EE 6503 POWER ELECTRONICS
UNIT II
PHASE-CONTROLLED CONVERTERS

1. INTRODUCTION

The diode rectifiers provide a fixed output voltage only. To obtain controlled output voltages, phase controlled thyristors are used instead of diodes. The output voltage of the thyristor is varied by controlling the delay or firing angle of thyristors. Presently phase controlled AC to DC converters employing thyristors are extensively used for changing constant AC input voltage to controlled DC output voltage.

A phase control thyristor is turned on by applying a short pulse to its gate and turned off due to natural or line commutation; and in the case of highly inductive load, it is turned off by firing another thyristor of the rectifier during the negative half cycle of input voltage.

Any industrial applications make use of controllable DC power. Examples of such applications are given below.

1.1 APPLICATION OF CONTROLLED RECTIFIER

- Steel rolling mills, paper mills, printing presses and textile mills employing dc motor drives.
- Traction systems working on DC
- Electrochemical and electrometallurgical processes
- Magnet power supplies
- Portable hand tool drives
- HVDC transmission

1.2 CLASSIFICATION OF RECTIFIER

Single phase rectifier are classified as 1-Φ half wave and 1-Φ full wave rectifier. Three phase rectifier are classified as 3-Φ half wave rectifier and 3-Φ full wave rectifier. 1-Φ Full wave rectifier are classified as1-Φmid point type and 1-Φ bridge type rectifier. 1-Φ bridge type rectifier are classified as 1-Φ half controlled and 1-Φ full controlled rectifier. 3-Φ full wave rectifier are again classified as 3-Φmid point type and 3-Φ bridge type rectifier. 3-Φ bridge type rectifier are again divided as 3-Φ half controlled rectifier and 3-Φ full controlled rectifier.

1.3 FIRING ANGLE

It is defined as the angle between the zero crossing of the input voltage and the instant the thyristor is fired. It is denoted by α.

2. ONE PULSE CONVERTER

- A single phase half wave circuit is one which produces only one pulse of load current during one cycle of source voltage.

- As the circuit produces only one load current pulse for one cycle of sinusoidal source voltage, this circuit represents a single phase half wave thyristor circuit.

2.1 SINGLE PHASE HALF WAVE CONTROLLED RECTIFIER WITH R LOAD

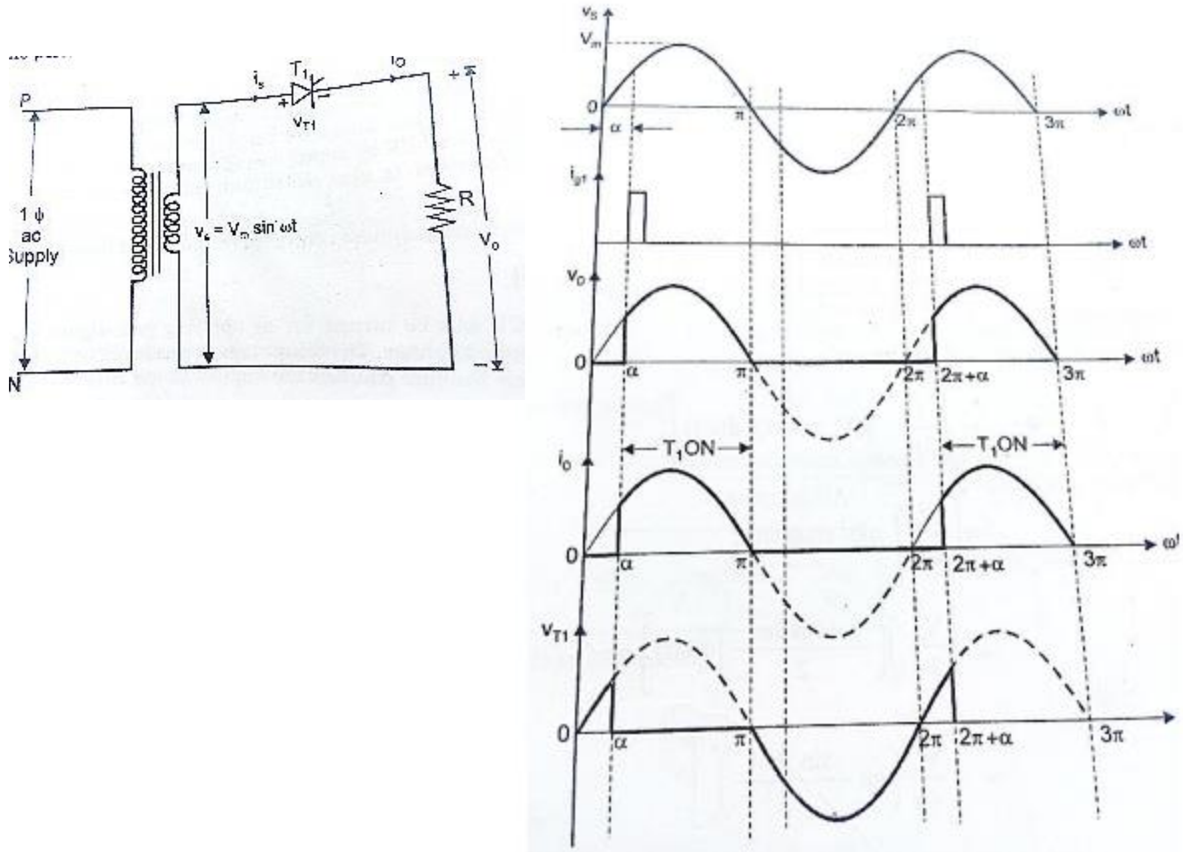


Fig. 2.1 Single Phase Half Wave Controlled Rectifier with R Load

- The circuit is energized by a line voltage or secondary voltage of the transformer, $v_s = v_m$ sinwt.
- It is assumed that the peak supply voltage never exceeds the forward and reverse blocking ratings of the thyristor.

During positive half cycle

- The anode is positive with respect to its cathode, and the thyristor is said to be forward biased.
- When T is triggered at wt=α, T conducts and the input voltage appears across the load.
- During the period α< wt<π, we can get the output voltage and current.

During negative half cycle

- The thyristor is negative with respect to its cathode, and T is said to be reverse biased.
- T blocks the flow of load current and no voltage is applied across the load R.
- By varying the firing angle α, the output voltage can be controlled.

Single phase half wave controlled rectifier with R load :

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

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

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

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

$$\boxed{V_{odc} = \frac{V_m}{2\pi}\left[1+\cos\alpha\right]}$$

Maximum o/p voltage V_o occurs at $\alpha = 0$

$$V_{om} = \frac{V_m}{2\pi}\left[1+\cos 0\right]$$

$$V_{om} = \frac{V_m}{2\pi}\left[1+1\right].$$

$$\boxed{V_{om} = \frac{V_m}{\pi}}$$

Average load current :-

$$I_o = \frac{V_o}{R} = \frac{V_m}{2\pi R}\left[1+\cos\alpha\right]$$

RMS value of the o/p voltage:

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

RMS value of current:

$I_{or} = V_{or}/R.$

Power delivered to resistive load $= I_{or}^2 R.$

2.2 SINGLE PHASE HALF WAVE CONTROLLED RECTIFIER WITH R-L LOAD

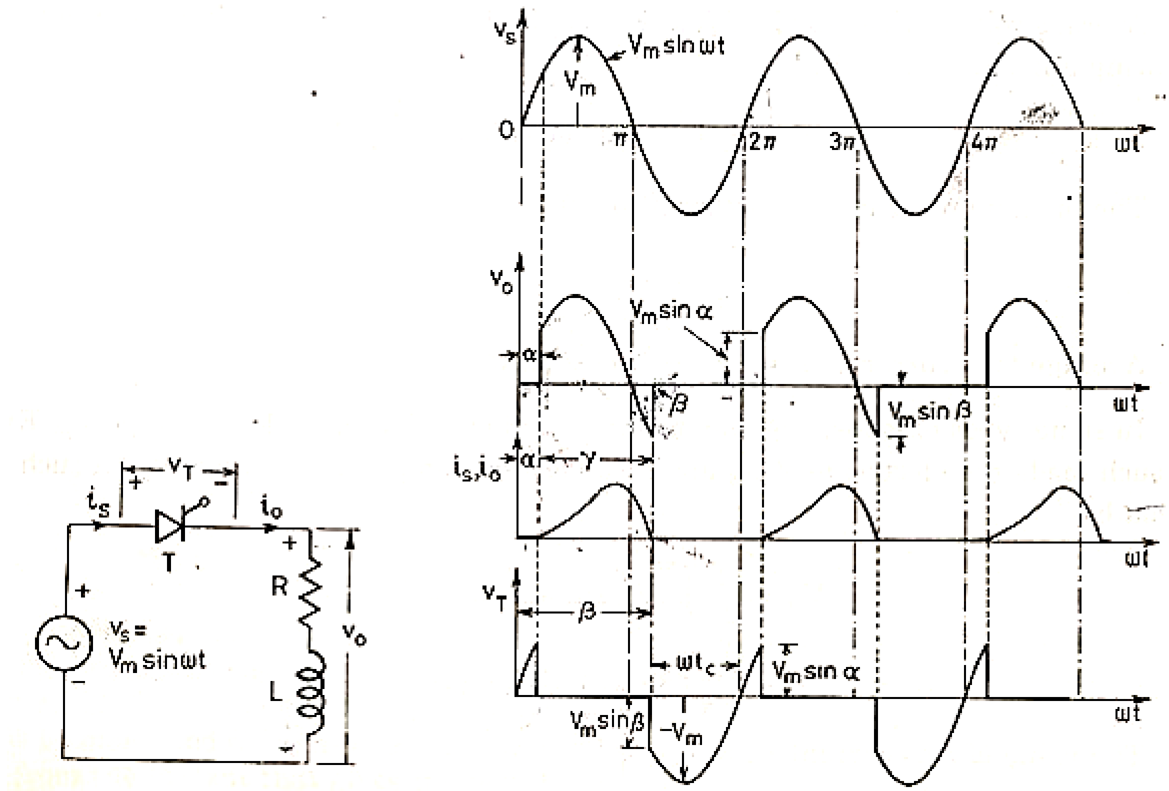


Fig. 2.2 Single phase half wave controlled rectifier with R-L load

- **At wt=α**

  T is turned on by applying the gate signal. The load voltage v_o at once becomes equal to source voltage v_s.
  But inductance L forces the load or output current i_o rise gradually.
  After sometime i_o reaches maximum value the then begins to decrease.
- **At wt= π**
  v_o is zero but io is not zero beacause of the load inductance L.
- **After wt= π**
  After wt= π, SCR is subjected to reverse anode voltage, but it will not be turned off as the load current i_o is not less than the holding current.
  At some angle β>π, i_o reduces to zero and T is turned off as already it is reverse biased.
- **After wt=β**
  After wt=β, v_o=0 and i_o=0.
  Angle β is called extinction angle and γ= β-α is called the conduction angle.

1ϕ Half wave controlled rectifier with RL load:

i) Average load voltage (V_{dc})

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

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

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

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

ii) Average load current (I_{dc}):

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

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

iii) RMS load voltage :-

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

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

2.3 SINGLE PHASE HALF WAVE CONTROLLED RECTIFIER WITH R-L LOAD AND FREE WHEELING DIODE

- The load current i_o waveform can be improved by connecting a freewheeling diode across load. A freewheeling diode is also called as commutation diode or by-pass diode or fly wheeling diode.
- **At wt=0**, source voltage is becoming positive and T is said to be forward biased.
- **At wt=α**, T is triggered and source voltage V_s appears across the load as V_o.

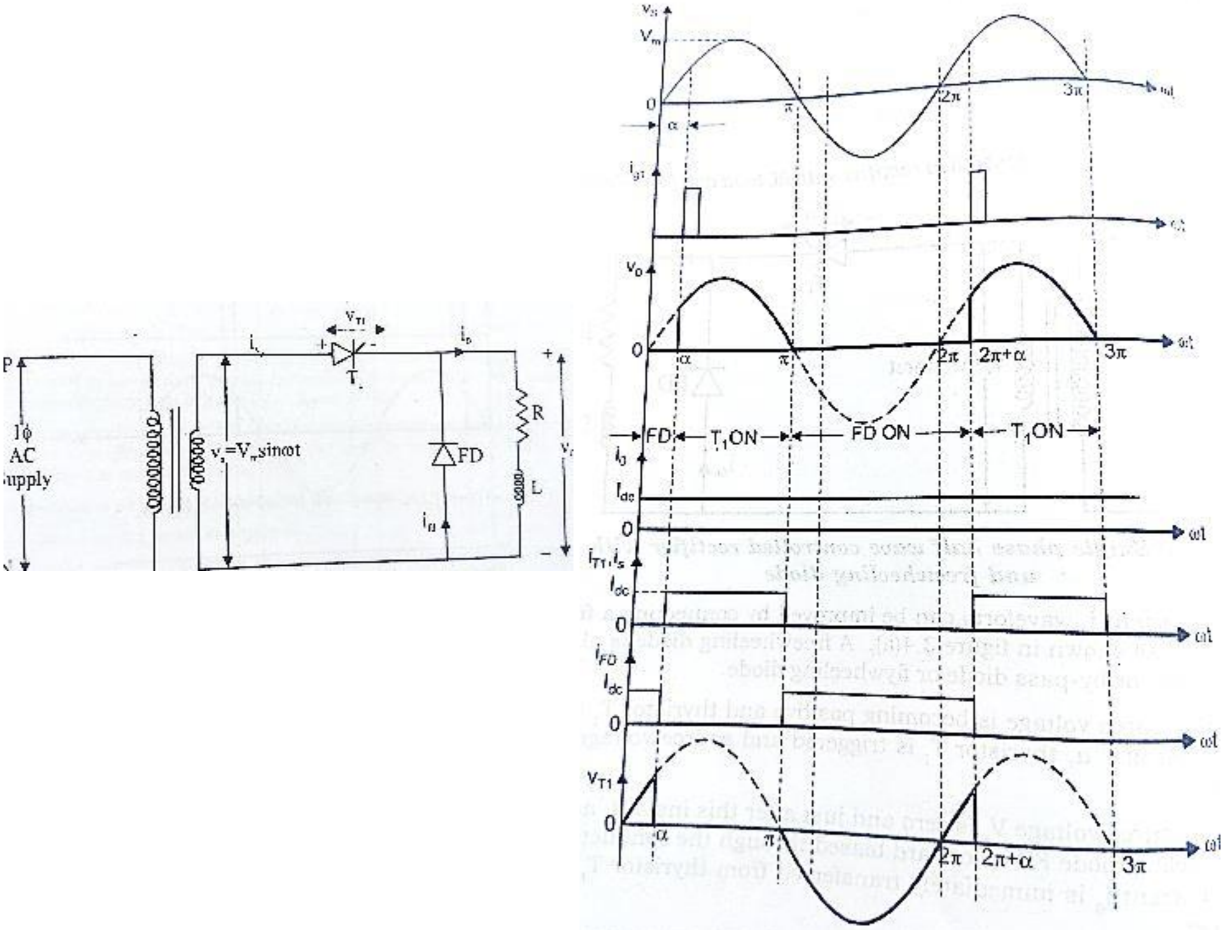


Fig. 2.3 Single phase half wave controlled rectifier with R-L load and freewheeling diode

- **At wt=π**, V_s is zero and just after this instant, as V_s tends to reverse, freewheeling diode FD is forward biased through the conducting SCR. As a result i_o is immediately transferred from T to FD.
- **At wt=π**, T is subjected to reverse voltage and zero current so T is turned off. It is assumed that the load current does not decay to zero during freewheeling period until SCR is triggered again at $(2\pi+\alpha)$.
- During the freewheeling period, output voltage V_o is zero.

1φ half wave controlled rectifier with free wheeling diode:

i) Average load voltage:

$$V_{dc} = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \, d\omega t.$$

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

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

$$\boxed{V_{dc} = \frac{V_m}{2\pi}\left[1+\cos\alpha\right]}.$$

ii) Average load current:

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

$$\boxed{I_{dc} = \frac{V_m}{2\pi R}\left[1+\cos\alpha\right]}$$

2.3.1 ADVANTAGES OF USING FREEWHEELING DIODE

- Input power factor is improved.
- Load current waveform is improved and thus the load performance is better.

2.3.2 MAIN FUNCTIONS OF FREEWHEELING DIODE

- It prevents reversal of load voltage except for small diode voltage drop.
- I transfers the load current away from the rectifier, thereby allowing all of its thyristors to regain their blocking states.

2.4 SINGLE PHASE HALF WAVE CONTROLLED RECTIFIER WITH RLE LOAD

Here the load consists of RLE load. The emf E in the load may be battery or back emf in a dc motor.

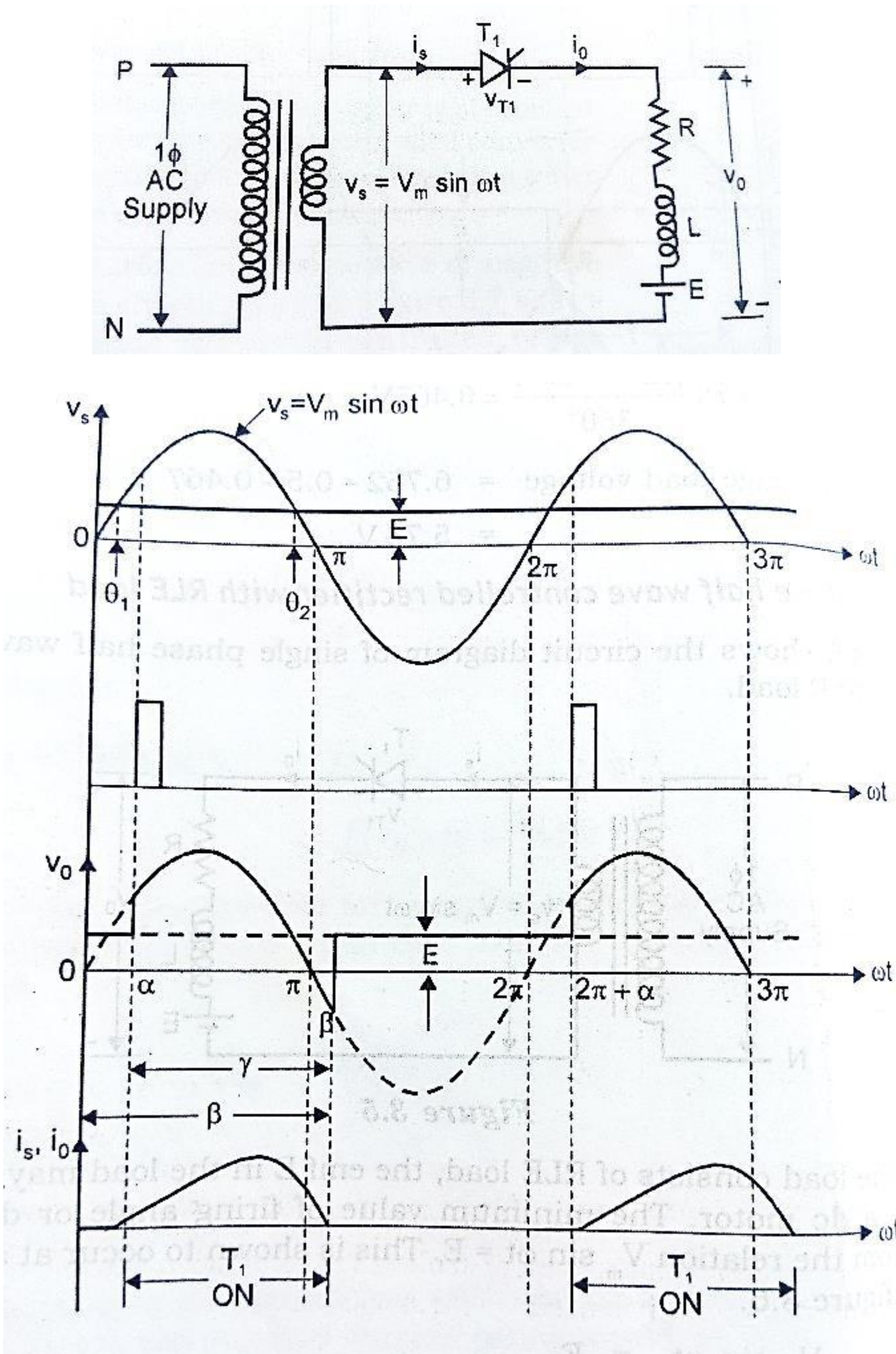


Fig. 2.4 Single phase half wave controlled rectifier with RLE load

Calculating firing angle

V_m sinwt= E

V_m sinθ1=E

$\sin\theta_1 = E/V_m$

Minimum value of firing angle $\theta_1 = \sin^{-1}(E/V_m)$

Maximum value of firing angle $\theta_2 = \pi - \theta_1$

- **During positive half cycle**

  T is fired at an angle $\alpha > \theta_1$.

  At α= 0 to θ1, as the thyristor is reverse biased, load current i_o is zero and load voltage V_o=E.

  At wt=α, T is triggered and comes to on state. The load voltage follows the source voltage and i_o increases.

  At wt=π, V_o=0 and i_o=0.

  At wt=β

  Due to inductance in the load, the load current io reaches to zero at wt=β.

  The load voltage goes to negative and reaches to zero at wt=β.

  At wt=β, i_o=0, then T is turned off automatically.

- **During the negative half cycle**

  T is reverse biased.

  During the period β to 2π+α, i_o is zero but V_o= E.

1φ Half wave controlled rectifier with RLE load:

Average output voltage: (V_{dc})

$$V_{dc} = \frac{1}{2\pi}\left[\int_\alpha^\beta V_s\, d\omega t + \int_\beta^{2\pi+\alpha} E\cdot d\omega t\right]$$

$$= \frac{1}{2\pi}\left[\int_\alpha^\beta V_m \sin\omega t \cdot d\omega t + \int_\beta^{2\pi+\alpha} E\cdot d\omega t\right]$$

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

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

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

Average load current: I_{dc}

$$V_{dc} = E + I_{dc}\cdot R$$

$$I_{dc} = \frac{V_{dc} - E}{R}.$$

3. TWO PULSE CONVERTERS

- The two pulse converter can be classified as
  1. Single phase fully controlled rectifier (Two quadrant converter)
  a. Midpoint b. Bridge
  2. Single phase half controlled rectifier (Semi converter)

3.1 SINGLE PHASE FULLY CONTROLLED BRIDGE RECTIFIER WITH R LOAD

- **During positive half cycle**
  T1, T2 are forward biased and they are triggered simultaneously.
  At wt=α, T1, T2 are conducting, then current flows through the path P-T1-R-T2-N.
  At wt=π, V_s falls to zero and current also goes to zero. Hence T1, T2 are turned off.
- **During negative half cycle**
  T3, T4 are forward bias and they are triggered simultaneously.
  At wt=π+α, T3, T4 are conducting, then current flows through the path N-T3-R-T4-P.
  At wt= 2π, Supply voltage Vs and current goes to zero and T3, T4 are turned off.
- The output voltage can be varied by varying the firing angle α.
- So, the load current is always discontinuous with purely resistive load.
- By using full converter with R load, the output voltage and output current is always positive.
- A fully controlled rectifier with R load acts as a one quadrant converter.

6 pulse converters:

1φ fully controlled bridge rectifier with R load

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

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

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

$$\boxed{V_{dc} = \frac{V_m}{\pi}\left(1+\cos\alpha\right)}$$

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

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

RMS Load voltage:

$$V_{orms} = \left[\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \cdot d\omega t\right]^{1/2}$$

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

$$= V_m\left[\frac{1}{\pi}\int\frac{(1-\cos 2\omega t)}{2} d\omega t\right]^{1/2}$$

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

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

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

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

RMS load current:

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

Source current $I_S = I_{orms}$.

$$I_T = \frac{1}{2\pi R}\int_{\alpha}^{\pi} V_m \sin\omega t \cdot d\omega t.$$

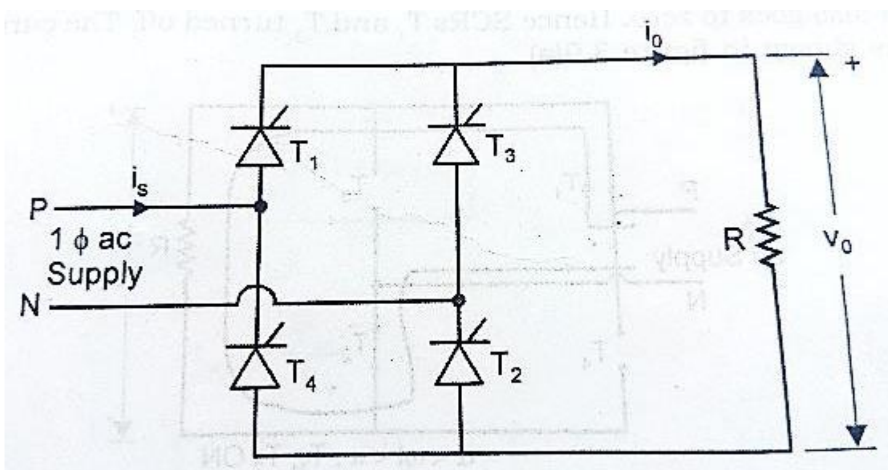
$$= \frac{V_m}{2\pi R}\int_{\alpha}^{\pi} \sin\omega t \cdot d\omega t. = \frac{V_m}{2\pi R}\left[-\cos\omega t\right]_{\alpha}^{\pi} = \frac{V_m}{2\pi R}\left[-\cos\pi + \cos\alpha\right]$$

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

$$= \frac{V_{dc}}{2R} = \boxed{\frac{I_{dc}}{2} = I_T}$$

RMS current through thyristor:

$$I_{TR} = \frac{I_{orms}}{\sqrt{2}}$$



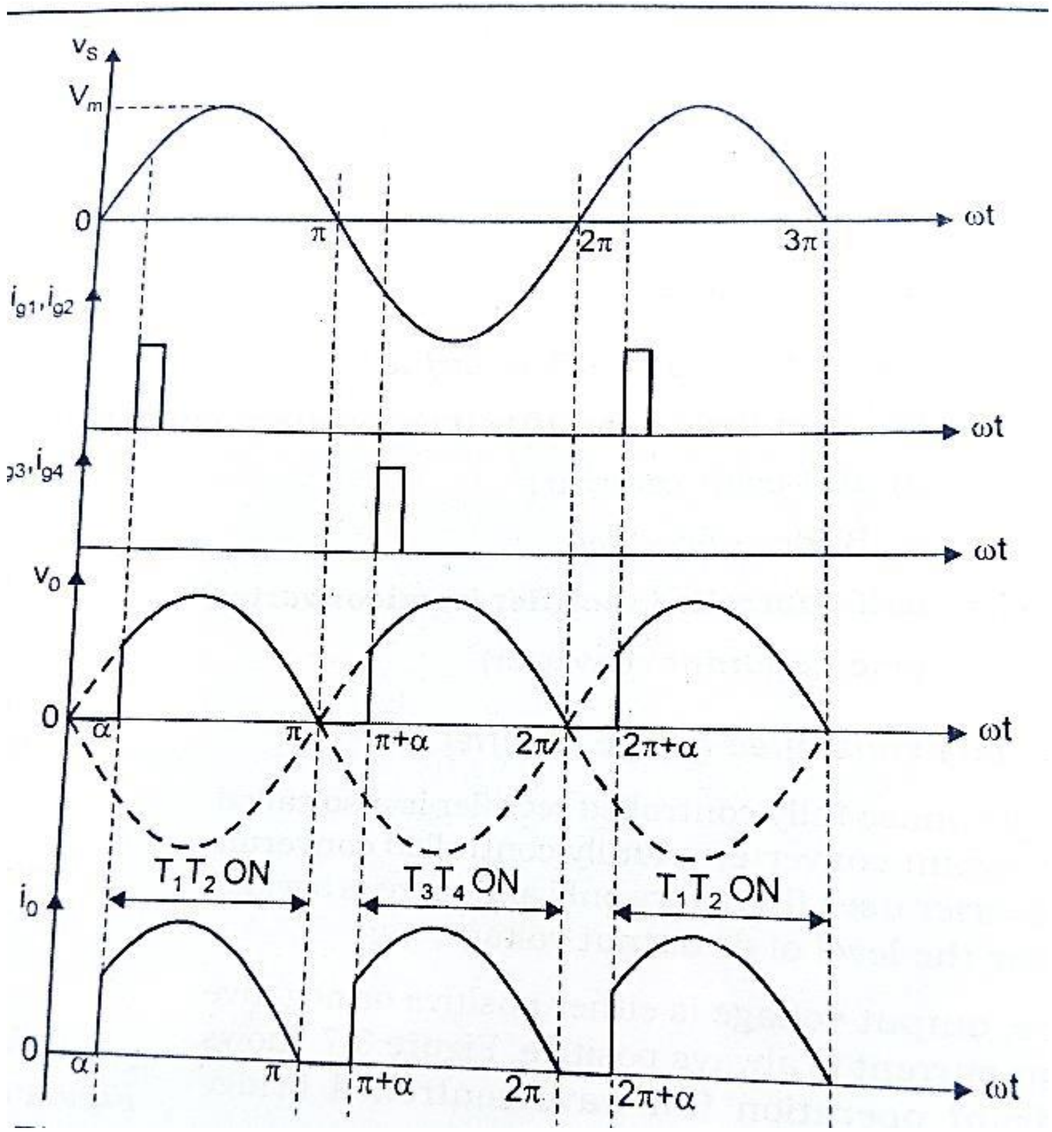


Fig. 3.1 Single phase fully controlled bridge rectifier with R load

3.2 SINGLE PHASE FULLY CONTROLLED BRIDGE RECTIFIER WITH RL LOAD

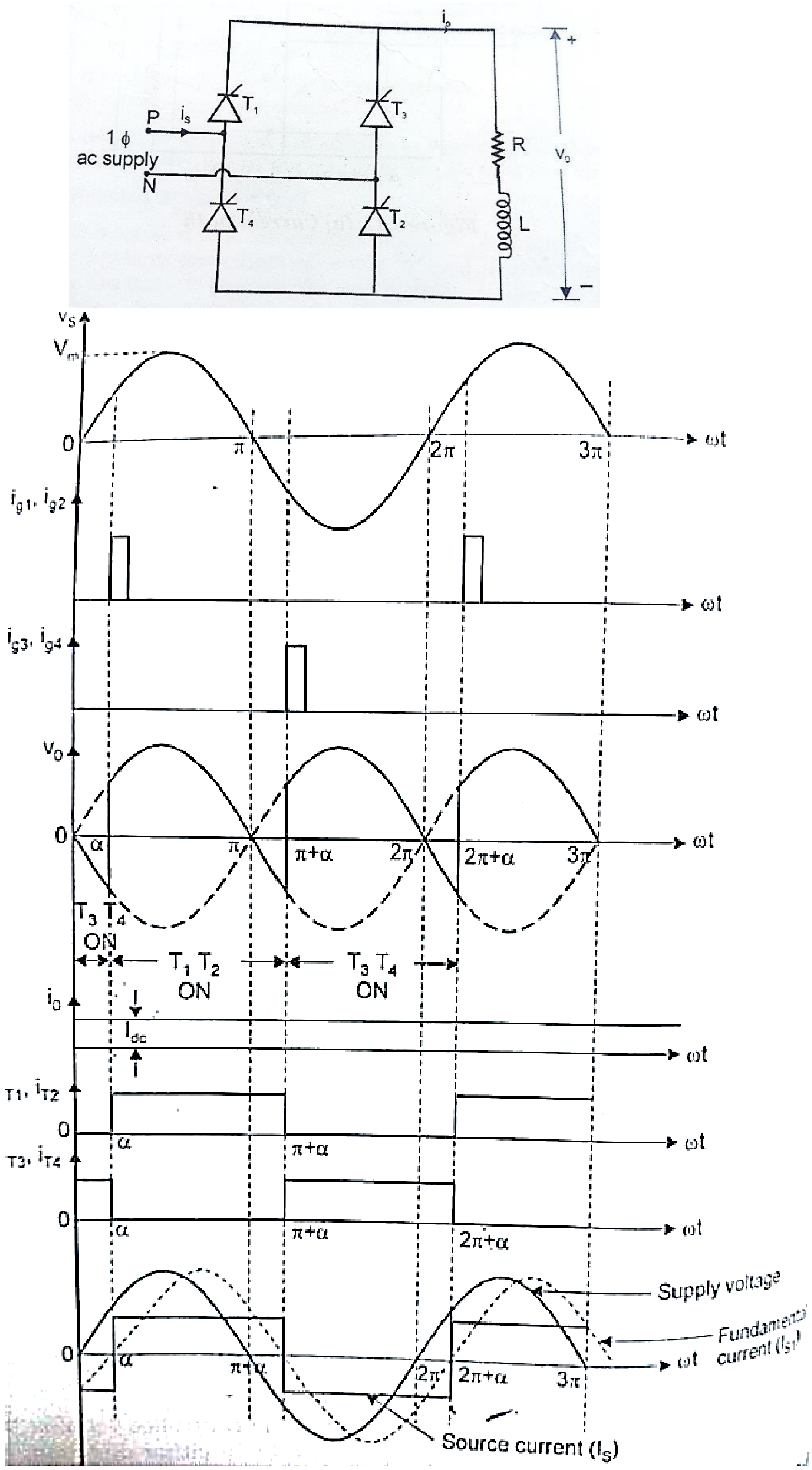


Fig.3.2 Single phase fully controlled bridge rectifier with RL load-Rectification mode (α< 90º)

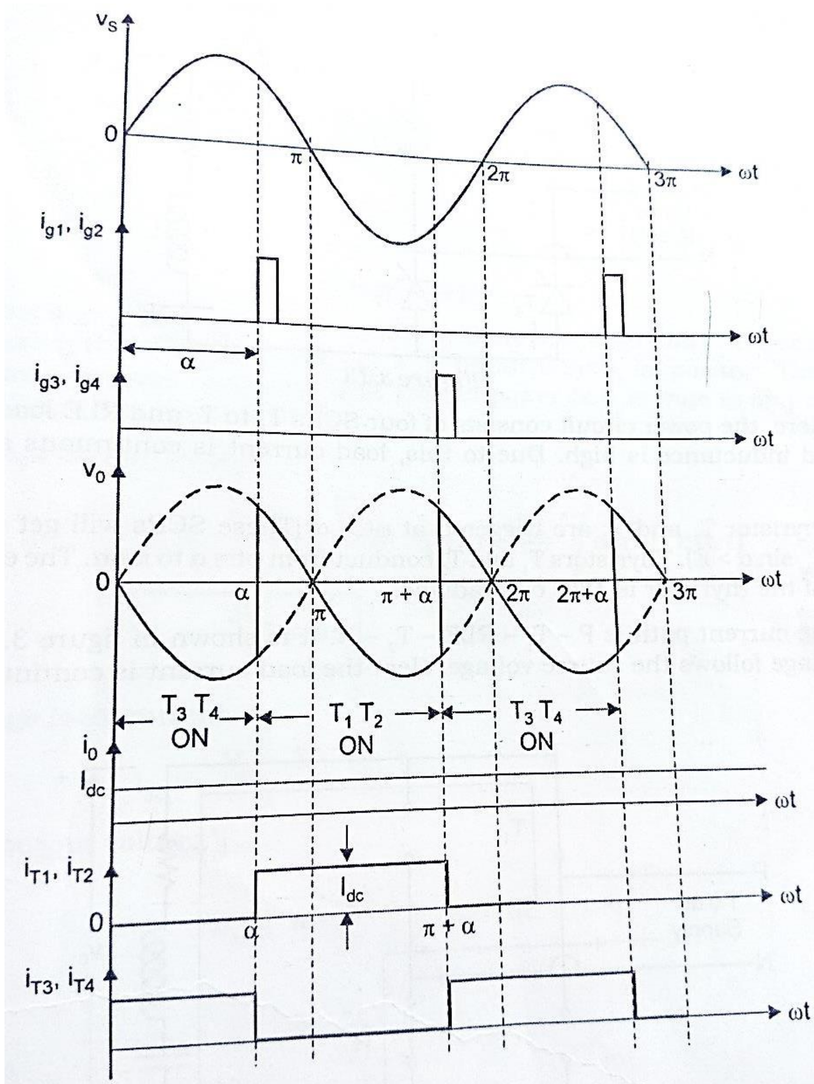


Fig. 3.3 Single phase fully controlled bridge rectifier with RL load- Inversion mode (α>90º)

Firing

- Thyristors should be triggered for their conduction.
- T1, T2 must be fired together in order for the current flow and T3, T4 must be fired together for next half cycle. Both T1, T2 are fired from the same firing angle.

Inductance

- Inductance L is used to reduce the ripple. A large value of inductor is used for continuous steady state current in the load. A small value of L will produce a discontinuous load current for large firing angles.

Voltage & current wave form

- The voltage wave form at the DC terminals consists of steady state DC component and an AC ripple component, having a fundamental frequency equal to twice that of supply frequency.

- The input line current has a square waveform and the fundamental component of this waveform is in phase with the supply voltage.
- **At firing angle wt=α (30º)**
- T1, T2 are triggered. Current flows through the path P-T1-RL-T2-N.
- Supply voltage appears across the load and forces the current through the load. This load current i_o is assumed to be continuous. The load current flows from source to load which is taken as positive.
- **At firing angle wt=π**
- Source voltage reverses, but due to the very large inductance , the current is maintained in the same direction at constant magnitude I which keeps T1, T2 in conducting state and hence negative supply voltage appears across the load.
- **At firing angle wt=π+α**
- T3, T4 are triggered and with this, the negative line voltage reverse biases T1, T2 and T1, T2 are commutated. The current path is N-T3-RL-T4-P.

- So, the line current is positive when T1, T2 are conducting and negative when T3, T4 are conducting.
- By varying the firing angle (0º to 180º), the average load voltage can be varied continuously from positive maximum to negative maximum, assuming continuous load current flow in the output terminals.
- The output voltage is reversible, even though the current flow in the output is unidirectional
- Because the power flow can be in either direction, two modes of operation is possible.

MODE-I: Rectification mode (α< 90º)

- During the interval α to π, both Vs and I_s are positive. Therefore power flows from AC source to load.
- During the interval π to π+α, both Vs is negative and I_s is positive. Therefore the load returns some of its energy to the supply system.
- But the net power flow is from AC source to load because π-α<α.
- From the equation of V_{dc} if α<90º, the voltage at the load terminal is positive, the power flows for AC side to DC side and the converter operates as a rectifier. i.e., The power flows from source to load.

MODE-II: Inversion Mode (α>90º)

- The firing pulses are retarded for 120º i.e., α=120º
- The output voltage waveform now contains a mean negative component. Also from the V_{dc} equation, if α>90º, the voltage at the load terminal is negative, therefore the power flows from DC side to AC side and the converter operates as a line commutated inverter. In this mode the power flows from load to source.
- In practical case, a DC battery is connected in the load side, then only we can get the inversion.

1φ fully controlled rectifier with RL load:

Average output voltage (V_{dc}).

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

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

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

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

$$= \frac{V_m}{\pi}\left(-(-1\times\cos\alpha)+\cos\alpha\right].$$

$$= \frac{V_m}{\pi}(2\cos\alpha);$$

$$V_{dc} = \frac{V_m}{\pi}(2\cos\alpha)$$

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

Average load current (I_{dc})

$$I_{dc} = \frac{V_{dc}-E}{R}$$

RMS o/p voltage. $\boxed{V_{orms} = \frac{V_m}{\sqrt{2}} = V_s}$

Average current through thyristor.

$I_{TA} = I_{dc}/2$

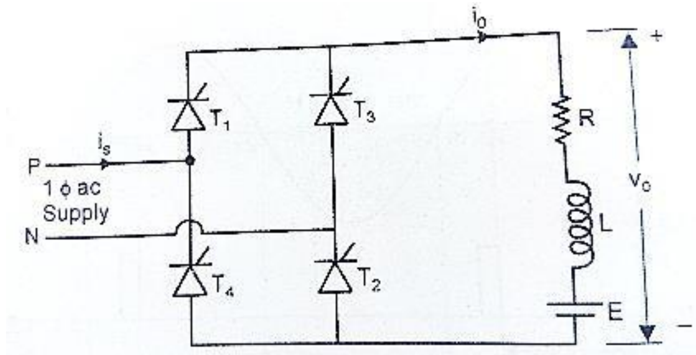
RMS current through thyristor (I_{TR})

$$\boxed{I_{TR} = I_{dc}/\sqrt{2}}$$

3.3 SINGLE PHASE FULLY CONTROLLED BRIDGE RECTIFIER WITH RLE LOAD

- Here, the power circuit consists of four SCRs T1 to T4 and RLE load. Due to this, the load current is continuous and ripple free.
- **At wt=α**, T1, T2 are triggered and they conduct from wt=α to π+α. The conduction period of the thyristors is 180º or π radians.
- The current path is P-T1-RLE-T2-N. The load voltage follows the source voltage and the load current is continuous.

- **At $wt=\pi+\alpha$**, forward biased thyristors T3, T4 are triggered. The supply voltage turns off T1, T2 by line or natural commutation and the load current is transferred from T1, T2 to T3, T4. T3, T4 conduct from $wt=\pi+\alpha$ to $2\pi+\alpha$.
- The current path is N-T3-RLE-T4-P.
- **During $wt=\alpha$ to π**, both V_s and I_s is positive. Therefore power flows from AC source to load.
- **During $wt=\pi$ to $\pi+\alpha$**, Vs is negative but I_s is positive. Therefore power flows from load to source.
- But the net power flow is from supply to load because $\pi-\alpha>\alpha$.



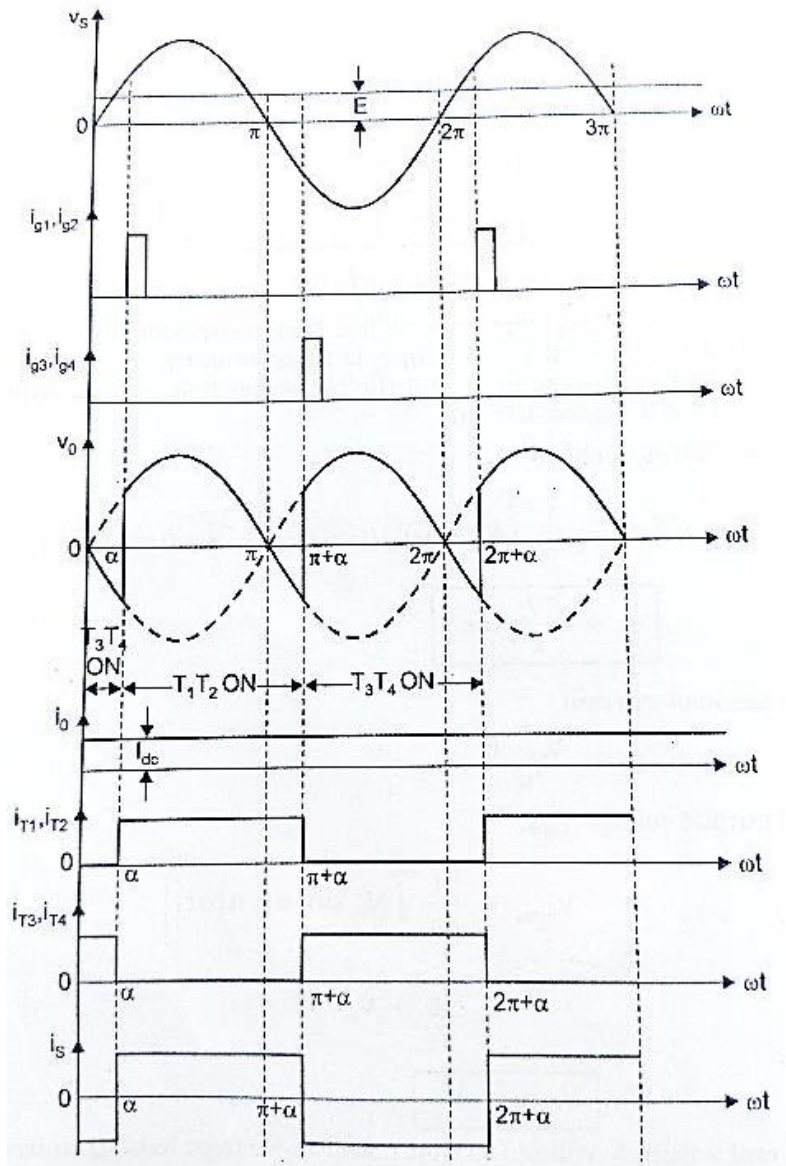
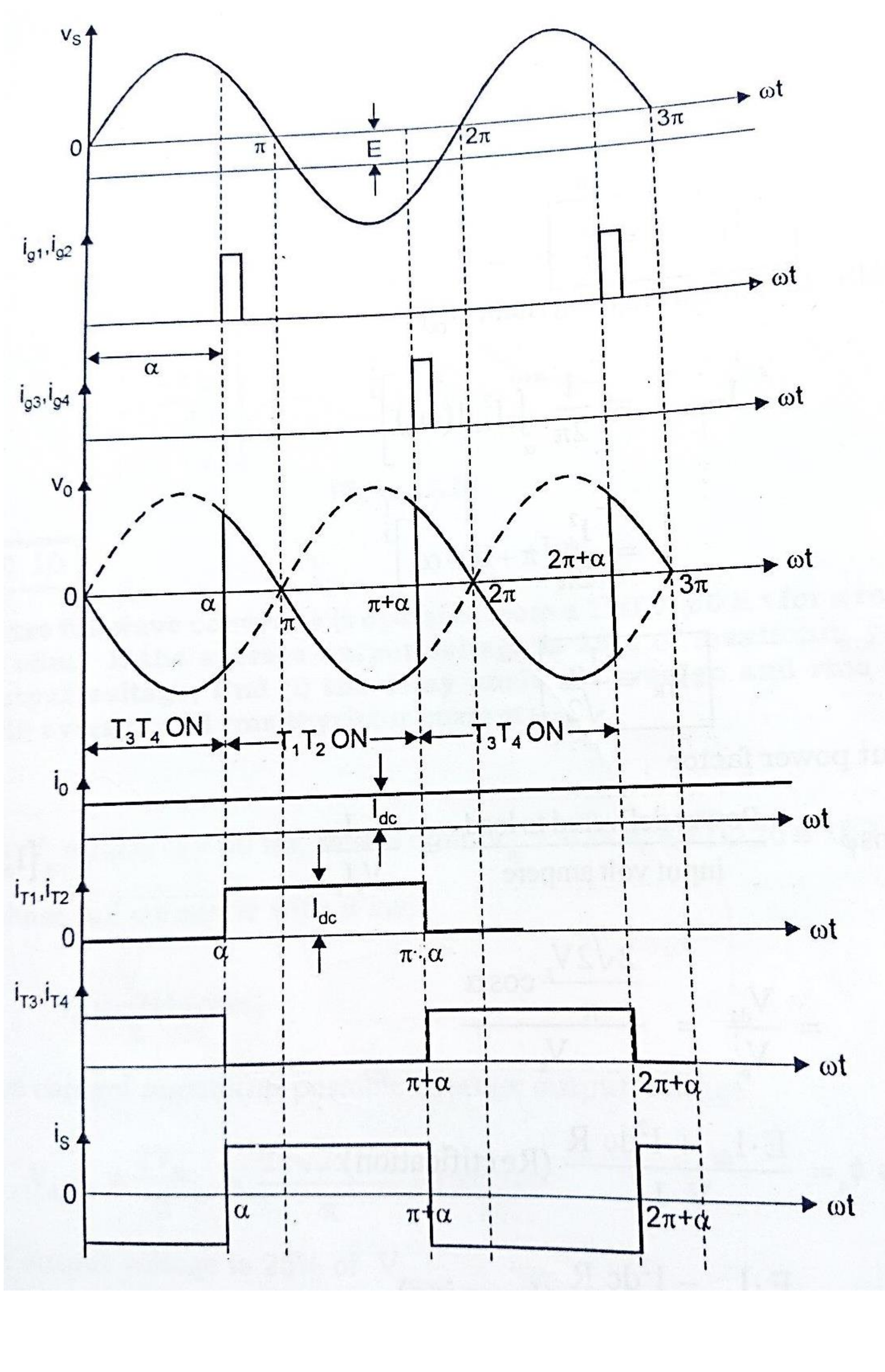
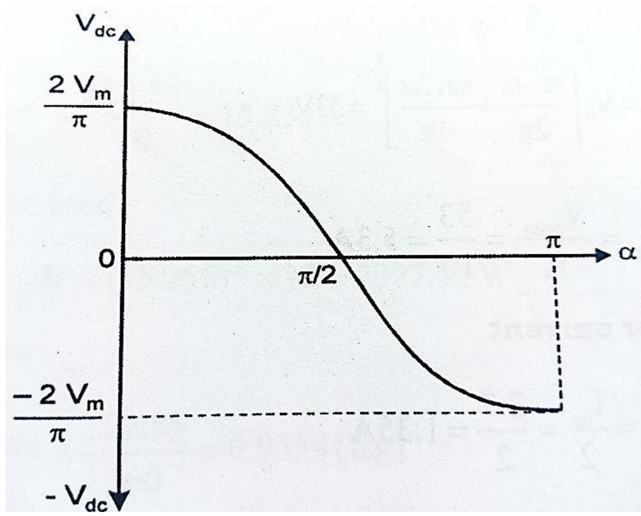


Fig. 3.4 Single phase fully controlled bridge rectifier with RLE load. A. circuit b. rectification mode



c. RLE Inversion Mode (α>90º)

- Back emf> Supply voltage so that power flows from load to source.
- For α> 90°, the average output voltage becomes negative. Here, the load circuit emf E must be reversed.
- This source E will feed power back to AC supply. i.e., the power flows from load to source.
- This operation of full converter is called inverter operation of the converter. It is also called line commutated inverter. This type of operation is used in the regenerative breaking mode of a DC motor.

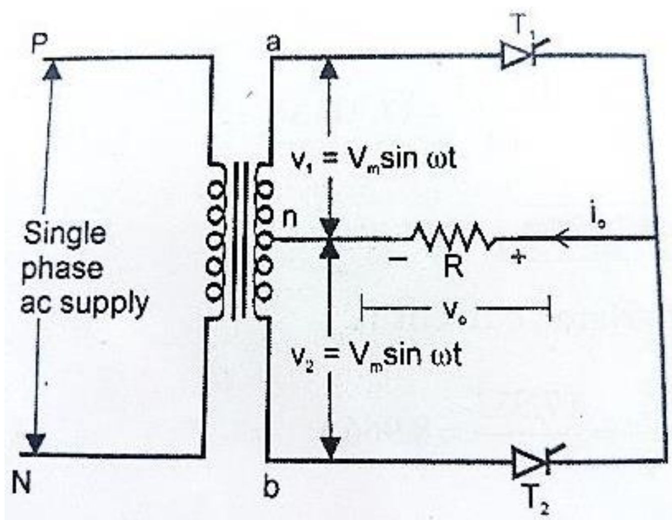


3.4 SINGLE PHASE FULL WAVE MID POINT CONTROLLED RECTIFIER

- It consists of two SCRs and a center tapped transformer. It is also called two pulse converter because two triggering pulses are to be generated during every cycle of the supply to trigger SCRs. It is generally used for low rating rectifiers.

3.5 SINGLE PHASE FULL WAVE MID POINT CONVERTER WITH R LOAD

- The input voltage is coupled through the transformer to the center tapped secondary.
- **During positive half cycle (0 to π),** when terminal 'a' of the transformer is positive with respect to terminal b, T1 is forward biased and T2 is reverse biased.
- When T1 is triggered at a firing angle α, current would flow from terminal 'a' through T1, the load 'R' and back to the center-tap of the transformer. The current path is (a-T1-R-n).
- The current continuous to flow up to angle π, when the line voltage reverses its polarity and T1 is turned off due to line commutation.
- **During negative half-cycle** (π to 2π), the terminal 'b' of the transformer is positive with respect to 'n'. T2 is forward biased.
- At wt= π+α, T2 is triggered and the current path is b-T2-R-n. This current continues till angle 2π, then T2 is turned off.
- Both SCRs are triggered with the same firing angle, hence they share the load current equally.



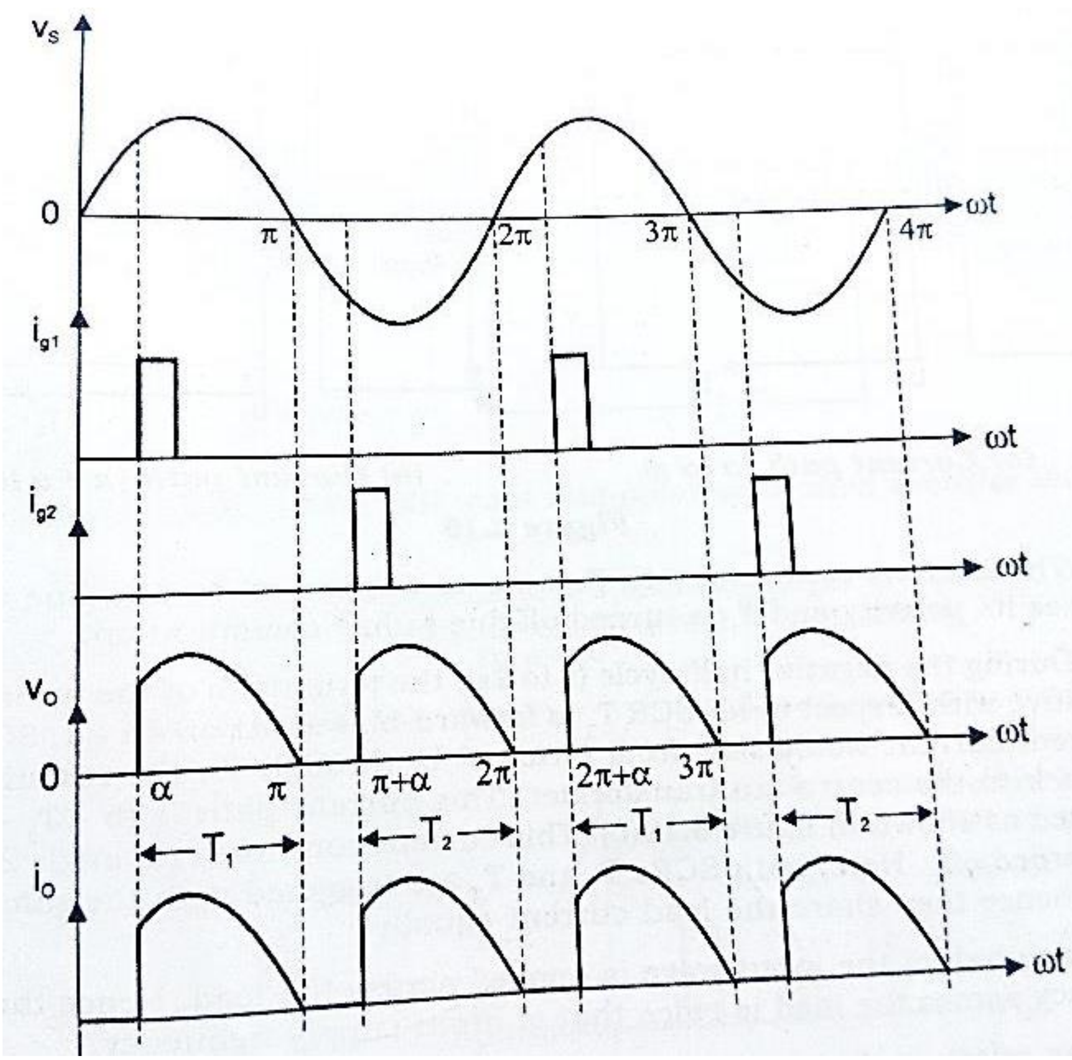


Fig. 3.5 Single phase full wave midpoint converter with R load

- Each half of the input wave is applied across the load. Hence the ripple frequency across the load is twice that of input frequency.

3.6 SINGLE PHASE FULL WAVE MID POINT CONVERTER WITH RL LOAD

- T1 can be triggered in to the on state at any time after V_1 goes positive. Once T1 is turned on, current builds up in the inductive load, maintaining T1 in the on state up to the period when V_1 goes negative.
- When V_1 goes negative, V_2 becomes positive and the triggering of T2 immediately turns on T2 which takes up the load current.
- The peak voltage across the thyristor is $2V_m$, that is maximum value of the transformer secondary voltage.
- The load current can be continuous or discontinuous depending on the inductance value.
- The load current is continuous if L is greater than its critical value and discontinuous if L is less than its critical value.
- Assume, L is large and the conduction period is 180º (continuous current conduction)
- Both SCRs are delayed with the same delay angle, hence they share the load current equally.
- Due to large L and continuous current conduction, the thyristors continue to conduct even when the anode voltages are negative with respect to cathode.

Some important points from equation

1. The highest value of the voltage will be when the firing angle α is zero.
2. For α=30º, power flows from source to load (rectification mode)
3. As α increases, the average output DC voltage decreases. For α=90º, output voltage is zero
4. For α>90º, the Dc voltage goes negative and the power flows from load to source (inversion mode). At α=180º, the negative DC voltage is maximum.
5. As the firing angle increases to 180º, the period for which the thyristor is reverse biased, reduces. To turn off a thyristor it must be reverse biased.

1φ full wave mid point controlled rectifier with RL load:

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

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

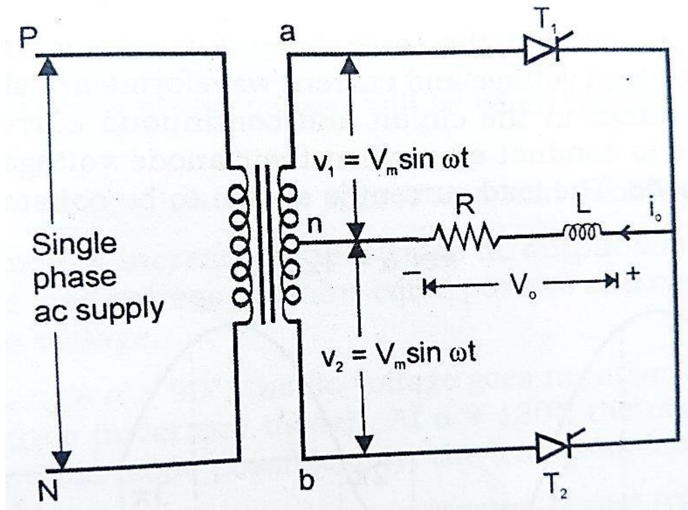
$$= \frac{V_m}{\pi}\left(-\cos(\pi+\alpha) + \cos\alpha\right)$$

$$= \frac{V_m}{\pi}\left[-(\overset{(-1)}{\cos\pi}\cos\alpha - \overset{0}{\sin\pi}\sin\alpha) + \cos\alpha\right]$$

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

$$= \frac{V_m}{\pi}\left(2\cos\alpha\right).$$

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



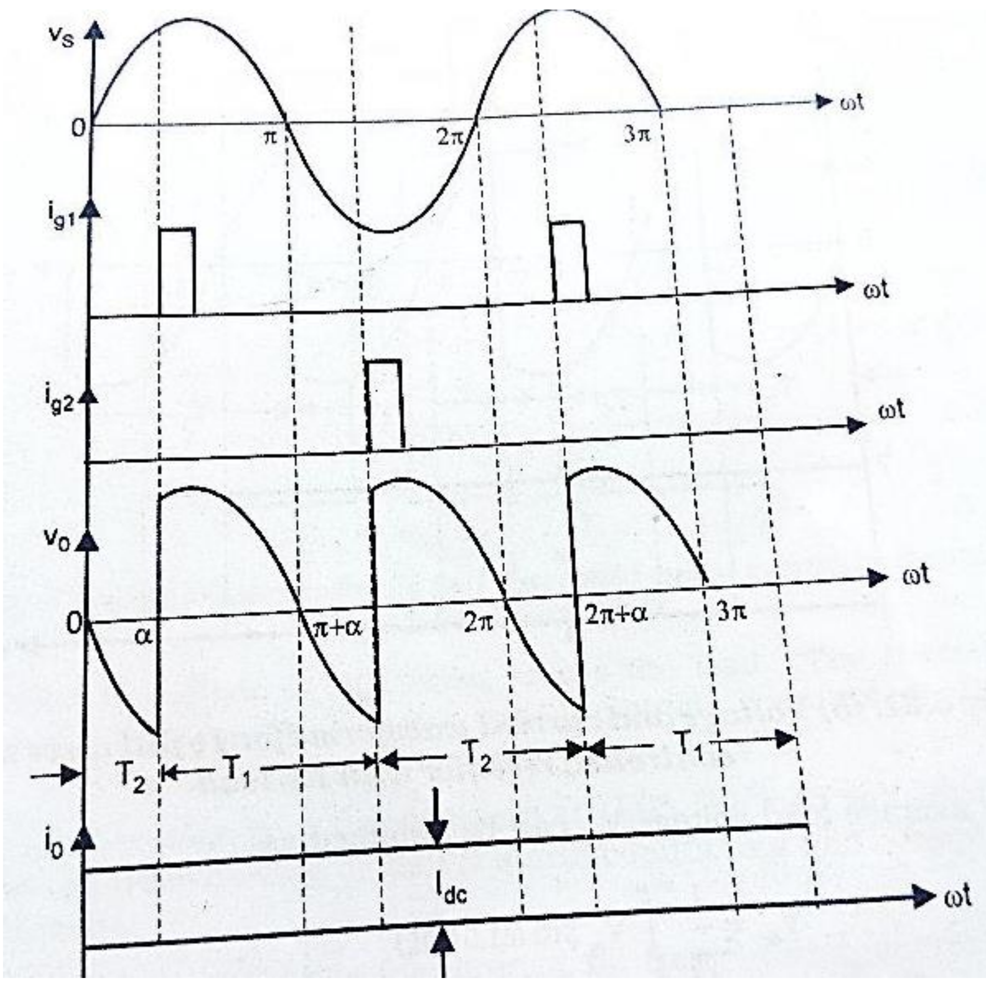
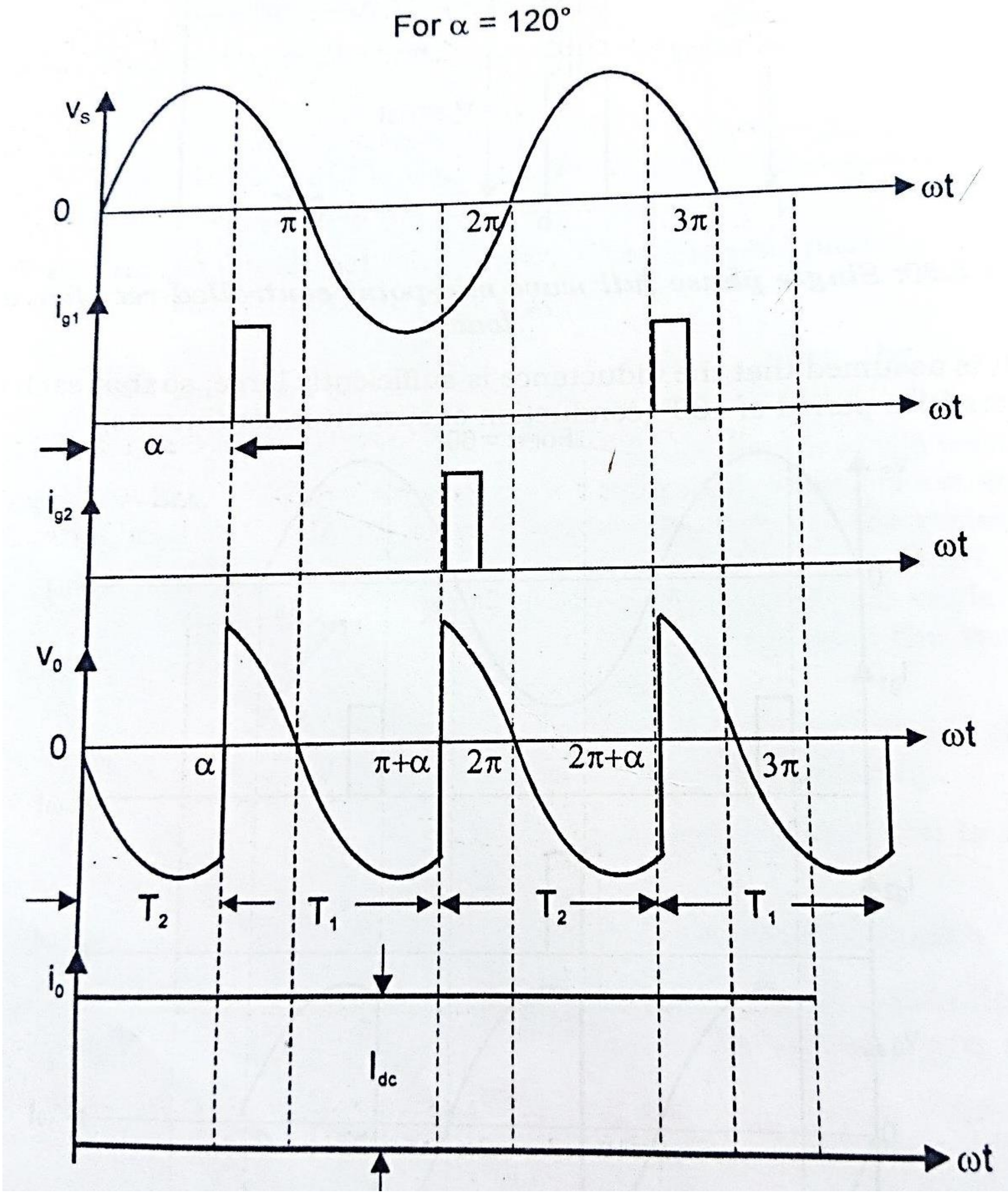
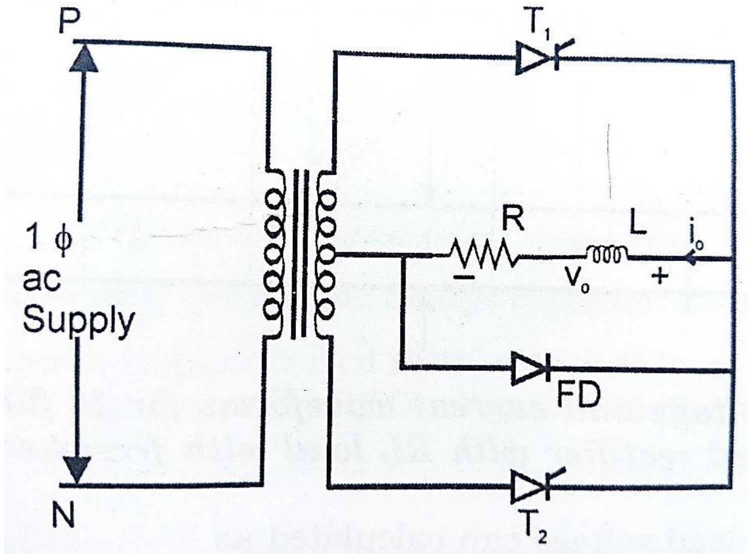


Fig. 3.6 a. Single phase full wave mid-point converter with RL load (α=60º)



b. Single phase full wave mid-point converter with RL load (α=120º)

3.6 SINGLE PHASE FULL WAVE MID POINT CONVERTER WITH FREEWHEELING DIODE



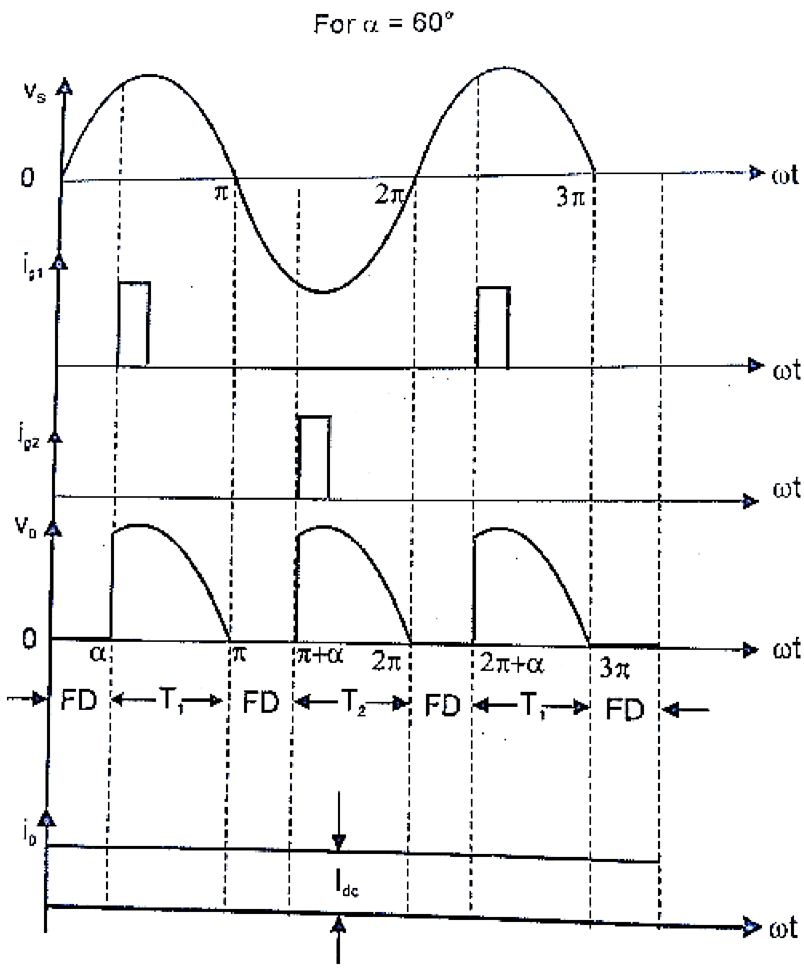


Fig. 3.7 Single phase full wave mid-point converter with freewheeling diode

- A freewheeling diode is connected across the load. The thyristors are triggered with delay angle α. The α is varied to obtain the variable DC voltage at the load.
- As the input voltage goes through zero at 180º, the load voltage cannot be negative since the freewheeling diode FD starts conducting.
- A constant load current is maintained by freewheeling current through the load. The inductive energy of the load circulates current through the feedback diode which decays depending on the time constant of the load.

1φ full wave mid point with free wheeling Diode:

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

$$\boxed{V_{dc} = \frac{V_m}{\pi}[1+\cos\alpha]}.$$

DC current: $I_{dc} = \frac{V_{dc}}{R} = \frac{V_m}{\pi R}(1+\cos\alpha]$.

Current through free wheeling diode: $I_{FD} = I_{dc} \cdot \frac{\alpha}{\pi}$.

$$I_{FD} = \frac{V_m}{\pi R}[1+\cos\alpha] \cdot \frac{\alpha}{\pi}$$

$$= \frac{V_m}{\pi^2 R}(\alpha + \alpha\cos\alpha).$$

3.7 SINGLE PHASE SEMI CONVERTER

- A semi converter uses mixture of diodes and thyristors and there is a limited control over the level of DC output voltage. It is a one quadrant converter. Here, the output voltage and current is always positive. It is also known as two pulse converter.

3.7.1 SINGLE PHASE HALF CONTROLLED BRIDGE RECTIFIER WITH R LOAD

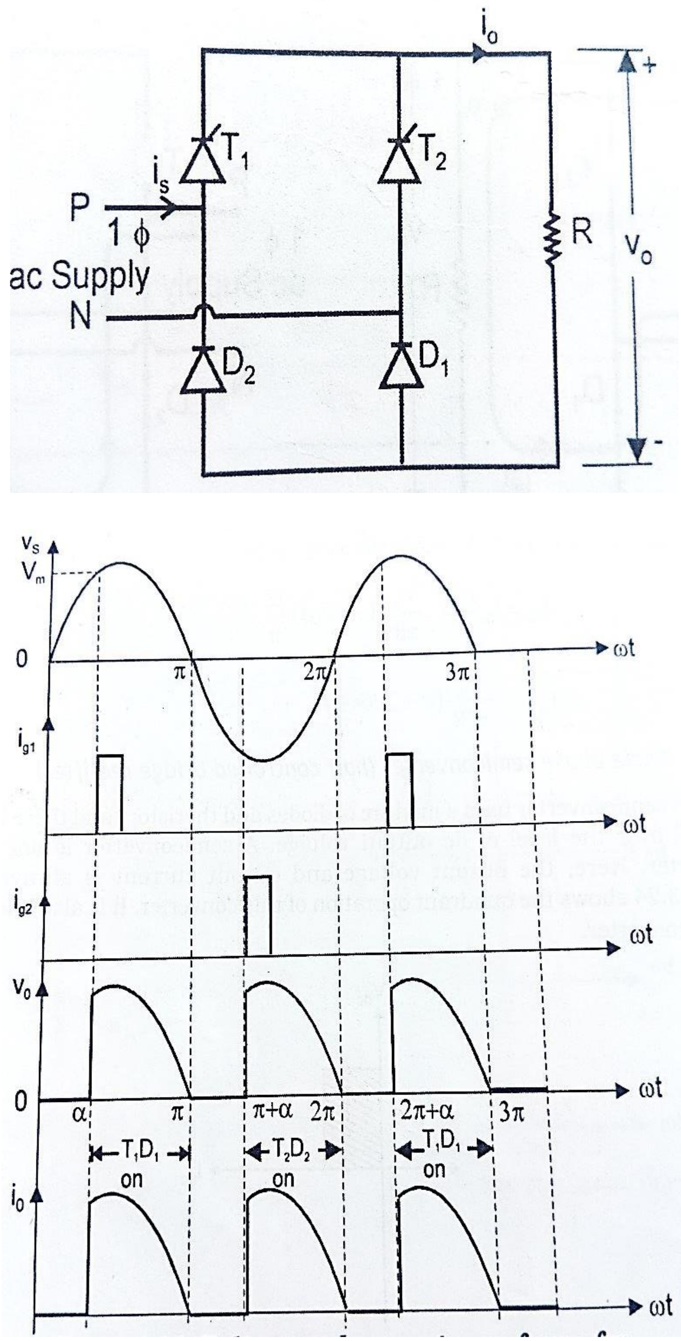


Fig. 3.8 Single phase half controlled rectifier with R load

- It consists of two thyristors T1, T2 and two diodes D1, D2.
- During positive half supply of the AC supply, T1 and D1 are forward biased. When T1 is triggered at a firing angle wt=α, T1 and D1 come to on state. Now the load current path is P-T1-R-D1-N. During this period we get positive output voltage and current.
- At wt=π, the load current and load voltage reach to zero, then T1, D1 come to off state due to natural commutation.
- During negative half cycle of the AC supply, T2 and D2 is forward biased. When T2 is triggered at firing angle wt=π+α, t2 and D2 come to on state. The load current path is N-T2-R-D2-P. During this period we get positive output voltage and current.
- At wt=2π, the load voltage and current reaches to zero, then T2, D2 come to off state due to natural commutation.

1φ Semi converter: rectifier with R load:

(or) Half controlled bridge

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

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

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

Average load current:-

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

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

RMS load voltage

$$V_{orms} = V_m\left[\frac{\pi-\alpha}{2\pi} + \frac{\sin 2\alpha}{4\pi}\right]^{1/2}$$

RMS load current:

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

$$\boxed{I_s = I_{orms}}$$

Average current through thyristor.

$$I_{TA} = I_{dc}/2$$

RMS current through thyristor

$$I_{TR} = \frac{I_{orms}}{\sqrt{2}}$$

3.7.2 SINGLE PHASE HALF CONTROLLED BRIDGE RECTIFIER WITH RL LOAD

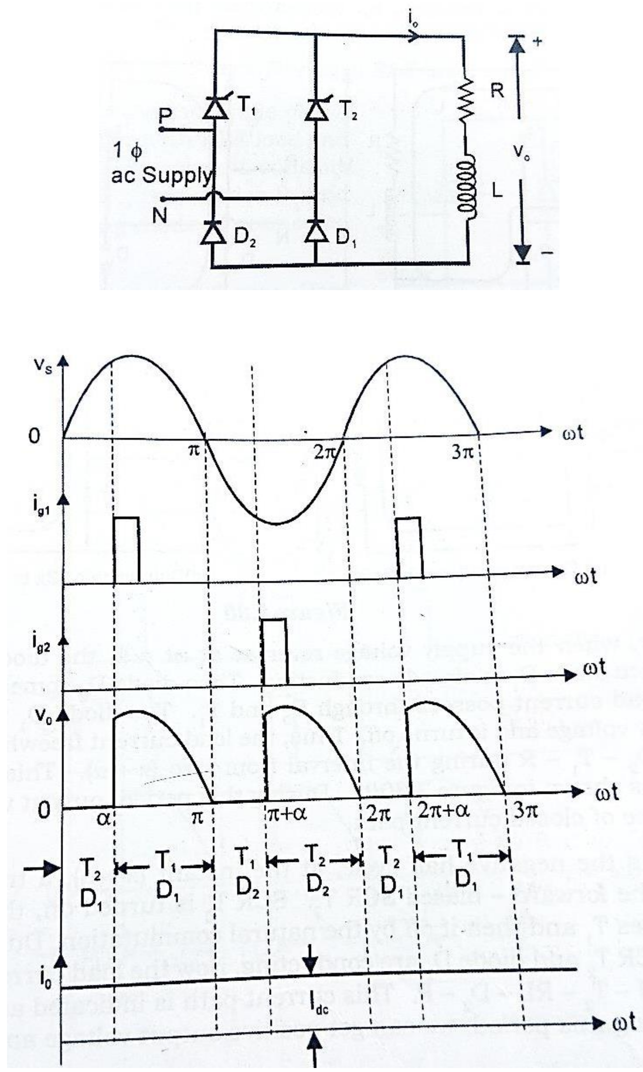


Fig. 3.9 Single phase half controlled bridge rectifier with RL load

- Here the inductance value should be large, for the load should be continuous.
- **During positive half cycle (0 to π)**
- T1, D1 are forward biased. At wt=α, T1, D1 comes to on state. Now the current path is P-T1-RL-D2-N.
- When the supply voltage reverses at wt=π, the diode D2 is forward biased since D1 is already conducting. Then D2 comes to on state and the load current passes through D2, T1.
- D1 is reverse biased due to supply voltage and it is turned off. Thus the load current freewheels through the path L-D2-T1-R during the interval from π to π+α. During this period, output voltage will be zero because of closed current path.
- **During negative half cycle**
- At the instant (π+α), a triggering pulse is applied to the forward biased SCR T2.
- T2 is turned on. The supply voltage reverse biases T1 and T1 is turned off by natural commutation.

- During the period ($\pi+\alpha$) to 2π, T2 and D2 are conducting. The current path is N-T2-RL-D2-P.
- During this period we can get the positive output voltage and current.
- When the supply voltage reverses at wt=2π, D1 is forward biased since D2 is already conducting.
- D1 comes to on state and load current passes through D1 and T2. D2 is reverse biased due to the supply voltage and it is turned off.
- Thus,
- The load current freewheels through the path L-D1-T2-R during the interval from 2π to ($2\pi+\alpha$).
- During this period output current is positive and output voltage is zero due to the closed circuit.

3.7.3 SINGLE PHASE HALF CONTROLLED RECTIFIER WITH RLE LOAD AND FREEWHEELING DIODE

- It consists of two SCRs T1, T2, two diodes D1, D2 and a freewheeling diode is connected across the load. The load is RLE type. The inductance is large and the load current is assumed to be continuous.
- After wt=0, T1 is forward biased, only when source voltage V_m sinwt exceeds E. Thus T1 is triggered at firing angle wt=α such that Vm sinα>E.
- At w=α, T1, D1 comes to the on state.
- For the period α to π, load current i_o flows through the path P-T1-RLE-D1-N. During that period, we can get positive output voltage and current.
- During the period, π to $\pi+\alpha$, the input voltage is negative and freewheeling diode FD is forward biased.
- FD conducts to provide the continuity of current in inductive load. The load current is transferred from T1 and D1 to FD. SCR T1, Diode D1 are turned off.
- During that period, we can get zero output voltage and positive output current.
- During negative half cycle, T2 will be forward biased only when the source voltage is more than E.
- At wt=$\pi+\alpha$, source voltage exceeds E and T2 is triggered. Soon after $\pi+\alpha$, FD is reverse biased and is therefore turned off. Now the load current is transferred from FD to T2, D2.
- The current path is N-T2-RLE-D2-P. During this period $\pi+\alpha$ to 2π we can get positive output voltage and current.
- At wt=2π, FD is again forward biased, i_o is transferred from T2 and D2 to FD as explained before.
- The source current is positive from α to π when T1, D1 conduct and is negative from $\pi+\alpha$ to 2π when T2, D2 conduct.

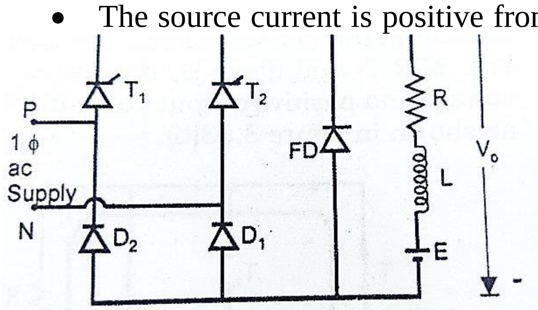


Fig. 3.10. a

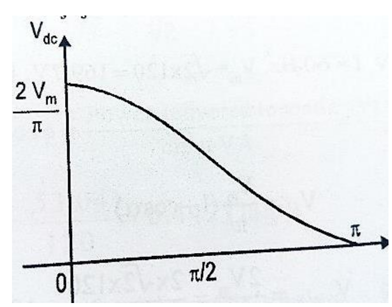


Fig.c

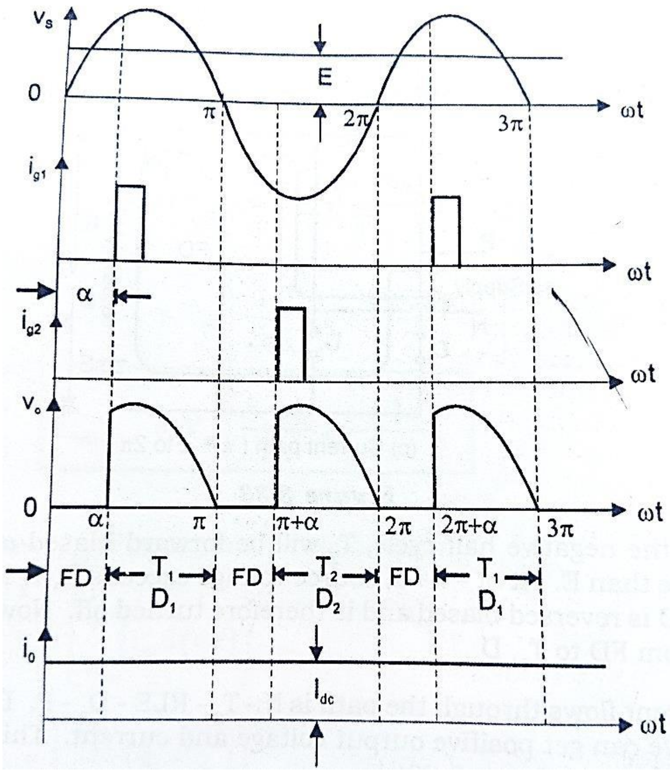


Fig. b Single phase half controlled rectifier with RLE load and freewheeling diode

Half controlled bridge rectifier with RLE & freewheeler

Average DC o/p voltage:

$$V_{dc} = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \cdot d\omega t.$$

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

$$\boxed{V_{dc} = E + I_{dc}R}$$

Average o/p current (I_{dc})

$$I_{dc} = \frac{V_{dc}-E}{R}$$

RMS o/p voltage (V_{orms})

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

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

Average current through freewheeling Diode

$$I_{FDA} = \frac{I_{dc}}{\pi}\alpha$$

RMS current through FD:

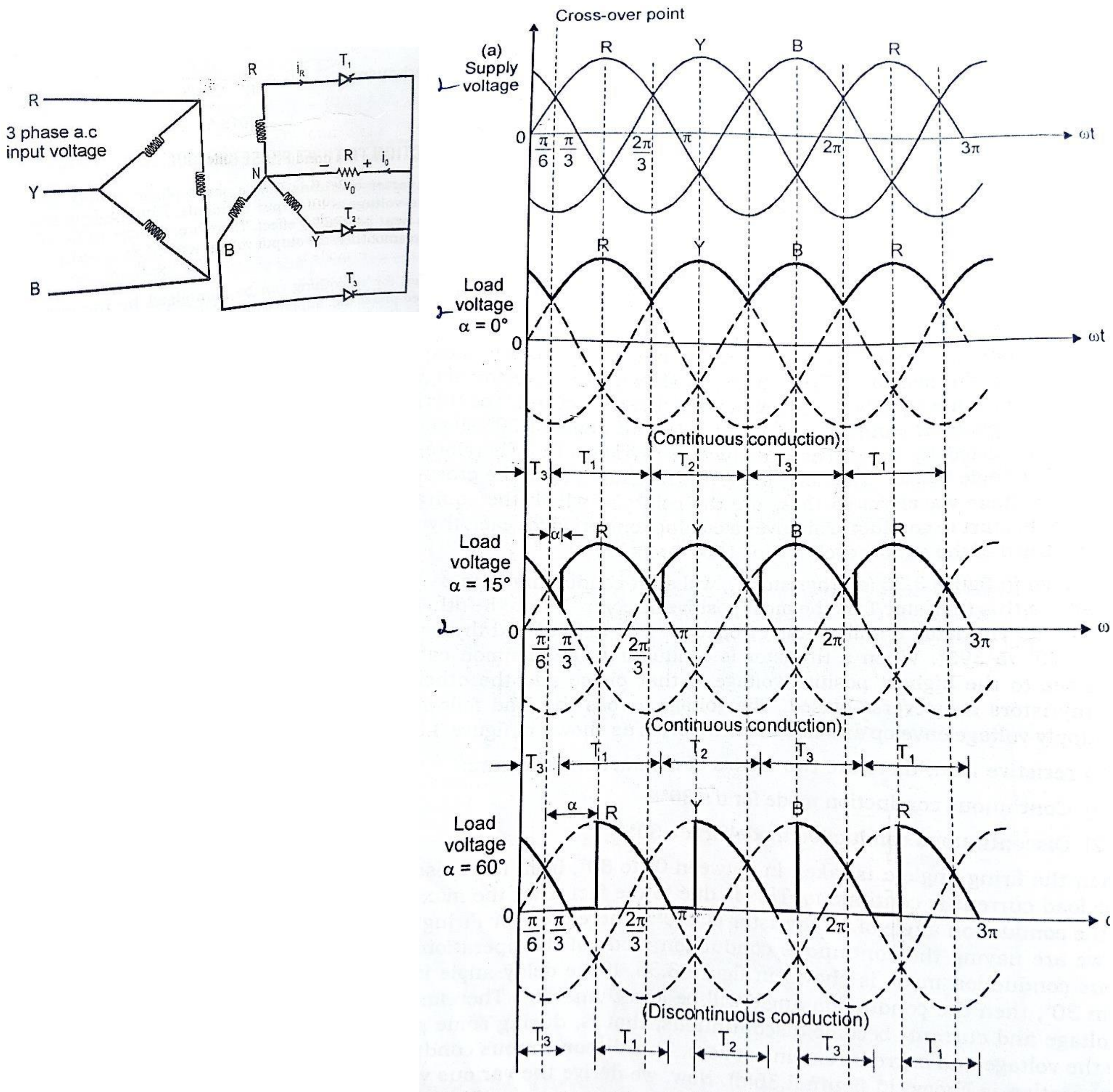
$$I_{FDR} = I_{dc}\left[\frac{\alpha}{\pi}\right]^{1/2}$$

... controlled rect. with R load:

4. THREEPULSE CONVERTERS

Three pulse converter is also known as the three phase half wave controlled rectifier. The simplest type of phase controlled converter operating from a three phase supply is the three pulse mid-point converter.

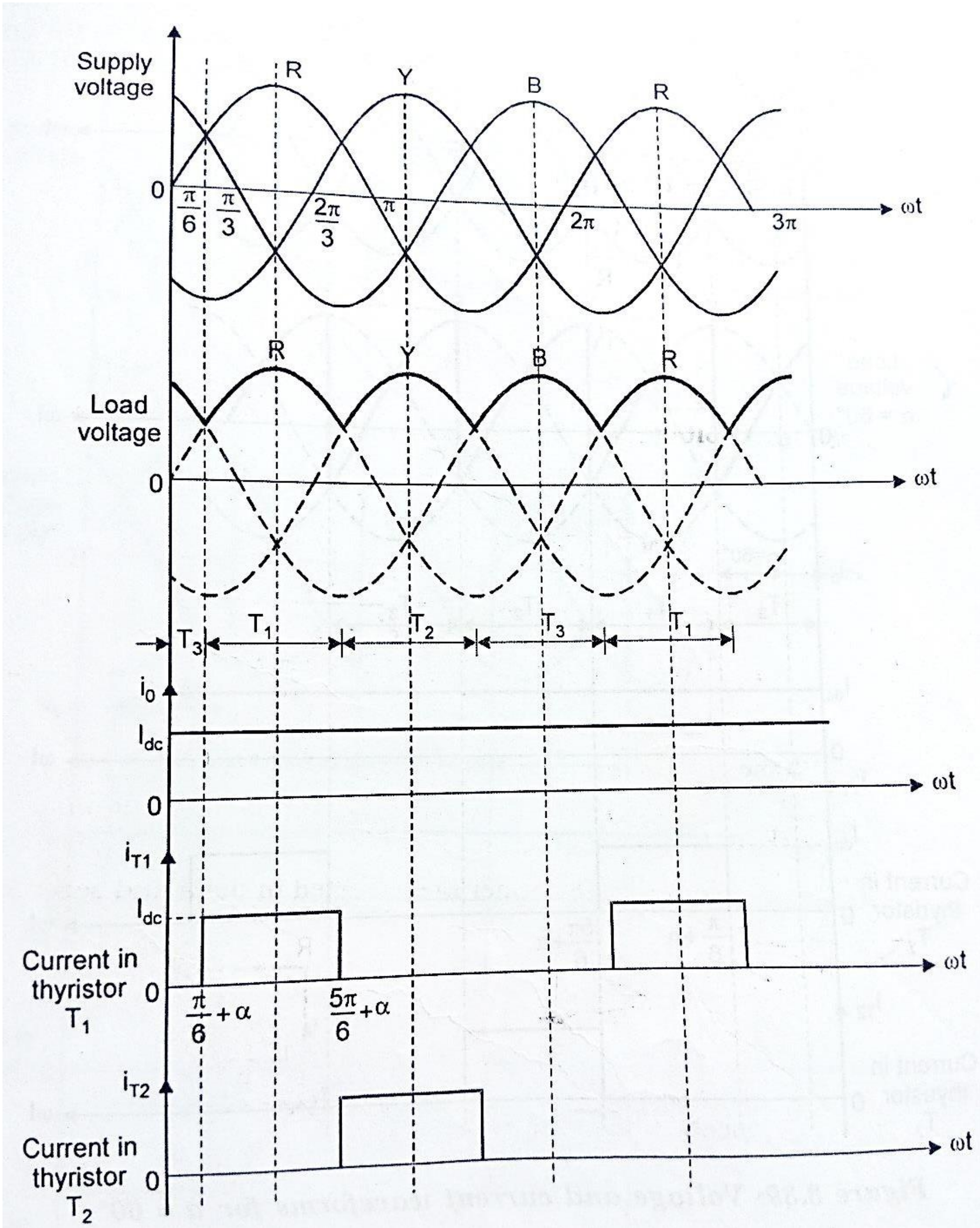
4.1 THREE PHASE HALF WAVE CONTROLLED RECTIFIER WITH R LOAD



4.1. a Three phase half wave controlled rectifier with R load

- This configuration is called mid-point configuration because, all the phase emfs can have a common terminal which may be considered as the neutral point or mid-point.

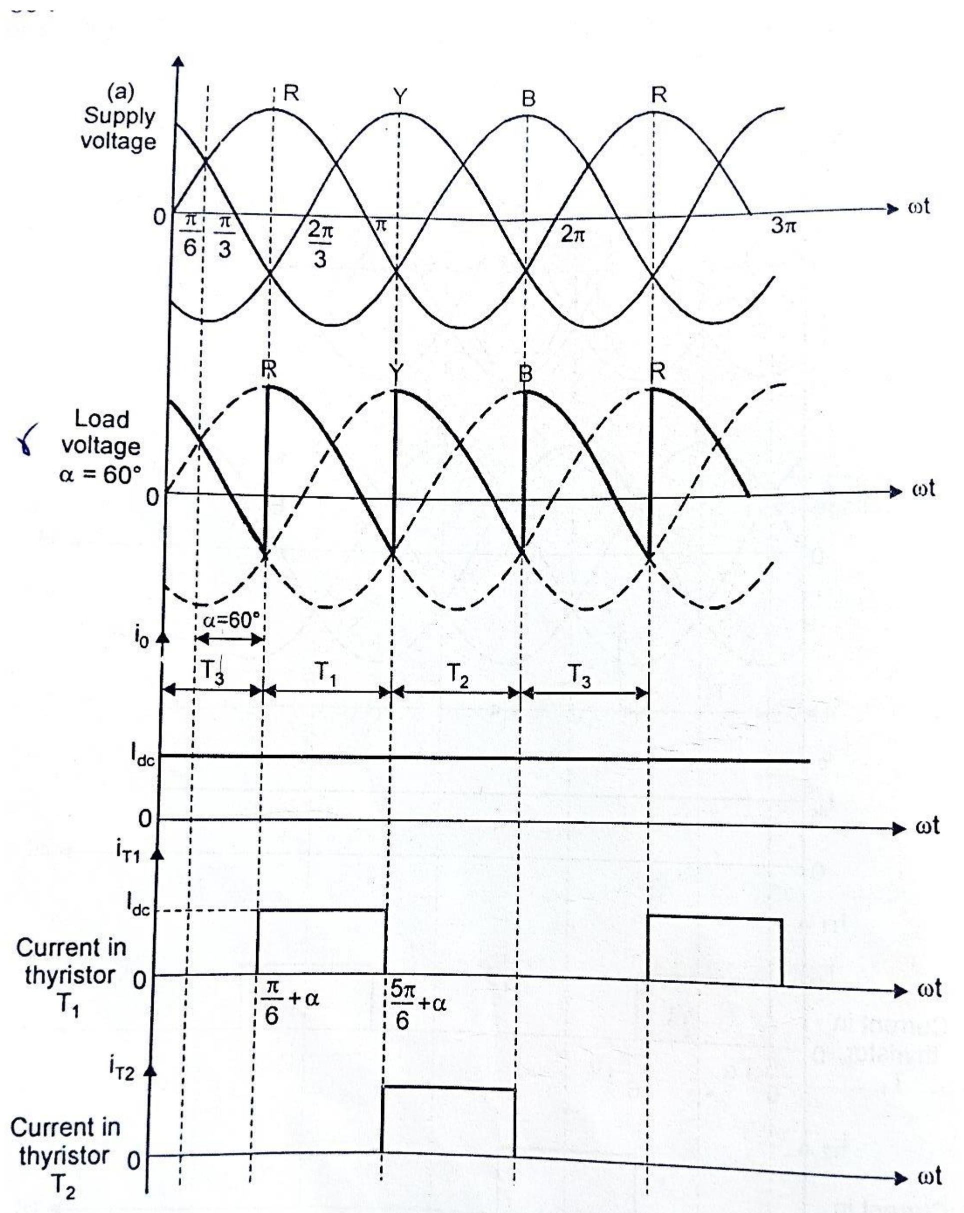
- The primary is connected in delta and secondary is connected in star. The load is connected to the neutral point.
- For the analysis of the circuit, the leakage inductance and on state thyristor drops are assumed to be zero. The vector diagram is shown in figure.



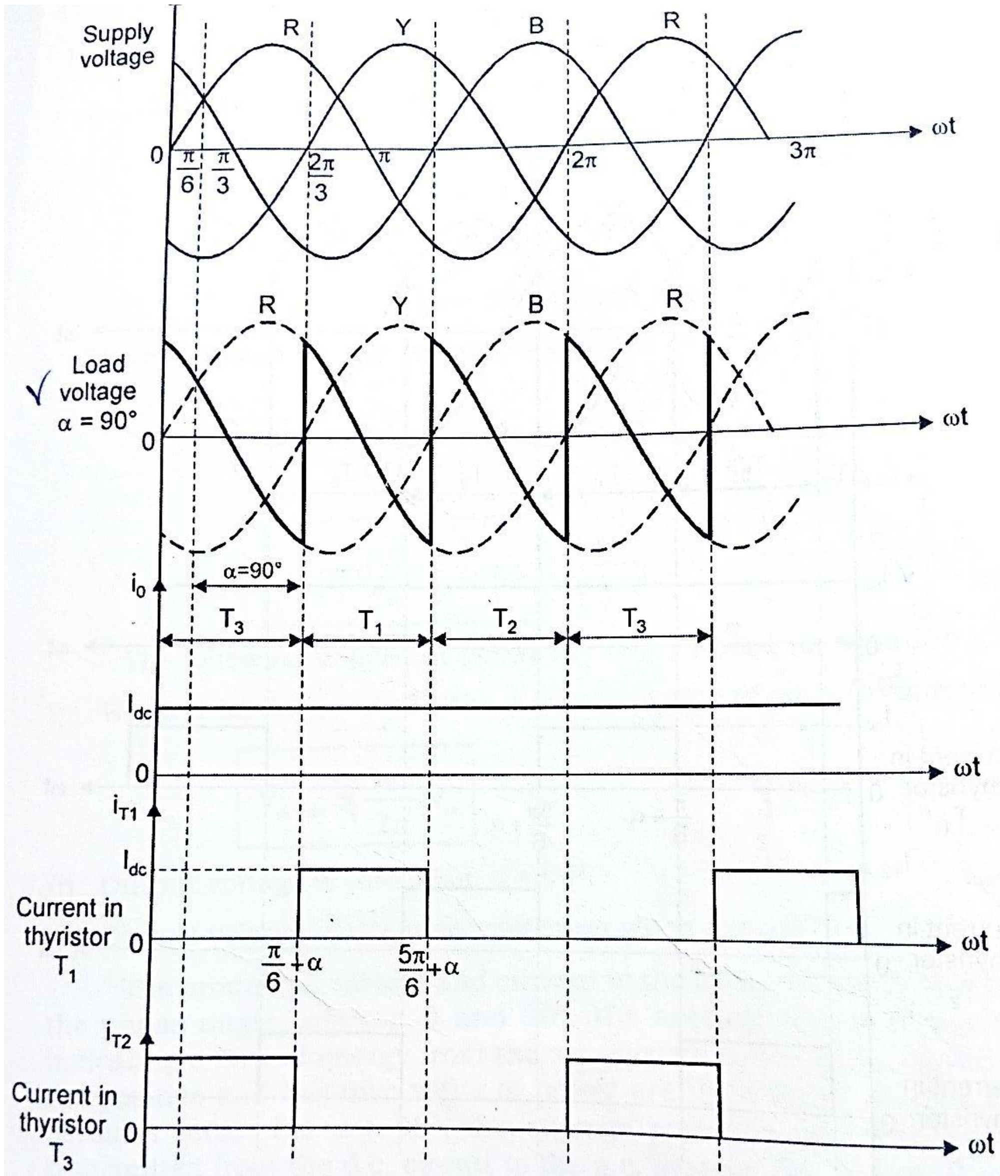
b. voltage current waveforms for α= 0°

- The circuit function is in such a way that only one thyristor is conducting at any instant, the one which is connected to the phase having the highest instantaneous positive value.
- The firing angle α for a particular thyristor connected in a particular phase is therefore measured from 30° with respect to the corresponding phase voltage.
- From the vector diagram, phase R and phase B are equally positive with respect to the neutral.

- T1 connected to R phase cannot be triggered below 30º since it is already reverse biased by the already conducting thyristor T3. Therefore the minimum delay angle is $\pi/6$.
- The delay angle is measured from the cross over point of the voltage waveform at which the equivalent thyristors would start to conduct. So each thyristor conducts for one third of the supply cycle period (120º or $2\pi/3$).



c. voltage current waveforms for α= 60º



d. voltage current waveforms for α= 90º

- As shown in figure 1, T1 will conduct from wt=30º to wt=150º, as this T1 is most positive compared to the other two thyristors.
- T2 will conduct from wt=150º to 270º and T3 from wt=270º to 390º.
- With resistive load there are two modes of conduction.
- Continuous conduction mode for $\alpha \leq 30º$.
- Discontinuous conduction mode for $\alpha > 30º$
- When the firing angle α is taken in between 0º and 30º , the load current is continuous from the cross over point. This is due to the fact that the conduction angle of an thyristor is 120º. Therefore for firing angle $\alpha \leq 30º$ we have continuous current conduction.
- If the delay angle is kept more than 30º, then the conduction angle will be less than 120º. Therefore output voltage and current will be discontinuous, i.e during some part of the cycle, the voltage and current remains zero.

- **When α=0º**
- Each thyristor conducts for a period of 120º of the input AC supply and the fundamental frequency of the ripple voltage at the DC terminal 3 times the supply frequency i.e., there are three pulses at the output.
- **When α=60º**
- Each SCR blocks for a 60º period, prior to the instant at which it is triggered. The average voltage at the DC terminals has been reduced and the fundamental component of the AC input current waveforms now lag the voltage by 60º.
- **When α=90º**
- Each SCR now blocks forward and reverse voltage for equal periods of time. The average voltage at the DC terminals is zero and the fundamental AC input current lags the voltage by 90º. Therefore as the firing angle is increased the average DC output voltage is zero when α=90º. Because of the large reactor, the current remains continuous.
- Hence by varying the delay angle from 0 to 90º, rectifier operation is obtained i.e, power flows from source to load.
- **When α=120º**
- The blocking voltage across each SCR is now in the forward direction. Therefore the mean DC voltage at the DC terminals is negative. This implies that, the source of voltage must be present in the DC circuit which is driving the current against the counter voltage in DC terminals of the converter. i.e., power flows from load to source.

3φ Half wave controlled rect. with R load:

$$V_{dc} = \frac{1}{\frac{2\pi}{3}} \int_{\alpha+30}^{\alpha+150} V_m \sin\omega t \, d\omega t.$$

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

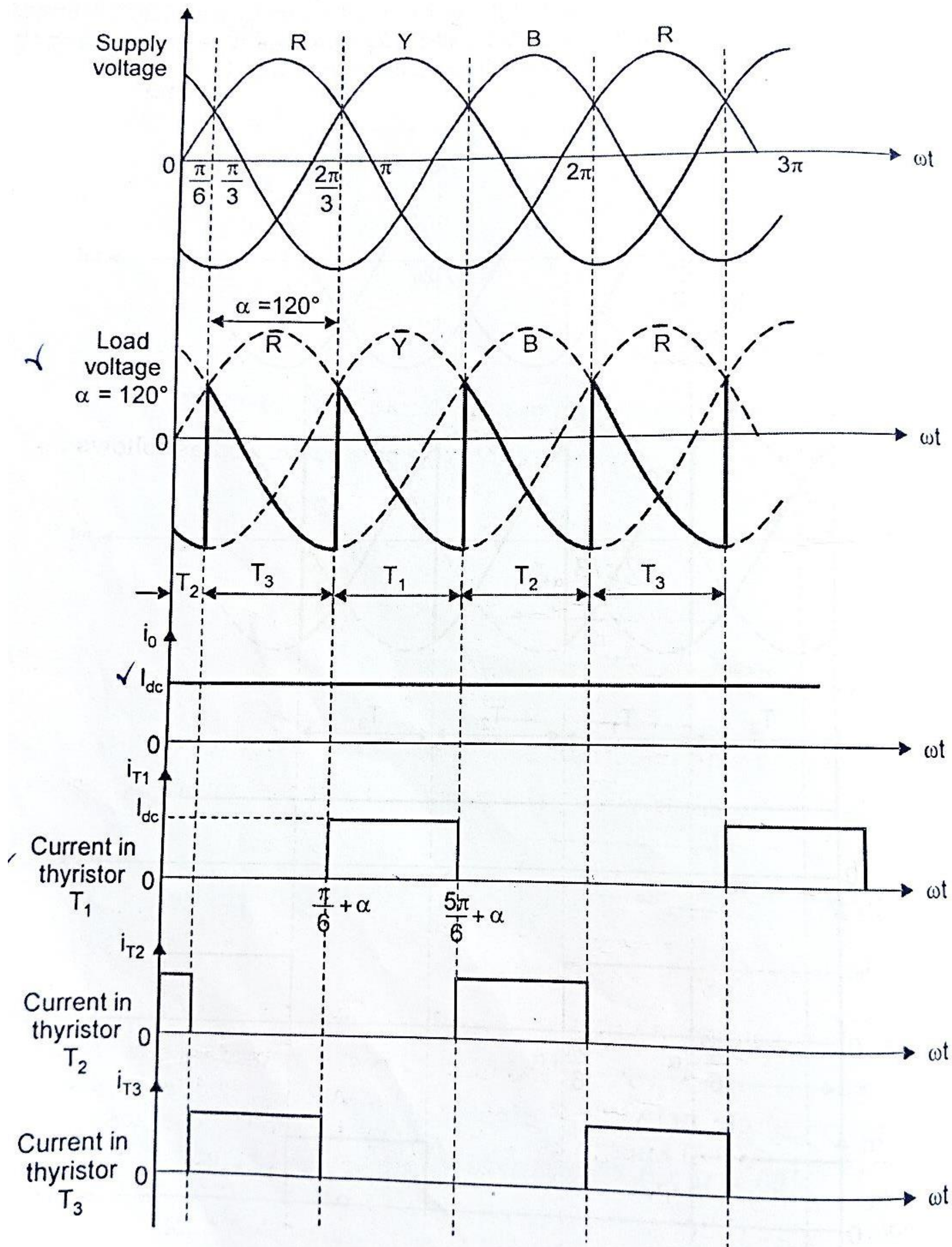
$$= \frac{3V_m}{2\pi} \left(-\cos(\alpha+150) + \cos(\alpha+30)\right)$$

$$= \frac{3V_m}{2\pi} \left[\left(-\cos\alpha\cos150^\circ - \sin\alpha\sin150\right) + \left(\cos\alpha\cos30 - \sin\alpha\sin30\right)\right]$$

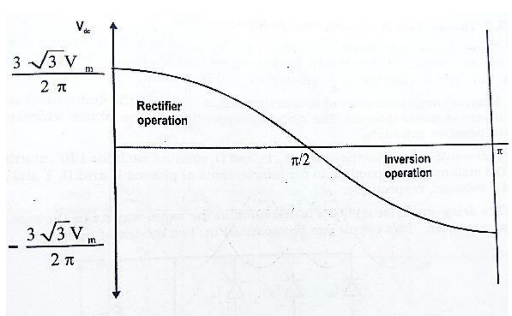
$$= \frac{3V_m}{2\pi} (1.72\cos\alpha) = \frac{3\sqrt{3}\,V_m}{2\pi}\cos\alpha$$

when $\alpha = 0^\circ$

$$\boxed{V_{dc\,max} = \frac{3\sqrt{3}}{2\pi} V_m}$$



e. voltage current waveforms for α= 120º



f. Graph: Vdc vs α

4.2 THREE PHASE HALF CONTROLLED BRIDGE RECTIFIER

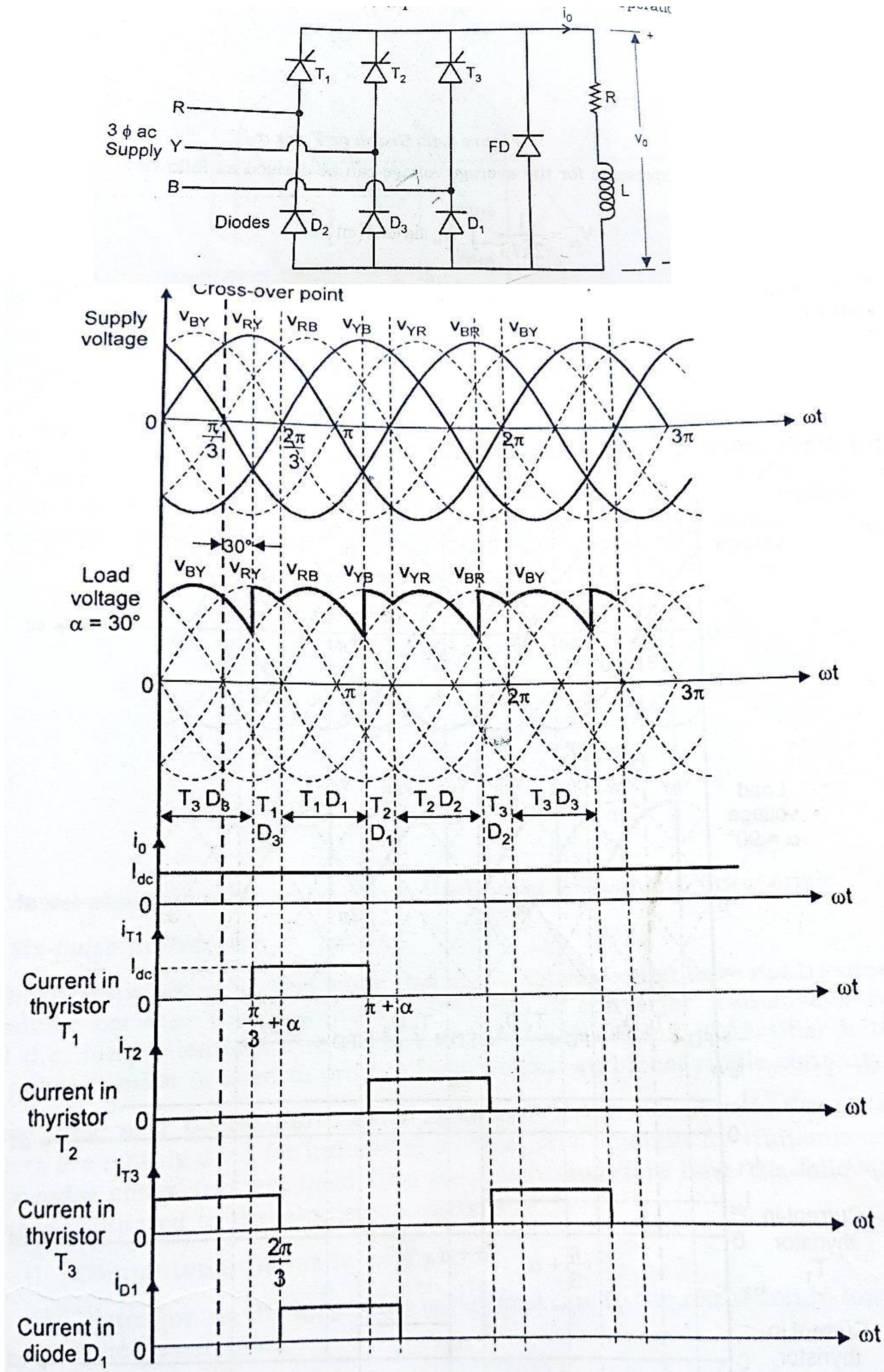


Fig. 4.2 Continuous conduction mode

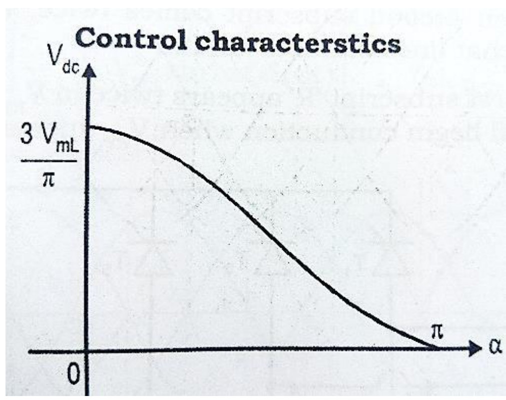
- It consists of three SCRs in three arms and diodes in the other three arms. Here, the source impedance is neglected.
- Diode D1, D2, D3 conduct each for 120º. This circuit can be explained in two modes of operation.

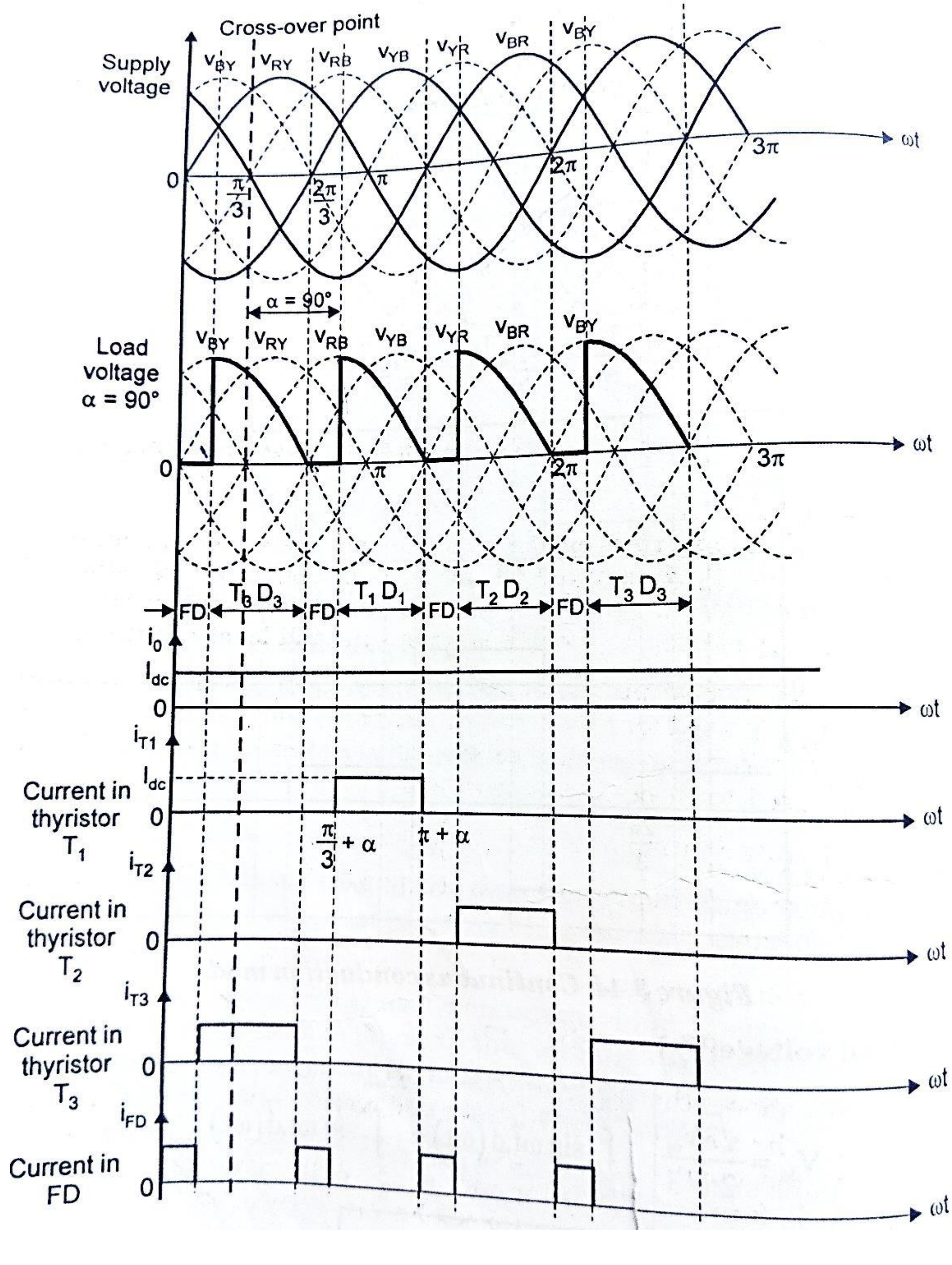
Mode 1: Continuous conduction mode

- At instant ($\pi/3+\alpha$), T1 is triggered with a firing angle $\alpha<60^\circ$. Since R-Y has the highest value compared to other phases, T1 becomes on. The current path is R-T1-R-L-D3-Y.
- Then, phase R-B has the maximum value. Therefore, the current path shifts from Y to B, i.e, T1 continues to conduct but current changes from D3 to D1. Therefore T1 conducts for 120º, which is the maximum conduction period of the SCRs.
- For $\alpha<60^\circ$, the output voltage will never become negative. The output voltage waveforms repeat for every 120º.

Mode 2: Dis Continuous conduction mode

- This mode occurs for firing angles $\alpha>60^\circ$. The output voltage becomes zero because of the freewheeling action. Freewheeling period is ($\alpha-\pi/3$). Therfore input current flows for the period ($\pi-\alpha$) in each half cycle.
- When α increases, the duration of input current pulse decreases and the harmonic content in the source current increases.





Dis Continuous conduction mode

5. SIX PULSE CONVERTER

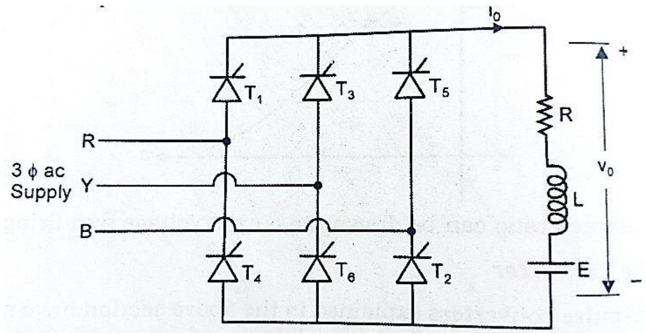
Six pulse converters are mainly used for industrial applications. The six pulse converters have the following advantages

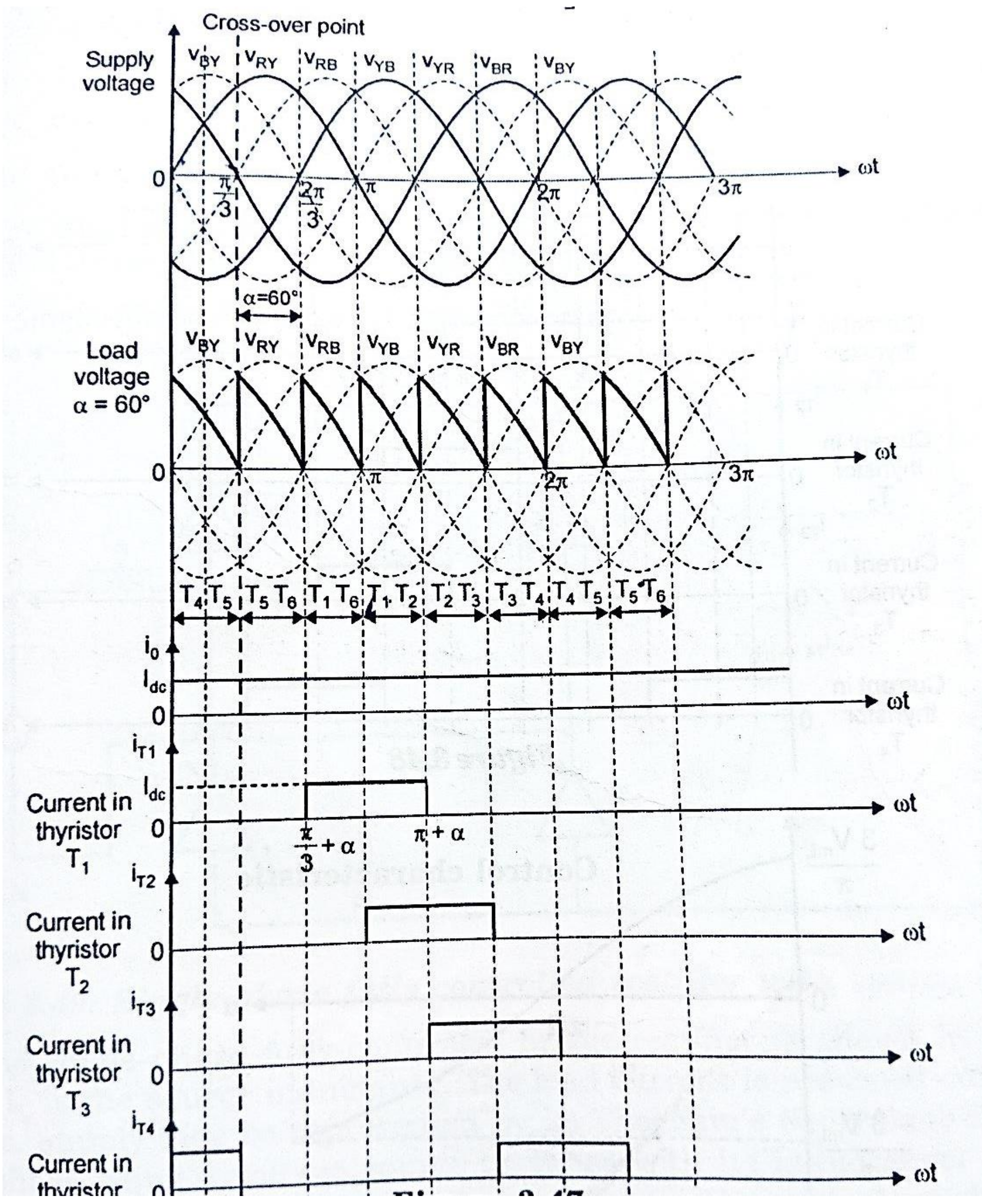
ADVANTAGES

- Commutation is made very simple
- Distortion on the input side is reduced due to reduction in lower order harmonics.
- Inductance required in series is considerably decreased.

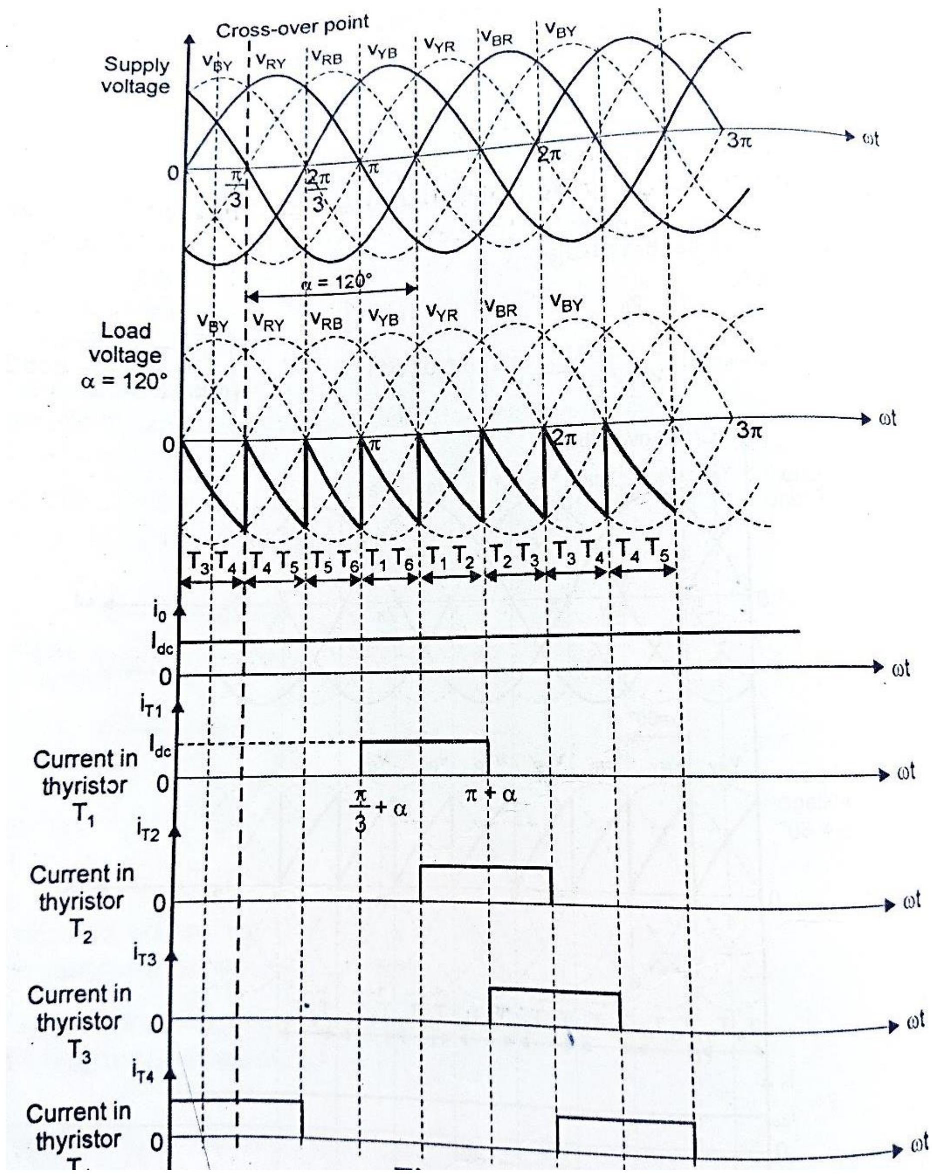
5.1 THREE PHASE FULLY CONTROLLED BRIDGE RECTIFIER

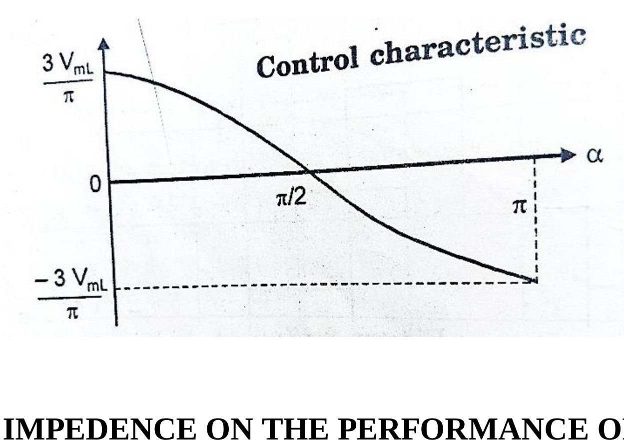
- The circuit consists of six thryristors. Here, two group of thyristors, one is positive group and another one is negative group.
- Here, T1, T3, T5 forms a positive group, whereas T2, T4, T6 forms a negative group. The positive group thyristors are turned on when the supply voltage is positive and negative group of thyristors are turned on when the supply voltage is negative.
- For our easy understanding, line voltages instead of phase voltage are used. The line voltages are Vry, Vrb, Vyb, Vyr, etc.
- The subscripts in sequence appear twice. When first subscript appears twice, the SCR in the positive group pertaining to that line conducts for 120º.
- When second subscript comes twice, the SCR in the negative group pertaining to that line conducts for 120º.
- For example, first subscript 'R' appears twice in V_{RY}, V_{RB}. Therefore SCR from positive group T1, will begin conduction when RY appears. i.e., at wt= 60º.
- In V_{RB}, V_{YB}, second subscript 'B' appears twice, therefore SCR from negative group T2 will begin conduction when V_{RB} appears. i.e. from wt=120º.
- Similarly first subscript 'Y' appears twice in V_{YB}, V_{YR}, so SCR from positive group T3 will begin conduction when V_{YB} appears. i.e., from wt= 180º.
- For α=60º, T1 is turned on at (π/3+60) =120º, T2 at wt= 180º, T3 at wt= 240º and so on.
- When T1 is turned on at wt=120º, T5 is turned off. T6 is already conducting.
- As T1, T6 are connected to R and Y respectively, load voltage must be V_{RY}.
- When T2 is turned on, T6 is commutated. As T1, T2 are now conducting, the load voltage is V_{RB}.
- For α=120º, T1 is triggered at wt=180º, T2 is triggered at wt= 240º and so on.
- From this wave form the output voltage is negative. This means DC source is delivering power to AC source. This operation is called line commutated inverter operation.
- For α=0º to 90º, the converter operates in rectification mode and 90º to 180º, the converter operates in inversion mode.





5.1. a Three phase fully controlled bridge rectifier





6. EFFECT OF SOURCE IMPEDENCE ON THE PERFORMANCE OF CONVERTER

- In single phase and three phase converters, it is assumed that the current transfers from the outgoing SCRs to the incoming SCRs instantaneously.

- When T1, T2 are fired in a single phase T3, T4 are turned off and the current transfers from T3, T4 to T1, T2.
- It is possible only if the voltage source has no internal impedance. Actually, the source possesses internal impedance and time is required for a current change to take place.
- Thus in practice , the commutation process may occupy a quite significant period of time, during which both “incoming” and “outgoing” SCRs are simultaneous in conduction.

This period, during which the outgoing and incoming thyristors are conducting, is known as the overlap angle μ or commutation angle.

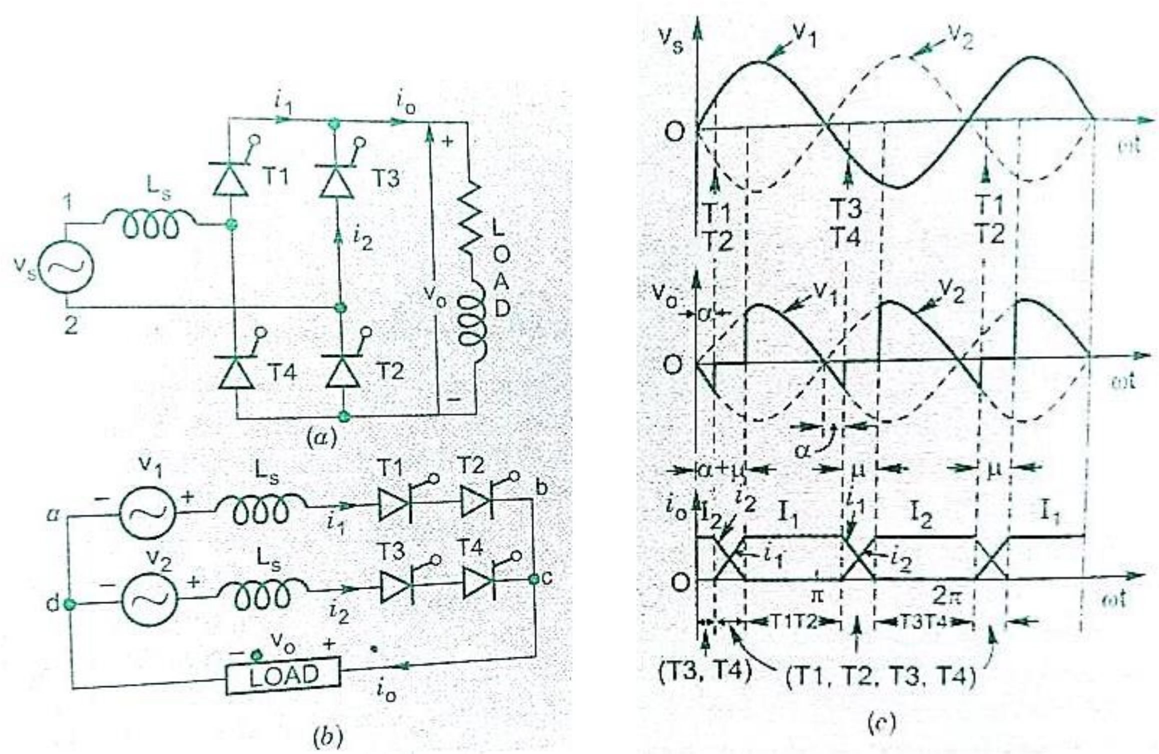
6.1 EFFECTS OF SOURCE INDUCTANCE

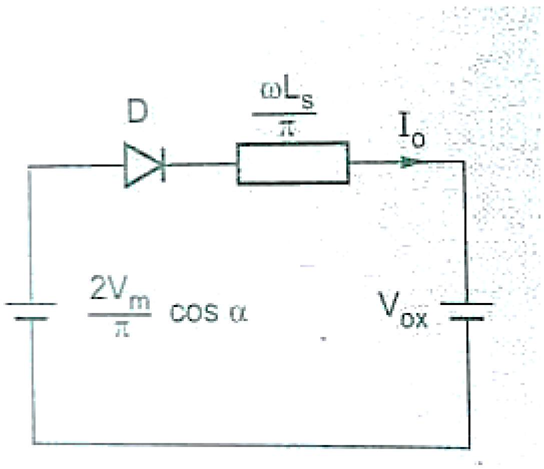
- It lowers the mean output voltage
- It distorts the output voltage and current waveforms
- It modifies the performance of the converter

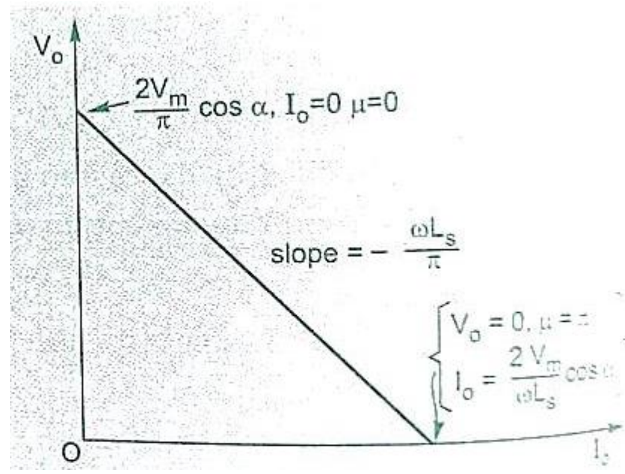
6.1.1 SINGLE PHASE FULL CONVERTER

- In the single phase full converter Ls is the source inductance. The load current is assumed constant.
- When terminal 1 of source voltage Vs is positive, current i1 flows through Ls, T1, load and T2. This is shown in fig.b. i.e., L, T1, T2 and load.
- Similarly when terminal 2 of Vs is positive, load current i2 flows through T3, load and T4 and this is shown as V2, Ls, T3, T4 and load.
- When T1, T2 are triggered at a firing angle α, the commutation of already conducting thyristors T3, T4 begins.
- Because of the presence of source inductance Ls, the current through outgoing thyristors T3, T4 decreases gradually to zero from its initial value of Io; whereas in incoming thyristors T1, T2, the current builds up gradually from zero to full value of load current Io.

Fig. 6.1.a. Circuit b. Equivalent circuit c. Current & voltage waveforms with L_s







- From the above equivalent circuit D merely indicates that the load current is unidirectional. Ls is to present an equivalent resistance of magnitude wLs/π ohms in series with internal voltage of the rectifier (2Vm/π) cosα.
- The voltage drop due to Ls is proportional to Io and L. Thus as the load current increases, the commutation interval increases and as a consequence, the average output voltage decreases.
- As long as μ<π, there is some output voltage. When μ=π, the load will be permanently short circuited by SCRs and the output voltage will be zero because during overlap, all SCRs will be conducting.

6.1.2 THREE PHASE FULL CONVERTER

- The figure shows a three phase full converter bridge with a source inductance L_s in each line. The load current is assumed constant.
- Fig.b shows the various conduction of SCRs with firing angle α=0 and overlap angle μ=0.
- From wt=0º to 30º; T5, T6 conduct.
- At wt=30º, T5 is outgoing SCR and T1 is incoming SCR and both T5, T1 belong to positive group.
- As T1 is triggered, current through T5 starts decaying while through T1 current begins to build up.

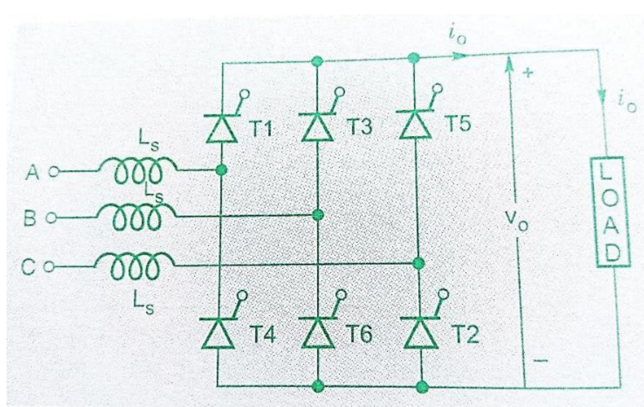


Fig. 6.2. a. Three phase full converter circuit

- At wt=30º+μ, I5 is zero while I1=Io. Therefore from wt=30º to 30º+μ, three SCRs T5, T6, T1 conduct.
- After wt=30+μ; T6, T1 conduct.
- At wt=90º, as T2 is triggered, I6 begins to decrease and I2 starts building up. Therefore from wt=90º to 90º+μ, three SCRs T6, T1, T2 conduct.
- At wt=90º+μ, I6=0, I2=Io. After wt=90º+μ, only two SCRs T1, T2 conduct. This sequence of operation repeats with other SCRs of the full converter.
- When positive group of SCRs are undergoing commutation, two SCRs from the positive group and one SCR from negative group conduct.
- After the commutation of positive group is completed, only two SCRs conduct; one from positive group and another one form negative group.
- Similarly, when negative group of thyristors are undergoing commutation, three SCRs conduct, two from the negative group and one from the positive group and these are followed by two SCRs, one from positive group and one from negative group and so on.
- Conduction of various thyristors shown in fig.c is as follows:
- 5-6,5-6-1,6-1,6-1-2,1-2,1-2-3,2-3,2-3-4,3-4,3-4-5,4-5,4-5-6,5-6 and so on.
- It is seen that three and two SCRs conduct alternatively. For 6-pulse converter, there are six shaded areas indicating six commutations per cycly of source voltage.
- During commutation of T5 and T1, the output voltage is obtained by taking average of corresponding phase voltages V_c and V_a of the positive group.
- This means that voltage from wt= 30º to30+μ follows the curve $(V_a+V_c)/2$ from the positive group (jk).
- During commutation of T6 and T2, the voltage waveform from the negative group is $(V_b+V_c)/2$ as indicated by mn.
- During commutation of T1, T3, the voltage is $(V_a+V_b)/2$ indicated by op and so on.
- The firing angle is taken zero to highlight the effect of source inductance.
- The effect of source inductance is t oreduce the average DC output voltage. This reduction is proportional to the area ‘jkl’.
- The average value of this fall in output voltage due to overlap is equal to the area ‘jkl’.

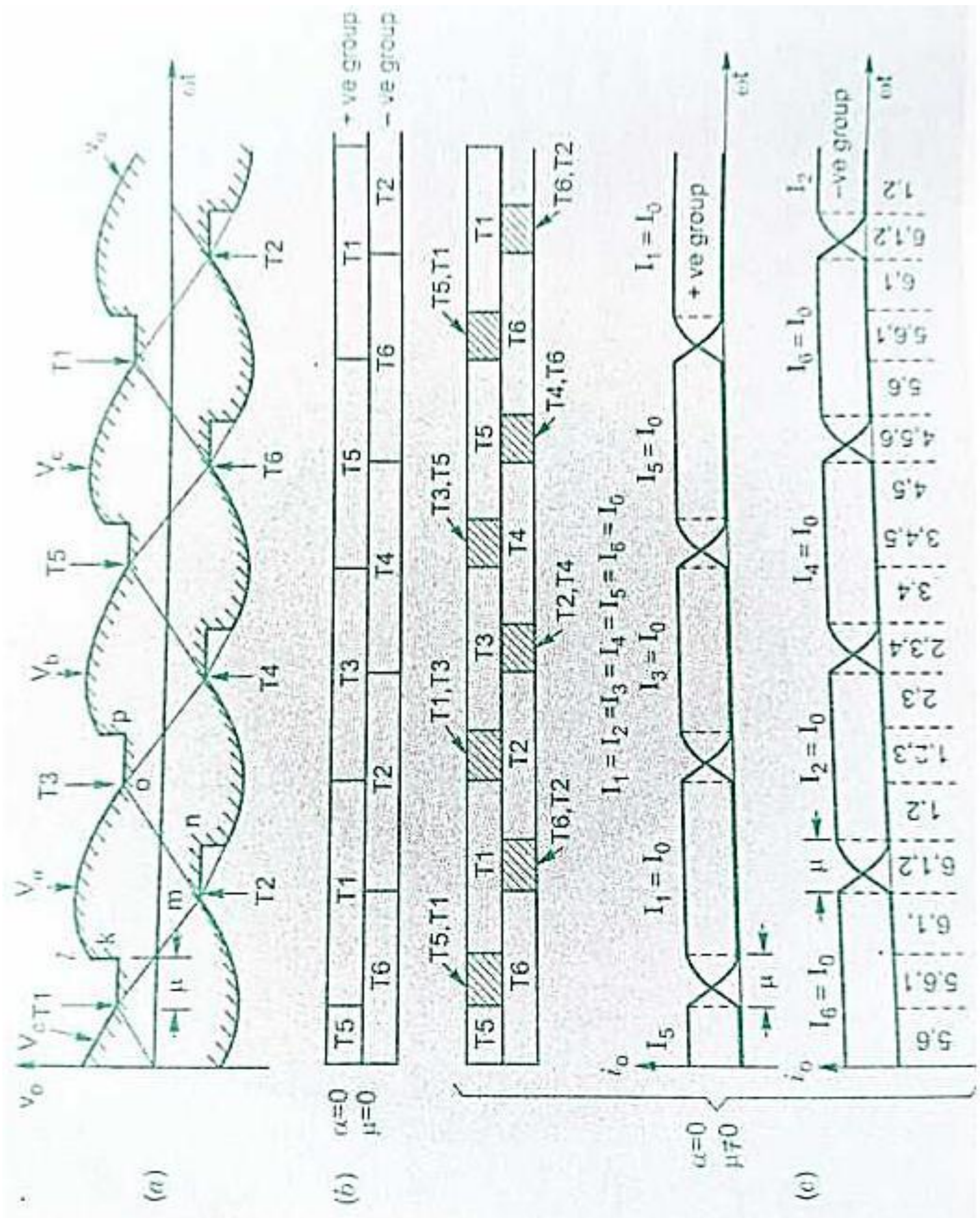


Fig. 6.2.b. Current and voltage waveforms

7. DUAL CONVERTERS

- A full converter operates as a rectifier in first quadrant (V_o,I_o positive) from α=0º to 90º and as an inverter (V_o negative I_o positive) from α=90º to 180º in the fourth quadrant.
- In the first quadrant, power flows from AC source to the DC load and in the fourth quadrant, power flows from DC circuit to the AC source.
- Four quadrant operation without any mechanical switchover can be achieved by connecting two full converters. Such an arrangement using two full converters in antiparallel and connecting to the same DC load is called a dual converter.

- There are two functional modes of dual converter, one is non circulating current mode and the other is circulating- current mode. Here, we use non- circulating type of dual converters in single phase and three phase.
- Converter 1 operates in first and fourth quadrant and the second converter operates in second and third quadrant.
- Thus a dual converter using two full converters can give four quadrant operation.

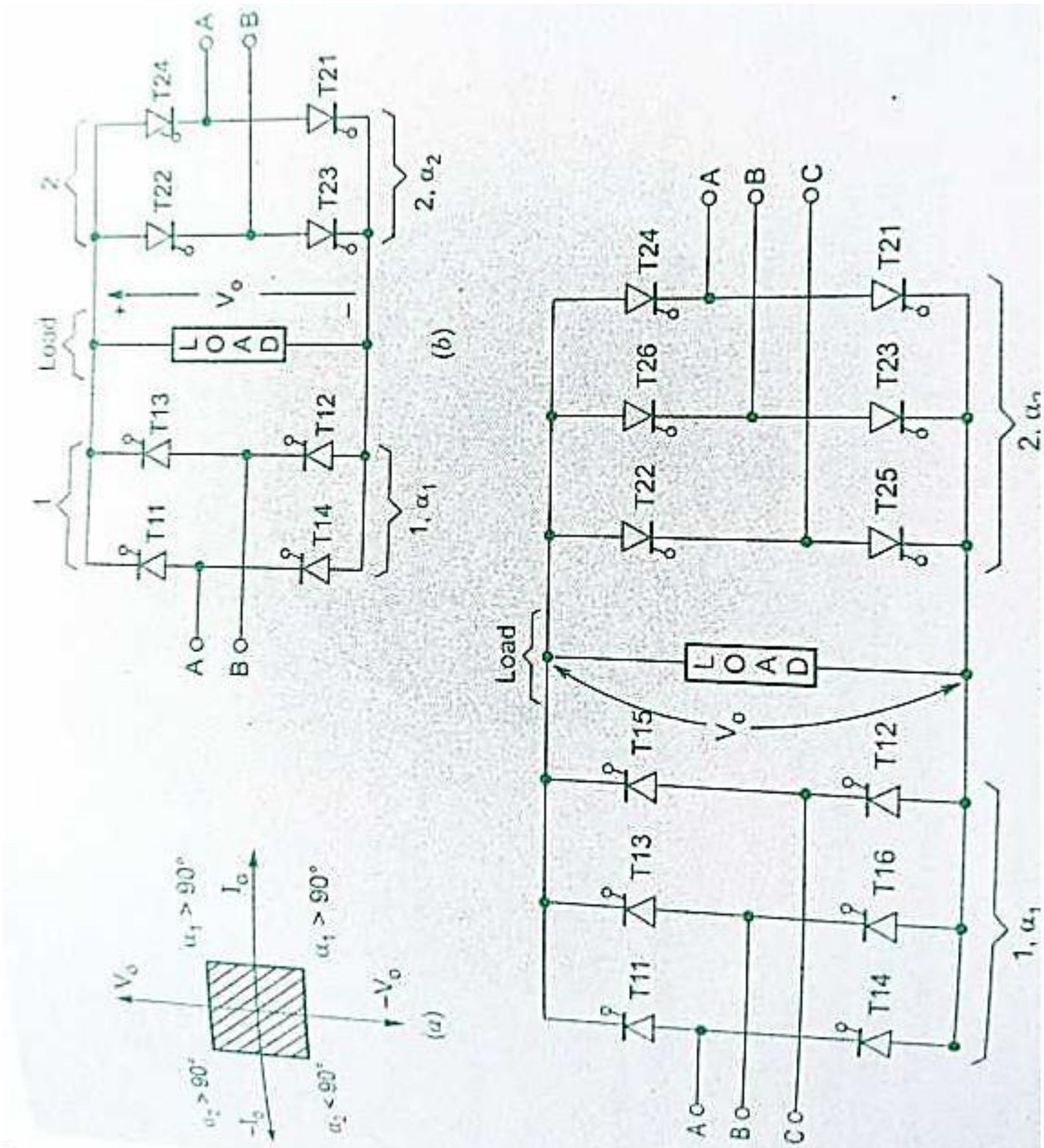


Fig.7.1.a. Four quadrant diagram. Non circulating type b. single phase dual converter. C. Three phase dual converter

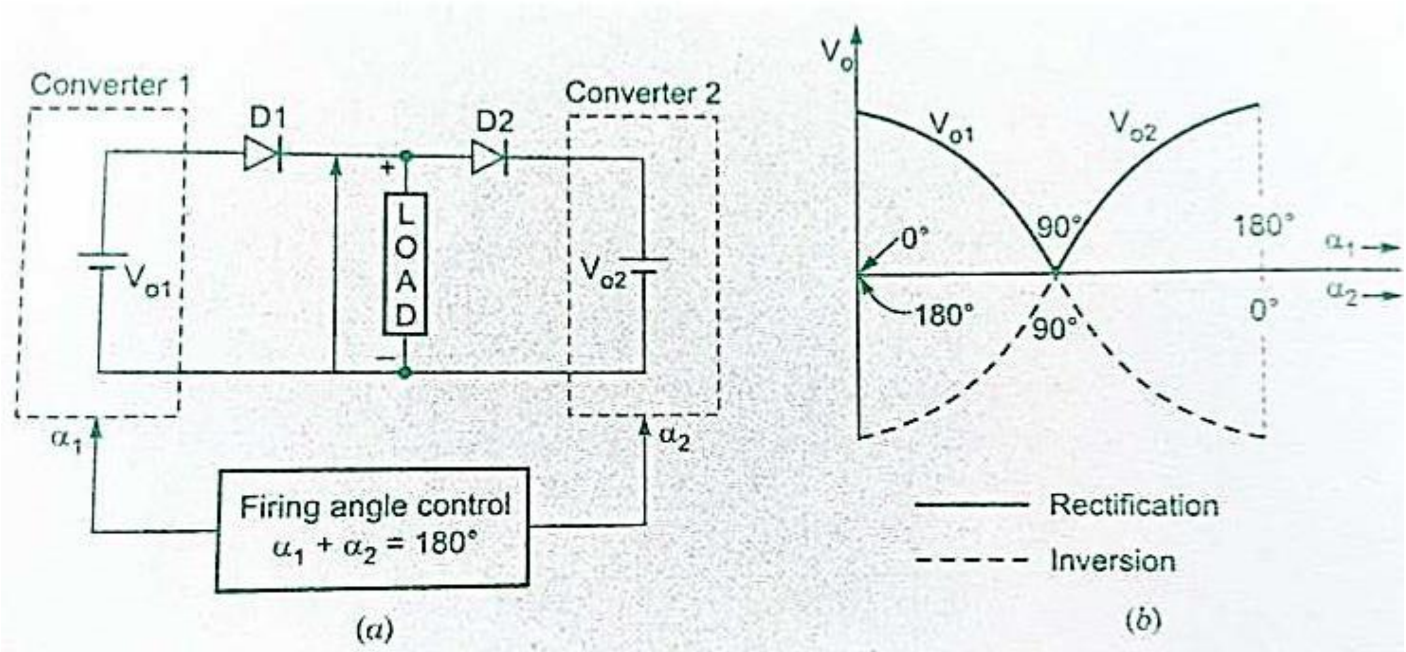


Fig. 7.2.a. Equivalent circuit b. Variation of terminal voltage for an ideal dual converter

7.1 PRACTICAL DUAL CONVERTER

- With the firing angles controlled in a manner that $\alpha_1+\alpha_2 = 180^o$ and with both the converters in operation, their average output voltages are equal and have the same polarity. One converter will be operating as a rectifier with firing angle α1 and other as an inverter with firing angle (180-α1).
- Though their average output voltages are equal, yet their instantaneous voltages V_{o1}, V_{o2} are out of phase in a practical dual converter. This results in a voltage difference when the two converters are interconnected and as a consequence, a large circulating current flows between two converters, but not through the load. In practical dual converters, this circulating current is limited to a tolerable value by inserting a reactor between the two converters. If the converters are triggered suitably, this circulating current can be avoided.

a. Dual converter without circulating current

- In this converter, only one con converter is in operation and it alone carries the entire load current.
- Only, this converter receives the triggering pulse and the triggering pulse to the other converter is removed.
- If suppose, the converter 1 is in operation and the converter 2 must be turned on, then first the firing pulse to the converter 1 should be removed so that its load current will decay to zero and converter 1 will be made to conduct.
- Now the current in converter 2 will build up through the load in the reverse direction.
- As firing pulses are withdrawn from converter1, it is idle as long as the converter 2 is in operation.
- It should be ensured that during changeover from one converter to another converter, the load current must decay to zero.
- After the outgoing converter stopped working, a delay time of 10 to 20 m sec is introduced before applying firing pulses to the incoming converter.

- This time delay ensures the reliable commutation of SCRs in the outgoing converter.
- If the incoming converter is triggered, before completely turning off the outgoing converter, then the circulating current will flow between the converters.
- With non-circulating current mode of dual converter, the load current may be continuous or discontinuous.

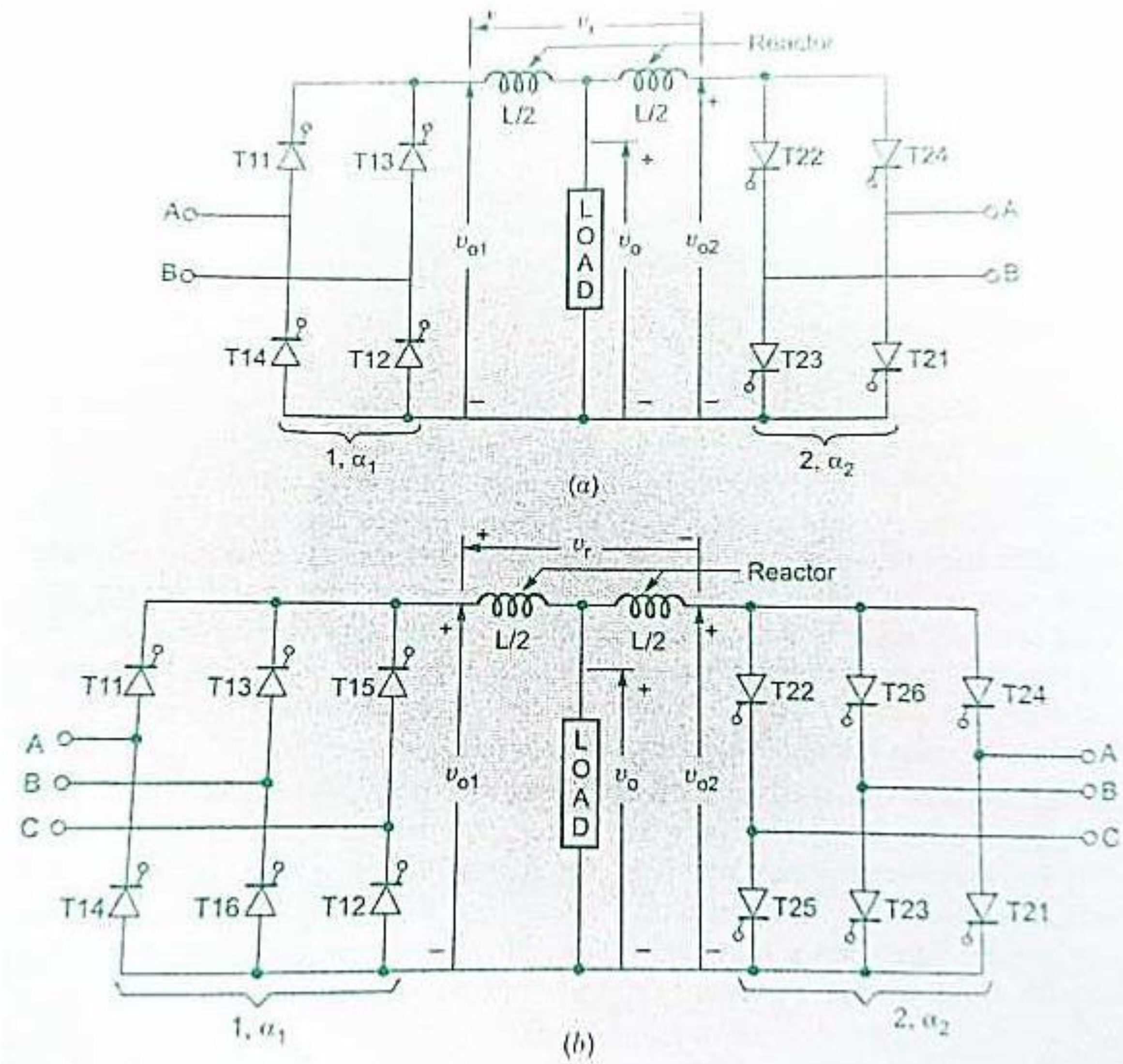
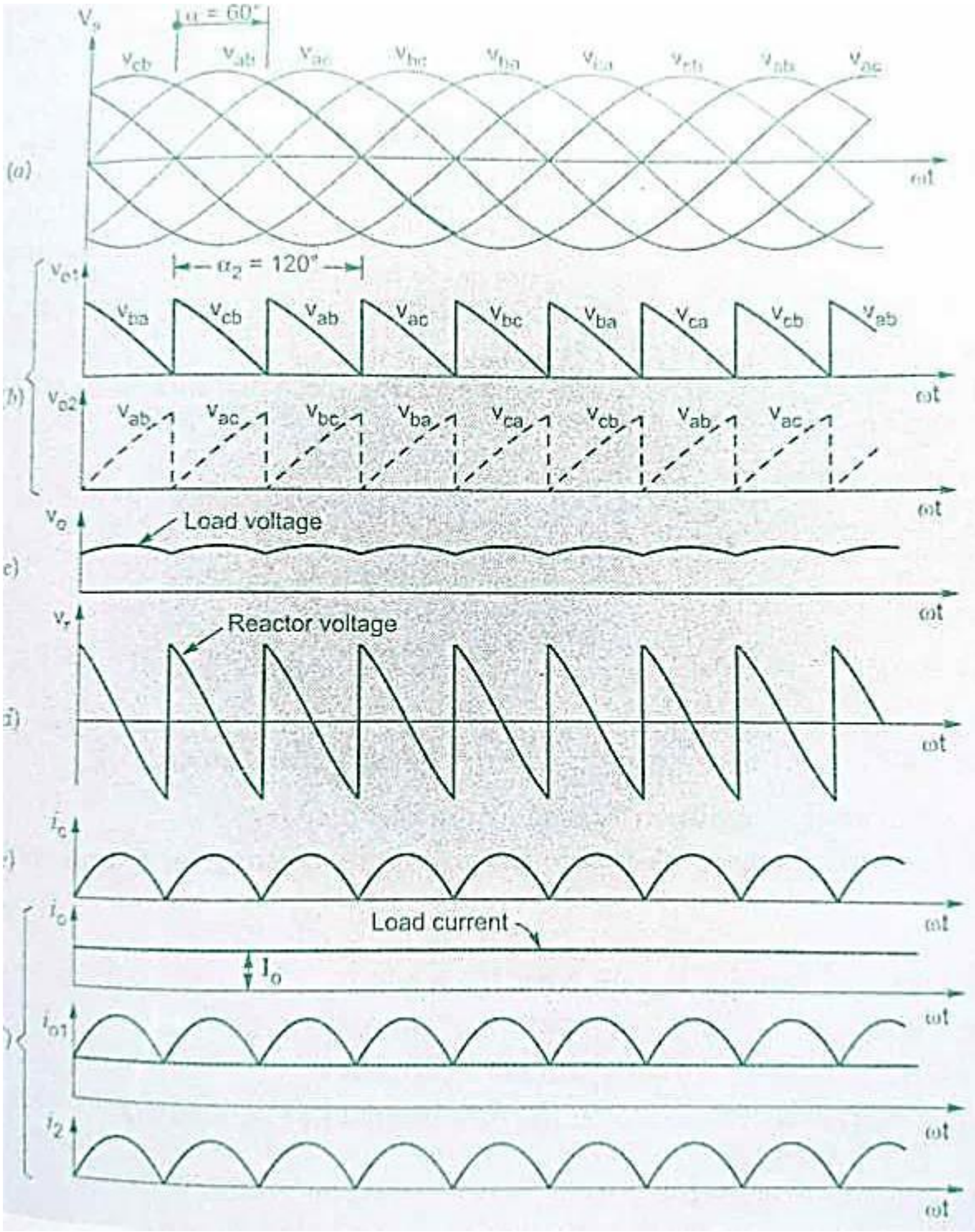


Fig. 7.3 circulating current type dual converter a. single phase supply. B. Three phase supply

Dual converter with circulating current

- In this mode a reactor is inserted in between converters 1 and 2. This reactor limits the value of circulating current to a reasonable value.
- The firing pulses for the converters is so adjusted that $\alpha_1+\alpha_2=180^o$. If firing angle of the converter 1 is 60^o, then the firing angle of the another converter is 120^o.
- So, Converter1 works as a rectifier and the converter2 works as an inverter.

- Though the output voltage at the terminals of both the converters has the same average value and same polarity, their instantaneous output voltage waveforms are not similar as shown by v_{o1}, v_{o2}.
- As a consequence of it, circulating current flows between the converters. This circulating current is limited by the reactor.
- The role of two converters can be changed by changing the firing angles of both the converters.



- This can be done by giving the firing pulse greater than 90º to converter1 and less than 90º to converter2. By this change, the converter1 will act as an inverter and the converter2 will act as the rectifier.

Disadvantages

1. A reactor is required to limit the circulating current. The size and cost of this reactor may be quite significant at higher power levels.
2. Circulating current causes more losses in the converters, hence the efficiency and power factor are low. As the converters have to handle load as well as circulating currents, the thyristors for two converters are rated for higher currents.

Dual converter operation with waveforms

Following assumptions are made in the circulating current mode.

- Reactor is lossless
- The firing angles of the converters are so controlled that $\alpha_1+\alpha_2=180^o$.
- Let α1 be equal to 60º, then for converter 2, $\alpha_2=120^o$.
- With $\alpha_1=60^o$, the output voltage vo1 for converter 1 is indicated by thick line in fig. a. This output voltage vo1 is shown as as V_{ab} in Fig. b from wt=120º to 180º. In this manner v_{o1} is drawn for other intervals.
- With $\alpha_2=120^o$ for converter 2, the output voltage is negative as shown by thick line in fig.a.
- As the average values of output voltages of both the converters are positive, the output voltage V_{o2} of converter 2 must also be shown positive above the reference line wt. In this manner V_{o2} waveform is drawn positive as V_{ba}, V_{ca},V_{cb}.

PART-A

1. **What is the function of freewheeling diodes in controlled rectifier?**

   A "freewheeling diode" is put into a circuit to protect the switching device from being damaged by the reverse current of an inductive load.It is normally placed in a circuit so that it does not conduct when the current is being supplied to the inductive load.

2. **What is commutation angle or overlap angle?**

   The commutation period when outgoing and incoming thyristors are conducting is known as overlap period. The angular period, when both devices share conduction is known as the commutation angle or overlap angle

3. **What are the advantages of six pulse converter?**

   a. Commutation is made simple.

   b. Distortion on the ac side is reduced due to the reduction in lower order harmonics.

   c. Inductance reduced in series is considerably reduced.

4. **What is meant by commutation?**

   It is the process of changing the direction of current flow in a particular path of the circuit. This process is used in thyristors for turning it off.

5. **What are the types of commutation?**

   a. Natural commutation

   b. Forced commutation

6. **Mention some of the applications of controlled rectifier.**

   a. Steel rolling mills, printing press, textile mills and paper mills employing DC motor drives.

   b. DC traction

   c. Electro chemical and electro-metallurgical process

   d. Portable hand tool drives

   e. Magnet power supplies

   f. HVDC transmission system

7. **What are the different methods of firing circuits for line commutated converter?**

   a. UJT firing circuit.

   b. The cosine wave crossing pulse timing

   control. c. Digital firing schemes.

8. **What are the advantages of three phase converter over single phase converter?**

   - Three phase power distribution requires lesser amount of copper or aluminium for transferring the same amount of power as compared to single phase power
   - The size of a three phase motor is smaller than that of a single phase motor of the same rating
   - Three phase motors are self-starting as they can produce a rotating magnetic field.

- The single phase motor requires a special starting winding as it produces only a pulsating magnetic field.
- The ripple factor of rectified dc produced from three phase power is less than the dc produced from single phase supply.
- Three phase motors have better power factor regulation.
- Three phase generators are smaller in size than single phase generators as winding phase can be more efficiently used.

9. What is meant by forced commutation?

In this commutation, the current flowing throughthe thyristor is forced to become zero by external circuitry

10. What is meant by natural commutation?

Here the current flowing through the thyristor goes through a natural zero and enable the thyristor to turn off.

11. What is meant by natural and forced commutation? Natural commutation

Here the current flowing through the thyristor goes through a natural zero and enable the thyristor to turn off.

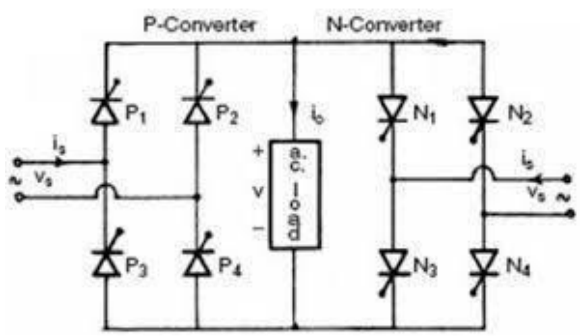
Forced commutation:

In this commutation, the current flowing through the thyristor is forced to become zero by external circuitry.

12. Write the expression for output DC voltage in a single phase fully controlled half converter.

$$V_{d\alpha} = \frac{1}{\pi}\int_{\alpha}^{\pi} V_{\max} \sin \omega t d(\omega t) = \frac{V_{\max}}{\pi}(1 + \cos \alpha)$$

13. Draw the circuit diagram of single phase dual converter.



14. Give any two differences between single phase full converter and semi converter.

Fully controlled rectifier uses only SCR's Negative output voltages are obtained two quadrant control wide range control costly semi converter uses diodes and SCR's only positive output voltages are obtained one quadrant control only positive half cycles are controlled.

15. What is meant by phase control?

In this method, thyristor switches connect the load to the ac source for a portion of each half cycle of input voltage.

16. Compare half controlled rectifier and full controlled rectifier.

S.no	Half controlled	Full controlled
1	Uses un controlled element (diod diodes	Uses controlled element switches
2	Output voltage is constant	adjustable

17. What is dual converter?

The fully controlled converter can produce a reversible direct output voltage with output current in one direction, and in terms of a conventional voltage/ current is said to be capable of operation in two quadrants, the first and fourth

18. Write the expression for output dc voltage in a single phase fully controlled full converter for RL load

$$V_{d\alpha} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_{\max} \sin \omega t d(\omega t) = \frac{2V_{\max}}{\pi}\cos\alpha$$

19. Define Total Harmonic Distortion (THD).

The total harmonic distortion, or THD, of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency.

20. Define ripple factor

Ripple factor (γ) may be defined as the ratio of the root mean square (rms) value of the ripple voltage to the absolute value of the dc component of the output voltage, usually expressed as a percentage. However, ripple voltage is also commonly expressed as the peak-to-peak value.

21. What is meant by phase control? (Nov/Dec- 2014)

22. Why power factor of semiconverter is better than full converter (Nov/Dec- 2014, Nov/Dec- 2014)

23. Compare half controlled rectifier and full controlled rectifier (May/ June- 2014)
24. What is dual converter? Mention its functional mode of operation. (May/ June- 2014)
25. Mention disadvantages of dual converter with circulating current mode of operation. (Nov/Dec- 2013)
26. What is the inversion mode of rectifiers? (Nov/Dec- 2012)
27. Give any two difference between single phase full converter and semi converter. (Nov/Dec- 2011)
28. What is meant by line commutated inverter? (Nov/Dec- 2011)
29. Draw the circuit diagram of single phase dual converter. (Nov/Dec- 2010)
30. Define the term voltage ripple factor and current ripple factor. (Nov/Dec- 2010)
31. Mention some of the applications of converter. (Nov/Dec- 2015)
32. What are the performance parameters of phase controlled converters?. (Apr/May- 2015)
33. What is the effect of load inductance in three phase fully controlled converters? (Apr/May- 2015)
34. What is the effect of source impedance on the performance of converter? (Apr/May- 2015)
35. Draw circuit and waveform of ideal dual converter. (Apr/May- 2015)

PART-B

1. Explain about Rectifiers and specify their applications. (16) (www.university questions.in)

2. Describe using a power circuit and relevant waveforms the working of a single phase full converter with RL load. (16) (www.university questions.in), Describe the working of a single phase full converter in the rectifier mode with RL load. Discuss how one pair of SCRs is commutated by an incoming pair of SCRs. Illustrate your answer with the waveforms of source voltage, load voltage and source current. Assume continuous conduction. Also derive the expressions for average and RMS output voltage. (Nov/Dec-2013)

3. Write neat sketch and output voltage waveforms explain the working of single phase bridge rectifier. (16) (www.university questions.in)

4. Discuss the operation of single phase half wave rectifier with RLE load .Also derive its average output voltage equations. (16) (www.university questions.in)

5. Describe the working of single phase fully controlled bridge converter in the rectifying mode. And derive the expressions for average output voltage and RMS output voltage. (16) (www.university questions.in), With a neat circuit diagram and waveforms explain the principle of operation of two quadrant two pulse converter in the rectifying and inverting mode of operation.(10) (Apr/May- 2015), Explain with circuit and output waveform working of single phase two pulse fully controlled converter with RL load. (16) (Apr/May- 2015)

6. Describe the working of single phase and three phase Dual converter. (16) (www.university questions.in, (www.Vidyarthiplus.com), Describe briefly the working of Dual converter with a neat circuit diagram.(8) (Nov/Dec-2013)

7. Explain the operating principle of single phase dual converter. ((Nov/Dec-2015)
Explain the two functional modes of dual converter with necessary diagrams. (16) (May/ June- 2014), Explain the operation of dual converter with complete circuit diagram and waveforms. (Nov/Dec- 2014), Explain the operation of single phase dual converter with circulating and non-circulating conduction current type. (www.Vidyarthiplus.com), With neat sketch describe voltage and current waveforms of a circulating current type dual converter. (16) (Apr/May- 2015)

8. Derive the expressions for average output voltage and RMS output voltage of single phase semi converter. (16) (www.university questions.in)

9. Describe the working of 3 phase fully controlled bridge converter in the Rectifying mode. And derive the expressions for average output voltage and RMS output voltage. (16) (www.university questions.in), Draw the circuit diagram and explain the operation of three phase fully controlled bridge rectifier feeding R load and derive the expression for average output voltage.(8) (Apr/May- 2015)

10. Derive the expressions for average output voltage and RMS output voltage of three phase semi converter. (16) (www.university questions.in), Explain the operation of three phase semiconverter with neat wave forms ((Nov/Dec-2012), Explain the operation of three phase semi converter with RLE load. Sketch associated waveforms. (www.Vidyarthiplus.com)

11. Explain the operation of three phase full converter and also derive the expression for its average output voltage. (16) (www.university questions.in)

12. Explain the operation of 3 phase 3 pulse converter with R load. Derive for average output voltage. (16) (Nov/Dec-2015)

13. A single phase full converter is connected with R load. The source voltage is 230V, 50 Hz. The average load current is 10 Amps. For R=20 ohms. Find the firing angle. (6) (Nov/Dec-2015, Nov/Dec-2011)

14. Describe the operation of a single phase two pulse bridge converter using 4 SCR'S with relevant waveforms. (10) (Nov/Dec-2010)

15. Discuss the working of above converter in the converter mode with RLE load. (6) (Nov/Dec-2010)

16. A single phase semi converter is operated from 120 V 50 Hz ac supply. The load current with an average value I_{dc} is continuous and ripple free firing angle
$\alpha = \pi/6$. Determine.
(1) Displacement factor
(2) Harmonic factor of input current
(3) Input power factor. (10) (Nov/Dec-2010)

17. Explain the working of three phase full converter with R load for the firing angles of 60º, 90º and 150º. (16) ((Nov/Dec-20101)

18. Explain the operation of single phase full bridge converter with RL load for continuous and discontinuous load currents. (10) (Nov/Dec-2011)

19. Explain the working of a single phase full converter in the rectifier mode with the RL load. Discuss how one pair of SCRs is commutated by an incoming pair of SCRs. Illustrate your answer with the waveforms of source voltage, load voltage and source current. Assume continuous conduction. Also derive the expressions for average and rms output voltage. (16) (www.Vidyarthiplus.com)

20. Discuss the effect of source inductance on the performance of single phase full converter. (16) (May/ June- 2014), Explain the effect of source inductance in controlled rectifiers. (Apr/May- 2015)

21. Explain the effect of source inductance in the operation of three phase fully controlled converter indicating clearly the conduction during one cycle with relevant waveform. (www.Vidyarthiplus.com)

22. A 230 V, 50 Hz, supply is connected to load resistance of 12 ohms through half wave controlled rectifier. If the firing angle is 60º, determine
i. average output voltage (4)
ii. rms output voltage (4)
iii. ratio of rectification (4) and
iv. Transformer utilization factor (4). (Nov/ Dec- 2012, Nov/ Dec- 2014)

23. Explain the operation of three phase half wave controlled converter with inductive load. Sketch the associated waveforms. (16) (www.Vidyarthiplus.com)

24. Define displacement factor, power factor, harmonic factor and current dissertation factor. (8) (Apr/May- 2015)