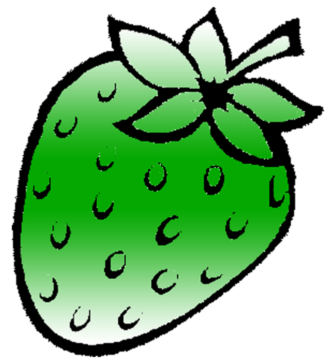
STRAWBERRY



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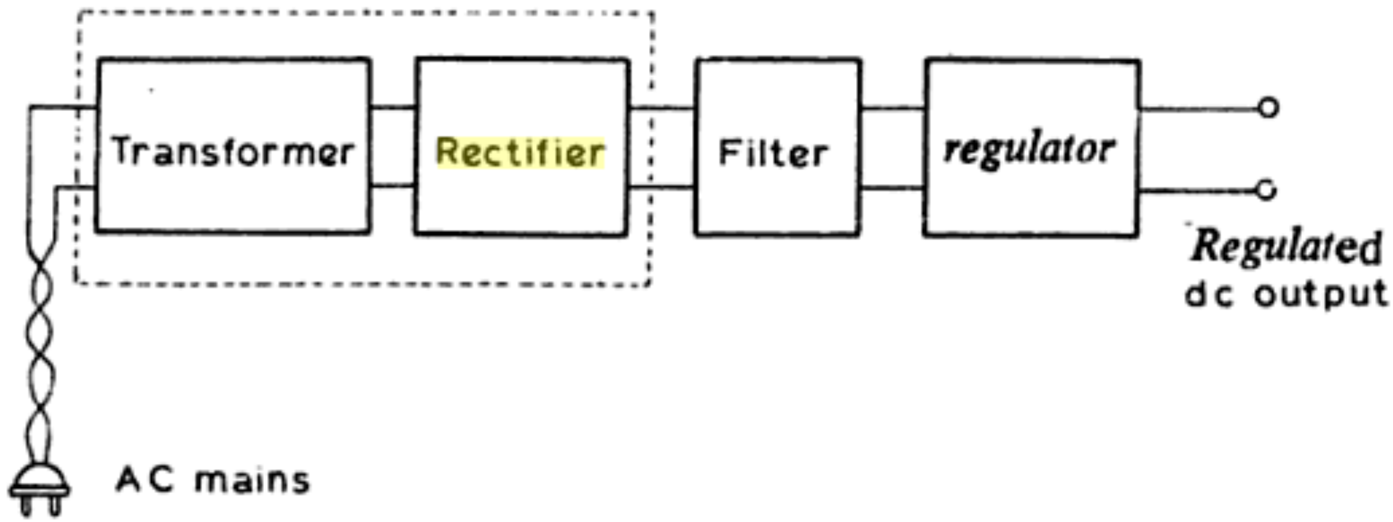
Unit 2- Application of Diodes

Contents

Rectifiers

Block diagram of Power Supply



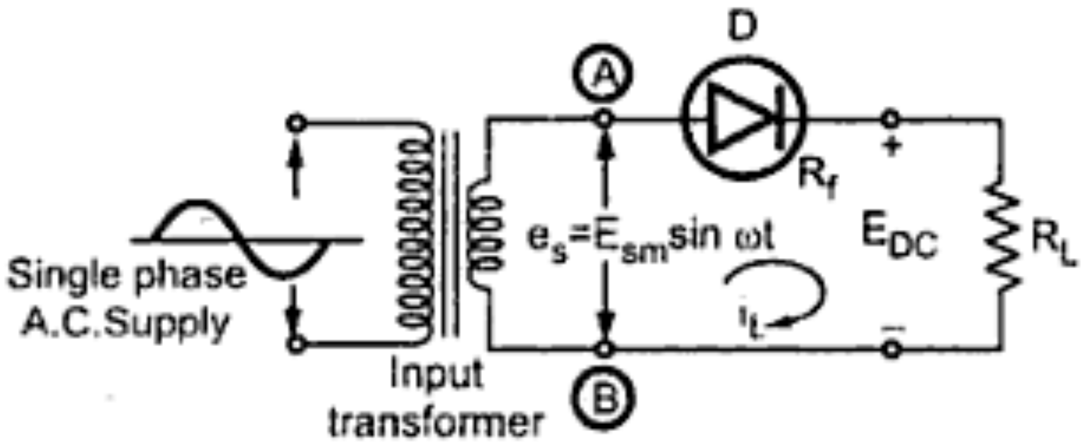
Rectifier

- A circuit that converts ac voltage of main supply into pulsating dc voltage using one or more pn junction diodes.

- Half Wave Rectifier
- Full Wave Rectifier
  - Center Tap Rectifier
  - Bridge Rectifier

Half Wave Rectifier

Circuit Diagram



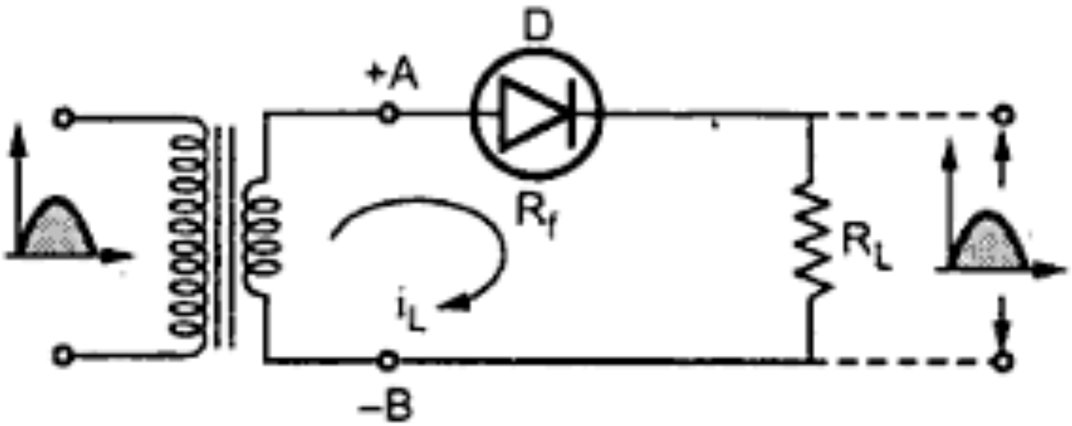
Half wave rectifier

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

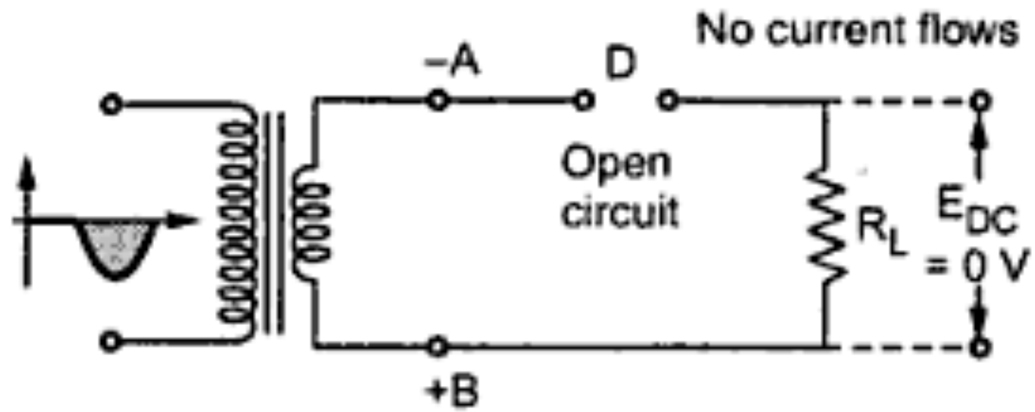
$\omega = 2\pi f$

f = supply frequency

Operation of Half Wave Rectifier

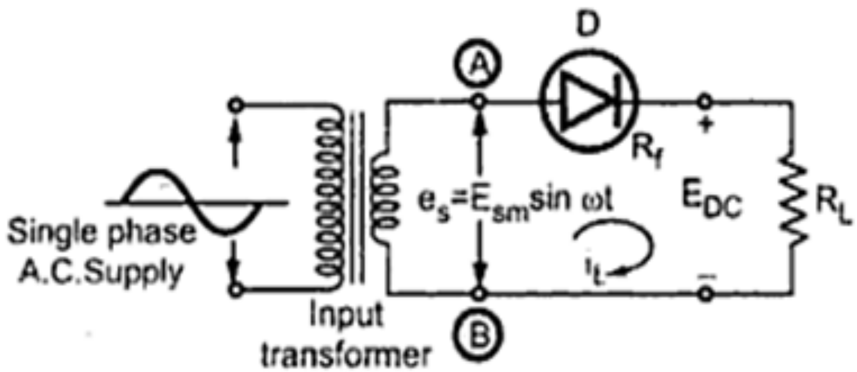


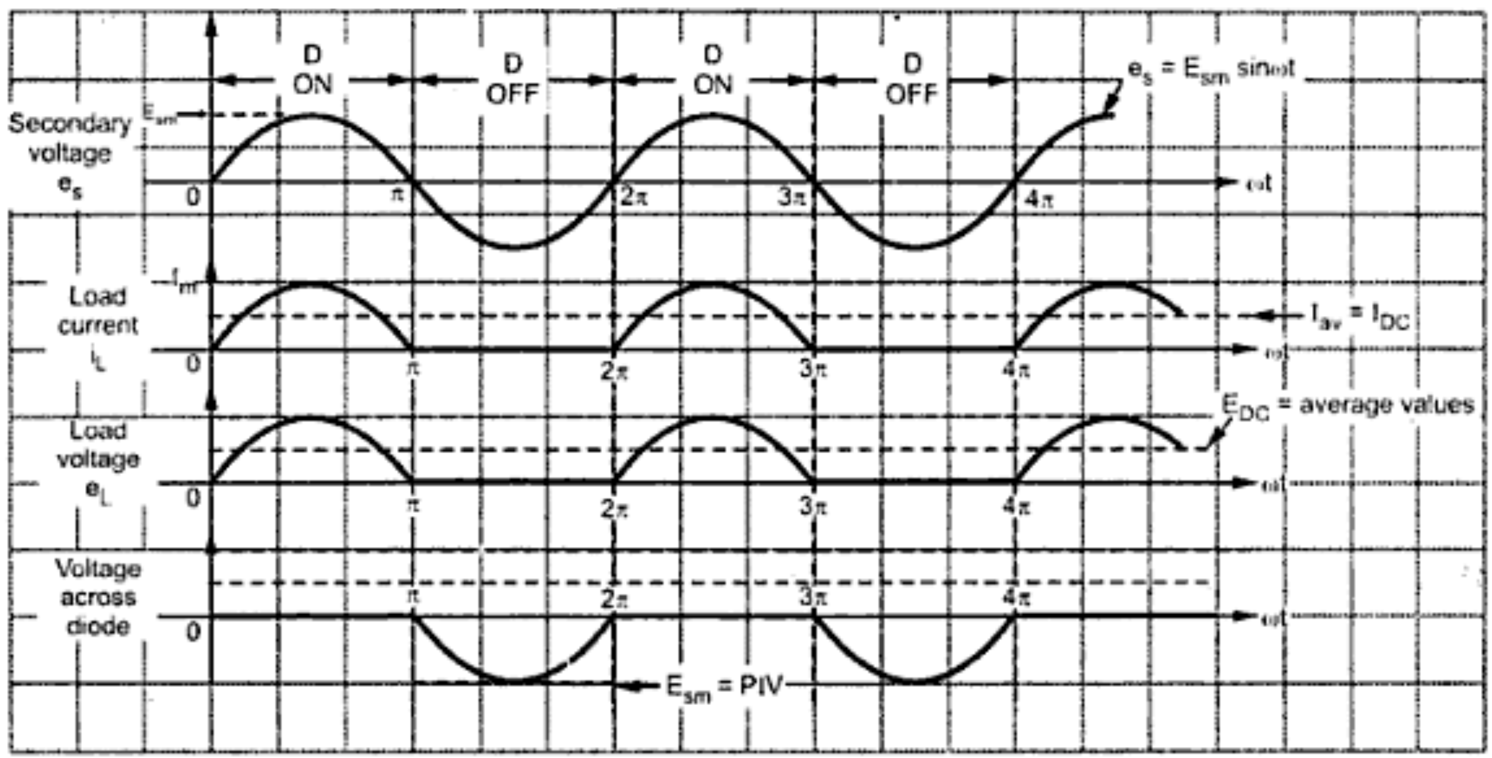
(a) Diode forward biased



(b) Diode reverse biased

Waveform of Half Wave Rectifier





Load current and load voltage waveforms for half wave rectifier

Average DC load Current (I_{DC})

Mathematically, current waveform can be described as,

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

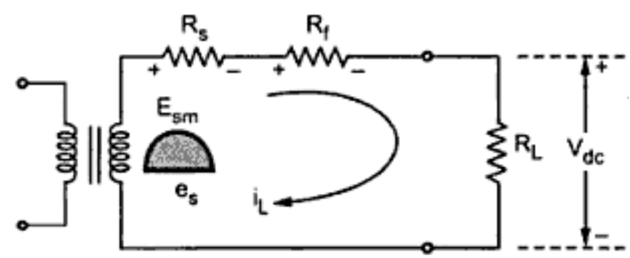
$$i_L = 0 \qquad \text{for } \pi \le \omega t \le 2\pi$$

I_m = peak value of load current

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

$$I_{DC} = \frac{I_m}{\pi} = \text{average value}$$

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



(a) Equivalent circuit

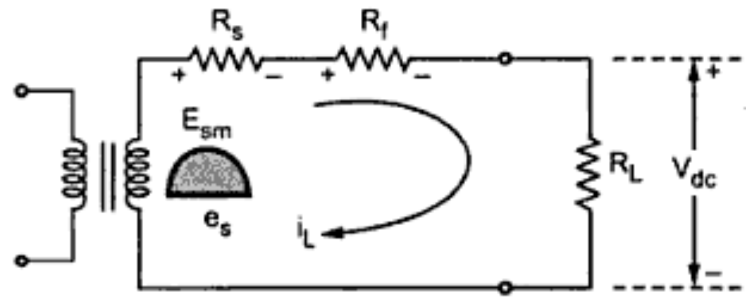
where R_s = resistance of secondary winding of transformer. If R_s is not given it should be neglected while calculating I_m.

Average DC voltage (Edc)

$$E_{DC} = I_{DC} R_L$$

$$E_{DC} = \frac{I_m}{\pi} R_L$$

$$= \frac{E_{sm}}{(R_f + R_L + R_s)\,\pi} R_L$$



(a) Equivalent circuit

But as R_f and R_s are small compared to R_L, $(R_f + R_s)/R_L$ is negligibly small compared to 1. So neglecting it we get,

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

RMS Load Current (Irms)

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

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

RMS Load Voltage (Erms)

$$E_{L\,(RMS)} \approx \frac{E_{sm}}{2}$$

DC Power Delivered to the load

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

$$\text{D.C. Power output} = I_{DC}^2 R_L = \left[\frac{I_m}{\pi}\right]^2 R_L = \frac{I_m^2}{\pi^2} R_L$$

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

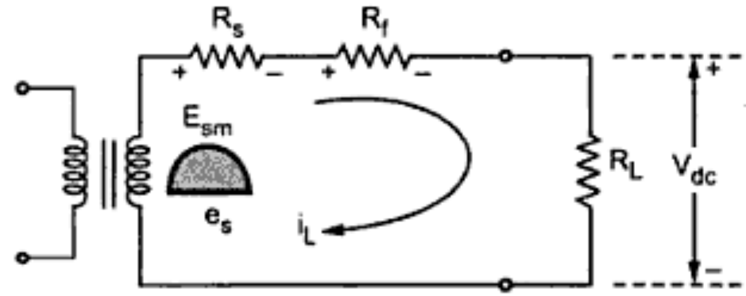
AC input power from transformer secondary

The power input taken from the secondary of transformer is the power supplied to three resistances namely load resistance R_L, the diode resistance R_f and winding resistance R_s. The a.c. power is given by,

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

$$I_{RMS} = \frac{I_m}{2} \quad \text{for half wave,}$$

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



(a) Equivalent circuit

How effectively a rectifier converts ac into dc:

- Rectifier Efficiency (η)

$$\eta = \frac{\text{D.C. output power}}{\text{A.C. input power}} = \frac{P_{DC}}{P_{AC}}$$

- Ripple Factor (r)

$$\text{Ripple factor} \quad \gamma = \frac{\text{R.M.S. value of a.c. component of output}}{\text{Average or d.c. component of output}}$$

Rectifier Efficiency (η)

Tells us the percentage of total input ac power that is converted into useful dc output power.

$$\eta = \frac{\text{D.C. output power}}{\text{A.C. input power}} = \frac{P_{DC}}{P_{AC}}$$

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

$\eta = 40.6\ \%$

Under best conditions (no diode loss) only 40.6% of the ac input power is converted into dc power.

The rest remains as the ac power in the load

Ripple Factor

Measure of purity of the dc output of a rectifier

Defined as the ratio of ac component of the output wave to the dc component in the wave

$$\text{Ripple factor} \quad \gamma = \frac{\text{R.M.S. value of a.c. component of output}}{\text{Average or d.c. component of output}}$$

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

Ripple Factor

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

Now for a half wave circuit, $I_{RMS} = \frac{I_m}{2}$ $I_{DC} = \frac{I_m}{\pi}$

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

$$\gamma = 1.211$$

This indicates that the ripple content in the output are 1.211 times the dc component.

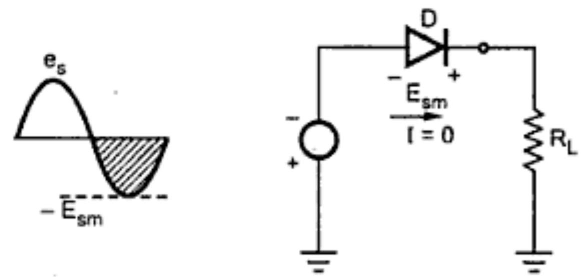
i.e. 121.1 % of dc component.

The ripple factor is very high.

Therefore a half wave rectifier is a poor converter of ac to dc.

The ripple factor is minimized using filter circuits along with the rectifier.

Peak Inverse Voltage (PIV)



Thus PIV occurs at the peak of each negative half cycle of the input, when diode is reverse biased and not conducting.

PIV = Em

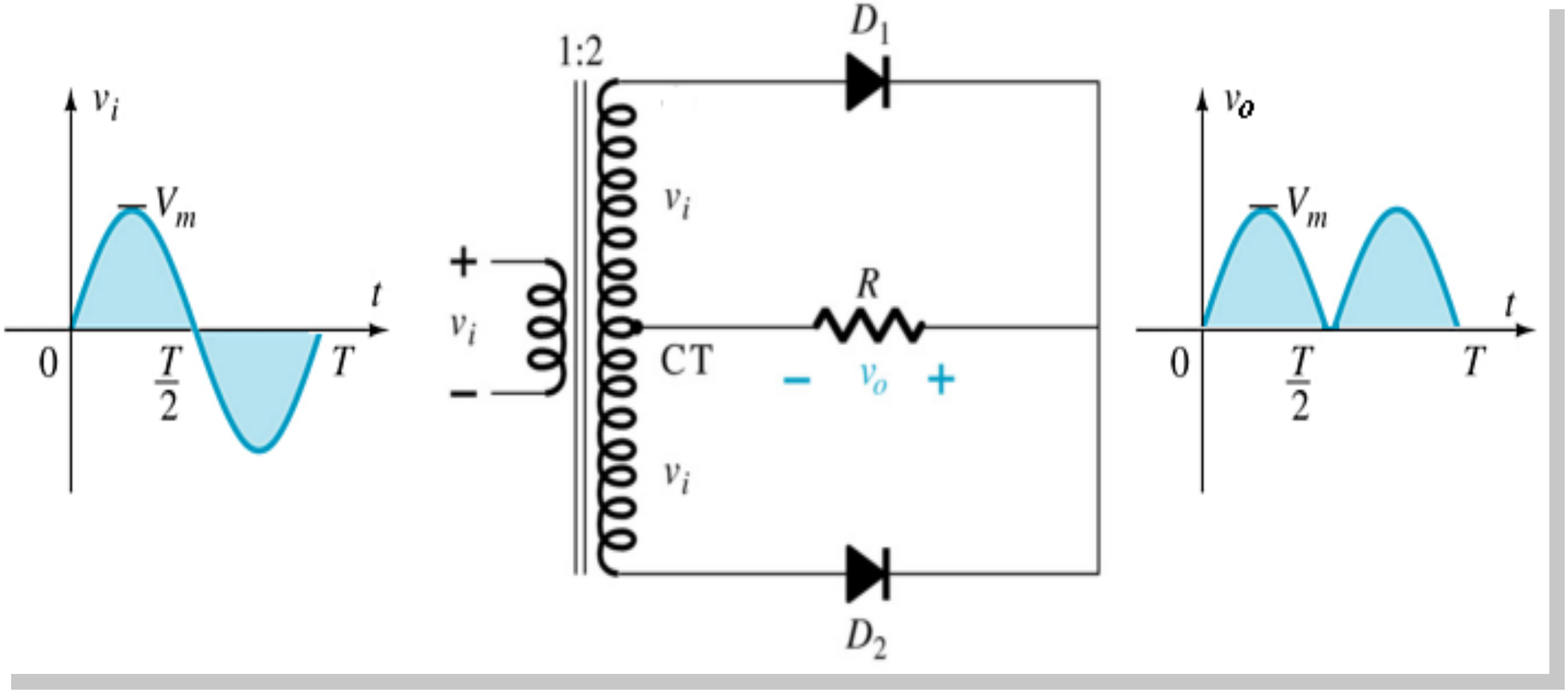
Diode must be selected based on the PIV rating and the circuit specification.

Disadvantage of HWR

- The ripple factor of half wave rectifier is 1.21, which is quite high.
- The output contains lot of ripples
- The maximum theoretical efficiency is 40%.
- The practical value will be quite less than this.
- This indicates that HWR is quite inefficient.

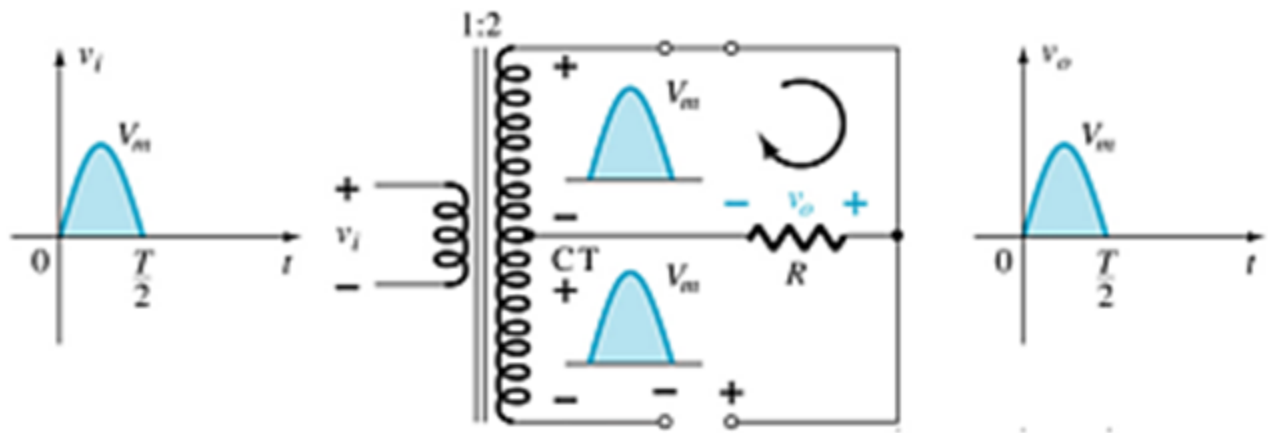
Half WaveRectifier

Center Tap Rectifier

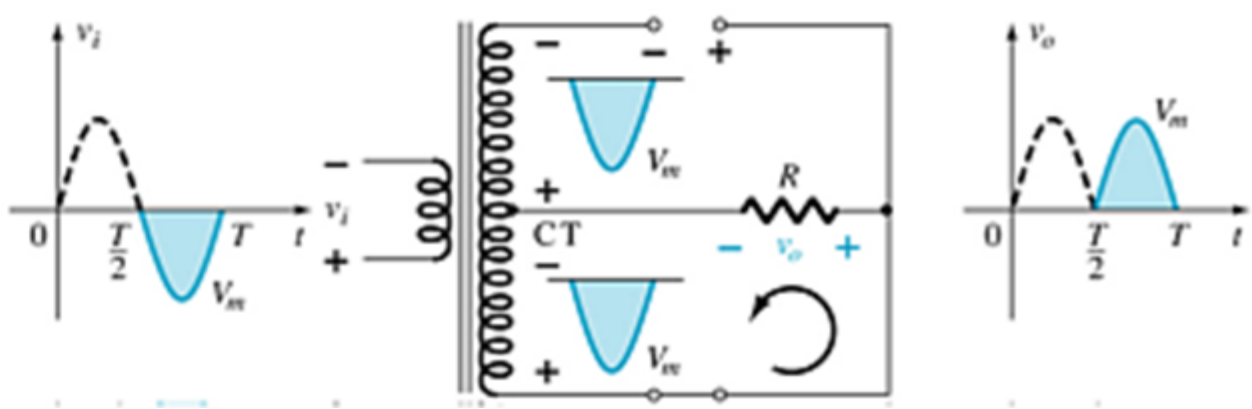


Working of Center Tap Rectifier

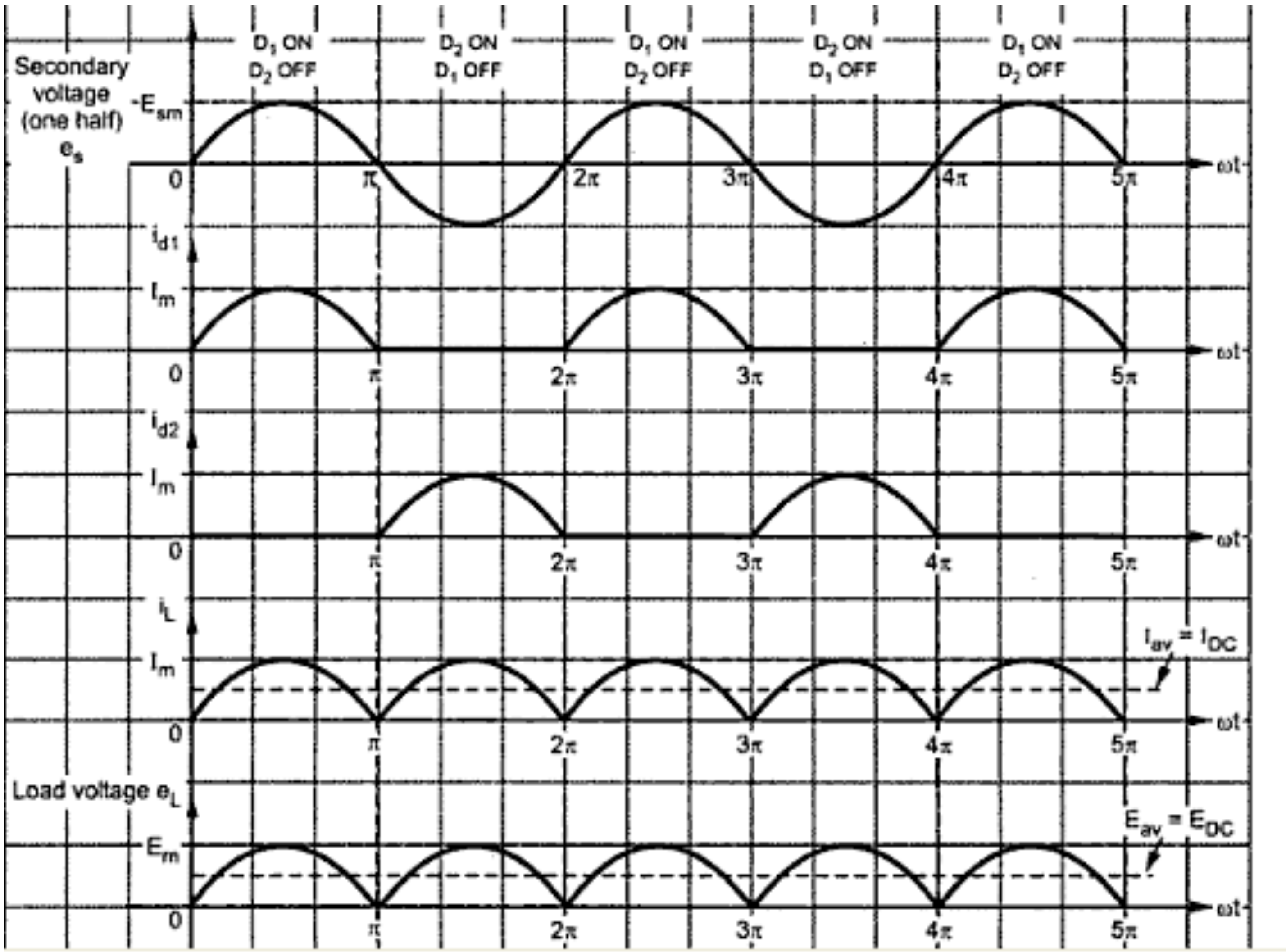
Current Flow during the positive half of the input cycle



Current Flow during the negative half of the input cycle



Waveforms



D1 ON D2 OFF
D2 ON D1 OFF
D1 ON D2 OFF
D2 ON D1 OFF
D1 ON D2 OFF
Secondary voltage (one half) es
Esm
0
π
2π
3π
4π
5π
ωt
id1
Im
id2
iL
Iav = IDC
Load voltage eL
Em
Eav = EDC

Average DC current

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

$$\boxed{I_{DC} = \frac{2I_m}{\pi}}$$ for full wave rectifier

Average (DC) Voltage

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

Substituting value of I_m,

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

But as R_f and $R_s << R_L$ hence $\frac{R_f + R_s}{R_L} << 1$

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

RMS Load Current (Irms)

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

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

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

RMS Load Voltage

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

DC Output Power

$$\text{D.C. Power output} = E_{DC} I_{DC} = I_{DC}^2 R_L$$

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

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

AC input power (Pac)

The a.c. power input is given by,

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

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

Rectifier Efficiency (η)

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

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

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

But if $R_f + R_s << R_L$, neglecting it from denominator

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

$$\therefore \quad \%\ \eta_{max} = \frac{8}{\pi^2} \times 100 = 81.2\ \%$$

Ripple Factor

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

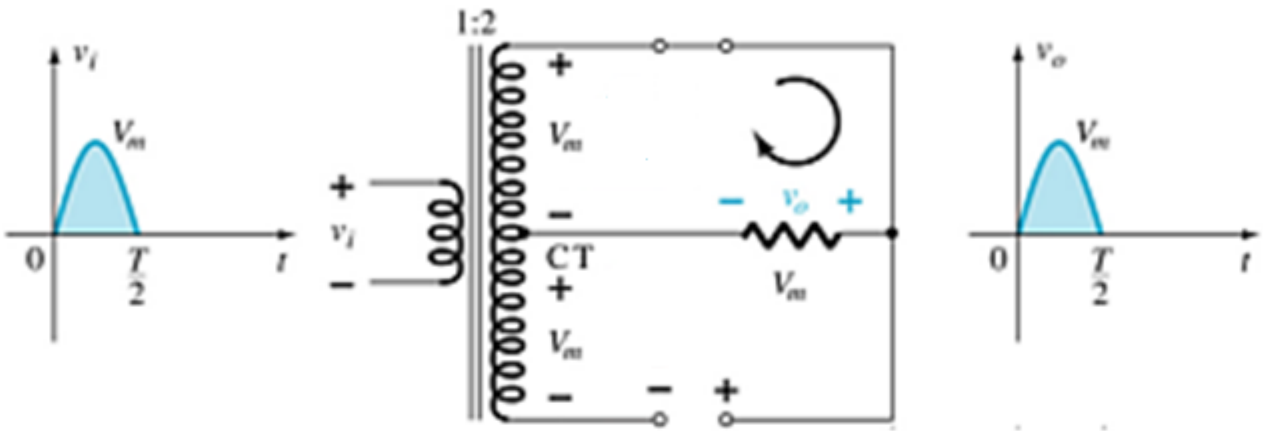
For full wave $I_{RMS} = I_m/\sqrt{2}$ and $I_{DC} = 2I_m/\pi$

$$\text{Ripple factor} = \sqrt{\left[\frac{I_m/\sqrt{2}}{2I_m/\pi}\right]^2 - 1} = \sqrt{\frac{\pi^2}{8} - 1}$$

$$\boxed{\text{Ripple factor} = \gamma = 0.48}$$

This indicates that the ripple contents in the output are 48% of the dc component which is much less than that for the half wave rectifier.

Peak Inverse Voltage



PIV of diode = 2 E_{sm}

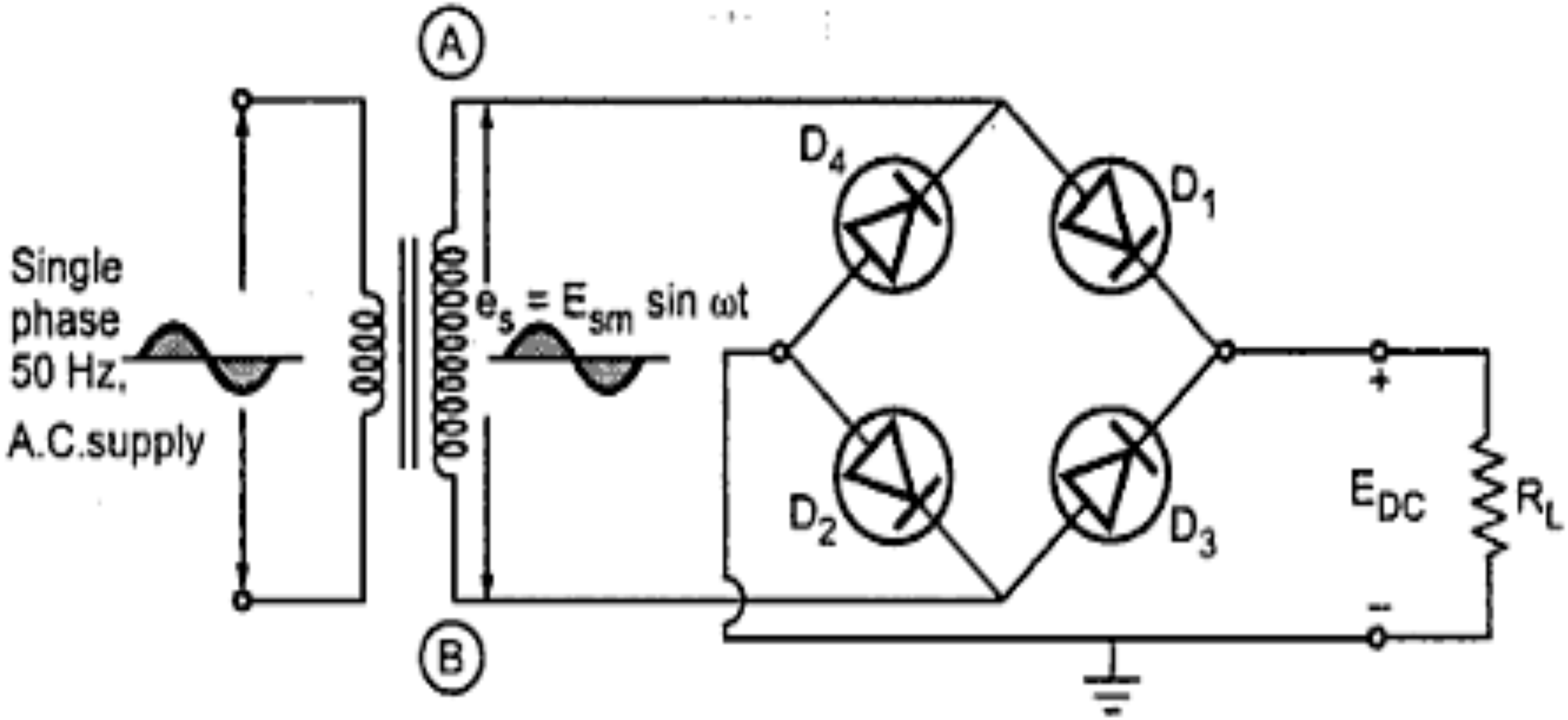
Advantages of Full Wave Rectifier

- Efficiency is higher.
- The large dc power output
- The ripple factor is less

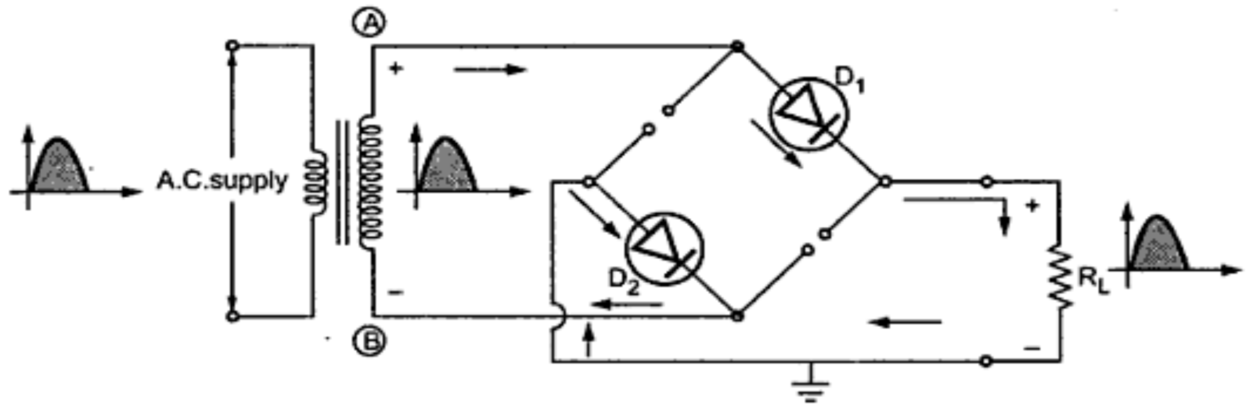
Disadvantages of Full Wave Rectifier

- PIV rating of diode is higher.
- Higher PIV diodes are larger in size and costlier.
- The cost of center tap transformer is high.

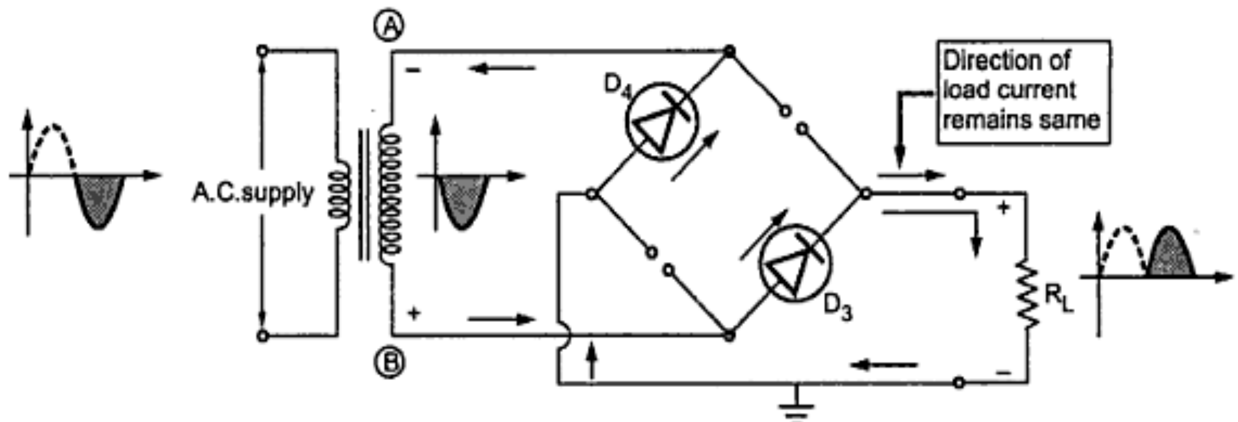
Bridge Rectifier



Working of Bridge Rectifier

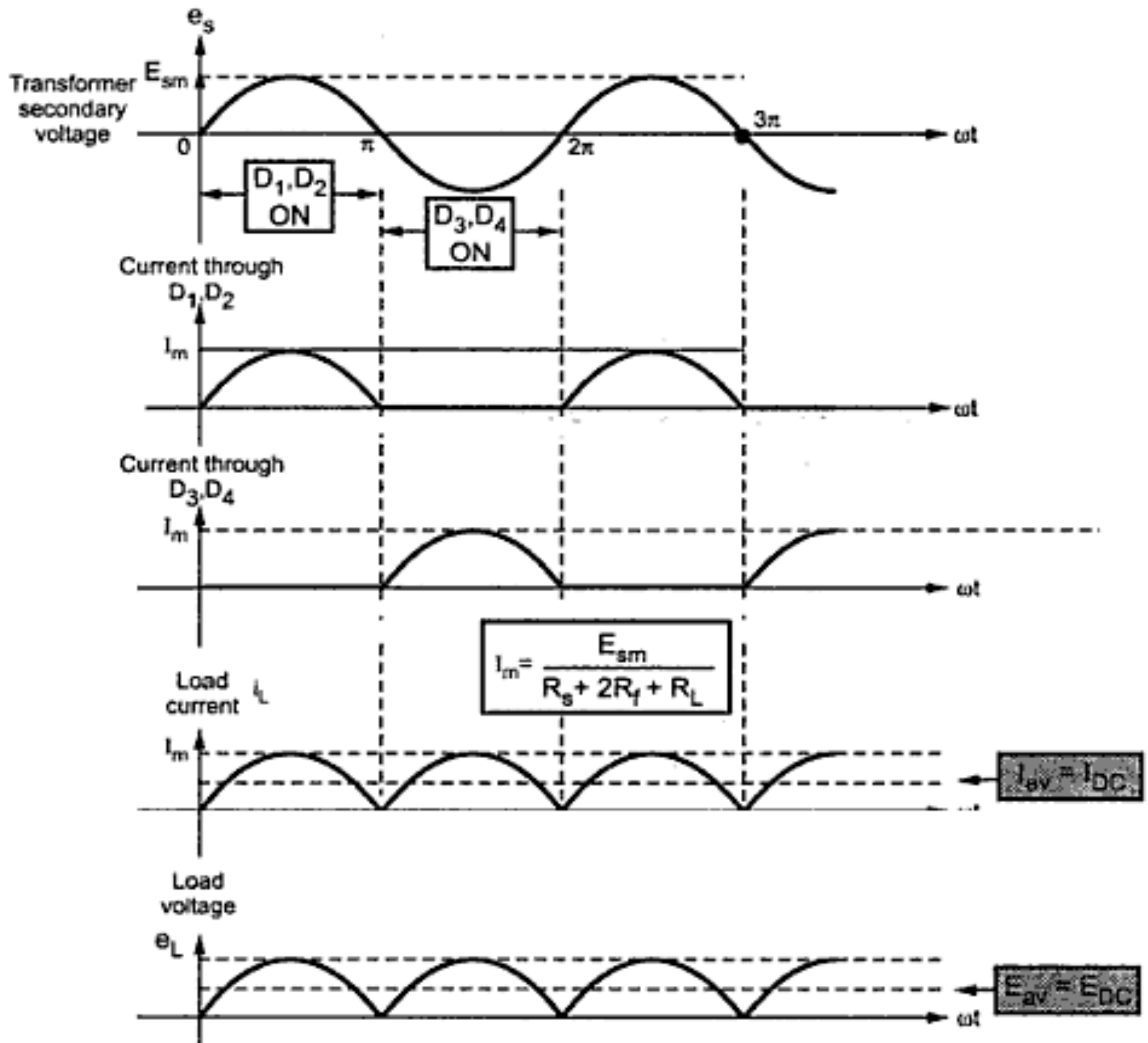


Current flow during positive half cycle



Current flow during negative half cycle

Waveforms of Bridge Rectifier



Parameters :

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

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

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

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

$$\eta = \frac{8R_L}{\pi^2 (R_s + 2R_f + R_L)}, \ \% \ \eta_{max} = 81.2\%$$

$$\gamma = 0.48$$

Advantages of Bridge Rectifier

- It does not need center tap transformer secondary.
- The transformer secondary voltage of CT rectifier is 2Vm, where as in Bridge the transformer secondary must have a peak voltage of Vm. That is the transformer secondary of CT rectifier must have double the number of turns. Such transformers are costlier.
- If stepping up or stepping down of voltage is not needed, we may even do away without transformer.
- Each diode in center tap has a PIV rating of 2Vm, whereas diodes in bridge rectifier needs a PIV rating of Vm. Hence the diodes for use in center tap rectifier are costlier than meant for bridge rectifier.

Disadvantages of Bridge Rectifier

- It requires four diodes, two of which conduct in alternate half cycles. This creates a total voltage drop of 1.4V (if Si diodes are used).
- Therefore this creates a problem if low dc voltage is required.
- The secondary voltage is low and two diode voltage drop of 1.4V becomes significant.