DEPARTMENT OF ELECTRICAL ENGINEERING
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Lecture Notes on Basic Electronics

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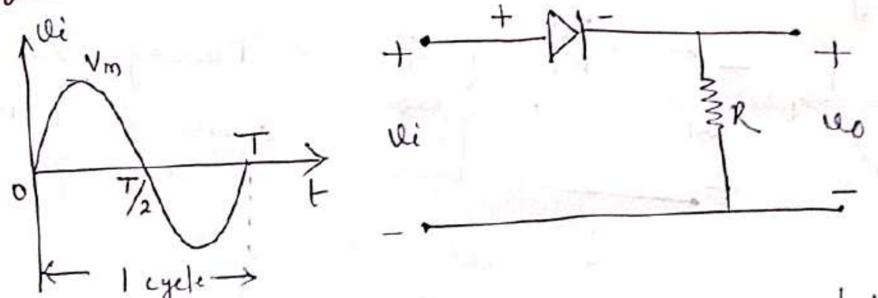
Disclaimer

Rectifier

→ Rectifier is a device which converts the sinusoidal ac voltage into either positive or negative pulsating dc.

→ The rectifier typically needs one, two or four diodes. Rectifiers may be either half-wave or full-wave (Centre-tap and bridge) type.

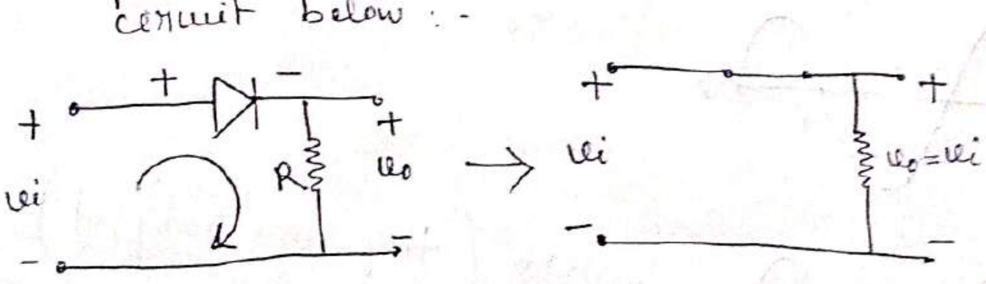
Half-wave Rectifier

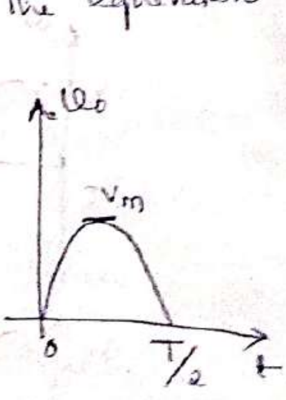


$v_i = V_m \sin \omega t$ (Half-wave rectifier)

→ When a single rectifier unit is placed in series with the load across an ac supply, it converts alternating voltage into uni-directional pulsating voltage using one half cycles of the applied voltage.

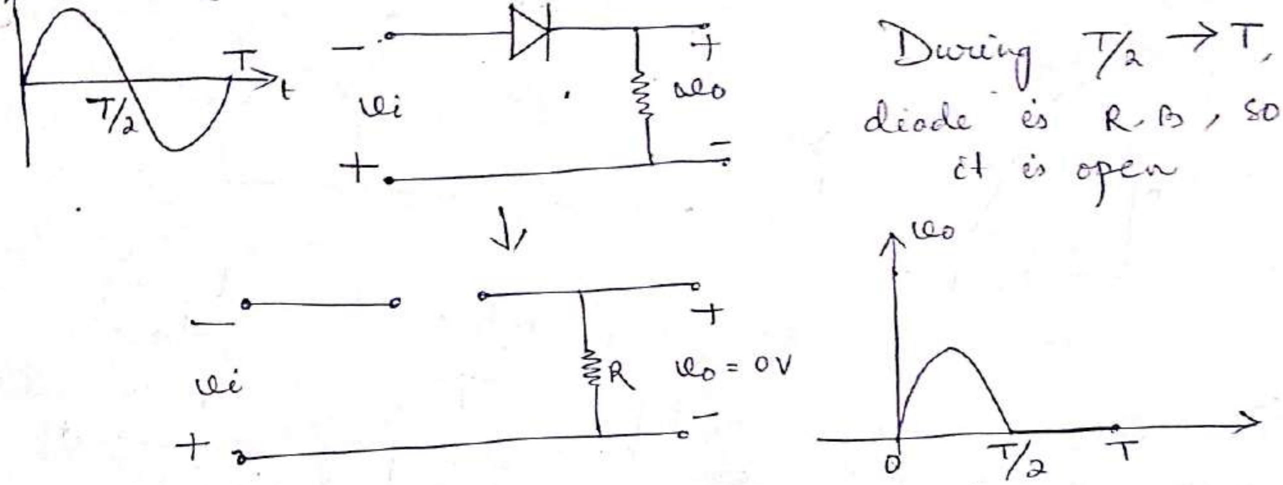
→ During the interval $t = 0 \to T/2$, the polarity of the applied voltage v_i is such as to turn on the diode. Substituting the short circuit equivalence for the diode will result in the equivalent circuit below:-





→ During the forward biased condition, the input voltage during the positive half cycles is directly applied to the load resistance R. Thus, the waveform of the output voltage is of same shape as that of the input ac voltage.

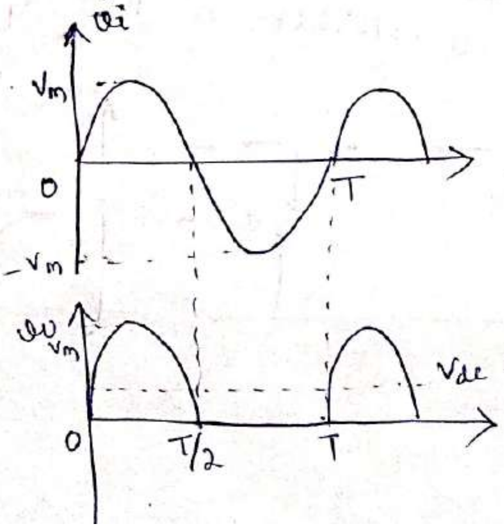
→ For the period T/2 → T (i.e during the negative half cycle of the input ac voltage), the ideal diode produces an "off" state and $v_o = iR = 0(R) = 0V$ for the period T/2 → T. Thus, for the negative half cycle no power is delivered to the load.



During T/2 → T, diode is R.B, so it is open

(Non conduction region T/2 → T)

→ The process of removing one-half the input signal to establish a dc level is called half wave rectification.

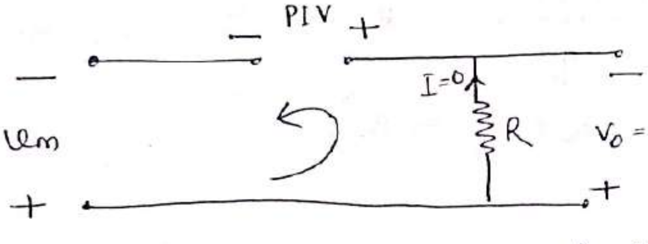


$V_{dc} = 0.318 V_m$ (Half-wave rectified signal)

Analysis

1. Peak Inverse Voltage (PIV)

→ PIV rating is the voltage rating that must not be exceeded in the reverse-bias region or the diode will enter the zener avalanche region.



(PIV rating of the diode)

→ It is obvious that the PIV rating of the diode must equal or exceed the peak value of the applied voltage.

$$\boxed{\text{PIV rating} \geq V_m}$$

2. Peak current :-

During forward biased condition

$$I = I_{max} \sin \omega t$$

During reverse biased condition

$$I = 0$$

If r_f is the internal resistance of the diode,

$$\boxed{I_{max} = \frac{V_m}{R + r_f}}$$

3. DC output current :

$$I_{dc} = \frac{1}{2\pi} \int_0^{2\pi} I \, d(\omega t)$$

$$= \frac{1}{2\pi} \left[\int_0^{\pi} I_{max} \sin \omega t \, d(\omega t) + \int_{\pi}^{2\pi} 0 \, d(\omega t) \right]$$

$$= \frac{I_{max}}{2\pi}\left\{-\cos\omega t\right\}_0^{\pi} = \frac{I_{max}}{\pi} = 0.318\, I_{max}$$

$$\boxed{I_{dc} = 0.318\, I_{max}}$$

4. DC output voltage :-

$$V_{dc} = I_{dc} R = \frac{V_m \times 0.318}{R + r_f} \times R$$

$$\simeq 0.318\, V_m \quad \left(\because R + r_f \simeq R\right)$$

$$\boxed{V_{dc} = 0.318\, V_m}$$

5. RMS value of current :-

$$I_{rms}^2 = \frac{1}{2\pi}\int_0^{2\pi} i^2\, d(\omega t)$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} I_{max}^2 \sin^2\omega t\, d(\omega t) + \int_{\pi}^{2\pi} 0\, d(\omega t)\right]$$

$$= \frac{I_{max}^2}{2\pi}\left[\int_0^{\pi} \frac{(1-\cos 2(\omega t))}{2}\, d(\omega t)\right]$$

$$= \frac{I_{max}^2}{4}$$

$$\boxed{I_{rms} = \frac{I_{max}}{2}}$$

6. RMS value of output voltage :-

$$V_{rms} = I_{rms} R = \frac{I_{max}}{2} R$$

$$= \frac{V_m}{2(R + r_f)} \cdot R$$

$$\Rightarrow \boxed{V_{rms} = \frac{V_m}{2}} \quad \left(\because R + r_f \simeq R\right)$$

7. Rectification Efficiency :-

— This is defined as the ratio of dc output power to ac input power.

$$\eta = \frac{\text{DC power delivered to the load}}{\text{Ac input power}}$$

$$\text{Dc output power} = I_{dc}^2 R_L = (0.318\, I_{max})^2 R_L$$

Ac input power

= power dissipated across the diode + power dissipated in the load resistance R_L

$$= I_{rms}^2 r_f + I_{rms}^2 R_L = \frac{I_{max}^2}{4}(R + r_f)$$

$$\eta = \frac{(0.318\, I_{max})^2 R \times 4}{I_{max}^2 (R + r_f)}$$

$$\eta = 0.406 = 40.6\,\% \quad (\because R + r_f \cong R)$$

— This is the maximum possible efficiency for a half-wave rectifier.

8. Ripple factor :-

→ The pulsating output of a rectifier can be considered to contain a dc component and ac components called the <u>ripples</u>.

→ The ripple voltage or current is measured in terms of the ripple factor which is defined as the ratio of the effective value of the ac components of voltage (or current) present in the output from the rectifier to the direct or average value of the output voltage (or current).

— The effective value of the load current is given as

$$I_{rms}^2 = I_{dc}^2 + I_{ac}^2$$

Ripple factor $\gamma = \frac{I_{ac}}{I_{dc}} = \frac{\sqrt{I_{rms}^2 - I^2_{dc}}}{I_{dc}}$

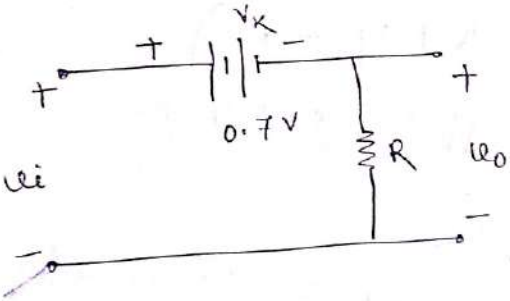
$$= \sqrt{\left[\frac{I_{rms}}{I_{dc}}\right]^2 - 1}$$

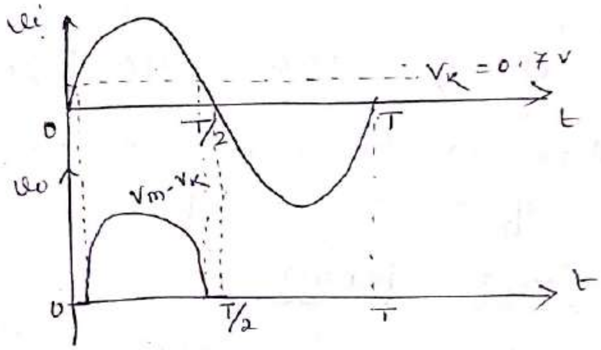
$I_{rms} = I_{max}/2$, $I_{dc} = I_{max}/\pi$

$$\gamma = \sqrt{(1.57)^2 - 1} = 1.21$$

$$\boxed{\gamma = 1.21}$$

→ The effect of using a Silicon diode with $V_K = 0.7\,V$ is demonstrated for the forward-bias region





(Effect of V_K on half-wave rectified signal)

$$\boxed{V_{dc} \simeq 0.318(V_m - V_K)}$$

Advantages

→ Simple circuit and low cost.

Disadvantages :-

→ Ripple factor is high.

→ Rectification efficiency is quite low.

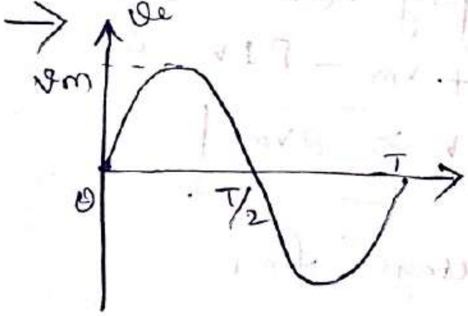
Full-wave Rectifier

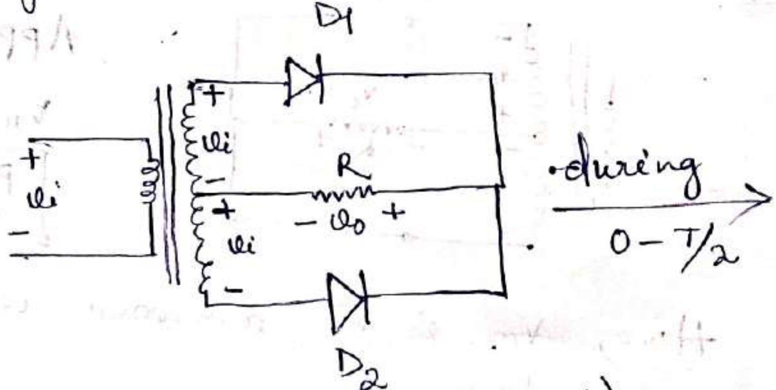
In full-wave rectifiers both half cycles of the input are utilized. There are two types of full-wave rectifier circuit namely
(a) Centre-tap rectifier
(b) Bridge rectifier

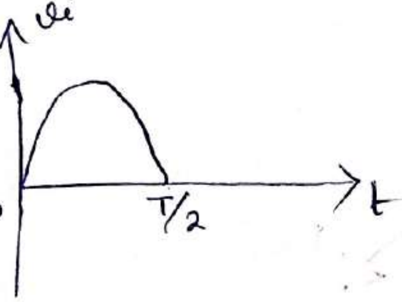
Centre-tap full-wave rectifier :-

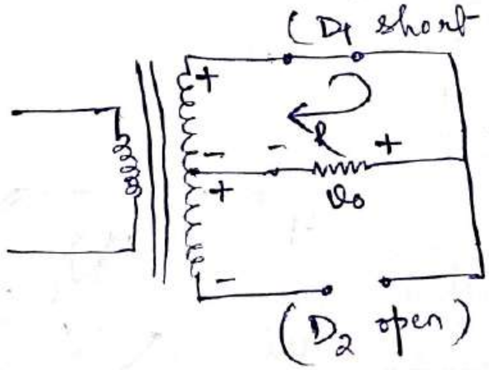
→ The ac input is applied through a transformer, the anodes of the two diodes D_1 and D_2 are connected to the opposite ends of the centre-tapped secondary winding and two cathodes are connected to each other and are connected through the load resistor R.

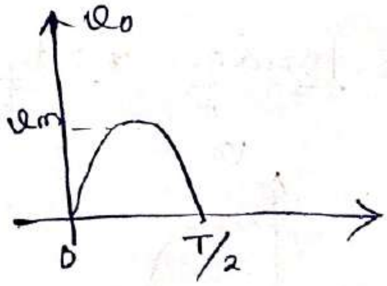
→ During positive portion of v_i, D_1 is short circuit equivalent and D_2 is the open-circuit equivalent. Hence, the output voltage reflects the input half of the positive cycle.

→


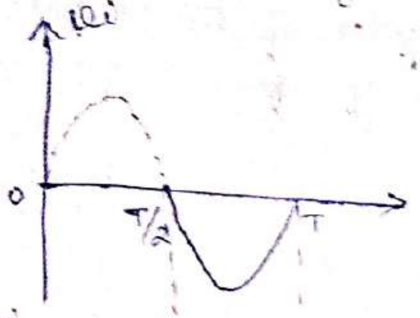


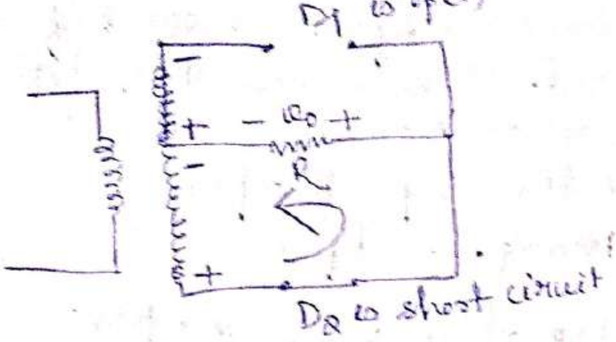


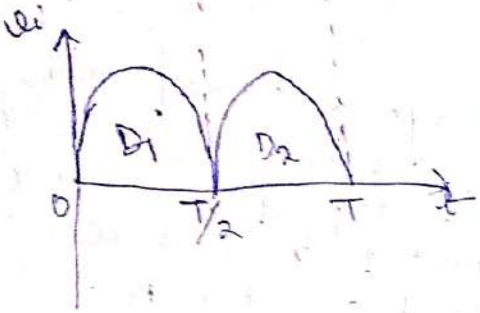




→ During the second half-cycle of the input voltage D_2 is forward biased and D_1 is reverse-biased. During this half cycle of the input, only the diode D_2 conducts and current flows through the load resistance.

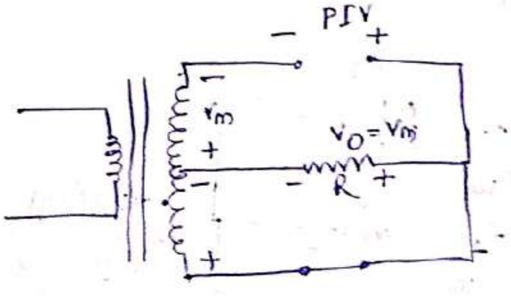






→ Thus, the direction of flow of current through R remains the same during both halves of the input voltage.

PIV



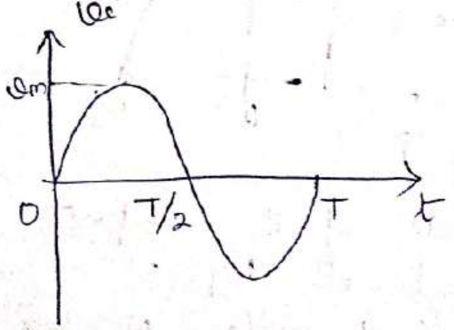
Applying KVL

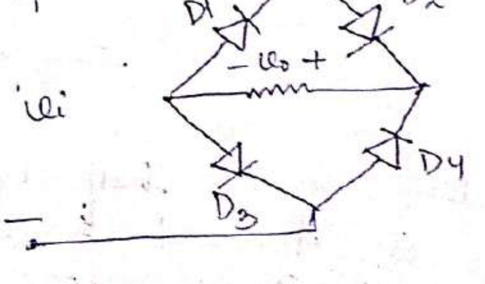
$V_m + V_m - PIV = 0$

$\boxed{PIV \geq 2V_m}$

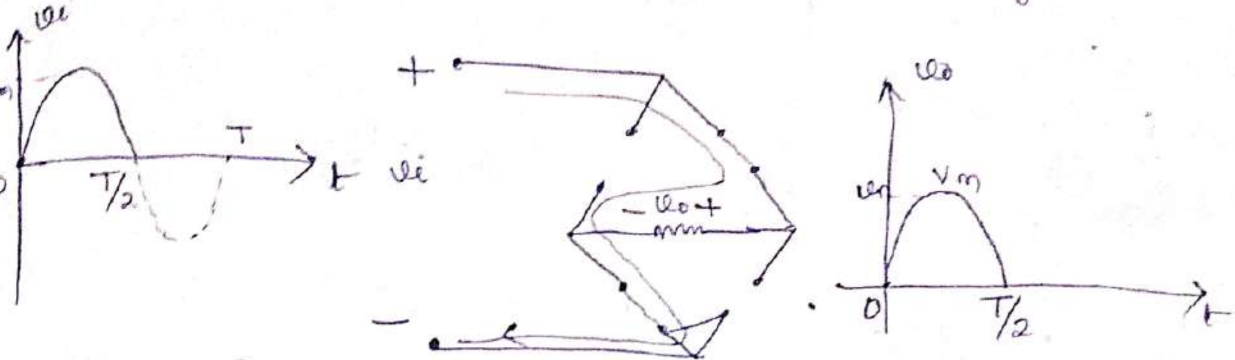
Here, V_m is the maximum voltage for secondary.

Bridge Rectifier





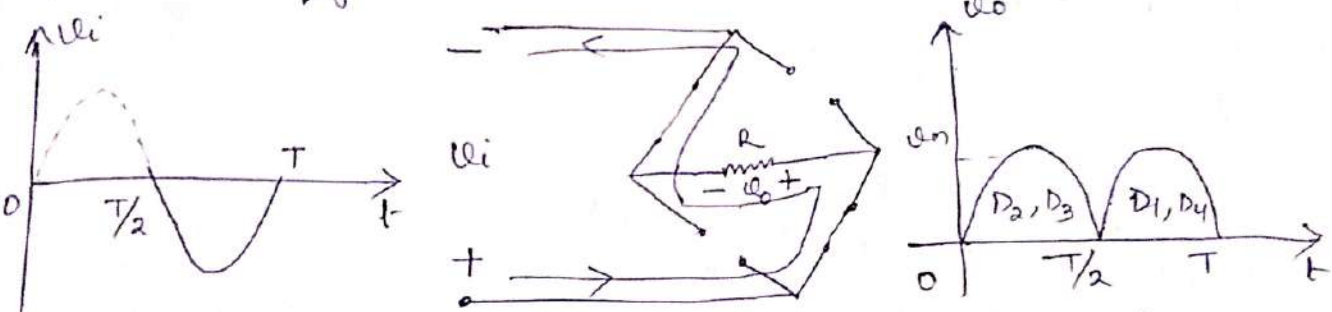
→ During the period $t = 0$ to $T/2$, D_2 and D_3 are conducting, whereas D_1 and D_4 are in the "off" state. The net result is shown in fig. below



(Conduction path for the positive region of v_i)

→ Since the diodes are ideal, the load voltage is $v_o = v_i$.

→ During the negative region of the input, D_1 and D_4 are conducting. The resulting configuration and the polarity across the load resistor R is shown in figure below



(conduction path for the negative region of v_i)

Analysis of full-wave Rectifier:-

1) Peak current:-

Instantaneous voltage applied to the rectifier is given as

$$V = V_m \sin \omega t$$

The peak value of current flowing through the load is

$$\boxed{I_{max} = \frac{V_m}{R + r_f}}$$ (centre-tap rectifier)

$$\boxed{I_{max} = \frac{V_m}{R + 2r_f}}$$ (Bridge rectifier)

$$\boxed{I_{max} = \frac{V_m}{R}}$$ $(r_f = 0)$

2) <u>Output dc current</u> :-

$$I_{dc} = \frac{1}{\pi}\int_0^{\pi} i \, d(\omega t) = \frac{1}{\pi}\int_0^{\pi} I_{max} \sin \omega t \, d(\omega t)$$

$$= \frac{I_{max}}{\pi}\left[-\cos(\omega t)\right]_0^{\pi}$$

$$\Rightarrow \boxed{I_{dc} = \frac{2 I_{max}}{\pi}}$$

3) <u>Dc output voltage</u>

Average or dc value of voltage across the load is given as

$$V_{dc} = I_{dc} R = \frac{2 I_{max}}{\pi} R$$

Let $r_f = 0$

$$V_{dc} = \frac{2 V_m}{\pi R} \cdot R$$

$$\boxed{V_{dc} = \frac{2 V_{max}}{\pi}}$$

4) <u>RMS or effective value of current</u> :-

RMS or effective value of current flowing through the load resistance R is given as

$$I_{rms}^2 = \frac{1}{\pi}\int_0^{\pi} I^2 \, d(\omega t)$$

$$= \frac{1}{\pi}\int_0^{\pi} I_{max}^2 \sin^2(\omega t) \, d(\omega t)$$

$$= \frac{I_{max}^2}{\pi}\int_0^{\pi}\left[\frac{1 - \cos 2(\omega t)}{2}\right] d(\omega t)$$

$$= \frac{I_{max}^2}{2\pi}\left[\pi - 0\right]$$

$$\Rightarrow \quad I_{rms}^2 = \frac{I_{max}^2}{2} \quad \Rightarrow \quad \boxed{I_{rms} = \frac{I_{max}}{\sqrt{2}}}$$

5) RMS value of output voltage

RMS value of voltage across the load is given as

$$V_{rms} = I_{rms} \cdot R = \frac{I_{max}}{\sqrt{2}} \cdot R$$

Substituting the value of I_{max}, ~~ass~~ and assuming $r_f = 0$

$$V_{rms} = \frac{V_m}{R\sqrt{2}} \cdot R$$

$$\Rightarrow \quad \boxed{V_{rms} = \frac{V_m}{\sqrt{2}}}$$

6) Rectification Efficiency :-

Power delivered to the load

$$P_{dc} = I_{dc}^2 \cdot R = \left(\frac{2 \cdot I_{max}}{\pi}\right)^2 R = \frac{4 I_{max}^2}{\pi^2} R$$

AC input power

$$\boxed{\begin{array}{l} P_{ac} = I_{rms}^2 \left(R + \cancel{2} r_f\right) \longrightarrow \text{Centre-tap} \\ P_{ac} = I_{rms}^2 \left(R + 2 r_f\right) \longrightarrow \text{Bridge} \end{array}}$$

$$\text{Rectification Efficiency } \eta = \frac{P_{dc}}{P_{ac}} = \frac{\frac{4}{\pi^2} \cdot I_{max}^2 R}{\frac{I_{max}^2}{2}\left(R + r_f\right)}$$

Assuming $r_f = 0$

$$\eta = \cancel{4} \; \frac{8}{\pi^2} = 0.812$$

$$\boxed{\eta = 81.2\,\%}$$

for centre - tap :-

$$\boxed{\eta = \frac{0.812}{1 + \frac{r_f}{R}}}$$

for Bridge rectifier :-

$$\boxed{\eta = \frac{0.812}{1 + \frac{2r_f}{R}}}$$

7. **Ripple factor :-**

$$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

$$I_{rms} = I_{max}/\sqrt{2} \quad , I_{dc} = \frac{2I_{max}}{\pi}$$

$$\gamma = \sqrt{\left(\frac{I_{max}/\sqrt{2}}{2I_{max}/\pi}\right)^2 - 1} = \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1}$$

$$= \sqrt{(1.11)^2 - 1} = 0.482$$

Ripple factor of full-wave rectifier is

~~γ = one~~

$$\boxed{\gamma = 0.482}$$

8. The peak value of the output voltage of centre-tap rectifier is $\boxed{V_o = V_i - V_K}$

- The peak value of the output voltage of bridge rectifier is $\boxed{V_o = V_i - 2V_K}$

Advantages of Full-wave Rectifier :-

→ Rectification efficiency is double that of half-wave rectifier.

→ Ripple factor is low.