UNIT- V

POWER SUPPLIES AND ELECTRONIC DEVICE TESTING

Linear mode power supply - Rectifiers - Filters - Half wave Rectififer power supply - Full wave Rectifier power supply - Voltage supply regulators: voltage regulation - Linear series, shunt and switching voltage regulators - Over voltage protection BJT and MOSFET - Switched Mode power supply (SMPS) - power supply performance and Testing - Troubleshooting and Fault Analysis, Design of Regulated power supply.

RECTIFIERS:-

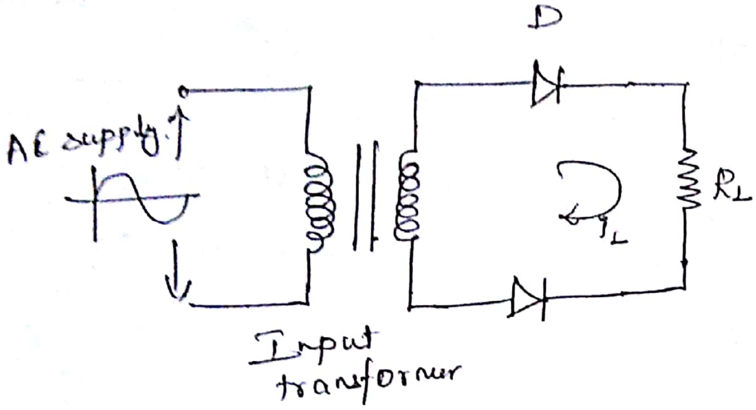
* A rectifier is a device which converts a.c. voltage to pulsating d.c. voltage using one (or) more p-n junction diodes.

* A p-n junction diode conducts when forward biased while it doesnot conduct when reverse biased. Hence it can be used to converts a.c. supply to dc supply.

* Various types of rectifiers using diodes are
  (i) Half wave rectifier
  (ii) Full wave rectifiers
  (iii) Bridge rectifier.

Half wave Rectifier:-

Half wave rectifier circuit consists of resistive load, rectifying element i.e p-n junction diode, and the source of ac voltage, all connected in series.



* To obtain the desired dc voltage across the load, the ac voltage is supplied to rectifier circuit using suitable step-up (or) step-down transformer, mostly a step-down one, with necessary turns ratio.

* The input voltage to the half-wave rectifier circuit is a sinusoidal ac voltage, having a frequency which is the supply frequency 50 Hz given by,

$$e_s = E_{sm} \sin\omega t \qquad \omega = 2\pi f$$

$f \rightarrow$ supply frequency.

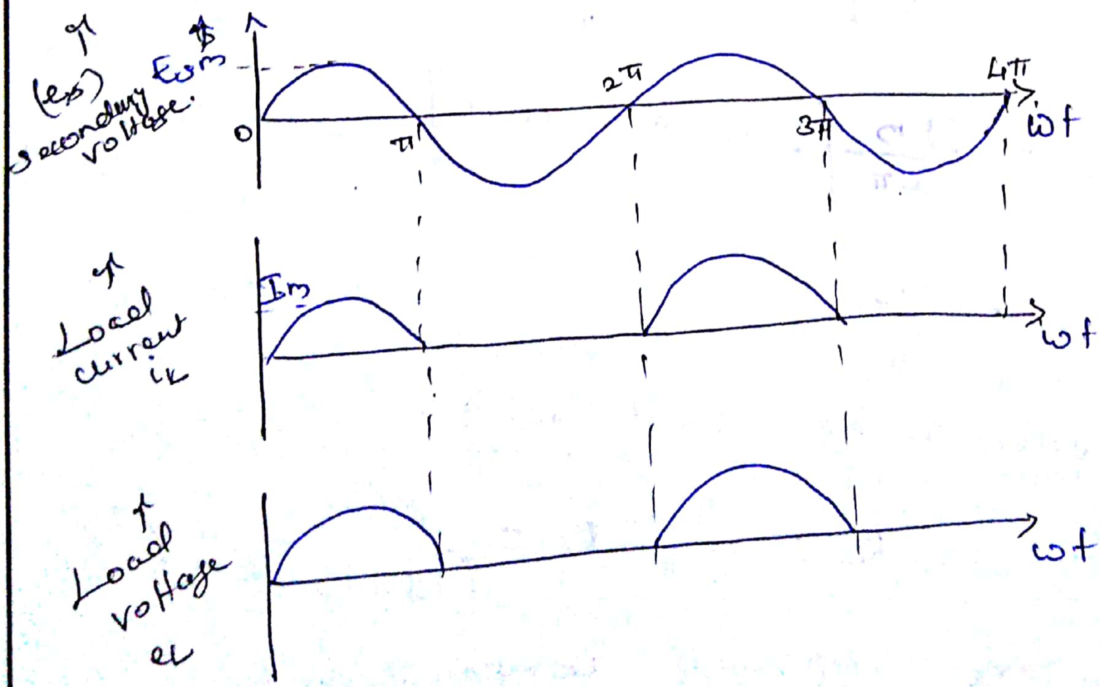
* The transformer decides the peak value of the secondary voltage. If N_1 are the primary number of turns and N_2 are the secondary number of turns and E_{pm} is the peak value of the primary voltage then,

$\frac{N_2}{N_1} = \frac{E_{sm}}{E_{pm}}$ $E_{sm} \rightarrow$ Peak value of the secondary ac voltage

* During the positive half cycle of input ac voltage, terminal A becomes positive with respect to terminal (B). The diode is forward biased and the current flows in the circuit in the clockwise direction. This current also flows through R_L.

* During negative half cycle when terminal (A) is negative with respect to terminal (B), diode becomes reverse biased. Hence no current flows in the circuit.

* Thus the circuit current which is also the load current, is in the form of half sinusoidal pulses.



Peak value of load current is,

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

where $R_f \rightarrow$ Forward resistance of diode

$R_s \rightarrow$ Resistance of secondary winding of transformer.

Parameters :-

① Average (or) dc value of load current :-

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

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

$$= \frac{I_m}{2\pi} \Big[-\cos(\omega t) \Big]_0^{\pi}$$

$$= \frac{I_m}{2\pi} \Big[-\cos \pi - \cos 0 \Big]$$

$$= \frac{I_m}{\pi}$$

② The average dc load voltage (E_{DC}).

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

R_s and R_L are very small compared to R_L.

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

(3) RMS value of the load current (I_{RMS}):

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

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

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

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

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

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

RMS value of load voltage:-

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

$$E_{L(rms)} = \frac{E_{sm}}{2}$$

(4) Output DC power:-

$$P_{DC} = E_{DC} I_{DC}$$

$$= I^2_{DC} R_L$$

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

$$P_{DC} = \frac{I_m^2}{\pi^2} R_L$$

5). Input AC power:-

P_{AC} is the ac power taken from the secondary of transformer.

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

$$= \left(\frac{I_m}{2}\right)^2 [R_s + R_f + R_L]$$

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

6). Rectifier Efficiency:-

Rectifier efficiency is defined as the ratio of output dc power to input ac power.

$$\eta = \frac{P_{DC}}{P_{AC}} = \frac{\frac{I_m^2}{\pi^2} R_L}{\frac{I_m^2}{4}[R_f + R_L + R_s]}$$

$$= 0.406 \frac{R_L}{R_f + R_L + R_s}$$

If $(R_f + R_s) << R_L$, then

$$\% \eta_{max} = 0.406 \times 100$$

$$\boxed{\% \eta_{max} = 40.6 \%}$$

* More the rectifier efficiency, less the ripples.

Ripple Factor :-

Ripple factor tells how smooth is the output.

It is defined as the ratio of RMS value of ac component in the output to the average or dc component present in the output.

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

RMS value of total ac current is,

$$I_{RMS} = \sqrt{I^2_{ac} + I^2_{DC}}$$

$$\Rightarrow I_{ac} = \sqrt{I^2_{RMS} - I^2_{DC}}$$

$$\therefore \text{Ripple factor} = \frac{I_{ac}}{I_{DC}}$$

$$= \frac{\sqrt{I^2_{RMS} - I^2_{DC}}}{I_{DC}} = \sqrt{\left[\frac{I_{RMS}}{I_{DC}}\right]^2 - 1}$$

This is the general expression for ripple factor and can be used for any rectifier circuit.

For Half wave rectifier,

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

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

$$= 1.21$$

$$\boxed{\gamma\% = 121\%}$$

The ripple factor for half wave rectifier is very high which indicates that the half wave circuit is a poor converter of ac to dc.

Peak Inverse Voltage

It is the peak voltage across the diode in the reverse direction.

In HWR, the load current is ideally zero when the diode is reverse biased and hence the maximum value of the voltage that can exist across the diode is E_{sm}.

$$\therefore \boxed{PIV = E_{sm}}$$

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Voltage Regulation:

It is the factor which tells us about the change from no load to full load condition.

$$\% \text{ Voltage Regulation} = \frac{V_{dc}(NL) - V_{dc}(FL)}{V_{dc}(FL)} \times 100$$

Less the value of voltage regulation, better is the performance of rectifier circuit.

Transformer Utilization factor :— TUF

It is the ratio of dc power delivered to the load to the ac power rating of the transformer.

$$TUF = \frac{\text{DC power delivered to the load}}{\text{Ac power rating of the transformer.}}$$

$$P_{DC} = I_{DC}^2 R_L = \frac{I_m^2}{\pi^2} R_L$$

AC power rating of transformer $= E_{RMS} \, I_{RMS}$

$$P_{AC} = \frac{E_m}{\sqrt{2}} \frac{I_m}{2} = \frac{I_m R_L}{\sqrt{2}} \times \frac{I_m}{2} = \frac{I_m^2}{2\sqrt{2}} R_L$$

$$\therefore \; TUF = \frac{\frac{I_m^2}{\pi^2} R_L}{\frac{I_m^2}{2\sqrt{2}} R_L}$$

$$= \frac{2\sqrt{2}}{\pi^2} = 0.287$$

ADVANTAGES

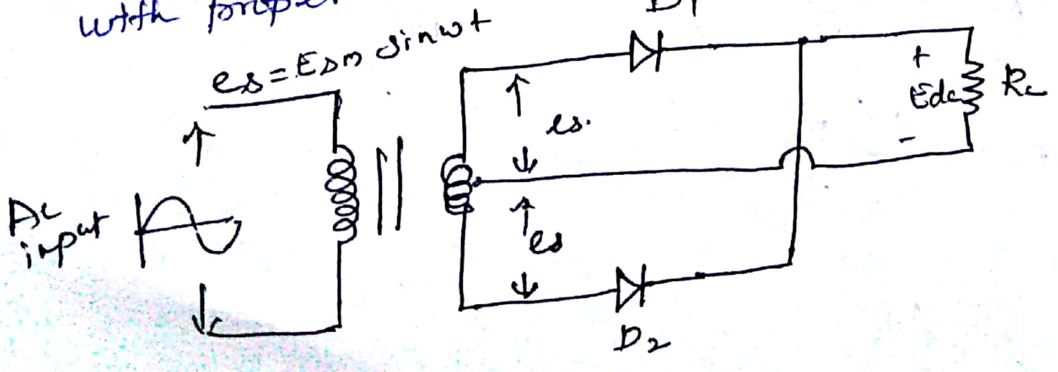
* Only one diode is sufficient
* The circuit is easy to design
* No centre tap on the transformer is necessary.

DISADVANTAGES

* The ripple factor is quite high
* The maximum theoritical rectification efficiency is found to be 40% , which is very low.

FULL WAVE RECTIFIER

* The full wave rectifier conducts during both positive and negative half cycle of input ac supply. In order to rectify both the half cycles of ac input, two diodes are used in the circuit.
* The diodes feed a common load R_L with the help of a center tap transformer. The ac voltage is applied through a suitable power transformer with proper turns ratio.



Operation :-

* During positive half cycle of the input, the diode D_1 will be forward biased and diode D_2 will be reverse biased.

* The Diode D_1 supplies the load current ie.

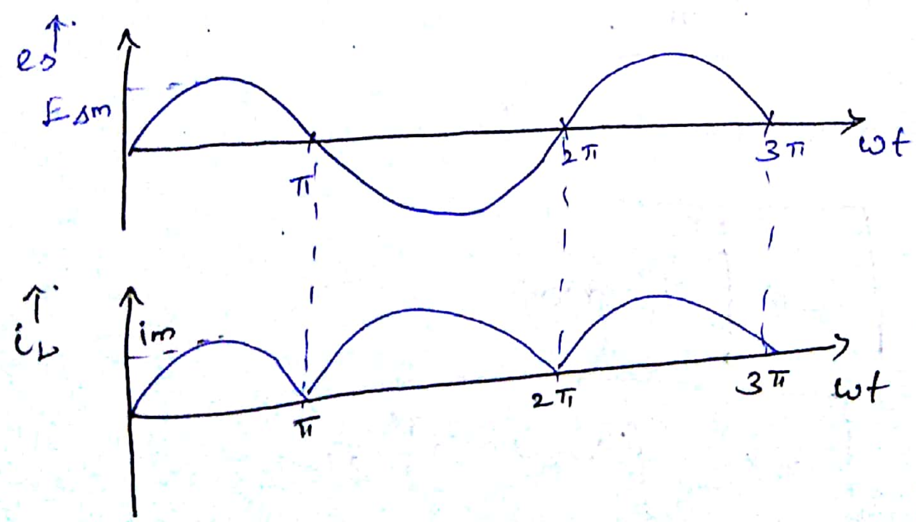
$i_L = i_{d1}$

* During negative half cycle, the diode D_2 conducts, diode D_1 will be in negative polarity.

* The diode diode D_2 supplies the load current

ie, $i_L = i_{d2}$.

The load current flows in both the half cycles of ac voltage and in the same direction through the load resistance. Hence we get rectified output across the load. The load current is sum of individual diode currents flowing in corresponding half cycles.



The maximum load current is,

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

Parameters:-

(1) DC Load current :-

The load current i_L is given by,

$$i_L = I_m \sin \omega t \qquad 0 \le \omega t \le 2\pi$$

$$I_{av} = I_{dc} = \frac{1}{2\pi} \int_0^{2\pi} i_L \, d\omega t$$

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

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

$$= \frac{I_m}{\pi} \left[+1 + 1 \right]$$

$$\boxed{I_{dc} = \frac{2 I_m}{\pi}}$$

(2) RMS Load Current :- I_{RMS}

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

$$= \sqrt{2 \times \frac{1}{2\pi} \int_0^{\pi} \left[I_m \sin \omega t \right]^2 d\omega t}$$

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

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

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

(3) DC power output :- P_{dc}

$$P_{DC} = E_{DC} I_{DC}$$

$$= I_{dc}^2 R_L$$

$$= \left[\frac{2I_m}{\pi}\right]^2 R_L = \frac{4}{\pi^2} \frac{E_{sm}^2}{(R_s + R_f + R_L)^2} \times R_L$$

$$\boxed{P_{dc} = \frac{4}{\pi^2} I_m^2 R_L}$$

(4) AC power input P_{AC} :-

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

$$= \left(\frac{I_m}{\sqrt{2}}\right)^2 (R_f + R_s + R_L)$$

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

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

5). Efficiency :-

$$\eta = \frac{P_{dc}\text{ (output)}}{P_{AC}\text{ (input)}}$$

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

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

$$= \frac{8 R_L}{\pi^2 R_L}$$

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

$$\eta (\%) = 81.2 \%$$

⑥ Ripple factor :- γ

$$\text{Ripple factor} = \sqrt{\left[\frac{I_{RMS}}{I_{DC}}\right]^2 - 1}$$

$$\gamma = \sqrt{\frac{I_m/\sqrt{2}}{2I_m/\pi} - 1}$$

$$= \sqrt{\frac{\pi^2}{8} - 1}$$

$$\gamma = 0.48$$

48% of ripple present in the dc component of output.

(7) Peak Inverse Voltage (PIV)

* When the diode is reverse biased then full transformer secondary voltage gets impressed across it. The drop across conducting diode is assumed zero.

* When D_2 is reversed biased, point A is at $-E_{sm}$ with respect to ground while point B is at $+E_{sm}$ with respect to ground, neglecting diode drop.

* ∴ Thus the total peak voltage across D_2 is $2E_{sm}$.

$$PIV \text{ of diode} = 2E_{sm}$$

where E_{sm} → maximum value of ac voltage across half the secondary of transformer.

(8) Ripple Frequency :-

$$i_L = i_{d1} + i_{d2}$$

$$= I_m \left[\frac{2}{\pi} - \frac{4}{3\pi}\cos 2\omega t - \frac{4}{15\pi}\cos 4\omega t \ldots \right]$$

The first term in the above series represents the average or dc value, while the remaining terms "ripple".

The lowest frequency of the ripple is $2f$, twice the supply frequency of ac supply.

∴ The ripple frequency in full wave rectifier is '$2f$' Hz.

Voltage Regulation :-

$$V_{dc}(NL) = \frac{2E_{sm}}{\pi} \qquad V_{dc}(FL) = I_{DC} R_L$$

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

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

$$= \frac{\frac{2I_m}{\pi}(R_f + R_L + R_S) - \frac{2I_m}{\pi} R_L}{\frac{2I_m}{\pi} R_L} \times 100$$

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

neglecting winding resistance R_s, the regulation can be expressed as,

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

Transformer Utilization factor (T.U.F):-

$$TUF = \frac{\text{DC power to the load}}{\text{AC power rating of secondary}}$$

$$= \frac{I_{DC}^2 R_L}{E_{RMS} I_{RMS}} = \frac{\left(\frac{2}{\pi} I_m\right)^2 R_L}{\frac{E_{sm}}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}}}$$

$$\because E_{sm} = I_m R_L$$

$$\therefore \text{Secondary TUF} = \frac{\frac{4}{\pi^2} \times I_m^2 R_L}{\frac{I_m^2 R_L}{2}} = \frac{8}{\pi^2}$$

$$TUF = 0.812$$

TUF for primary winding = 2 x TUF of half wave circuit

$$= 2 \times 0.287$$

$$= 0.574$$

Ave. TUF for full wave circuit will be,

$$\text{Ave. TUF} = \frac{\text{TUF of primary} + \text{TUF of secondary}}{2}$$

$$= \frac{0.574 + 0.812}{2}$$

$$\boxed{\text{Ave. TUF} = 0.693}$$

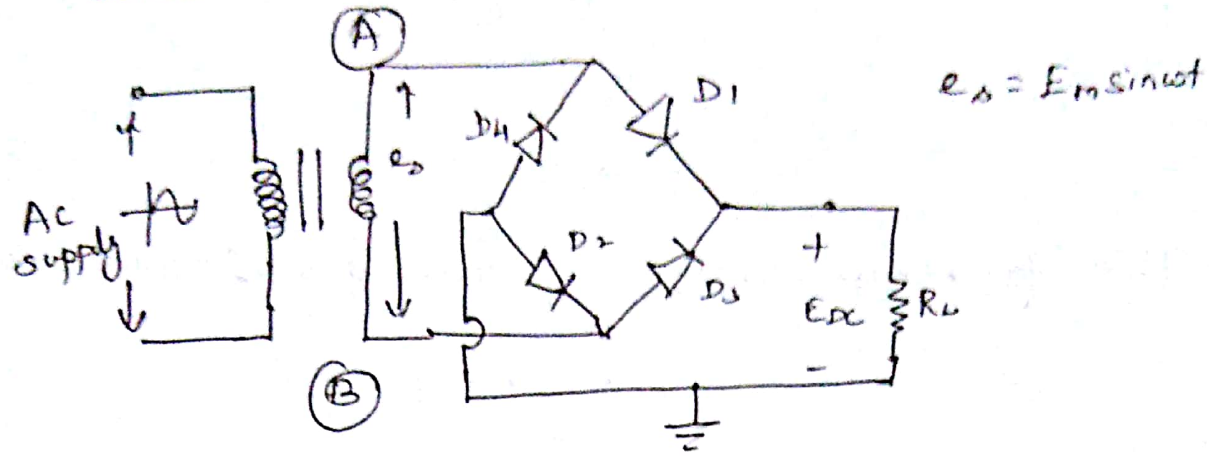
Advantages:-

1. The dc load voltage and current are more than half wave
2. No dc current through transformer windings hence no possibility of saturation.
3. TUF is better as transformer losses are less.
4. The efficiency is higher.
5. Large dc power output.
6. Ripple factor is less.

Disadvantages:-

1. PIV rating of diode is higher
2. Higher PIV diodes are larger in size and costlier.
3. Cost of centre-tap transformer is higher.

Bridge Rectifier :-



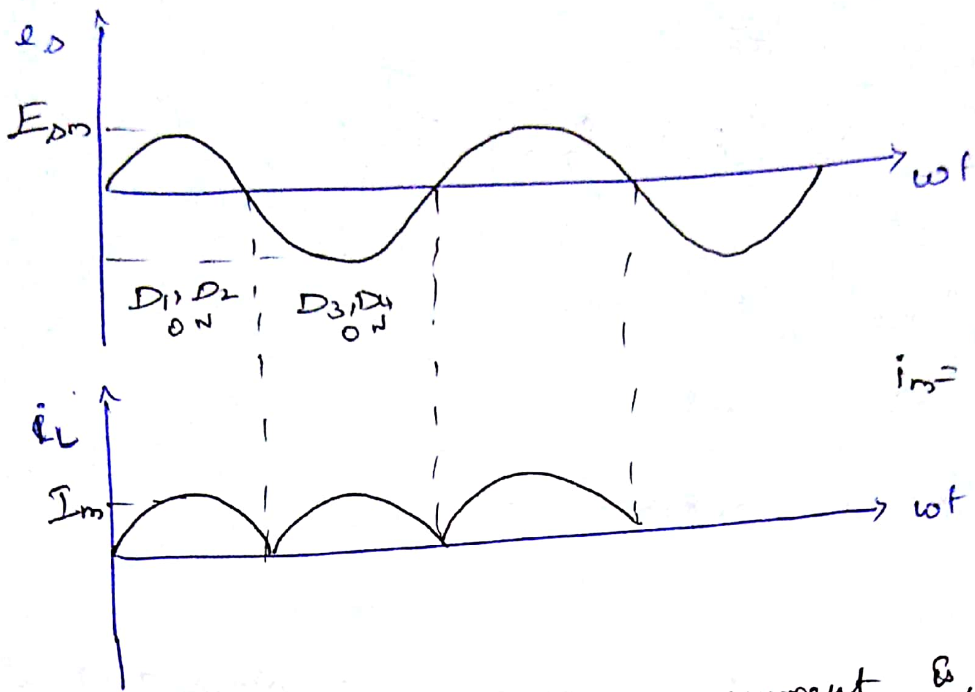
* During positive half cycle, the point A of secondary becomes positive. The diodes D_1 and D_2 will be forward biased, while D_3 and D_4 reverse biased.

* The two diodes D_1 and D_2 conduct in series with the load and the current flows.

* In the next half cycle, the polarity of ac voltage reverses hence point B becomes positive. Diodes D_3 and D_4 are forward biased while D_1 and D_2 reverse biased.

* The diodes D_3 and D_4 conducts in series with the load and the current flows.

* In both the cycles of ac, the load current flowing in the same direction, hence we get a full wave rectified output.



$i_m = \frac{E_{sm}}{R_s + 2R_f + R_L}$

The maximum value of load current is,

$$I_m = \frac{E_{sm}}{R_s + 2R_f + R_L}$$

* The only difference is that instead of R_f, the term $2R_f$ appears in the denominator.
* The PIV rating of the diodes is E_{sm}, as $2E_{sm}$ gets divided equally across two diodes.

The remaining expressions are identical to those derived for two diode full wave rectifier.

$$E_{DC} = I_{DC} R_L = \frac{2E_m}{\pi}$$

$$E_{RMS} = \frac{I_m}{\sqrt{2}} R_L = \frac{E_{sm}}{\sqrt{2}(R_s + 2R_f + R_L)} \cdot R_L$$

$$P_{DC} = I_{DC}^2 R_L = \frac{4}{\pi^2} I_m^2 R_L$$

$$P_{AC} = I_{RMS}^2 (R_s + 2R_f + R_L) = \frac{I_m^2 (2R_f + R_s + R_L)}{2}$$

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

$\% \eta_{max} = 81.2\%$

$\eta = 0.48$

TUF = 0.812

Advantages:-

1. Power transformer of a small size and less cost may be used.
2. No center tap is required in transformer secondary.
3. The currents in the secondary of the transformer are in opposite directions in two half cycles. Hence net dc component flowing is zero which reduces the losses and danger of saturation.
4. The transformer gets utilized effectively.
5. The circuit can be used for high voltage applications.