Single Phase Controlled Rectifier

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Principle of Phase-Controlled Converter Operation (Single-Phase Half-Wave Controlled Rectifier) With Resistive Load

During positive half-cycle of input voltage, $T_1$ is *forward biased* but $V_0=0$ until the thyristor is triggered (or fired) i.e. $I_G=0$.

When $T_1$ is fired at $\omega t=\alpha$, $T_1$ conducts and $V_o=V_s$.

$\alpha$ is called the *delay* or *firing angle*.
When the input voltage starts to be negative at $\omega t = \pi$, $T_1$ is reverse biased and it is turned-off.

By varying the firing angle $\alpha$, the output voltage can be controlled.
This converter is not normally used in industrial applications because its output has high ripple content and low ripple frequency.

If $f_s$ is the frequency of supply voltage, the lowest frequency of output ripple voltage is $f_s$. 

$$V_{dc} = \frac{1}{2\pi} \int_{0}^{\pi} V_m \sin \omega t d(\omega t) = \frac{V_m}{2\pi} \left[ -\cos \omega t \right]_{0}^{\pi} = \frac{V_m}{2\pi} [1 + \cos \alpha]$$

$V_{dc}$ can be varied from $V_m/\pi (\alpha = 0)$ to $0 (\alpha = \pi)$ by varying $\alpha$ from 0 to $\pi$.

The average output voltage becomes maximum when $\alpha = 0$ and the maximum output voltage $V_{dm}$ is

$$V_{dm} = \frac{V_m}{\pi}$$
Normalizing output voltage with respect to \( V_{dm} \), the normalized output voltage is:

\[ V_n = \left( V_{dc} / V_{dm} \right) = 0.5(1 + \cos \alpha) \]

RMS Load Voltage

\[ V_{rms} = \sqrt{\frac{1}{2\pi} \int_0^{\pi} V_m^2 \sin^2(\omega t) d(\omega t)} = \frac{V_m}{2} \sqrt{\frac{1}{\pi} \left[ \pi - \alpha + \frac{\sin 2\alpha}{2} \right]} \]

When, \( \alpha = 0 \), \( V_{rms} = V_m / 2 \).

When, \( \alpha = \pi \), \( V_{rms} = 0 \).
\[ V_{rms} = \frac{V_m}{2} \sqrt{\int_{\alpha}^{\pi} \frac{1}{\pi} (1 - \cos 2wt) \, dwt} \]

\[ = \frac{V_m}{2} \sqrt{\frac{1}{\pi} (wt - \frac{1}{2} \sin 2wt) \, dwt} \]

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

\[ = \frac{V_m}{2} \sqrt{\frac{1}{\pi} (\pi - \alpha + \frac{1}{2} (\sin 2\alpha))} \]
When the supply voltage reverse, the thyristor is kept conducting due to the fact that current through the inductance cannot be reduced to zero.

During negative voltage half-cycle, current continuous to flow till the energy stored in the inductance is dissipated in the load resistor and a part of the energy is fed back to the source. The effect of inductive load is increased in the conduction period of SCR.
Average Load Voltage

\[ V_{dc} = \frac{V_m}{2\pi} \int_{\alpha}^{\beta} \sin \omega t \, d\omega t = \frac{V_m}{2\pi} (\cos \alpha - \cos \beta) \]

RMS Load Voltage

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

\( \beta \) : Extinction angle

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\[ V_{\text{rms}} = \sqrt{\frac{V^2 m}{2\pi} \int_{\alpha}^{\beta} \sin^2(wt) \ dwt} \]

\[ = \sqrt{\frac{V^2 m}{2\pi} \int_{\alpha}^{\beta} \frac{1}{2} (1 - \cos(2wt)) \ dwt} \]

\[ = \sqrt{\frac{V^2 m}{2\pi} \int_{\alpha}^{\beta} \frac{1}{2} (wt - \frac{1}{2} \sin(2wt)) \ dwt} \]

\[ = \sqrt{\frac{V^2 m}{2\pi} \int_{\alpha}^{\beta} \frac{1}{2} \left\{ (\beta - \alpha) - \frac{1}{2} \left[ \sin(2\beta) - \sin(2\alpha) \right] \right\} \ dwt} \]

\[ = \frac{V m}{2\sqrt{\pi}} \sqrt{(\beta - \alpha) - \frac{1}{2} \left[ \sin(2\beta) - \sin(2\alpha) \right]} \]
The average load current can be obtained as shown in equation (3.14) by dividing the average load voltage by the load resistance, since the average voltage across the inductor is zero.

\[ I_{dc} = \frac{V_m}{2\pi R} \ast (\cos \alpha - \cos \beta) \]

\[ L \frac{di}{dt} + R \ast i = V_m \sin (\omega t), \quad \alpha \leq \omega t \leq \beta \]

\[ \frac{di}{dt} + \frac{R}{L} \ast i = \frac{V_m}{L} \sin (\omega t), \quad 0 \leq \omega t \leq \beta \]

Then, \[ i(\omega t) = e^{-\frac{R}{L}t} \left[ \int e^{\frac{R}{L}t} \ast \frac{V_m}{L} \sin \omega t \, dt + A \right] \]
\[ i(\omega t) = \frac{V_m}{R^2 + \omega^2 L^2} (R \sin \omega t - \omega L \cos \omega t) + Ae^{-\frac{R}{L}t} \]

Assume \( Z \angle \phi = R + j \omega L \). Then, \( Z^2 = R^2 + \omega^2 L^2 \),

\[ R = Z \cos \phi, \quad \omega L = Z \sin \phi \quad \text{and} \quad \tan \phi = \frac{\omega L}{R} \]

\[ i(\omega t) = \frac{V_m}{Z} (\cos \phi \sin \omega t - \sin \phi \cos \omega t) + Ae^{-\frac{\omega t}{\tan \phi}} \]

Then, \( i(\omega t) = \frac{V_m}{Z} \sin(\omega t - \phi) + Ae^{-\frac{\omega t}{\tan \phi}} \quad \alpha < \omega t < \beta \)

\[ i(\alpha) = 0. \]
\hat{A} = -\sin(\alpha - \phi)

\[i(\omega t) = \frac{V_m}{Z} \left( \sin(\omega t - \phi) - \sin(\alpha - \phi)e^{-\frac{\omega t - \alpha}{\omega L / R}} \right) \quad \alpha < \omega t < \beta\]
**Freewheeling Diode**

**Freewheeling Diode:** The diode which is used to commutate or transfer or bypass load current away from the rectifier or SCR whenever the load-voltage goes to a reverse state is called freewheeling diode. Freewheeling diode is also called commutating diode, flywheel diode, or bypass diode.

Freewheeling diode serves two main functions:

1. It prevents reversal of load voltage except for small diode voltage drop. It improves the power factor.
2. It transfers the load current away from the main rectifier or SCR, thereby allowing all of its thyristors to return to their blocking states.
Performance Parameters of Rectifier

The average value of the output voltage, \( V_{dc} \),
The average value of the output current, \( I_{dc} \),
The \textit{rms} value of the output voltage, \( V_{rms} \),
The \textit{rms} value of the output current, \( I_{rms} \),
The output DC power, \( P_{dc} = V_{dc} \times I_{dc} \),
The output AC power, \( P_{ac} = V_{rms} \times I_{rms} \).

The efficiency (or \textit{rectification ratio}) of a rectifier, which is figure of merits and permits us to compare the effectiveness, is defined as: \( \eta = \frac{P_{dc}}{P_{ac}} \).

The output voltage can be considered as being composed of two components: (1) the \textit{dc} value, and (2) the \textit{ac} component or ripple.

The effective (\textit{rms}) value of the \textit{ac} component of output voltage is
The form factor (FF), which is measure of the shape of output voltage is:

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

The ripple factor (RF) which is measure of the ripple content, if defined as

$$RF = \frac{V_{ac}}{V_{dc}} = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}} = \sqrt{\frac{V_{rms}^2}{V_{dc}^2}} - 1 = \sqrt{FF^2 - 1}$$

The transformer utilization factor (TUF) is defined as [if $V_s$ and $I_s$ are the rms voltage and current of input of rectifier)]
\[ TUF = \left( \frac{P_{dc}}{V_s I_s} \right) \]

\[ i_s(t) = I_{dc} + \sqrt{2} I_{s1} \sin(n \omega t + \phi_1) + \sum_{n=2,3,5, \ldots}^{\infty} \sqrt{2} I_{sn} \sin(n \omega t + \phi_n) \]

If \( \phi_1 \) is the angle between the fundamental components of the input current and voltage, \( \phi_1 \) is called the displacement angle. The displacement factor (DF) (displacement power factor) is defined as: \( DF = \cos \phi_1 \)

Total Harmonic Distortion (THD) measures the shape of supply current or voltage. THD should be greater than or equal to zero. The shape of supply current or voltage waveform is near to be sinewave as THD tends to be zero.
The harmonic factor (HF) (or total harmonic distortion, THD) is defined as if $I_{s1}$ is the fundamental component of the input current. Both $I_{s1}$ and $I_s$ are expressed in terms of rms:

$$THD_i = \sqrt{\frac{I_s^2 - I_{s1}^2}{I_{s1}^2}} = \sqrt{\frac{I_s^2}{I_{s1}^2}} - 1$$

$$THD_v = \sqrt{\frac{V_s^2 - V_{s1}^2}{V_{s1}^2}} = \sqrt{\frac{V_s^2}{V_{s1}^2}} - 1$$
The input *crest factor* (CF) is defined as

\[ CF = \frac{I_s(\text{peak})}{I_s} \]

In general, power factor in non-sinusoidal circuits can be obtained as following:

\[ PF = \frac{\text{Real Power}}{\text{Apparent Voltamperes}} = \frac{P}{V_s I_s} = \cos \phi \]

Where, \( \phi \) is the angle between the current and voltage. Definition is true irrespective for any sinusoidal waveform. But, in case of sinusoidal voltage (at supply) but non-sinusoidal current, the power factor can be calculated as the following:
Average power is obtained by combining in-phase voltage and current components of the same frequency.

\[
P = \frac{P}{V S} \frac{V}{I S} \cos \phi I = \frac{I S}{I S} \cos \phi I = \text{Distortion Factor} \times \text{Displacement Faactor}
\]

Where \( \phi I \) is the angle between the fundamental component of current and supply voltage.
Example 10.1: If a Single-Phase Half-Wave Controlled Rectifier has a purely resistive load and the delay angle is $\alpha = \pi/2$, calculate (i) the rectification efficiency, (ii) the form factor (FF), (iii) the ripple factor (RF), (iv) the TUF, and (v) the peak inverse voltage of thyristors.

Solution:

\[ V_{dc} = \frac{(V_m/2\pi)[1+\cos\alpha]}{0.1592V_m} \]
\[ I_{dc} = \frac{V_{dc}}{R} = 0.1592V_m/R \]

\[ V_{rms} = \sqrt{\frac{1}{\pi}} \left[ \frac{\pi - \alpha + (\sin 2\alpha/2)}{0.3536V_m} \right] = 0.3536V_m \]
\[ I_{rms} = \frac{V_{rms}}{R} = 0.3536V_m/R \]

(i) \[ \eta = \left[ \frac{V_{dc}}{V_{rms}} \right]^2 = \left[ \frac{0.1592V_m}{0.3536V_m} \right]^2 = 20.27\% \]

(ii) \[ FF = \left[ \frac{V_{rms}}{V_{dc}} \right] = \left[ \frac{0.3536V_m}{0.1592V_m} \right] = 222.1\% \]

(iii) \[ PF = \sqrt{FF^2 - 1} = \sqrt{(2.221)^2 - 1} = 198.3\% \]
(iv) The rms voltage of transformer secondary, \( V_s = V_{\text{rms}}/\sqrt{2} = 0.707V_m \). The rms value of the transformer secondary current is the same as that of the load, \( I_s = 0.3536V_m/R \).

The volt-ampere (VA) rating of the transformer, \( VA = V_s I_s = 0.707V_m \times 0.3536V_m/R \).

\[
TUF = \left( \frac{P}{V_s I_s} \right) = \frac{(0.1592V_m)^2}{(0.707V_m \times 0.3536V_m)} = 0.1014
\]

(v) The PIV = \( V_m \).
**Example 1** In the rectifier shown in Fig. 3.1 it has a load of $R = 15 \, \Omega$ and, $V_s = 220 \, \text{sin} \, 314 \, t$ and unity transformer ratio. If it is required to obtain an average output voltage of 70% of the maximum possible output voltage, calculate: (a) The firing angle, $\alpha$, (b) The efficiency, (c) Ripple factor (d) Transformer utilization factor, (e) Peak inverse voltage (PIV) of the thyristor and (f) The crest factor of input current.
Solution:

(a) $V_{dm}$ is the maximum output voltage and can be achieved when $\alpha = 0$, The normalized output voltage is shown in equation (3.3) which is required to be 70%. Then,

$$V_n = \frac{V_{dc}}{V_{dm}} = 0.5 \left(1 + \cos \alpha \right) = 0.7.$$ Then, $\alpha = 66.42^\circ = 1.15925$ rad.

(b) $V_m = 220$ V

$$V_{dc} = 0.7 \times V_{dm} = 0.7 \times \frac{V_m}{\pi} = 49.02 \text{ V}, \quad I_{dc} = \frac{V_{dc}}{R} = \frac{49.02}{15} = 3.268 \text{ A}$$

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

at $\alpha = 66.42^\circ$, $V_{rms} = 95.1217$ V. Then, $I_{rms} = 95.1217/15 = 6.34145$ A

$$V_S = \frac{V_m}{\sqrt{2}} = 155.56 \text{ V}$$
The \( \text{rms} \) value of the transformer secondary current is:
\[
I_S = I_{\text{rms}} = 6.34145 \text{ A}
\]
Then, the rectification efficiency is:
\[
\eta = \frac{P_{dc}}{P_{ac}} = \frac{V_{dc} \cdot I_{dc}}{V_{\text{rms}} \cdot I_{\text{rms}}}
\]
\[
= \frac{49.02 \cdot 3.268}{95.121 \cdot 6.34145} = 26.56\%
\]
(b) \( FF = \frac{V_{\text{rms}}}{V_{dc}} = \frac{95.121}{49.02} = \frac{\pi}{2 \sqrt{2}} = 1.94 \)
(c) \( RF = \frac{V_{ac}}{V_{dc}} = \sqrt{FF^2 - 1} = \sqrt{1.94^2 - 1} = 1.6624 \)
(d) \( TUF = \frac{P_{dc}}{V_S \cdot I_S} = \frac{49.02 \cdot 3.268}{155.56 \cdot 6.34145} = 0.1624 \)
(e) The PIV is $V_m$

(f) Crest factor of input current $CF$ is as following:

$$CF = \frac{I_{S\text{(peak)}}}{I_S} = \frac{V_m}{R} = \frac{14.6667}{6.34145} = 2.313$$
3.3 Single-Phase Full Wave Controlled Rectifier
3.3.1 Single-Phase Center Tap Controlled Rectifier With Resistive Load

Fig. 3.8 Center tap controlled rectifier with resistive load.
Fig. 3.9 The output voltage and thyristor T1 reverse voltage waveforms along with the supply voltage waveform.
Fig. 3.10 Load current and thyristors currents for Center tap controlled rectifier with resistive load.
\[ V_{dc} = \frac{1}{\pi} \int_{\alpha}^{\pi} V_m \sin(\omega t) \, d\omega t = \frac{V_m}{\pi} (-\cos \pi - \cos(\alpha)) = \frac{V_m}{\pi} (1 + \cos \alpha) \]

\[ V_n = \frac{V_{dc}}{V_{dm}} = 0.5 (1 + \cos \alpha) \]

\[ V_{rms} = \sqrt{\frac{1}{\pi} \int_{\alpha}^{\pi} (V_m \sin(\omega t))^2 \, d\omega t} = \frac{V_m}{\sqrt{2\pi}} \sqrt{\pi - \alpha + \frac{\sin(2\alpha)}{2}} \]
Example 4  The rectifier shown in Fig.3.8 has load of $R=15 \ \Omega$ and, $V_s=220 \sin 314 \ t$ and unity transformer ratio. If it is required to obtain an average output voltage of 70% of the maximum possible output voltage, calculate: - (a) The delay angle $\alpha$, (b) The efficiency, (c) The ripple factor (e) The peak inverse voltage (PIV)

\[ V_n = \frac{V_{dc}}{V_{dm}} = 0.5 (1 + \cos \alpha) = 0.7 , \text{ then, } \alpha = 66.42^\circ \]

(b) $V_m = 220$, then, $V_{dc} = 0.7 \cdot V_{dm} = 0.7 \cdot \frac{2 \cdot V_m}{\pi} = 98.04 \ V$

\[ I_{dc} = \frac{V_{dc}}{R} = \frac{98.04}{15} = 6.536 \ A \]

\[ V_{rms} = \frac{V_m}{\sqrt{2\pi}} \sqrt{\pi - \alpha + \frac{\sin(2\ \alpha)}{2}} \]

at $\alpha = 66.42^\circ$ $V_{rms} = 134.638 \ V$

Then, $I_{rms} = 134.638/15 = 8.976 \ A$
\[
\eta = \frac{P_{dc}}{P_{ac}} = \frac{V_{dc} \times I_{dc}}{V_{rms} \times I_{rms}} \\
= \frac{98.04 \times 6.536}{134.638 \times 8.976} = 53.04% \\
\]

(c) \[ FF = \frac{V_{rms}}{V_{dc}} = \frac{134.638}{98.04} = 1.3733 \text{ and,} \]

\[ RF = \frac{V_{ac}}{V_{dc}} = \sqrt{FF^2 - 1} = \sqrt{1.3733^2 - 1} = 0.9413 \]

(e) The PIV is 2 \( V_m \)
3.3.2 Single-Phase Fully Controlled Rectifier Bridge With Resistive Load
Fig. 3.12 Various voltages and currents waveforms for converter shown in Fig. 3.11 with resistive load.
\[ V_{dc} = \frac{1}{\pi} \int_{\alpha}^{\pi} V_m \sin(\omega t) \, d\omega t = \frac{V_m}{\pi} \left[ -\cos \pi - (-\cos(\alpha)) \right] = \frac{V_m}{\pi} (1 + \cos \alpha) \]

\[ V_n = \frac{V_{dc}}{V_{dm}} = 0.5 (1 + \cos \alpha) \]

\[ V_{rms} = \sqrt{\frac{1}{\pi} \int_{\alpha}^{\pi} (V_m \sin(\omega t))^2 \, d\omega t} = \frac{V_m}{\sqrt{2\pi}} \sqrt{\pi - \alpha + \frac{\sin(2\alpha)}{2}} \]
Single-phase full-wave controlled rectifier loaded with highly inductive load:

This load represents a DC motor

E: back emf of armature of the DC motor = K \( w \) (\( K \) is constant and \( w \) motor speed)

\[
\frac{E_1}{E_2} = \frac{W_1}{W_2}
\]

R: armature resistance of the DC motor

L: armature inductance of the DC motor
\[ v = V_m \sin \omega t \]

(c) Waveforms
In a single-phase full converter circuit consists of four thyristors. Full converters are also known as *Two quadrant converters*. This converter is extensively used in industrial applications up to 15 kW.

During the positive half-cycle, $T_1$ and $T_2$ are forward biased, and when these two thyristors are fired simultaneously at $\omega t=\alpha$, the load is connected to the input supply through $T_1$ and $T_2$.

Due to the inductive load, $T_1$ and $T_2$ will continue to conduct beyond $\omega t=\pi$, even though the input voltage is already negative.
During the negative half-cycle, $T_3$ and $T_4$ are forward biased, and when these two thyristors are fired simultaneously at $\omega t = \pi + \alpha$, SCRs $T_1$ and $T_2$ will be turned off due to \textit{line or natural commutation}, and the load is connected to the input supply through $T_3$ and $T_4$. Due to the inductive load, $T_3$ and $T_4$ will continue to conduct beyond $\omega t = 2\pi$, even though the input voltage is already positive.

**Rectification Mode:** During the period from $\alpha$ to $\pi$, the input voltage $v_s$ and the input current $i_s$ are positive; and the power flows from the supply to the load. The converter is said to be operated in \textit{rectification} mode.

**Inversion Mode:** During the period from $\pi$ to $\pi + \alpha$, $v_s$ is negative and $i_s$ is positive; and there will be reverse power flow from the load to the source. The converter is said to be operated in \textit{inversion} mode.
### Table 7 Operation states

<table>
<thead>
<tr>
<th>Period</th>
<th>Conducting Thyristors</th>
<th>Output Voltage ((v_o))</th>
<th>Load Current ((i_o))</th>
<th>Supply Current ((i_s))</th>
<th>Thyristor Voltage ((v_T))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\alpha \leq \omega t &lt; \pi + \alpha)</td>
<td>(T_1 &amp; T_2)</td>
<td>(v_s)</td>
<td>(I_a)</td>
<td>(I_a)</td>
<td>(-v_s) for (T_3 &amp; T_4)</td>
</tr>
<tr>
<td>(\pi + \alpha \leq \omega t &lt; 2\pi + \alpha)</td>
<td>(T_3 &amp; T_4)</td>
<td>(-v_s)</td>
<td>(I_a)</td>
<td>(-I_a)</td>
<td>(v_s) for (T_1 &amp; T_2)</td>
</tr>
</tbody>
</table>

\[
V_{dc} = \frac{1}{\pi} \int_{\alpha}^{\pi + \alpha} v_s(\omega t) d\omega t = \frac{1}{\pi} \int_{\alpha}^{\pi + \alpha} V_m \sin(\omega t) d\omega t d\omega t
\]

\[
\therefore V_{dc} = \frac{2}{\pi} \frac{V_m}{\pi} \cos(\alpha)
\]
Since the load is a highly inductive load. Then, the load current is considered constant (ripple free current) and equal to the average value of the load current $I_{dc}$ as follows,

$$I_{dc} = I_a = \frac{V_{dc} - E}{R} = \frac{2V_m}{\pi} \cos(\alpha) - E$$

In case the load doesn’t contain a DC battery “$E$” (or a back emf) in addition to the highly inductive load, the load current will be

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

Therefore, the average output voltage can vary from $\frac{2V_m}{\pi}$ to $-\frac{2V_m}{\pi}$ when varying $\alpha$ from $\pi$ to 0, respectively.
Rectifying Mode: If $\alpha < 90^\circ$, the average voltage at the dc terminal is positive, therefore, the power flows from ac side to dc side and the converter operates as a rectifier.

Inverting Mode: If $\alpha > 90^\circ$, the average voltage at the dc terminal is negative, therefore, the power flows from dc side to ac side and the converter is operating as a “line commutated inverter”.
\[ V_{rms} = \sqrt{\frac{1}{\pi} \int_0^{\pi+\alpha} \{v_s(\omega t)\}^2 \, d\omega t} = \sqrt{\frac{1}{\pi} \int_0^{\pi+\alpha} \{V_m \sin(\omega t)\}^2 \, d\omega t} \]

\[ \therefore V_{rms} = \frac{V_m}{\sqrt{2}} = 0.707 \, V_m \]

Since the load current is constant over the studied period, therefore the rms value of the load current \( I_{rms} \) is

\[ I_{rms} = I_{dc} = I_a \]

The PRV for any thyristor in this configuration is \((V_m)\).
Example: 220 V AC supply fed dc motor by a full wave controlled bridge rectifier. The DC motor has armature resistance $2 \, \Omega$ and the back emf equals 80 V when the speed is 1000 rpm and the armature current 10 A. find the firing angle at this case and in case when the speed is 500 rpm at the same armature current
1- Mark right or wrong (√ or ×) for the following:

i- SCR needs a continuous current for keeping it in a conducting state.

ii- The current and voltage ratings of BJT are higher than those of MOSFET.

iii- Power Transistors Have controlled turn-on and turn-off characteristics.

iv- The fast recovery diode has rated power greater than that of shotcky diode.

v- SCR turned off by applying a negative gate current pulse.

vi- Power Transistors needs only a pulse to make it conducting and thereafter it remains conducting.

vii- SCR has dv/dt lower than GTO.
2- Single-Phase Half-Wave Controlled Rectifier With inductive Load (R-L). If the transformer secondary output voltage is 50 V, the load resistance is 5 Ω, the thyristor firing angle is \(\pi/6\) (rad) and the inductive load make extinction angle \((\beta)\) equals \(4\pi/3\) (rad). Find:

(i) Draw the output waveforms of load voltage, current and thyristor voltage

(ii) \(V_{\text{rms}}\) and \(V_{\text{dc}}\) of the output load voltage

(iii) Form factor

(iv) Ripple factor

(v) Peak inverse voltage of thyristor