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TITLE: PHASE CONTROLLED CONVERTER.

OBJECTIVE:

To know the concept of controlled converter

APPLICATIONS:

PED laboratory – Power Electronics equipment.

UNIVERSITY QUESTIONS:

* Phase Controlled Rectifier, the output voltage is varied by varying the firing angle of Thyristor.

* It is turned on by applying a short pulse to its gate and turn off due to nature (or) forced commutation.

Classification :-

1) Input based.

a) 1φ converter

b) 3φ converter

2) Based on operation

a) 1 quadrant

b) 2 quadrant

c) 4 quadrant

3) Based on Pulse no.

a) 1 Pulse converter

b) 2 Pulse converter

c) 3 Pulse converter

d) 6 Pulse converter

e) 12 Pulse converter.

Firing Angle (α) :-

It is defined as angle between instant thyristor would conduct if it were a diode and the instant it is triggered.

Assumption in SCR :-

1) No voltage drop across them

2) Holding current is zero

3) No reverse current.

One Pluse Converter (or)

Single Phase Half Controlled Rectifier :-

i) Resisitive load :-

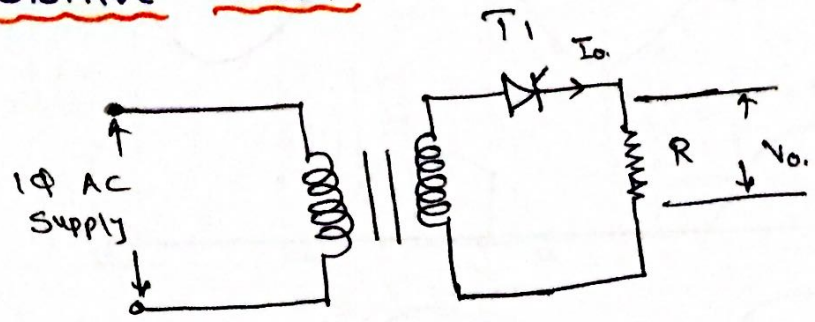

Fig : 2.1.

Operation :-

* During "+ve" half cycle anode of SCR is w.r.to cathode.

* Forword Blocking mode gate is applied.

* When SCR is fired at "α" full supply voltage is applied to load.

* load is Purely resistive, I wave obtained is identical to voltage waveform.

* Load I will flow until it is commutated by reversal of Vs. at $\omega t = \pi$.

* α to π → conduction is called "Conduction angle".

* By varying "α" Phase relationship b/w Load I start and Vs can be controlled and the term "Phase control" is used for controlling the I_L.

* During "-ve" half cycle of Vs, SCR blocks the voltage and no voltage across the load.

Waveform :-

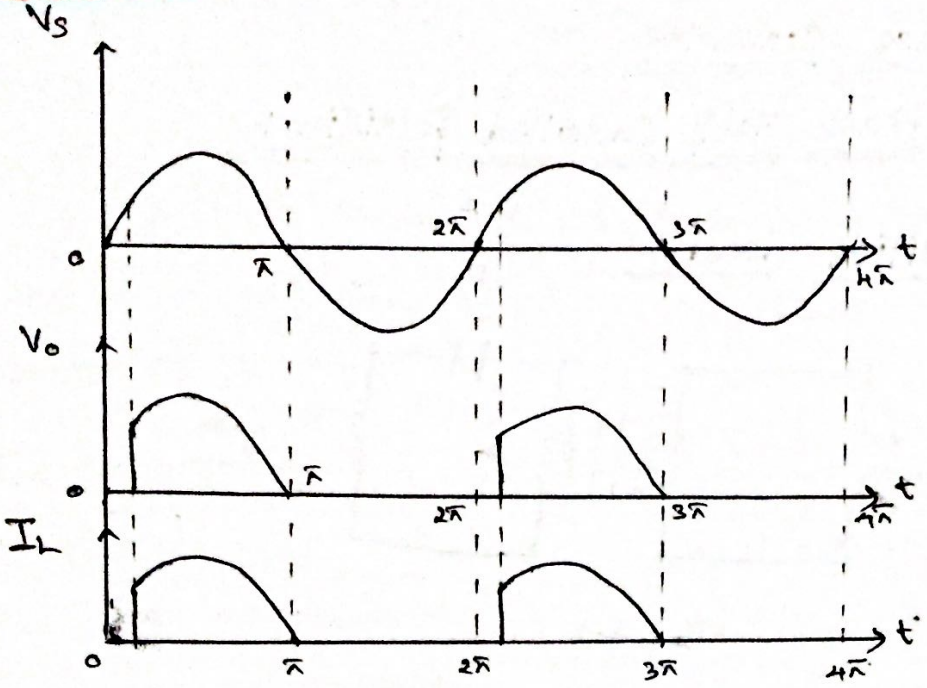

Fig : 2.2

Derivation :-

Avg. $V_o = \frac{1}{T}\int_0^T V_s \, d(\omega t) \rightarrow (1)$

Now, $V_s = V_m \sin(\omega t)$

$$V_{o(avg)} = \frac{1}{2\pi}\int_0^{2\pi} V_m \sin(\omega t) \, d(\omega t) \rightarrow (2)$$

$$= \frac{1}{2\pi}\int_\alpha^{\pi} V_m \sin(\omega t) \, d(\omega t) \rightarrow (3)$$

$$\therefore V_{o(avg)} = \frac{V_m}{2\pi}[1+\cos\alpha] \rightarrow (4)$$

$$I_{o(avg)} = \frac{V_o}{R} \rightarrow (5)$$

$$\text{RMS } V_o = V_{o(RMS)} = \left[\frac{1}{T}\int_0^T V_s^2 \, d(\omega t)\right]^{1/2} \rightarrow (6)$$

$$= \left[\frac{1}{2\pi}\int_\alpha^{\pi} V_m^2 \sin^2(\omega t) \, d(\omega t)\right]^{1/2} \rightarrow (7)$$

$$\therefore V_{o(RMS)} = \left[\frac{V_m^2}{2\pi}\left[(\pi-\alpha) + \frac{\sin 2\alpha}{2}\right]\right] \rightarrow (8)$$

ii) Inductive load (R-L) :-

Diagram :-

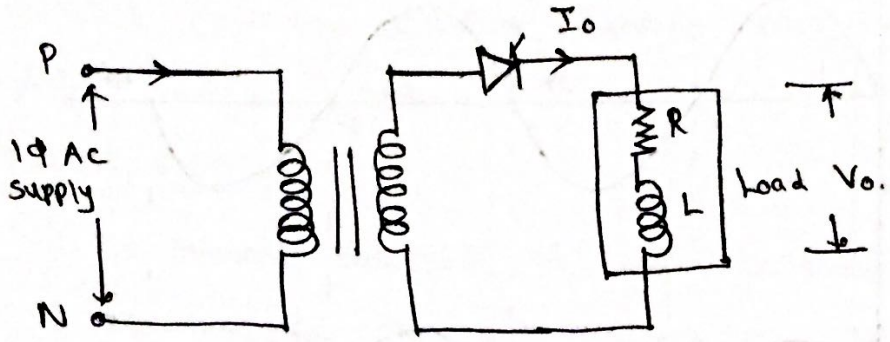

Fig: 2.3

Operation :-

* RL load changes when compared to R load.
* At "α" SCR is triggered and I_{load} ↑.
* But L force the load & I_o ↑
* Then I_o reach max. begins to ↓.
* Energy stored in inductor during α to π and V_o is zero. then V_s start reverse but SCR kept conducting.
* After π SCR is subject to reverse anode voltage but it will not turn off as I_{load}, I_o is not less than holding I.
* Continuous to "$\pi+\alpha$" afterwards to zero.
* During negative half cycle SCR blocks the V_s from $\pi+\alpha$ to 2π.

Derivation :-

$$V_o = \frac{1}{T}\int_0^T V_s \cdot d(\omega t) \rightarrow (1)$$

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

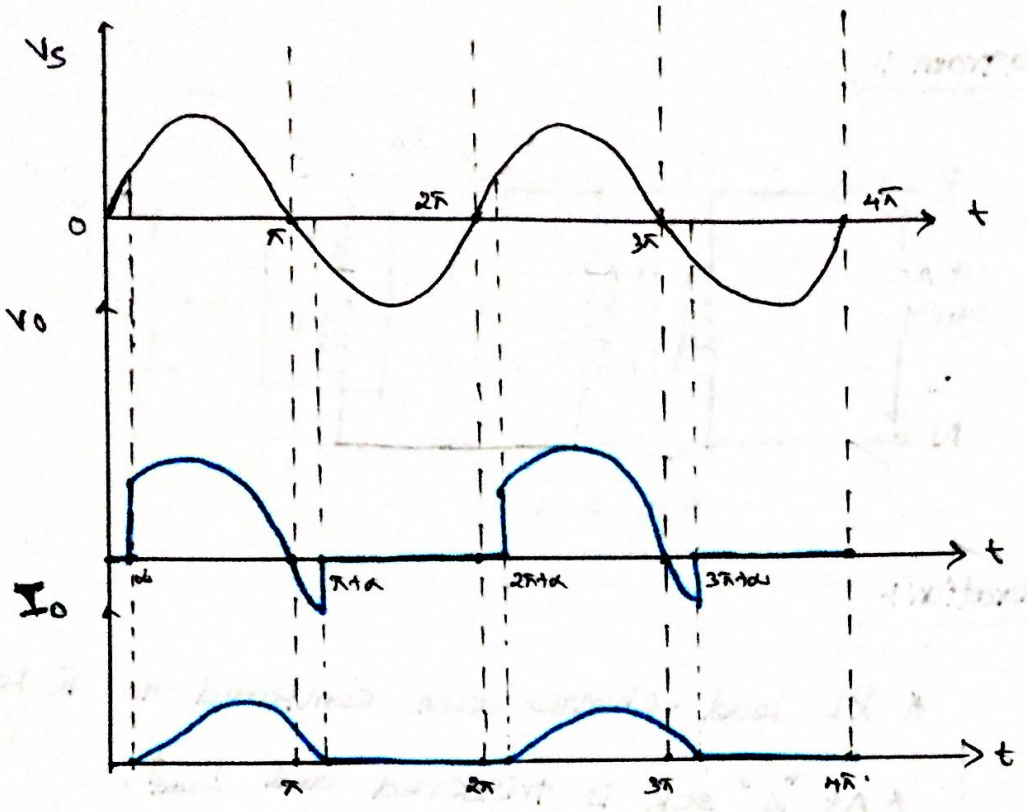

Fig: 2.4.

$$V_{o(avg)} = \frac{V_m}{\pi} \cos\alpha \quad \rightarrow (3)$$

$$I_{o(avg)} = \frac{V_{o(avg)}}{R} \quad \rightarrow (4)$$

$$V_{o(RMS)} = \left[\frac{1}{T}\int_0^T V_s^2 \, d(\omega t)\right]^{\frac{1}{2}} \quad (5)$$

$$\therefore V_{o(RMS)} = \left[\frac{V_m^2}{4\pi}\left[(\beta-\alpha) + \frac{\sin 2\alpha}{2}\right]\right] \quad \rightarrow (6)$$

iii) Effect of Freewheeling diode :-

* The function of freewheeling (or) commutating (or) by-pass diode is to commutate (or) transfer load current from the rectifier whenever load voltage goes into reverse state.

Function of FWD :-

1) It Prevent reversal of load voltage

2) It transfer the load current from the rectifier thereby allowing the thyristor to regain blocking states.

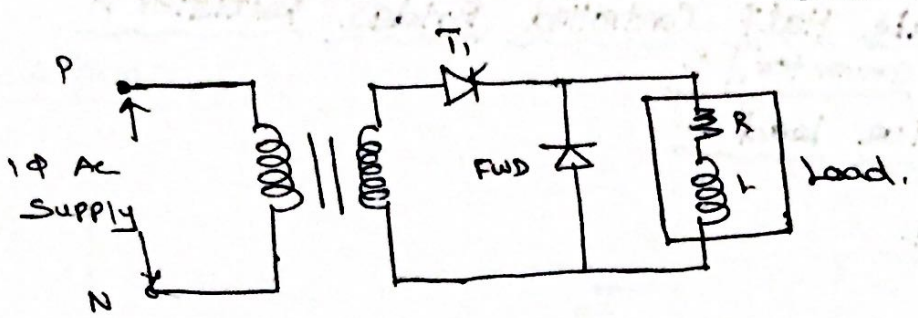

Fig: 2.5.

* During "+ve" half cycle, voltage is induced in inductor.

* During "-ve" after 180°, energy stored in inductor causes current flow.

* At, polarity of inductor change which in turn forward bias the FWD and load I flow through diode not through source

Advantages of FWD :-

1) Improved input Power Factor

2) Load I wave waveform is improved.

Wave form :-

Same as R-Load. diagram.

Derivation :-

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

$$V_{o(RMS)} = \left[\frac{V_m^2}{4\pi}\left[(\pi-\alpha)+\frac{\sin 2\alpha}{2}\right]\right]^{1/2}.$$

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Single Phase Half Controlled Bridge Rectifier :- [2-Pulse Converter] :-

i) Resistive load :-

Diagram :-

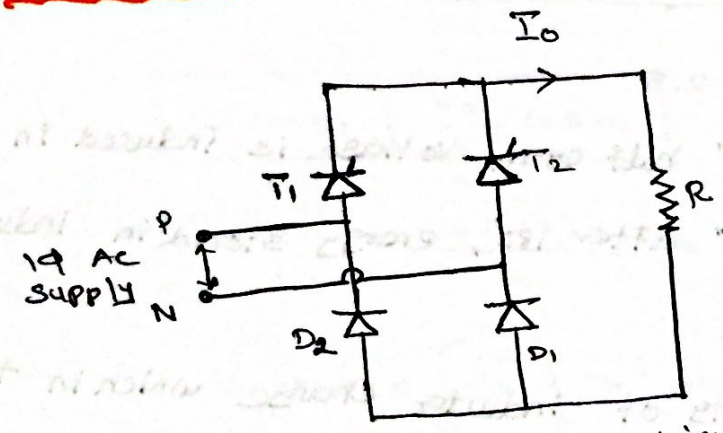


Fig : 2.6 Symmetrical

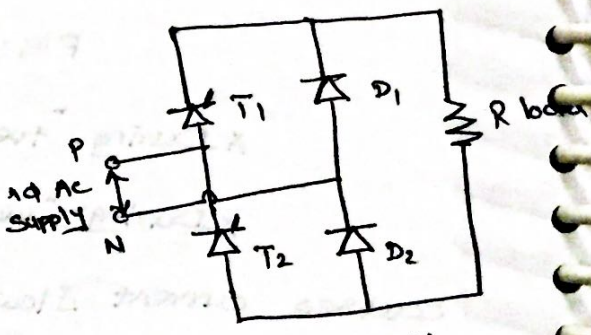


Fig : 2.7 Asymmetrical.

operation :-

* Half controlled converter also know as "semi converter" in Fig 2.6 & 2.7.

* 2 diff. variation with R load.

* Symmetrical → 2 SCR same potential - single gate Pulse trigger

* Asymmetrical → separate trigger to be used.

* symmetrical configuration of half controlled bridge circuit is considered.

* "+ve" half cycle - T_1 & D_1 conduct.

* I flow Path P → T_1 → R load → D_1 → N.

* I flow from wt = α to π.

* During "-ve" half cycle T_2 & D_2 conduct.

* I Path N → T_2 → R load → D_2 → P.

* Current is continuous from π+α to 2π.

Wave form :-

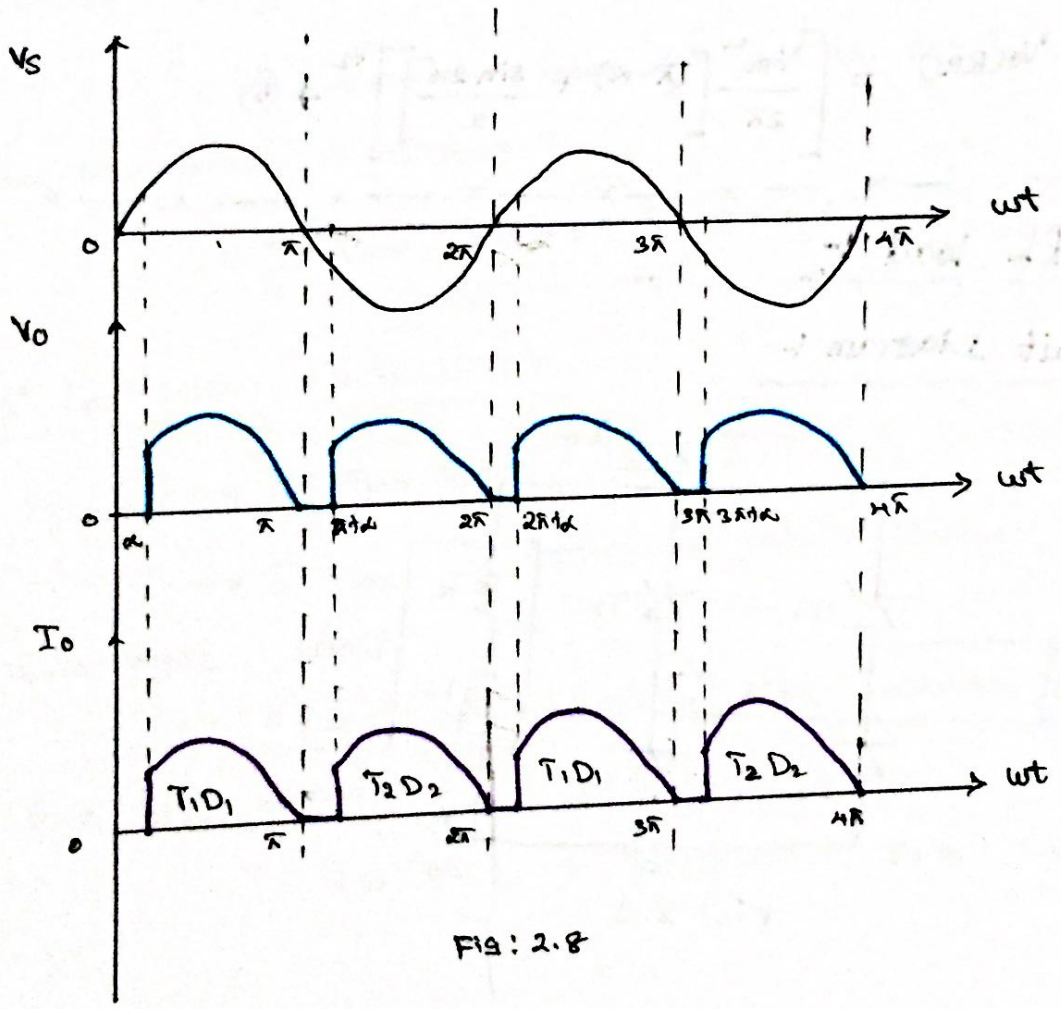


Fig : 2.8

Operation :-

* 2 Pulse, 1φ half controlled bridge converter with RL load.

* T_1 is triggered at "α" during "+ve" half cycle.

* I flow $P \rightarrow T_1 \rightarrow RL \rightarrow D_1 \rightarrow N$.

* Inductance is assumed to be large continuous load current.

* "-ve" half cycle, voltage reverse.

* at $\omega t = \pi$, D_2 is turn ON. D_1 is off.

* I load flow through T_1 and D_2.

* Load I freewheel through $D_2 \rightarrow T_1 \rightarrow$ "R-L" during time of "π to $\pi+\alpha$".

* At $\omega t = \pi+\alpha$, Pulse applied to SCR T_2, T_1 is off due to reverse biasing of T_1.

* I flow $N \rightarrow T_2 \rightarrow RL \rightarrow D_2 \rightarrow P$.

a) Continuous Conduction :-

* In this mode, load I ↑ and ↓ gradually.

* I flow is continuous due to large value of load inductance.

* During freewheeling time interval, load I ↓ from max to min.

* This mode is performed in motor control applications.

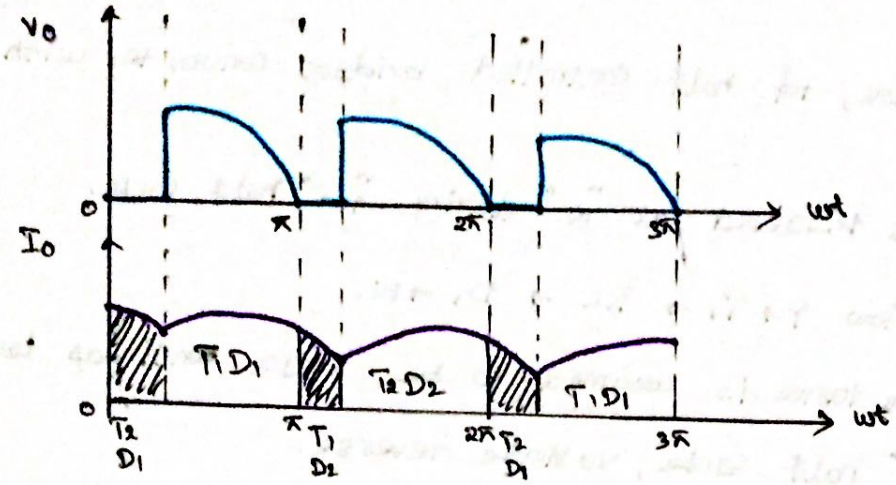
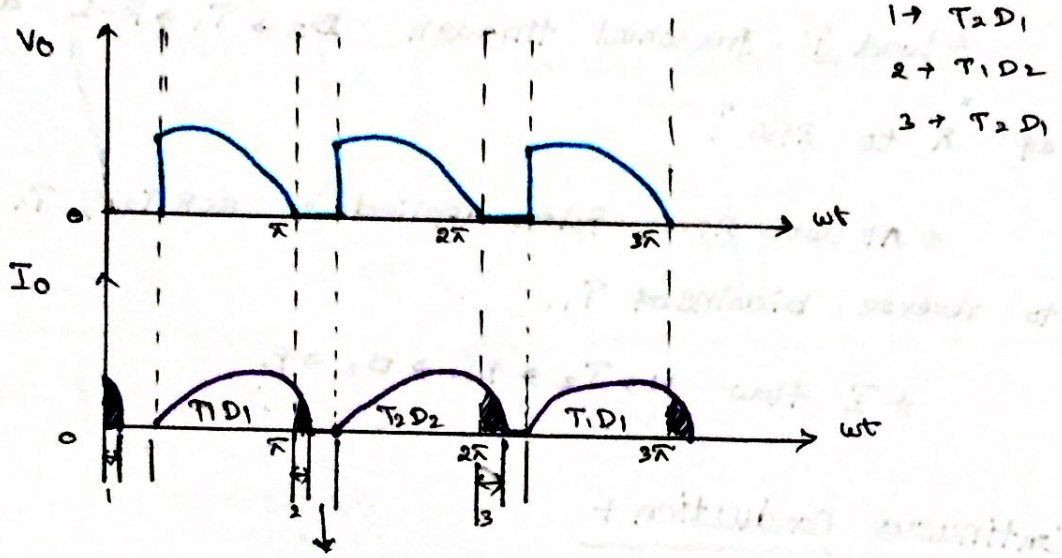


Fig : 2.10

b) Dis continuous conduction :-



1 → T2 D1
2 → T1 D2
3 → T2 D1

Fig : 2.11.

* In this mode, Inductance is not sufficient to maintain conduction in freewheeling time interval.

* load I ↓ to zero. before another SCR ON.

* Conduction angle ↓ $\beta < (\pi + \alpha)$

* It is not suitable for speed control of DC Motors.

TITLE: SINGLE FULL WAVE CONTROLLER RECTIFIER [2-Pulse]

OBJECTIVE:

To know about Single Phase full controlled converter concept.

APPLICATIONS:

NPRCET - PED Laboratory - converter kit.

UNIVERSITY QUESTIONS:

Single phase full controlled Rectifier :-

1) Mid Point Converter :-

i) Resistive load :-

Diagram :-

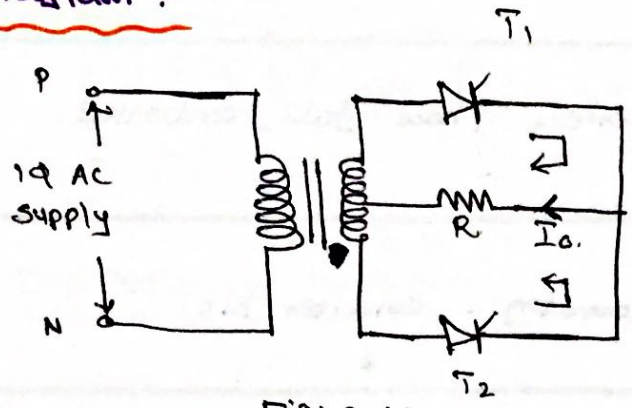


Fig: 2.12.

Operation :-

* The circuit has 2 SCR with centre tapped secondary of a 1φ transformer.

* During "+ve" half cycle, T_1 is forward biased condition. and T_2 is reverse biased.

* T_1 triggered at "α".
* I flow through P → T_1 → R → N.
* I continuous flow at $\omega t = \pi$.
* During "-ve" half cycle, T_1 is off (Reverse).
* T_2 is forward bias.
* It triggered at "$\pi + \alpha$".
* I continuous flow at 2π. and T_2 is off.

Derivation :-

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

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

$$\therefore V_{o(avg)} = \frac{V_m}{\pi} \left[1 + \cos \alpha \right] \rightarrow (3)$$

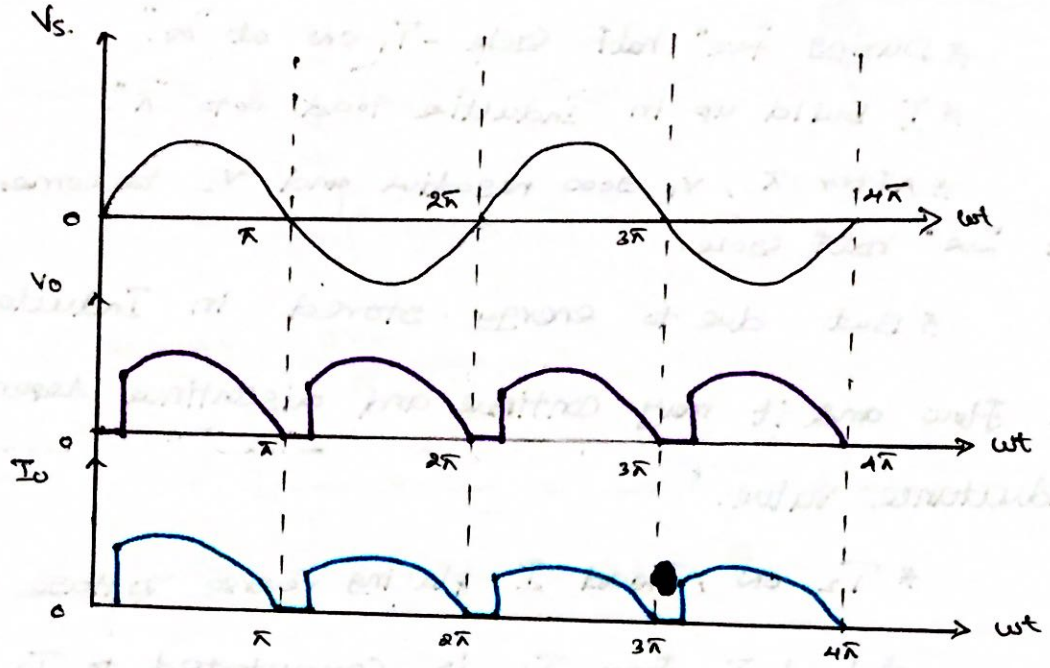


Fig: 2.13.

$$I_{o(avg)} = \frac{V_o}{R} = \frac{V_m}{\pi R}[1+\cos\alpha] \rightarrow (4)$$

$$V_{o(RMS)} = \left[\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2(\omega t)\, d(\omega t)\right]^{1/2} \rightarrow (5)$$

$$V_{o(RMS)} = \left[\frac{V_m^2}{2\pi}\left[(\pi-\alpha) + \frac{\sin 2\alpha}{2}\right]\right]^{1/2} \rightarrow (6)$$

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ii) RL load :-

Diagram :-

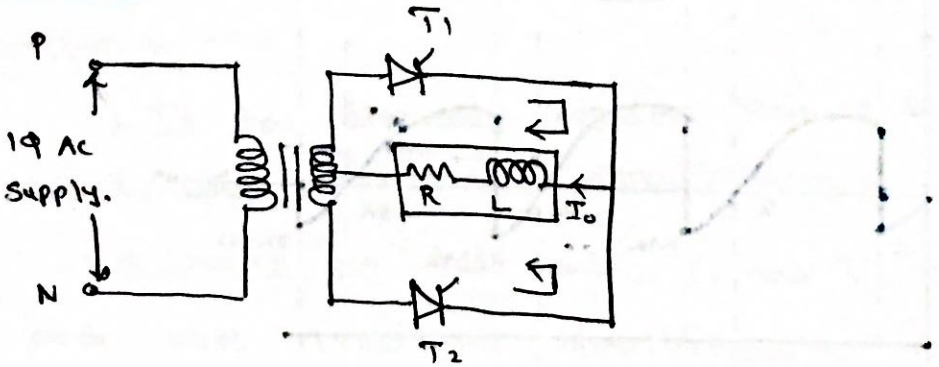

Fig: 2.

Operation :-

* During "+ve" half cycle - T_1 ON at "α".
* I build up in Inductive load upto "π".
* After π, V_1 goes negative and V_2 becomes "+ve" at "-ve" half cycle.
* But due to energy stored in Inductor, load I flow and it may continue and discontinue depends on inductance value.
* T_2 ON, load I placing reverse voltage across T_1.
* Load I from T_1 is commutated to T_2.
* Peak reverse voltage that appear across is "$2V_m$"
* Inductance assumed is of large enough to maintain load I continuous.
* Both SCR share the load I equally.

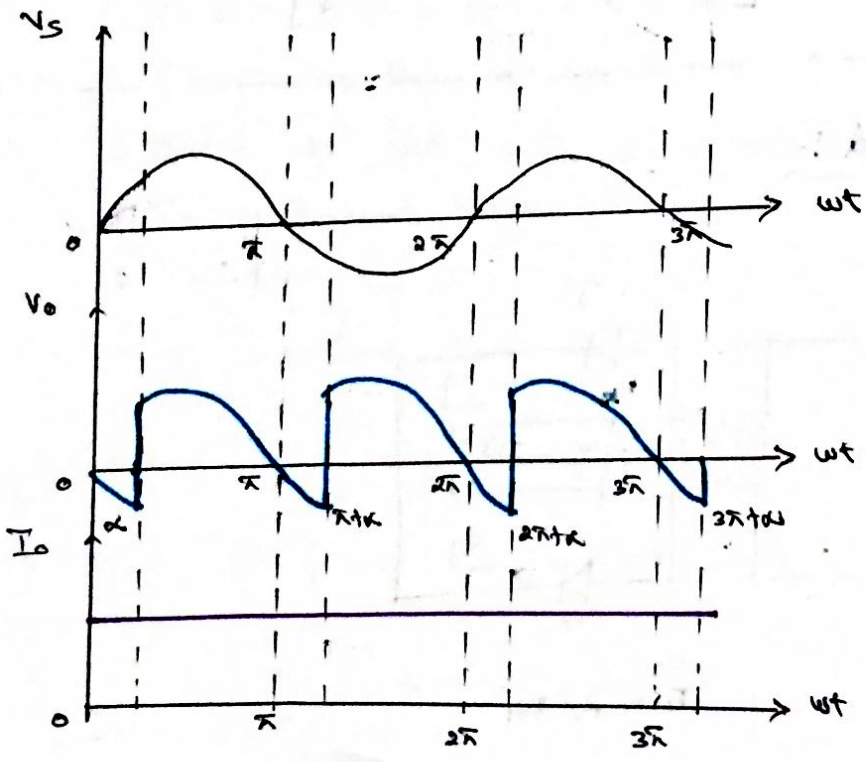

Fig : 2.15

Derivation :-

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

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

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

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2) 1φ Full controlled Bridge Rectifier :

i) R load :-

Diagram :-

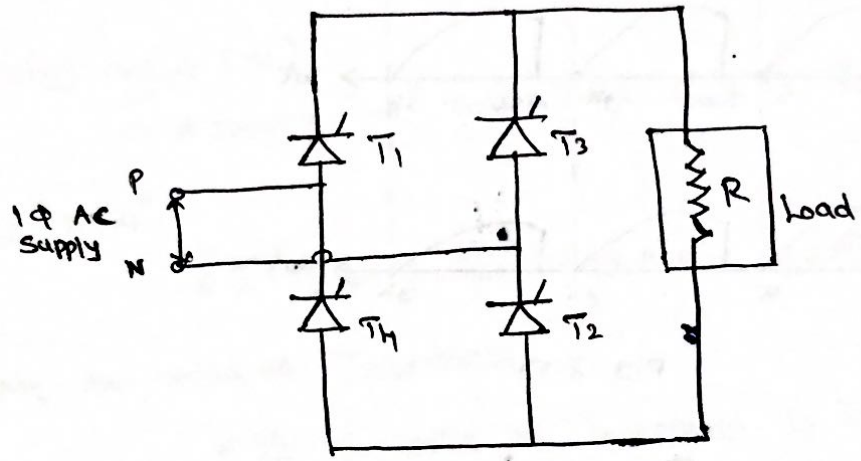


Fig : 2.16

operation :-

* It has diagonally opposite pair of SCR are made to conduct and commutated simultaneously.

* During "+ve" half cycle, T_1 and T_2 are forward bias and are triggered simultaneously.

* I flow P → T_1 → R → T_2 → N.

* It conduct wt = α to wt = π.

* During "-ve" half cycle T_1 & T_2 are line commutated (or) turn off.

* At (π+α), SCR T_3 & T_4 are forward bias.

* I flow N → T_3 → R → T_4 → P.

* When I falls to zero, T_3 & T_4 are line commutated.

Wave form :-

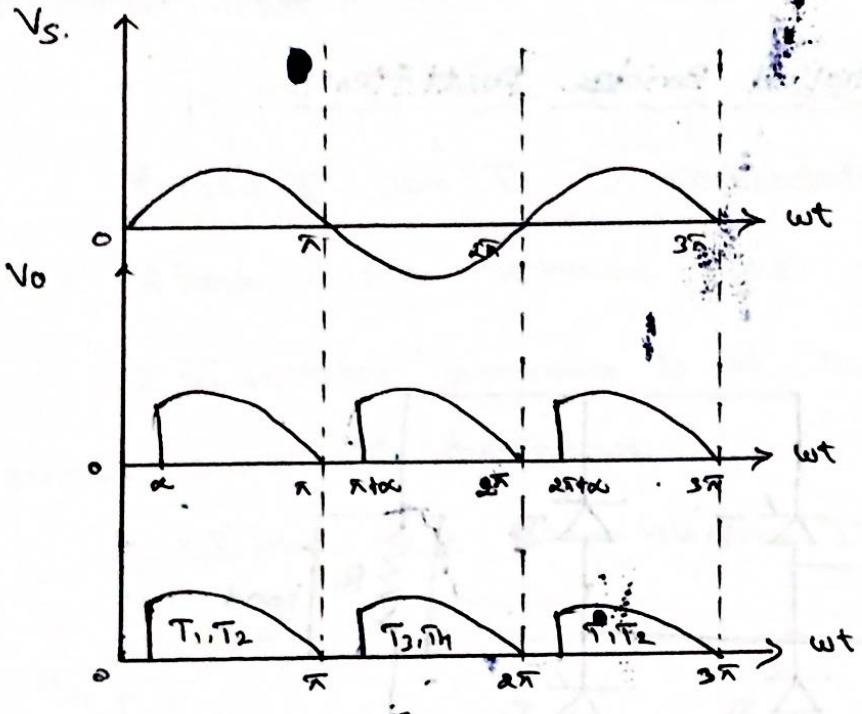


Fig : 2.17

~~ii) R~~ ~~load~~ :-

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

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

ii) RL load :-

Diagram :-

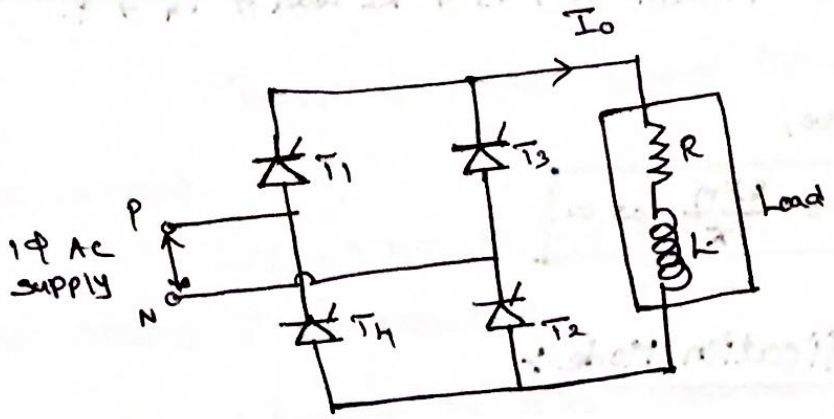


Fig: 2.18

Operation :-

* 1φ fully controlled circuit with R.L load.
* During "+ve" half cycle SCR T_1 & T_2 are triggered at firing angle (α).
* During "-ve" half cycle SCR T_3, T_4 are triggered at "$\pi+\alpha$".
* I flow is continuous and discontinuous depending upon the value of Inductance.
* If the value of inductance is large, I flow is continuous.
* For $\alpha = 60°$, T_1, T_2 are triggered. at "+ve" halfcycle
* I flow path P → T_1 → RL load → T_2 → N.
* I_o is assumed to be constant.
* I flow from P to N. & takes its Positive.
* At $\omega t = \pi$, Voltage reverse in "-ve" half cycle.
* Value of Inductance is large, I is maintained in same direction at same magnitude, T_1 & T_2 conduct.

* At $\omega t = \pi + \alpha$, T_3 & T_4 are fired.

* T_1 & T_2 are reverse biased by T_3 and T_4 respectively.

* I flow through N → T_3 → RL load → T_4 → P.

I is continuous,

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

Mode :1 Rectification Mode :-

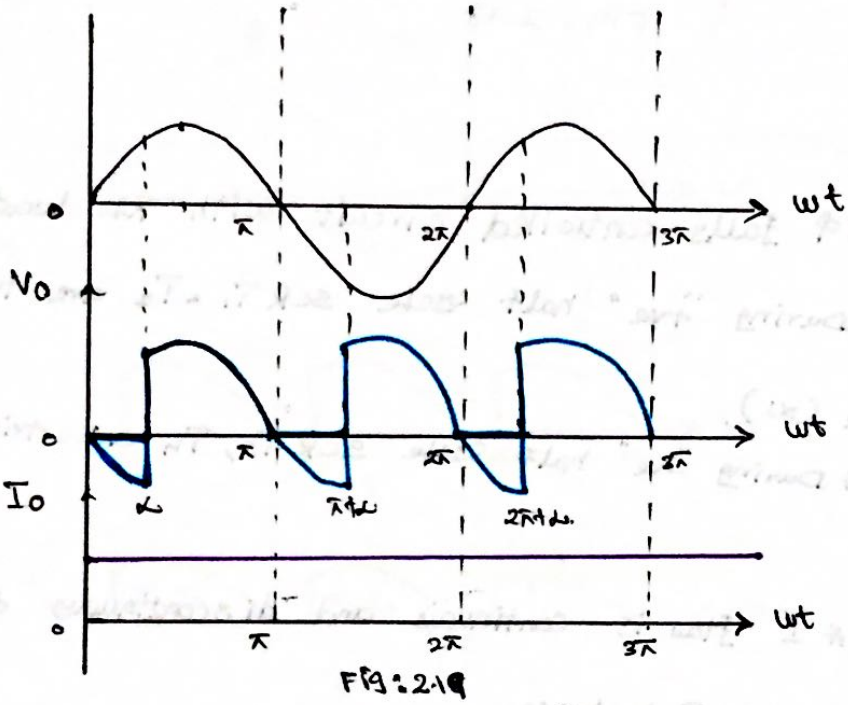


Fig : 2.19

* In this mode, AC Source to DC load because $(\pi - \alpha) > \alpha$.

* During this time interval α to π, supply voltage and I are positive. Fig 2.19.

* Power flow from source to load during α to π.

* when π to $(\pi+\alpha)$, supply voltage is reactive where I_s is positive

* During π to $(\pi+\alpha)$ Power flow from load to source.

* when $\alpha < 90$, Power flow from source to load and this mode is said to rectification mode.

Mode 2 : Inverting Mode :-

* Assume, the firing angle $\alpha = 135^\circ$ ($\alpha > 90^\circ$).

* Inverting mode, Power flow from DC Load to AC source.

* At $\omega t = 0$ to α, supply voltage is positive and supply I is negative.

* During the time interval 0 to α, Power flow from load to source.

* From, $\omega t = \alpha$ to π, both voltage and I are positive and hence Power flow from AC source to DC load.

* When $\alpha > 90^\circ$, $(\pi - \alpha) < \alpha$ and the Power is delivered from the DC side of the converter to AC side and the converter is operating as Line Commutated Inverter.

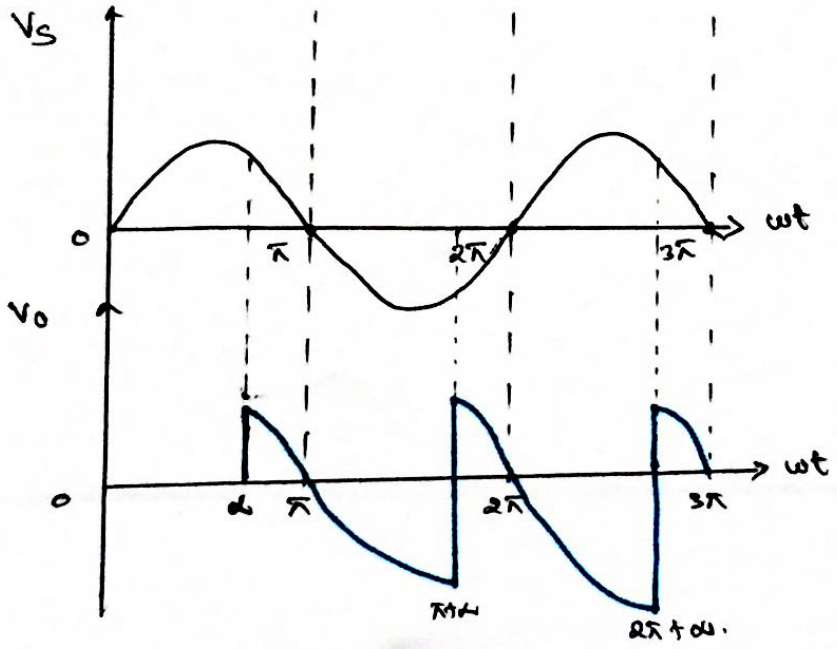


Fig : 2.20

TITLE: 3 PULSE CONVERTERS.

OBJECTIVE:

To know about 3φ half wave controlled rectifier concept.

APPLICATIONS:

PED laboratory - 3φ rectifier kit.

UNIVERSITY QUESTIONS:

* 3 Pulse converters are also known as 3φ half wave controlled rectifier, with mid point connection.

1R load :-

Diagram :-

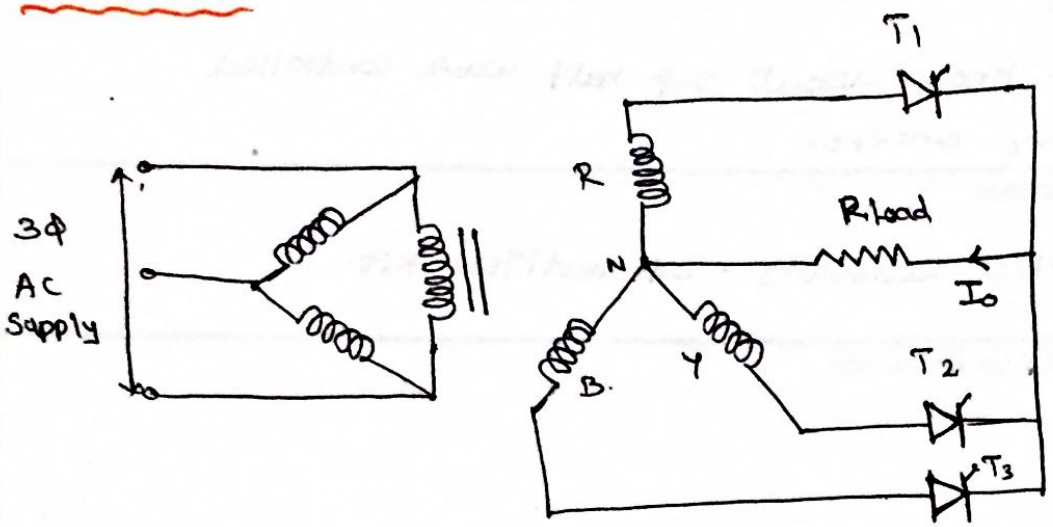


Fig : 2.21.

operation :-

* The Primary is connected in delta fashion and secondary in star.

* A neutral Point (or) mid Point is considered.

* The load is connected to neutral Point.

* Min. firing angle is 30° and conduction Period of each thyristor = $\frac{1}{3}$ of cycle Period (120°)

* T_1 will start conducting from wt = 30° to 150° as T_1 is most Positive as compared to the other 2 SCR T_2 & T_3.

* T_2 will conduct from wt = 150° to wt = 270°

* T_3 will conduct from wt = 270° to wt = 390° (30°).

* When an SCR is conducting, common terminal P rises to highest Positive voltage of that Place and other 2 blocking SCR are reversed biased.

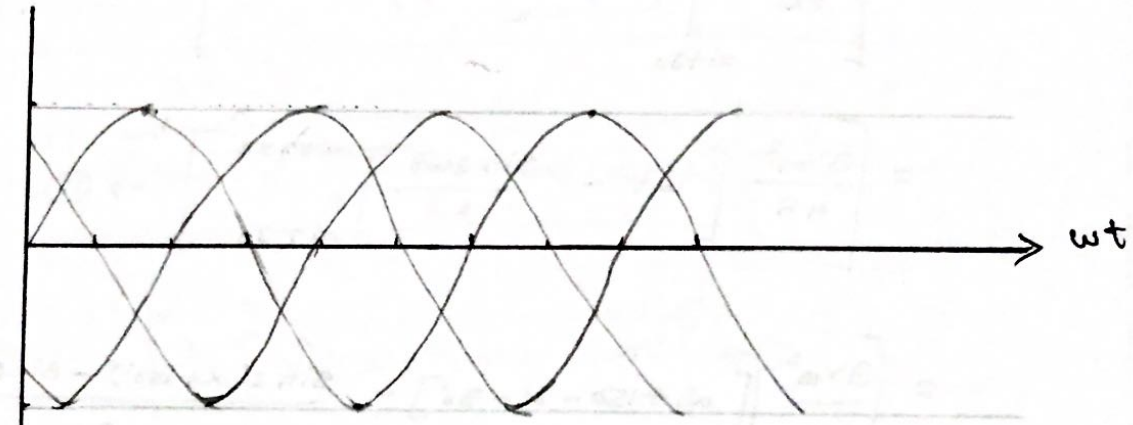
With R-load 2 modes of conduction are possible,

a) Continuous conduction mode for $\alpha \leq 30^\circ$

b) Discontinuous conduction mode for $\alpha > 30^\circ$

* When α lies b/w 0° and 30°, continuous conduction is possible and maximum value for conduction angle of SCR is 120°

* When $\alpha > 30^\circ$, discontinuous flow occurs and conduction angle of SCR is $< 120^\circ$.



a) Continuous conduction mode ($0 \leq \alpha \leq 30^\circ$).

$$V_{o(avg)} = \frac{1}{T} \int_{0}^{T} V_m \sin(\omega t) \cdot d(\omega t) \rightarrow (1)$$

$$= \frac{3}{2\pi} \int_{\alpha+30}^{\alpha+150^\circ} V_m \sin(\omega t)\, d(\omega t) \rightarrow (2)$$

$$= \frac{3V_m}{2\pi} \left[-\cos(\omega t) \right]_{\alpha+30}^{\alpha+150} \rightarrow (3)$$

$$= \frac{3V_m}{2\pi} \left[\cos(\alpha+30) - \cos(\alpha+150^\circ) \right] \rightarrow (4)$$

$$V_{o(avg)} = \frac{3V_m}{2\pi}\left[(\cos\alpha\cos 30^\circ - \sin\alpha\sin 30^\circ) - (\cos\alpha\cos 150^\circ + \sin\alpha\sin 150^\circ)\right] \rightarrow (6)$$

$$= \frac{3V_m}{2\pi}\left[\sqrt{3}\cos\alpha\right] \rightarrow (7)$$

$$\therefore V_{o(avg)} = \frac{3\sqrt{3}V_m}{2\pi}\cos\alpha \rightarrow (8).$$

$$V_{o(RMS)} = \left[\frac{3}{2\pi}\int_{\alpha+30}^{\alpha+150^\circ} V_m^2 \sin^2(\omega t)\, d(\omega t)\right]^{1/2} \rightarrow (9)$$

$$= \left[\frac{3V_m^2}{2\pi}\int_{\alpha+30}^{\alpha+150^\circ}\left(\frac{1-\cos 2(\omega t)}{2}\right) d(\omega t)\right]^{1/2} \rightarrow (10)$$

$$= \left[\frac{3V_m^2}{4\pi}\left[\omega t - \frac{\sin 2\omega t}{2}\right]_{\alpha+30}^{\alpha+150^\circ}\right]^{1/2} \rightarrow (11)$$

$$= \left[\frac{3V_m^2}{4\pi}\left[[\alpha+150-\alpha-30^\circ] - \frac{\sin 2(\alpha+150^\circ) - \sin 2(\alpha+30^\circ)}{2}\right]\right]^{1/2}$$

$$\therefore V_{o(RMS)} = V_m\left[\frac{1}{2} + \frac{3\sqrt{3}}{8\pi}\cos 2\alpha\right]^{1/2} \rightarrow (12).$$

b) Discontinuous Conduction Mode ($30^\circ \leq \alpha \leq 150^\circ$)

$$V_{o(avg)} = \frac{3}{2\pi} \int_{\alpha+30}^{180^\circ} V_m \sin(\omega t)\, d(\omega t) \rightarrow (1)$$

$$= \frac{3}{2\pi} \int_{\alpha+30}^{\pi} V_m \sin(\omega t)\, d(\omega t) \rightarrow (2)$$

$$= \frac{3}{2\pi} \left[-\cos \omega t \right]_{\alpha+30}^{\pi} \rightarrow (3)$$

$$= \frac{3}{2\pi} \left[\cos(\alpha+30^\circ) - \cos\pi \right] \rightarrow (4)$$

$$\therefore V_{o(avg)} = \frac{3V_m}{2\pi} \left[1 + \frac{\sqrt{3}\cos\alpha}{2} - \frac{\sin\alpha}{2} \right] \rightarrow (5)$$

(or)

$$V_{o(avg)} = \frac{3V_m}{2\pi} \left[1 + \cos(\alpha+30^\circ) \right] \rightarrow (6).$$

$$V_{o(RMS)} = \left[\frac{3}{2\pi} \int_{\alpha+30^\circ}^{\pi} V_m^2 \sin^2(\omega t)\, d(\omega t) \right]^{1/2} \rightarrow (7)$$

$$= \left[\frac{3V_m^2}{2\pi} \int_{\alpha+30^\circ}^{\pi} \left(\frac{1-\cos 2\omega t}{2} \right) d(\omega t) \right]^{1/2} \rightarrow (8)$$

$$= \left[\frac{3V_m^2}{4\pi} \left[(\pi - \alpha - 30) - \left(\frac{\sin 2\omega t}{2} \right)_{\alpha+30^\circ}^{\pi} \right] \right]^{1/2} \rightarrow (9)$$

$$\therefore V_{o(RMS)} = \sqrt{3} V_m \left[\frac{5}{24} - \frac{\alpha}{4\pi} + \frac{1}{8\pi} \sin\left(2\alpha + \frac{\pi}{3} \right) \right]^{1/2} \rightarrow (10)$$

2) RL load :-

Diagram :-

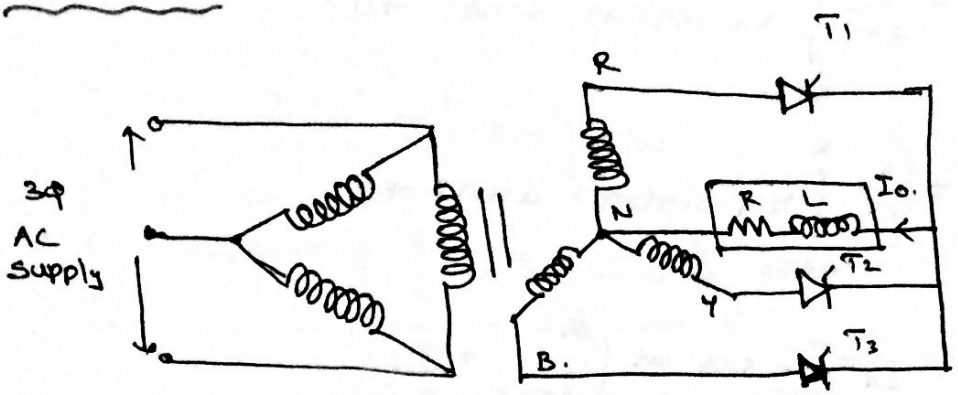


Fig : 2.22

Operation :-

* The Primary of the transformer is connected in Δ and secondary in Y with RL Load is connected in mid Point.

* T_1, T_2 and T_3 are connected in R, Y & B.

* The current wave for transformer secondary winding are assumed rectangular for simplifying the analysis.

* Each SCR block forward voltage for a period of 45°. Prior to the instant at which it is fired.

* The avg. voltage at the DC terminal is reduced and it is Positive.

* Now converter is working as rectifier.

* 3 Pulse converter for firing angle $\alpha > 90°$ ($\alpha = 135°$)

* The blocking voltage developed across the SCR is in forward direction.

* The mean DC voltage at DC terminal is negative.

* The energy is transfered from DC load side to AC supply system.

* The converter is operating in inverting mode when $\alpha > 90^\circ$.

$$V_o = \frac{3}{2\pi} \int_{\alpha+30}^{\alpha+150} V_m \cdot \sin(\omega t) \cdot d(\omega t) \rightarrow (1)$$

$$\therefore V_o = \frac{3\sqrt{3}}{2\pi} V_m \cdot \cos\alpha \rightarrow (2).$$

case: 1. $\alpha = 0$ $\quad V_{o(max)} = \frac{3\sqrt{3}}{2\pi} V_m.$

case: 2 $\quad \alpha = 90^\circ \quad V_o = 0$

case: 3 $\quad \alpha = 180^\circ \quad V_{o(-max)} = \frac{-3\sqrt{3}}{2\pi} V_m.$

3φ Half Controlled Bridge Converter :
[3φ semi converter] :-

1) R load :-

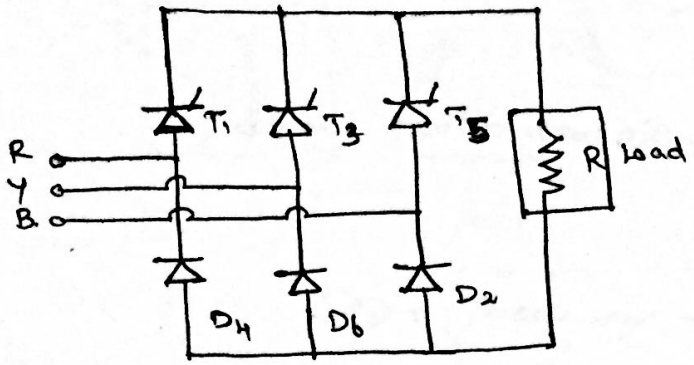


Fig : 2.23.

operation :-

i) Diode start conducting as soon as they are forward biased.

ii) Line voltage conduct in sequence V_{RY}, V_{RB}, V_{YB}, V_{YR}, V_{BR} and V_{BY}.

iii) Line voltage which has the highest value will conduct.

Conducting Line Volt.		Conducting Devices.
V_{RY}	-	$D_6 T_1$
V_{RB}	-	T_1, D_2
V_{YB}	-	D_2, T_3
V_{YR}	-	T_3, D_4
V_{BR}	-	D_4, T_5
V_{BY}	-	T_5, D_6.

Case :1 $\alpha \leq 60^\circ$

$$V_{o(avg)} = \frac{3}{2\pi}\left[\int_{30^\circ+\alpha}^{90^\circ} V_{RY}.(\omega t).\,d(\omega t). + \int_{90^\circ}^{150^\circ+\alpha} V_{RB}.(\omega t).d(\omega t)\right] \rightarrow (1)$$

$$= \frac{3}{2\pi}\left[\int_{30^\circ+\alpha}^{90^\circ} \sqrt{3}.V_m.\sin(\omega t+30^\circ).d(\omega t) + \int_{90^\circ}^{150^\circ+\alpha} \sqrt{3}\,V_m.\sin(\omega t-30^\circ).\,d(\omega t)\right] \rightarrow (2).$$

$$= \frac{3\sqrt{3}}{2\pi}V_m.\left[\left[-\cos(\omega t+30^\circ)\right]_{30^\circ+\alpha}^{90^\circ} - \left[\cos(\omega t-30^\circ)\right]_{90}^{150^\circ+\alpha}\right] \rightarrow (3)$$

$$= \frac{3\sqrt{3}V_m}{2\pi}\left[\cos(60^\circ+\alpha) - \cos(120^\circ) + \cos(60^\circ) - \cos(120^\circ+\alpha)\right]$$

$$= \frac{3\sqrt{3}V_m}{2\pi}\left[1+\cos(60^\circ+\alpha) - \cos(120^\circ+\alpha)\right]$$

$$\therefore V_{o(avg)} = \frac{3\sqrt{3}}{2\pi}V_m\left[1+\cos\alpha\right] \rightarrow (4).$$

$$V_{o(rms)} = \left[\frac{1}{2\pi}\int_{\bullet}^{2\pi} V_o^{\,2}(\omega t).\,d(\omega t)\right]^{1/2} \rightarrow (5)$$

$$= \left[\frac{3}{2\pi}\left[\int_{30^\circ+\alpha}^{90^\circ}\left(\sqrt{3}V_m\sin(\omega t+30^\circ)\right)^2.d(\omega t) + \int_{90^\circ}^{150^\circ+\alpha}\left(\sqrt{3}V_m.\sin(\omega t-30^\circ)\right)^2 d(\omega t)\right]\right]^{1/2} \rightarrow (6)$$

$$= \left[\frac{9V_m^{\,2}}{2\pi}\left[\int_{60^\circ+\alpha}^{120^\circ}\sin^2(\omega t).\,d(\omega t). + \int_{60^\circ}^{120^\circ+\alpha}\sin^2(\omega t).\,d(\omega t)\right]\right]^{1/2} \rightarrow (7)$$

$$V_{o(rms)} = \frac{3V_m}{2\pi}\left[\frac{2\pi}{3\pi} + \frac{\sqrt{3}}{2\pi}(1+\cos 2\alpha)\right]^{1/2} \rightarrow (9)$$

$$\therefore V_{o(rms)} = \frac{3V_m}{2\pi}\left[\frac{2}{3} + \frac{\sqrt{3}}{2\pi}(1+\cos\alpha)\right]^{1/2} \rightarrow (10).$$

case: 2 $\alpha \geq 60^\circ$

$$V_{o(avg)} = \frac{3}{2\pi}\int_{30^\circ+\alpha}^{210^\circ} \sqrt{3}.V_m.\sin(\omega t - 30^\circ).\, d(\omega t) \rightarrow (1)$$

$$= \frac{3\sqrt{3}V_m}{2\pi}\left[-\cos(\omega t - 30^\circ)\right]_{30^\circ+\alpha}^{210^\circ} \rightarrow (2)$$

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

$$V_{o(rms)} = \left[\frac{3}{2\pi}\int_{30^\circ+\alpha}^{210^\circ}\left[\sqrt{3}V_m\sin(\omega t - 30^\circ)\right]^2 d(\omega t)\right]^{1/2} \rightarrow (4)$$

$$= \left[\frac{9V_m^2}{2\pi}\int_{\alpha}^{180^\circ}\sin^2(\omega t).\, d(\omega t)\right] \rightarrow (5).$$

$$= \left[\frac{9V_m^2}{2\pi}\int_{\alpha}^{180^\circ}\left(\frac{1-\cos 2\omega t}{2}\right).\, d(\omega t)\right] \rightarrow (6).$$

$$\therefore V_{o(rms)} = \frac{3V_m}{2\pi}\left[\frac{\pi-\alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}\right]^{1/2} \rightarrow (9).$$

2) RL Load :-

Diagram :-

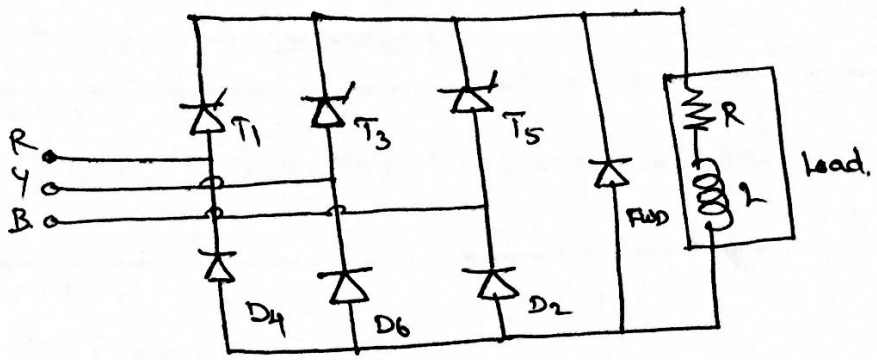


Fig: 2.23

Operation :-

* The average and RMS output voltage are same as R Load.

* Continuous conduction occur $\alpha < 60^\circ \Rightarrow \alpha = 30^\circ$

* Discontinuous conduction occur $\alpha > 60 \Rightarrow \alpha = 90^\circ$

* waveform for $\alpha = 90^\circ$. where output voltage is zero during freewheeling period which makes the waveform discontinuous.

* SCR and Diode conduct for 1/3 of duty cycle(120°) if firing angle $\alpha = 0^\circ \leq \alpha \leq 120^\circ$

* PIV rating of SCR and diode is $\sqrt{3} V_m$.

* If SCR conduct Phase current is positive and if diode conduct Phase current is negative.

* During conduction period, load current I_o is equal to conducting current.

TITLE: SIX PULSE CONVERTER.

OBJECTIVE:

To know about the six pulse converter concept.

APPLICATIONS:

PED laboratory – 3φ converter kit.

UNIVERSITY QUESTIONS:

3ϕ Fully controlled Bridge converter :-

6 Pulse converter :-

1) R load :-

Diagram :-

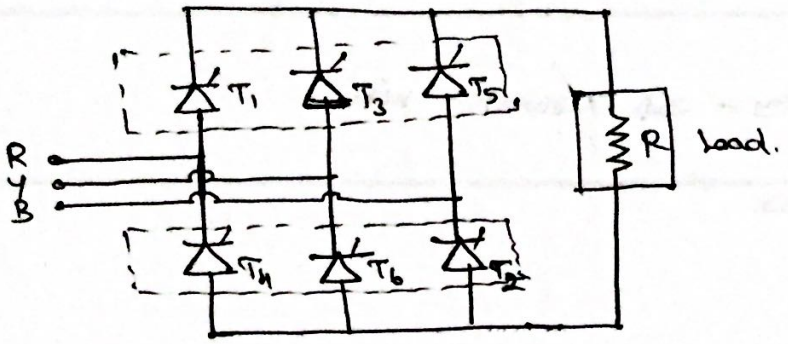


Fig : 2.24.

Operation :-

* Six Pulse converter with R Load.
* Each SCR has be triggered twice during conduction cycle with firing interval of 60°.
* Output waveform for $\alpha = 30°$.
* The output waveform is 6 pulse wave with "α" has ripple frequency of 300 Hz. (50 Hz × 6).

a) Continuous Conduction Mode [$0 \leq \alpha \leq 60°$] :-

* Conduction is continuous when $\alpha \leq 60°$.
* During the interval from 0 to 60°
* V_{RY} is Predominating and applied across the circuit.
* At 60°, V_{RB} is fired.
* V_{RB} Conduct for another 60° when V_{YB} is triggered
* Hence load I for α b/w 0 to 60°.

$$V_{o(avg)} = \frac{1}{T}\int_0^T V_s \cdot d(\omega t) \rightarrow (1)$$

$$= \frac{1}{2\pi}\int_0^{2\pi} V_s \cdot d(\omega t) \rightarrow (2)$$

$\alpha < 60^\circ$

$$\therefore V_{o(avg)} = \frac{6}{2\pi}\int_{\alpha+30}^{\alpha+90} \sqrt{3}\, V_m \sin(\omega t + 30^\circ)\, d(\omega t) \rightarrow (3)$$

$$= \frac{3\sqrt{3}V_m}{\pi}\int_{\alpha+30+30}^{\alpha+90+30} \sin(\omega t)\, d(\omega t) \rightarrow (4)$$

$$= \frac{3\sqrt{3}V_m}{\pi}\int_{\alpha+60}^{\alpha+120} \sin(\omega t)\, d(\omega t) \rightarrow (5)$$

$$= \frac{3\sqrt{3}V_m}{\pi}\left[-\cos(\omega t)\right]_{\alpha+90}^{\alpha+120} \rightarrow (6)$$

$$= \frac{3\sqrt{3}V_m}{\pi}\left[\cos(\alpha+90^\circ) - \cos(\alpha+120^\circ)\right]$$

$$\therefore V_{o(avg)} = \frac{3\sqrt{3}V_m}{\pi}\cos\alpha \rightarrow (7)$$

b) Discontinuous mode [$60^\circ \leq \alpha \leq 120^\circ$] :-

*When $60^\circ \leq \alpha \leq 120^\circ$, V_{RY} conduct upto π after which both scr T_1 and T_6 are commutated because phase Y is positive with respect to B.

*After, 60°, when T_1 & T_2 are fired, V_{RB} conduct upto π.

*The load current remain 0 from π to next firing angle. which makes load current discontinuous.

$$V_{o(avg)} = \frac{6}{2\pi} \int_{30^\circ+\alpha}^{150^\circ} \sqrt{3}\, V_m \sin(\omega t + 30^\circ)\, d(\omega t) \rightarrow (1)$$

$$= \frac{3\sqrt{3} V_m}{\pi} \int_{30^\circ+\alpha}^{150^\circ} \sin(\omega t + 30^\circ)\, d(\omega t) \rightarrow (2)$$

$$= \frac{3\sqrt{3} V_m}{\pi} \int_{60^\circ+\alpha}^{180^\circ} \sin(\omega t)\, d(\omega t) \rightarrow (3)$$

$$= \frac{3\sqrt{3} V_m}{\pi} \left[-\cos \omega t \right]_{60^\circ+\alpha}^{180^\circ} \rightarrow (4)$$

$$\boxed{V_{o(avg)} = \frac{3\sqrt{3} V_m}{\pi} \left[1 + \cos(60+\alpha) \right]} \rightarrow (5).$$

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2) RLE Load :-

Diagram :-

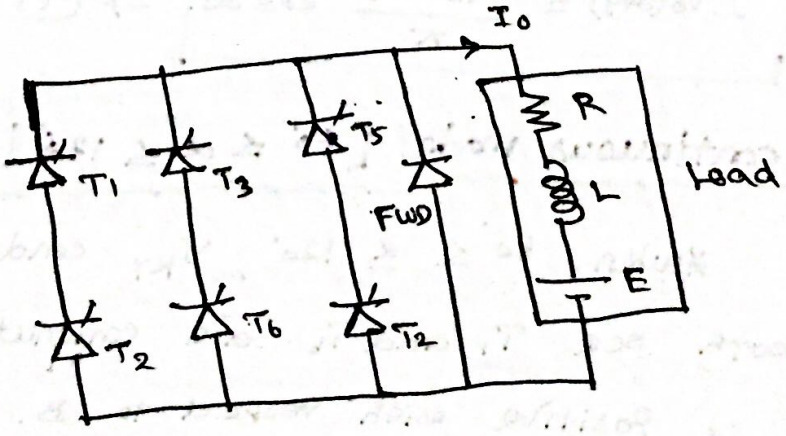


Fig : 2.25

Operation :-

* The output waveform for $\alpha = 0°, 30°, 60°, 90°, 120°, 150°$ & $180°$.

* The load inductance is assumed to be very large to produce constant load current.

* waveform are similar to that of R load for $\alpha = 0°, 30°$ & $60°$.

* If $\alpha > 60°$, waveform differ due to the nature of inductive load and voltage goes negative.

* If T_6 and T_1 are continuously conducting upto $(90° + \alpha)$ till T_2 is triggered.

* T_2 when triggered commutate T_6 and $T_1 T_2$ starts conducting.

* when $\alpha = 90°$, the area under positive and negative cycle are equal.

$$V_{o(avg)} = \frac{6}{2\pi} \int_{30°+\alpha}^{90°+\alpha} \sqrt{3}\, V_m \sin(\omega t - 30°)\, d(\omega t) \rightarrow (1)$$

$$= \frac{6}{2\pi} \int_{60°+\alpha}^{120°+\alpha} \sqrt{3}\, V_m \sin(\omega t)\, d(\omega t) \rightarrow (2)$$

$$= \frac{3\sqrt{3} V_m}{\pi} \left[-\cos(\omega t) \right]_{60°+\alpha}^{120°+\alpha} \rightarrow (3)$$

$$\therefore V_{o(avg)} = \frac{3\sqrt{3} V_m}{\pi} \cos\alpha \rightarrow (4) \quad 0 \le \alpha \le 180°$$

$$V_{O(RMS)} = \left[\frac{6}{2\pi}\int_{30^\circ+\alpha}^{90^\circ+\alpha}\left[\sqrt{3}\,V_m \sin(\omega t+30^\circ)\,d(\omega t)\right]^2\right]^{1/2} \rightarrow (5)$$

$$= \left[\frac{9V_m^2}{2\pi}\left[\omega t - \frac{\sin 2\omega t}{2}\right]_{60^\circ+\alpha}^{120^\circ+\alpha}\right]^{1/2} \rightarrow (6)$$

$$= \frac{9V_m^2}{2\pi}\left[\right]$$

$$\boxed{V_{O(RMS)} = \frac{3V_m}{2}\left[\frac{2}{3} + \frac{\sqrt{3}\cos 2\alpha}{\pi}\right]^{1/2}} \rightarrow (7).$$

a) Rectified

a) Rectifier operation ($\alpha < 90^\circ$) :-

* waveform of rectifier operation when "α" lies b/w 0° and 90°.

* The avg. voltage developed is positive for $\alpha = 0^\circ$, 30°, 60°.

* when $\alpha = 90^\circ$, avg. voltage is 0.

* upto $\alpha < 90^\circ$, current flows from AC source to DC load and hence the converter is said to be operated in rectifier mode.

b) Inverter Mode :-

* waveform of converter from $\alpha > 90^\circ - 180^\circ$
* negative half cycle > positive half cycle.
* Power transfer load to source.
* It operate Inverter mode.

TITLE: Performance Factor of line Commutated Converters.

OBJECTIVE:

To know about the performance factor of line commutated converter concepts.

APPLICATIONS:

UNIVERSITY QUESTIONS:

Performance Factor :-

a) Input Displacement Angle Factor [ϕ_1] :-

It is defined as the angular displacement between the fundamental component of AC line current and line to neutral voltage.

b) Input Displacement Factor ($\cos\phi_1$) :-

DSF = $\cos\alpha$ for 2 Pulse converter.

c) Input Power Factor :-

It is defined as ratio of the total mean input Power to total RMS input V-A.

$$P.F = \left[\frac{I_1}{I_{rms}}\right] \cos\phi_1.$$

For 2 pulse converter,

$$P.F = \left[\frac{2\sqrt{2}\, I_o}{\pi I_o.}\right] \cos\alpha = \frac{2\sqrt{2}}{\pi} \cos\alpha.$$

d) DC Voltage Ratio (ν) :-

It is ratio of mean DC terminal voltage at given firing angle "α" to max. possible voltage for $\alpha = 0^\circ$.

For 2 Pulse converter,

$$\nu = \frac{\frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m . \sin(\omega t) . d(\omega t)}{\frac{1}{\pi}\int_{0}^{\pi} V_m . \sin(\omega t) . d(\omega t).}$$

$$= \frac{\left[-\cos(\omega t)\right]_{\alpha}^{\pi+\alpha}}{\left[-\cos(\omega t)\right]_{0}^{\pi}}$$

$$\nu = \frac{2\cos\alpha}{2} = \cos\alpha.$$

e) Input Current Distortion Factor :-

It is the ratio of RMS amplitude of the fundamental component to the total RMS amplitude.

$$= \frac{I_1}{I_{rms}}$$

2 Pulse converter,

$$= \frac{2\sqrt{2}\, I_o}{\pi I_o} = \frac{2\sqrt{2}}{\pi}$$

f) Input Harmonic Factor (I_H) :-

The input harmonic factor is defined as the ratio of total harmonic current to the fundamental component.

$$I_H = \frac{\left[I_{rms}^2 - I_1^2\right]^{1/2}}{I_1}$$

2 Pulse Converter,

$$I_H = \left[\frac{\pi^2}{8} - 1\right]^{1/2}$$

g) Voltage Ripple Factor (K_v) :-

It is the ratio of the rot harmonic content of the output voltage to average output voltage.

$$K_v = \frac{\sqrt{V_{o(rms)}^2 - V_o^2}}{V_o}$$

2 Pulse converter,

$$K_v = \left[\frac{\pi^2}{8\cos^2\alpha} - 1\right]^{1/2}$$

h) Current Ripple Factor (k_I) :-

It is ratio of rms harmonic content of the output voltage to the avg output current.

$$k_I = \frac{\sqrt{I_{o(rms)}^2 - I_o^2}}{I_o}$$

i) Active Power Input (P_i) :-

It is the Product of RMS line voltage and RMS fundamental component of current and displacement factor.

$$P_i = V_{o(rms)} \times I_1 \times \cos\alpha.$$

2 pulse converter, $P_i = \frac{2V_m}{\pi} I_o \cdot \cos\alpha.$

j) Reactive Power Input (Q_i) :-

$$Q_i = V_{o(rms)} \cdot I_1 \cdot \sin\alpha.$$

$$= \frac{2V_m}{\pi} I_o \cdot \sin\alpha.$$

k) Rectification Ratio (or) Efficiency (η) :-

$$\eta = \frac{P_{dc}}{P_{in}} = \frac{V_o' I_o}{V_{rms} I_{rms}}$$

l) Form Factor (FF) :-

It is measure of shape of output voltage.

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

m) Ripple factor :

$$RF = \frac{V_{ac}}{V_o}$$

n) TUF :- $TUF = \frac{P_o}{V_s I_s}$

TITLE: Dual converter.

OBJECTIVE:

To know about the dual converter concepts.

APPLICATIONS:

UNIVERSITY QUESTIONS:

Dual Converters :-

* If 4 quadrant operation of a DC motor is required without any mechanical changeover switch.

* Reversible rotation and reversible torque, a single converter need the addition of either a changeover contactor to reverse the armature connections.

* 2 full converter can be connected back to back to the load circuit.

* Such arrangement wing 2 full converter in antiparallel and connected to same Dc motor is called dual converter.

* Both voltage and current of either Polarity are obtained with a dual converter,

* The system will provide the 4 quadrant operation.

* 1φ & 3φ dual converter using bridge type converter circuits.

* The output terminal of each converter having same potential are connected together each through a reactor.

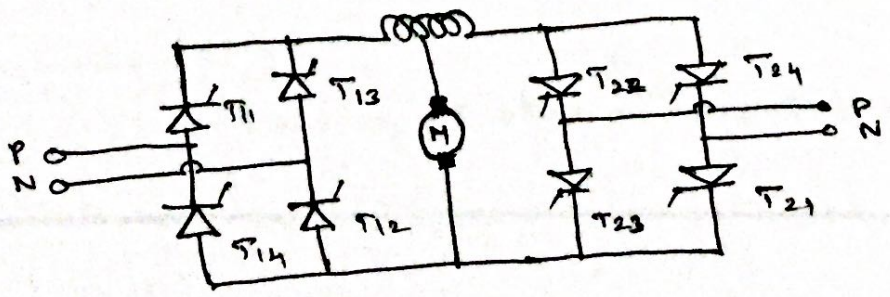


Fig : 2.29

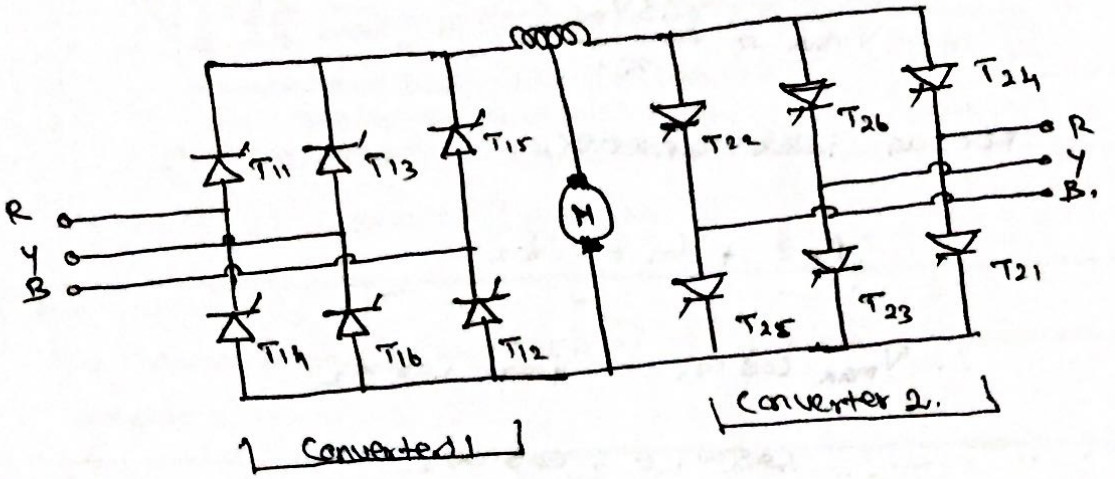


Fig: 2.30

* 4 Possible quadrant operation thus resulting can be translated into 4 (steady-state) combinations of motor torque and rotation.

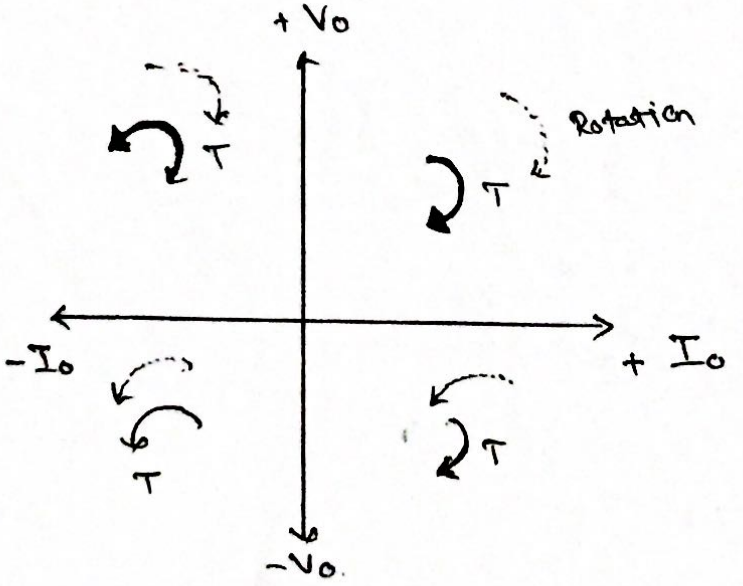


Fig: 2.31

$$V_{o1} = V_{max} \cos\alpha_1$$

$$V_{o2} = V_{max} \cos\alpha_2$$

where for a single phase full-wave converter

$$V_{max} = \frac{2V_m}{\pi}$$

For 3φ wave converter,

$$V_{max} = \frac{3\sqrt{3}V_m}{\pi}$$

For an ideal converter,

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

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

$$\therefore \cos\alpha_1 = -\cos\alpha_2$$

$$\therefore \alpha_1 = 180^\circ - \alpha_2$$

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

TITLE: Effect of Source Impedance.

OBJECTIVE:

To know about the effect of source impedance concepts.

APPLICATIONS:

UNIVERSITY QUESTIONS:

Effect of source Impedance :-

* Here, done Previously, source impedance was assumed as zero.

* But source Posses internal impedance.

* If the impedance is resistive, there will be voltage drop across the resistance and avg. voltage at the output reduced by $I_o . R_s$.

* For 3φ converter drop = $2 I_o . R_s$.

* Source Inductance causes the incoming and outgoing SCR to conduct together during certain during which is known as overlap period and corresponding angle is called overlap angle (μ) commutation angle (μ).

1. Single Phase Fully controlled converter :-

Diagram :-

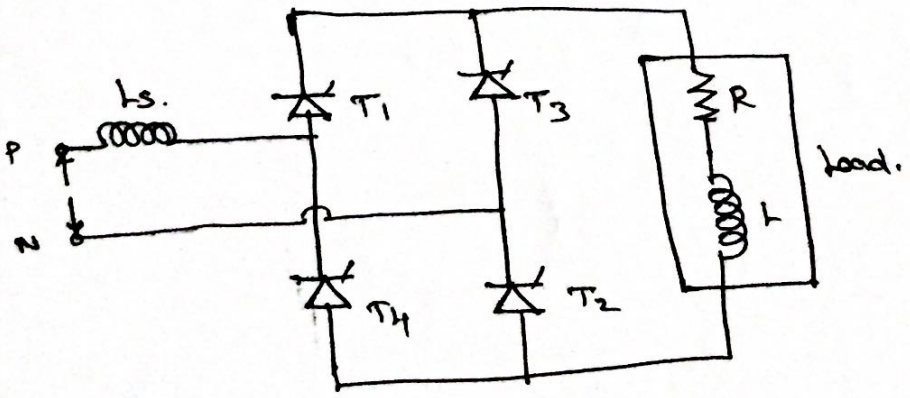


Fig : 2.26

* 1φ full converter with RL load and Source Inductance (L_s).

* The commutation overlap is Predominant in Full Converter than semi converter.

* During the half cycle P is +ve. w.r.to N.

* $V_{s1} = V_m \sin \omega t$.

* Current I_{T1} path is P → L_s → T_1 → RL → T_2 → N.

* During -ve half cycle, I path I_{T3} is

N → T_3 → RL → T_4 → L_s → P.

* $V_{s2} = -V_m \sin \omega t$.

* During commutation, T_1 T_2 and T_3 T_4 conduct.

Applying KVL.

$$V_{s1} - L_s \frac{di_{T1}}{dt} = V_{s2} - L_s \frac{di_{T3}}{dt} \rightarrow (1)$$

$$V_{s1} - V_{s2} = L_s \left[\frac{di_{T1}}{dt} - \frac{di_{T3}}{dt} \right] \rightarrow (2)$$

Load current is assumed to be constant.

$$I_o = I_{T1} + I_{T3} \rightarrow (3)$$

(3). diff. w.r.to. t.

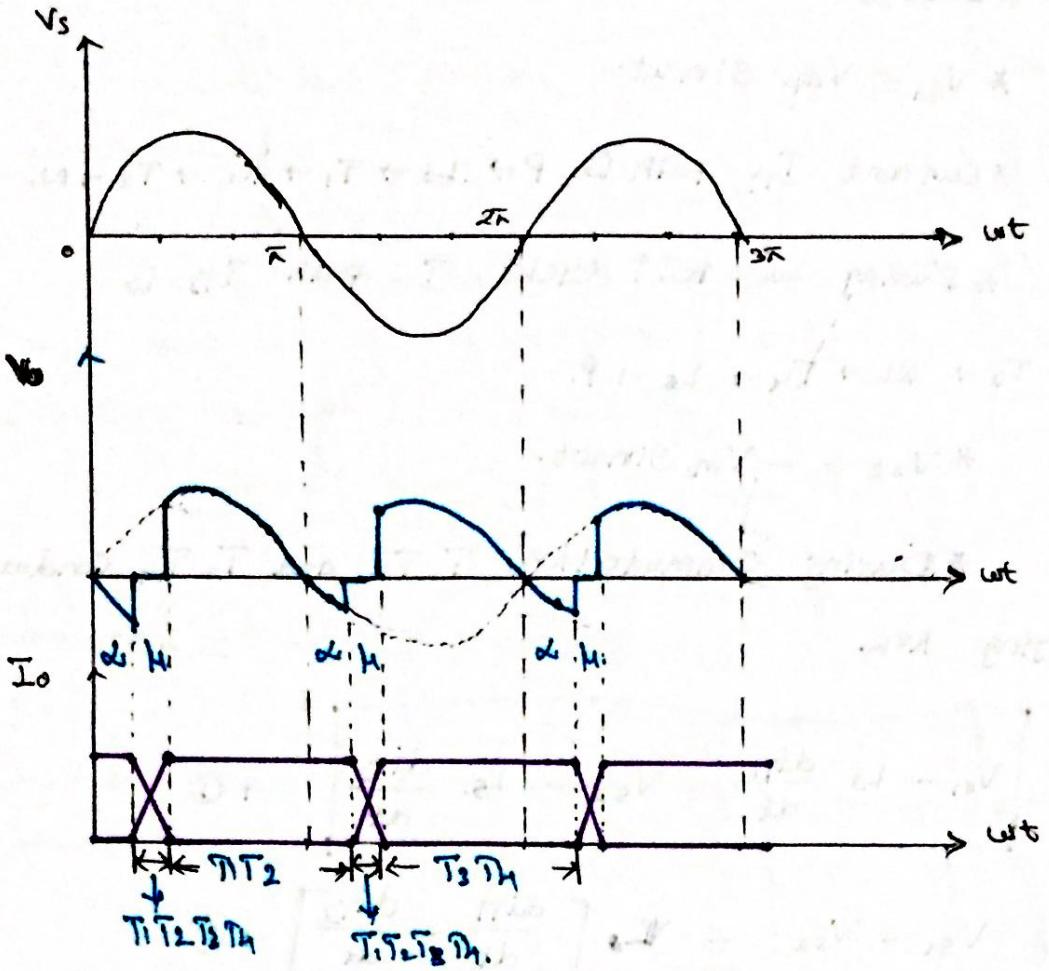
$$0 = \frac{dI_{T1}}{dt} + \frac{dI_{T3}}{dt} \rightarrow (4)$$

$$\therefore \frac{dI_{T1}}{dt} = -\frac{dI_{T3}}{dt} \rightarrow (5).$$

$$\therefore 2V_{sm} \sin \omega t = L_s \cdot 2 \cdot \frac{di_{T1}}{dt} \rightarrow (6)$$

$$\therefore \frac{di_{T1}}{dt} = \frac{V_m}{L_s} \cdot \sin \omega t \rightarrow (7).$$

If the overlap angle is μ, then current through $T_1 T_2$ build up from 0 to I_o.



$$I_o \int_0 di_T = \frac{V_m}{L_s} \int_{\alpha/\omega}^{\frac{\alpha+\mu}{\omega}} \sin(\omega t).\, d(\omega t). \quad \rightarrow (8)$$

$$I_o = \frac{V_m}{\omega L_s} \left[-\cos \omega t\right]_{\alpha}^{\alpha+\mu}. \quad \rightarrow (9)$$

$$I_o = \frac{V_m}{\omega L_s} \left[\cos\alpha - \cos(\alpha+\mu)\right] \quad \rightarrow (10)$$

$$V_o = \frac{V_m}{\pi} \int_{\alpha+\mu}^{\pi+\alpha} \sin(\omega t).\, d(\omega t). \quad \rightarrow (11)$$

$$= \frac{V_m}{\pi} \left[-\cos \omega t\right]_{\alpha+\mu}^{\pi+\alpha} \quad \rightarrow (12)$$

$$= \frac{V_m}{\pi} \left[\cos(\alpha+\mu) - \cos(\pi+\alpha)\right] \quad \rightarrow (13)$$

Let $\cos(\alpha+\mu) = \cos\alpha - \frac{\omega L_s}{V_m} I_o$ → (14)

∴ Sub (14) in (13) ⇒.

$$\therefore V_o = \frac{V_m}{\pi}\left[\cos\alpha + \cos\alpha - \frac{\omega L_s}{V_m} I_o\right] \rightarrow (15)$$

$$= \frac{2V_m}{\pi}\cos\alpha - \frac{\omega L_s}{\pi} I_o \rightarrow (16)$$

$$\therefore V_o = \frac{2V_m}{\pi}\cos(\alpha+\mu) + \frac{\omega L_s}{\pi} I_o \rightarrow (17)$$

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2) 3φ Fully controlled Bridge converter :-

Diagram :-

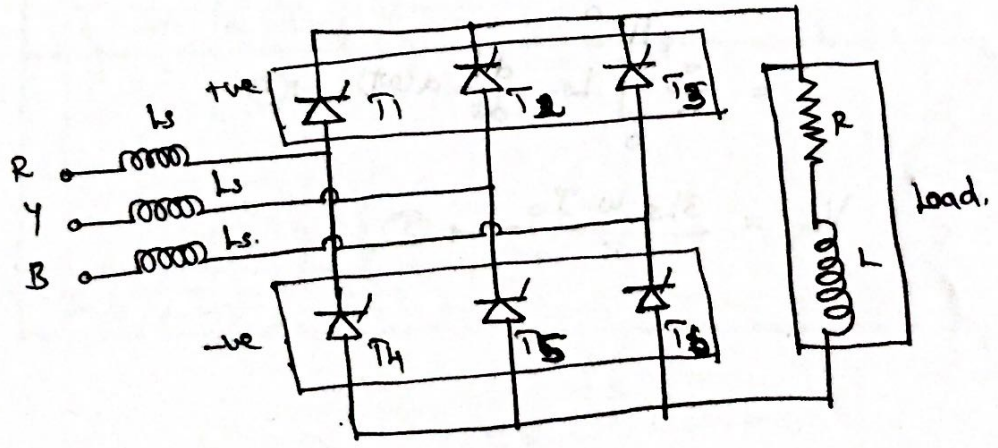

Fig: 2.27

Operation :-

* Thyristor T_1, T_2, T_3 → +ve group.
* T_4, T_5, T_6 → -ve group.
* The effect of source inductance due to transformer leakage reactance.

When "+ve" group of SCR undergo commutation 2SCR from "+ve" group and 1 SCR from "-ve" group.

After commutation of Positive group is completed, only 2SCR conduct, 1 from "+ve" group and 2 from "-ve" group.

During "-ve" group commutation, 2 SCR from "-ve" and 1 SCR from "+ve".

From the instant $wt = 0^\circ$ to 30° SCR T_3 & T_5 con

At $wt = 30^\circ$, T_2 is outgoing T_1 is incoming SCR. and both belonged to same group.

i_{T3} ↓ and i_{T1} ↑ from $wt = 30$ to H.

Reduction in output voltage due to overlap,

$$= \frac{3}{\pi} \int_0^H V_L \cdot d(wt) \rightarrow (1)$$

$$= \frac{3}{\pi} \int_0^H L_s \cdot \frac{di}{dt} d(wt) \rightarrow (2)$$

$$V_o = \frac{3 L_s \cdot w \cdot I_o}{\pi} \rightarrow (3)$$

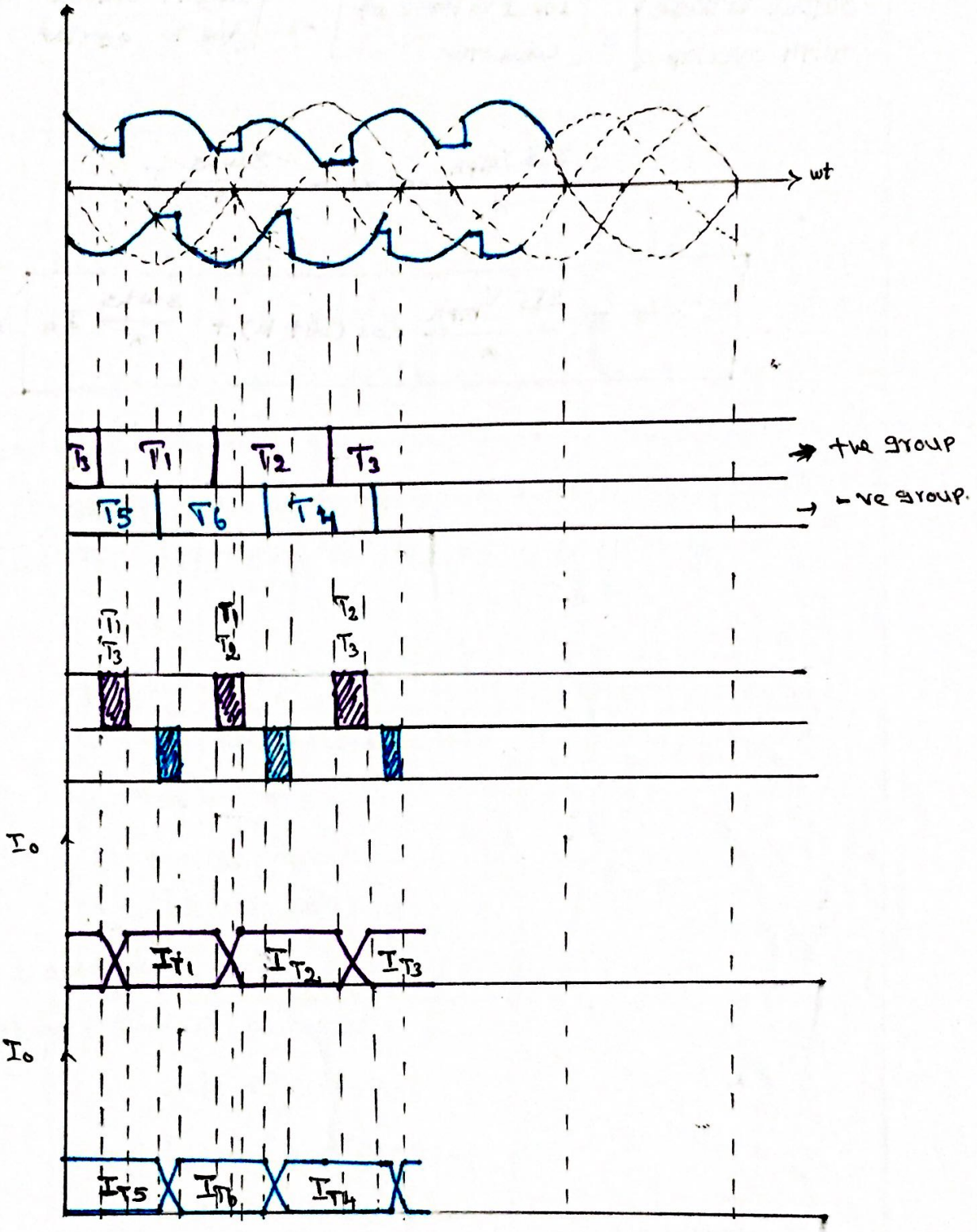
wt
T3
T1
T2
T3
+ve group
T5
T6
T4
-ve group
T1
T3
T1
T2
T2
T3
Io
IT1
IT2
IT3
Io
IT5
IT6
IT4

Fig: 2.28

Output voltage with overlap = [Input voltage of converter] − [fall in output voltage due to overlap]

$$= \frac{3\sqrt{3}\,V_{mph}}{\pi}\cos\alpha - \frac{3\omega L_s}{\pi} I_o$$

$$\therefore V_o = \frac{3\sqrt{3}\,V_{mph}}{\pi}\cos(\alpha + \mu) + \frac{3\omega L_s}{\pi} I_o$$