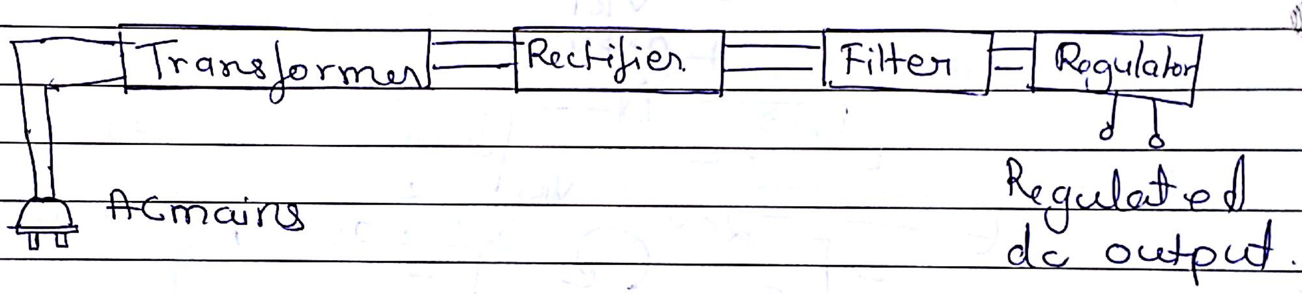
Sinusoidal inputs: Half-Wave Rectification.

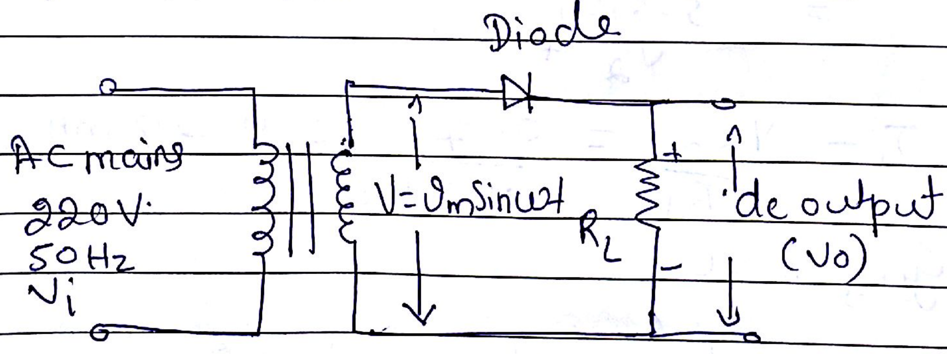
Use of diodes in Rectifiers:

Electric energy is available in homes and industries in India in the form of alternating voltage. 220 V (rms) at a frequency of 50 Hz.

Block diagram of a power supply:



Half Wave Rectifier:



- The transformer allows us to step the voltage up or down.
- It reduces the risk of electrical shock.

The diode forms a series circuit with the secondary of the transformer and the load resistor R_L.

The primary of the transformer is connected to the powermains. An ac voltage is induced across the secondary of the transformer. This voltage may be less than or equal to or greater than primary voltage depending upon the turns ratio of the transformer.

The voltage across the secondary be

$$v = V_m \sin \omega t$$

- V_m is the peak value of this alternating voltage.

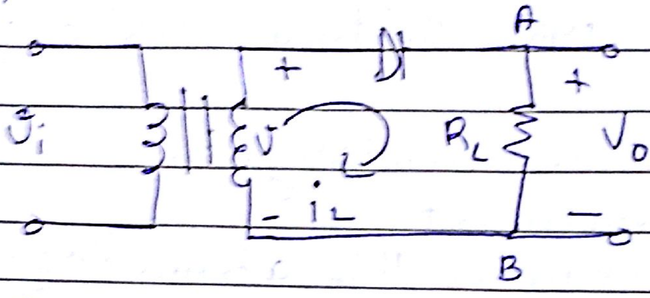
- During the positive half cycle of the input voltage, the diode is forward biased because it tries to push the current in the direction of diode arrow. The diode conducts & current i_L flows through the load resistor R_L. This current makes the terminal A positive w.r.t. to B.

During negative half cycle of the input voltage, the polarity gets reversed. The voltage v_i tries to send current against the direction of diode arrow. The diode is now reversed biased. & hence the circuit is open circuit & no current flows through the circuit.

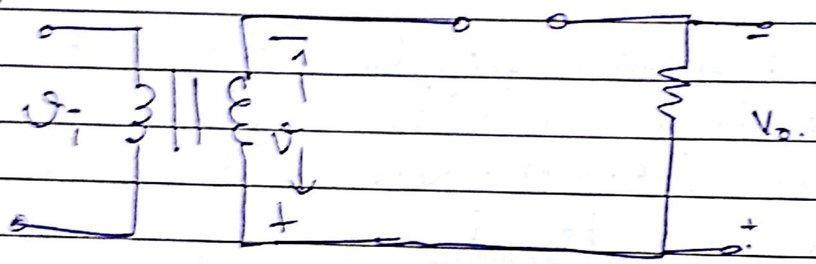
The complete waveform of the voltage v_o across the load is not perfect dc, but at least unidirectional

Halfwave rectifier (a) During +ve half cycle
b) During negative half cycle

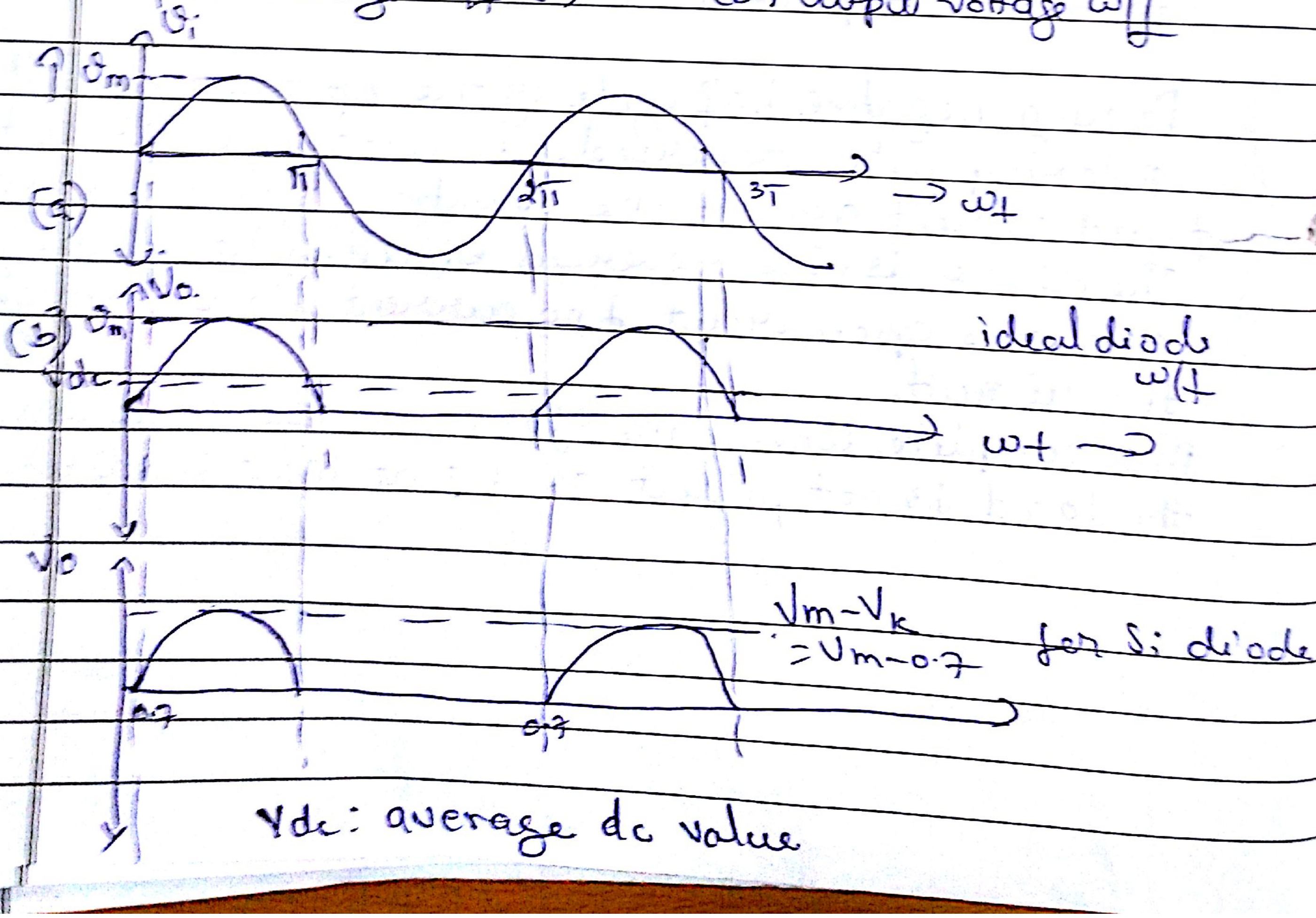
a)



b)



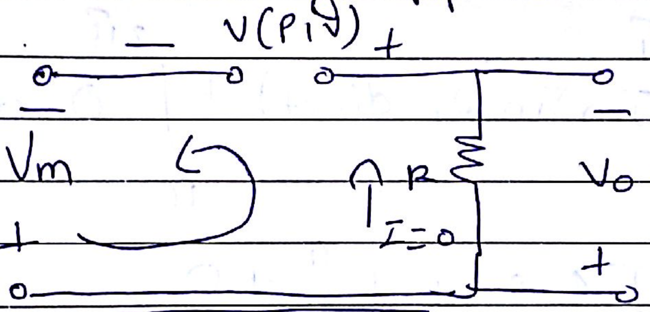
Input voltage w/f (a) (b) Output voltage w/f



V_{dc} : average dc value

Halfwave Rectifier: PIV (PRV): PIV must not be exceeded in the reverse bias region or diode will enter the zener avalanche region.

During the negative half cycle of the input; the diode is reversed biased, The whole input voltage appears across the diode. When the input reaches it's peak value V_m, in negative half cycle, the voltage across the diode is also maximum. This PIV, PIV rating of the diode must equal or exceed the peak value of applied voltage.



$V_o = IR = 0R = 0V$

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

Output dc Voltage (V_{dc})

The average value of a sine wave over one complete cycle is zero. For half wave rectifier circuit, there is some average dc current.

$\frac{V_o}{R_L}$ for every point will give i_L.

$i_L = I_m \sin \omega t$; for $0 \leq \omega t \leq \pi$

$i_L = 0$; for $\pi \leq \omega t \leq 2\pi$

I_m : peak value of the current i_L.

$$\boxed{I_m = \frac{V_m}{R_L}}$$

To find dc or average value of current we find net area under the curve over one complete cycle 0 to 2π. & then divide this area by the base i.e. 2π.

$$\text{Area} = \int_0^{2\pi} i_L \, d(\omega t)$$

$$= \int_0^{\pi} I_m \sin\omega t \, d(\omega t) + \int_{\pi}^{2\pi} 0 \cdot d(\omega t)$$

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

$$= I_m \left[-\cos\pi - (-\cos 0)\right]$$

$$= I_m \left[-(-1) + 1\right]$$

$$= I_m (1+1) = 2 I_m.$$

~~Iavg~~

Average value of load current

$$I_{avg} = I_{dc} = \frac{\text{area}}{\text{base}} = \frac{2 I_m}{2\pi}$$

$$\therefore I_{dc} = I_m / \pi$$

The dc voltage developed across the load R_L

$$\boxed{V_{dc} = I_{dc} \times R_L = \frac{I_m}{\pi} \times R_L} = \frac{V_m}{\pi}$$

∴ with assumptions (a) diode resistance in F.B is zero & (b). Secondary winding of transformer has zero resistance.

With F.B resistance r_d.

$$I_m = \frac{V_m}{(R_L + r_d)}$$

$\therefore$

$$V_{dc} = \frac{V_m \times R_L}{(R_L + r_d)\pi} = \frac{V_m}{\pi(1 + r_d/R_L)}$$

$$V_{dc} \cong \frac{V_m}{\pi} \quad \text{if } (r_d << R_L)$$

$$\boxed{V_{dc} \cong 0.318 V_m}$$

Prob: The turns ratio of a transformer used in a half wave rectifier is $n_1 : n_2 = 12:1$. The primary is connected to power mains, 220 V, 50 Hz. Assuming $r_d = 0$ in F.B. Calculate the dc voltage across the load. What is PIV of the diode?

Soln: The maximum (peak value) primary voltage is

$$V_p = \sqrt{2}\, V_{rms} = \sqrt{2} \times 220 = 311\text{ V}.$$

$\therefore$ max. secondary voltage is

$$V_m = \frac{n_2}{n_1} V_p = \frac{1}{12} \times 311 = 25.9\text{ V}.$$

$$V_{dc} = \frac{V_m}{\pi} = \frac{25.9}{\pi} = 8.24\text{ V}$$

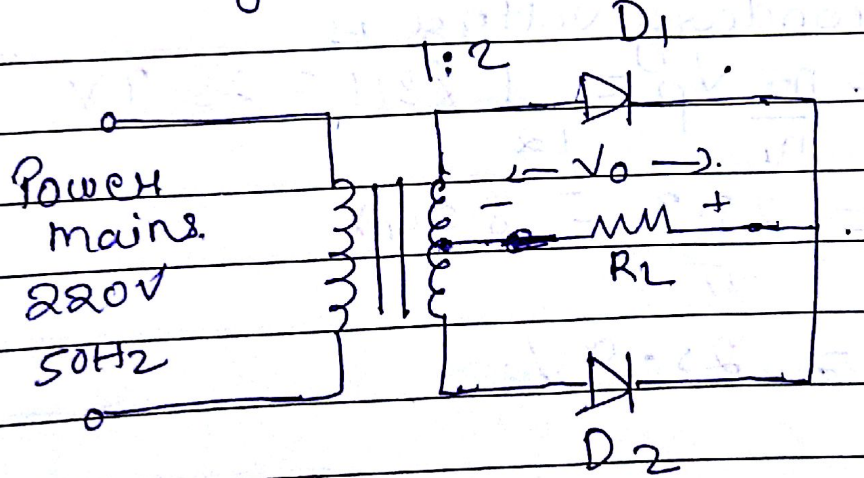
$$PIV = V_m = 25.9\text{ V}.$$

Full-Wave Rectifier:

- In half wave rectifier, we utilize only one half cycle of the input voltage
- In full wave rectifier we utilize both the half cycle
- Alternate half cycles are inverted to give a unidirectional load current.

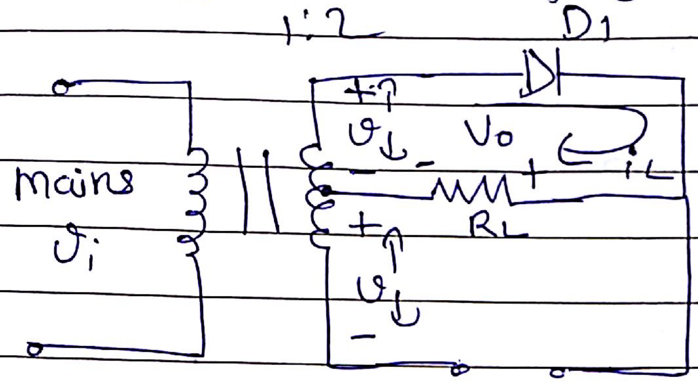
Centre Tap Rectifier: It uses two diodes D1 and D_2.

- During the positive half cycles of secondary voltage, the diode D1 is forward biased and D2 is reverse biased. The current flows through the diode D1, load resistor R_L & upper half of the winding.
- During negative half cycles diode D2 becomes forward biased & D1 reverse biased. Now D2 conducts & D1 becomes open.
- The current flows through diode D2, load resistor R_L and lower half of the winding.
- The load current through resistor R_L for the both cycles is in the same direction.

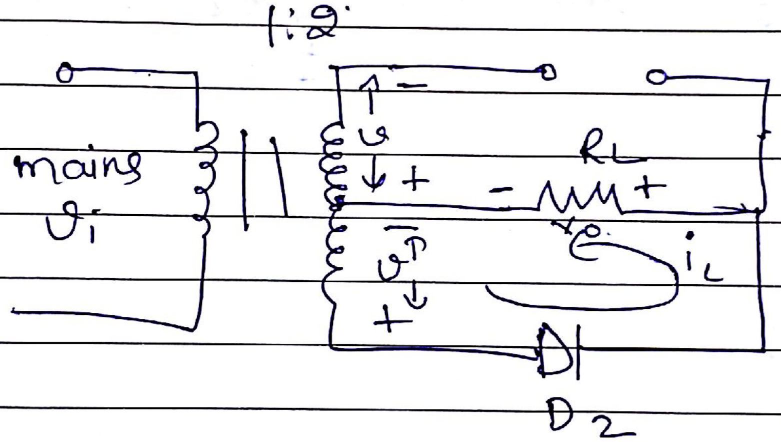


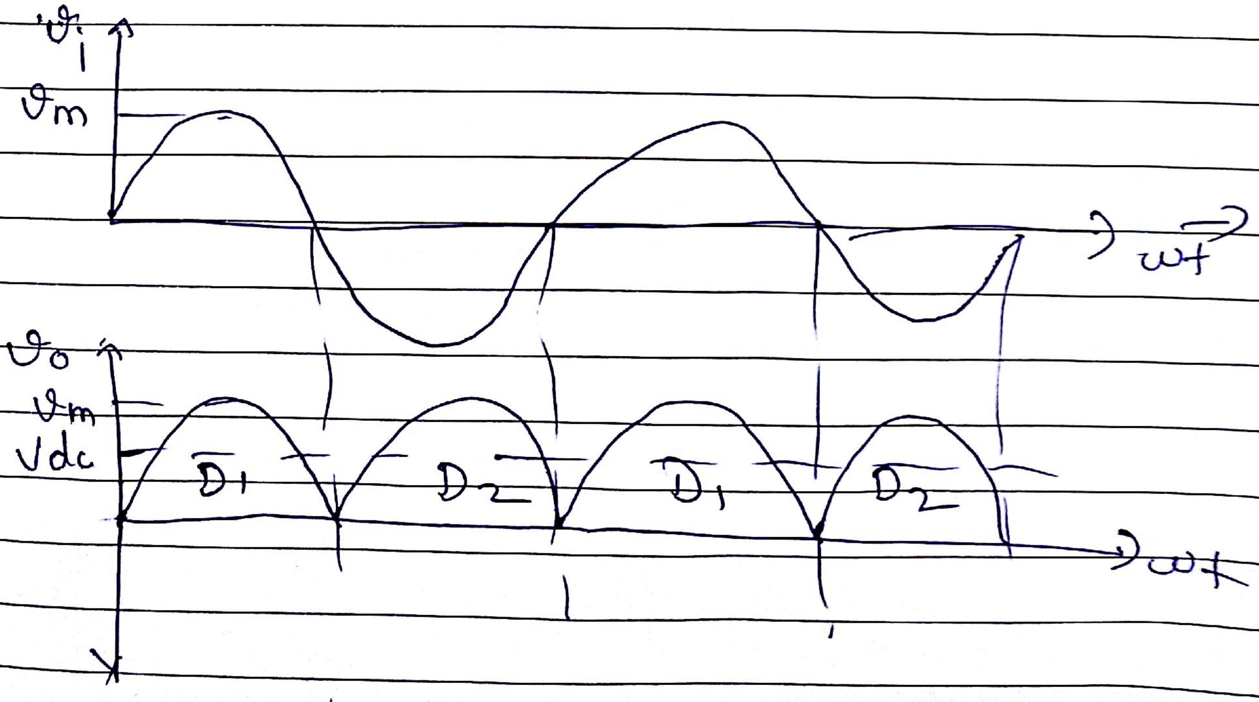
center tap full wave rectifier

b) During Positive half cycle of input voltage.



c) During Negative half cycle of i/p voltage





$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

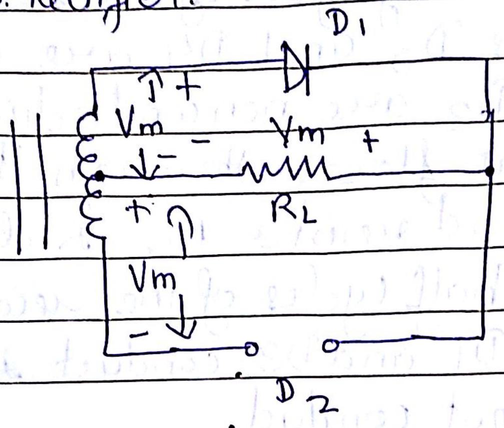
$$V_s = \frac{N_s}{N_p} V_p$$

For center tapped,

$n = 1$, $V_{sec} = V_p/2$

$n = 2$, $V_{sec} = \frac{V_p}{2} \times 2 = V_p$

Centre-Tap. Rectifier. : Peak Inverse Voltage.

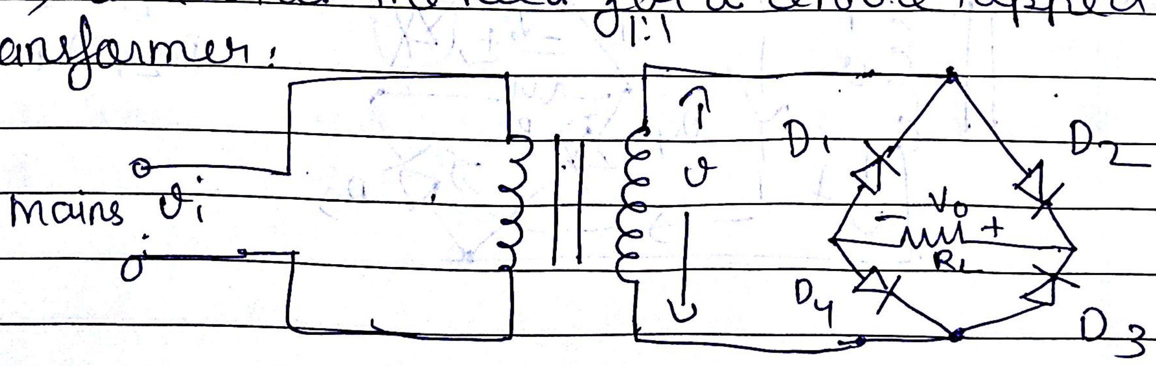


- At the instant ~~th~~ secondary voltage reaches its positive maximum value., the voltage Vm is the maximum voltage across half of the secondary winding. At this instant. diode D1 is conducting & offers almost zero resistance. The whole of the voltage Vm across the upper half winding appears across the load resistor R_L.
- Therefore the reverse voltage that. appears. across non conducting diode D_2 is sum of. Voltage across lower half winding & voltage across the load resistor R_L.

$$\therefore \quad V_m + V_m = 2V_m$$

$$PIV \geq 2V_m.$$

- Bridge Rectifier: It requires four diodes instead of two, & avoids the need for a centre tapped transformer.



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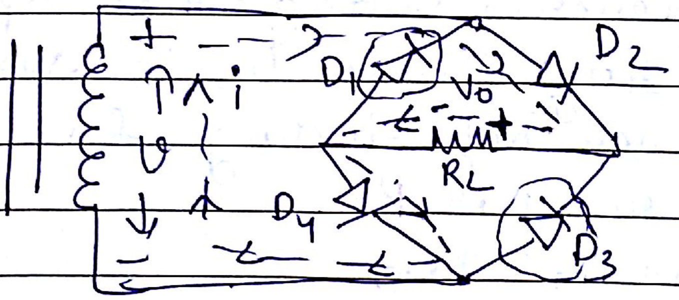
During the positive half cycle of the secondary voltage, diodes D_2 and D4 are conducting & diodes D1 & D_3 are non conducting.
Therefore current flows through the secondary winding, D2, load resistor R_L & diode D4.

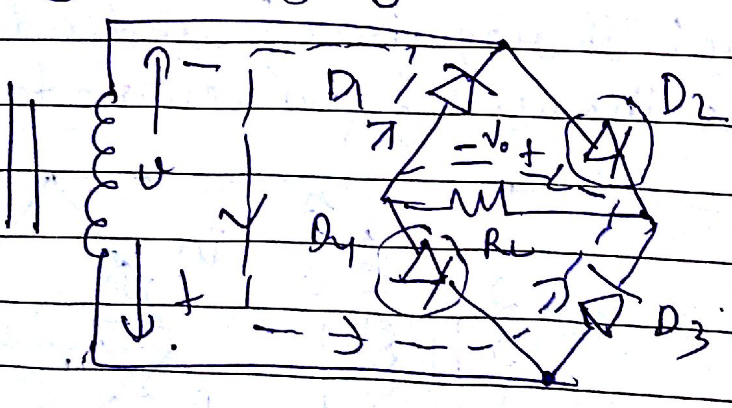
- During negative half cycles of the secondary voltage, diodes D1 and D3 conduct & diodes D_2 and D_4 do not conduct.
- The current flows through secondary winding diode D_1, load resistor R_L & diode D3.
- In both cases, the current passes through the load resistor in same direction. therefore, a fluctuating unidirectional voltage is developed across the load.

During +ve half cycle.

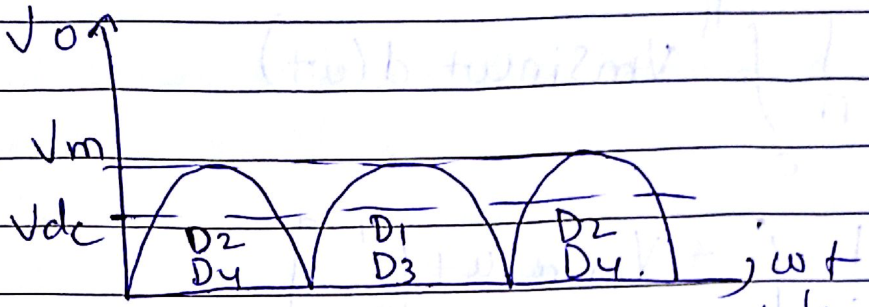


D_2, D_4 on
D_1 & D_3 off

During −ve half cycle



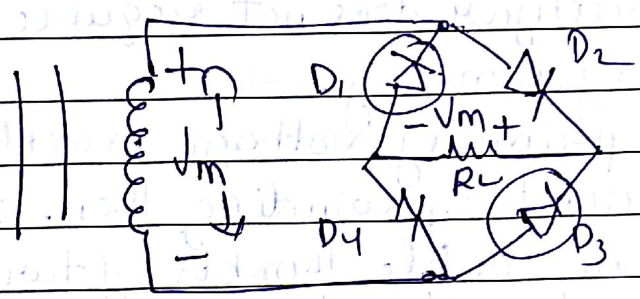
D_1, D_3 on
D_2, D_4 off.



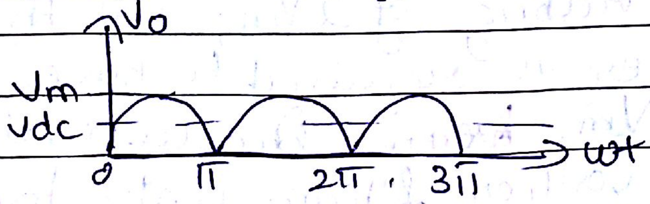
O/p w/f of Bridge rectifier.

Peak Inverse Voltage:

- When secondary voltage reaches its positive peak value, V_m, the diodes D2 and D4 are conducting & D1 & D_3 are R.B & are non conducting.
The entire voltage V_m across the secondary winding appears across the load resistor R_L.
The reverse voltage across the non conducting diode D_1 or D3 is also V_m. Thus. PIV = V_m.



Output dc Voltage:



$v_0 = V_m \sin\omega t \quad 0 < \omega t < \pi$

$= -V_m \sin\omega t \quad \pi \le \omega t < 2\pi$

−ve signe, because in 2nd half cycle wave is inverted.

The average or dc value of voltage is $V_{dc} = \frac{\text{Area}}{\text{Base}}$

$$V_{dc} = \frac{1}{\pi}\int_0^{\pi} v_0 \, d(\omega t)$$

$$V_{dc} = \frac{1}{\pi}\int_0^{\pi} V_m \sin\omega t \, d(\omega t)$$

$$= \frac{1}{\pi}\left[-V_m \cos\omega t \Big|_0^{\pi}\right]$$

$$= \frac{V_m}{\pi}\left[-\cos\pi + \cos 0\right]$$

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

$$\boxed{V_{dc} = 2V_m/\pi}$$

Advantages of Bridge Rectifier over Centretapped.

- Bridge rectifier does not require centre tapped secondary winding.
- To have primary voltage exactly in both the half of secondary winding then secondary must have double number of turns in transformer for centre tapped rectifier.
- Each of the two diodes in centre tap rectifier must have PIV rating of $2V_m$, But the diode in bridge rectifier is required to have PIV rating of only V_m. ~~Hence~~ Diodes with high PIV rating are costlier. Hence centretap rectifier is costlier than Bridge Rectifier.

Disadvantages: Bridge rectifier requires four diodes

- Can't be use for very low voltages.

Prob: The turns ratio of the transformer used in a bridge rectifier is $n_1 : n_2 : 12 : 1$. The primary is connected to 220V, 50Hz power mains. Assuming that the diode voltage drops to be zero, find dc voltage across the load. What is the PIV of each diode? If the same dc voltage is obtained by using a centre-tap rectifier, what is the PIV?

soln: The max. primary voltage is

$$V_p = \sqrt{2} V_{rms} = \sqrt{2} \times 220 = 311V$$

$\therefore$ maximum secondary voltage is

$$V_m = \frac{n_2}{n_1} V_p = \frac{1}{12} \times 311 = 25.9V$$

the dc voltage across the load is

$$V_{dc} = \frac{2V_m}{\pi} = \frac{2 \times 25.9}{\pi} = 16.48V$$

The PIV for bridge rectifier is

$$PIV = V_m = 25.9V.$$

For centre tap rectifier, the PIV is

$$PIV = 2V_m = 2 \times 25.9 = 51.8V$$

How effectively A rectifier converts AC into DC.

The output waveform of rectifier has an average or dc value over which are superimposed a number of ac sinusoidal components of different frequencies. These undesired ac components are called ripples

How effectively a rectifier converts ac power into dc power is called ripple factor and rectification efficiency.

The ripple factor is a measure of purity of the dc output of a rectifier & is defined as

$$r = \frac{\text{rms value of the components of wave}}{\text{average or dc value}}$$

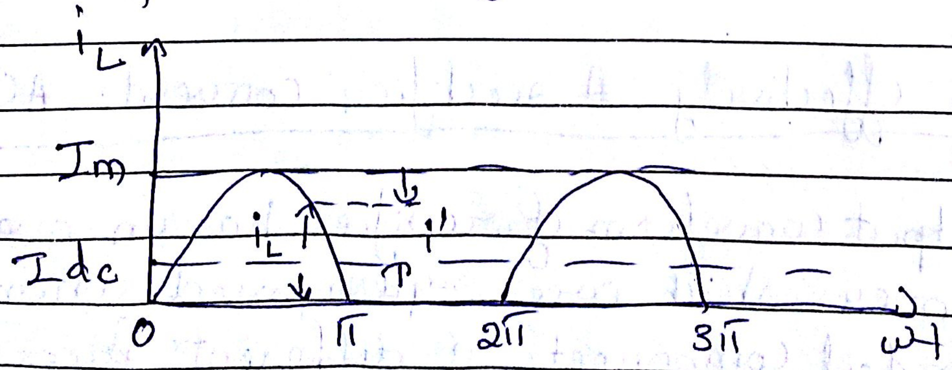
The rectification efficiency tells us what percentage of total ac power is converted into useful dc output power.

$$\eta = \frac{\text{dc power delivered to load}}{\text{ac input power from transformer secondary}}$$

$$\eta = \frac{P_{dc}}{P_{ac}}$$

Performance of Half Wave Rectifier:

Half wave rectified current wave.



$i_L = I_m \sin \omega t$; for $0 \le \omega t \le \pi$

$= 0$; for $\pi \le \omega t \le 2\pi$.

RMS Value of current: The rms or effective value of the current flowing through the load is given as

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

where current i_L is load current.

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

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

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

$$= \sqrt{\frac{I_m^2}{4\pi}\left[\pi - \frac{\sin 2\pi}{2} - \left[0 - \sin 0\right]\right]}$$

$$= \sqrt{\frac{I_m^2}{4\pi}\left[\pi - 0\right]}$$

$$= \sqrt{\frac{I_m^2 \times \pi}{4\pi}} = \sqrt{\frac{I_m^2}{4}}$$

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

I_{rms} is the rms value of total current (dc + ac comp.)

The instantaneous value of ac fluctuation is the difference of instantaneous total value and dc value.

i.e $i' = i_L - I_{dc}$

$\therefore$ the rms value of ac component is

$$I'_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} (i_L - I_{dc})^2 \, d(\omega t)}$$

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

$$= \sqrt{I_{rms}^2 + I_{dc}^2 - 2 I_{dc}^2 \, d(\omega t)}$$

$$= \sqrt{I_{rms}^2 + I_{dc}^2 - 2 I_{dc}^2}$$

$$I'_{rms} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

$$r = \frac{I'_{rms}}{I_{dc}} = \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{dc}}$$

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

$$\frac{I_{rms}}{I_{dc}} = \frac{I_m/2}{I_m/\pi} = 1.57$$

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

Rectification Efficiency: For a half wave rectifier, the dc power delivered to the load is

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

Total input ac power is

$$P_{ac} = I_{rms}^2 (r_d + R_L) = \left(\frac{I_m}{2}\right)^2 (r_d + R_L).$$

$$\therefore \eta = \frac{P_{dc}}{P_{ac}} = \frac{(I_m/\pi)^2 R_L}{(I_m/2)^2 (r_d + R_L)} \times 100\%$$

$$= \frac{40.6}{1 + r_d/R_L} \%.$$

if. $r_d \ll R_L$

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

Transformer Utilization Factor (TUF) of ~~single~~ of ~~phase to~~ Half wave Rectifier

TUF = dc power delivered to load / ac rating of Transformer secondary

$= P_{dc} / P_{ac\ rated}$

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

P_{ac} = rated voltage of secondary $= V_m/\sqrt{2}$.

$I_{rms} = I_m/2$

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$$\therefore TUF = \frac{\left(\frac{I_m}{\pi}\right)^2 R_L}{\frac{V_m}{\sqrt{2}} \times \frac{I_m}{2}}$$

$$= \frac{\frac{I_m \quad R_L}{\pi^2}}{V_m / \sqrt{2}\,2}$$

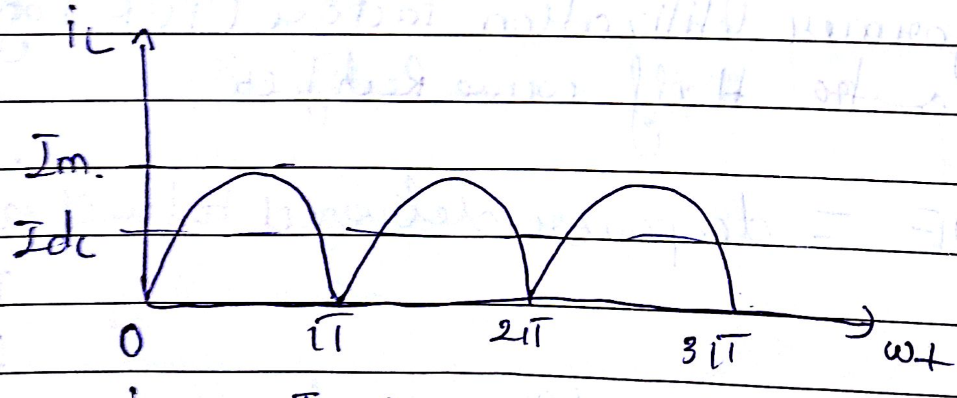
$$= \frac{\cancel{I_m} \times \cancel{R_L} \times 2\sqrt{2}}{\pi^2 \times \cancel{I_m} \cancel{R_L}}$$

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

$$= 0.287.$$

Performance of Full-Wave Rectifier.

Full wave rectified current wave.



$i_L = I_m \sin \omega t.$

RMS. Value of Current:

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

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

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

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

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

$$= \sqrt{\frac{I_m^2}{\pi \times 2}\left[\pi - 0\right]}$$

$$= \sqrt{\frac{I_m^2 \times \pi}{\pi \times 2}} = \sqrt{\frac{I_m^2}{2}} = \frac{I_m}{\sqrt{2}}$$

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

The dc or average value of current I_{dc}.

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

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

Ripple Factor:

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

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

$$= 0.482.$$

Rectification Efficiency:

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

and total input ac power is

$$P_{ac} = I_{rms}^2 (r_d + R_L)$$
$$= \left(\frac{I_m}{\sqrt{2}}\right)^2 (r_d + R_L)$$

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{(2I_m/\pi)^2}{(I_m\sqrt{2})^2 (r_d + R_L)} \times 100\%$$

$$= \frac{81.2}{1 + r_d/R_L} \%$$

$$= 81.2 \text{ when } r_d << R_L$$

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ob: In a centre tap full wave rectifier, the load resistance $R_L = 1k\Omega$. Each diode has a forward bias dynamic resistance r_d of 10Ω. The voltage across half the secondary winding is $220 \sin 314t$. Find (a). the peak value of current.
(b) the dc or average value of current.
(c) the rms value of current.
(d) the ripple factor.
(e) the rectification efficiency.

soln: The voltage across half the secondary winding is. $v = 220 \sin 314t$

(a) The peak value of voltage is
$V_m = 220V$.

~~b)~~ The peak value of current.

$$I_m = \frac{V_m}{r_d + R_L} = \frac{220}{10+1000} = 0.2178 A$$
$$= 217.8 mA$$

b) $I_{dc} = \frac{2I_m}{\pi}$
$= 138.66 mA$

c) ~~b)~~ The rms value of current

$$I_{rms} = \frac{I_m}{\sqrt{2}} = 154 mA$$

(d.) Ripple factor.

$$r = \sqrt{\frac{I_{rms}^2}{I_{dc}^2} - 1}$$
$$= \sqrt{\left(\frac{154}{138.66}\right)^2 - 1}$$
$$= 0.482.$$

e) Rectification efficiency $\eta = \frac{P_{dc}}{P_{ac}} = \frac{I_{dc}^2 R_L}{I_{rms}^2 (r_d + R_L)}$

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$$= \frac{P_{dc}}{P_{ac}} = 80.26\%$$