

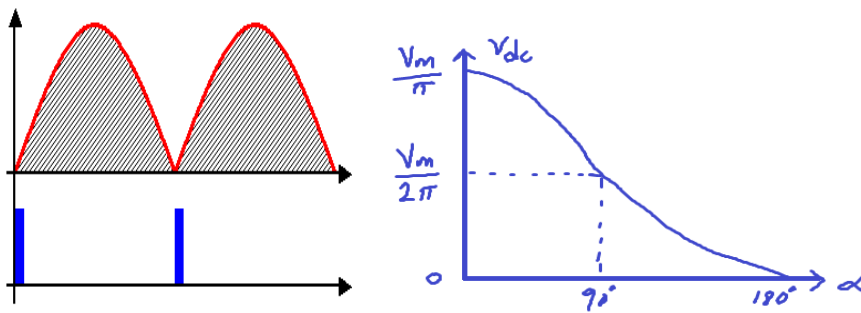
UNIVERSITY OF Hilla		LECTURE : 6
ENGINEERING FACULTY		SUBJECT : power Electronics
Medical Device Technology Engineering		LECTURE'S TITLE: 1 PH(H&FW)CR
Asst. Lec. Morteza Abbas Imran		DATE : 2024/2025

AC-DC Conversion (Single Phase Half Controlled Rectification)

Diode rectifiers produce a fixed output voltage. In order to control the output voltage of a rectifier, **thyristors** must be used instead of diodes. The output voltages of these rectifiers are varied by varying the delay or firing angle of the thyristor.

Thyristors are turned on by the application of a short pulse to the gate and they are turned off by the process of natural or line commutation.

The triggering angle (α) of the devices is controlled by control circuit. The input to the controlled rectifier is normally AC mains. The output of the controlled rectifier is adjustable DC voltage.



There are two types of phase control converters:

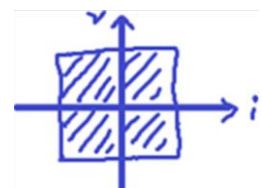
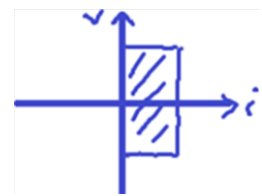
- 1- Single phase converters .
- 2- Three-phase converters

Each type of converter can be divided into three categories:

–**Semiconverter** : one quadrant converter, having one polarity of voltage and current .

–**Full converter**: two quadrant device whose output voltage polarity can be either positive or negative but whose output current has one polarity.

–**Dual converter**: four quadrant device whose output voltage and current can be of either positive or negative polarity.



1- single phase half wave controlled rectifier a-with resistive load (R)

For the positive half cycle of V_s ,

T_1 is forward biased and when

the thyristor is fired at $\omega t = \alpha$ it conducts and input voltage appears across the load.

When the input voltage goes negative at $\omega t = \pi$ thyristor is reverse biased and it is turned off.

The firing angle (or delay angle) is defined as the time after the input voltage starts to go positive until the thyristor is fired at $\omega t = \alpha$.

For this converter: $0 \leq \alpha \leq 180^\circ$

$$V_{dc} = \frac{1}{2\pi} \int_{\alpha}^{\pi} V_m \sin \omega t d\omega t = \frac{V_m}{2\pi} [-\cos \omega t]_{\alpha}^{\pi}$$

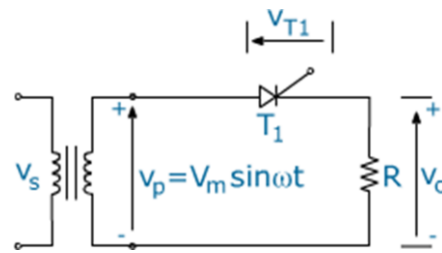
$$= \frac{V_m}{2\pi} (1 + \cos \alpha)$$

$$I_{dc} = \frac{V_{dc}}{R} = \frac{V_m}{2\pi R} (1 + \cos \alpha)$$

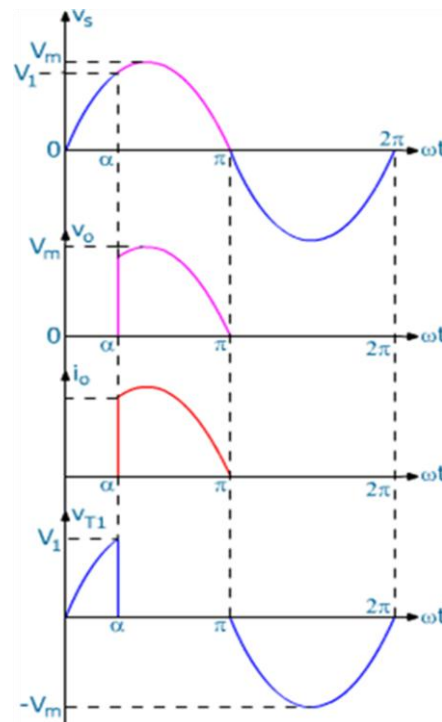
$$V_{rms} = \sqrt{\frac{1}{2\pi} \int_{\alpha}^{\pi} V_m^2 \sin^2 \omega t d\omega t} = \sqrt{\frac{V_m^2}{4\pi} \int_{\alpha}^{\pi} (1 - \cos 2\omega t) d\omega t}$$

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

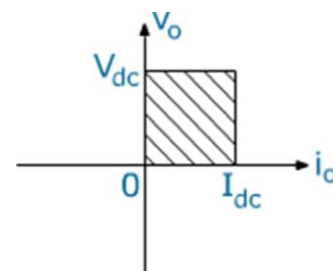
$$I_{rms} = \frac{V_{rms}}{R}$$



circuit



waveform



quadrants

b- with inductive load (RL)

At $\omega t = \alpha$, thyristor is turned on by gating signal. The load voltage v_o at once becomes equal to source voltage v_s . But the inductance L forces the load, or output, current i_o to rise gradually. After some time, i_o reaches maximum value and then begins to decrease.

At $\omega t = \pi$, v_o is zero but i_o is not zero because of the load inductance L .

After $\omega t = \pi$, SCR is subjected to reverse anode voltage but it will not be turned off as load current i_o is not less than the holding current.

At some angle $\beta > \pi$, i_o reduces to zero and SCR is turned off as it is already reverse biased.

After $\omega t = \beta$, $v_o = 0$ and $i_o = 0$. At $\omega t = 2\pi + \alpha$,

SCR is triggered again, v_o is applied to the load and load current develops as before. The voltage equation for the circuit is

$$V_m \sin \theta = Ri_o + L \frac{di_o}{dt}$$

The load current i_o consists of two components:

1- The steady state component i_s

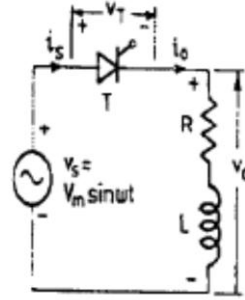
$$i_s = \frac{V_m}{\sqrt{R^2 + (\omega L)^2}} \sin(\omega t - \phi)$$

Where $\phi = \tan^{-1} \frac{\omega L}{R}$. Here ϕ is the angle by which rms current I_s and V_s .

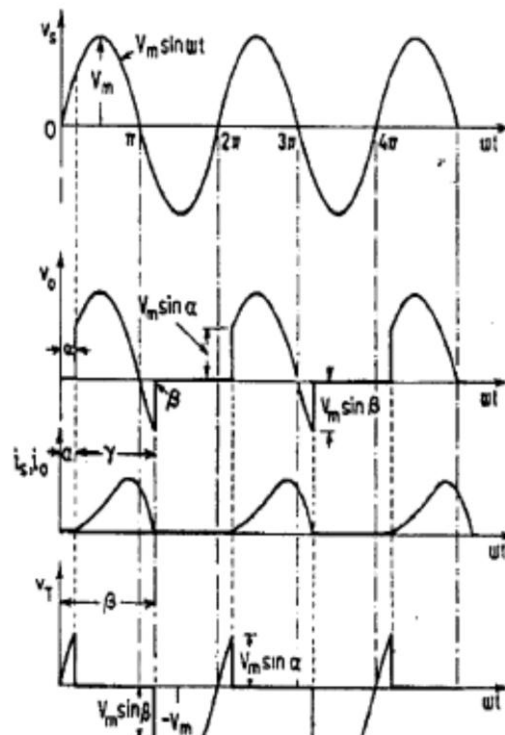
2- The transient component i_t

$$Ri_t + L \frac{di_t}{dt} = 0$$

Its solution gives, $i_t = Ae^{-(R/L)t}$



Circuit



$$i_o = i_s + i_t = \frac{V_m}{Z} \sin(\omega t - \phi) + Ae^{-(R/L)t} \dots\dots\dots(1)$$

$$\text{Where } Z = \sqrt{R^2 + (\omega L)^2}$$

Constant A can be obtained from the boundary condition at $\omega t = \alpha$.

At this time $t = \frac{\alpha}{\omega}$, $i_o = 0$. Thus,

$$0 = \frac{V_m}{Z} \sin(\alpha - \phi) + Ae^{-R\alpha/L\omega}$$

$$A = -\frac{V_m}{Z} \sin(\alpha - \phi)e^{-R\alpha/\omega L}$$

Substitution of A in eq.(1) gives

$$i_o = \frac{V_m}{Z} \sin(\omega t - \phi) - \frac{V_m}{Z} \sin(\alpha - \phi) \exp.\left\{-\frac{R}{\omega L}(\omega t - \alpha)\right\}$$

For $\alpha < \theta < \beta$

$$V_{mean} = \frac{1}{2\pi} \int_{\alpha}^{\beta} V_m \sin \theta d\theta = \frac{V_m}{2\pi} (\cos \alpha - \cos \beta)$$

$$I_{mean} = \frac{V_m}{2\pi R} (\cos \alpha - \cos \beta)$$

$$V_{rms} = \left[\frac{1}{2\pi} \int_{\alpha}^{\beta} (V_m \sin \theta)^2 d\theta \right]^{1/2}$$

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

c-with freewheeling diode

$$V_{mean} = \frac{1}{2\pi} \int_{\alpha}^{\pi} V_m \sin \theta d\theta = \frac{V_m}{2\pi} (1 + \cos \alpha)$$

$$I_{mean} = \frac{V_{mean}}{R} = \frac{V_m}{2\pi R} (1 + \cos \alpha)$$

To remove the negative part from the load voltage wave form freewheeling diode is used in the circuit diagram.

Here, at zero crossing of v_s to negative half cycle ,

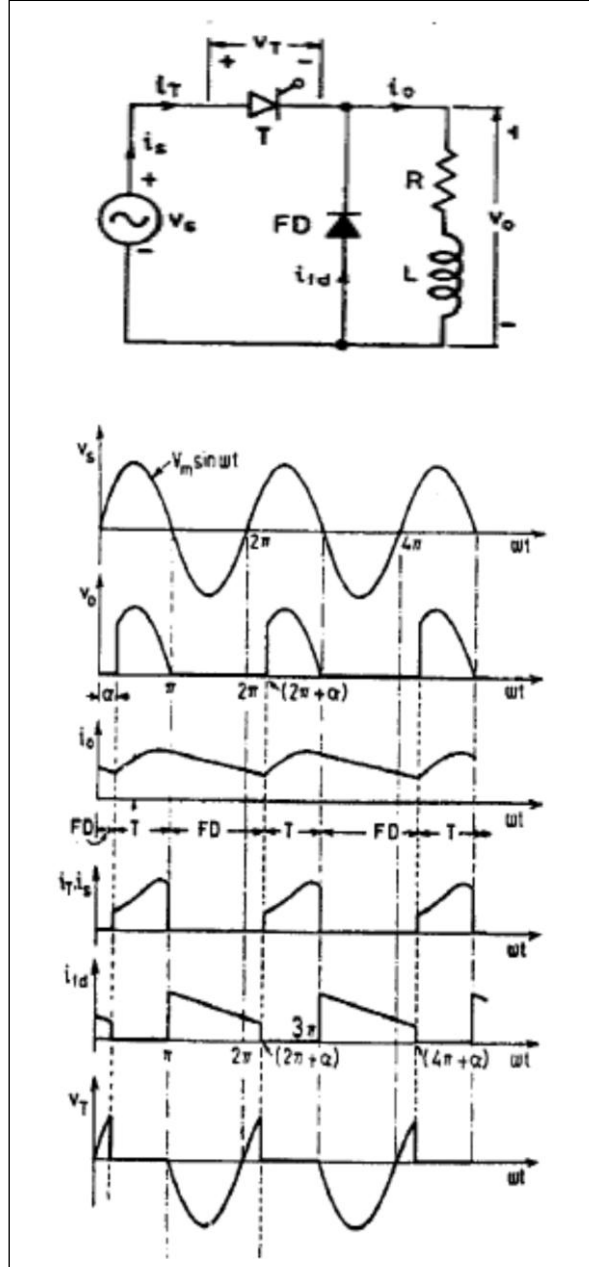
$L \frac{di}{dt}$ will cause f_d to forward biased.

The thyristor will be reverse biased by the supply voltage and turned off. Load current will flow through the loop (L- R - f_d).

As seen from the load current waveform that, during the positive half cycle of v_s , f_d is reversed biased and the load current equation is found from $V_o = Ri + L \frac{di}{dt}$.

During the negative half cycle of v_s , f_d will be forward biased due to $L \frac{di}{dt}$, hence i_o is found from the equation $0 = Ri + L \frac{di}{dt}$.

It can be seen from the load current waveform that increasing L to a very high value cause the load current waveform to approach a dc shape.



2-Single phase bridge controlled rectifier a-with resistive load

The dc output voltage of the converter with resistive load is given by

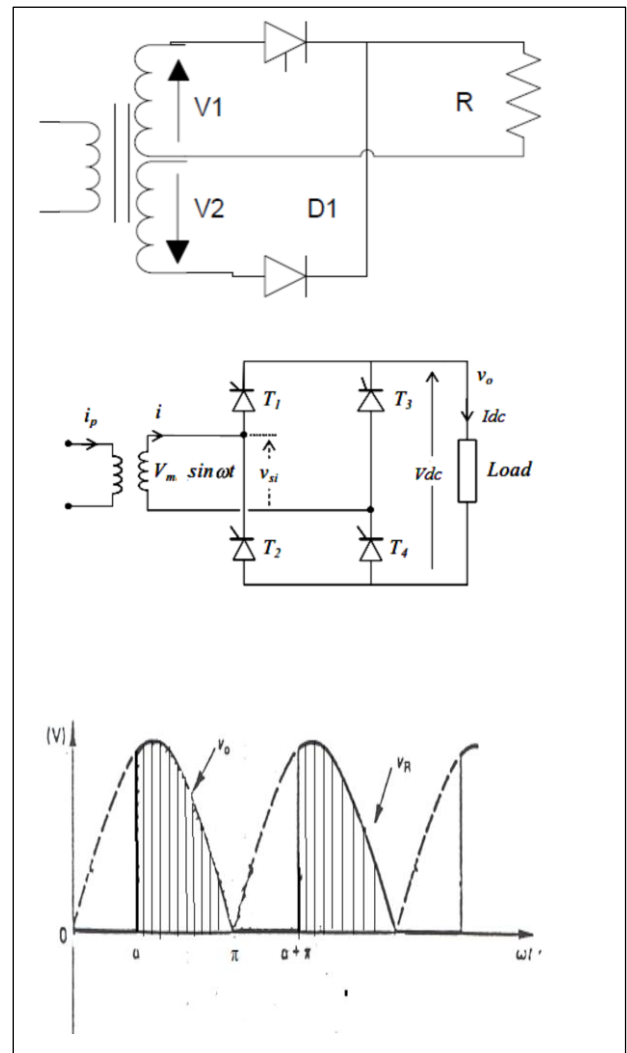
$$V_{dc} = \frac{1}{\pi} \int_{\alpha}^{\pi} V_m \sin \omega t \, d\omega t$$

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

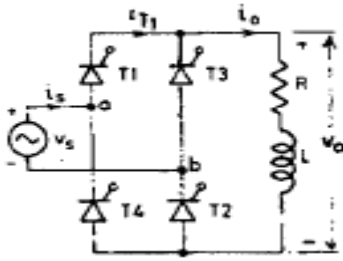
The RMS output voltage of the converter with resistive load is given by

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

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

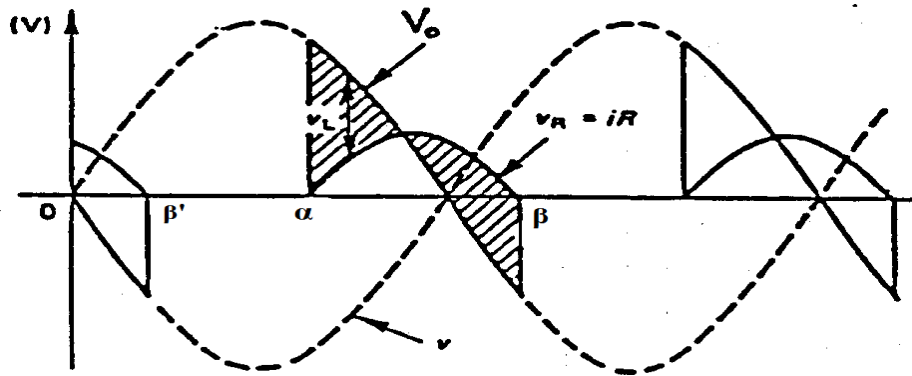


b- with R – L load



I- Case of R - L load with small L / R ratio : (Discontinuous load current).

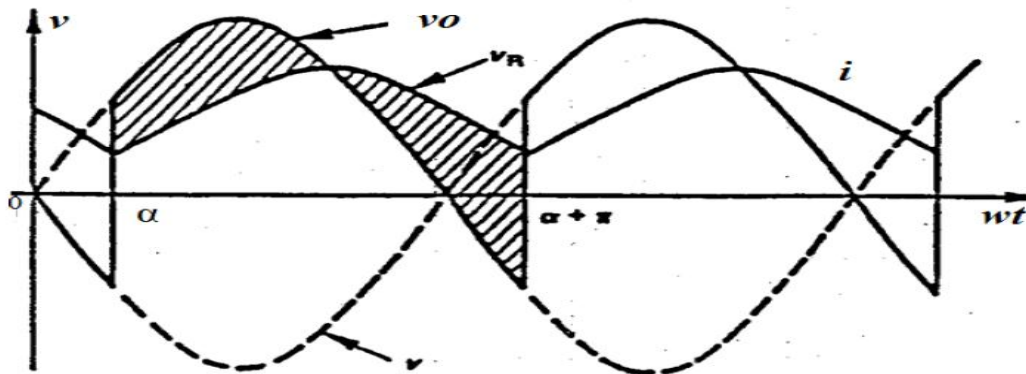
In this case the current will be discontinuous as shown in Fig



For $\alpha \leq \omega t \leq \beta$, the circuit equation is given by :-

II- Case of R - L load with large L / R ratio : (Continuous load current).

Under these conditions, a thyristor is still conducting when another is forward-biased and is turned on. The first device is instantaneously reverse- biased by the second device which has been turned on. The first device is commutated and load current is instantaneously transferred on the incoming device . In this case the current is continuous



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

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

Under all delay angle condition, the average current is given by:

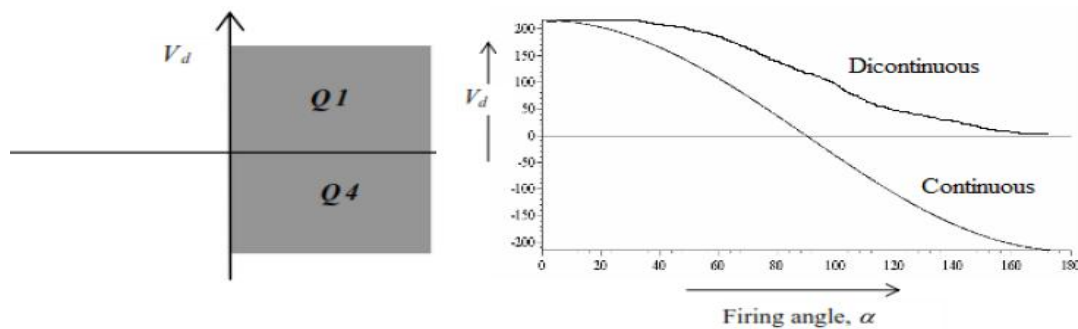
$$I_{dc} = \frac{V_{dc}}{R}$$

From the above voltage equation, if the firing angle is greater than 90° , the average voltage can be negative. Thus if the firing angle is suddenly increased to 170° , a large negative voltage will be applied to the load and the power is fed back to the supply. This process is known as 'INVERSION'.

The graph shown in Fig. 6.7 gives the relation between the firing angle and the output voltage in p.u. for the two modes of operation (continuous and discontinuous) for full-wave single-phase rectifier.

Rule – of- thumb: To find roughly the current is continuous or discontinuous:

If $\pi + \alpha < \beta$ The current is continuous
 If $\pi + \alpha > \beta$ The current is discontinuous



c- Single-phase Half – Controlled (Semiconverter) Rectifier

Fig. a shows a single-phase half-controlled (semiconverter) rectifier. This configuration consists of a combination of thyristors and diodes and used to eliminate any negative voltage occurrence at the load terminals. This is because the diode D_f is always activated (forward biased) whenever the load voltage tends to be negative. For one total period of operation of this circuit, the corresponding waveforms are shown in Fig. b

$$V_{mean} = \frac{1}{\pi} \int_{\alpha}^{\pi} V_m \sin \theta d\theta = \frac{V_m}{\pi} (1 + \cos \alpha)$$

$$I_{fd \text{ rms}} = \left[\frac{2}{2\pi} \int_0^{\alpha} (I_{mean})^2 d\theta \right]^{1/2} = I_{mean} \sqrt{\frac{\alpha}{\pi}}$$

Compared to the full controlled circuit, the half controlled circuit is cheaper, but ac supply current is more distorted due to its zero periods.

