Rectifier:

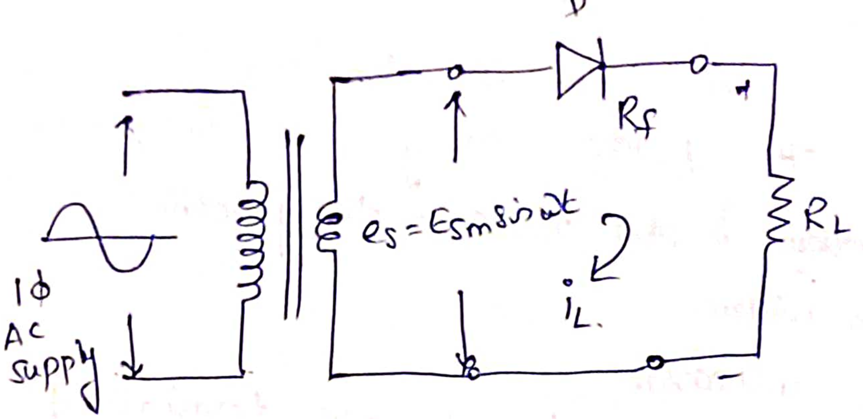
A rectifier is a device which converts ac voltage to pulsating dc voltage.

T→Temperature

Two types of rectifier

→ Half wave rectifier

→ Full wave rectifier



In a transformer N_1 are 1° turns, N_2 are 2° turns

$E_{pm} \rightarrow$ peak value of 1° ac voltage

$E_{sm} \rightarrow$ " " " 2° ac voltage

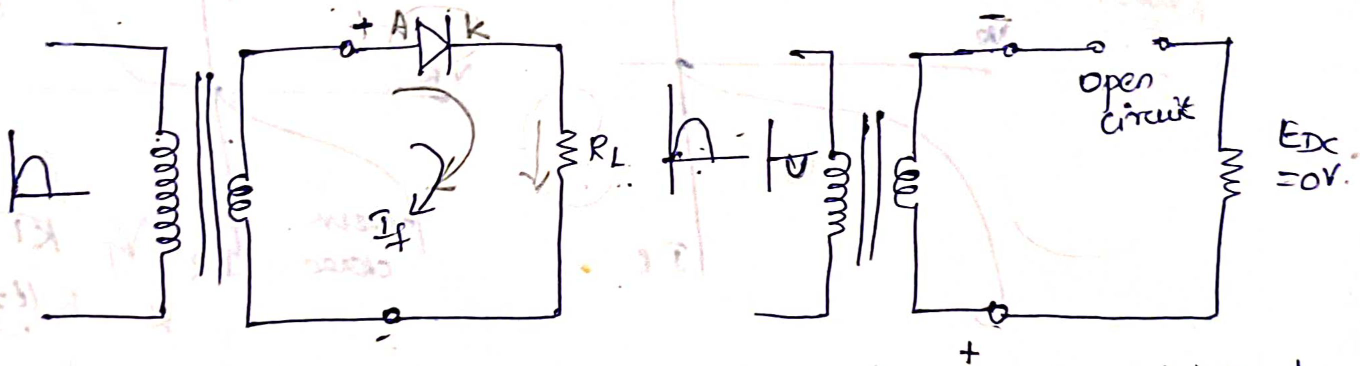
$$\frac{N_2}{N_1} = \frac{E_{sm}}{E_{pm}}$$

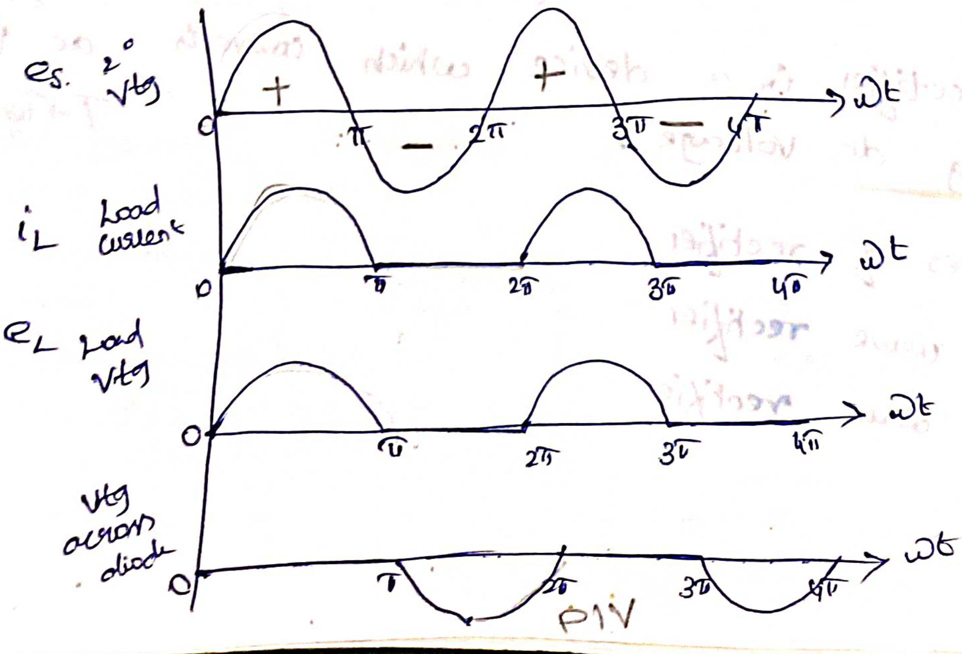
$$e_s = E_{sm} \sin \omega t$$

$$\omega = 2\pi f$$

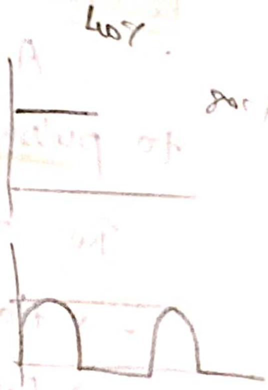
f = supply frequency

Operation.





$\rightarrow$ forward biased



current (I_{DC}).

Mathematically current waveform can be described as

$$i_L = I_m \sin \omega t \quad \text{for } 0 \le \omega t \le \pi$$

$$i_L = 0 \quad \text{for } \pi \le \omega t \le 2\pi$$

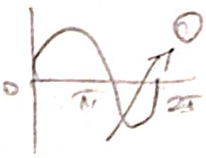
I_m is the peak value of Load current.

$$I_{DC} = \frac{1}{2\pi}\int_0^{2\pi} i_L \, d(\omega t) = \frac{1}{2\pi}\int_0^{2\pi} I_m \sin \omega t \cdot d\omega t$$

$V_m \sin \omega t$

$I_m \sin \omega t$

$$= \frac{1}{2\pi}\int_0^{\pi} I_m \sin \omega t \cdot d\omega t = \frac{I_m}{2\pi}\left[-\cos \omega t\right]_0^{\pi}$$



$$= -\frac{I_m}{2\pi}\left[\cos\pi - \cos 0\right] = -\frac{I_m}{2\pi}[-1-1] = \frac{I_m}{\pi}$$

$$\boxed{I_{DC} = \frac{I_m}{\pi}}$$

Apply KVL, $I_m = \dfrac{E_{sm}}{R_f + R_L + R_s}$. $\qquad I = \dfrac{V}{R}$

if R_s is not given it can be neglected. $\qquad I_m = \dfrac{V_m}{R_L}$

* Average DC Load Voltage (E_{DC}).

$$E_{DC} = I_{DC} R_L \qquad V = IR$$

$$= \frac{I_m}{\pi} \times R_L = \frac{E_{sm}}{(R_f + R_L + R_s)\pi} \times R_L \qquad V_{DC} = I_{DC} R$$

R_f, R_s are very small compared to R_L.

$$E_{DC} = \frac{E_{sm}}{\pi\left[\dfrac{R_f + R_s}{R_L} + 1\right]} \quad \text{is neglected.} \qquad = \frac{V_m}{\cancel{R_L}\pi} \cancel{R_L}$$

$$V_{DC} = \frac{V_m}{\pi}$$

$$\boxed{E_{DC} = \frac{E_{sm}}{\pi}}$$

* RMS value of Load current:

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

$(i_L)^2$

$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\omega t \cdot d\omega t}$$

$$= I_m \sqrt{\frac{1}{2\pi}\int_0^{\pi} \frac{[1-\cos 2\omega t]}{2} \, d\omega t}$$

$$= I_m \sqrt{\frac{1}{2\pi}\left\{\frac{\omega t}{2} - \frac{\sin 2\omega t}{4}\right\}_0^{\pi}}$$

$$= I_m \sqrt{\frac{1}{2\pi}\left(\frac{\pi}{2}\right)} \quad \because \sin 2\pi = \sin 0 = 0$$

$$= \frac{I_m}{2}.$$

$$\boxed{I_{rms} = \frac{I_m}{2}.}$$

* RMS value of Load Voltage.

$$E_L(RMS) = I_{rms} R_L = \frac{I_m}{2} R_L.$$

$$= \frac{E_{sm}}{2(R_f + R_L + R_s)} \times R_L = \frac{E_{sm}}{2\left[1 + \frac{R_f + R_s}{R_L}\right]}$$

neglected

$$\boxed{E_L(RMS) = \frac{E_{sm}}{2.}}$$

* DC Power Output. (P_{DC})

$$P_{DC} = E_{DC} I_{DC} = I_{DC} R_L I_{DC} = I_{DC}^2 R_L$$

$$= \left[\frac{I_m}{\pi}\right]^2 R_L = \frac{I_m^2}{\pi^2} R_L.$$

P_{dc}

AC pow...

$V_{rms} = I_m R$

$\frac{V_m}{2\cancel{R}} \times \cancel{R}$

$\eta = \frac{P_{out}}{P_{in}} \times 100$

$= \frac{P_{DC}}{P_{AC}} \times 100$

$= P = V_{DC} I_{DC}$

$$\boxed{P_{DC} = \frac{E_{sm}^2 R_L}{\pi^2 [R_f + R_L + R_s]^2}}$$

* AC power input (P_{AC})

$$P_{AC} = I_{RMS}^2 [R_L + R_f + R_s].$$

$$I_{RMS} = \frac{I_m}{2}$$

$$\boxed{P_{AC} = \frac{I_m^2}{4} [R_L + R_f + R_s].}$$

$$\frac{\cancel{I_m^2}}{\pi^2} \times \cancel{R_L}$$

$$\frac{\cancel{I_m^2}}{4} \times \cancel{R_L}$$

* Rectifier efficiency

$$\eta = \frac{\text{DC output power}}{\text{AC input power}} = \frac{P_{DC}}{P_{AC}}$$

$$\eta = \frac{\frac{I_m^2}{\pi^2} R_L}{\frac{I_m^2}{4} [R_f + R_L + R_s]} = \frac{(4/\pi^2) R_L}{(R_f + R_L + R_s)}$$

$\frac{\pi^2}{4}$ $4/\pi^2$

$= 4.06$.

$$\eta = \frac{0.406}{1 + \left(\frac{R_f + R_s}{R_L}\right)}.$$

$\ll 1$. neglected.

$$\% \eta = 40.6\%.$$

* Ripple factor

$$\gamma = \frac{\text{RMS value of ac component of output}}{\text{Average or dc component of output.}}$$

I_{ac} = RMS value of ac component present in output

I_{DC} = dc component present in output

I_{RMS} = RMS value of total output current.

$$I_{rms} = \sqrt{I_{ac}^2 + I_{DC}^2}$$

$\therefore \quad I_{ac} = \sqrt{I_{RMS}^2 - I_{DC}^2}$

as per definition Ripple factor $= \dfrac{I_{ac}}{I_{DC}}$.

$$\gamma = \frac{\sqrt{I_{RMS}^2 - I_{DC}^2}}{I_{DC}}$$

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

$$I_{RMS} = \frac{I_m}{2}, \quad I_{DC} = \frac{I_m}{\pi}$$

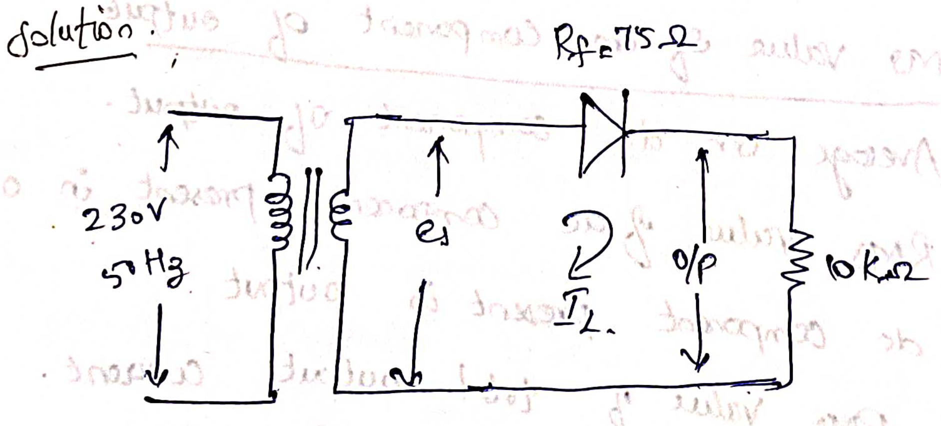
$$\gamma = \sqrt{\left[\frac{\left(\frac{I_m}{2}\right)}{\left(\frac{I_m}{\pi}\right)}\right]^2 - 1} = \sqrt{\frac{\pi^2}{4} - 1} = \sqrt{1.4674}$$

$$\boxed{\gamma = 1.211.}$$

Problem.

A half wave rectifier circuit is supplied from a 230V, 50 Hz supply with a step down ratio of 3:1 to a resistive load of 10 KΩ. The diode forward resistance is 75 Ω while transformer 2° resistance is 10 Ω. Calculate maximum, average, RMS value of current, DC output Voltage, efficiency of ripple factor.

Solution:



3:1

$N_1 : N_2$

data :

$R_f = 75\,\Omega$, $R_L = 10k\Omega$, $R_1 = 10\,\Omega$

$E_p = 230V$, $\frac{N_1}{N_2} = \frac{3}{1}$ ie $\frac{N_2}{N_1} = \frac{1}{3}$.

$$\frac{N_2}{N_1} = \frac{E_S\ (RMS)}{E_P\ (RMS)}$$

$$\frac{1}{3} = \frac{E_S(RMS)}{230}$$

$$E_S\ (RMS) = \frac{230}{3} = 76.667\,V.$$

$E_{sm} = \sqrt{2}\ E_S\ (RMS) = \sqrt{2} \times 76.667 = 108.423V$

$I_m = \frac{E_{sm}}{R_s + R_f + R_L} = \frac{108.423}{10 + 75 + 10 \times 10^3} = 10.75\,mA$

$I_{av} = I_{DC} = \frac{I_m}{\pi} = \frac{10.75}{\pi} = 3.422\,mA$

$I_{RMS} = \frac{I_m}{2} = \frac{10.75}{2} = 5.375\,mA$

E_{DC} = dc output Voltage $= I_{DC} R_L$

$= 3.422 \times 10^{-3} \times 10 \times 10^3 = 34.22V.$

$$\eta = \frac{P_{DC}}{P_{AC}} \times 100$$

P_{DC} = dc output power $= E_{DC}\ I_{DC} = 34.22 \times 3.422 \times 10^{-3}$

$= 0.1171\ W$

$P_{AC} = I^2_{RMS}\ [R_s + R_f + R_L]$

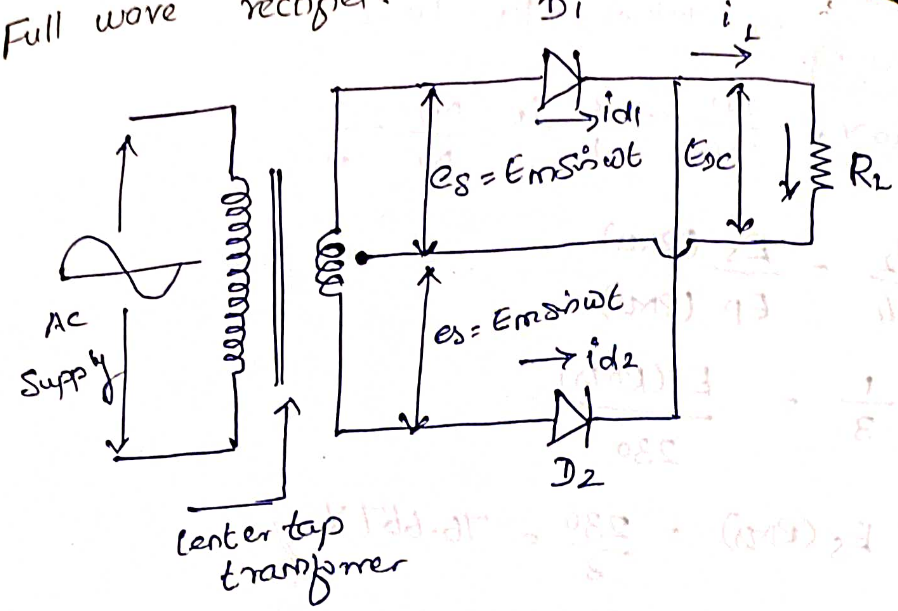
$= (5.375 \times 10^{-3})^2\ [10 + 75 + 10 \times 10^3]$

$= 0.2913$

$$\%\eta = \frac{0.1171}{0.2913} \times 100 = 40.19\%.$$

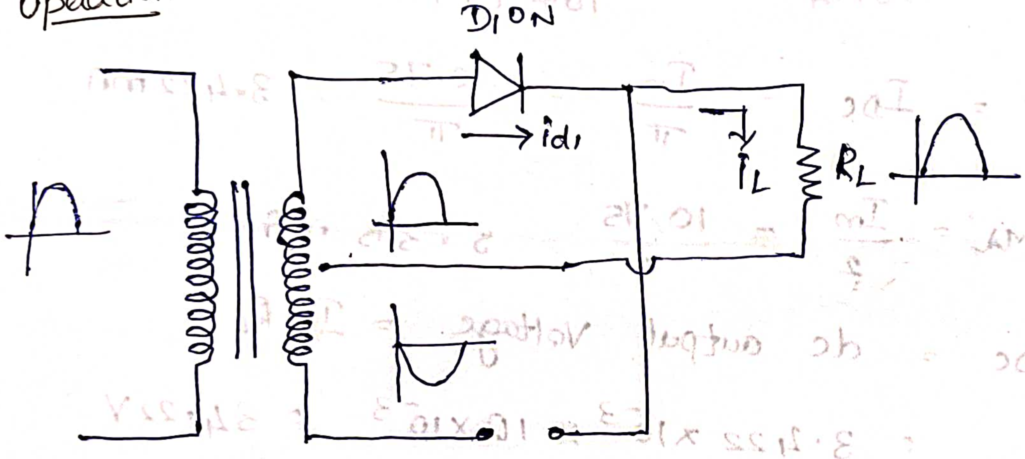
$\gamma = 1.21$ for half wave rectifier

Full wave rectifier :-



It conducts during both +ve and -ve half cycle. In order to rectify both the half cycles, 2 diodes are used.

Operation :-



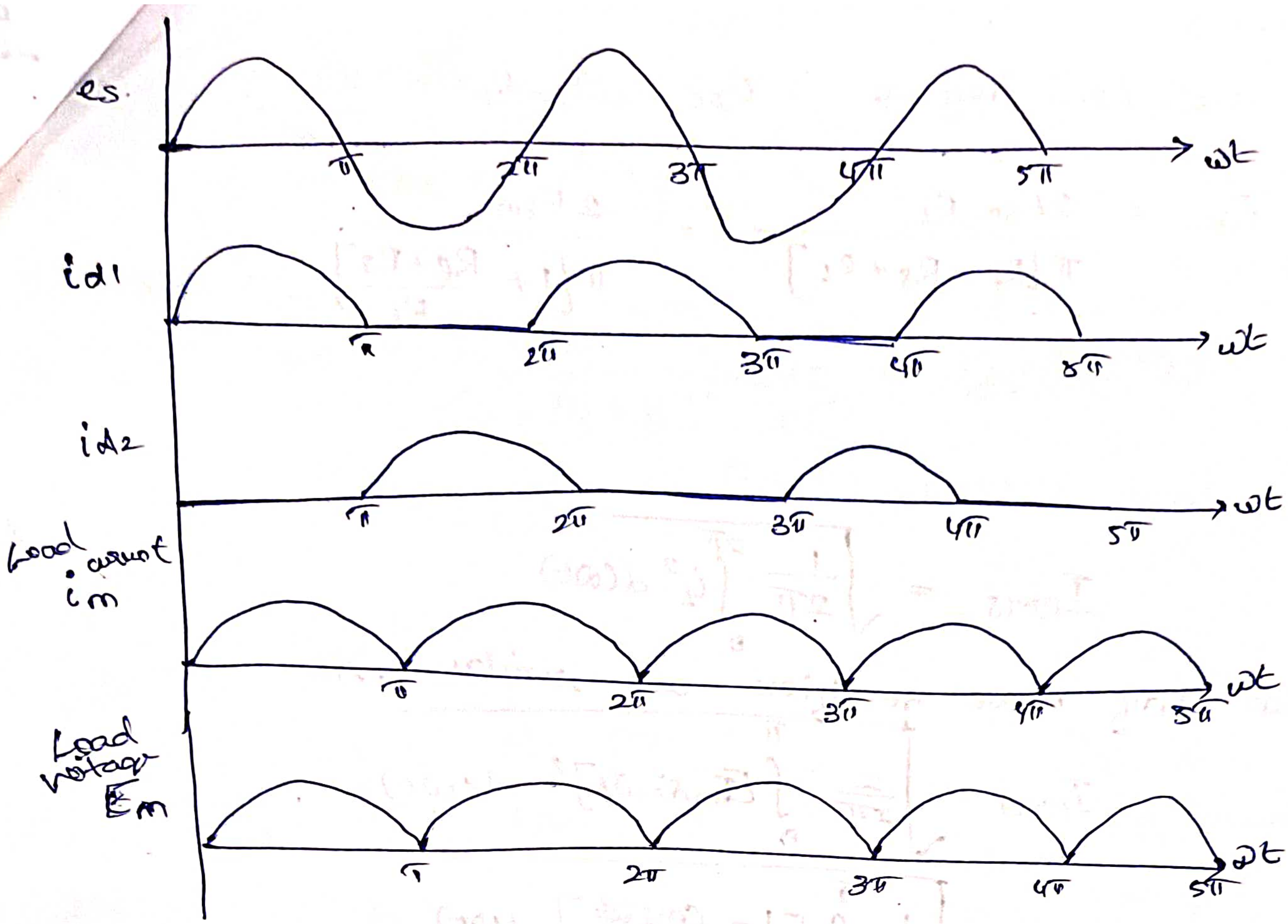
$D_1 \rightarrow$ forward biased it will conduct

$D_2 \rightarrow$ reverse " it will be as an open circuit.
and will not conduct.

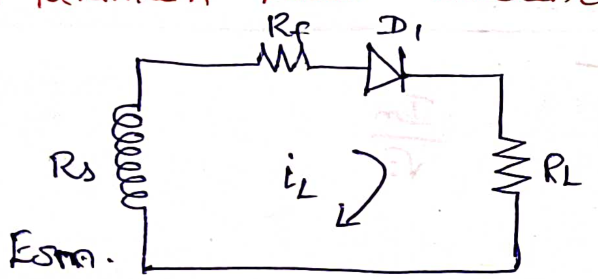
$i_L = i_{d1}$.

$i_L = i_{d2}$.

The Load current flows in both the half cycles of ac voltage and it will be in the same direction through Load resistance.



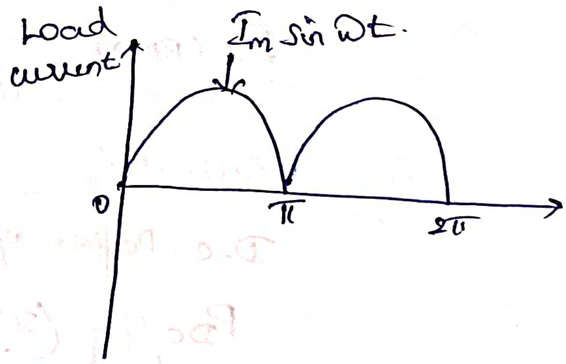
Maximum Load Current :-



$$I_m = \frac{E_{sm}}{R_s + R_f + R_L}$$

I_m is the maximum value of load current i_L.

Average DC Load current (I_{DC}).



$i_L = I_m \sin \omega t \qquad 0 \le \omega t \le \pi$

$$I_{av} = I_{DC} = \frac{1}{\pi}\int_0^{\pi} i_L \, d(\omega t)$$

$$= \frac{1}{\pi}\int_0^{\pi} I_m \sin \omega t \cdot d\omega t$$

$$= \frac{I_m}{\pi}\left[(-\cos\omega t)_0^{\pi}\right] = \frac{I_m}{\pi}\left[-\cos\pi - (-\cos 0)\right]$$

$$= \frac{I_m}{\pi}(1 - (-1)) = \frac{2I_m}{\pi}$$

$$I_{DC} = 2I_m/\pi.$$

Average DC Load Voltage

d.c. Load Voltage, $E_{DC} = I_{DC} R_L = \frac{2 I_m R_L}{\pi}$

$$E_{DC} = \frac{2 E_{sm} R_L}{\pi [R_f + R_s + R_L]} = \frac{2 E_{sm}}{\pi \left[1 + \frac{R_f + R_s}{R_L}\right]}$$

$$E_{DC} = \frac{2 E_{sm}}{\pi}$$

RMS Load current (I_{RMS}).

$$I_{RMS} = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} i_L^2 \, d(\omega t)}$$

Two half wave rectifiers are similar, so

$$I_{RMS} = \sqrt{\frac{2}{2\pi} \int_0^{\pi} [I_m \sin \omega t]^2 \cdot d(\omega t)}$$

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

$$= I_m \sqrt{\frac{1}{2\pi} (\pi)} = \frac{I_m}{\sqrt{2}}$$

$$I_{RMS} = \frac{I_m}{\sqrt{2}}.$$

RMS Value of Load Voltage

$$E_{L(RMS)} = I_{RMS} R_L = \frac{I_m}{\sqrt{2}} R_L.$$

DC Power Output :-

$$\text{D.c. Power o/p} = E_{DC} I_{DC} = I_{DC}^2 R_L. \qquad \because E_{DC} = I_{DC} R_L$$

$$P_{DC} = \left(\frac{2 I_m}{\pi}\right)^2 R_L = \frac{4 I_m^2 R_L}{\pi^2}$$

Sub I_m.

$$P_{DC} = \frac{4}{\pi^2} \frac{E_{sm}^2}{(R_s + R_f + R_L)^2} \times R_L$$

power Input (P_{AC}).

$$P_{AC} = I_{RMS}^2 (R_f + R_S + R_L) = \left(\frac{I_m}{\sqrt{2}}\right)^2 (R_f + R_S + R_L)$$

$$P_{AC} = \frac{I_m^2 (R_f + R_S + R_L)}{2}.$$

Sub I_m.

$$P_{AC} = \frac{E_{sm}^2}{(R_f + R_S + R_L)^2} \times \frac{1}{2} \times (R_f + R_S + R_L)$$

$$P_{AC} = \frac{E_{sm}^2}{2(R_f + R_S + R_L)}$$

Rectifier Efficiency η.

$$\eta = \frac{P_{DC}\ \text{Output}}{P_{AC}\ \text{input}} = \frac{\frac{4}{\pi^2} I_m^2 R_L}{\frac{I_m^2 (R_f + R_S + R_L)}{2}}$$

$$\eta = \frac{8 R_L}{\pi^2 (R_f + R_S + R_L)}$$ $R_f + R_S \ll R_L$.

$$\eta = \frac{8 R_L}{\pi^2 (R_L)} = \frac{8}{\pi^2}$$

$$\eta = \frac{8}{\pi^2} \times 100 = 81.2\%.$$

Voltage Regulation :-

$$(V_{dc})_{NL} = \frac{2 E_{sm}}{\pi}$$

$$(V_{dc})_{FL} = I_{DC} R_L$$

$$\%R = \frac{(V_{dc})_{NL} - (V_{dc})_{FL}}{(V_{dc})_{FL}} \times 100$$

$$\%R = \frac{\frac{2E_{sm}}{\pi} - I_{DC} R_L}{I_{DC} R_L} \times 100$$

$$\because I_m = \frac{E_{sm}}{R_f + R_L + R_s}.$$

$$E_{sm} = I_m (R_f + R_L + R_s)$$

$$= \frac{\frac{2 I_m}{\pi}[R_f + R_L + R_s] - \frac{2 I_m}{\pi} R_L}{\frac{2 I_m}{\pi} R_L} \times 100$$

$$I_{DC} = \frac{2 I_m}{\pi}$$

$$\% R = \frac{R_f + R_L + R_S - R_L}{R_L} \times 100$$

$$\% R = \frac{R_f + R_S}{R_L} \times 100$$ Neglecting resistance

$$\% R = \frac{R_f}{R_L} \times 100.$$

PROBLEMS :

In a centre-tapped full wave rectifier, the rms half secondary voltage is 9V, Assuming ideal diodes and load resistance $R_L = 1K\Omega$, find : 1. peak current 2. DC load Voltage 3. RMS current 4. Ripple factor 5. Efficiency

Solution : $E_S(rms) = 9V$, $R_L = 1K\Omega$.

i) $$I_m = \frac{E_{sm}}{R_L}$$

$$E_{sm} = \sqrt{2}\, E_S(rms) = \sqrt{2} \times 9 = 12.7279\ V.$$

$$I_m = \frac{12.7279}{1 \times 10^3} = 12.7279\ mA.$$

ii) $$I_{DC} = \frac{2I_m}{\pi} = \frac{2 \times 12.7279}{\pi} = 8.1028\ mA$$

$$E_{DC} = I_{DC} R_L = 8.1028 \times 10^{-3} \times 1 \times 10^3 = 8.1028\ V$$

(iii) $$I_{RMS} = \frac{I_m}{\sqrt{2}} = \frac{12.7279}{\sqrt{2}} = 9mA.$$

(iv) $$\text{Ripple factor} = \sqrt{\left[\frac{I_{rms}}{I_{DC}}\right]^2 - 1} = \sqrt{\left(\frac{9}{8.1028}\right)^2 - 1} = 0.48.$$

(v) $$P_{DC} = I_{DC}^2 R_L = (8.1028)^2 \times 1 \times 10^3 = 65.65\ mW$$

$$P_{AC} = I_{rms}^2 R_L = 9^2 \times 1 \times 10^3 = 81\ mW$$

$$\% \eta = \frac{P_{DC}}{P_{AC}} \times 100 = \frac{65.65}{81} \times 100 = 81.04\%.$$