Phase Controlled Rectifiers

5

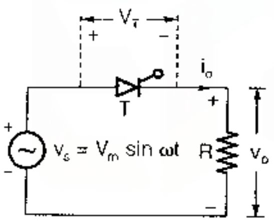
Uncontrolled rectifier use diode and it convert fixed ac to fixed dc but controlled rectifier use SCR and it convert fixed ac to variable dc. By changing firing angle α, output also changes.

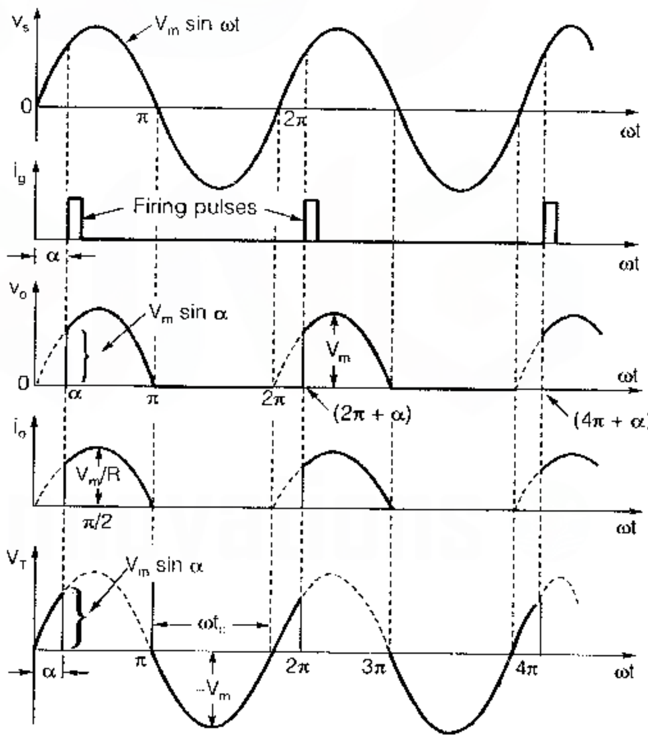
In all phase controlled rectifier natural commutation take place.

Single Phase Half Wave Rectifier

It is also called as one pulse converter because for one cycle of supply voltage we get one pulse at output voltage.

(a) With R load:





From: 0 to α T → OFF

α to π T → ON

- Average load voltage

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

where, α = Firing angle

V_m = Maximum value of sinusoidal source voltage

- RMS value of load voltage

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

- RMS current

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

- Power dissipated in R load

$$P = V_{or}\, I_{or} = I_{or}^2 R = \frac{V_{or}^2}{R}$$

- Input power factor

$$\text{p.f.} = \frac{\text{Power delivered to load}}{\text{Input VA}}$$

$$\text{p.f.} = \frac{V_{or}}{V_s}$$

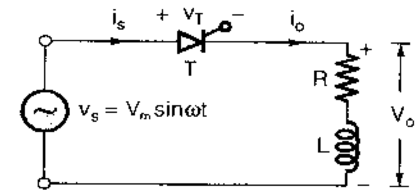
- Circuit turn-off time

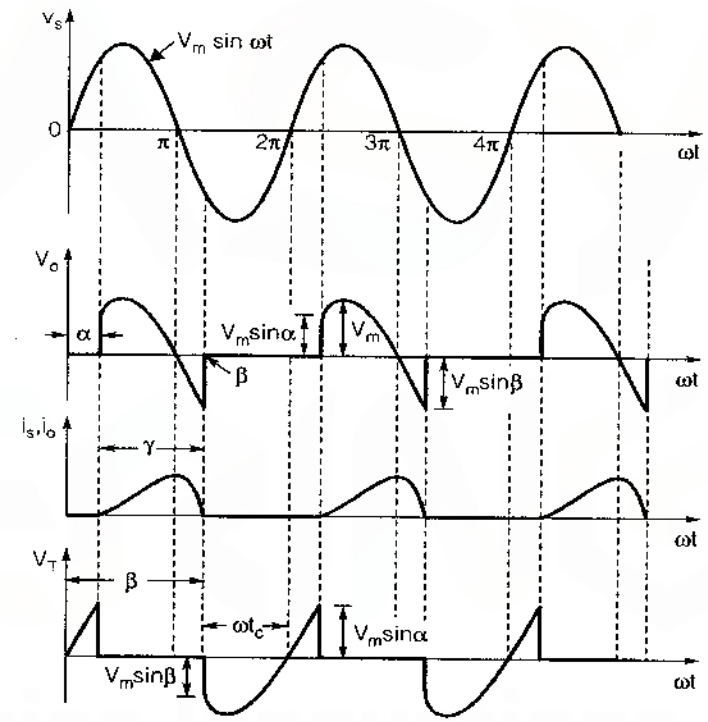
$$t_c = \frac{\pi}{\omega}\ \text{sec}$$

Remember:

- Circuit turn-off time must be more than the SCR turn-off time for satisfactory commutation.
- The source current introduces DC component in the supply transformer and saturate the transformer. This is disadvantage of 1φ-half wave rectifier.

(b) RL Load:





- Average load voltage

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

- Rms load voltage

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

where, β = Extinction angle

- Conduction angle

$$\gamma = \beta - \alpha$$

- Circuit turn-off time

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

Remember:

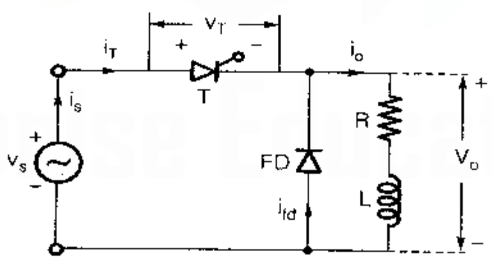
- From $\omega t = \pi$ to β, thyristor is forced to conduct in negative supply by the stored energy in the inductor, here energy is fed back to source.
- At $\omega t = \beta$, inductor fed back its whole energy to source.

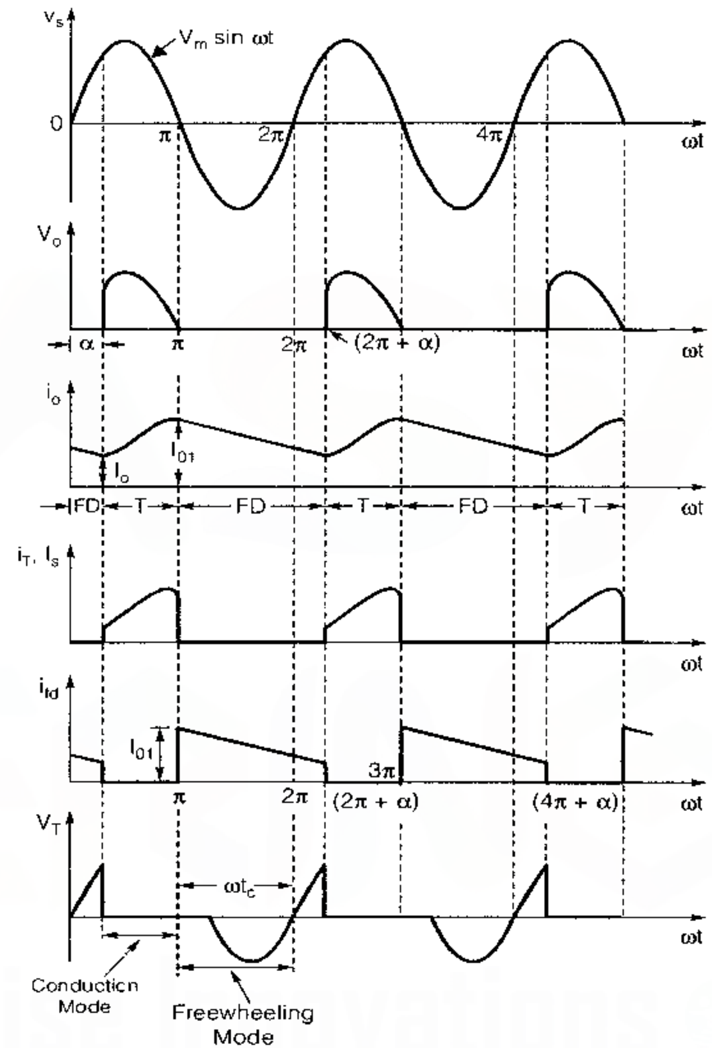
(c) RL Load with Freewheeling Diode:

The performance of converter is improve by connecting a free wheeling diode across the load.

Advantage of freewheeling diode:

- Power factor improve.
- Negative spikes in output voltage are removed.
- The overall current waveform is improved.
- Overall converter efficiency improves.





- The average output voltage

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

- The average output current

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

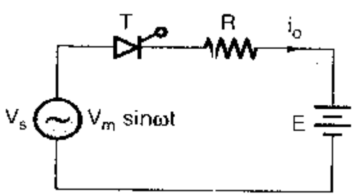
- The RMS output voltage

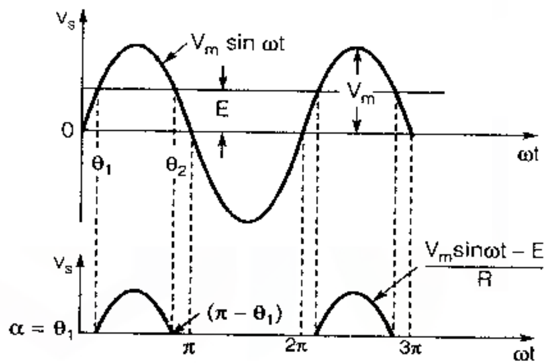
$$V_{or} = \frac{V_m}{2\sqrt{\pi}}\left[(\pi-\alpha)+\frac{1}{2}\sin 2\alpha\right]^{1/2}$$

- Circuit turn-off time

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

(d) RE Load or Charging Battery





- Charging current

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

- Minimum value of firing angle

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

- Maximum value of firing angle

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

- Range of firing angle

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

- Conduction angle of thyristor

$$\gamma = \theta_2 - \alpha$$

- Circuit turn-off time of thyristor

$$t_c = \frac{2\pi+\theta_1-\theta_2}{\omega} = \frac{\pi+2\theta_1}{\omega}$$

- Average output voltage:

$$V_o = \frac{1}{2\pi}[V_m(\cos\alpha-\cos\theta_2)+E(2\pi+\alpha-\theta_2)]$$

- Average charging current of battery

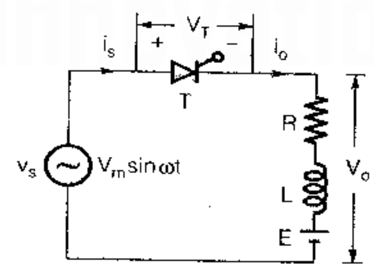
$$I_o = \frac{1}{2\pi R}[V_m(\cos\alpha-\cos\theta_2)-E(\theta_2-\alpha)]$$

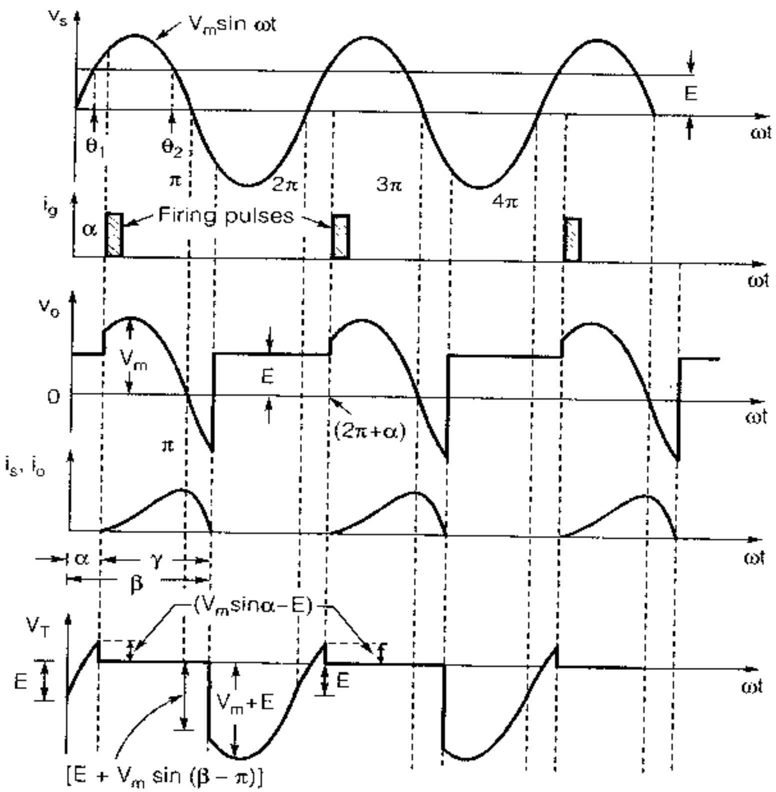
- Power supplied by battery = EI_o

Remember:

When continuous gate signal is given to SCR, it behaves like diode.

(e) RLE Load or DC Machine Load





- Minimum value of firing angle

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

- Maximum value of firing angle, $\theta_2 = (\pi - \theta_1)$
- Average load current

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

- Average load voltage

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

or

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

- Maximum reverse voltage to thyristor = $(V_m + E)$
- Circuit turn-off time

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

- RMS load current

$$I_{or} = \left[\frac{1}{2\pi R^2}\left\{(E^2 + V_s^2)(\pi - 2\alpha) + V_s^2 \sin 2\alpha - 4V_m E\cos\alpha\right\}\right]^{1/2}$$

- Power delivered to load

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

- Power factor

$$PF = \frac{I_{or}^2 R + I_o E}{V_s I_{or}}$$

Remember:

High value of inductance results in continuous conduction.

Single Phase Full-wave Converter

Full-wave rectifier is 2 pulse rectifier, for one cycle of voltage wave we get 2 pulse of current wave.

It has two configuration:

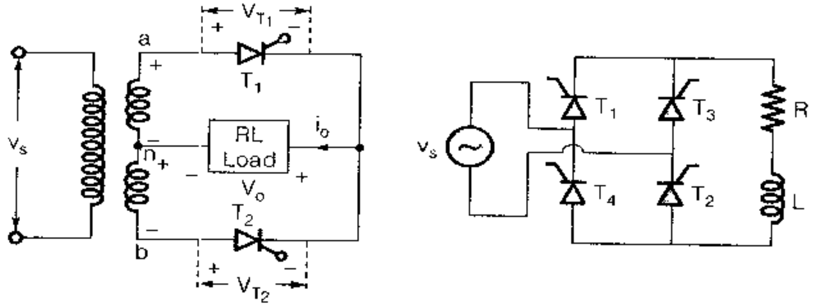
(i) Mid point converter

(ii) Bridge converter

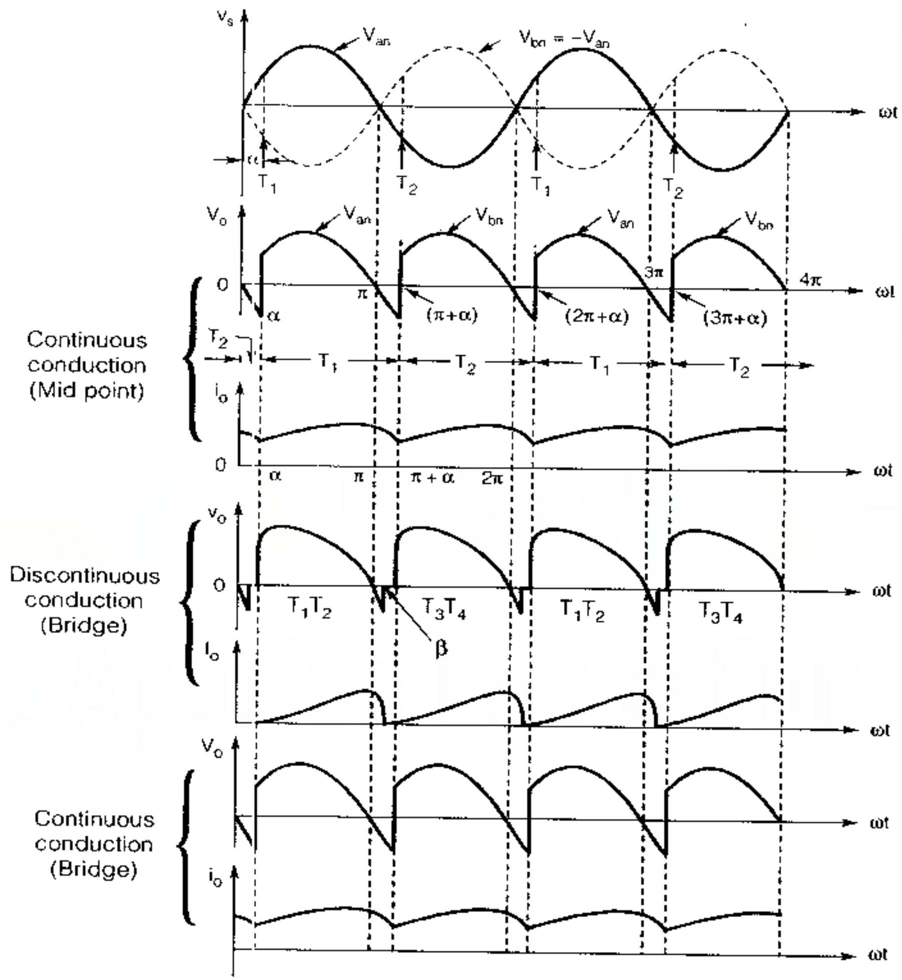
Remember:

- SCRs are subjected to a peak inverse voltage of $2V_m$ in mid point converter and V_m in bridge converter.
- Mid point configuration is used in case, the terminals on D.C. side have to be grounded.
- Bridge configuration is preferred over midpoint configuration.

(a) RL Load



(Mid point connection) (Bridge connection)



(i) Discontinuous conduction:

- Average output voltage

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

- RMS output voltage

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

- Power factor

$$\cos\phi = \frac{V_{or}}{V_{sr}}$$

- Circuit turn-off time (t_c)

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

(ii) Continuous conduction:

- Average output voltage

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

- RMS output voltage

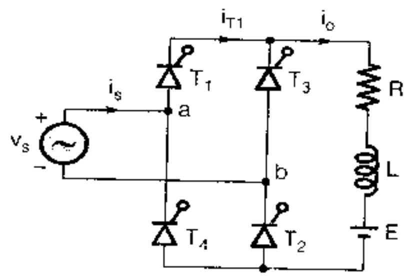
$$V_{or} = \frac{V_m}{\sqrt{2}}$$

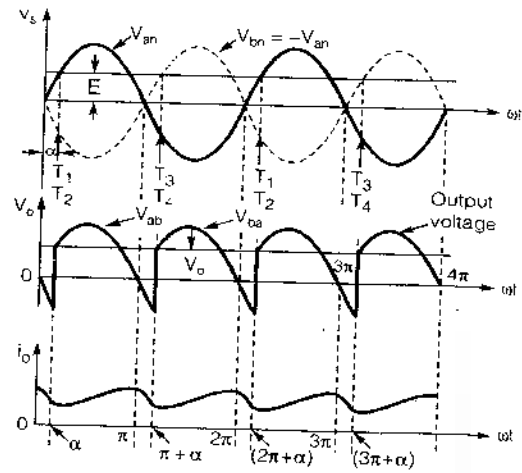
- Circuit turn-off time

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

(b) RLE Load

(i) For continuous conduction





(Continuous conduction)

- Average output voltage

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

- RMS value of output voltage

$$V_{or} = V_s$$

- Circuit turn-off time

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

(ii) For discontinuous conduction

- Average output voltage

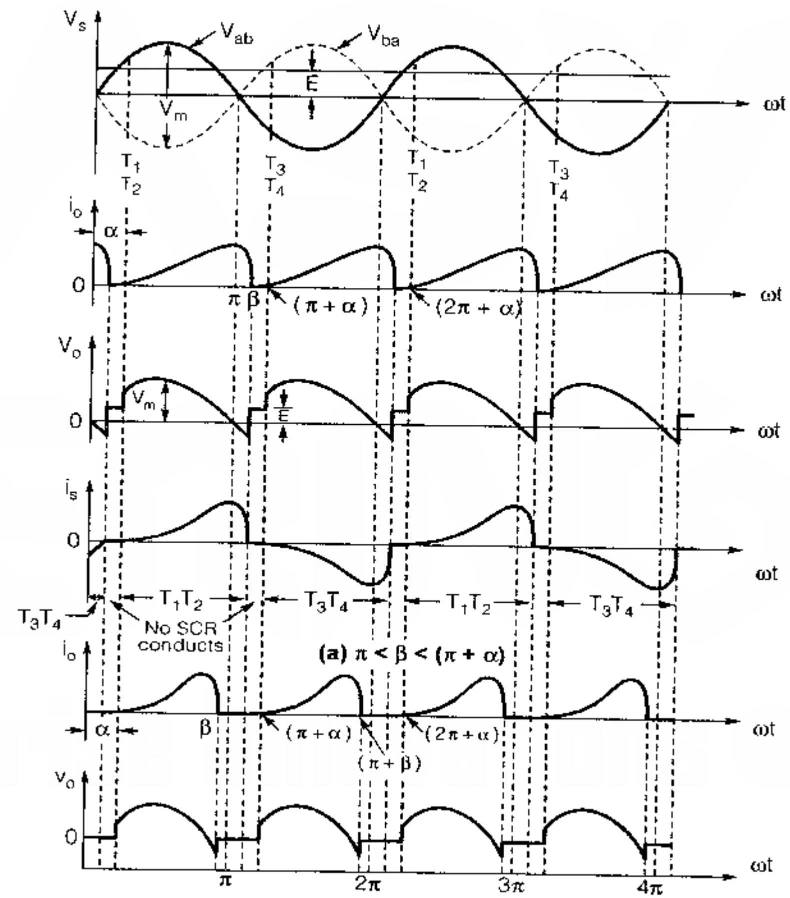
$$V_o = \frac{1}{\pi}[V_m(\cos\alpha - \cos\beta) + E(\pi + \alpha - \beta)]$$

- Average output current

$$I_o = \frac{V_o - E}{R}$$

- Circuit turn-off time

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

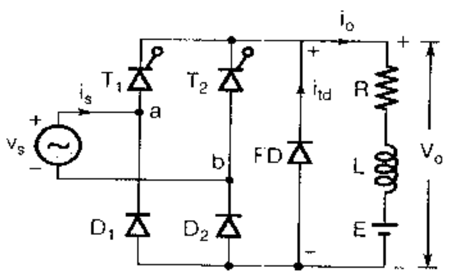


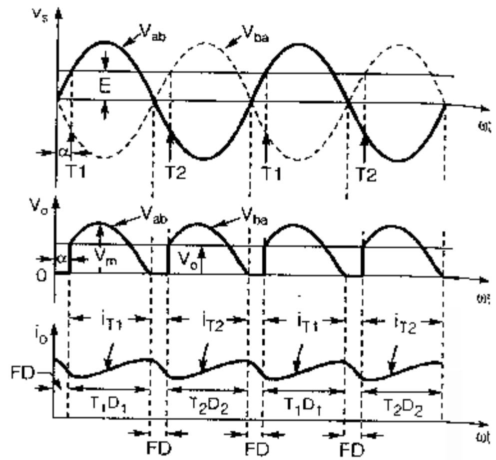
(b) $\beta < \pi$

(Discontinuous Conduction)

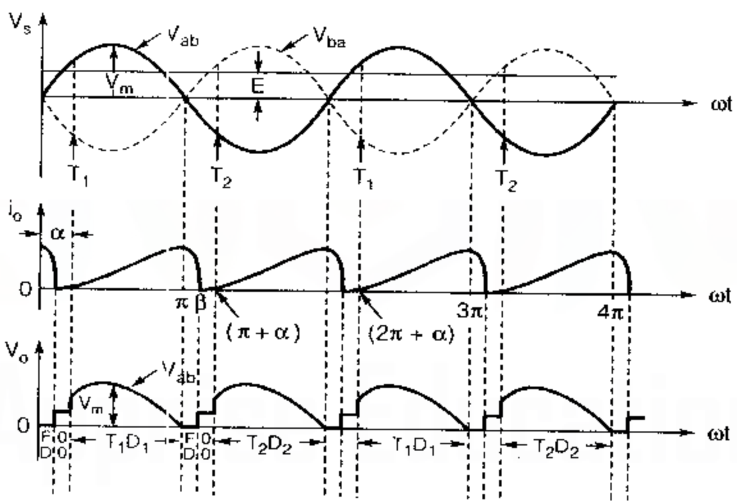
Single Phase Semiconverter

Semiconductor also known as half-controlled rectifier or 2 pulse converter.



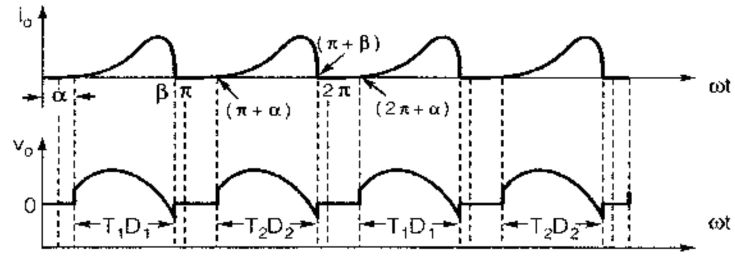


(Continuous conduction)



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

Discontinuous conduction



(b) $\beta < \pi$ and $V_m \sin\beta < E$ (Discontinuous conduction)

(i) Continuous conduction:

- Average output voltage

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

- RMS output voltage

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

- Circuit turn-off time

$$t_c = \frac{\pi - \alpha}{\omega}$$ (without freewheeling diode)

$$t_c = \frac{\pi}{\omega}$$ (with free wheeling diode)

(ii) Discontinuous conduction

- Average output voltage

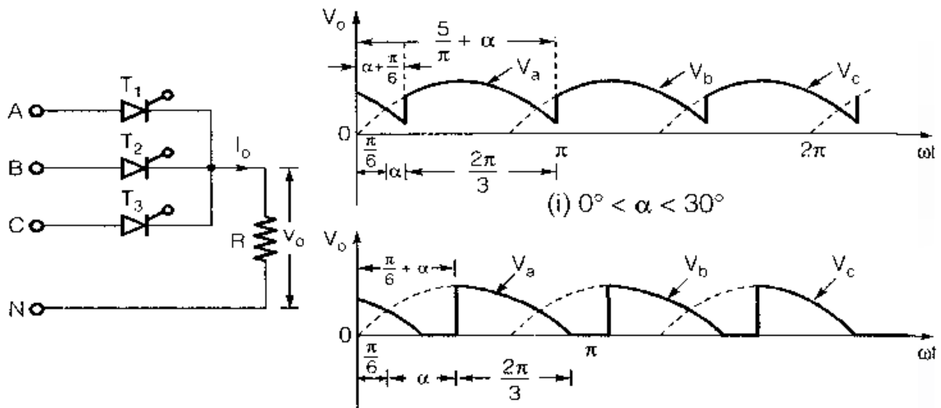
$$V_o = \frac{1}{\pi}[V_m(1 + \cos\alpha) + E(\pi + \alpha - \beta)]$$

Note:

- For $\beta < \pi$, freewheeling diode does not conduct.
- Freewheeling diode prevents the occurance of dead short circuit of source.
- Single phase full converter is two quadrant converter and single phase semiconverter is one quadrant converter.

3ϕ Half-Wave Controlled Converter

- It is a 3-pulse converter



(i) 0° < α < 30°

(ii) 30° < α < 150°

when, $\boxed{\alpha \le \frac{\pi}{6}}$ continuous conduction

$\boxed{\alpha > \frac{\pi}{6}}$ discontinuous conduction

(a) R Load

Case-1: when α < 30°

❑ Average output voltage

$$\boxed{V_0 = \frac{3\sqrt{3}}{2\pi} V_{mp} \cos\alpha = \frac{3V_{ml}}{2\pi} \cos\alpha}$$

❑ RMS value of output voltage

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

Both formula valid for

(i) R load when α < 30°.

(ii) RL load for any value of α.

where V_{mp} = Maximum value of phase voltage

$V_{ml} = \sqrt{3}\, V_{mp}$ = Maximum value of line voltage

Case-2: when α > 30°

❑ Average output voltage

$$\boxed{V_0 = \frac{3V_{mp}}{2\pi}\left[1 + \cos\left(\alpha + \frac{\pi}{6}\right)\right]}$$

❑ RMS value of output voltage

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

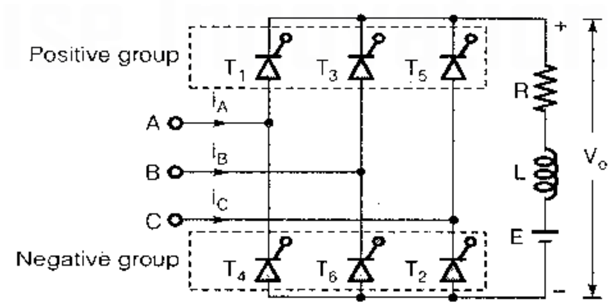
Both formula valid for

(i) R load when α > 30°.

(ii) RL load with freewheeling diode when α > π/6.

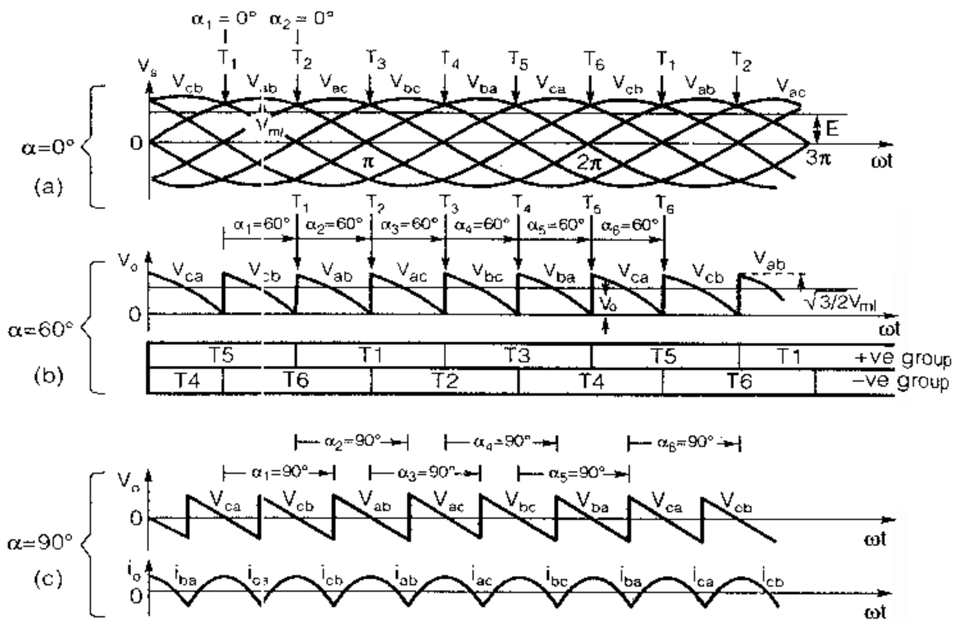
(iii) RLE load with F.D. when α > π/6.

3ϕ-Full converter



6 Pulse Converter

Positive group of SCR fired at an interval of 120°, similarly negative group of SCR are fired with an interval of 120° amongst them. But SCR from both the group are fired at an interval of 60°. At any time two SCRs, one from positive group and other from negative group must conduct together.



For R Load

Case 1: when α ≤ 60°

- Average output voltage

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

- RMS output voltage

$$V_{or} = \sqrt{\frac{3}{2\pi}}\,V_{ml}\left[\frac{\pi}{3} + \frac{\sqrt{3}}{2}\cos 2\alpha\right]^{1/2}$$

Above formulae valid for

(i) R load when $\alpha \le 60°$.

(ii) RL and RLE load any value of α.

Case 2: when α > 60°

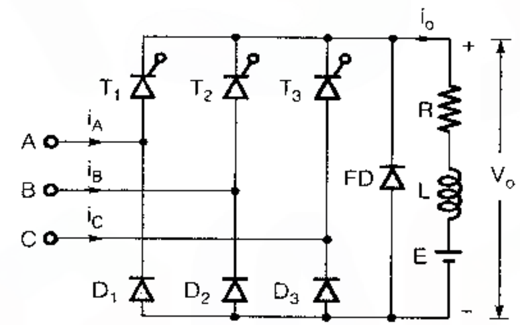
Average output voltage

$$V_o = \frac{3V_{ml}}{\pi}\left[1 + \cos\left(\alpha + \frac{\pi}{3}\right)\right]$$

Note:

Formula valid for R load $\alpha > 60°$ and for RL, RLE load with FD.

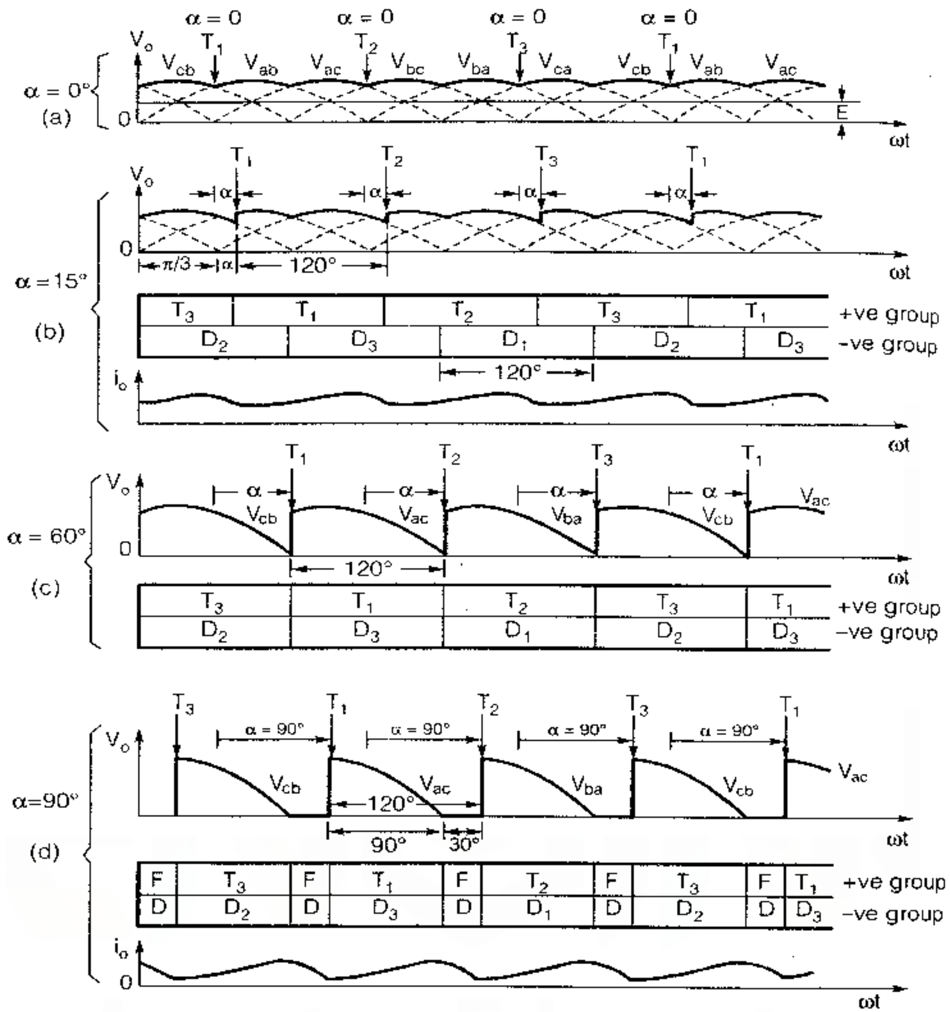
3ϕ Half Controlled Rectifier (or) 3ϕ Semiconverter



For

$\alpha < 60° = 6$ pulse

$\alpha \ge 60° = 3$ pulse



Case-1: when α < 60°

- ❑ Average output voltage

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

- ❑ RMS value of output voltage

$$V_{or} = \frac{V_{ml}}{2}\sqrt{\frac{3}{\pi}}\left[\frac{2\pi}{3}+\frac{\sqrt{3}}{2}(1+\cos 2\alpha)\right]^{1/2}$$

Case-2: when α ≥ 60°

- ❑ Average output voltage

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

- ❑ RMS value of output voltage

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

Remember:

- For α ≤ 60°, freewheeling diode does not conduct.
- 3ϕ-semiconverter is only one quadrant converter.
- In 3ϕ-semiconverter, breaking mode is not possible.

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