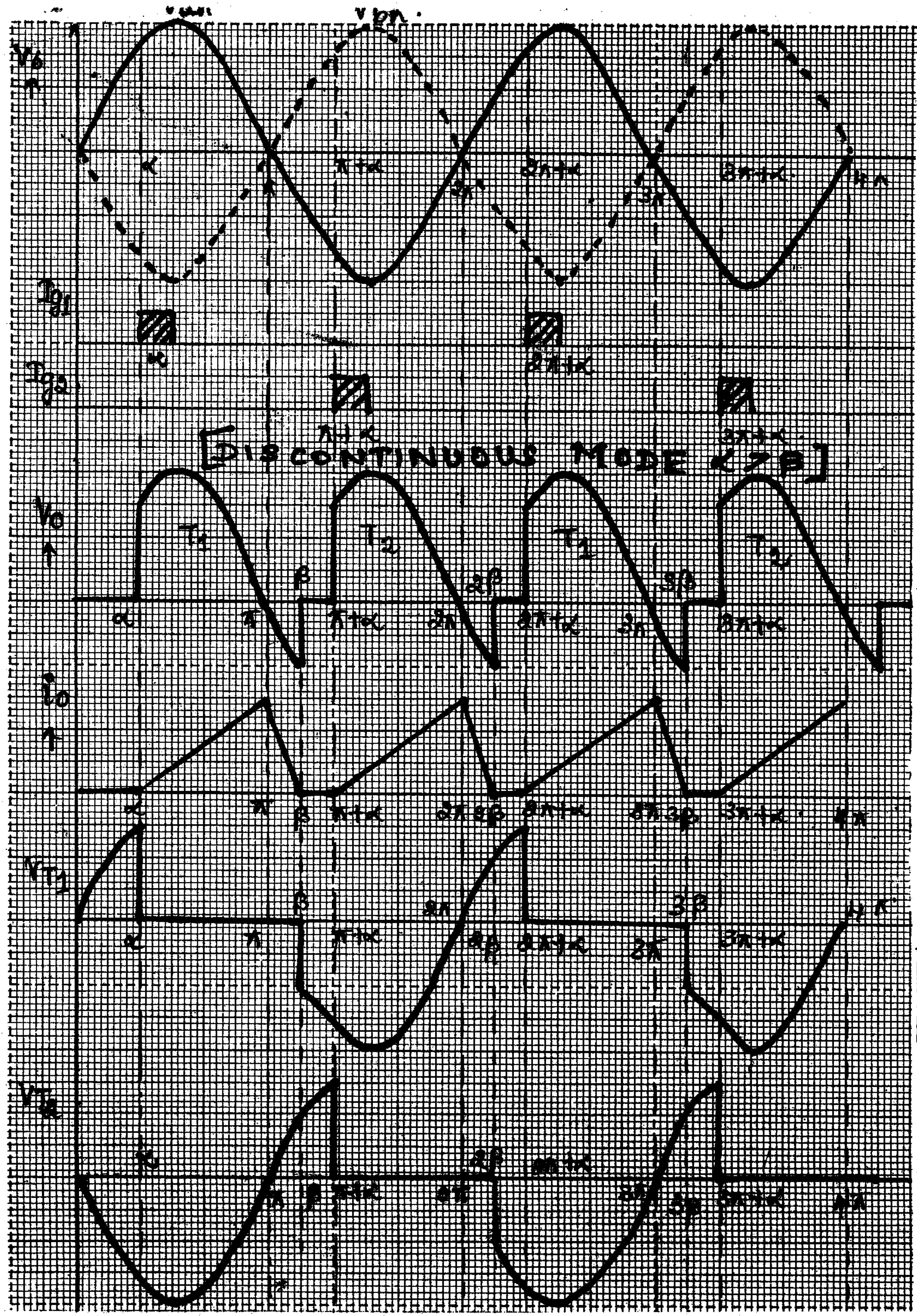
i_{T2} = slowly $\uparrow$ing due to RL load.

i_0 = " " " " "

$V_0 = V_{bn}$.

At $\omega t = 2\pi$:- SCR T_2 is RB, but does not turn OFF due to i_0.

At $\omega t = 2\pi + \beta$: $i_0 \downarrow$ to zero SCR T_2 is OFF. $\therefore$ at $\omega t = \beta$; $V_0 = 0$; $i_0 = 0$; $V_{T2} = V_{bn}$; $V_{T1} = V_{an}$,



Equations for discontinuous mode:

$$V_{o(avg)} = \frac{1}{\pi}\int_\alpha^\beta V_m \sin\omega t\, d\omega t = \frac{V_m}{\pi}\left[-\cos\omega t\right]_\alpha^\beta$$

$$= -\frac{V_m}{\pi}\left[\cos\beta - \cos\alpha\right] = \frac{V_m}{\pi}\left[\cos\alpha - \cos\beta\right]$$

$$\therefore \boxed{V_{o(avg)} = \frac{V_m}{\pi}\left[\cos\alpha - \cos\beta\right]}$$

$$I_{o(avg)} = \frac{V_{o(avg)}}{R} = \frac{V_m}{\pi R}\left[\cos\alpha - \cos\beta\right]$$

$$V_{orms} = \sqrt{\frac{1}{\pi}\int_\alpha^\beta V_m^2 \sin^2\omega t\, d\omega t}$$

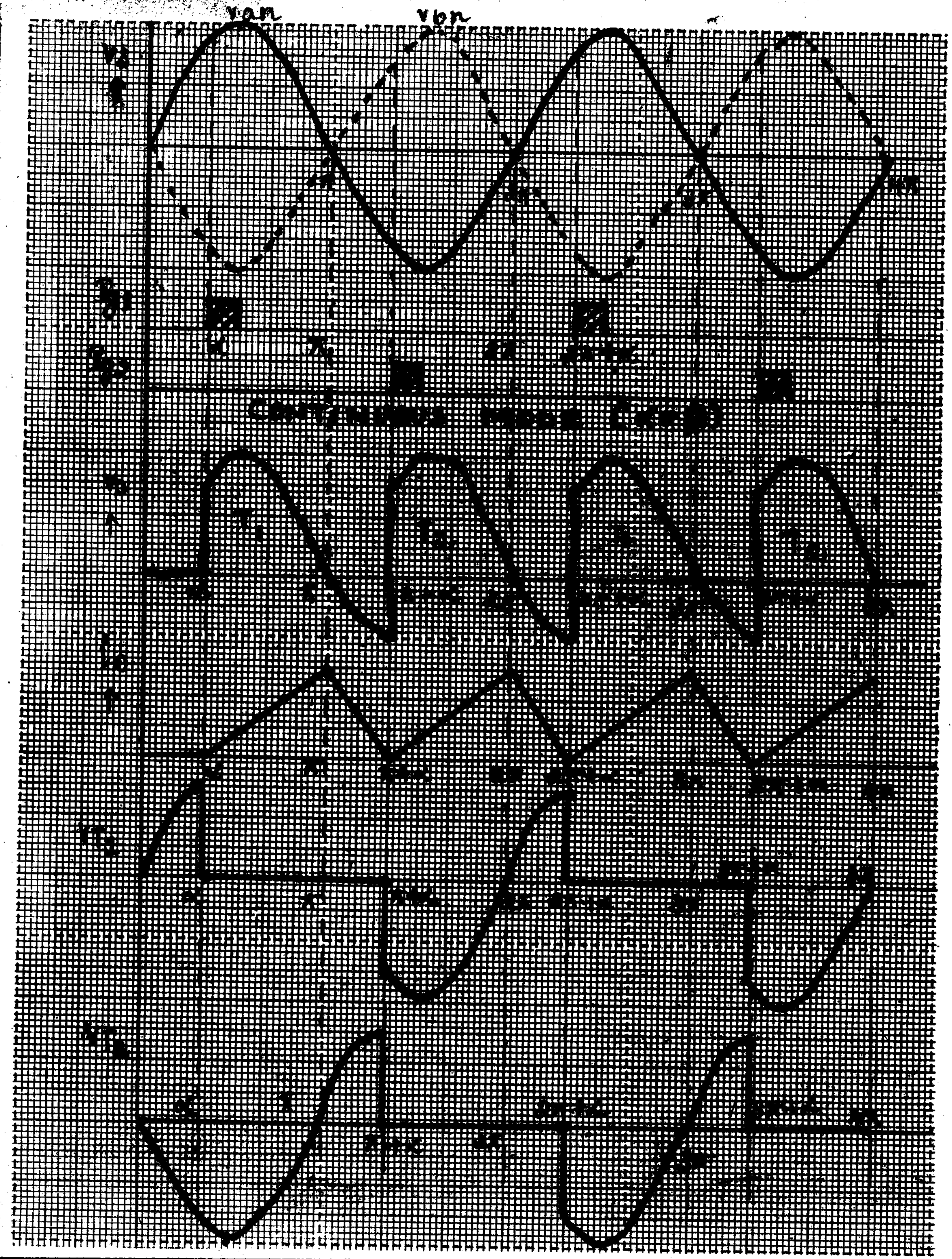
$$= \sqrt{\frac{V_m^2}{\pi}\int_\alpha^\beta \left(\frac{1 - \cos 2\omega t}{2}\right) d\omega t}$$

$$= \sqrt{\frac{V_m^2}{2\pi}\left[(\omega t)_\alpha^\beta - \left(\frac{\sin 2\omega t}{2}\right)_\alpha^\beta\right]}$$

$$\boxed{V_{orms} = \frac{V_m}{\sqrt{2\pi}}\sqrt{\left[\beta - \alpha\right] - \frac{1}{2}\left[\sin 2\beta - \sin 2\alpha\right]}}$$

$$I_{orms} = \frac{V_{orms}}{R}$$

$$P = V_{orms} * I_{orms}$$



For continuous mode:

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

$$= \frac{-V_m}{\pi}\left[\cos\omega t\right]_{\alpha}^{\pi+\alpha} \qquad \cos(\pi+\alpha) = -\cos\alpha$$

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

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

$$V_o(avg) = \frac{2V_m}{\pi}\cos\alpha.$$

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

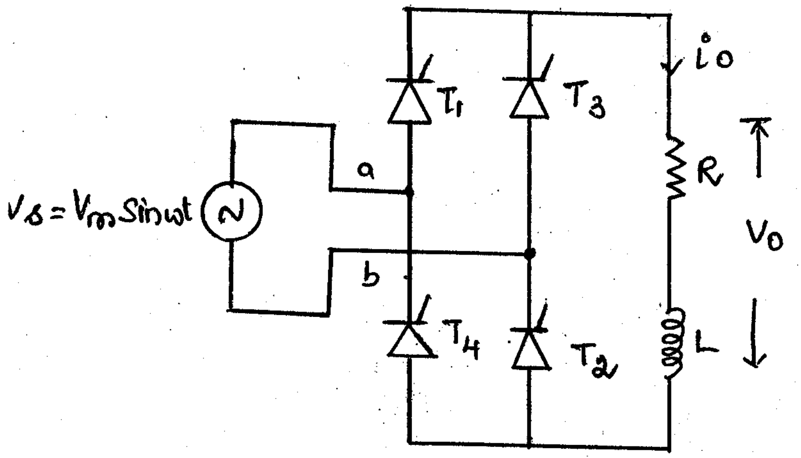
$$= \sqrt{\frac{V_m^2}{\pi}\int_{\alpha}^{\pi+\alpha}\left(1 - \frac{\cos 2\omega t}{2}\right) d\omega t}$$

$$= \sqrt{\frac{V_m^2}{2\pi}\left\{(\omega t)_{\alpha}^{\pi+\alpha} - \frac{1}{2}\left[\sin 2\omega t\right]_{\alpha}^{\pi+\alpha}\right.}$$

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

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

1φ FULL WAVE BRIDGE RECTIFIER WITH RL LOAD:-



* $V_s = V_m \sin\omega t$ = Supply Vge.
* SCRs T_1, T_2 conduct in +ve half cycle.
* SCRs T_3, T_4 conduct in −ve half cycle.

* In +ve half cycle:-

* In +ve half cycle terminal 'a' is +ve w.r.t. terminal 'b'.
* a is +ve; b is −ve.
* $V_{ab} = +V_m \sin\omega t$.
* $V_{ba} = -V_m \sin\omega t$.
* V_{ab} supplies SCRs T_1, T_2 so they are forward biased.
* V_{ba} supplies SCRs T_3, T_4, so they are reverse biased.
* SCR T_1, T_2 are turned on at $\omega t = \alpha$.

∴ load current flows through $a - T_1 - R - L - T_2 - b$.

From $\omega t = 0$ to α.

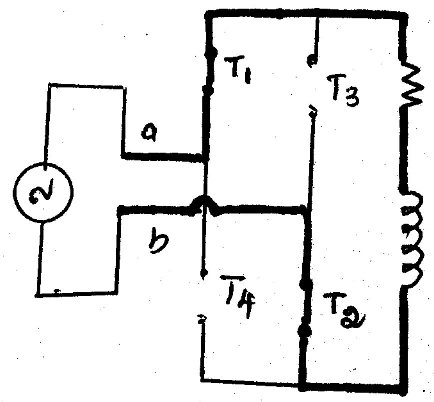
* SCR $T_1 T_2$ is FB
* SCR $T_3 T_4$ is RB

$V_{T_1} = V_{T_2} = V_{ab}$

$V_{T_3} = V_{T_4} = V_{ba}$

$i_o = 0$

$V_o = 0$.



At $\omega t = \alpha$ SCR T_1, T_2 are turned ON.

From $\omega t = \alpha$ to π.

* SCR T_1, T_2 are ON
* $\therefore V_{T_1} = V_{T_2} = 0$
* Due to Inductive load current through SCR T_1, T_2

$\uparrow$es very slowly ∴ i_0 = increases slowly.

* $i_0 = \uparrow$es and reaches maximum at $\omega t = \pi$.
* $V_0 = V_s$

At $\omega t = \pi$ [During -ve half cycle]:-

* At $\omega t = \pi$; SCR T_1, T_2 are reverse biased.

[∵ in -ve cycle, a is -ve; b is +ve; ∴ $V_{ab} = -V_m \sin \omega t$; $V_{ba} = +V_m \sin \omega t$]

* SCR T_3, T_4 are forward biased.
* Though SCR T_1, T_2 are reverse biased at $\omega t = \pi$,

they do not turn OFF because the current i_0 does not drop below holding current.

* i_0 takes some time to fall to zero. The time

taken by i_0 to falls to zero is "β". It is called extinction angle.

Based on the value of β we can divide the operation into two modes.

a) discontinuous mode ($\alpha > \beta$)

* when 'β' is less than 'α', i_0 reaches zero

at β before the turning ON of the next SCR at 'α'.

b) Continuous mode: ($\alpha = \beta$)

* when $\alpha = \beta$ the current reaches to zero at the same time when the next SCR is turned ON.

∴ **From π to β :**

* i_0 gradually reduces and falls to zero at $\omega t = \beta$.

∴ SCR T_1, T_2 is turned OFF at $\omega t = \beta$.

∴ $V_{T_1} = V_{T_2} = 0$ till β.

$V_{T_3} = V_{T_4} = V_{ba}$

$i_0 = 0$ at β.

$V_0 = V_{ab}$ till β.

From β to $\pi + \alpha$: NO SCR conducts.

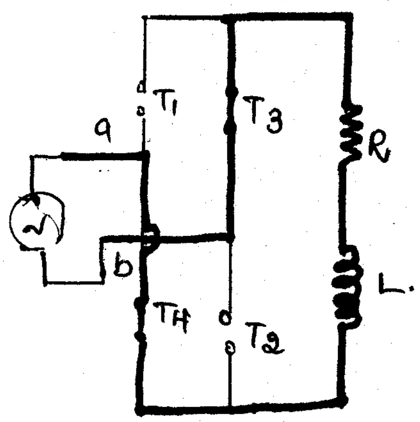
$v_0 = 0$ $T_1 T_2 = RB$

$i_0 = 0$ $T_3 T_4 = FB$

$V_{T_1} = V_{T_2} = V_{ab}$

$V_{T_3} = V_{T_4} = V_{ba}$.

At $\omega t = \pi + \alpha$



At $\omega t = \pi + \alpha$ SCR T_3, T_4 is turned ON.

∴ $V_{T_3} = V_{T_4} = 0$

SCR T_1, T_2 are RB, ∴ $V_{T_1} = V_{T_2} = V_{ab}$

i_0 = slowly ↑es due to RL load.

$V_0 = V_s$.

* i_0 flows through b − T_3 − R − L − T_4 − a.

At $\omega t = 2\pi$:-

* SCR T_3, T_4 is RB, but does not turn OFF because i_0 is not less than holding current.

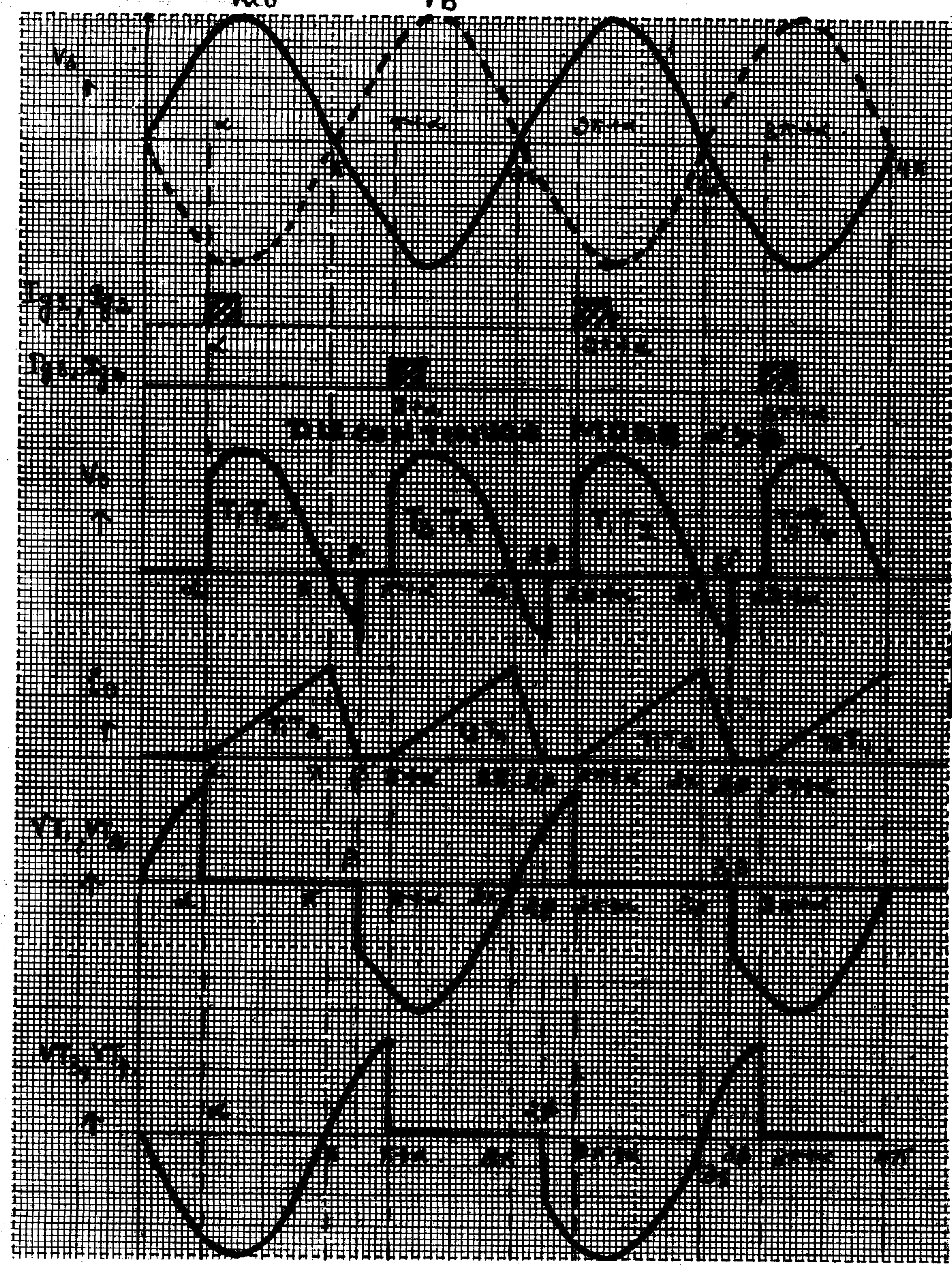
∴ $V_0 = V_{ba}$.

At $\omega t = 2\pi + \beta$

* i_0 ↓ to zero ∴ SCR T_3, T_4 is OFF.

∴ at $\omega t = 2\pi + \beta$; $V_0 = 0$; $i_0 = 0$; $V_{T_3} = V_{T_4} = V_{ba}$

$V_{T_1} = V_{T_2} = V_{ab}$.



Equations for discontinuous mode:-

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

$$\boxed{V_o(avg) = \frac{V_m}{\pi}\left[\cos\alpha - \cos\beta\right]}$$ already solved in Page (62)

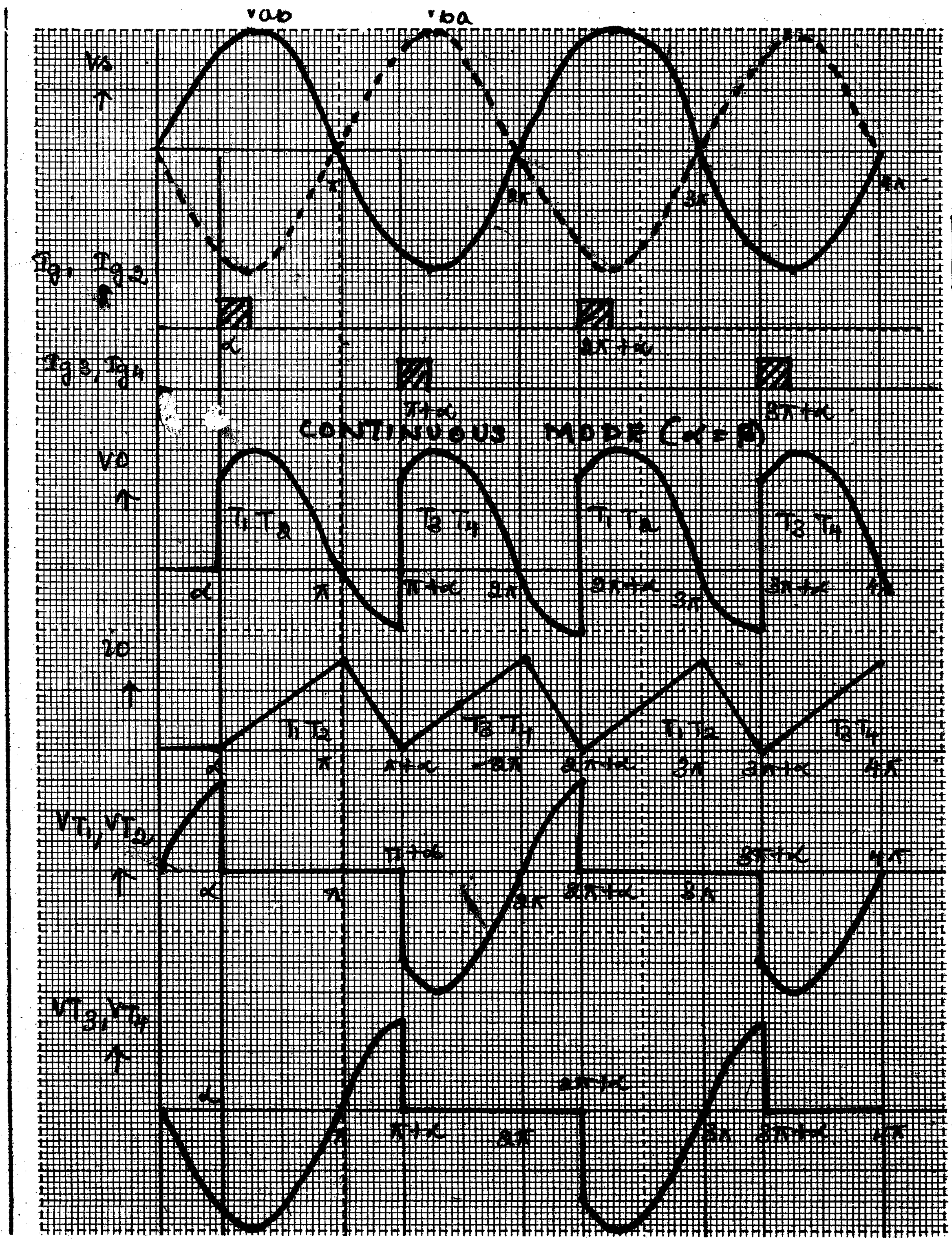
$$I_o(avg) = \frac{V_m}{\pi R}\left[\cos\alpha - \cos\beta\right]$$

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

$$\boxed{V_o(rms) = \frac{V_m}{\sqrt{2\pi}}\sqrt{[\beta-\alpha] - \frac{1}{2}\left[\sin 2\beta - \sin 2\alpha\right]}}$$

$$I_{orms} = \frac{V_{orms}}{R}.$$

$$P = V_{orms} * I_{orms}.$$



Eqns for continuous mode:-

$$V_{o(avg)} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t \cdot d\omega t.$$

$$\boxed{V_{o(avg)} = \frac{2V_m}{\pi}\cos\alpha.}$$

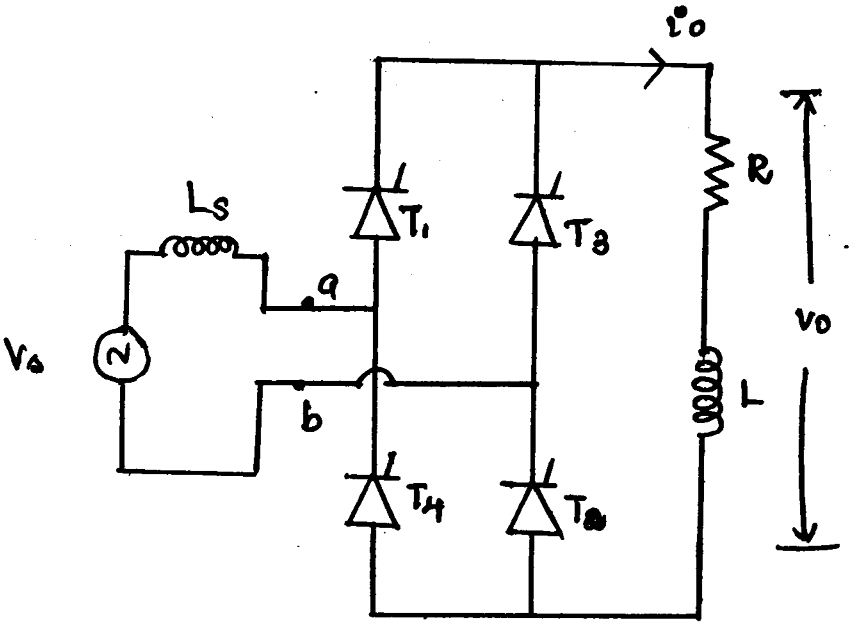
$$V_{orms} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m^2 \sin^2\omega t \cdot d\omega t.}$$

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

$$\boxed{P = V_{orms} * I_{orms}}$$

$$I_{orms} = \frac{V_{orms}}{R}.$$

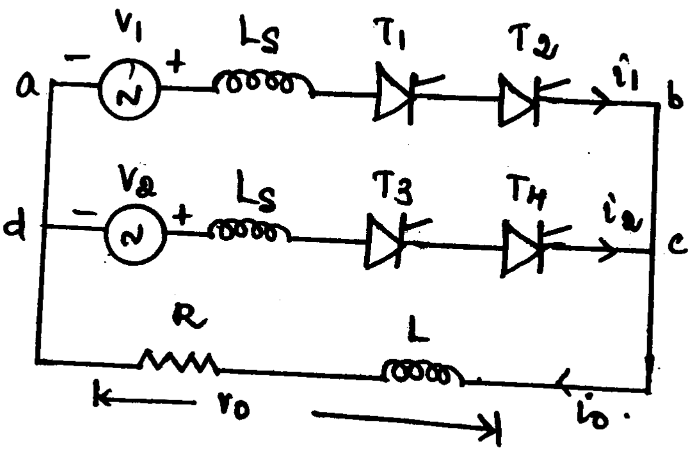
EFFECT OF SOURCE INDUCTANCE (L_s) ON PERFORMANCE OF RECTIFIER WITH RL LOAD



L_s = Source Inductance

L = Load Inductance.

Equivalent circuit.



* Load current i_0 is assumed constant.

* when terminal 'a' of source vge is +ve, current i_1 flows thro' L_s, T_1, load and T_2 and this is shown in equivalent circuit as $V_1 - L_s - T_1 - T_2$ — RL load.

* when terminal 'b' of source vge is +ve; current i_2 flows thro' L_s, T_3, load, T_4 and this is shown in equiv ckt as $V_2 - L_s - T_3 - T_4$ — RL load.

* when T_1, T_2 are triggered at firing angle α, the SCRs T_3, T_4 which have been already conducting will be commutating.

* i.e., the current through the incoming SCRs T_1, T_2 builds up very slowly, whereas due to presence of source inductance (L_s) the current through the outgoing SCRs T_3, T_4 decreases very slowly.

* ∴ during this period all 4 SCRs T_1, T_2, T_3, T_4 are conducting. This period is called as overlap period and the angle is called as overlap angle "μ".

<u>working:-</u>

<u>From ($\alpha+\mu$ to $\pi+\alpha$):-</u>

* From $\omega t = \alpha+\mu$ to $\pi+\alpha$, SCRs T_1 and T_2 will be conducting.

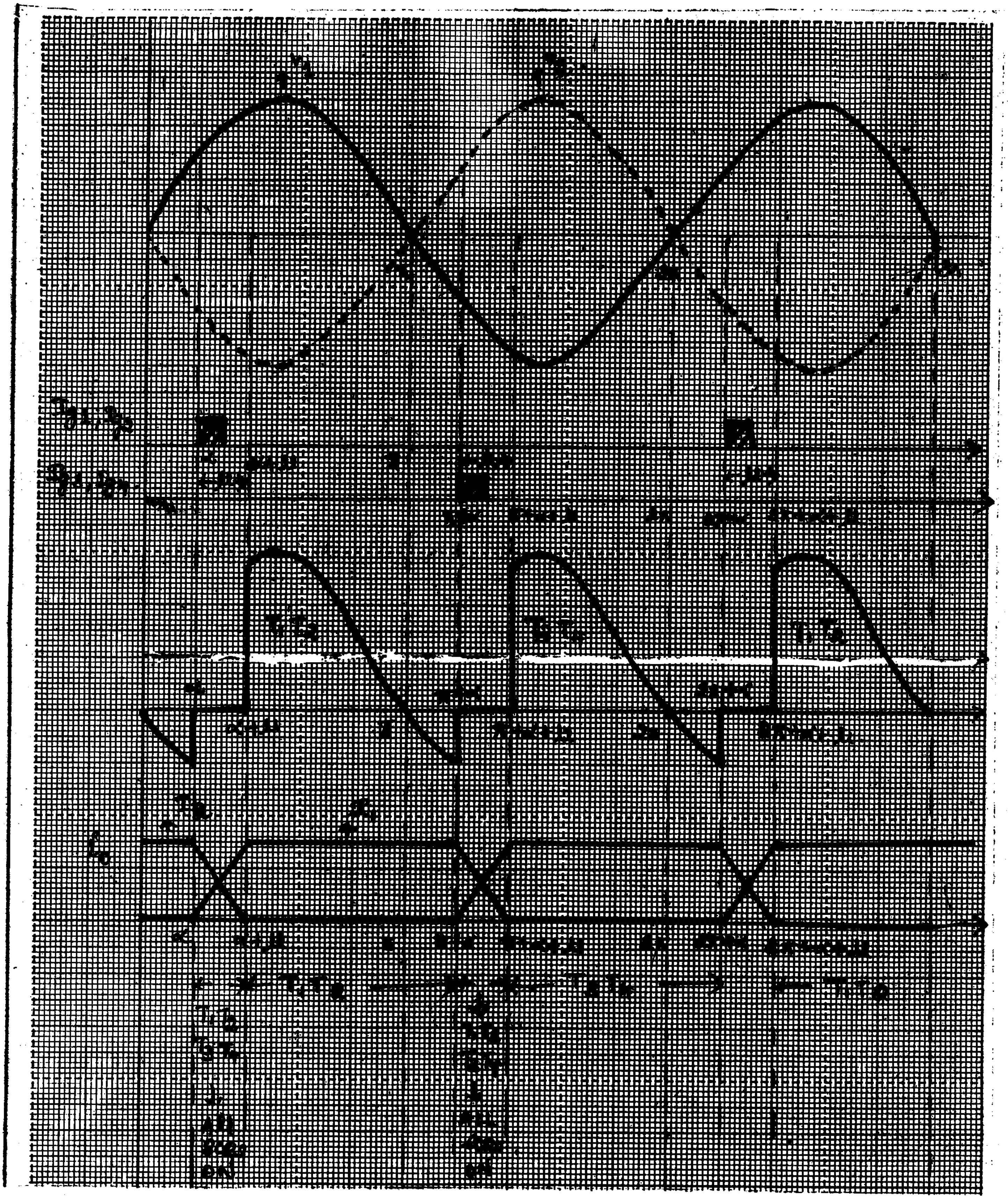
* At $\omega t = \pi+\alpha$, the supply vge is -ve.

* SCRs T_3 and T_4 are triggered at $\omega t = \pi+\alpha$. ∴ current through T_3, T_4 ↑es slowly.

* At $\omega t = \pi+\alpha$, SCRs T_1, T_2 does not turn OFF because energy stored in source inductance (L_s) induces a vge that fwd biases T_1, T_2.

∴ from $\omega t = \pi+\alpha$ to $\omega t = \pi+\alpha+\mu$ SCRs T_1, T_2, T_3, T_4 are conducting. This period is called overlap period.

* At $\omega t = \pi+\alpha+\mu$ current thro' T_1, T_2 reduces to zero and turns OFF. and cunt thro' T_3, T_4 reaches max value.



From the equivalent circuit

Vge across ab = Vge across cd ($\because$ they are $\parallel^{el}$ paths)

i.e.,

$$V_1 - L_s \cdot \frac{di_1}{dt} = V_2 - L_s \frac{di_2}{dt}$$

$$V_1 - V_2 = L_s \frac{di_1}{dt} - L_s \frac{di_2}{dt} = L_s \left[\frac{di_1}{dt} - \frac{di_2}{dt} \right]$$

$V_1 = V_m \sin \omega t$; $V_2 = -V_m \sin \omega t$; $\therefore V_1 - V_2 = V_m \sin \omega t - (-V_m \sin \omega t)$

$$V_1 - V_2 = 2V_m \sin \omega t$$

$\therefore 2V_m \sin \omega t = L_s \left[\frac{di_1}{dt} - \frac{di_2}{dt} \right]$; $\frac{di_1}{dt} - \frac{di_2}{dt} = \frac{2V_m \sin \omega t}{L_s} \rightarrow (1)$

we know that $i_1 + i_2 = i_0$ [But i_0 is constant]

$$\therefore \frac{di_1}{dt} + \frac{di_2}{dt} = 0 \rightarrow (2)$$

On adding eqn (1) and (2)

$\frac{di_1}{dt} + \frac{di_2}{dt} + \frac{di_1}{dt} - \frac{di_2}{dt} = \frac{2V_m \sin \omega t}{L_s}$; $2\frac{di_1}{dt} = \frac{2V_m}{L_s} \sin \omega t$

$$\therefore \frac{di_1}{dt} = \frac{V_m}{L_s} \sin \omega t$$

$$di_1 = \frac{V_m}{L_s} \sin \omega t \cdot dt$$

w.k.T., $i_1 = i_0$ at $\omega t = \alpha + \mu$ (or) $t = \frac{\alpha + \mu}{\omega}$; $i_1 = 0$ at $\omega t = \alpha$ (or) $t = \frac{\alpha}{\omega}$

$\therefore \int_0^{i_0} di_1 = \int_{\alpha/\omega}^{(\alpha+\mu)/\omega} \frac{V_m}{L_s} \sin \omega t \cdot dt$, $[i_1]_0^{i_0} = \frac{-V_m}{L_s} \left[\frac{\cos \omega t}{\omega} \right]_{\frac{\alpha}{\omega}}^{\frac{\alpha+\mu}{\omega}}$

$$\therefore i_0 = -\frac{V_m}{\omega L_s} \left[\cos \omega * \frac{\alpha + \mu}{\omega} - \cos \omega * \frac{\alpha}{\omega} \right]$$

$$\boxed{i_0 = \frac{V_m}{\omega L_s} [\cos \alpha - \cos(\alpha + \mu)]} \rightarrow (3)$$

$$V_0(avg) = \frac{1}{\pi}\int_{\alpha+\mu}^{\alpha+\pi} V_m \sin\omega t \cdot d\omega t = -\frac{V_m}{\pi}\left[\cos\omega t\right]_{\alpha+\mu}^{\alpha+\pi}$$

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

$$\boxed{V_0(avg) = \frac{V_m}{\pi}\left[\cos\alpha + \cos(\alpha+\mu)\right]} \rightarrow (4)$$

From eqn (3)

$$i_0 = \frac{V_m}{\omega L_s}\left[\cos\alpha - \cos(\alpha+\mu)\right]$$

$$\frac{i_0\,\omega L_s}{V_m} = \cos\alpha - \cos(\alpha+\mu) \quad \text{(or)}$$

$$\boxed{\cos(\alpha+\mu) = \cos\alpha - \frac{i_0\,\omega L_s}{V_m}} \rightarrow (5).$$

Substituting (5) in (4)

$$V_0(avg) = \frac{V_m}{\pi}\left[\cos\alpha + \cos\alpha - \frac{i_0\,\omega L_s}{V_m}\right]$$

$$\boxed{V_0(avg) = \frac{2V_m}{\pi}\cos\alpha - \frac{i_0\,\omega L_s}{\pi}} \rightarrow (6)$$

From eqn (3)

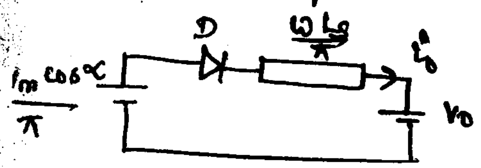
$$i_0 = \frac{V_m}{\omega L_s}\left[\cos\alpha - \cos(\alpha+\mu)\right] \quad \text{(or)} \quad \boxed{\cos\alpha = \frac{i_0\,\omega L_s}{V_m} + \cos(\alpha+\mu)} \rightarrow (7)$$

Substituting (7) in (4).

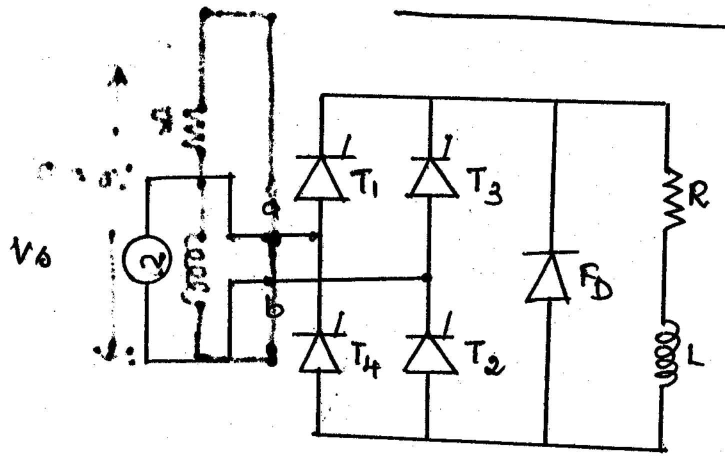
$$V_0(avg) = \frac{V_m}{\pi}\left[\frac{i_0\,\omega L_s}{V_m} + \cos(\alpha+\mu) + \cos(\alpha+\mu)\right]$$

$$\boxed{V_0(avg) = \frac{i_0\,\omega L_s}{\pi} + \frac{2V_m}{\pi}\cos(\alpha+\mu)} \rightarrow (8)$$

From eqn (6) dc equiv ckt is drawn as follows.



1φ FULL WAVE BRIDGE RECTIFIER WITH RL LOAD AND FREE WHEELING DIODE



* Waveform of load current i_0 is improved by connecting a free-wheeling diode (F_D) across the load.
* F_D prevents the reversal of load vge.

Advantages of F_D:-

* Improves input power factor angle.
* Improves load current waveform.
* Better load performance.

In +ve half cycle:-

* a is +ve; b is −ve; $V_{ab} = +V_m \sin\omega t$; $V_{ba} = -V_m \sin\omega t$.
* Vab forward biases SCR T_1, T_2.
* V_{ba} reverse biases SCR T_3, T_4.
* Forward biased SCR T_1, T_2 are turned ON at $\omega t = \alpha$.

From $\omega t = 0$ to α :-

* SCR $T_1 T_2$ is FB
* SCR $T_3 T_4$ is RB

$V_{T_1} = V_{T_2} = V_{ab}$

$V_{T_3} = V_{T_4} = V_{ba}$

$i_0 = 0$

$V_0 = 0$.

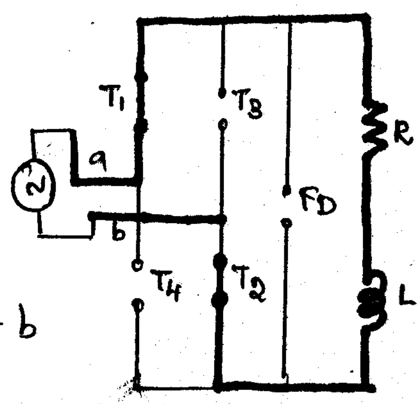
* F_D is RB and does not conduct.

$V_{FD} = V_s$

At $\omega t = \alpha$; SCR T_1, T_2 are turned ON

From $\omega t = \alpha$ to π

* T_1, T_2 are ON
* ∴ $V_{T_1} = V_{T_2} = 0$
* Due to RL load i_0 ↑ very slowly and reaches max value at $\omega t = \pi$; ie $i_0 = $ ↑
* i_0 flows thro' a − T_1 − R − L − T_2 − b
* $V_0 = V_s$
* $V_{FD} = V_s$.



At $\omega t = \pi$: to $\omega t = \pi + \alpha$.

SCR T_1, T_2 is RB

* T_3, T_4 are FB

* F_D is forward biased and conducts.

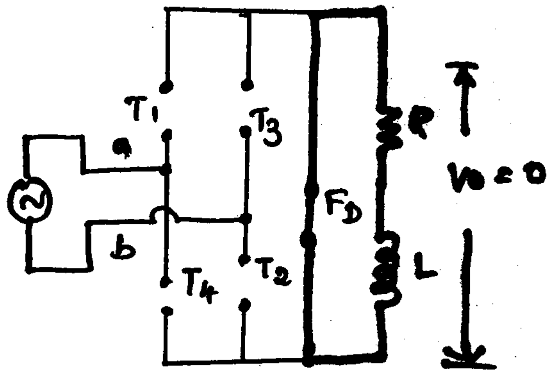
* So current i_0 discharges thro' F_D.

* ∵ F_D is connected in $\parallel^{el}$ to load, when F_D conducts Vge across $F_D = 0$,

∴ Vge across load $V_0 = 0$

$i_0 = \downarrow$ thro' F_D.

F_D conducts till the next SCR is turned ON.



$V_{T_1} = V_{T_2} = V_{ab}$

$V_{T_3} = V_{T_4} = V_{ba}$

$V_{F_D} = 0$

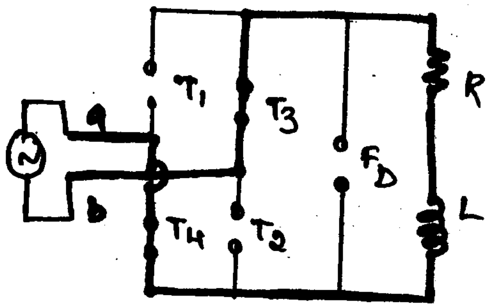
At $\omega t = \pi + \alpha$:-

F_D is RB and turns OFF

SCR T_3 T_4 are turned ON

∴ $V_{F_D} = V_s$

$V_{T_3} = V_{T_4} = 0$



$i_0 \uparrow$ slowly and flows thro' $b - T_3 - R\text{-}L - T_4 - a$.

From $\omega t = \pi + \alpha$ to 2π.

T_3, T_4 conducts

∴ $V_{T_3} = V_{T_4} = 0$

Due to RL load $i_0 \uparrow$ slowly and reaches max at $\omega t = 2\pi$

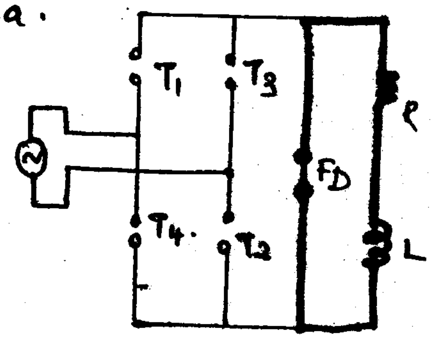
∴ $i_0 = \uparrow$

$V_0 = V_s$

∴ F_D is reverse biased ∴ $V_{F_D} = V_s$.

At $\omega t = 2\pi$ ∴ $V_0 = 0$; T_3, T_4 are RB; ∴ $V_{T_3} = V_{T_4} = V_{ba}$.

At $\omega t = 2\pi$ F_D is FB and conducts; ∴ $V_{F_D} = 0$

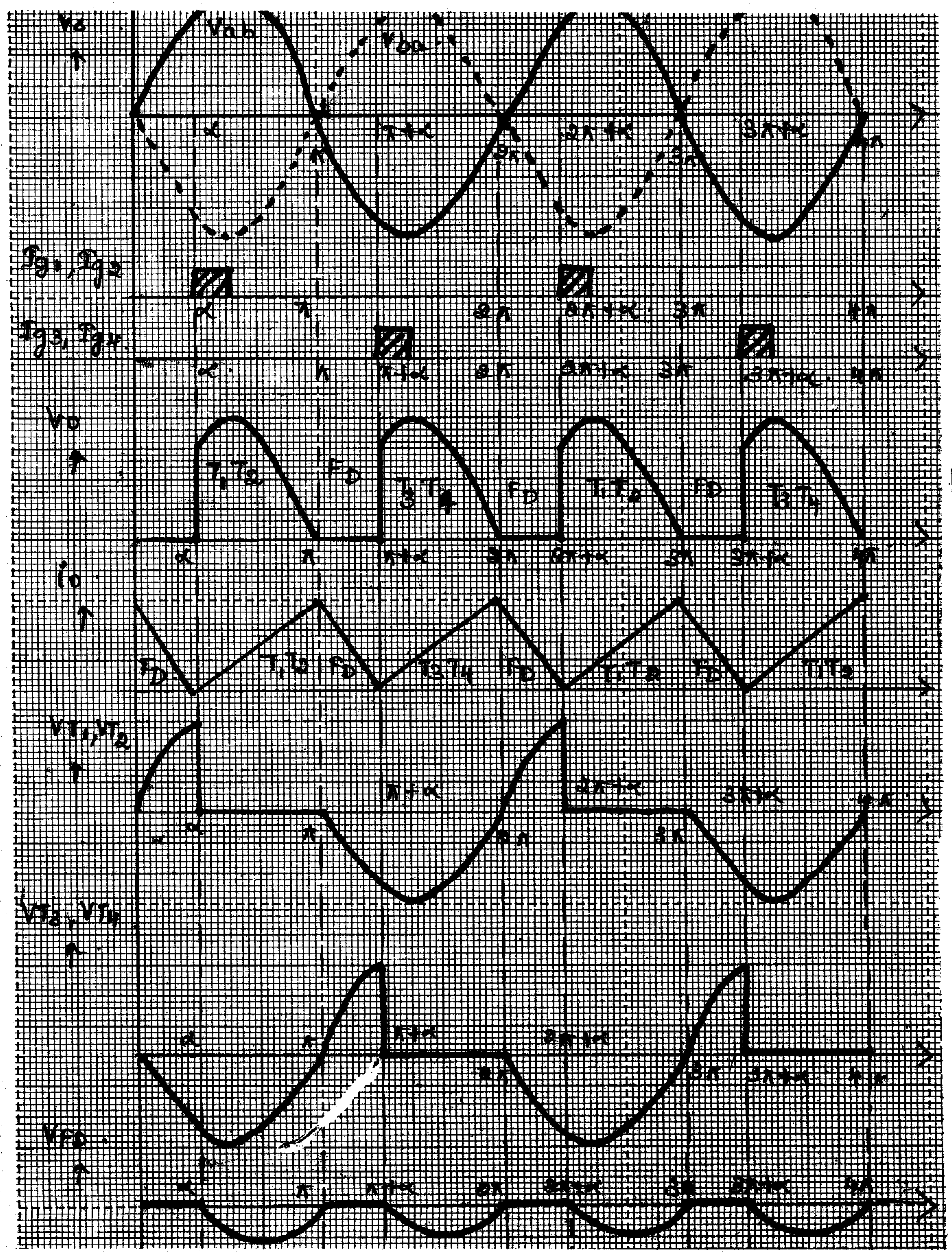


From $\omega t = 2\pi$ to $2\pi + \alpha$.

Diode F_D conducts.

$i_0 \downarrow$ and reaches zero at $2\pi + \alpha$.

F_D conducts till the next SCR turns ON.



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

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

$$I_0(avg) = \frac{V_m}{\pi R}\left[1+\cos\alpha\right]$$

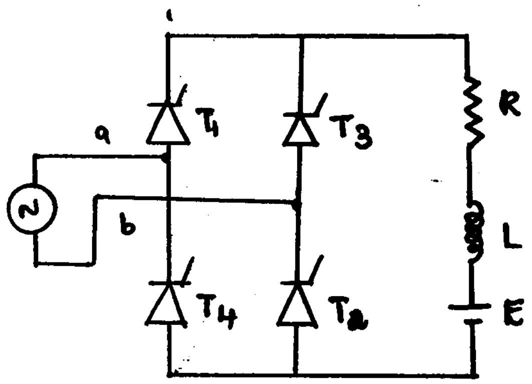
$$V_{0rms} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \cdot d\omega t}$$

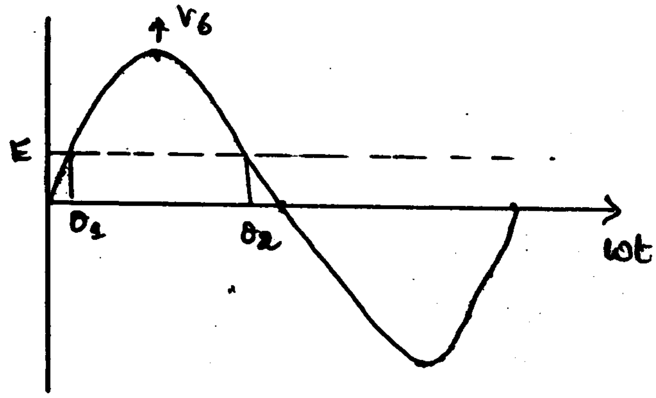
$$\boxed{V_{0rms} = \frac{V_m}{\sqrt{2\pi}}\sqrt{(\pi-\alpha) + \frac{1}{2}\sin 2\alpha}}$$

$$\boxed{I_{0rms} = \frac{V_m}{R\sqrt{2\pi}}\sqrt{\pi-\alpha + \frac{1}{2}\sin 2\alpha}}$$

$$P = V_{0rms} * I_{0rms}$$

1φ FULL WAVE CONVERTER WITH RLE LOAD:





* It is an RLE load, where E is load circuit emf.
* E may be due to battery in load (or) may be generated emf of a dc motor.
* Till $\omega t = \theta_1$; V_s is < E so SCR will be Reverse biased and cannot be turned ON.
* SCR can be triggered only after θ_1.

During +ve half cycle:

At $\omega t = \alpha$; SCR $T_1 T_2$ conduct

From $\omega t = 0$ to α

SCR T_1, T_2 is FB

From $\omega t = \alpha$ to π

$T_1 T_2$ conducts

$V_{T_1} = V_{T_2} = 0$

$i_0 = \uparrow$

$V_0 = V_s$.

At $\omega t = \pi$

$T_1 T_2$ = RB

$i_0 = \downarrow$

$V_0 = V_s$

At $\omega t = \pi + \alpha$.

$i_0 = 0$

$V_0 = 0$

$T_1 T_2$ = OFF

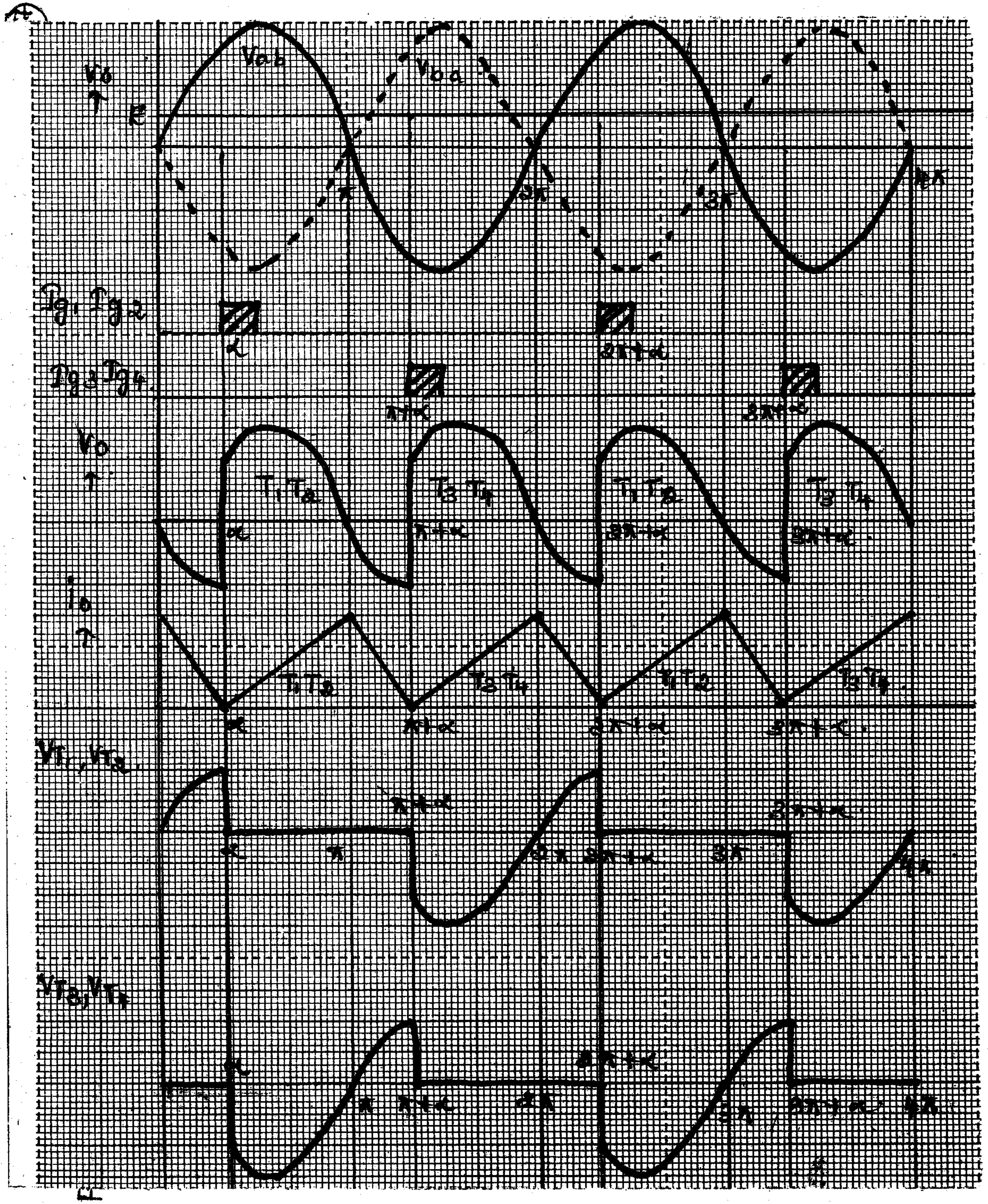
From $\omega t = \pi + \alpha$ to 2π.

$T_3 T_4$ = conducts

$V_{T_3} = V_{T_4} = 0$

$i_0 = \uparrow$.

$V_0 = V_s$.



$$V_{o(avg)} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t \cdot d\omega t.$$

$$\boxed{V_{o}(avg) = \frac{2V_m}{\pi}\cos\alpha.}$$

$$V_{o}(rms) = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m^2 \sin^2\omega t \cdot d\omega t}.$$

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

$$P = V_{orms} * I_{orms}.$$

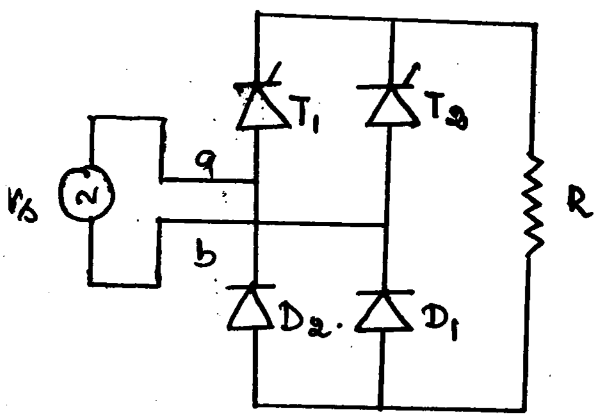
1∅ FULL WAVE HALF CONTROLLED BRIDGE RECTIFIER [OR] SEMICONVERTER.

* Semiconverter is a combination of diodes and SCRs.

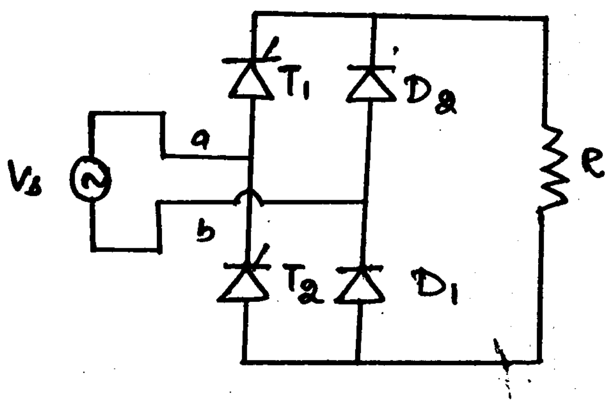
1∅ SEMICONVERTER WITH R LOAD:-

* Semiconverter is connected in two configuration

a) Symmetrical configuration



b) Asymmetrical Configuration.



Symmetrical configuration:-

* In this configuration, cathodes of two SCRs are at same potential.
* So their gates can be connected together and a single gate pulse can be used to trigger both the SCRs.
* which ever SCR is forward biased will turn ON.

Asymmetrical configuration:-

In this configuration seperate triggering circuits are used.

Here only waveforms for symmetrical configuration is explained.

Positive half cycle:-

* Terminal a is +ve, b is −ve
* $V_{ab} = V_m \sin \omega t$; $V_b = -V_m \sin \omega t$.
* V_{ab} supplies SCR T_1 and diode D_1.
* ∴ T_1 and D_1 are forward biased.
* At $\omega t = \alpha$ SCR T_1 is turned ON.
* i_0 flows thro' a − T_1 − R − D_1 − b

From $\omega t = 0$ to α.

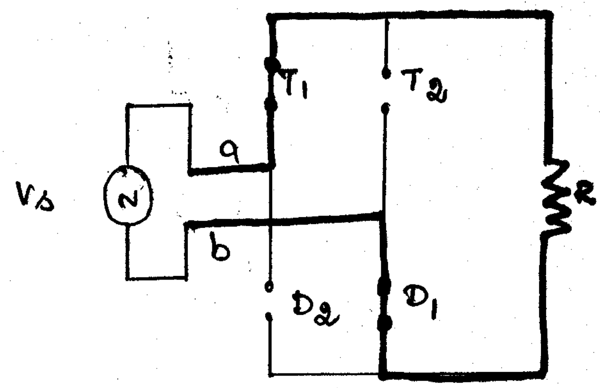
T_1 and D_1 and forward biased

∴ $V_{T_1} = V_{ab}$

$V_{D_1} = 0$

$i_0 = 0$

$V_0 = 0$



From $\omega t = \alpha$ to π

T_1 is turned ON at $\omega t = \alpha$

∴ $V_{T_1} = 0$

$V_{D_1} = 0$

i_0 = ↑ing and reaches zero at $\omega t = \pi$

$V_0 = V_s$ and reaches zero at $\omega t = \pi$.

At $\omega t = \pi$; $i_0 = V_0 = 0$.

At $\omega t = \pi$; Supply vge reaches zero and so T_1 and D_1 and RB and is turned OFF.

From $\omega t = \pi$ to $\pi + \alpha$

at $\omega t = \pi$; T_2 and D_2 and forward biased

∴ $V_{T_2} = V_{ba}$.

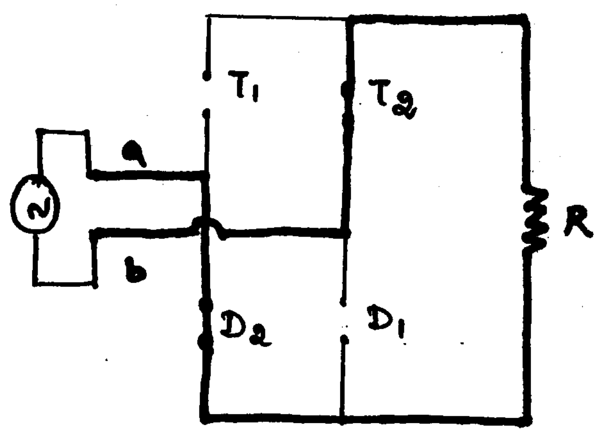
$V_{D_2} = 0$

$i_0 = 0$

$V_0 = 0$.

From $\omega t = \pi + \alpha$ to 2π.

* At $\omega t = \pi + \alpha$; SCR T_2 is ON
* D_2 is already ON



$V_{T_2} = 0$

$V_{D_2} = 0$

i_0 = ↑ing

$V_0 = V_s$.

* At $\omega t = 2\pi$; $i_0 = 0$, $V_0 = 0$

Also at $\omega t = 2\pi$ SCR T_2 and diode D_2 is RB and is turned OFF.

$$\therefore V_0(avg) = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin \omega t \cdot d\omega t$$

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

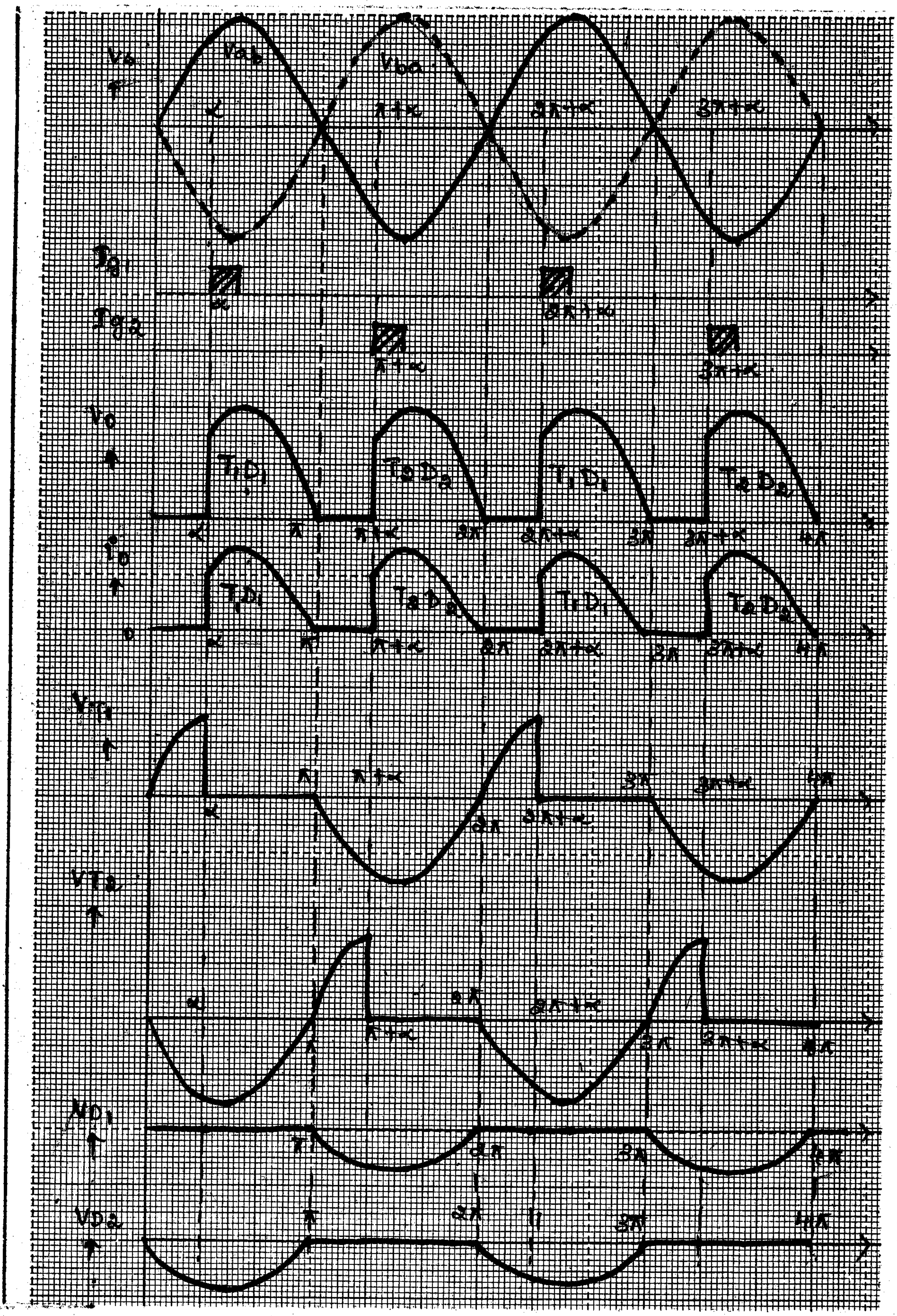
$$V_0(rms) = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2 \omega t \, d\omega t}$$

$$\boxed{V_{0rms} = \frac{V_m}{\sqrt{2\pi}}\sqrt{\pi - \alpha + \frac{1}{2}\sin 2\alpha}}$$

$$I_0(avg) = \frac{V_0(avg)}{R} = \frac{V_m}{\pi R}[1+\cos\alpha]$$

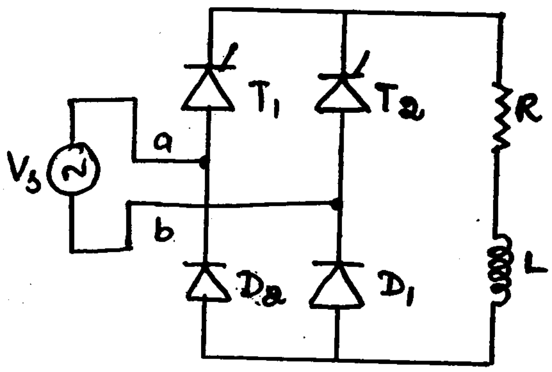
$$I_{0rms} = \frac{V_m}{R\sqrt{2\pi}}\sqrt{\pi - \alpha + \frac{1}{2}\sin 2\alpha}$$

$P = V_{0rms} * I_{0rms}$.


Vs
Vab
Vba
α
π+α
2π+α
3π+α
ig1
ig2
Vo
T1D1
T2D2
io
VT1
VT2
VD1
VD2
π
2π
3π
4π

SEMI CONVERTER WITH RL LOAD:-

SYMMETRICAL CONFIGURATION:-



In the +ve half cycle:-

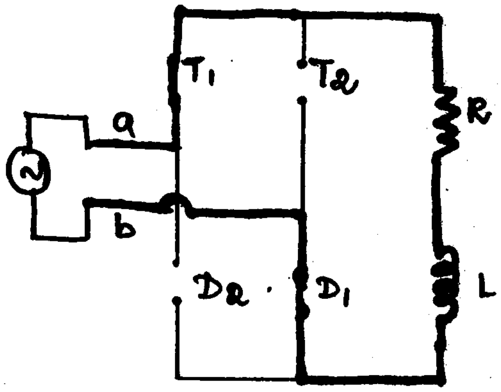
* a is +ve; b is -ve.
* SCR T_1 and diode D_1 is FB
* At $\omega t = \alpha$; SCR T_1 is turned ON.

From $\omega t = 0$ to α:-

SCR T_1 and diode D_1 are FB.

$\therefore V_{T_1} = V_{ab}$; $V_{D_1} = 0$

$i_0 = 0$; $V_0 = 0$



From $\omega t = \alpha$ to π :-

At $\omega t = \alpha$; SCR T_1 is ON

$\therefore V_{T_1} = 0$

$V_{D_1} = 0$

$\therefore$ T_1 and D_1 conduct

i_0 flows thro' $a - T_1 - R - L - D_1 - b$.

$i_0 = \uparrow$ing slowly due to RL load.

$V_0 = V_s$

At $\omega t = \pi$; SCR T_1 and D_1 are reverse biased.

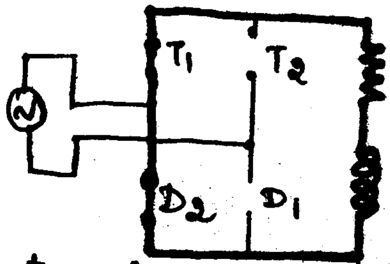
At $\omega t = \pi$ to $\pi + \alpha$

Though at $\omega t = \pi$; SCR T_1 is RB it is not turned OFF $\because$

i_0 is higher than holding current.

But at $\omega t = \pi$; D_1 is RB and turns OFF

But at $\omega t = \pi$; SCR T_1 and Diode D_2 is ON



$\therefore$ From $\omega t = \pi$ to $\pi + \alpha$ T_1 and D_2 conducts. $\therefore V_0 = 0$

$i_0 = \downarrow$

$\therefore$ the load is shorted

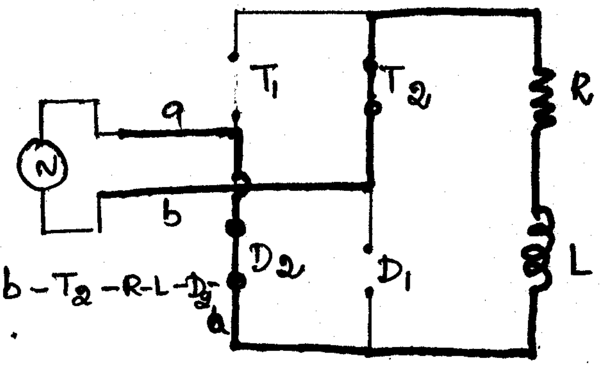
At $\pi + \alpha$ $i_0 = 0$ and SCR T_1 is OFF.

Also at $\pi + \alpha$ SCR T_2 is turned ON.

At $\omega t = \pi + \alpha$; SCR T_2 is ON

D_2 is FB and is already ON

From $\omega t = \pi + \alpha$ to 2π

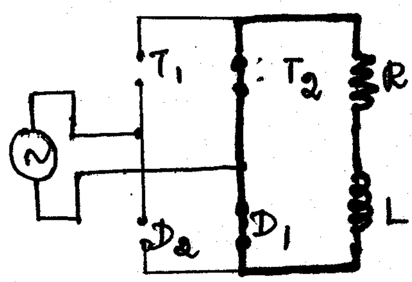


* T_2 and D_2 conduct;
* $V_{T2} = 0$; $V_{D2} = 0$, i_0 flows thro' b – T_2 – R – L – D_2 – a
* i_0 = slowly ↑ses due to RL load.
* i_0 = max at $\omega t = 2\pi$.

At $\omega t = 2\pi$, SCR T_2 is RB but does not turn OFF because i_0 is higher than holding current.

But diode D_1 and SCR T_1 is FB at $\omega t = 2\pi$.

From $\omega t = 2\pi$ to $2\pi + \alpha$.



i_0 ↓ slowly and reaches to zero at $2\pi + \alpha$.

∴ T_2 and D_1 conduct from $\omega t = 2\pi$ to $2\pi + \alpha$.

∴ $V_{T_2} = V_{D_1} = 0$ ∴ $V_0 = 0$

At $\omega t = 2\pi + \alpha$ i_0 reaches zero and so SCR T_2 is turned OFF.

At $\omega t = 2\pi + \alpha$ SCR T_1 is turned ON.

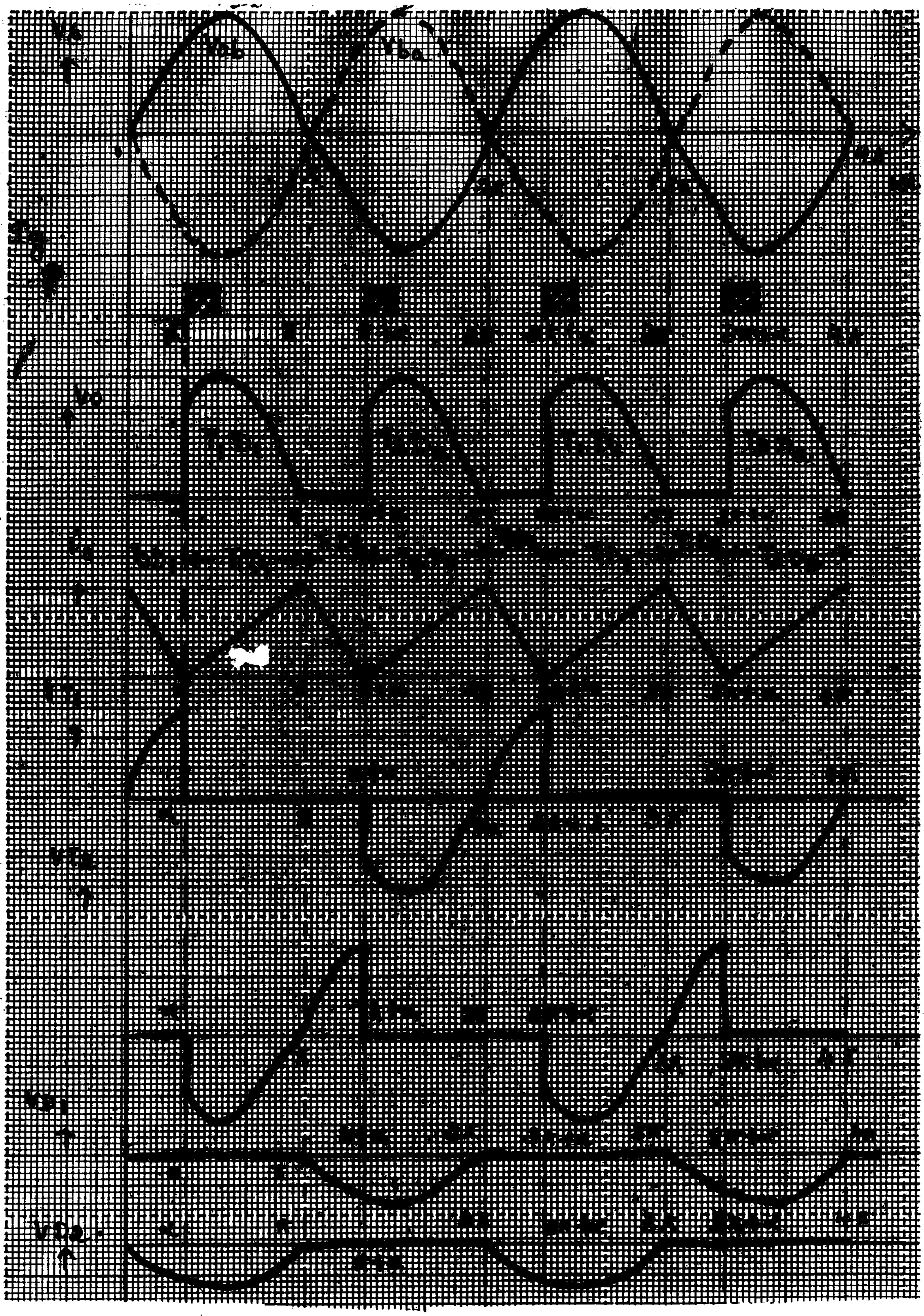
* already diode D_1 is ON

∴ T_1 and D_1 conducts

From $\omega t = 2\pi + \alpha$ to 3π

T_1 and D_1 conducts

$V_{T_1} = 0$; $V_{D_1} = 0$.

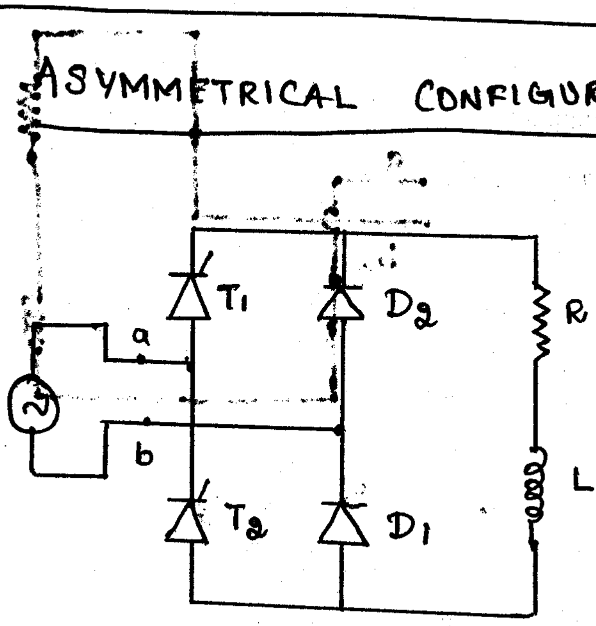


$$V_0(avg) = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \cdot d\omega t = \frac{V_m}{\pi}\left[1+\cos\alpha\right]$$ [Already solved]

$$V_0(rms) = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \cdot d\omega t} = \frac{V_m}{\sqrt{2\pi}}\sqrt{\pi-\alpha+\frac{1}{2}\sin 2\alpha}$$

1ϕ SEMICONVERTER WITH RL LOAD :-

ASYMMETRICAL CONFIGURATION :-



In the +ve half cycle

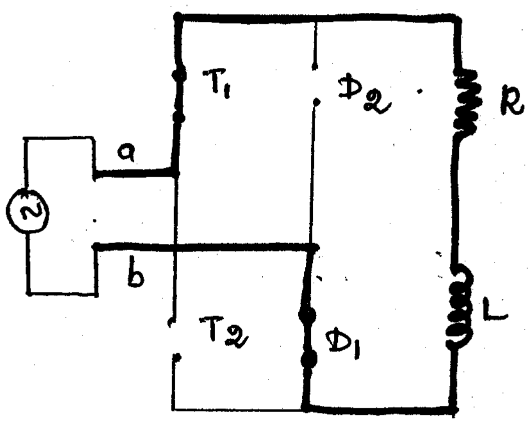
* a is +ve ; b is -ve.
* SCR T_1 and diode D_1 is FB
* At $\omega t = \alpha$; SCR T_1 is turned ON.

From $\omega t = 0$ to α :-

* SCR T_1 and D_1 are FB

∴ $V_{T1} = V_{ab}$; $V_{D1} = 0$.

$i_0 = 0$; $V_0 = 0$



From $\omega t = \alpha$ to π :-

* At $\omega t = \alpha$, SCR T_1 is ON

∴ $V_{T1} = 0$; $V_{D1} = 0$

i_0 = ↑ing. slowly due to RL load.

∴ T_1 and D_1 conducts i_0 flows thro' a - T_1 - R - L - D_1 - b.

$V_0 = V_s$

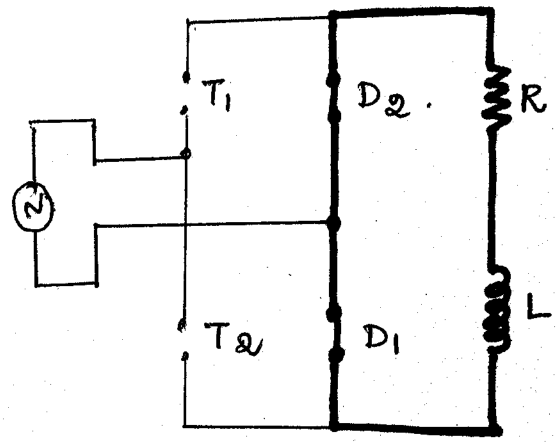
At $\omega t = \pi$

* SCR T_1 is RB and turns OFF
* SCR T_2 is FB

∴ $V_{T1} = V_{ab}$; $V_{T2} = V_{ba}$.

* i_0 is max at $\omega t = \pi$

From $\omega t = \pi$ to $\pi + \alpha$.



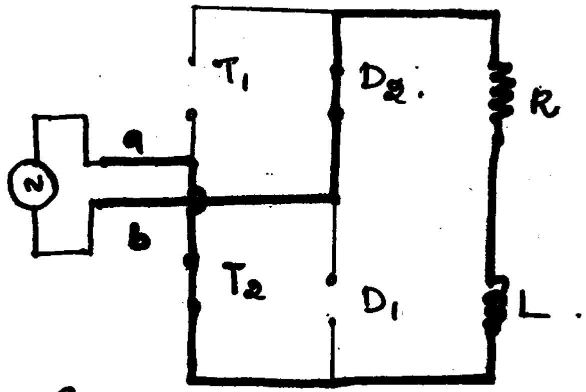
* Diode D_1 and D_2 conducts.
* So i_0 freewheels thro' $D_1 D_2$.
* i_0 ↓ and reaches zero at $\omega t = \pi + \alpha$.

∴ from π to $\pi + \alpha$; $V_0 = 0$ ∴ load is shorted.

At $\omega t = \pi + \alpha$; SCR T_2 is ON.

From $\omega t = \pi + \alpha$ to 2π

Diode D_2 is FB



$V_{T2} = 0$

$V_{D2} = 0$

∴ T_2 and D_2 conducts.

$V_0 = V_s$.

$i_0 = \uparrow^{es}$ slowly due to RL load.

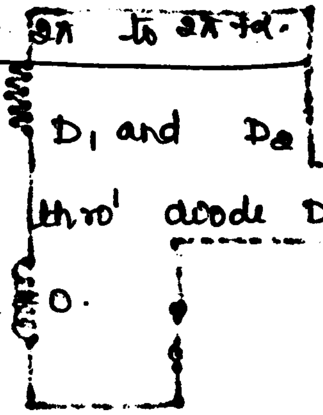
* i_0 flows thro' b – D_2 – R – L – T_2 – a.

At $\omega t = 2\pi$

SCR T_2 is RB and turns OFF

∴ $V_{T2} = V_{ba}$.

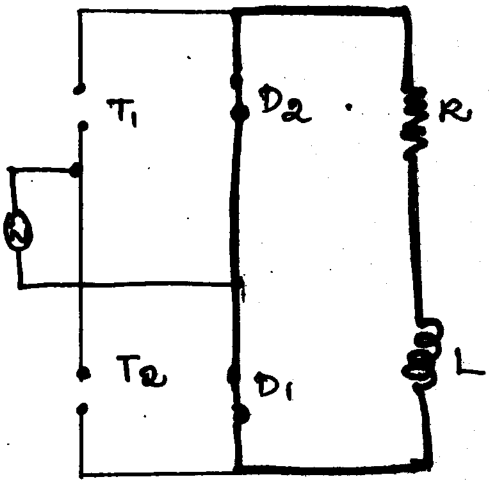
From $\omega t = 2\pi$ to $2\pi + \alpha$.



* Diode D_1 and D_2 conducts.

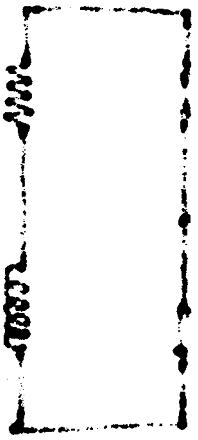
* i_0 ↓ thro' diode D_1, D_2 and reaches zero

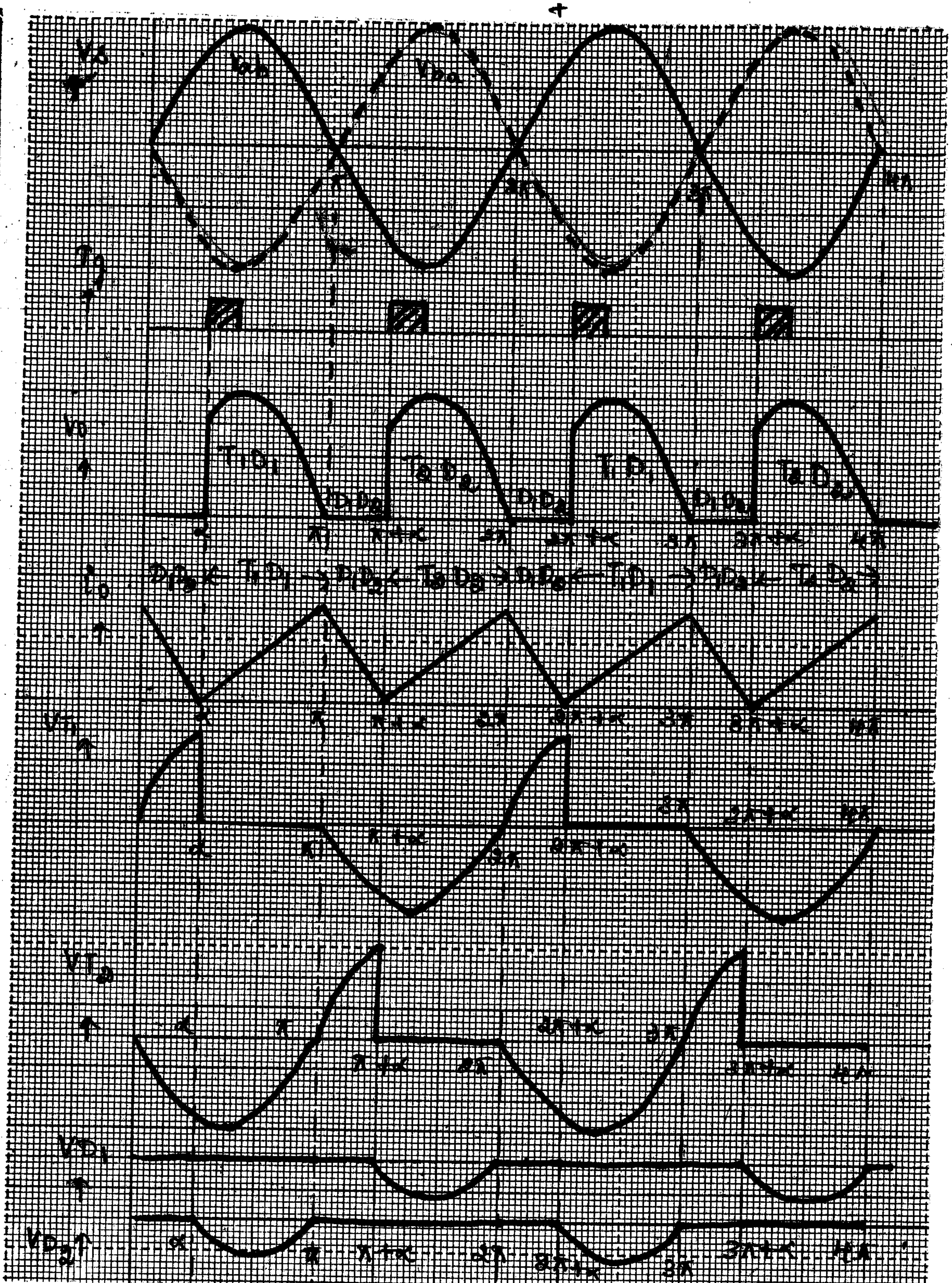
$V_{D1} = V_{D2} = 0$.



At $\omega t = 2\pi + \alpha$

Again T_1 & D_1 will conduct.

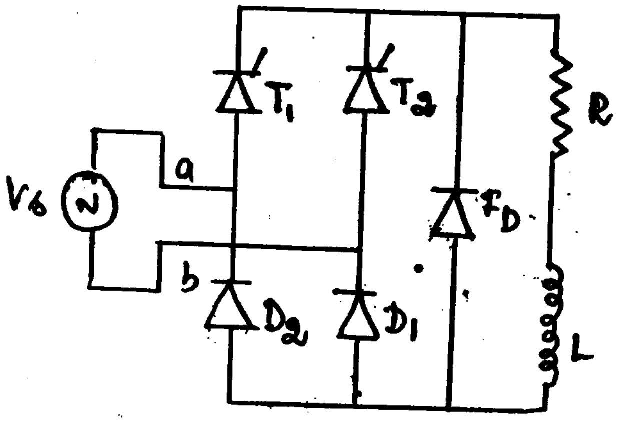




$$V_0(\text{avg}) = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \, d\omega t = \frac{V_m}{\pi}\left[1+\cos\alpha\right]$$

$$V_0(\text{rms}) = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \, d\omega t} = \frac{V_m}{\sqrt{2\pi}}\sqrt{\pi-\alpha+\frac{1}{2}\sin 2\alpha}$$

1Ø SEMICONVERTER WITH RL LOAD AND FREEWHEELING DIODE



In +ve half cycle

From $\omega t = 0$ to α.

* T_1 and D_1 is FB

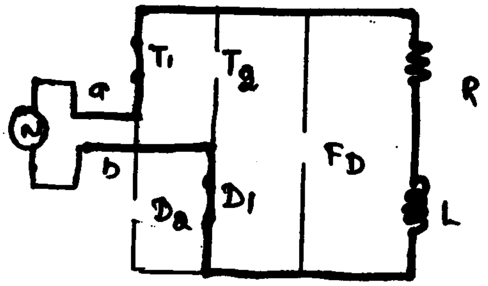
[Give explanation as in previous cases]

At $\omega t = \alpha$:-

* T_1 is turned ON.

From $\omega t = \alpha$ to π :-

* T_1 and D_1 conducts.
* $i_0 \uparrow$ due to RL load.
* $V_0 = V_s$

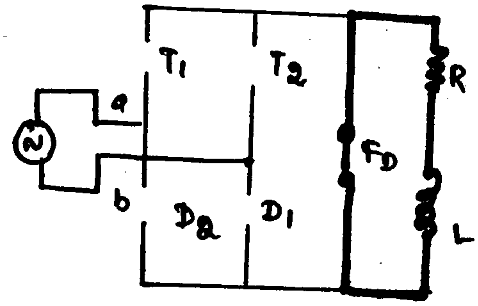


From π to $\pi + \alpha$:-

F_D conducts.

$i_0 = 0$ at at $\pi + \alpha$.

$V_0 = 0$.

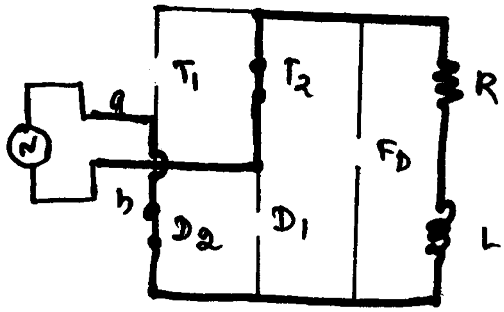


From $\omega t = \pi + \alpha$ to 2π

T_2, D_2 conducts.

$i_0 = \uparrow$ due to RL load.

$V_0 = V_s$.

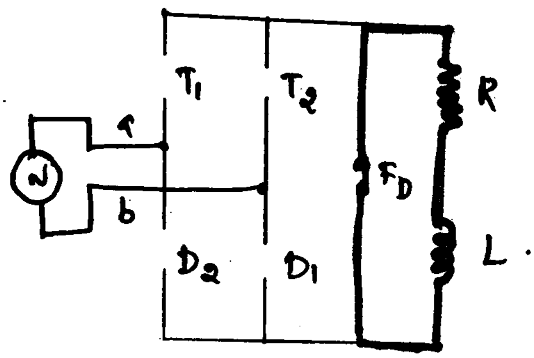


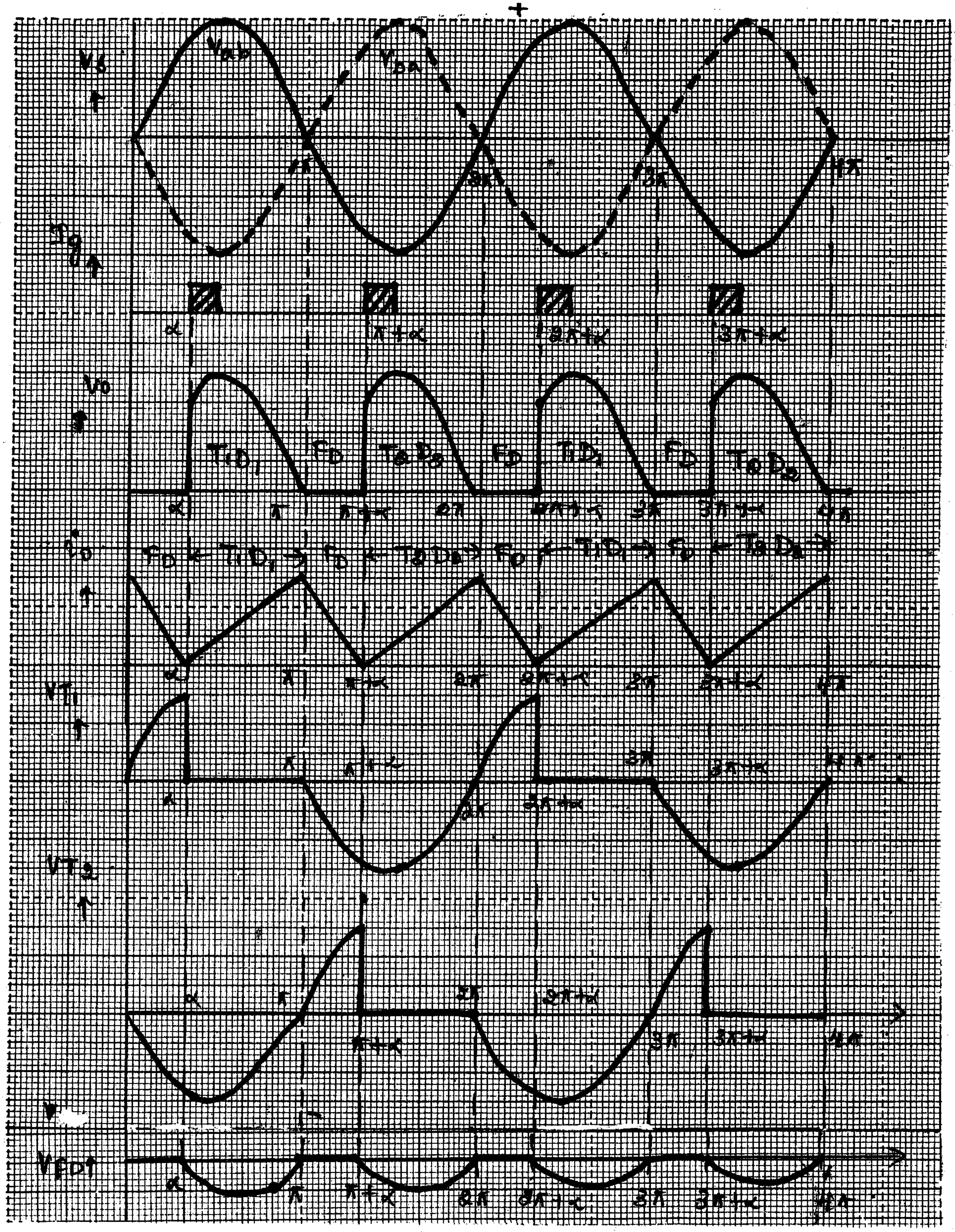
From $\omega t = 2\pi$ to $2\pi + \alpha$

FD conducts

$i_0 \downarrow$ to zero

$V_0 = 0$.

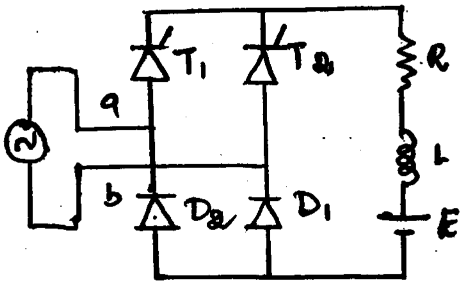




$$V_0(avg) = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \cdot d\omega t = \frac{V_m}{\pi}\left[1+\cos\alpha\right]$$

$$V_0(rms) = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \cdot d\omega t} = \frac{V_m}{\sqrt{2\pi}}\sqrt{\pi-\alpha+\frac{1}{2}\sin 2\alpha}$$

1φ SEMICONVERTER WITH RLE LOAD:-



when no device is conducting $V_0 = E$

In +ve half cycle:-

From 0 to α.

$T_1 D_1$ is FB

But T_1 is Not ON

so $V_0 = E$

From ωt = α to π

T_1 is ON at α

$V_0 = V_s$ slowly

$i_0 = \uparrow$ due to RL Load

At ωt = π

T_1 is RB and OFF

$V_0 = E$

$i_0 = \downarrow$

From ωt = π to π+α

T_1 OFF, D_1 OFF

T_2, D_2 = FB.

$V_0 = E$

$i_0 = \downarrow$ to zero.

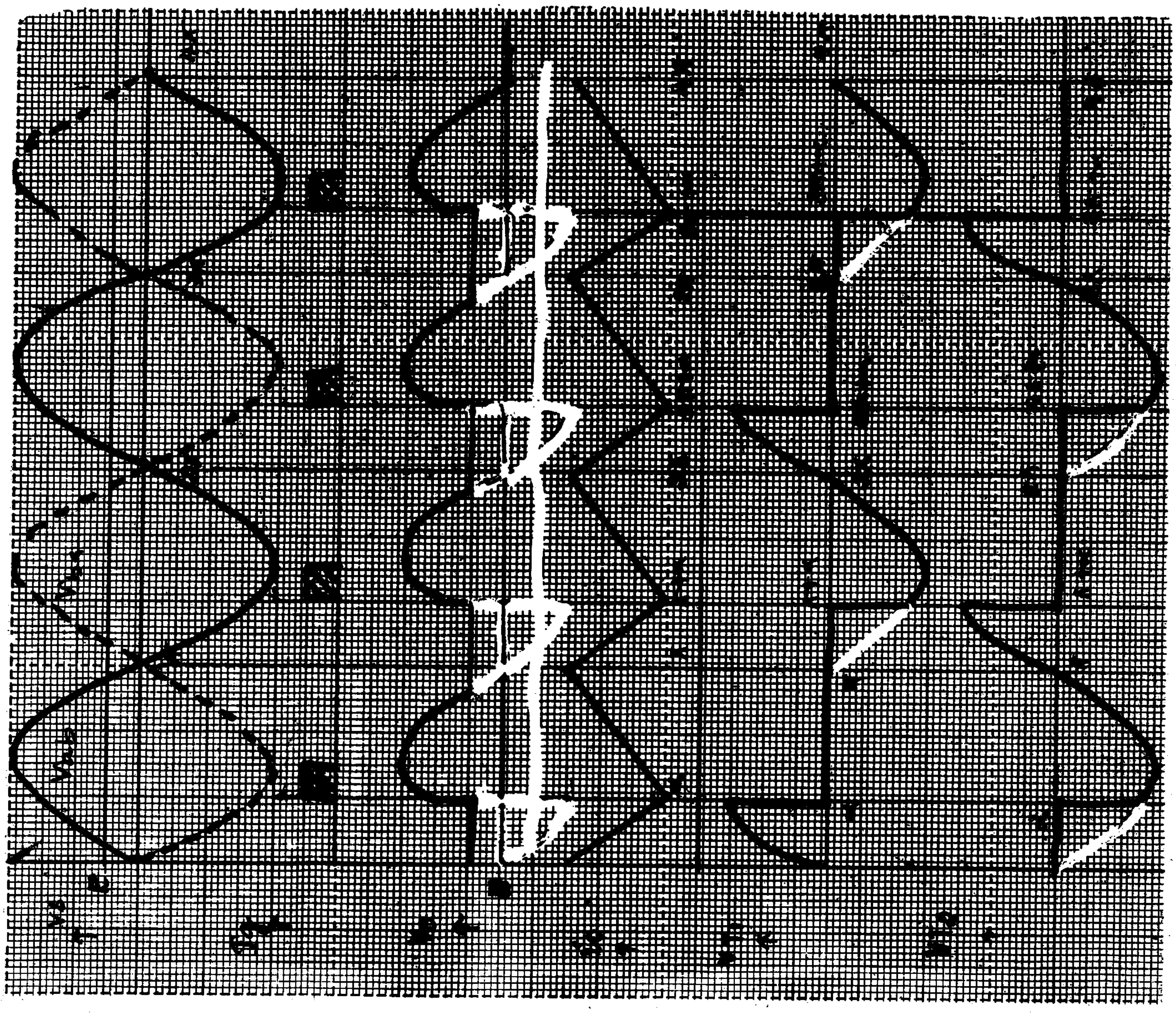
From ωt = π+α to 2π

$T_2 D_2$ = ON

$V_0 = V_s$ slowly.

$i_0 = \uparrow$ due to RL load

$$V_0 = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t \, d\omega t = \frac{2V_m}{\pi}\cos\alpha$$



THREE PHASE CONVERTER:-

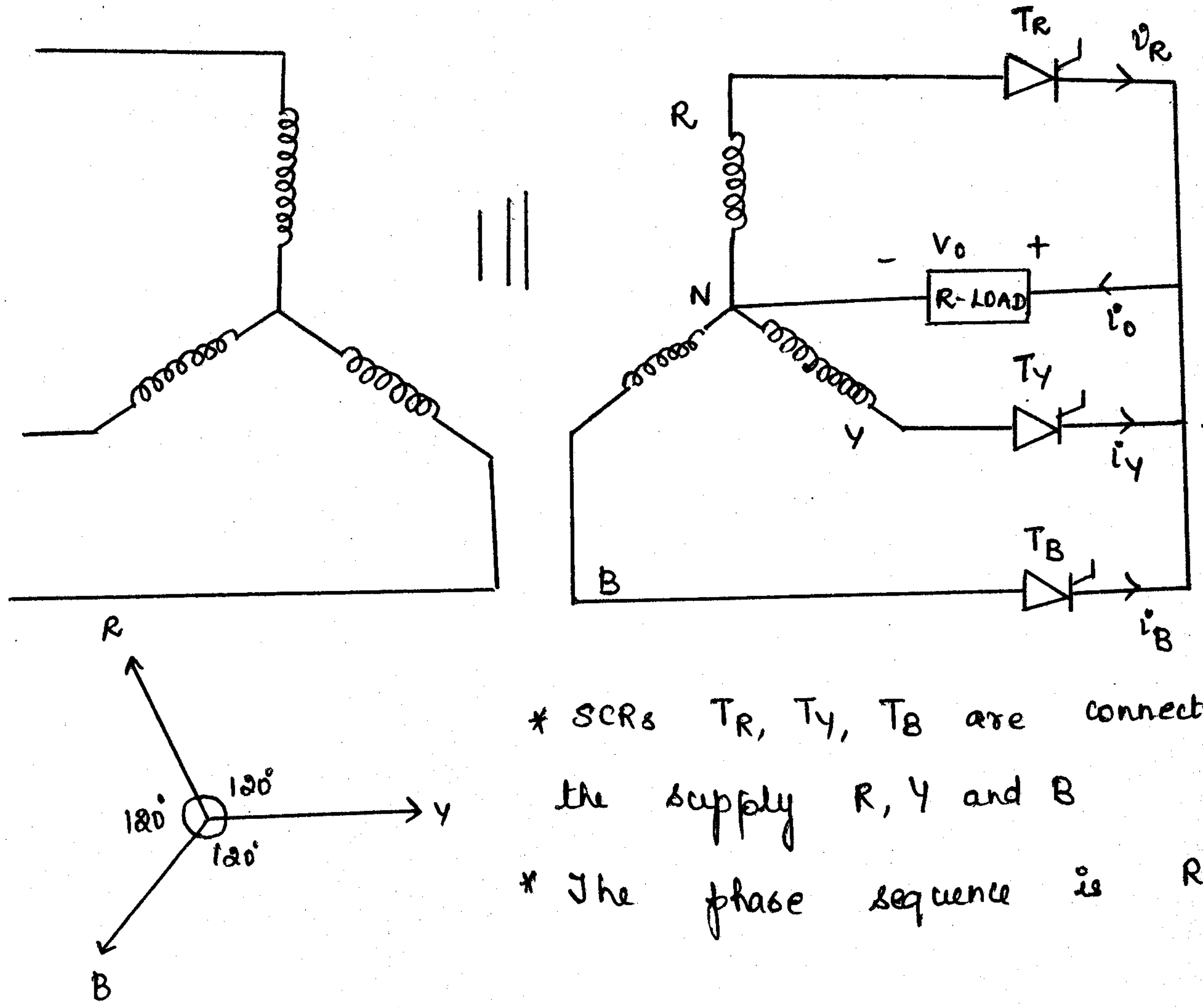
The advantages of three phase converter over single phase converter is

* average output voltage is high.
* Distortion is low.
* Amplitude of ripple is reduced.

Types of three phase converter:-

* Three phase half wave converter.
* Three phase full wave converter → 3ϕ semi converter [half controlled]; 3ϕ full converter [full controlled]

THREE PHASE HALF WAVE CONVERTER WITH R LOAD:-



* SCRs T_R, T_Y, T_B are connected to the supply R, Y and B
* The phase sequence is RYB.

* All the three phases are displaced from each other by an angle of 120°.

* R-phase is taken as reference.
* Y phase lags R by an angle of 120°
* B phase lags R by an angle of 240°.

* Among the three phases, the SCR connected to the phase with highest positive voltage can be triggered

* No SCR can be triggered below a phase angle of 30°.

* i.e., If R phase is more positive, T_R can be turned ON.

* If Y phase is more positive, T_Y can be ON.
* If B phase is more +ve, T_B can be ON.

* Every SCR will conduct for a maximum of 120° after it has been turned ON.

* At $\omega t = 30°$; V_{RN} is more positive than V_{BN}, V_{CN}.

∴ SCR connected to R phase i.e T_R can be triggered, because it is forward biased.

* T_R cannot be turned ON before $\omega t = 30°$ because it is reverse biased by the already conducting SCRs.

NOTE :-

∴ $\omega t = 30$ corresponds to $\alpha = 0$,

(or) $\boxed{\omega t = \alpha + 30°}$ (or) $\boxed{\alpha = \omega t - 30°}$.

∴ If we say $\alpha = 0$, it means $\omega t = 30°$

∴ If an SCR is triggered at $\alpha = 0$ ($\omega t = 30$) it will conduct for 120° ie $\alpha = 0 + 120 = 120^\circ$ (or) ($\omega t = \alpha + 30 = 120 + 30 = 150^\circ$).

* Similarly the next SCR will be triggered 180° after the first SCR is triggered.

* ie if SCR T_R is triggered at $\alpha = 30^\circ$ ($\omega t = 60$) then T_Y will be triggered at $\alpha = 150$ ($\omega t = 180$). and so on.

* T_B will be triggered at $\alpha = 270$ ($\omega t = 300$).

Max value of α is 180°. SCR

Modes :-

a) When $\alpha \leq 30^\circ$ → conduction mode.

b) when $\alpha > 30^\circ$ and $< 150^\circ$ → discontinuous mode.

c) when $\alpha \geq 150$ → no conduction mode.

For $\alpha = 0^\circ$ [ie $\omega t = 30^\circ$]

T_R is turned ON at $\omega t = 30^\circ$

T_Y is turned ON at $\omega t = 150$

T_B is turned ON at $\omega t = 270^\circ$

Duration	More Positive	Forward bias	Fired SCR	o/p vge.
$\omega t = 30^\circ$ to 150°	R phase is more +ve	T_R is FB	T_R is ON	$V_O = V_{RN}$
$\omega t = 150^\circ$ to 270°	Y phase is more +ve	T_Y is FB	T_Y is ON	$V_O = V_{YN}$
$\omega t = 270$ to 390°	B is +ve	T_B is FB	T_B is ON	$V_O = V_{BN}$.

For $\alpha = 30°$; $\omega t = 60°$

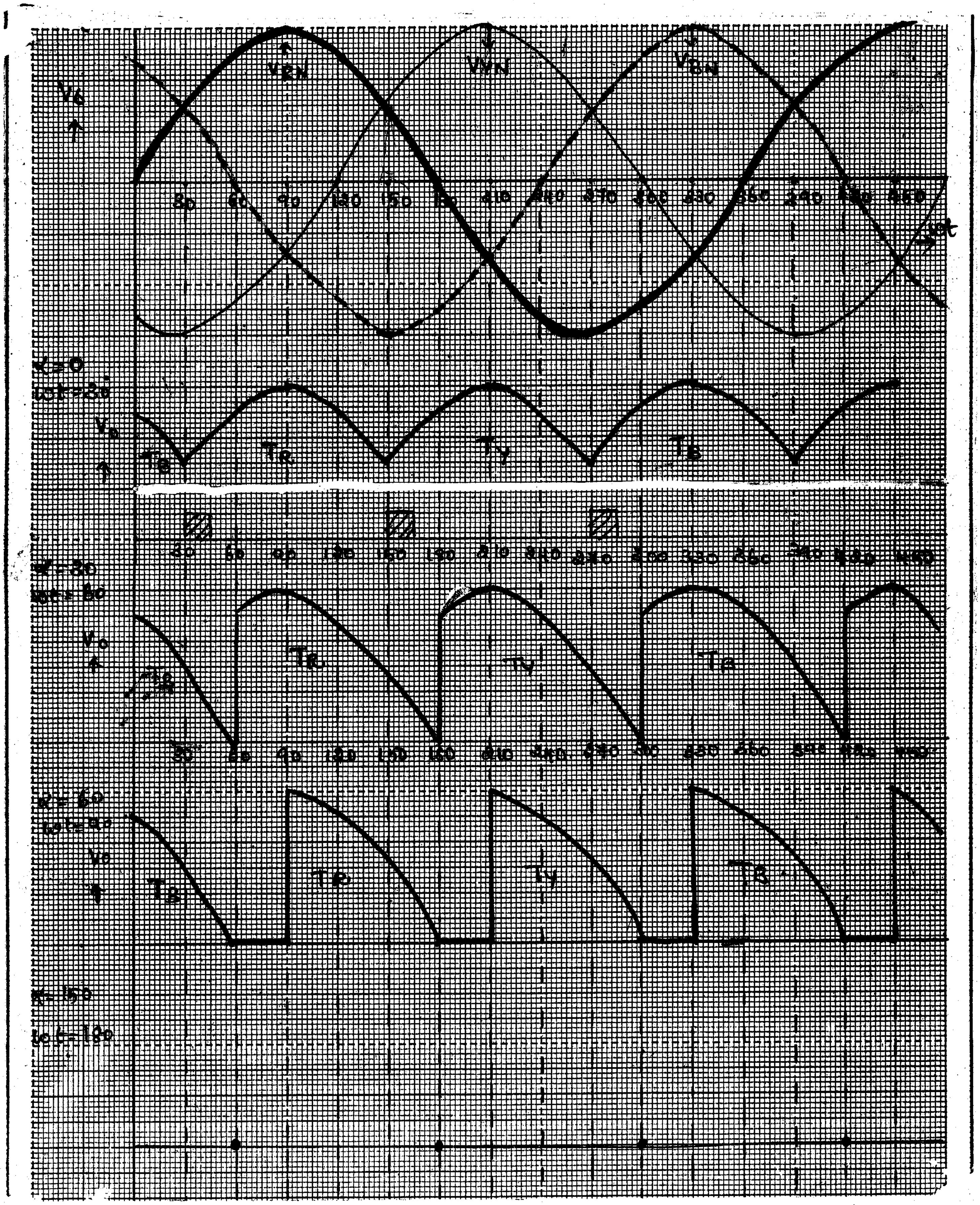
∴ T_R is ON at $\omega t = 60°$; T_Y is ON at $\omega t = 180°$; T_B is ON at $\omega t = 300°$.

Duration	More Positive phase.	Forward bias	Conducting SCR	O/P Vge.
$\omega t = 60$ to $180°$	R is more +ve	T_R	T_R	$V_0 = V_{RN}$
$\omega t = 180$ to 300	Y is more +ve	T_Y	T_Y	$V_0 = V_{YN}$
$\omega t = 300$ to 420	B is more +ve	T_B	T_B	$V_0 = V_{BN}$.

For $\alpha = 60°$. $\omega t = 90°$

. T_R is ON at $\omega t = 90$; T_Y is ON at $\omega t = 210$; T_B is ON at $\omega t = 330$

Duration	More Positive Phase	Forward bias	Conducting SCR	O/P Vge.
($\omega t = 90$ to 210)				
$\omega t = 90$ to 180	R is +ve	T_R	T_R	$V_0 = V_{RN}$
from $\omega t = 180$ to 210	Y is +ve	T_Y	No conduction ∵ T_Y is ON only at $\omega t = 210$	$V_0 = 0$
$\omega t = 210$ to 330				
$\omega t = 210$ to 300	Y is +ve	T_Y	T_Y	$V_0 = V_{YN}$
$\omega t = 300$ to 330	B is +ve	T_B	No conduction ∵ T_B is ON only at $\omega t = 330°$	$V_0 = 0$
$\omega t = 330$ to 450				
$\omega t = 330 \rightarrow 420$	B is +ve	T_B	T_B	$V_0 = V_{BN}$
$\omega t = 420 \rightarrow 450$	R is +ve	T_R	No conduction	$V_0 = 0$


V_0
V_{RN}
V_{YN}
V_{BN}
ωt
α=0
ωt=30°
V_0
T_B
T_R
T_Y
T_B
α=30
ωt=60
V_0
T_B
T_R
T_Y
T_B
α=60
ωt=90
V_0
T_B
T_R
T_Y
T_B
α=150
ωt=180

$$V_0(avg) = \frac{1}{2\pi/3}\int_{\frac{\pi}{6}+\alpha}^{\frac{5\pi}{6}+\alpha} V_m \sin\omega t \cdot d\omega t = \frac{3V_m}{2\pi}\left[-\cos\omega t\right]_{\frac{\pi}{6}+\alpha}^{\frac{5\pi}{6}+\alpha}$$

$$= -\frac{3V_m}{2\pi}\left[\cos\left(\frac{5\pi}{6}+\alpha\right) - \cos\left(\frac{\pi}{6}+\alpha\right)\right]$$

$$V_0(avg) = -\frac{3V_m}{2\pi}\left[\cos\frac{5\pi}{6}\cos\alpha - \sin\frac{5\pi}{6}\sin\alpha - \cos\frac{\pi}{6}\cos\alpha + \sin\frac{\pi}{6}\sin\alpha\right]$$

$$\left[\sin\frac{\pi}{6} = 0.5;\ \sin\frac{5\pi}{6} = 0.5;\ \cos\frac{5\pi}{6} = \frac{-\sqrt{3}}{2};\ \cos\frac{\pi}{6} = \frac{\sqrt{3}}{2}\right]$$

$$= -\frac{3V_m}{2\pi}\left[\cos\frac{5\pi}{6}\cos\alpha - \sin\frac{5\pi}{6}\sin\alpha + \cos\frac{5\pi}{6}\cos\alpha + \sin\frac{5\pi}{6}\sin\alpha\right]$$

$$= -\frac{3V_m}{2\pi}\left[2\cos\frac{5\pi}{6}\cos\alpha\right] = +\frac{3V_m}{2\pi}\left[2 * \frac{\sqrt{3}}{2}\cos\alpha\right]$$

$$\therefore \boxed{V_0(avg) = \frac{3\sqrt{3}\,V_m\cos\alpha}{2\pi}}$$

$$V_0(rms) = \sqrt{\frac{1}{2\pi/3}\int_{\frac{\pi}{6}+\alpha}^{\frac{5\pi}{6}+\alpha} V_m^2\sin^2\omega t\, d\omega t} = \sqrt{\frac{3V_m^2}{2\pi}\int_{\frac{\pi}{6}+\alpha}^{\frac{5\pi}{6}+\alpha}\left(\frac{1-\cos 2\omega t}{2}\right)d\omega t}$$

$$= \sqrt{\frac{3V_m^2}{4\pi}\left[\omega t - \frac{\sin 2\omega t}{2}\right]_{\frac{\pi}{6}+\alpha}^{\frac{5\pi}{6}+\alpha}}$$

$$= \sqrt{\frac{3V_m^2}{4\pi}\left[\frac{5\pi}{6}+\alpha-\frac{\pi}{6}-\alpha - \frac{1}{2}\left[\sin 2\left(\frac{5\pi}{6}+\alpha\right) - \sin 2\left(\frac{\pi}{6}+\alpha\right)\right]\right]}$$

$$= \frac{\sqrt{3}V_m}{2\sqrt{\pi}}\sqrt{\frac{2\pi}{3} - \frac{1}{2}\left[\sin\left(\frac{5\pi}{3}+2\alpha\right) - \sin\left(\frac{\pi}{3}+2\alpha\right)\right]}$$

$$\left[\sin\frac{\pi}{3} = \frac{\sqrt{3}}{2};\ \cos\frac{\pi}{3} = 0.5;\ \sin\frac{5\pi}{3} = -\frac{\sqrt{3}}{2};\ \cos\frac{5\pi}{3} = 0.5\right]$$

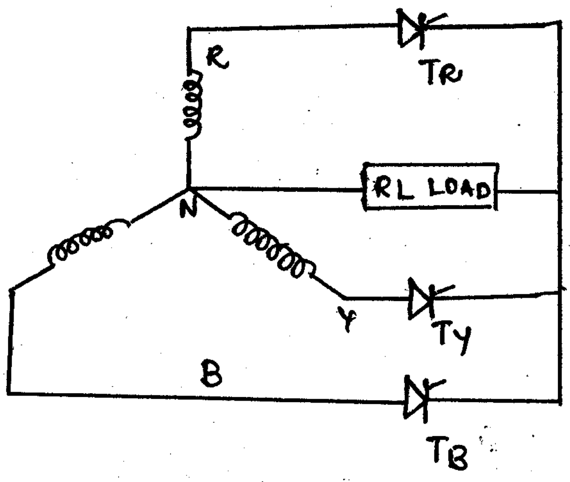
$$= \frac{\sqrt{3}V_m}{2\sqrt{\pi}}\sqrt{\frac{2\pi}{3} - \frac{1}{2}\left[\sin\frac{5\pi}{3}\cos 2\alpha + \cos\frac{5\pi}{3}\sin 2\alpha - \sin\frac{\pi}{3}\cos 2\alpha - \cos\frac{\pi}{3}\sin 2\alpha\right]}$$

$$= \frac{\sqrt{3}V_m}{2\sqrt{\pi}}\sqrt{\frac{2\pi}{3} - \frac{1}{2}\left[\sin\frac{5\pi}{3}\cos 2\alpha + \cos\frac{5\pi}{3}\sin 2\alpha + \sin\frac{5\pi}{3}\cos 2\alpha - \cos\frac{5\pi}{3}\sin 2\alpha\right]}$$

$$= \frac{\sqrt{3}V_m}{2\sqrt{\pi}}\sqrt{\frac{2\pi}{3} - \frac{1}{2} * 2\sin\frac{5\pi}{3}\cos 2\alpha} = \frac{\sqrt{3}V_m}{2\sqrt{\pi}}\sqrt{\frac{2\pi}{3} + \frac{\sqrt{3}}{2}\cos 2\alpha}$$

$$\therefore V_0(rms) = \frac{\sqrt{3}V_m}{2\sqrt{\pi}}\sqrt{\frac{2\pi}{3} + \frac{\sqrt{3}}{2}\cos 2\alpha}.$$

3φ HALF WAVE CONVERTER WITH RL LOAD:-



* T_R, T_Y and T_B are 3 SCRs connected across R, Y and B phase respectively.
* The SCR connected to the phase with highest +ve value is triggered.

* T_R is triggered when R phase is more +ve (ie V_{RN} is +ve)
* T_Y is triggered when Y phase is more +ve.
* T_B is triggered when B phase is more +ve.

* Every SCR will conduct for a maximum of 120° after it has been turned ON. Next SCR will turn ON 120° after turn ON of the previous SCR.
* If we say $\alpha = 0$, it means $\omega t = 30°$.

  α can vary b/w 0 to 120° (or) $\omega t = 30°$ to 150°.

For $\alpha = 0°$; $\omega t = 30°$ [T_R is ON at $\omega t = 30$; T_Y is ON at $\omega t = 150$, T_B is ON at $\omega t = 270$]

Duration.	More +ve	Forward bias	conducting SCR	o/p vge.
$\omega t = 30° \rightarrow 150$	R phase is more +ve	T_R	T_R	$V_0 = V_{RN}$
$\omega t = 150 \rightarrow 270°$	Y phase is more +ve	T_Y	T_Y	$V_0 = V_{YN}$
$\omega t = 270 \rightarrow 390°$	B phase is more +ve	T_B	T_B	$V_0 = V_{BN}$

For $\alpha = 30°$, $\omega t = 60°$

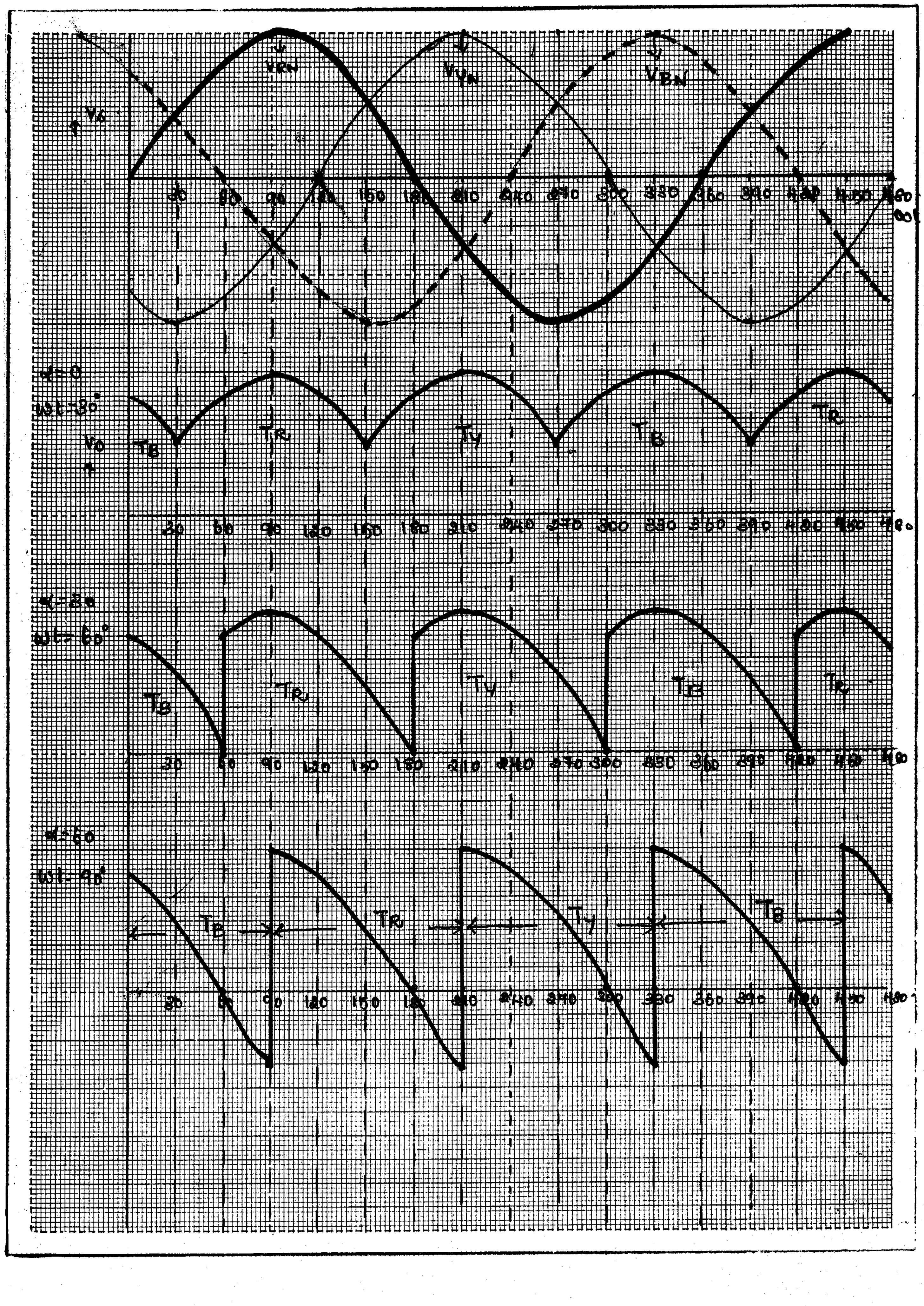
∴ T_R is ON at $\omega t = 60$, T_Y is ON at $\omega t = 180$, T_B is ON at $\omega t = 300$.

Duration	More +ve phase.	Forward biased SCR	Conducting SCR	o/p vge.
$\omega t = 60 \rightarrow 180$	R is more +ve.	T_R	T_R	$V_o = V_{RN}$
$\omega t = 180$ to 300	Y is more +ve	T_Y	T_Y	$V_o = V_{YN}$
$\omega t = 300$ to 420	B is more +ve	T_B	T_B	$V_o = V_{BN}$

For $\alpha = 60°$, $\omega t = 90°$

T_R is ON at $\omega t = 90$, T_Y is ON at $\omega t = 210$; T_B is ON at $\omega t = 330$.

Duration.	More +ve phase.	Forward biased SCR	Conducting SCR	o/p vge.
$\omega t = 90 \rightarrow 180$	R is more +ve	T_R	T_R	$V_o = V_{RN}$
$\omega t = 180 \rightarrow 210$	Y is more +ve	T_Y. ↓ though T_Y is FB it is turned ON only at $\omega t = 210$	T_R conducts because due to RL load current takes time to reach zero.	$V_o = V_{RN}$
$\omega t = 210 \rightarrow 300$	Y is +ve	T_Y	T_Y	$V_o = V_{YN}$
$\omega t = 300 \rightarrow 330$	B is +ve	T_B is FB (ON only at 330)	T_Y still conducts due to RL load current reaches zero slowly	$V_o = V_{YN}$
$\omega t = 330 \rightarrow 420$	B is +ve.	T_B	T_B	$V_o = V_{BN}$
$\omega t = 420 \rightarrow 450$	R is +ve	T_R	T_B still conducts because curnt takes time to reach zero due to RL load	$V_o = V_{BN}$


VRN
VYN
VBN
V0
ωt
30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480
α=0
ωt=30°
TB
TR
TY
TB
TR
α=30
ωt=60°
TB
TR
TY
TB
TR
α=60
ωt=90°
TB
TR
TY
TB

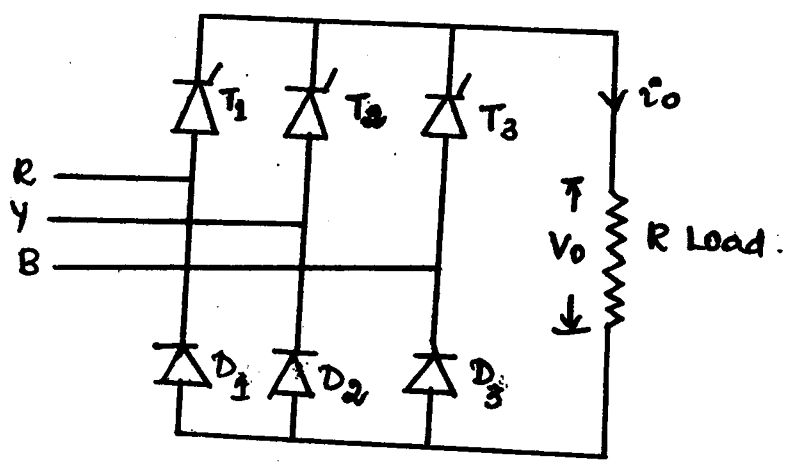
3ϕ FULLWAVE CONVERTER:-

It is further divided into

a) 3ϕ full wave half controlled converter (or) 3ϕ semiconverter.

b) 3ϕ full wave fully controlled converter (or) 3ϕ Full converter.

3ϕ SEMICONVERTER:- [with R load].



* Semiconverter uses 3 SCRs T_1, T_2, T_3 and three diodes D_1, D_2, D_3.

* T_1, T_2 and T_3 are the POSITIVE GROUP SCRs.

* D_1, D_2 and D_3 are the NEGATIVE GROUP diodes.

* By varying the firing angle of the conduction of SCRs in the positive group is varied. But the conduction of diodes in the negative group remains the same.

* The combination of diodes and SCRs conduct for a time period of 120°.

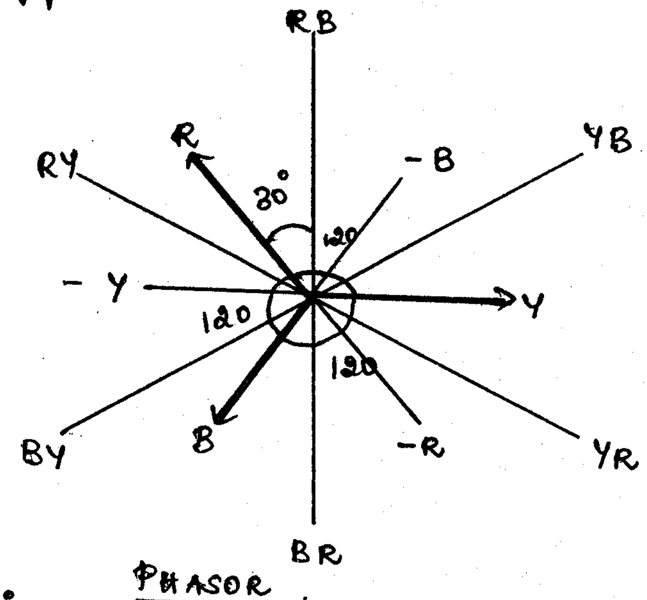
* During every 120° one device from the +ve group and one device from the -ve group will conduct.

* SCR connected to the more +ve phase will conduct.

* Diode connected to the more -ve phase will conduct.

* V_{RN}, V_{YN} & V_{BN} are phase Vges

* when any SCR and diode conducts the line Vg is applied to the load. ∴ it is necessary to draw line Vges.



V_{RY} leads R by 30°

V_{RB} lags R by 30°

RYB
↓
V_{RY}
V_{RB}
V_{YB}
V_{YR}
V_{BR}
V_{BY}

Phase	SCR	DIODE
R	T_1	D_1
Y	T_2	D_2
B	T_3	D_3

For $\alpha = 0°$; $\omega t = 30°$

T_1 is turned ON at $\omega t = 30°$,
T_2 is turned ON at $\omega t = 150$,
T_3 is turned ON at $\omega t = 270$,

From $\omega t = 30 \rightarrow 90°$

* R phase is more +ve and Y phase is more -ve.

∴ T_1 is connected to R phase is turned ON.
D_2 connected to Y phase is forward biased

∴ T_1 D_2 conducts.

T_1 D_2
R Y = V_{RY}.

∴ $V_0 = V_{RY}$. (o/p traces V_{RY} line waveform).

From $\omega t = 90 \rightarrow 150°$

* R phase is more +ve; B phase is more -ve.
* T_1 is connected to R phase.
* D_3 is connected to B phase.

∴ $T_1 D_3$ conducts

$V_0 = V_{RB}$.

From $\omega t = 150 \rightarrow 210°$

* Y phase is more +ve; B phase is more -ve.
* T_2 is connected to Y phase. It is triggered at $\omega t = 150$.
* D_3 is connected to B phase

∴ $T_2 D_3$ conducts.

$V_0 = V_{YB}$.

From $\omega t = 210 \rightarrow 270$.

* Y phase is more +ve, R phase is more -ve.
* T_2 is connected to Y phase.
* D_1 is connected to R phase.
* $T_2 D_1$ conducts

$V_0 = V_{YR}$.

From $\omega t = 270 \rightarrow 330°$

* B phase is more +ve; R phase is more -ve.
* T_3 is connected to B phase; D_1 is connected to R phase.
* $T_3 D_1$ conducts; $V_0 = V_{BR}$.

From $\omega t = 330 \rightarrow 390°$

* B phase is more +ve; Y phase is more -ve.
* T_3 is connected to B phase; D_2 is connected to Y phase.
* $T_3 D_2$ conducts; $V_0 = V_{BY}$

$$V_0(avg) = \frac{1}{2\pi/3}\int_{\frac{\pi}{6}+\alpha}^{\frac{5\pi}{6}+\alpha} V_m \sin\omega t \cdot d\omega t = \frac{3}{2\pi}\left\{\int_{\frac{\pi}{6}+\alpha}^{\frac{\pi}{2}} V_{RY}\, d\omega t + \int_{\frac{\pi}{2}}^{\frac{5\pi}{6}+\alpha} V_{RB}\, d\omega t\right\}$$

(RY waveforms exists from ($\frac{\pi}{6}+\alpha$ to $\pi/2$), RB from $\frac{\pi}{2}$ to $\frac{5\pi}{6}+\alpha$)

From phasor diagram, $V_{RY} = \sqrt{3} V_m \sin(\omega t + 30°) = \sqrt{3} V_m \sin(\omega t + \frac{\pi}{6})$

$V_{RB} = \sqrt{3} V_m \sin(\omega t - 30) = \sqrt{3} V_m \sin(\omega t - \frac{\pi}{6})$

$$\therefore V_0(avg) = \frac{3}{2\pi}\left\{\int_{\frac{\pi}{6}+\alpha}^{\frac{\pi}{2}} \sqrt{3} V_m \sin(\omega t + \frac{\pi}{6}) d\omega t + \int_{\frac{\pi}{2}}^{\frac{5\pi}{6}+\alpha} \sqrt{3} V_m \sin(\omega t - \frac{\pi}{6}) d\omega t\right\}$$

$$= \frac{3\sqrt{3} V_m}{2\pi}\left\{\left[-\cos(\omega t + \frac{\pi}{6})\right]_{\frac{\pi}{6}+\alpha}^{\pi/2} + \left[-\cos(\omega t - \frac{\pi}{6})\right]_{\frac{\pi}{2}}^{\frac{5\pi}{6}+\alpha}\right\}$$

$$= \frac{-3\sqrt{3} V_m}{2\pi}\left\{\left[\cos(\frac{\pi}{2}+\frac{\pi}{6}) - \cos(\frac{\pi}{6}+\alpha+\frac{\pi}{6})\right] + \left[\cos(\frac{5\pi}{6}+\alpha-\frac{\pi}{6}) - \cos(\frac{\pi}{2}-\frac{\pi}{6})\right]\right\}$$

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

$$= \frac{-3\sqrt{3} V_m}{2\pi}\left\{\cos\frac{2\pi}{3} - \cos\frac{\pi}{3}\cos\alpha + \sin\frac{\pi}{3}\sin\alpha + \cos\frac{2\pi}{3}\cos\alpha - \sin\frac{2\pi}{3}\sin\alpha - \cos\frac{\pi}{3}\right\}$$

$$= \frac{-3\sqrt{3} V_m}{2\pi}\left\{-\frac{1}{2} - \frac{1}{2}\cos\alpha + \frac{\sqrt{3}}{2}\sin\alpha - \frac{1}{2}\cos\alpha - \frac{\sqrt{3}}{2}\sin\alpha - \frac{1}{2}\right\}$$

$$= \frac{3\sqrt{3} V_m}{2\pi}\left[\frac{1}{2} + \frac{1}{2}\cos\alpha + \frac{1}{2}\cos\alpha + \frac{1}{2}\right]$$

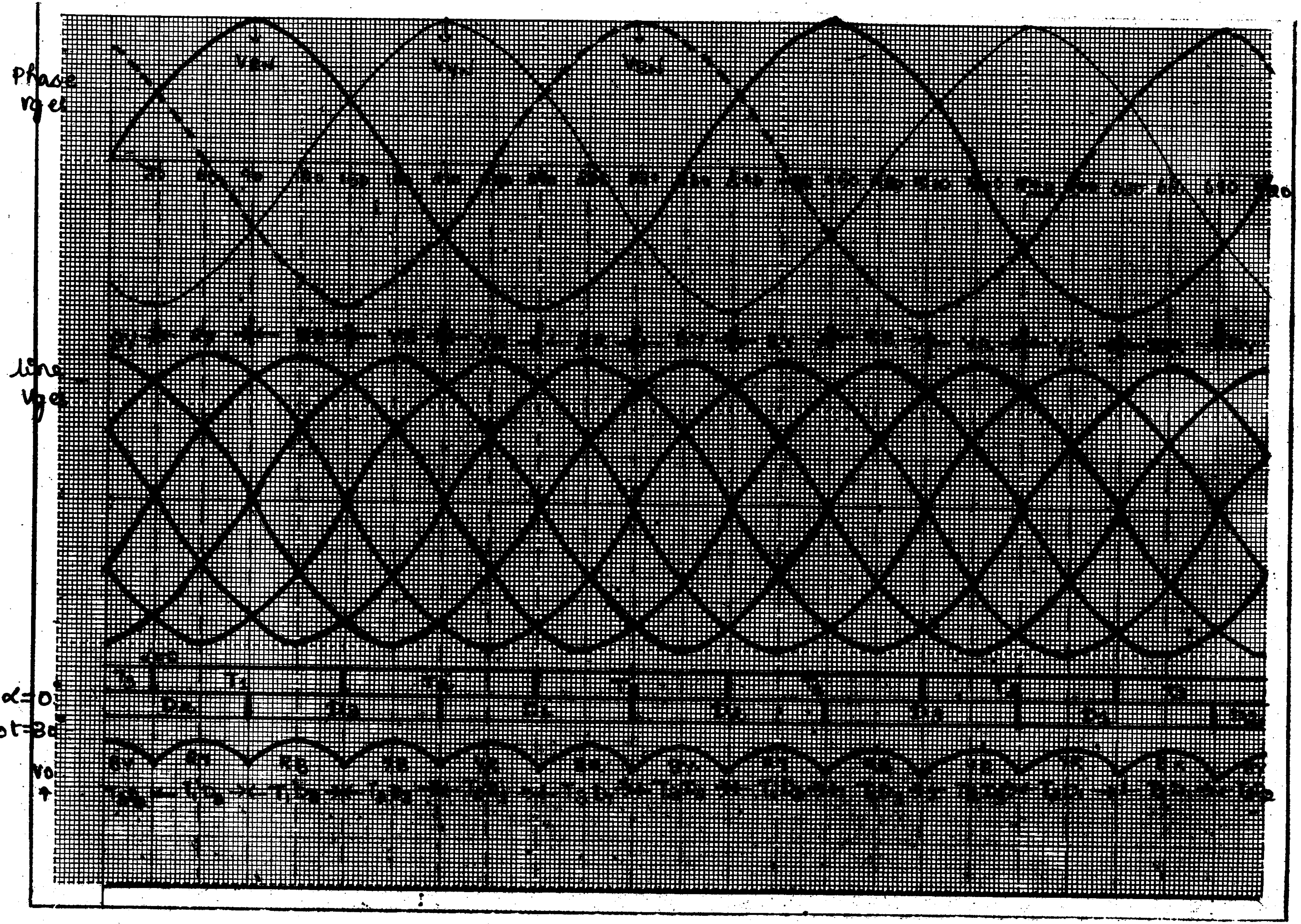
$$= \frac{3\sqrt{3} V_m}{2\pi}\left[1 + \cos\alpha\right]$$

$$\therefore \boxed{V_0(avg) = \frac{3\sqrt{3} V_m}{2\pi}\left[1 + \cos\alpha\right]}$$

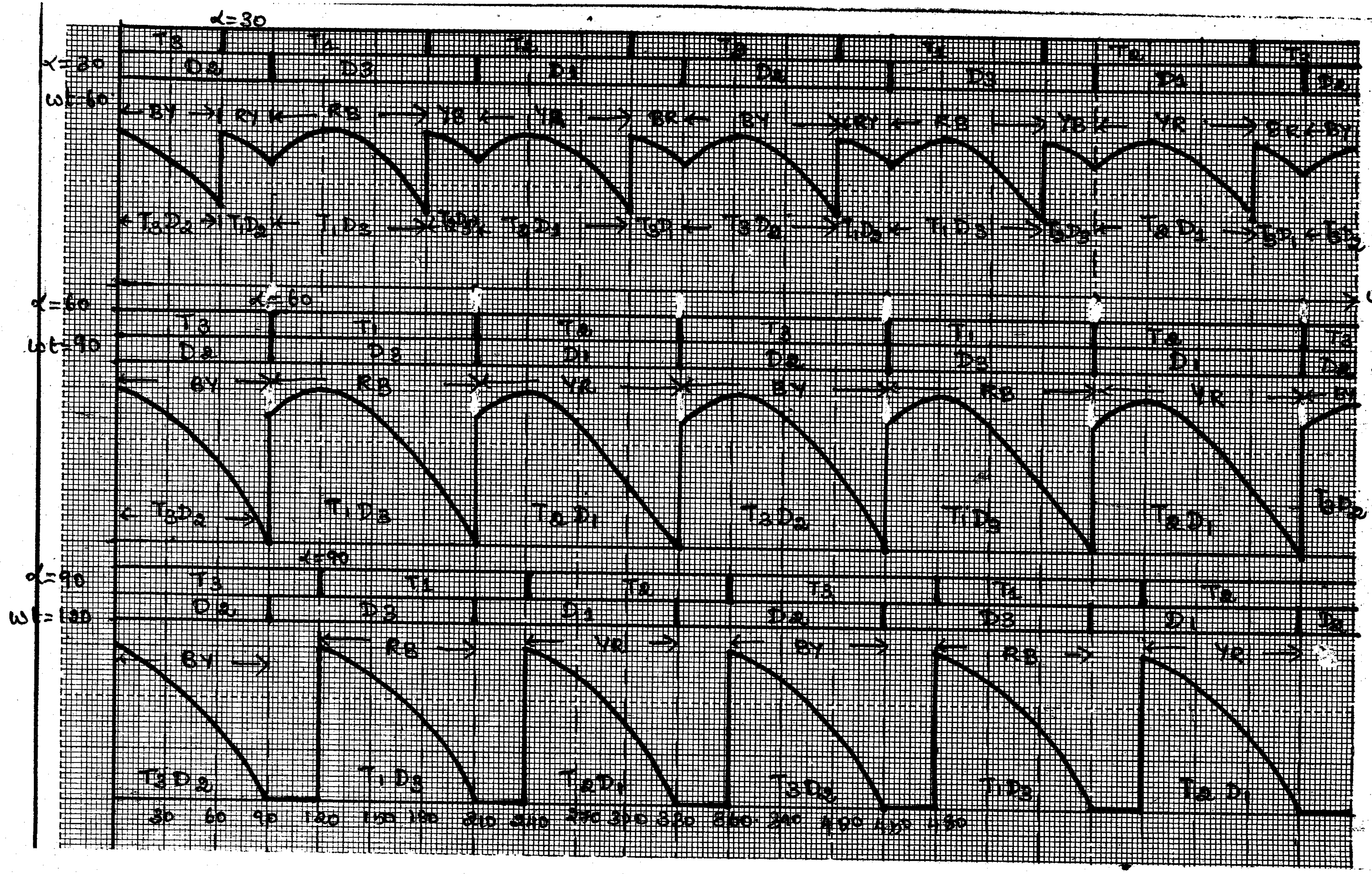
This is derived for $\alpha = 30°$ (or) for $\alpha < 60°$

<u>For $\alpha \geq 60$</u>

$$V_0 = \frac{1}{2\pi/3}\int_{\frac{\pi}{2}+\alpha}^{\pi+\pi/6} \sqrt{3} V_m \sin(\omega t - \pi/6)\, d\omega t = \frac{3\sqrt{3} V_m}{2\pi}\left[1 + \cos\alpha\right].$$

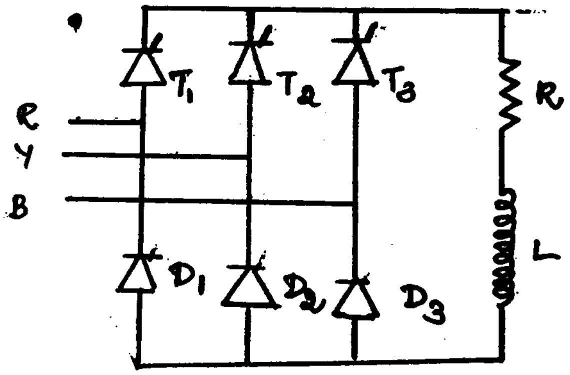


Phase Vge
line Vge
α=0
ωt=30
Vo


α=30
ωt=60
α=60
ωt=90
α=90
ωt=120
T3
T1
T2
D1
D2
D3
BY
RB
YR
RY
YB
BR
T3D2
T1D3
T2D1
T1D2
T2D3
T3D1
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480

3ϕ SEMICONVERTER WITH RL load.

[The waveforms and explanations are same as that of R load]



* T_1, T_2, T_3 are SCRs
* D_1, D_2, D_3 are diodes.
* $T_1 T_2 T_3$ are +ve group SCRs
* $D_1 D_2 D_3$ are −ve group diodes

* By varying the firing angle, the conduction of SCRs in the +ve group is varied. But the conduction of diodes in the −ve group remains the same.

* The combination of diodes and SCRs conduct for a time period of 120°.

* For every 120°, one device from the +ve group and one device from the −ve group will conduct.

* SCR connected to the more +ve phase will conduct.

* Diode connected to more −ve phase will conduct

* when any SCR and diode conducts the line Vge is applied to the load. ∴ it is necessary to draw line Vges.

For $\alpha = 0°$; $\omega t = 30°$

T_1 is turned ON at $\omega t = 30°$, T_2 is turned ON at $\omega t = 150$,

T_3 is turned ON at $\omega t = 150°$

From $\omega t = 30 \rightarrow 90°$

* R phase is more +ve; Y phase is more −ve.
* T_1 is connected to R phase and is turned ON.
* D_2 is connected to Y phase and conducts.

∴ $T_1 D_2$ conducts.

∴ $V_0 = V_{RY}$.

From $\omega t = 90$ to 150

* R is +ve; B is more −ve.
* T_1 is connected to R phase.
* D_3 is connected to B phase.

∴ $T_1 D_3$ conducts

$V_0 = V_{RB}$.

From $\omega t = 150$ to 210

* Y is more +ve; B is more −ve.
* T_2 is connected to Y phase.
* D_3 is connected to B phase.
* $T_2 D_3$ conducts.

$V_0 = V_{YB}$.

From $\omega t = 210$ to 270.

* Y phase is more +ve; R phase is more −ve.
* T_2 is connected to Y phase.
* D_1 is connected to R phase.
* $T_2 D_1$ conducts.

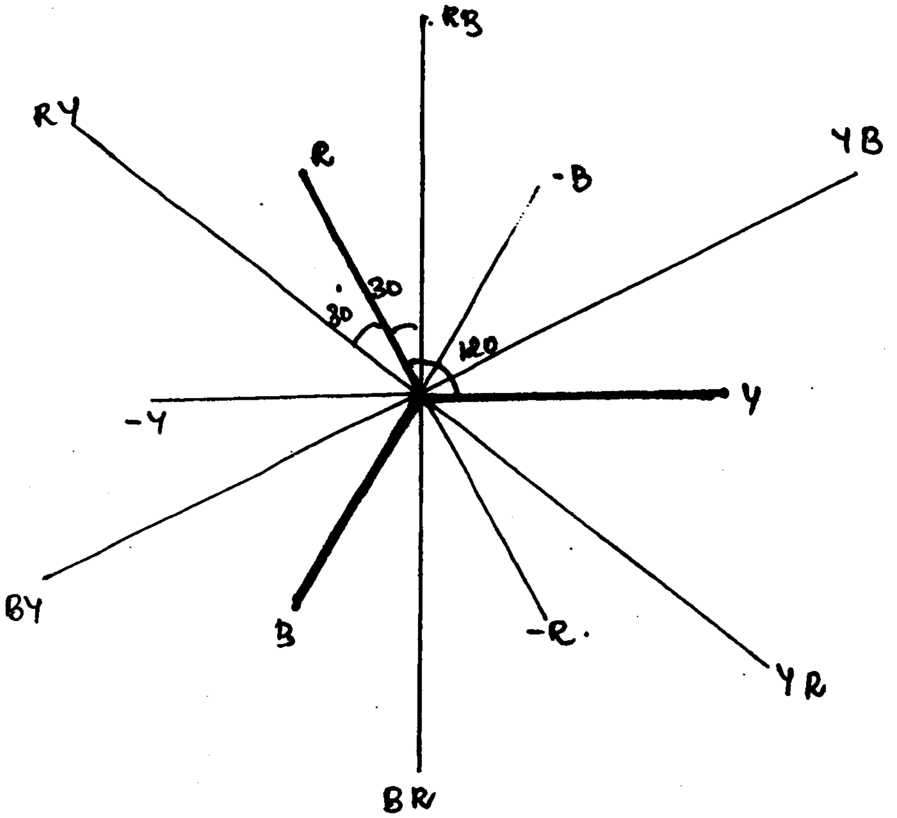
∴ $V_0 = V_{YR}$.

From $\omega t = 270 \to 330°$

* B phase is more +ve; R phase is more -ve.
* T_3 is connected to B phase.
* D_1 is connected to R phase.
* $T_3 D_1$ conducts.
* $V_o = V_{BR}$.

From $\omega t = 330 \to 390$.

* B phase is more +ve; Y phase is more -ve.
* T_3 is connected to B phase.
* D_2 is connected to Y phase.
* $T_3 D_2$ conducts.
* $V_0 = V_{BY}$.



phase	SCR	Diode
R	T_1	D_1
Y	T_2	D_2
B	T_3	D_3.

Similarly From $\omega t = 330 \rightarrow 360$ T_2 follows reverse vge.

From $\omega t = 450 \rightarrow 480$ T_3 follows reverse vge.

For $\alpha < 60^\circ$

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

$$= \frac{3}{2\pi} \left\{ \int_{\frac{\pi}{6}+\alpha}^{\frac{\pi}{2}} V_{RY}\, d\omega t + \int_{\frac{\pi}{2}}^{\frac{5\pi}{6}+\alpha} V_{RB}\, d\omega t \right\}$$

$V_{RY} = \sqrt{3} V_m \sin(\omega t + \frac{\pi}{6})$; $V_{RB} = \sqrt{3} V_m \sin(\omega t - \frac{\pi}{6})$

[Refer phasor diagram in page 82]

$$V_o(avg) = \frac{3}{2\pi} \left\{ \int_{\frac{\pi}{6}+\alpha}^{\frac{\pi}{2}} \sqrt{3} V_m \sin(\omega t + \frac{\pi}{6}) \cdot d\omega t + \int_{\frac{\pi}{2}}^{\frac{5\pi}{6}+\alpha} \sqrt{3} V_m \sin(\omega t - \frac{\pi}{6}) d\omega t \right\}$$

(Already solved in page 83)

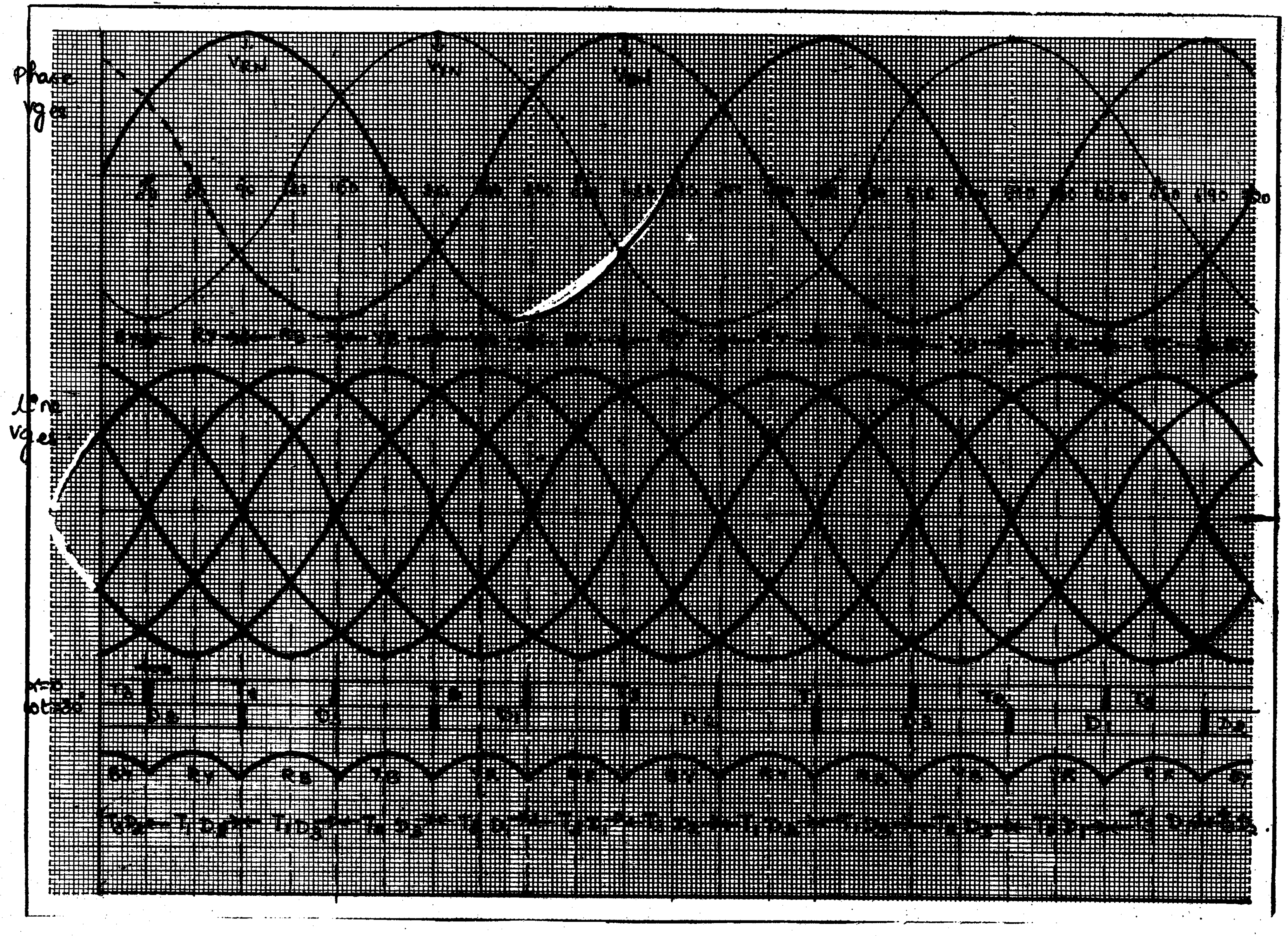
$$= \frac{3\sqrt{3} V_m}{2\pi} [1 + \cos\alpha]$$

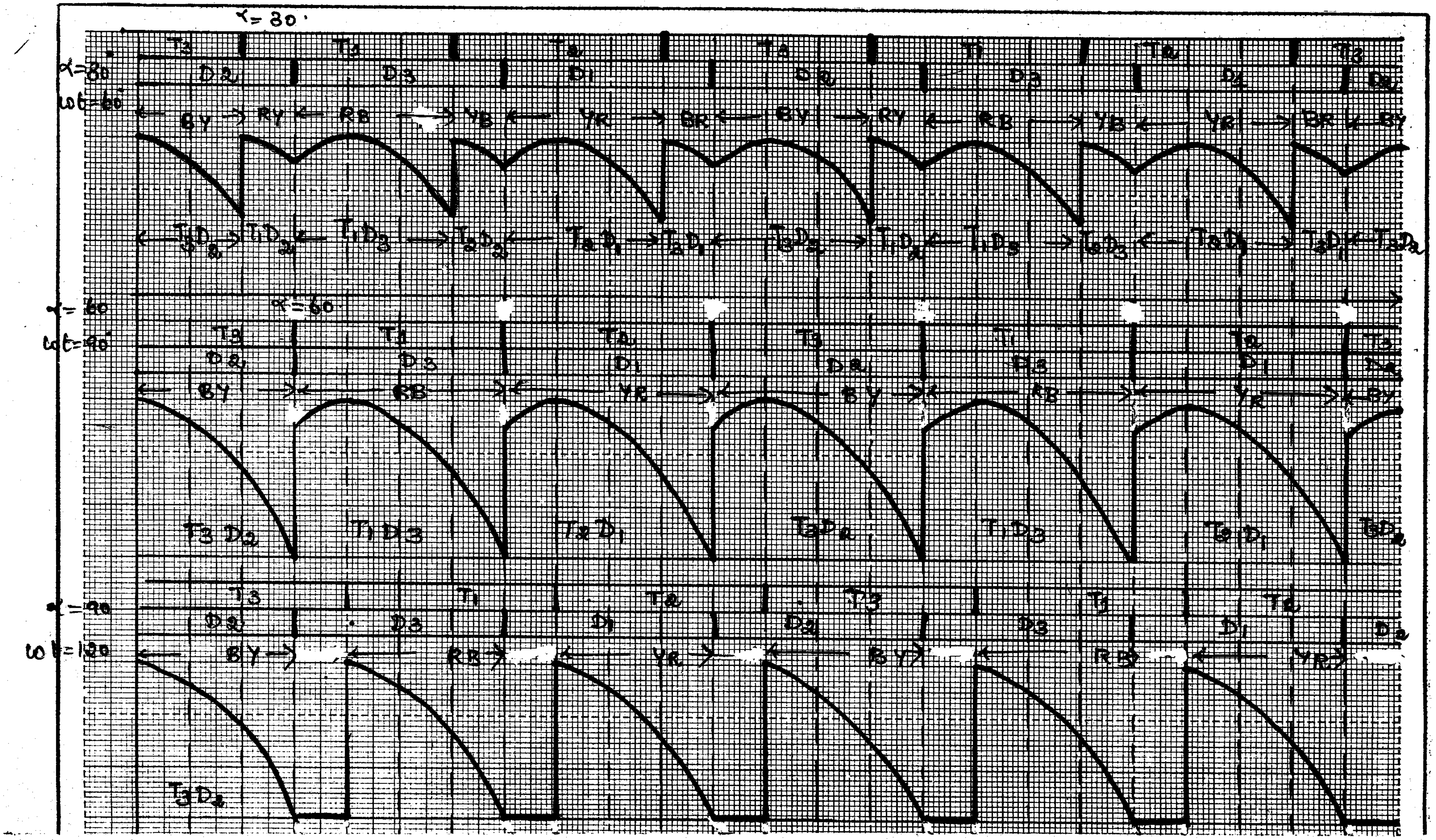
$$\therefore \boxed{V_o(avg) = \frac{3\sqrt{3} V_m}{2\pi} [1 + \cos\alpha]}$$

For $\alpha \geq 60^\circ$

$$V_o(avg) = \frac{1}{\frac{2\pi}{3}} \int_{\frac{\pi}{6}+\alpha}^{\frac{7\pi}{6}} V_{RB}\, d\omega t = \frac{3}{2\pi} \int_{\frac{\pi}{6}+\alpha}^{\frac{7\pi}{6}} \sqrt{3} V_m \sin(\omega t - \frac{\pi}{6}) d\omega t$$

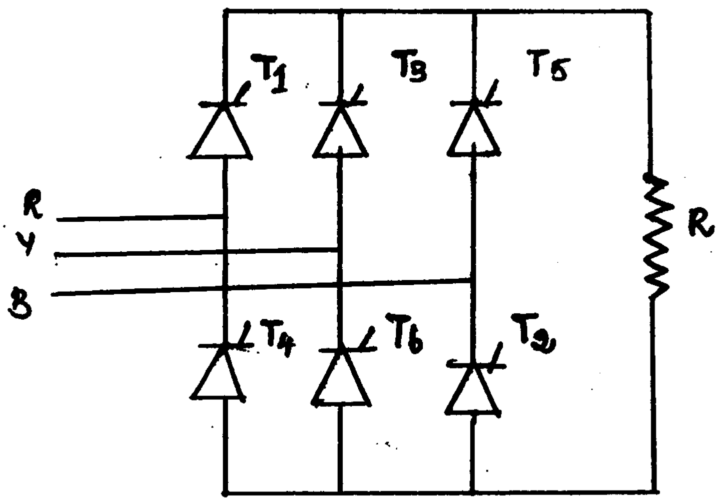
$$\therefore V_o(avg) = \frac{3\sqrt{3} V_m}{2\pi} [1 + \cos\alpha].$$


Phase Vges
Line Vges



γ = 30°
α = 30°
ωt = 60°
α = 60
ωt = 90°
α = 90
ωt = 120

3ϕ FULL CONVERTER:- [With R load].

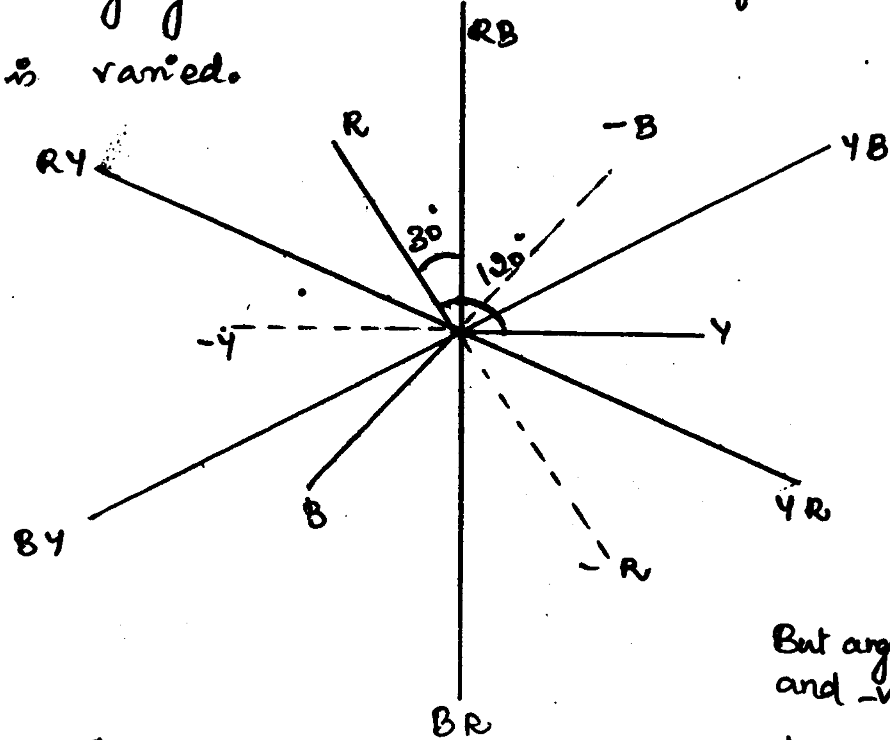


* Full converter consists of 6 SCRs.
* T_1, T_3, T_5 are SCRs of the +ve group.
* T_4, T_6, T_2 are SCRs of the -ve group.

* Only two SCRs conduct in any interval.
* Each SCR conducts for 120°.
* Every SCR pair conducts for an interval of 60°.
* SCRs are triggered in the sequence $T_1 \to T_2 \to T_3 \to T_4 \to T_5 \to T_6$.
* Triggering delay between individual SCRs is 60°.

i.e. if T_1 is triggered at $\alpha = 0$, then T_2 is triggered at $\alpha = 60$, T_3 at $\alpha = 120$; T_4 at $\alpha = 180$; T_5 at $\alpha = 240$; T_6 at $\alpha = 300$

* By varying α the conduction of SCRs in both the group is varied.



[i.e. If T_1 is ON at 30°, T_2 will turn ON 60° after T_1 and so on]

[angle delay b/w SCRs of +ve group is 120 i.e. T_1, T_3, T_5 conduct with 120° delay. T_2, T_4, T_6 conduct with 120° delay]

But angle delay b/w SCR of +ve and -ve group is 60°.

* Always a SCR from -ve group and one SCR from +ve group will conduct.

For $\alpha = 0$, $\omega t = 30$

+ve group

- → T_1 is ON at $\omega t = 30$;
- → T_3 is ON at $\omega t = 150$;
- → T_5 is ON at $\omega t = 270$;

−ve group

- * T_2 is ON at $\omega t = 90$
- * T_4 is ON at $\omega t = 210$
- * T_6 is ON at $\omega t = 330$.

From $\omega t = 30 \rightarrow 90$

- * R phase is more +ve; Y phase is more −ve.
- * T_1 is connected to R phase.
- * T_6 is connected to Y phase.
- * ∴ $T_1 T_6$ conducts.

  $V_0 = V_{RY}$.

From $\omega t = 90$ to 150.

- * R phase is more +ve, B phase is more −ve.
- * T_1 is connected to R phase.
- * T_2 is connected to B phase.
- * $T_1 T_2$ conducts

  $V_0 = V_{RB}$

From $\omega t = 150 \rightarrow 210$

- * Y phase is more +ve; B phase is more −ve.
- * T_3 is connected to Y phase.
- * T_2 is connected to B phase.
- * $T_3 T_2$ conducts

  $V_0 = V_{YB}$

From $\omega t = 210 \rightarrow 270$.

* Y phase is more +ve; R phase is more −ve.
* T_3 is connected to Y phase.
* T_4 is connected to R phase.
* $T_3 T_4$ conducts

$V_0 = V_{YR}$.

From $\omega t = 270 \rightarrow 330$

* B phase is more +ve; R phase is more −ve.
* T_5 is connected to B phase.
* T_4 is connected to R phase.
* $T_5 T_4$ conducts.

$V_0 = V_{BR}$

From $\omega t = 330 \rightarrow 390$

* B phase is more +ve, Y phase is more −ve.
* T_5 is connected to B phase.
* T_6 is connected to Y phase.
* $T_5 T_6$ conducts
* $V_0 = V_{BY}$.

output vge eqn.

For $\alpha \leq 60°$

$$V_{0(avg)} = \frac{1}{\pi/3} \int_{\frac{\pi}{6}+\alpha}^{\frac{\pi}{2}+\alpha} V_{RY}\, d\omega t = \frac{3}{\pi} \int_{\frac{\pi}{6}+\alpha}^{\frac{\pi}{2}+\alpha} \sqrt{3}\, V_m \sin\left(\omega t + \frac{\pi}{6}\right) d\omega t.$$

+

* All combinations of SCRs conduct only for 60°

∴ time period = 60° = π/3

$$\therefore V_o(avg) = \frac{3\sqrt{3}V_m}{\pi}\left[-\cos\left(\omega t+\frac{\pi}{6}\right)\right]_{\frac{\pi}{6}+\alpha}^{\pi/2+\alpha}$$

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

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

$$= -\frac{3\sqrt{3}V_m}{\pi}\left[\cos\frac{2\pi}{3}\cos\alpha - \sin\frac{2\pi}{3}\sin\alpha - \cos\frac{\pi}{3}\cos\alpha + \sin\pi/3 \sin\alpha\right]$$

$$= -\frac{3\sqrt{3}V_m}{\pi}\left[-0.5\cos\alpha - \frac{\sqrt{3}}{2}\sin\alpha - 0.5\cos\alpha + \frac{\sqrt{3}}{2}\sin\alpha\right]$$

$$= -\frac{3\sqrt{3}V_m}{\pi}\left[-\cos\alpha\right] = \frac{3\sqrt{3}V_m}{\pi}\cos\alpha$$

$$\therefore \boxed{V_o(avg) = \frac{3\sqrt{3}V_m}{\pi}\cos\alpha}$$

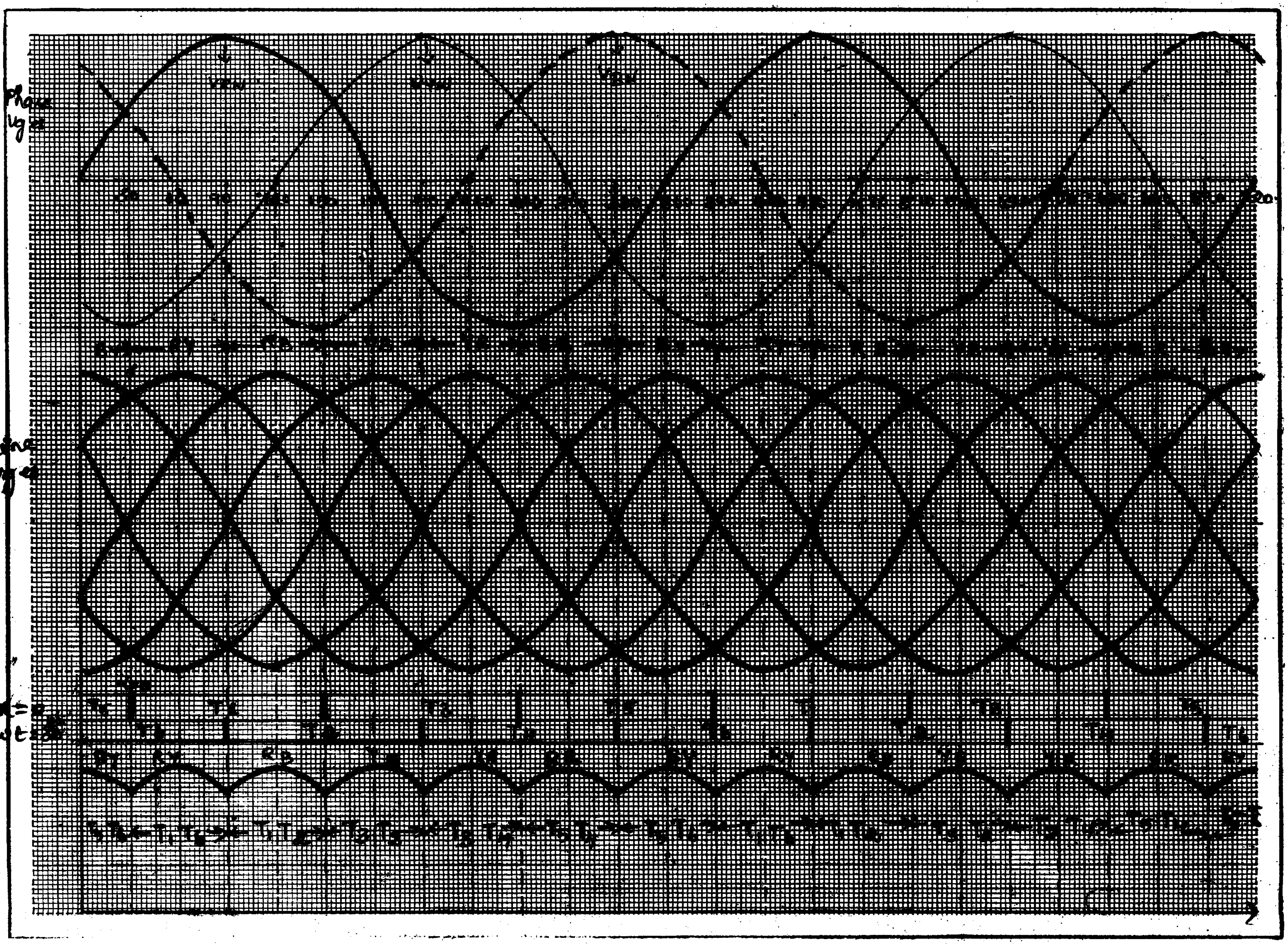
For $\alpha > 60°$

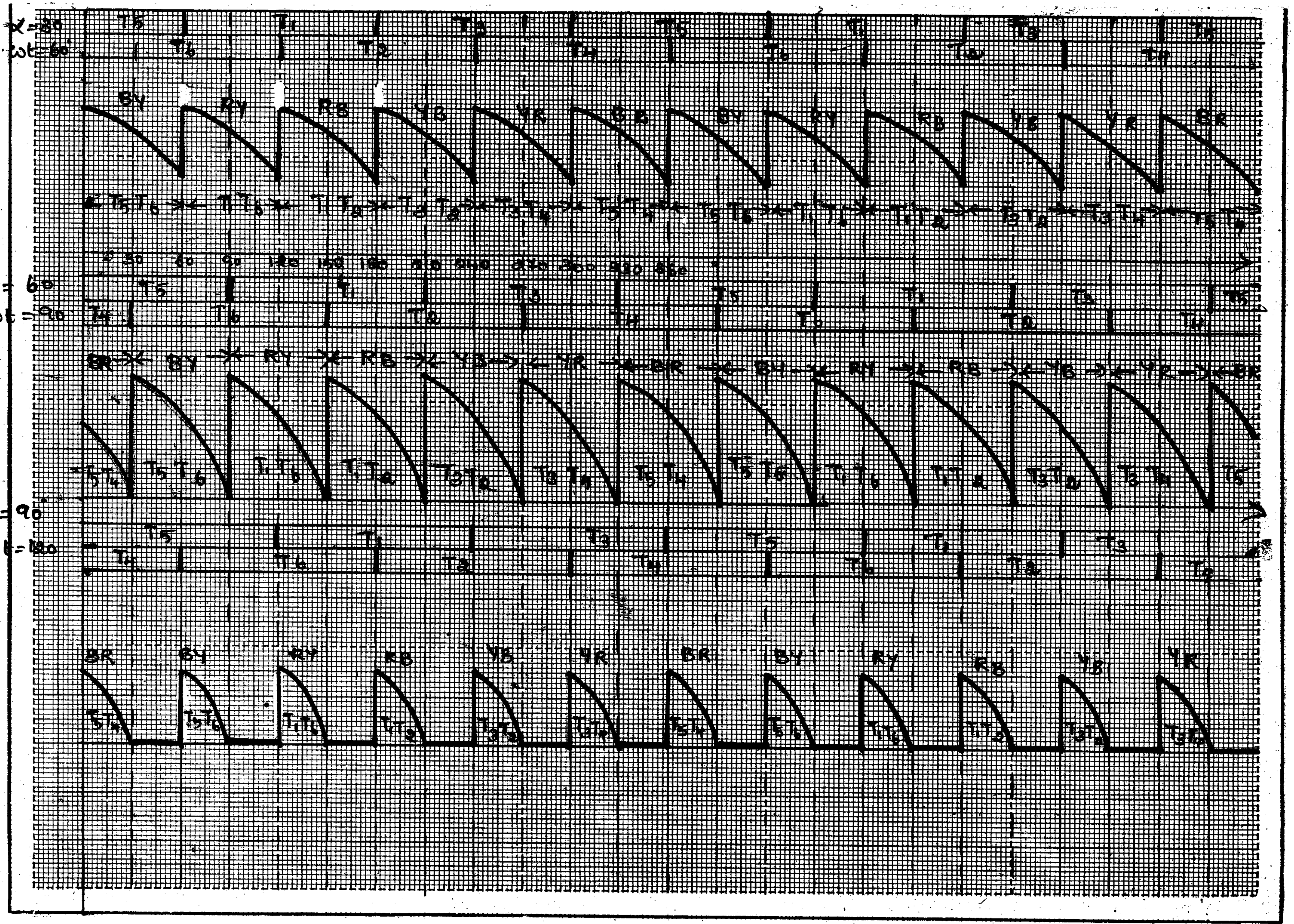
$$V_o(avg) = \frac{1}{\pi/3}\int_{\frac{\pi}{6}+\alpha}^{\frac{5\pi}{6}} V_{RY}\, d\omega t = \frac{3}{\pi}\int_{\frac{\pi}{6}+\alpha}^{\frac{5\pi}{6}} \sqrt{3}V_m \sin\left(\omega t+\frac{\pi}{6}\right) d\omega t$$

$$= \frac{3\sqrt{3}V_m}{\pi}\left[-\cos\left(\omega t+\frac{\pi}{6}\right)\right]_{\frac{\pi}{6}+\alpha}^{5\pi/6}$$

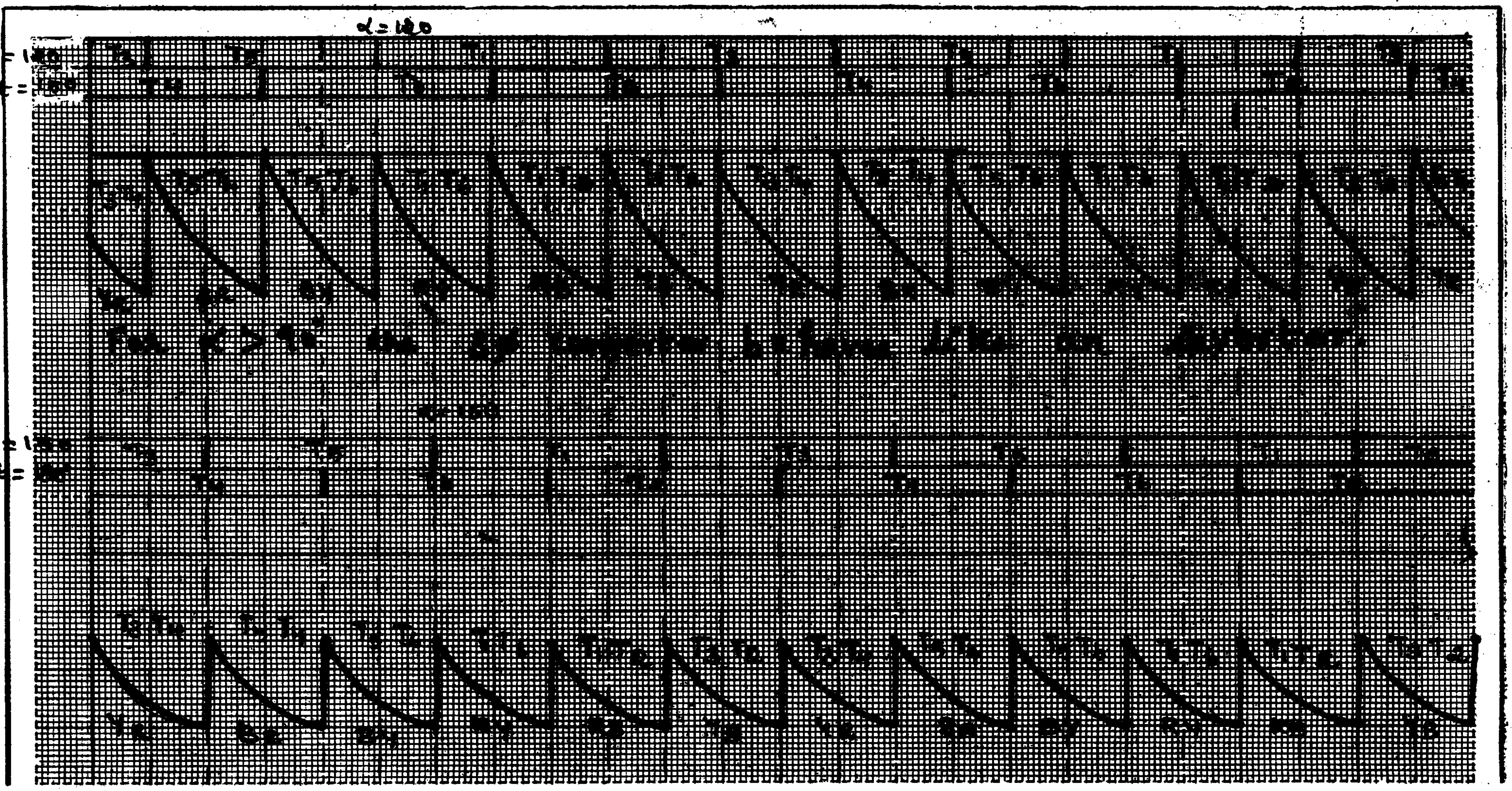
$$\boxed{V_o(avg) = \frac{3\sqrt{3}V_m}{\pi}\left[1+\cos\left(\frac{\pi}{3}+\alpha\right)\right]}$$

For $\alpha > 90°$ 3ϕ full converter behaves like inverter.

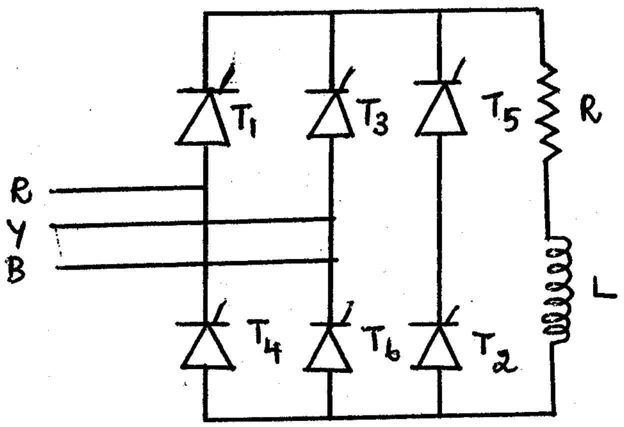

Phase Vg
Line Vg



α = 30° ωt = 60°
α = 60° ωt = 90°
α = 90° ωt = 180°
BY RY RB YB YR BR BY RY RB YB YR BR
30 60 90 120 150 180 210 240 270 300 330 360


α = 120

3φ FULL CONVERTER:- [with R-L load]



· The explanations are same as that of 3φ full converter with R-L load.

* Output voltage equation are also same.

* The waveforms are also same except for $\alpha = 90°$. For $\alpha = 90°$ the waveforms are as follows.

For $\alpha \leq 60°$;

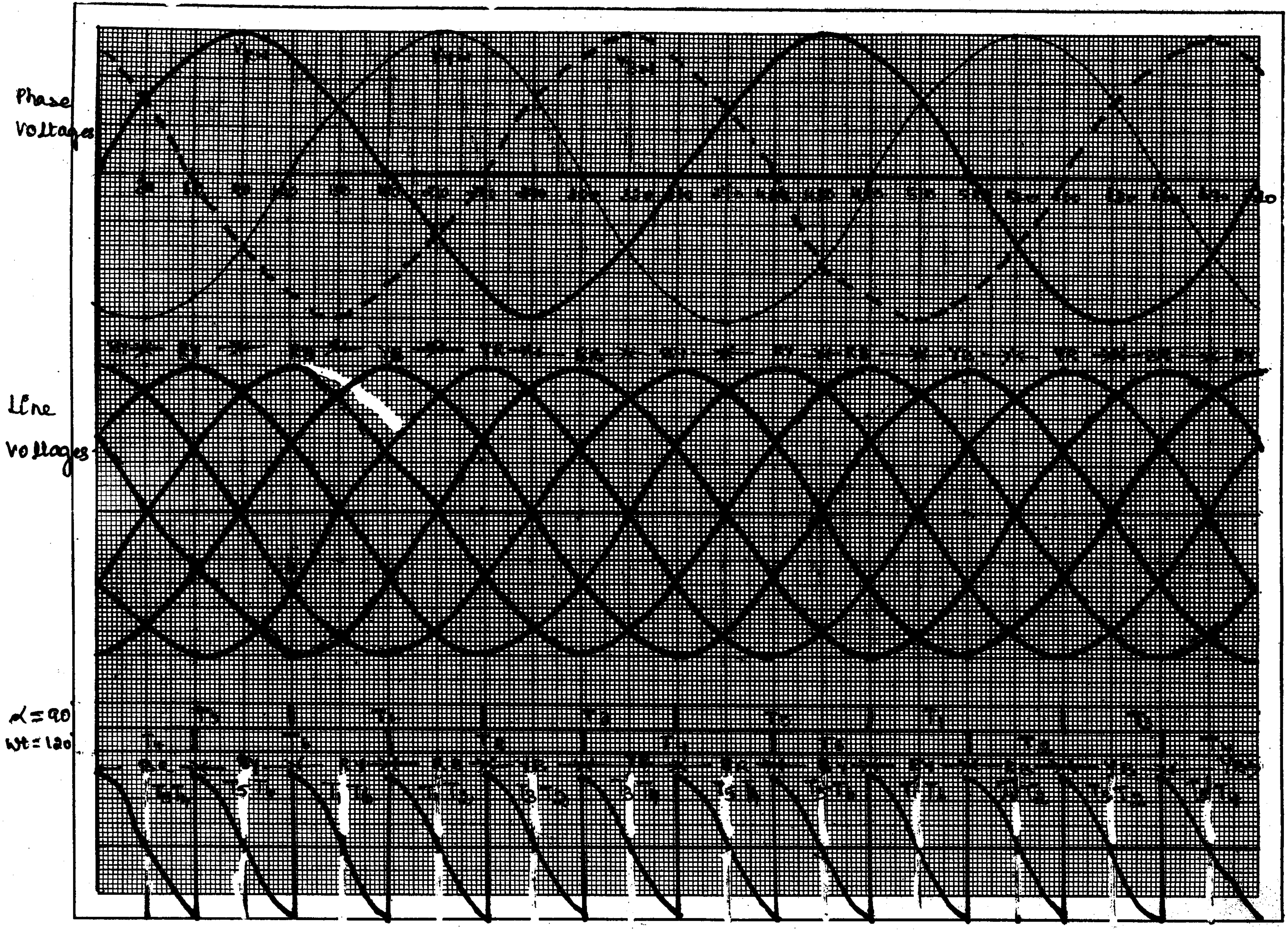
$$V_o(avg) = \frac{1}{\pi/3}\int_{\frac{\pi}{6}+\alpha}^{\frac{\pi}{2}+\alpha} V_{RY}\, d\omega t = \frac{3}{\pi}\int_{\frac{\pi}{6}+\alpha}^{\frac{\pi}{2}+\alpha} \sqrt{3}V_m \sin(\omega t + \frac{\pi}{6})\, d\omega t.$$

$$\therefore V_o(avg) = \frac{3\sqrt{3}V_m}{\pi}\cos\alpha$$ (already solved)

For $\alpha > 60°$:-

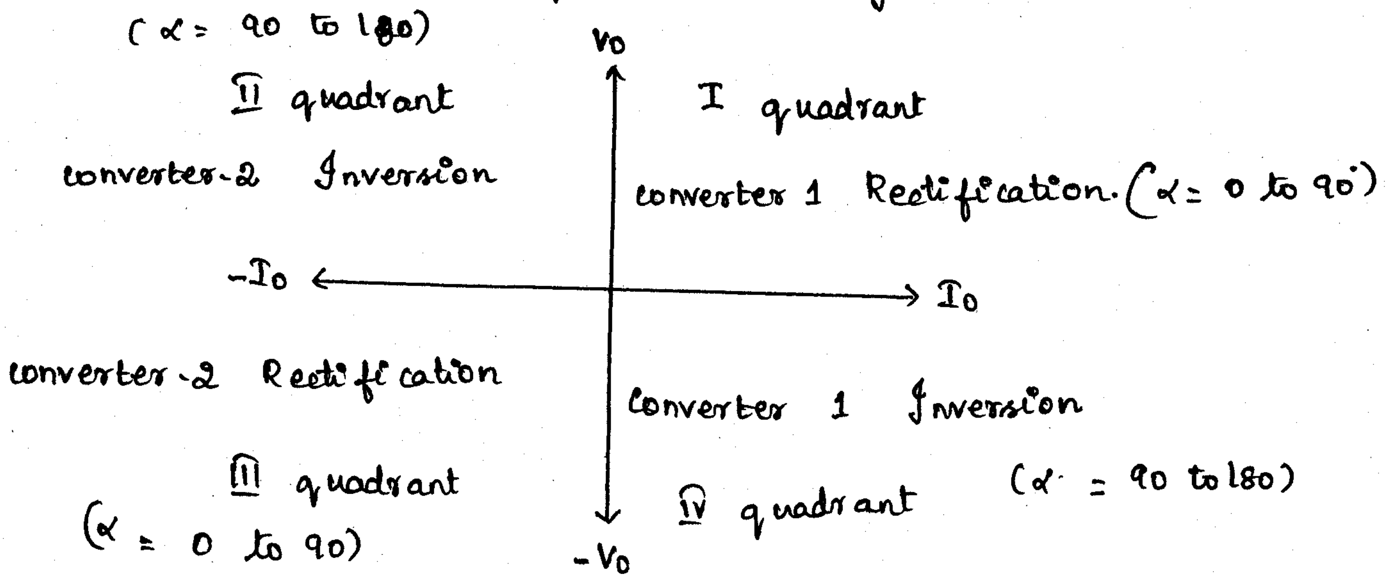
$$V_o(avg) = \frac{1}{\pi/3}\int_{\frac{\pi}{6}+\alpha}^{\frac{5\pi}{6}} V_{RY}\, d\omega t = \frac{3}{\pi}\int_{\frac{\pi}{6}+\alpha}^{\frac{5\pi}{6}} \sqrt{3}V_m \sin(\omega t + \frac{\pi}{6})\, d\omega t$$

$$V_o(avg) = \frac{3\sqrt{3}V_m}{\pi}\left[1 + \cos(\frac{\pi}{3} + \alpha)\right]$$

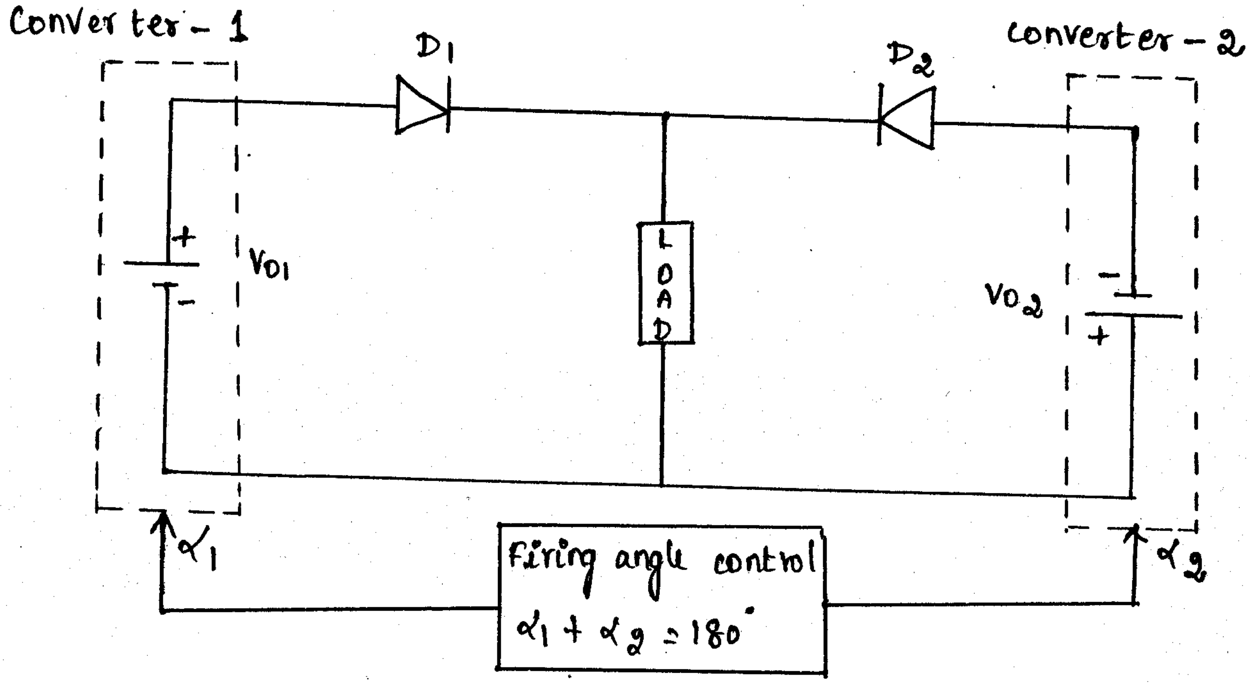

Phase Voltages
Line Voltages
α=90°
ωt=120°

DUAL CONVERTERS (OR) FOUR QUADRANT CONVERTER:-

* Two full converters connected in antiparallel (or) back to back with the load in parallel to them is called as a "dual converter."
* It can be operated in any one of the four quadrants
* The average value of output voltage and current can be either positive or negative.



PRINCIPLE OF DUAL CONVERTER (IDEAL DUAL CONVERTER):-



* Assume that the dual converter consists of two ideal converters connected in antiparallel.

V_{01} = avg o/p vge of converter 1

V_{02} = avg o/p vge of converter 2

* Diodes D_1 and D_2 connected in series indicate the unidirectional flow of current from the converters

* Load current can flow in either direction.

* Output voltages V_{01} and V_{02} are equal in magnitude but opposite in polarity

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

* So they drive current in opposite directions.

* when one converter acts as a rectifier the other converter acts as an inverter.

∴ the average output voltages ⇒ $V_{01} = V_{max}\cos\alpha_1$

$V_{02} = V_{max}\cos\alpha_2$

$\left[V_{max} = \frac{2V_m}{\pi} \text{ for } 1\phi \qquad V_{max} = \frac{3\sqrt{3}V_m}{\pi} \text{ for } 3\phi \right.$

α_1 = firing angle of converter 1; α_2 = firing angle of converter 2.

For ideal converter

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

ie $V_{max}\cos\alpha_1 = -V_{max}\cos\alpha_2$

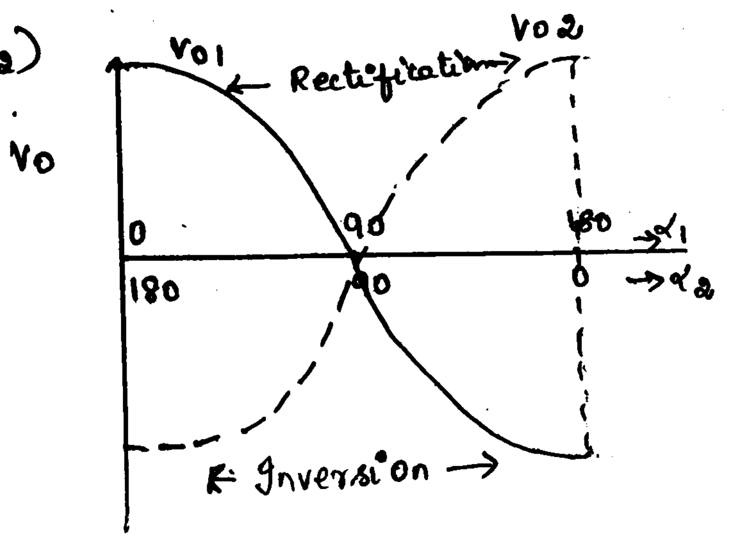
$\left[\therefore -V_{max}\cos\alpha_2 = V_{max}\cos(180-\alpha_2) \right.$

∴ $V_{max}\cos\alpha_1 = V_{max}\cos(180-\alpha_2)$

$\cos\alpha_1 = \cos(180-\alpha_2)$

$\alpha_1 = 180 - \alpha_2$

(or) $\boxed{\alpha_1 + \alpha_2 = 180}$



PRACTICAL DUAL CONVERTER :-

* Firing angle of converters are such that $\alpha_1 + \alpha_2 = 180$.
  * One converter acts as rectifier with firing angle α_1
  * Other converter acts as inverter with firing angle $\alpha_2 = 180 - \alpha_1$.
  * Average value of o/p vges are equal

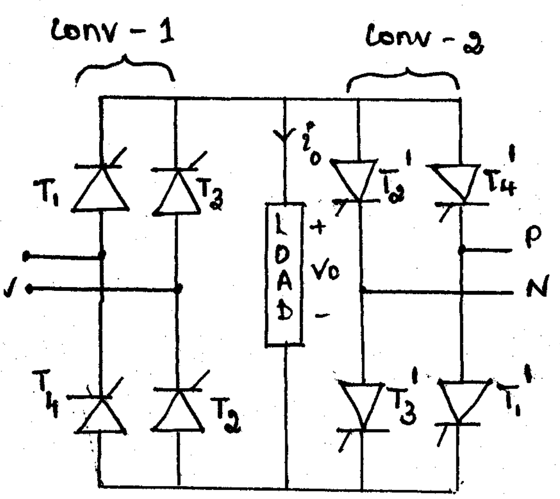
(BUT)

* Instantaneous values of vges are out of phase. This results in a voltage difference between the converters.
* ∴ a large circulating current flows between the two converters (but not through the load).
* circulating current can be avoided by suitably triggering the converters.

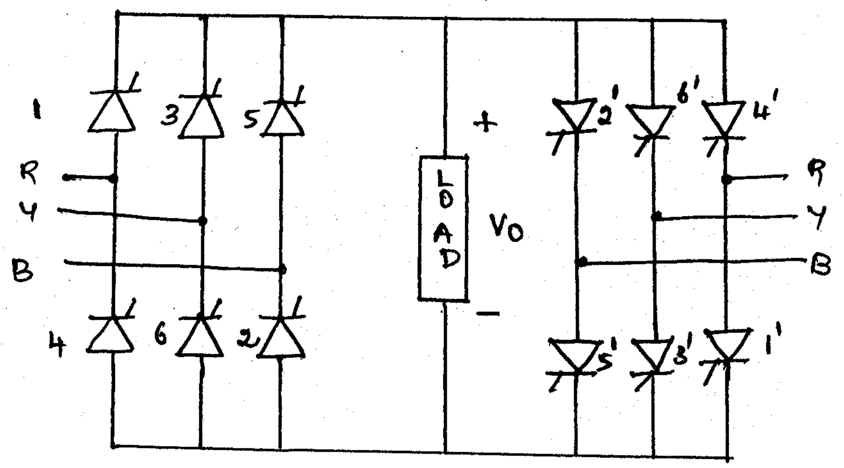
∴ a dual converter can be operated in two modes

1. Dual converter without circulating current.
2. Dual converter with circulating current.

DUAL CONVERTER WITHOUT CIRCULATING CURRENT :-



1Ø dual converter



3Ø dual converter

(without circulating current)

In this mode

* Only one converter operates at a time.
* Other converter is OFF by blocking gate pulses.

If converter 1 is ON :- For $\alpha > 90^\circ$ operates in I quadrant
$\alpha < 90^\circ$ " " IV quadrant

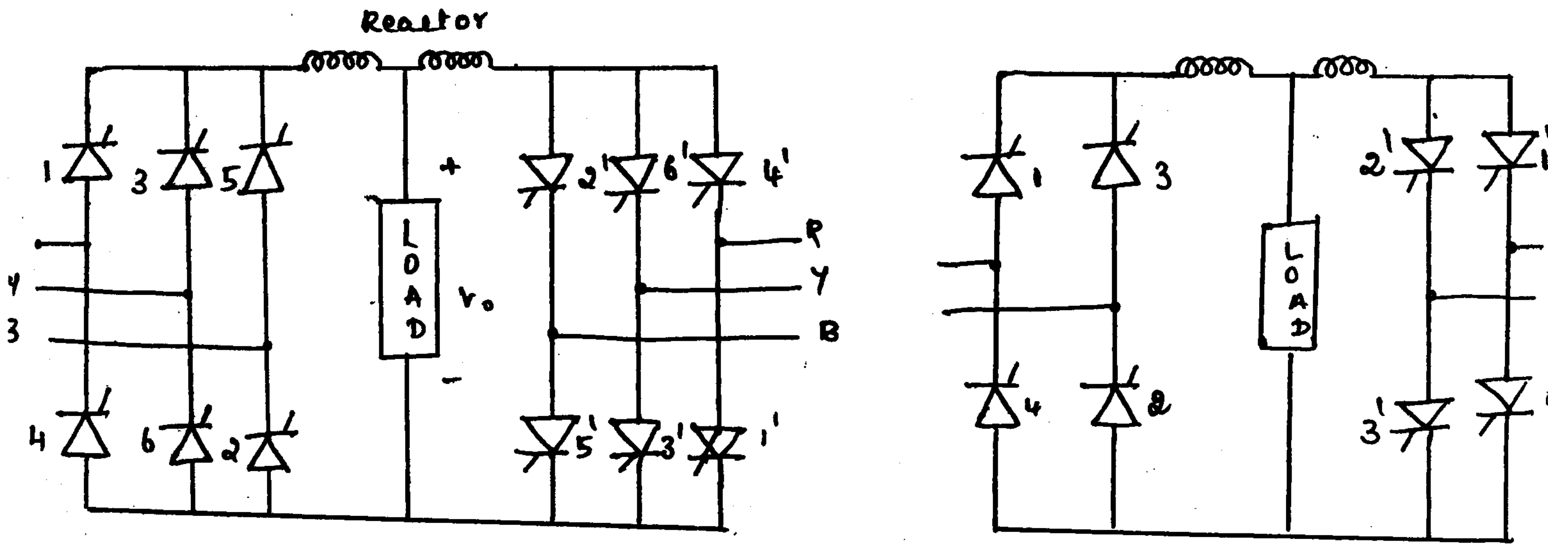
If converter 2 is ON :- For $\alpha > 90^\circ$ operates in II quadrant
$\alpha < 90^\circ$ " " III quadrant.

To turn ON the second converter,

* first switch OFF converter 1
* wait till load current decays to zero
* Give a delay of 10 to 20 msec and switch conv 2.

(If converter 2 is triggered before converter 1 is OFF then circulating current flows)

1. DUAL CONVERTER WITH CIRCULATING CURRENT:-



3ϕ dual converter 1ϕ dual converter

(with circulating current)

In this mode

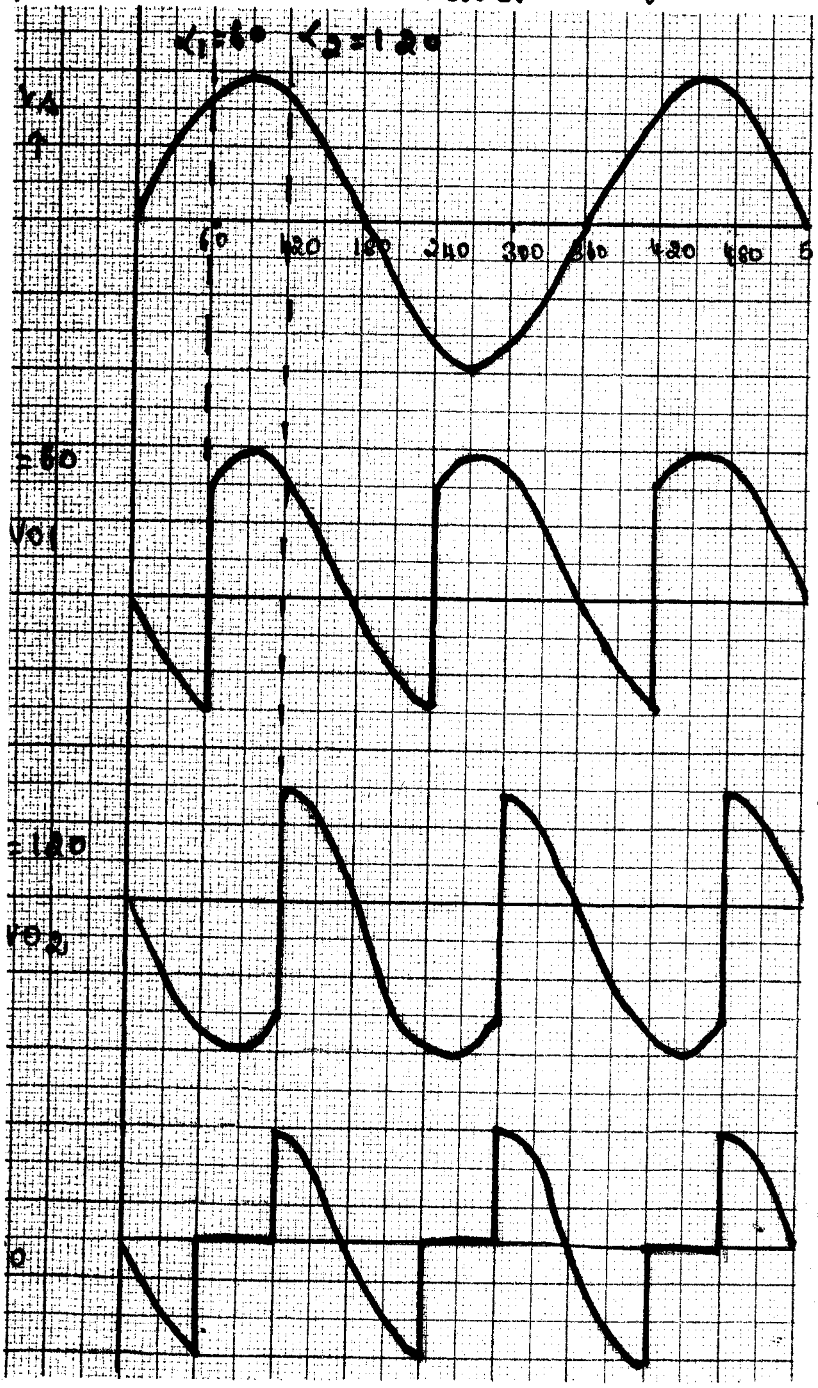
* Both converters operate at same time.
* One converter acts as rectifier while other acts as an inverter.

∴ the instantaneous values of output voltages are different, a circulating current flows. Magnitude of this current is limited by a reactor.

$$\alpha_1 + \alpha_2 = 180^\circ$$

[If $\alpha_1 = 60^\circ$; $\alpha_2 = 180 - \alpha_1 = 180 - 60 = 120^\circ$]

for 1φ dual converter. Waveforms are.



Advantages:-

* continuous conduction of both the converters.
* Power flow in either direction.
* change from one converter to other is faster.

Disadvantages:-

* cost and size of reactor is high.
* circulating current increases losses and reduces efficiency.
* SCRs are required of very high current rating (∵ load current and circulating curnt flows thro' SCRs)

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Difference between Half controlled and Fully controlled rectifiers

Half controlled converter	Fully controlled converter
1. This consists of half number of SCR's and half no of diodes.	Consist of only SCRs as the controlled devices.
• Operates in only one quadrant	Operates in two quadrants.
• Output voltage is always +ve	Output voltage can be −ve in case of inductive load.
• Internal freewheeling action is present	External freewheeling diode has to be connected.
• Power factor is better	power factor is poor than half converter.
• Inversion is not possible	Inversion is possible.
• Used for battery chargers, lighting and heater control	Used for dc motor drives.

Comparison between 3ϕ and 1ϕ converters.

S.No	Parameter	1ϕ converter	3ϕ converter
1.	Ripple content in output	More	Less
2.	Output power	Less upto 5 KW	More than 5 KW
3.	Ripple frequency	100 Hz	150 Hz and 300 Hz
4.	Control	Easy control	Complex control.
5.	Circuit Implementation	Less complex	Complex implementati
6.	Maximum supply power factor	0.9	0.955
7.	Supply and load derating	Higher	Less.

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