RECTIFIERS

Rectification :-

Rectification is the process of converting alternating current (ac) into direct current(dc).

Rectifier :-

Rectifier is a device that converts ac (alternating current) into dc (direct current). Semiconductor diodes are used as rectifying elements.

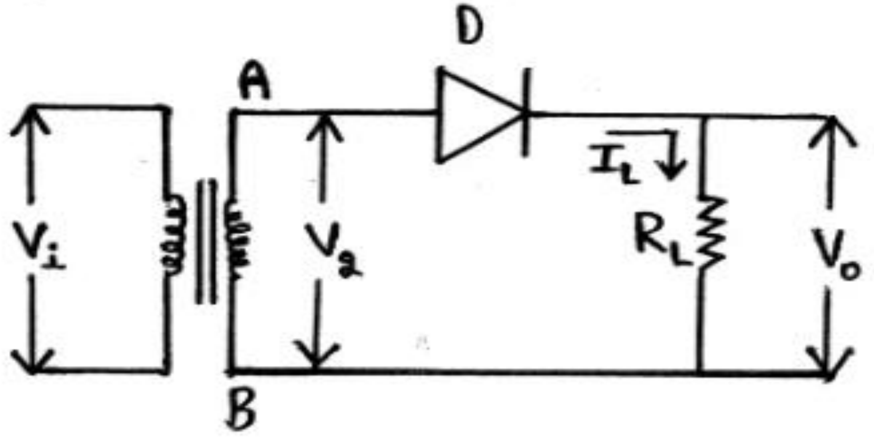
Rectifiers are classified into :

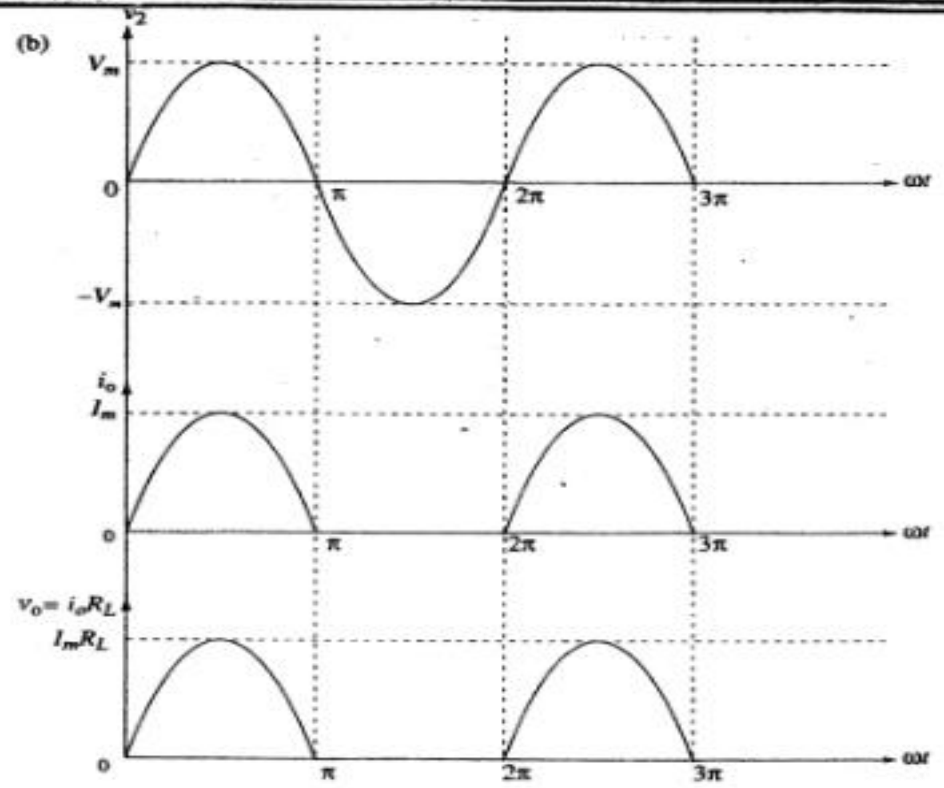
1. **Half wave rectifier (HWR)**
2. **Full wave rectifier (FWR)**

Full wave rectifier can be built in two ways :

1. **Full – wave rectifier using two diodes and a centre tapped transformer**
2. **Full-wave bridge rectifier using four diodes and an ordinary transformer. (FWBR)**

HALFWAVE RECTIFIER (HWR):-





(a) Half-wave rectifier. (b) Waveforms of transformer secondary voltage, load current and load voltage.

Half wave rectifier consists of a single diode in series with load resistance. The ac voltage across the secondary winding A & B changes polarities after half cycle.

Operation :-

During positive half cycle of the ac input voltage, end A becomes positive with respect to end B, the diode 'D' is forward biased and acts as a short circuit, thus the current flows in the circuit, Figure 2. The load voltage is given by $\boxed{V_O = I_L R_L}$.

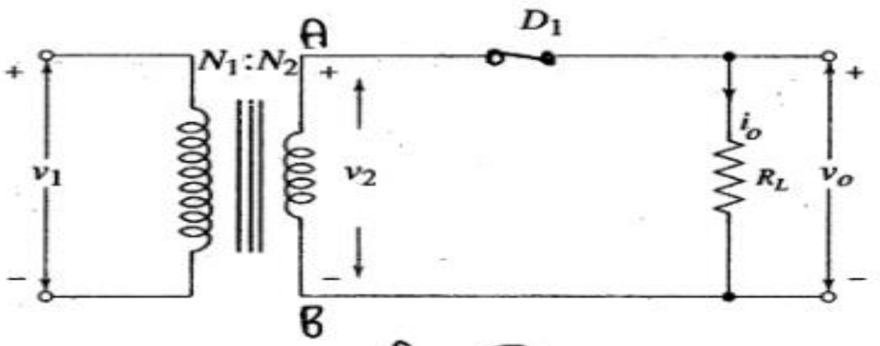


Fig ②

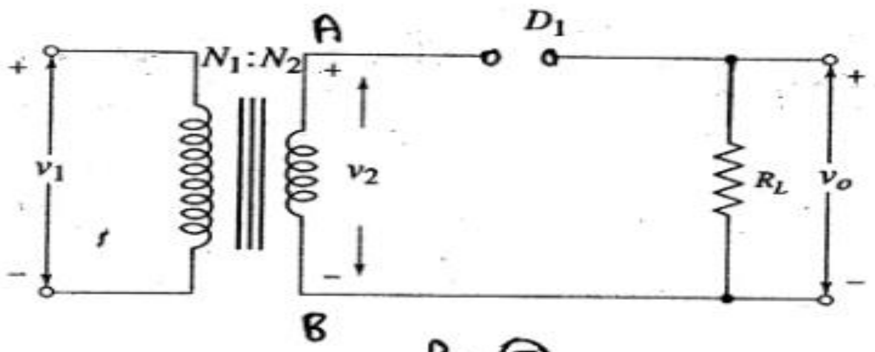


Fig ③

During negative half cycle of the ac input voltage, end A becomes

During negative half cycle of the ac input voltage, end A becomes negative with respect to end B, the diode 'D' is reverse biased and acts as a open circuit, thus **NO current** flows in the circuit, Figure 3. The load voltage is given by $\mathbf{V_O = 0 \times R_L}$.

Therefore $\boxed{\mathbf{V_O = 0v}}$

The dc output waveform is **expected** to be a **straight line** but the half wave rectifier gives output in the form of positive sinusoidal pulse. Hence the output is called **pulsating dc**.

The load current is given by :

$$I_L = \begin{cases} I_m \sin\omega t & 0 \leq \omega t \leq \pi \\ 0 & \pi \leq \omega t \leq 2\pi \end{cases}$$

Where $\boxed{I_m = \dfrac{V_m}{R_L}}$

1) **Average or dc load current (I_{dc} or I_{av}) :-**

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

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

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

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

$$= \frac{I_m}{2\pi}\left[-\cos\omega t\right]_0^{\pi}$$

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

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

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

$$= \frac{\cancel{2}I_m}{\cancel{2}\pi}$$

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

2) **Average dc load voltage (V_{dc}) :-**

$$V_{dc} = I_{dc} R_L$$

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

$$= \frac{V_m}{\cancel{R_L} \cdot \pi} \cancel{R_L}$$

$$\boxed{V_{dc} = \frac{V_m}{\pi}}$$

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

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

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

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

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

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

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

$$= \sqrt{\frac{I_m^2}{4\pi}\left[\int_0^{\pi} 1-\cos 2\omega t \cdot d\omega t + \int_{\pi}^{2\pi} 1-\cancel{\cos}^{\,0} 2\omega t \cdot d\omega t\right.}$$

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

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

$$\boxed{\sin^2\theta = \frac{1-\cos 2\theta}{2} \qquad \int \cos 2\theta = \frac{\sin 2\theta}{2}}$$

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

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

$$= \sqrt{\frac{I_m^2}{4\cancel{\pi}} \cdot \cancel{\pi}} \qquad = \sqrt{\frac{I_m^2}{4}}$$

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

4) RMS value of the load voltage (V_{RMS}) :-

$$V_{RMS} = I_{RMS} R_L$$

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

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

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

5) **DC output power** **(P_{dc}) :-**

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

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

$$= \left(\frac{V_m}{R_L}\right)^2 \cdot \frac{1}{\pi^2} R_L$$

$$= \frac{V_m^2}{R_L^{\cancel{2}} \pi^2} \cdot \cancel{R_L}$$

$$\boxed{P_{dc} = \left(\frac{V_m}{\pi}\right)^2 \cdot \frac{1}{R_L}}$$

6) AC output power (P_{ac}) :-

$$P_{ac} = I_{RMS}^2 R_L$$

$$\boxed{P_{ac} = \left(\frac{I_m}{2}\right)^2 R_L}$$

8) Ripple factor (γ):-

Ripple factor is defined as the ratio of RMS value of the ac component present in the rectified output to the dc component present in the rectified output.

$$\gamma = \frac{\text{RMS value of ac component of o/p}}{\text{dc component of o/p}}$$

$$= \sqrt{\frac{I_{RMS}^2}{I_{dc}^2} - 1} \qquad = \sqrt{\frac{\left(\cancel{I_m}/2\right)^2}{\left(\cancel{I_m}/\pi\right)^2} - 1}$$

$$= \sqrt{\frac{\frac{1}{4}}{\frac{1}{\pi^2}} - 1} \qquad = \sqrt{\frac{\pi^2}{4} - 1}$$

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

This indicates that the **amount of ac present in the output is 121 % of the dc voltage.**

7) Rectification efficiency (η):-

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

$$\eta = \frac{\text{DC o/p power}}{\text{AC I/p power}} = \frac{P_{dc}}{P_{ac}} = \frac{\frac{\cancel{I_m^2}}{\pi^2}\cancel{R_L}}{\frac{\cancel{I_m^2}}{4}\cancel{R_L}} = \frac{\frac{1}{\pi^2}}{\frac{1}{4}} = \frac{1}{\pi^2} \times \frac{4}{1}$$

$$\eta = 0.406$$

$$\boxed{\% \eta = 40.6\%}$$

In HWR, maximum 40.6% ac power gets converted to dc power in the load.

Advantages of HWR :-

1. Only one diode is required.
2. No centre-tap is required on the transformer.
3. PIV is same as secondary output voltage.

Disadvantages or demerits of HWR :-

1. The ripple factor is too high i.e. =1.21
2. Rectification efficiency is low i.e. 40.6%.

FWR with centre-tapped transformer :-

❖ **Explain with the help of a circuit diagram the working of a full wave rectifier. Derive expressions for**

i) I_{dc} ii) I_{rms} iii) V_{dc} iv) Ripple factor v) Rectifier efficiency.

Jan-10,5M

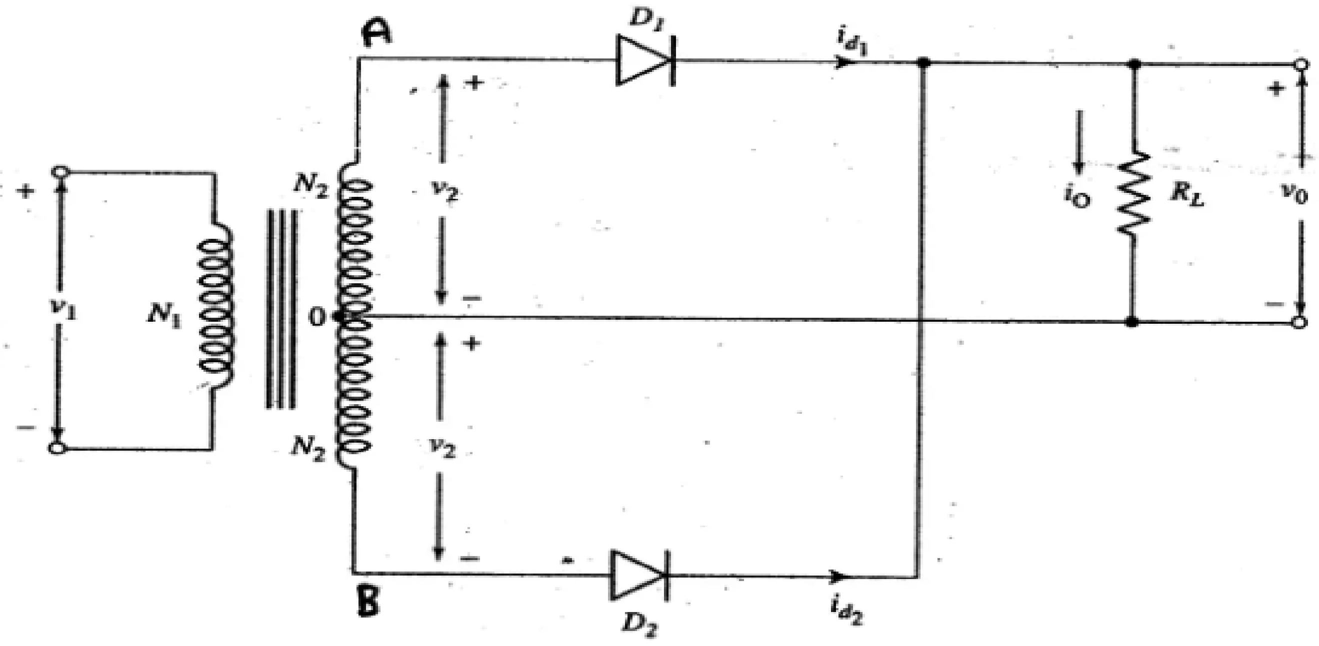


Figure 1. FWR using two diodes & a centre-tapped transformer.

Operation :-

During +ve half cycle :-

- During +ve half cycle of the ac input voltage, end A becomes +ve with respect to end B. the diode 'D₁' is forward biased and conducts while the diode D_2 is reverse biased and acts as open circuit and will not conduct as shown in fig 2.

- The diode D_1 **supplies** the **load current**. The conventional **current flow** is through diode D_1, load resistor R_L & the **upper half** of **secondary winding** as shown by the **dotted arrows.**

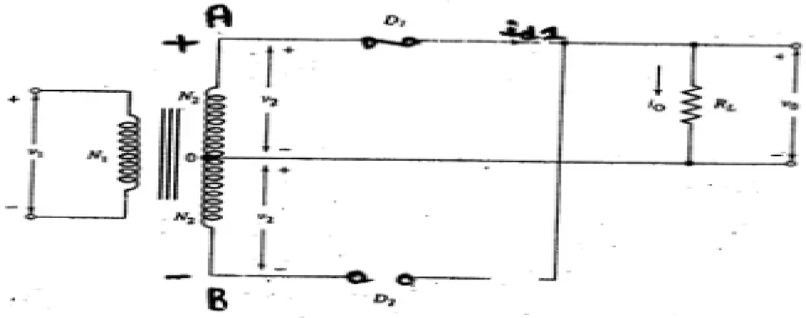


Fig 2.

During -ve half cycle :-

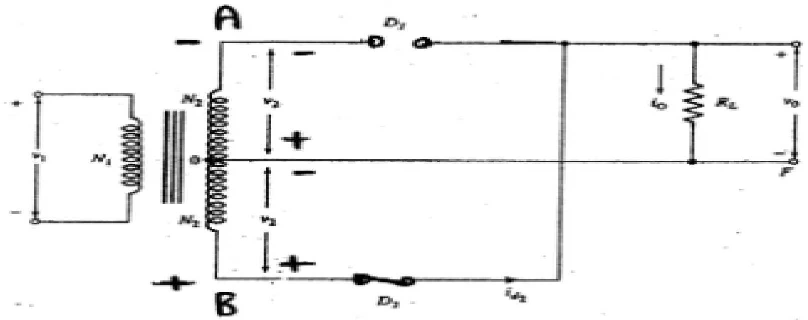


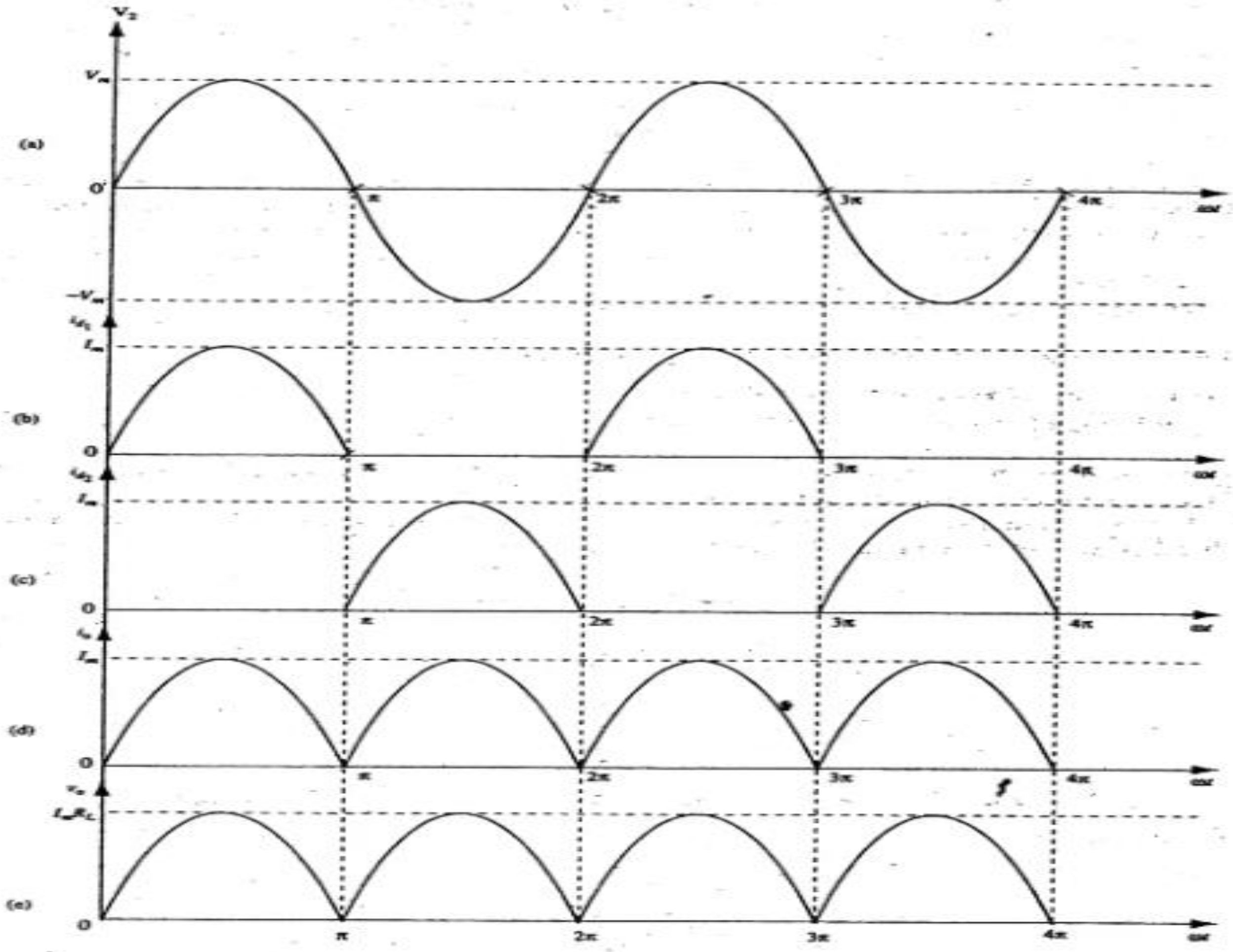
Fig 3.

- During <u>-ve half cycle</u> of the ac input voltage, end A becomes -ve with respect to end B, the diode 'D_2' is forward biased and conducts while the diode D_1 is reverse biased and acts as open circuit and will not conduct as shown in fig 3.

- The diode **D_2 supplies** the **load current**. The conventional **current flow** is through diode **D_2**, load resistor **R_L** & the **lower half** of **secondary winding** as shown by the **solid arrows.**

- From fig 2 & 3 it can be observed that **current** in the **load R_L** is in the **same direction** for **both half cycles** of **ac input voltage**.
  - For both the half cycles the current flows through load in the same direction. Hence we get two half cycles for one complete input signal.

I/O Waveforms



Voltage and current waveforms. (a) Secondary voltage waveform, (b) & (c) Diode current waveforms, (d) load current waveform, (e) load voltage waveform.

1) **Average or dc load current (I_{dc} or I_{av}) :-**

Consider one cycle of the load current I_L from 0 to π to obtain the average value which is dc value of load current.

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

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

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

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

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

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

2) **Average dc load voltage** (V_{dc}) :-

$$V_{dc} = I_{dc} R_L$$

$$= \frac{2I_m}{\pi} R_L$$

$$= \frac{2V_m}{\pi \cancel{R_L}} \cdot \cancel{R_L}$$

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

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

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

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

$$\boxed{\because \sin^2\theta = \frac{1-\cos 2\theta}{2}}$$

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

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

$$\boxed{\because \int \cos 2\theta \, d\theta = \frac{\sin 2\theta}{2}}$$

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

$$= I_m\sqrt{\frac{1}{2\pi}\left\{[\pi - 0] - \frac{1}{2}\left[\sin 2(\pi) - \sin 2(0)\right]\right\}}$$

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

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

4) **RMS value of the load voltage** (V_{RMS}) :-

$$V_{RMS} = I_{RMS} R_L$$

$$\boxed{V_{RMS} = \frac{I_m}{\sqrt{2}} R_L}$$

5) **DC output power** (P_{dc}) :-

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

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

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

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

6) AC output power (P_{ac}) :-

$$P_{ac} = I_{RMS}^2 R_L$$

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

$$\boxed{P_{ac} = \frac{I_m^2}{2} R_L}$$

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

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

7) Rectification efficiency (η):-

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{\frac{4}{\pi^2} \cancel{I_m^2} \cancel{R_L}}{\frac{\cancel{I_m^2}}{2} \cancel{R_L}} = \frac{\frac{4}{\pi^2}}{\frac{1}{2}} = \frac{4}{\pi^2} \times \frac{2}{1} = 0.812$$

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

8) Ripple factor (γ):-

$$\gamma = \sqrt{\frac{I^2_{RMS}}{I^2_{dc}} - 1}$$

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

$$= \sqrt{\left(\frac{1}{2} \times \frac{\pi^2}{4}\right) - 1} = \sqrt{\frac{\pi^2}{8} - 1}$$

$$\boxed{\gamma = 0.48}$$

This indicates that the amount of ac present in the output is 0.48 % of the dc voltage.

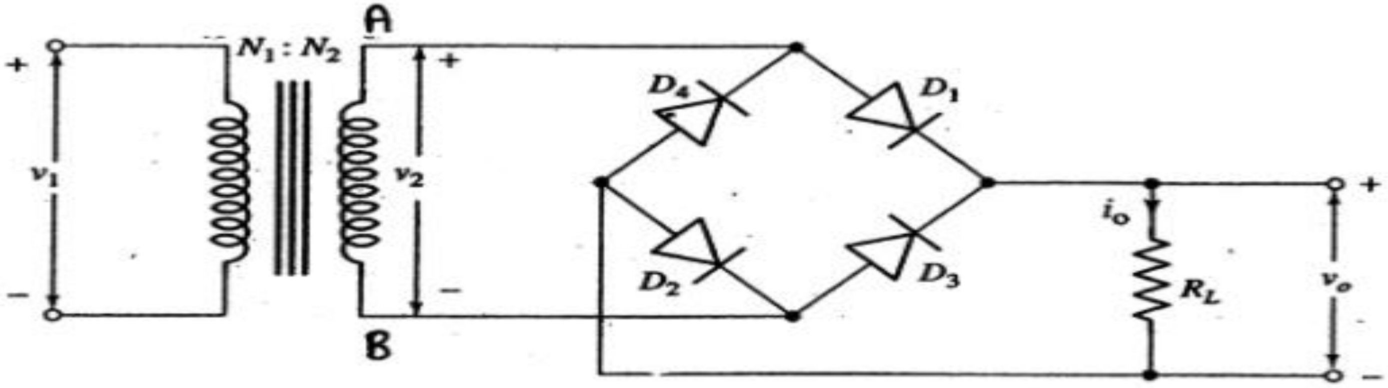
Advantages of FWR :-

1. The efficiency is twice that of HWR i.e. 81.2%
2. The ripple factor is much less than that of HWR
3. The dc output voltage and load current value are twice than HWR.
4. Large dc power output.

Disadvantages of FWR :-

1. PIV of diode the is higher.
2. Cost of centre-tap transformer is higher.
3. Output voltage is half of the secondary voltage.

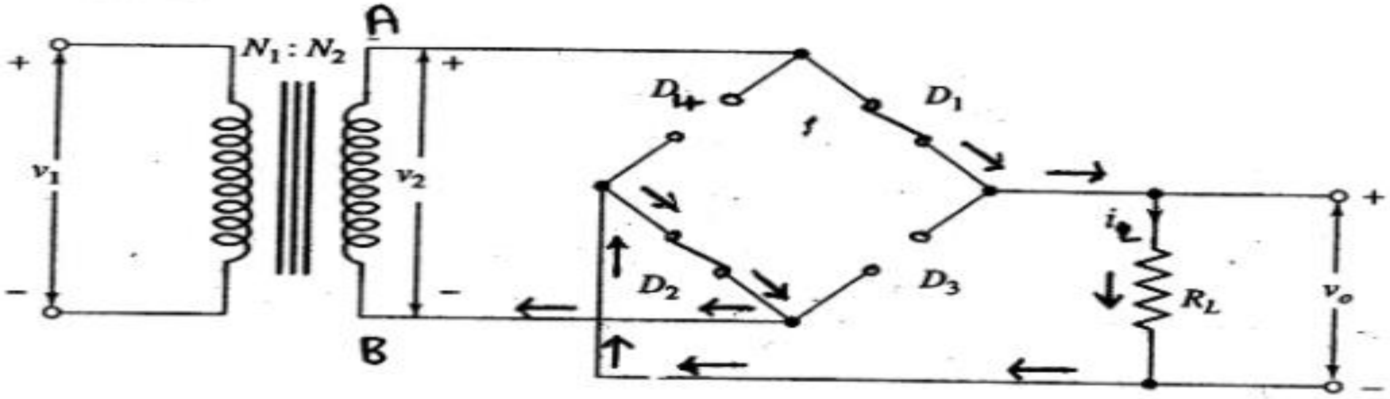
<u>**FULL WAVE BRIDGE Rectifier**</u> **(FWBR) :-**



Full-wave bridge rectifier.

<u>**Operation**</u> **:-**

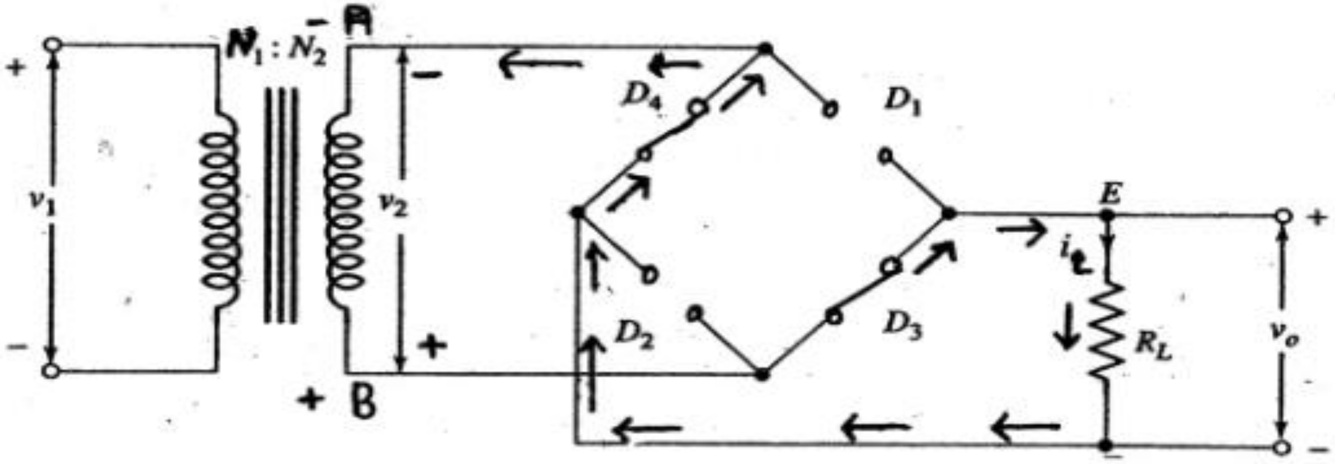
<u>**During +ve half cycle**</u> **:-**



- During **+ve half cycle** of the ac input voltage, end A becomes +ve with respect to end B. This makes diodes ***D_1 & D_2 forward biased***, while ***D_3 & D_4 are reverse biased.***

Therefore only **diodes D_1 & D_2 conducts**. The conventional ***current flows*** through the ***load resistance R_L*** and is shown by the **arrows.**

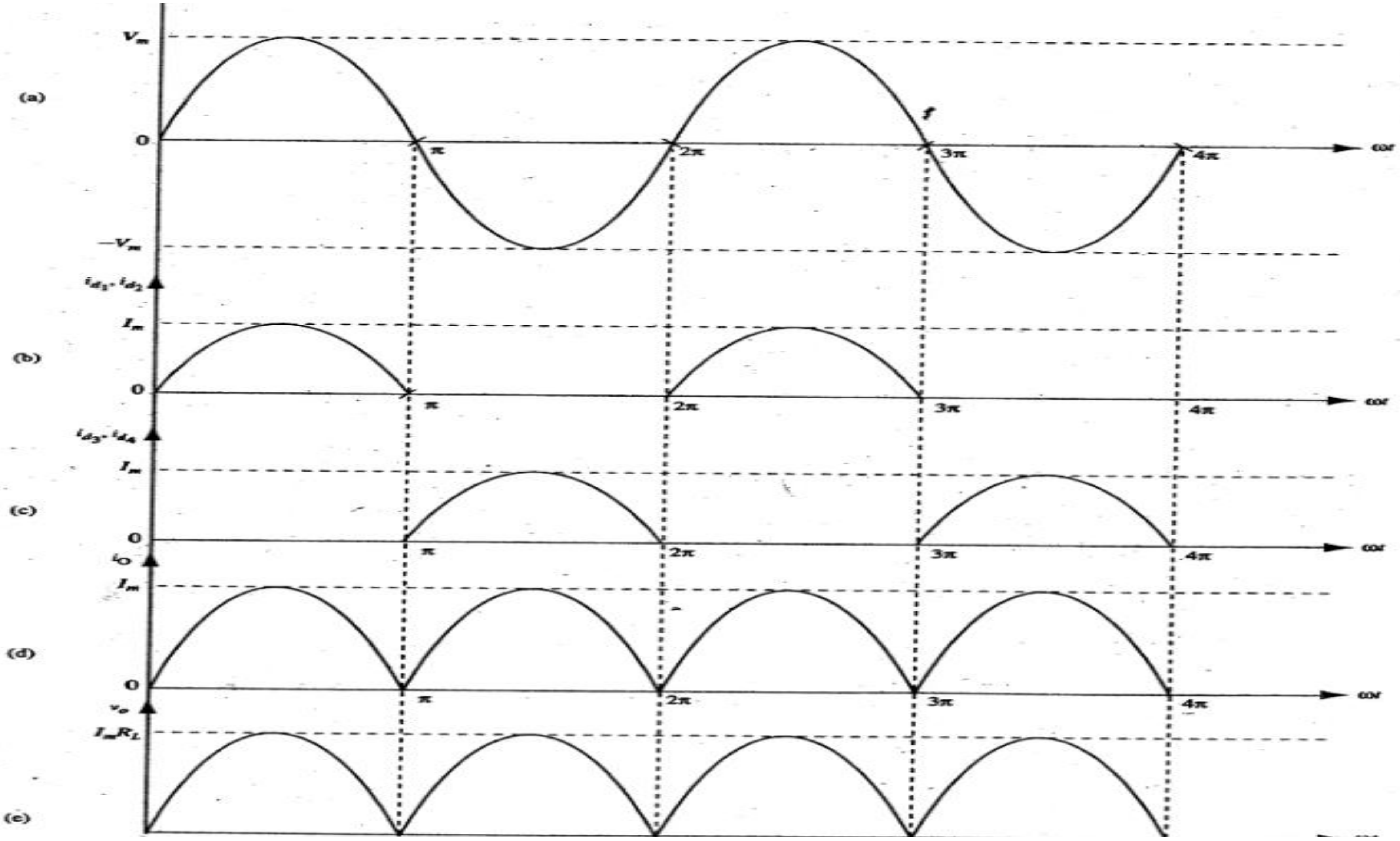
During –ve half cycle :-



- During **-ve half cycle** of the ac input voltage, end A becomes -ve with respect to end B. This makes diodes ***D_3 & D_4 forward biased***, while ***D_1 & D_2 are reverse biased.***

Therefore only **diodes D_3 & D_4 conducts**. The conventional ***current flows*** through the ***load resistance R_L*** and is shown by the **arrows.**

- For both the half cycles the current flows through load in the same direction. Hence we get two half cycles for one complete input signal.



(a)
V_m
0
$-V_m$
π
2π
3π
4π
ωt
(b)
i_{d_1}, i_{d_2}
I_m
(c)
i_{d_3}, i_{d_4}
(d)
i_O
(e)
v_o
$I_m R_L$

❖ **In a full wave bridge rectifier, the transformer secondary voltage is 100sinwt. The forward resistance of each diode is 25Ω and the load resistance is 950Ω. Calculate**

i) D.C. output voltage ii) ripple factor iii) Efficiency of rectification

iv) PIV across non-conducting diodes. **Jan-2003,8M**

Given : $V_S = 100 \sin\omega t$, $R_f = 25\,\Omega$, $R_L = 950\,\Omega$

WKT $V_S = V_m \sin\omega t$ $V_m = 100V$

Sol :-

$$* \quad I_m = \frac{V_m}{2R_f + R_L} = \frac{100}{(2 \times 25) + 950} = 0.1A$$

$$* \quad I_{dc} = \frac{2I_m}{\pi} = \frac{2 \times 0.1}{\pi} = 0.063A$$

i) $V_{dc} = I_{dc} R_L = 0.063 \times 950 = 59.85V$

ii) $\gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} = \sqrt{\left(\frac{0.0707}{0.063}\right)^2 - 1} = 0.048$

$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{0.1}{\sqrt{2}} = \underline{0.0707A}$

iii) $P_{dc} = I_{dc}^2 R_L = (0.063)^2 \times 950 = 3.85W$

$P_{ac} = (I_{rms})^2 \times (2R_f + R_L)$

$= (0.070)^2 \left[(2\times25) + 950\right]$

$P_{ac} = 5W$

iv) $\%\eta = \frac{P_{dc}}{P_{ac}} \times 100 = \frac{3.85W}{5W} \times 100 = 77\%$

❖ **In a two diode FWR circuit, the voltage across each half of the transformer secondary is 100V. The load resistance is 950Ω and each diode has a forward resistance of 50Ω. Find the load current and the rms value of the input current.**

June-2004,6M

Given: $V_S = 100V$, $R_f = 50\Omega$, $R_L = 950\Omega$.

* $V_m = \sqrt{2} \times 100 = 141.42V$

* $I_m = \dfrac{V_m}{R_f + R_L} = \dfrac{141.42V}{950\Omega + 50\Omega} = 0.141\ A$

* $I_{RMS} = \dfrac{I_m}{\sqrt{2}} = \dfrac{0.141}{\sqrt{2}} = 0.0997A$

* $I_{dc} = \dfrac{2I_m}{\pi} = \dfrac{2 \times 0.141}{\pi} = 0.090A$

❖ **A bridge rectifier is driving a load resistance of 100Ω. It is driven by a source voltage of 230v, 50Hz. Neglecting diode resistances. Calculate.**

i) Average DC voltage **ii) Average direct current** **iii) frequency of output waveform.**

Jan-2005, 6M

Given : $R_L = 100\Omega$, $V_S = 230V$, $f = 50Hz$

Sol :-

$$V_m = \sqrt{2} \times V_s = \sqrt{2} \times 230 = \underline{325v}$$

i) $$V_{dc} = \frac{2V_m}{\pi} = \frac{2 \times 325}{\pi} = \underline{206.9v}$$

ii) $$I_{dc} = \frac{2I_m}{\pi} = \frac{2 \times 3.25}{\pi} = \underline{2.06A}$$

Where $$I_m = \frac{V_m}{R_L} = \frac{325v}{100\Omega}$$

$$\boxed{I_m = 3.25A}$$

iii) O/p frequency $= 2f_{in} = 2 \times 50Hz = \underline{100Hz}$

❖ **In a full wave rectifier, the input is from a 30-0-30v transformer. The load and diode forward resistance are 100Ω and 10Ω respectively. Calculate the average voltage, rectification efficiency and percentage regulation.**

June-07,7M

Given : $V_S = 30V$, $R_L = 100\Omega$, $R_f = 10\Omega$.

* $V_m = \sqrt{2}\, V_s = \sqrt{2} \times 30 = \underline{42.4264V}$

* $I_m = \dfrac{V_m}{R_f + R_L} = \dfrac{42.4264V}{(100+10)\Omega} = \underline{0.3856A.}$

* $I_{dc} = \dfrac{2I_m}{\pi} = \dfrac{2 \times 0.3856}{\pi} = \underline{0.2455A}$

* $V_{dc} = I_{dc} R_L = 0.2455 \times 100 = \underline{24.55V}$

* $P_{dc} = I_{dc}^2 R_L = (0.2455)^2 \times 100 = \underline{6.027W}$

$$* \quad P_{ac} = I_{rms}^2 (R_f + R_L) = (0.272)^2 (10+100)\Omega = \underline{8.177\,W}$$

$$* \quad I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{0.3856}{\sqrt{2}} = \underline{0.272\,A}$$

$$* \quad \%\eta = \frac{P_{dc}}{P_{ac}} \times 100 = \frac{6.027\,W}{8.177\,W} = \underline{73.69\%}$$

$$* \quad \%\,\text{Regulation} = \frac{R_f}{R_L} \times 100 = \frac{10}{100} \times 100 = \underline{10}$$

Rectifiers with C-filters

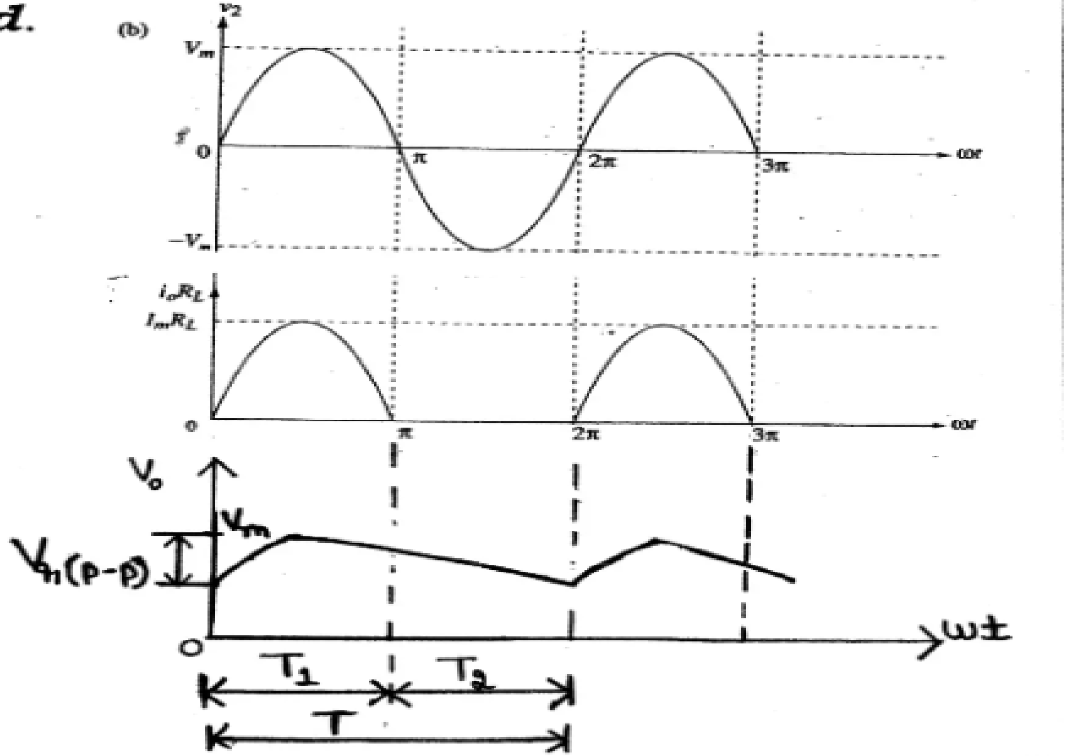
❖ What is a filter ? Why it is required.

Filter is a ***circuit*** used to ***reduce*** the ***ripple*** content ***present in*** the ***rectified output.*** The ripple content of rectified output can be filtered out by connecting a capacitor in parallel with R_L.

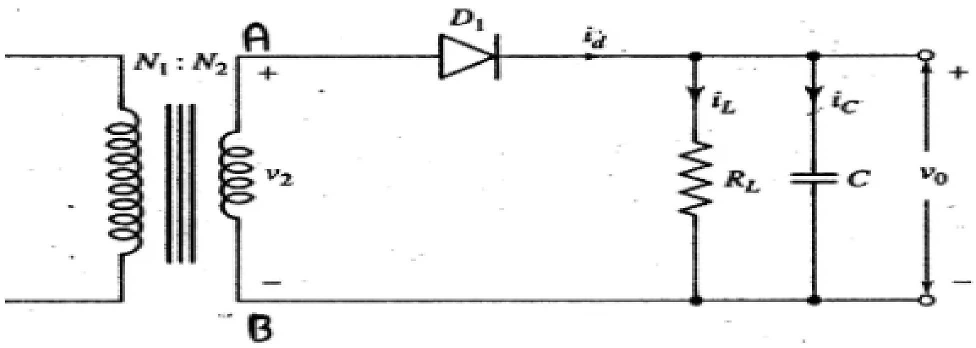
The ***output from rectifiers*** is ***not pure dc due*** to ***ripple*** content. In ***HWR*** ripple content is ***121%***, whereas in ***FWR*** it is ***48%***. In order to obtain ***pure dc***, ***filter circuits*** are ***required***.

Filter is a ***circuit*** used to ***reduce*** the ***ripple*** content ***present in*** the ***rectified output.*** The ripple content of rectified output can be filtered out by connecting a capacitor in parallel with R_L.

The ***output from rectifiers*** is ***not pure dc due*** to ***ripple*** content. In ***HWR*** ripple content is ***121%***, whereas in ***FWR*** it is ***48%***. In order to obtain ***pure dc, filter circuits*** are ***required***.



HWR with capacitor filter :-



Half-wave rectifier with capacitor filter.

During +ve half cycle of the ac input, the diode is forward biased and conducts and charges the capacitor to the peak value of V_m of the input voltage. When the input voltage falls below V_m, the diode stops conducting.

Now, the ***capacitor starts discharging*** through R_L and the ***capacitor voltage decreases***. The ***discharging*** of capacitor ***continues*** till the ***diode starts conducting again*** and ***charges*** the ***capacitor*** in the ***next +ve half cycle*** of the ac ***input*** voltage.

From figure 2, we find that **without capacitor filter, output voltage** varies between **zero** and **V_m. With capacitor filter**, the **output voltage** varies between **(V_m-$V_{r(p-p)}$)** and **V_m.**

This clearly indicates that the **shunting** of **R_L** by **'C' reduces** the **ripple** content in the output voltage. The ripple factor with **'C'** filter is given by

$$\boxed{\gamma = \frac{1}{2\sqrt{3} f C R_L}}$$