

## UNIT - II

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## Rectifiers and filters.

Introduction:

All electronic circuits need dc power supply either directly or from battery. Some of the electronic ckt's operates at fixed dc voltages.

so we have to design a electronic ckt which converts the ac supply voltage into dc voltage at the required level.

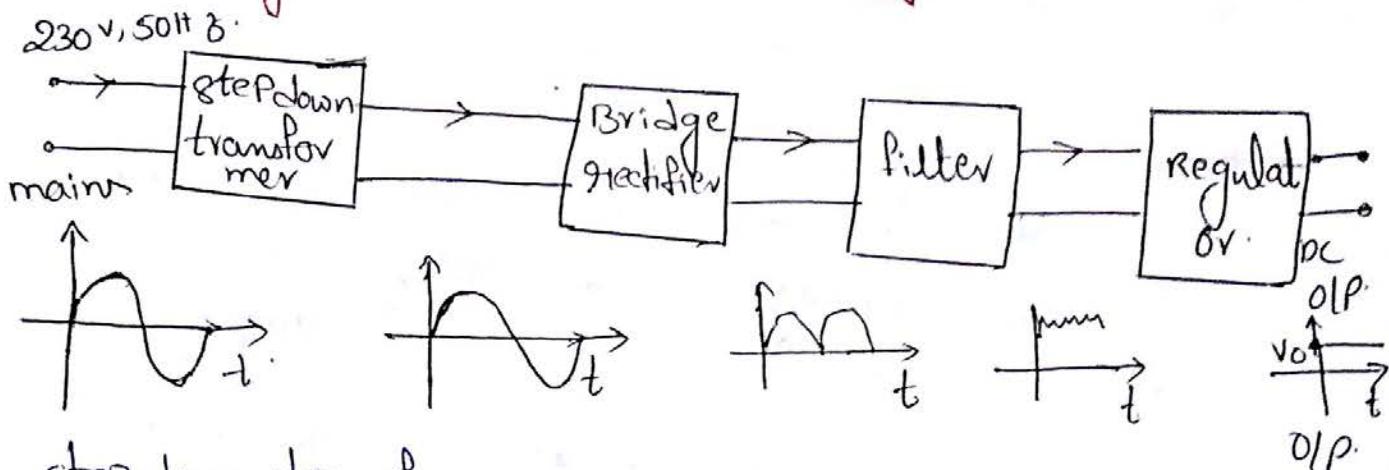
There are two types of conversion of power supply.

1. Ac to dc — linear mode Power Supply. LMPS

If the electronic ckt converts ac power supply into dc power supply then the ckt is known as linear mode power supply.

2. Dc to Ac or dc — switched mode Power Supply.

In certain applications dc-to-dc or dc-to-ac conversion is required such ckt's is known as switched mode power supply.



### Stepdown transformer:

The transformer converts household power supply (230v, 50Hz.) to required level of AC voltage.

### Rectifier:

The bidirectional voltage is converted into a unidirectional pulsating dc voltage.

### filter:

The unwanted ripples contents of this pulsating dc are removed by a filter.

### Regulator:

The regulator which gives a steady dc o/p independent of load variations and i/p supply fluctuations.

The electronic ckt (Amplifier) receives DC power supply for operation of the ckt.

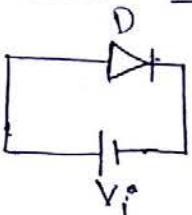
For transistor AC amplifier ckt for biasing DC supply is required. The i/p signal can be AC and so the output signal will be amplified AC signal without biasing with DC supply the ckt will not work.

so more or less all electronic A.c instruments -  
measure DC Power. To get dc powersupply we can use battery  
but they will get dried quickly and replacing them  
every time is a costly affair.

Hence it is economical to convert AC power supply into  
DC.

P-n junction is a diode which permits the easy flow of current in one direction but restrains the flow in the opposite direction.

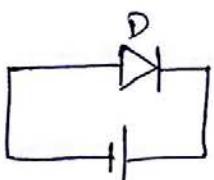
In Forward bias:



As we know that diode will be acted as a short ckt (in the forward bias i.e Ideal diode.)

In forward bias ideal diode acts has a short ckt. it does not offers any resistance so whatever the input given it will appears at the O/P.

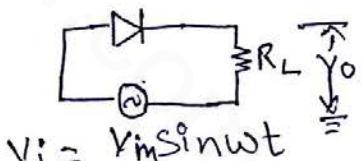
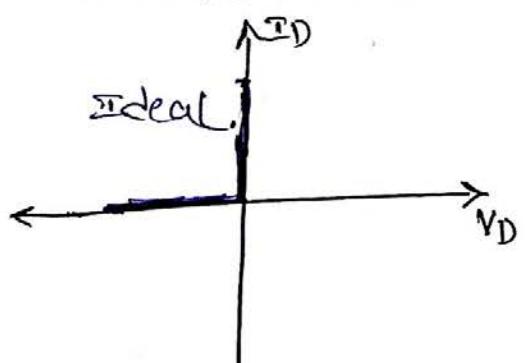
In Reverse bias



As we know that in Reverse bias the diode will be acted as an open ckt.

The ideal diode is open ckt in reverse bias. so it offers high resistance. so no O/P will be there.

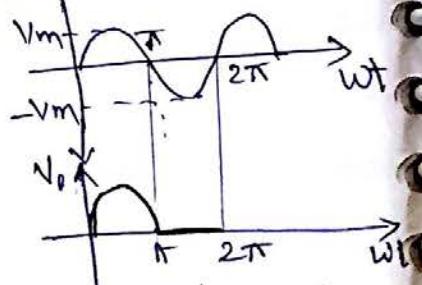
Ideal diode characteristics



$$V_i = V_m \sin \omega t$$

$$V_o = V_m \sin \omega t$$

$$V_{o\text{avg}} = -V_m \sin \omega t \quad \omega t = (\pi - 2\pi)$$



0-π Peak is +ve, diode is shorted we get the O/P; whatever the O/P value is there.

π-2π Peak is -ve diode is opened O/P will be zero.

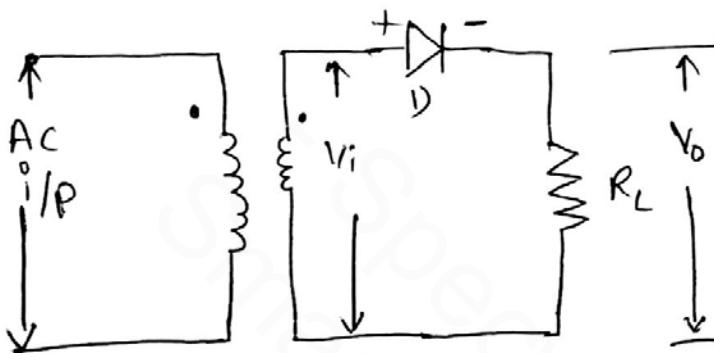
So diode converts bidirectional signal into unidirectional so diode acts as a rectifier.

Rectifier is defined as an electronic device used for converting AC voltage into unidirectional voltage.

Or

Rectifier is defined as an electronic device used for converting Bidirectional Voltage into unidirectional voltage.

So Rectifier uses the unidirectional devices they are P-N diode, vacuum diodes.



Ckt diagram of Halfwave rectifier.

Ac input is normally the Ac main supply (household voltage) since the voltage is 230V, 50Hz such a high voltage cannot be applied to the semiconductor diode. so step down transformer is used (i/p is more, o/p is less transformer).

The o/p voltage is measured across the load Resistor  $R_L$ . Since the peak value of Ac signal much larger than  $V_r$  (cutin) cutin voltage of diode we can neglect that value for Analysis.

If large dc voltage is required vacuum tubes should be used.

### Operation:

Let  $v_i$  be the voltage to the Primary of the transformer and it can be represented by mathematical equation as

$$V_i = V_m \sin \omega t \quad V_m \gg V_r$$

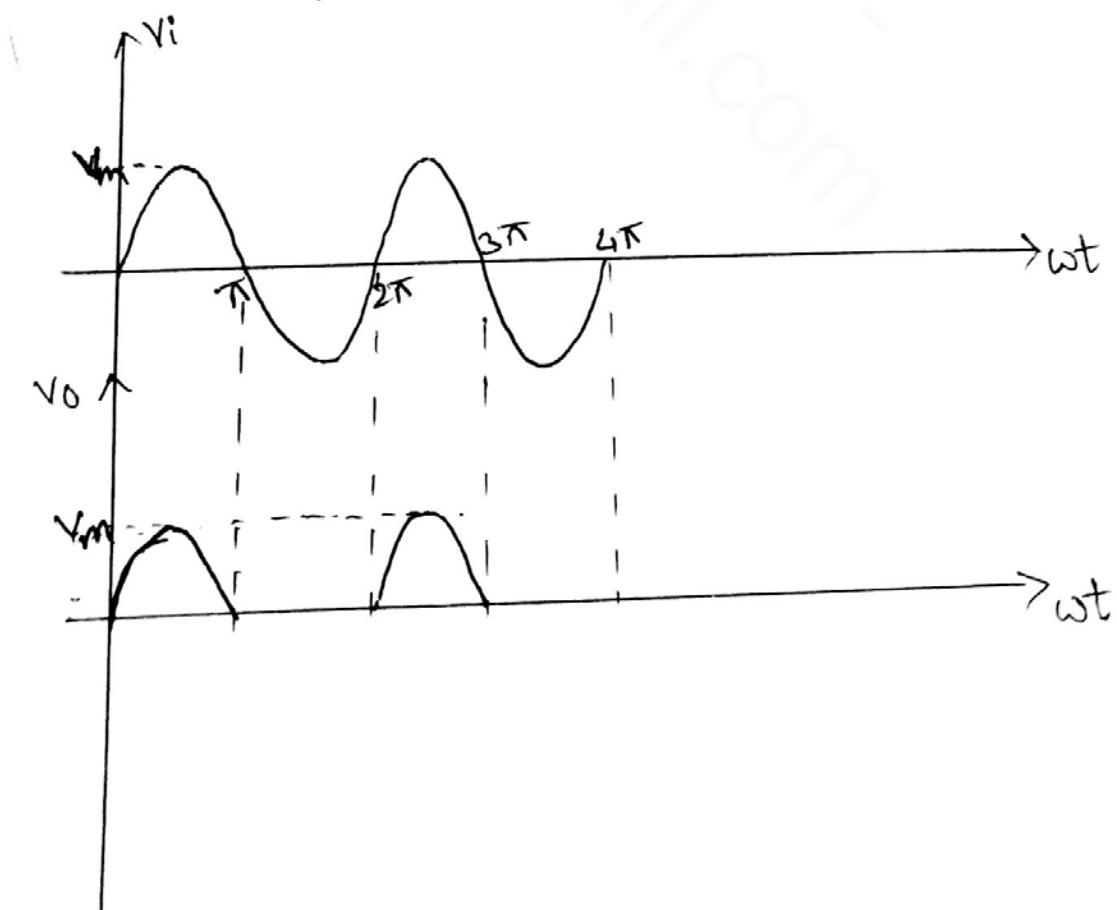
For +ve half cycle :

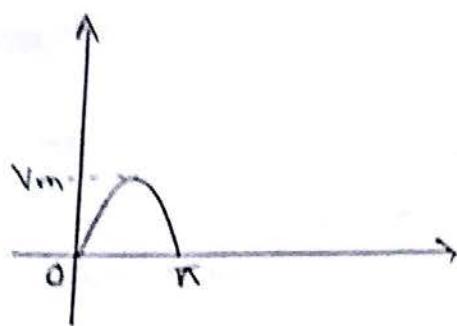
where  $V_r$  is the cutin voltage of the diode, if  $V_{IP}$  voltage is greater than  $V_r$  the diode conducts since during the +ve halfcycle of  $V_{IP}$  signal the anode (+ve) of the diode becomes positive w.r.t. to the cathode and so the diode conducts. i.e forward bias.

For an ideal diode  $R=0$  so the voltage drop across diode is zero. So whole  $V_{IP}$  will appear across the load resistance  $R_L$ .

For -ve half cycle :

In the -ve halfcycle of the input signal anode of the diode becomes negative w.r.t. cathode and hence D does not conduct (for an ideal diode in reverse bias  $R=\infty$  so  $I=0$ ) so no voltage across the  $R_L$  voltage is zero.





$$V = V_m \sin \omega t \\ = 0$$

$$0 \leq \omega t < \pi$$

$$\pi \leq \omega t \leq 2\pi$$

$$I = \frac{V_m}{R_p + R_s + R_L}$$

$R_p$  = diode forward Resistance

$R_s$  = transformer secondary resistance

$R_L$  = load resistance.

Reading of DC voltmeter or  $V_{dc}$  or Average voltage  $V_{avg}$ :

The DC meter is so constructed that it reads the average value.

$$\text{Average value} = \frac{\text{Area of curve}}{\text{Base}}$$

Average value or  $V_{avg}$

$$\text{Average voltage} = \frac{1}{T} \int_0^T V \cdot dt$$

for half wave rectifier

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

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

$$= \frac{V_m}{2\pi} \left[ -\cos \omega t \right]_0^\pi \Rightarrow \frac{V_m}{2\pi} \cdot [ \cos 0 - \cos \pi ]$$

$$= -\frac{V_m}{2\pi} [ (-1) - 1 ] = \frac{V_m}{2\pi} \times 2 = \frac{V_m}{\pi}$$

$$\therefore \cos \pi = -1 \\ \cos 0 = 1$$

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

$$I_{dc} = \frac{V_m}{(\pi \cdot R_L)}$$

$$V = IR \\ I = V/R.$$

If the Resistance of diode and secondary transformer is considered the total resistance will be  $R_s + R_D + R_L$  since these resistances are in series.

$$I_{dc} = \frac{V_{dc}}{R_s + R_D + R_L} \Rightarrow \frac{V_m}{\pi(R_s A_{RD}) + R_L}$$

V<sub>rm</sub> voltage or Reading of Acmeter or V<sub>ac</sub> Ac voltage.

An Ac ammeter is constructed such that the needle deflection indicates the effective R<sub>rm</sub> voltage or current passing through it w.vt Peak voltage, (V<sub>rm</sub> & V<sub>ac</sub> almost same) what is meant by V<sub>rm</sub> value. It is the value of DC which produces the same heating effect as the AC quantity, the magnitude of this equivalent DC is called the R<sub>rm</sub> of AC.

$$V_{ac} = \frac{1}{2\pi} \int_0^{\pi} V_m^2 \sin^2 wt dt + \int_{\pi}^{2\pi} 0 \cdot dt$$

$$\therefore V_{rm} = \sqrt{\frac{1}{T} \int_0^T V^2 dt}$$

$$= \frac{1}{2\pi} V_m^2 \int_0^{\pi} \frac{1 - \cos 2wt}{2} dt$$

$$= \frac{V_m^2}{2\pi} \int_0^{\pi} \frac{1 - \cos 2wt}{2} dt$$

$$= \frac{V_m^2}{4\pi} \left[ wt - \frac{\sin wt}{2} \right]_0^{\pi}$$

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

$$= \frac{V_m^2}{4\pi} \times \pi - 0 - 0 \quad \int \frac{V_m^2}{4} = \frac{V_m^2}{2}$$

$$V_{rm} = \frac{V_m}{2} \rightarrow V_{ac}$$

$$I_{AC} = \frac{V_{AC}}{R_L} \Rightarrow I_{AC} = \frac{V_m}{2 \cdot R_L}$$

### Ratio of Rectification or Efficiency n

$$\text{Efficiency (general)} = \frac{\text{o/p Power}}{\text{i/p Power}}$$

In the Rectifier o/p is in the form of DC & the i/p is the form of AC

80

$$n = \frac{\text{DC Power delivered to load}}{\text{AC i/p Power from secondary transformer}} \times 100$$

$$P_{DC} = V_{DC} \times I_{DC} = \frac{V_m}{2} \times \frac{V_m}{2 \cdot R_L}$$

$$n = \frac{\frac{V_m}{\pi} \times \frac{V_m}{\pi \cdot R_L}}{\frac{V_m}{2} \times \frac{V_m}{2 \cdot R_L}} = \frac{V_m}{\pi} \times \frac{V_m}{\pi R_L} \times \frac{2 \times 2 R_L}{V_m \times V_m} = 4/\pi^2$$

$$\Rightarrow n = 4/\pi^2 = 0.406.$$

$$\therefore \pi = \frac{22}{7} = 3.14$$

$$\% = 0.406 \times 100 = 40.6.$$

### Ripple factor: derivation

The purpose of a rectifier circuit is to convert AC to DC, but simple circuit shown before will not achieve this (i.e. Pure DC).

Ripple factor is a measure of the fluctuating components present in rectifier ckt.

Ripple factor  $\gamma$

$$\gamma = \frac{\text{Rms value of alternating component of the waveform}}{\text{Average value of the waveform}}$$

$$\left| V = \frac{I'_{rms}}{I_{DC}} \right| = \frac{\sqrt{V_{rms}}}{V_{DC}}$$

$I'_{rms}$  and  $V'_{rms}$  denote the value of the AC component of current or voltage in the OLP respectively.

For lab reference: while calculation or observing of vac (AC voltage)

Experimentally: A capacitor should be connected in series with the AC meter in order to block the DC component.

Ripple Factor should be small (Total current  $i = I_m \sin \omega t$  according to Fourier series, only AC is sum of DC and harmonics)

We shall now derive the expression for Ripple Factor.

$I'$  = AC current

$I$  = total current

$I_{DC}$  is the DC current

$$I' = (I - I_{DC}) \quad \therefore \text{ i.e. AC current} = \text{total current} - \text{DC current}$$

$$\text{Rms value of } I'_{rms} = \left[ \frac{1}{T} \int_0^T (I - I_{DC})^2 dt \right]^{1/2}$$

Since in halfwave rectifier  $T = 2\pi$

$$I' = \sqrt{\frac{1}{T} \int_0^T (I - I_{DC})^2 dt}$$

$$I' = \sqrt{\left( \frac{1}{T} \int_0^T I^2 dt - 2I \cdot I_{DC} + I_{DC}^2 \right) T}$$

$$I' = \sqrt{\frac{1}{T} \int_0^T I^2 dt - 2 \frac{I_{DC}}{T} \int_0^T I dt + \frac{1}{T} \int_0^T I_{DC}^2 dt}$$

$$I' = \sqrt{\frac{1}{T} \int_0^T I^2 dt} = (I'_{rms})^2 ; \frac{1}{T} \int_0^T I dt = I_{DC} \text{ or } \bar{I}_{avg}$$

$$I' = \sqrt{I'_{rms}^2 - 2I_{DC} \cdot I_{DC} + I_{DC}^2 \times \frac{1}{T} \int_0^T I^2 dt}$$

$$I' = \sqrt{I_{rms}^2 - I_{DC}^2} \quad N = \sqrt{\left(\frac{I_{rms}}{I_{DC}}\right)^2 - 1}$$

$$r = \frac{1}{I_{DC}}$$

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

If I take in terms of voltage then ripple factor is

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

Ripple factor of Halfwave is 0.0

$$V_{rms} = \frac{V_m}{2} \quad V_{DC} = \frac{V_m}{\pi}$$

$$r = \sqrt{\left(\frac{\frac{V_m}{2}}{\frac{V_m}{\pi}}\right)^2 - 1}$$

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

$$r = \sqrt{\frac{\pi^2}{4} - 1} \quad r = 1.21$$

Transformer utilization Factor:

Transformer utilization factor TUF;

Transformer utilization factor  $TUF = \frac{\text{Dc power delivered to the load}}{\text{Ac rating of transformer secondary}}$ .

In the Halfwave rectifier circuit, the rated voltage of the transformer secondary is  $\frac{V_m}{\sqrt{2}}$ .

The rms voltage of secondary transformer is  $V_{rms} = \frac{V_m}{\sqrt{2}}$

current in  $I_{rms} = \frac{I_m}{2}$

$$TUF = \frac{V_m}{\pi} \times \frac{I_m}{\pi} \times \frac{\sqrt{2}}{V_m} \times \frac{2}{I_m} = \frac{2\sqrt{2}}{\pi^2} = 0.287.$$

The transformer utilization factor for Halfwave rectifier is 0.287.

Peak inverse voltage

It is defined as the maximum reverse voltage that a diode can withstand without destroying the junction. The peak inverse voltage overall the ckt of the diode is ( $v_m$ ) negative peak of  $v_m$ . So for halfwave rectifier PIV is  $v_m$ .

Form factor

$$\text{Form factor} = \frac{\text{Rms value}}{\text{Average value}} = \frac{\left(\frac{v_m}{2}\right)}{\left(\frac{v_m}{\pi}\right)} = \frac{\pi}{2}$$

$$= 1.57$$

Peak factor

$$\text{Peak factor} = \frac{\text{Peak value}}{\text{Rms value}} = \frac{v_m}{\frac{v_m}{2}} = 2.$$

Inadvantages of HWR

1. Ripple factor is  $1.21 (r > 1)$
2. Low ratio of rectification ie efficiency (0.406)
3. Low TUF (0.281)

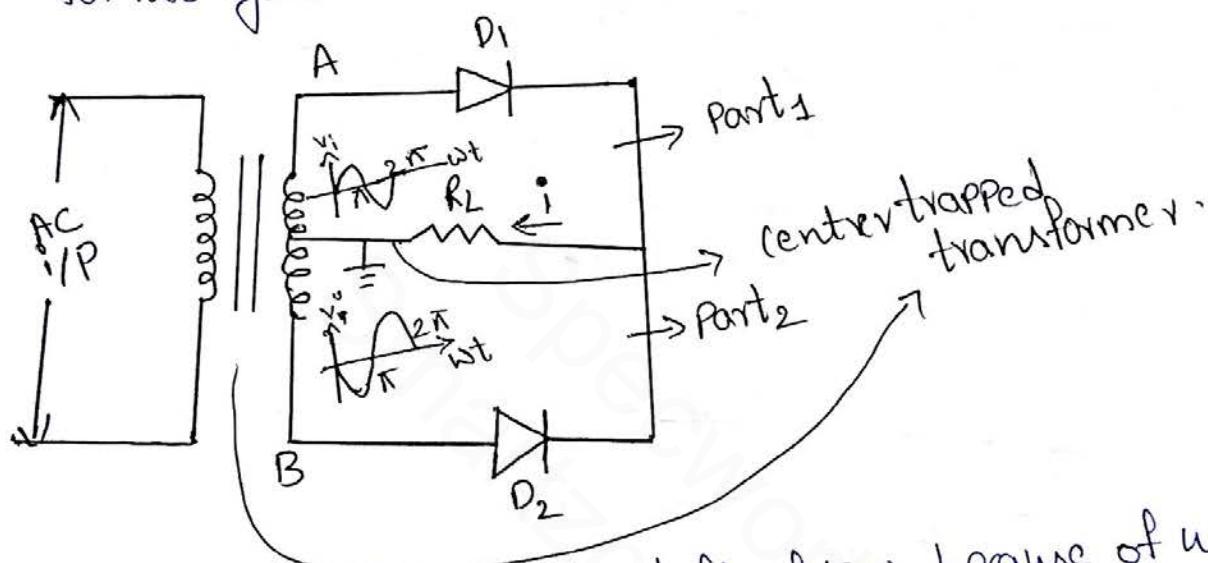
4.

## Fullwave Rectifier FWR :

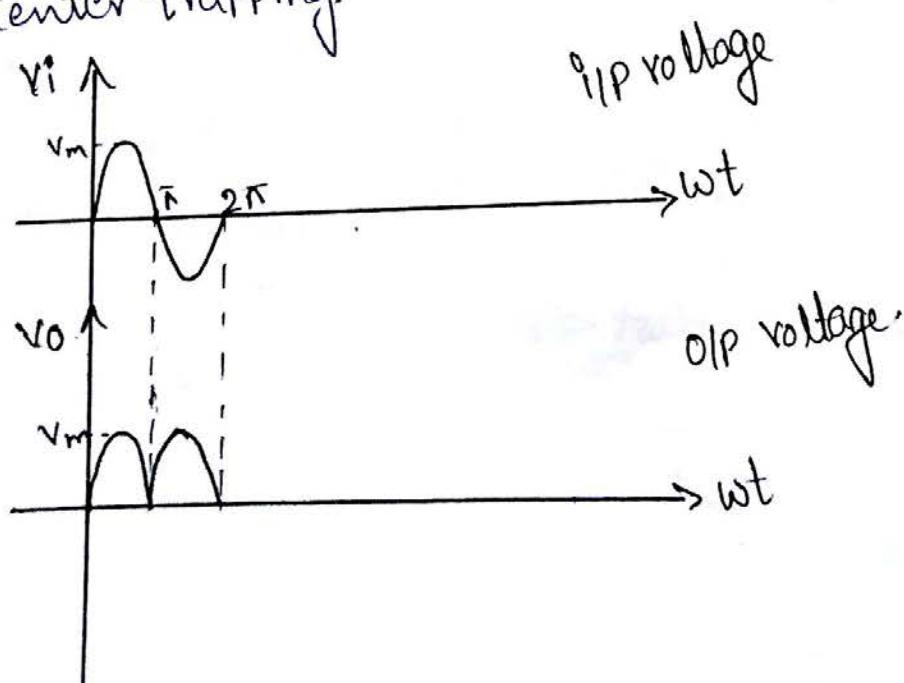
The Halfwave rectifier circuit has a poor ripple factor ( $r > 1$ ) since the AC voltage is greater than DC voltage. It cannot be better choice for us.

And efficiency of FWR is less since it is conducting only one half cycle (we get OLP voltage in only one half cycle) while iip is in two cycles.

Now we have to design a circuit such that it can conduct for two cycles.



In Part<sub>2</sub> there is a phase shift of  $180^\circ$  because of using center-trapped. A center-trapped transformer is essential to get fullwave rectification. So there is a phase shift of  $180^\circ$  because of center trapping.



Operation:

Since center-trapped transformer is used there is a phase shift of  $180^\circ$  in (Phase-2) Part 2.

For +ve half cycle  $0-\pi$ 

During the +ve half cycle  $D_1$  conducts and the current through  $D_2$  is zero. Since  $D_1$  is forward biased, and  $D_2$  is reverse biased. So the O/P appears across  $R_L$ .

For -ve half cycle  $\pi-2\pi$ 

During the -ve half cycle  $D_2$  conducts and the current through  $D_1$  is zero. Since  $D_2$  is forward biased,  $D_1$  is reverse biased. So the O/P appears across  $R_L$ .

From the above discussion we can say that for both the +ve halfcycle and -ve halfcycle we got the O/P in the unidirectional.

DC Voltage or Average Voltage

$$V_{DC} = \frac{1}{\pi} \int_0^{\pi} V_m \sin \omega t \cdot dt$$

$$= \frac{V_m}{\pi} \int_0^{\pi} \sin \omega t \cdot dt = \frac{V_m}{\pi} \left[ -\cos \omega t \right]_0^{\pi}$$

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

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

$$I_{DC} = \frac{2V_m}{\pi \cdot R_L}$$

$$\therefore I_{DC} = \frac{V_{DC}}{R_L}$$

AC voltage or RMS voltage

$$V_{RMS} = \sqrt{\frac{1}{\pi} \int_0^{\pi} V_m^2 \sin^2 \omega t \cdot dt}$$

$$= \sqrt{\frac{V_m^2}{\pi} \int_0^{\pi} \sin^2 \omega t \cdot dt}$$

$$= \sqrt{\frac{V_m^2}{\pi} \int_0^{\pi} \frac{1-\cos 2\omega t}{2} dt}$$

$$\therefore V_{RMS} = \sqrt{\frac{1}{\pi} \int_0^{\pi} V^2 dt}$$

$$1082\omega t = 1 - 2\sin^2 \omega t$$

$$\sin^2 \omega t = \frac{1 - \cos 2\omega t}{2}$$

$$\int \frac{1}{2} dt = \omega t / 2$$

$$\begin{aligned}
 &= \sqrt{\frac{V_m^2}{\pi} \left[ \frac{wt}{2} - \frac{\sin 2wt}{4} \right]_0^\pi} \quad \therefore |\cos 2wt = \frac{\sin 2w\pi}{2} \\
 &= \sqrt{\frac{V_m^2}{\pi} \left[ \frac{wt}{2} - \frac{\sin 2wt}{4} \right]_0^\pi} \Rightarrow \sqrt{\frac{V_m^2}{\pi} \left[ \left[ \frac{\pi}{2} - \frac{\sin 2\pi}{4} \right] - \left[ 0 - \frac{\sin 0}{4} \right] \right]} \\
 &= \sqrt{\frac{V_m^2}{\pi} \left[ \left( \frac{\pi}{2} - 0 \right) - 0 - 0 \right]} \quad = \sqrt{\frac{V_m^2}{\pi} \times \frac{\pi}{2}} = \frac{V_m}{\sqrt{2}} \\
 &\boxed{V_{rms} = \frac{V_m}{\sqrt{2}}} \quad I_{rms} = \frac{V_{rms}}{R_L} = \frac{V_m}{\sqrt{2} R_L}
 \end{aligned}$$

### Efficiency n

$n = \text{O/P Power}/\text{I/P Power}$   
 in the Rectifier ckt - O/P is in the form of DC w/ the I/P is AC

$$n = \frac{\text{dc O/P Power}}{\text{ac I/P Power}} = \frac{P_{dc}}{P_{ac}} = \frac{V_{dc} \times I_{dc}}{V_{rms} \times I_{rms}}$$

$$= \frac{2V_m}{\pi} \times \frac{2V_m}{\pi \cdot R_L} = \frac{2V_m \cdot 2V_m}{\pi \cdot R_L} \times \frac{\sqrt{2} \cdot \sqrt{2} \cdot R_L}{V_m V_m}$$

$$\frac{V_m}{\sqrt{2}} \times \frac{V_m}{\sqrt{2} \cdot R_L} = 0.812 \quad n.i. = 81.2\%$$

$$= \frac{4 \times 2}{\pi^2} = 8/\pi^2$$

$$\boxed{n.i. = 81.2\%}$$

### Ripple factor:

$$\begin{aligned}
 r &= \sqrt{\left( \frac{V_{rms}}{V_{dc}} \right)^2 - 1} \quad \approx \sqrt{\left( \frac{V_{rms}}{V_{dc}} \right)^2 - 1} \\
 &= \sqrt{\left( \frac{\frac{V_m}{\sqrt{2}}}{\frac{2V_m}{\pi}} \right)^2 - 1} \quad \approx \sqrt{\left( \frac{\frac{V_m}{\sqrt{2}} \times \frac{\pi}{2V_m}}{2V_m} \right)^2 - 1} \\
 &= \sqrt{\frac{\pi^2}{4 \times 2} - 1} \quad = \sqrt{\frac{\pi^2}{8} - 1} = 0.482
 \end{aligned}$$

Transformer utilization Factor TUF

$TUF = \frac{\text{dc power delivered to the load}}{\text{ac rating of the transformer secondary}}$

AC rating of the secondary

$$V_{rmsS} = \frac{V_m}{\sqrt{2}}$$

$$I_{rmsS} = \frac{I_m}{\sqrt{2}}$$

$$P_{dc} = V_{dc} \times I_{dc}$$

$$P_{ac \text{ sec}} = V_{rms} I_{rms}$$

$$TUF = P_{dc} / P_{ac \text{ sec}}$$

$$TUF = \frac{\frac{2V_m}{\pi} \times \frac{2V_m}{\pi \cdot R_L}}{\frac{V_m}{\sqrt{2}} \times \frac{V_m}{\sqrt{2}R_L}}$$

$$= 8/\pi^2 = 0.693$$

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

$$TUF = 0.693$$

Form factor:

Form Factor:  $\frac{V_{max} \text{ value of the o/p voltage}}{\text{Average value of the o/p voltage}}$

$$= \frac{V_m / \sqrt{2}}{\frac{2V_m}{\pi}} = \frac{\pi}{2\sqrt{2}} = 1.11$$

Peak factor:

Peak Factor =  $\frac{\text{Peak value of the output voltage}}{\text{V}_{rms} \text{ value of the output voltage}}$

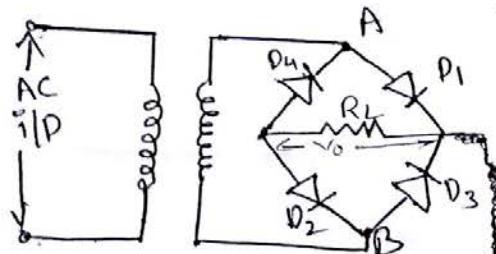
Disadvantages of FWR

1. Core trapped is very costly
2. Both DC & AC is present at O.P. (voltages)

Advantages:

1. Ripple factor is less when compared with HWR.
2. Efficiency is more than HWR.

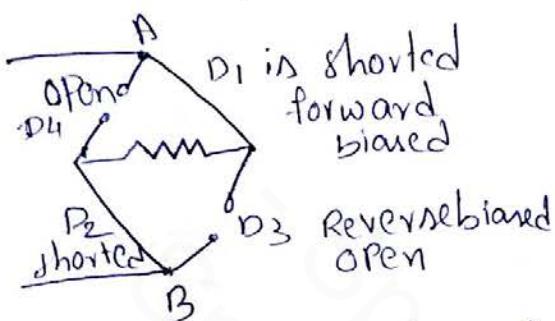
# Bridge Rectifier



The AC o/p voltage is applied to diagonally opposite ends of the bridge. The load resistance is connected between the other two ends of the bridge.

The need of center tapped transformer in fullwave rectifier is eliminated in the Bridge rectifier.

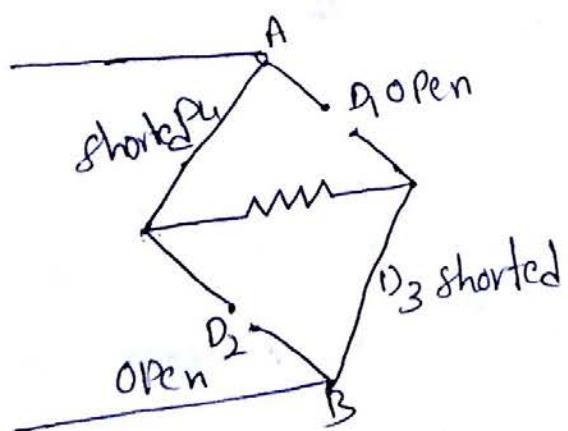
for +ve half cycle:



During +ve half cycle D<sub>1</sub> and D<sub>2</sub> is forward biased  
D<sub>3</sub> and D<sub>4</sub> is open

So the current will flow through D<sub>1</sub> first and then through R<sub>L</sub> and then through D<sub>2</sub> back to the ground. So there is voltage drop across R<sub>L</sub> i.e maximum voltage drop occurs.

-ve half cycle



During -ve half cycle  
D<sub>4</sub> w/ D<sub>3</sub>  
are forward biased,  
D<sub>1</sub> w/ D<sub>2</sub> are open

D<sub>4</sub> w/ D<sub>3</sub> are forward biased and they conduct, the current flows from D<sub>3</sub> through R<sub>L</sub> to D<sub>4</sub>. So in the -ve half cycle also there is voltage drop across R<sub>L</sub>. So the o/p will be same as fullwave rectifier.

The calculations and values of Bridge rectifier will be the same as the fullwave rectifier.

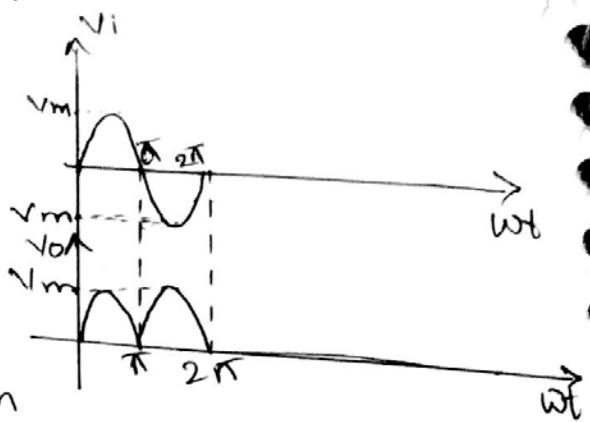
They are

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

$$V_{DC} = \frac{2V_m}{\pi}$$

If I consider the  $R_S, R_P, R_L$  then

$$I_{DC} = \frac{2V_m}{\pi(R_S + 2R_P + R_L)}$$



$\therefore$  Here 2 diodes come in to picture for each half cycle.

$2R_P$  is used since two diodes in series are conducting at the same time.

$$V_{AC} \text{ or } V_{rms} = \frac{V_m}{\sqrt{2}}$$

$$I_{rms} = \frac{V_{rms}}{R_L} = \frac{V_m}{\sqrt{2} \cdot R_L}$$

$$\eta \text{ efficiency} = 81.2\%$$

Advantages:

1. The Peak inverse voltage (PIV) across each diode is  $V_m$  and not  $2V_m$  as in the case of FWR.
2. center tapped transformer is not required

Disadvantages:

1. Four diodes are used.
2. There is some voltage drop across each diode, so op voltage will be slightly less compared to FWR. But these factors are minor compared to the advantages.

Fourier series are applied for periodic signals, the o/p of the rectifiers are periodic signals so we can apply Fourier series.

The Fourier series of a halfwave rectifier is

$$i = I_m \left[ \frac{1}{\pi} + \frac{1}{2} \sin \omega t - \frac{2}{\pi} \sum_{k=2,4,6}^{\infty} \frac{\cos k \omega t}{(k+1)(k-1)} \right] \quad \text{--- (1)}$$

The lowest angular frequency present in this expression is that of the primary source of AC power. i.e Basic Power frequency that occurs in the above equation.

All the other terms in the final expression are even harmonics of the primary frequency.

In fullwave rectifier the corresponding expressions are by recalling that the fullwave circuit consists essentially of two half wave circuits which are so arranged that one circuit conducts during one half cycle and the second operates during the second half cycle so that the currents are functionally related by expression  $i_1(\alpha) = i_2(\alpha + \pi)$  total load current

$$i = i_1 + i_2$$

$$i = I_m \left[ \frac{2}{\pi} - \frac{4}{\pi} \sum_{k=2,4,6,\dots}^{\infty} \frac{\cos k \omega t}{(k+1)(k-1)} \right].$$

The fundamental angular frequency  $\omega$  has been eliminated from the equation, the lowest frequency in the output being  $2\omega$  a second harmonic term.

A second desirable feature of the fullwave circuit is fact that the current pulses in the two halves of the transformer winding are in such directions that the magnetic cycle through which the iron of the core is taken is essentially that the alternating current. This eliminates any dc saturation of the transformer core, which would give rise to additional harmonics in the o/p.

A power supply must provide an essentially ripple-free source of power from ac line. It gives information that above that output of a rectifier contains ripple components in addition to dc term. Hence it is necessary to include a filter between the rectifier and the load in order to attenuate these ripple components.

### Comparison of Rectifier.

Particulars	Type of rectifier		
	Halfwave	Fullwave	Bridge
No. of diodes	1	2	4
Maximum efficiency	40.6%	81.2%	$\frac{2Vm}{\pi}$
$V_{dc}$ (no load)	$V_m/\pi$	$\frac{2Vm}{\pi}$	0.48
Ripple factor	1.21	0.48	$\frac{Vm}{2f}$
Peak inverse voltage	$V_m$	$2Vm$	$2f$
Output frequency	$f$	$2f$	0.812
Transformer utilisation factor	0.287	0.693	1.11
Form factor	1.57	2	$\sqrt{2}$
Peak factor			

The output of a rectifier contains DC component as well as AC component.

Filters are used to minimize the undesirable A.C i.e. ripple and pass the DC component to appear at the O.P.

As we know that the Rectifier O.P contains both AC and DC voltage to avoid or to reduce the AC voltage, we are going to use filters.

The O.P of the filters having the (fluctuation) ripples to avoid this we use regulators.

### Inductor Filters or choke filter

Inductor :

$$L = N\Phi/I$$

As we know that the inductor will not allow sudden changes of current. If in any ckt there are occurring sudden changes of current that can be avoided by using inductor.

The impedance of the Inductance can be as  $j\omega L$  or  $j2\pi fL$

For the DC voltage  $\Rightarrow$  Frequency  $f=0$

$$\boxed{X_L = j2\pi fL} \quad f=0 \Rightarrow X_L = j2\pi(0)L = j2\pi(0)0 = 0$$

$\Rightarrow$  short for DC it allows DC

For AC voltage

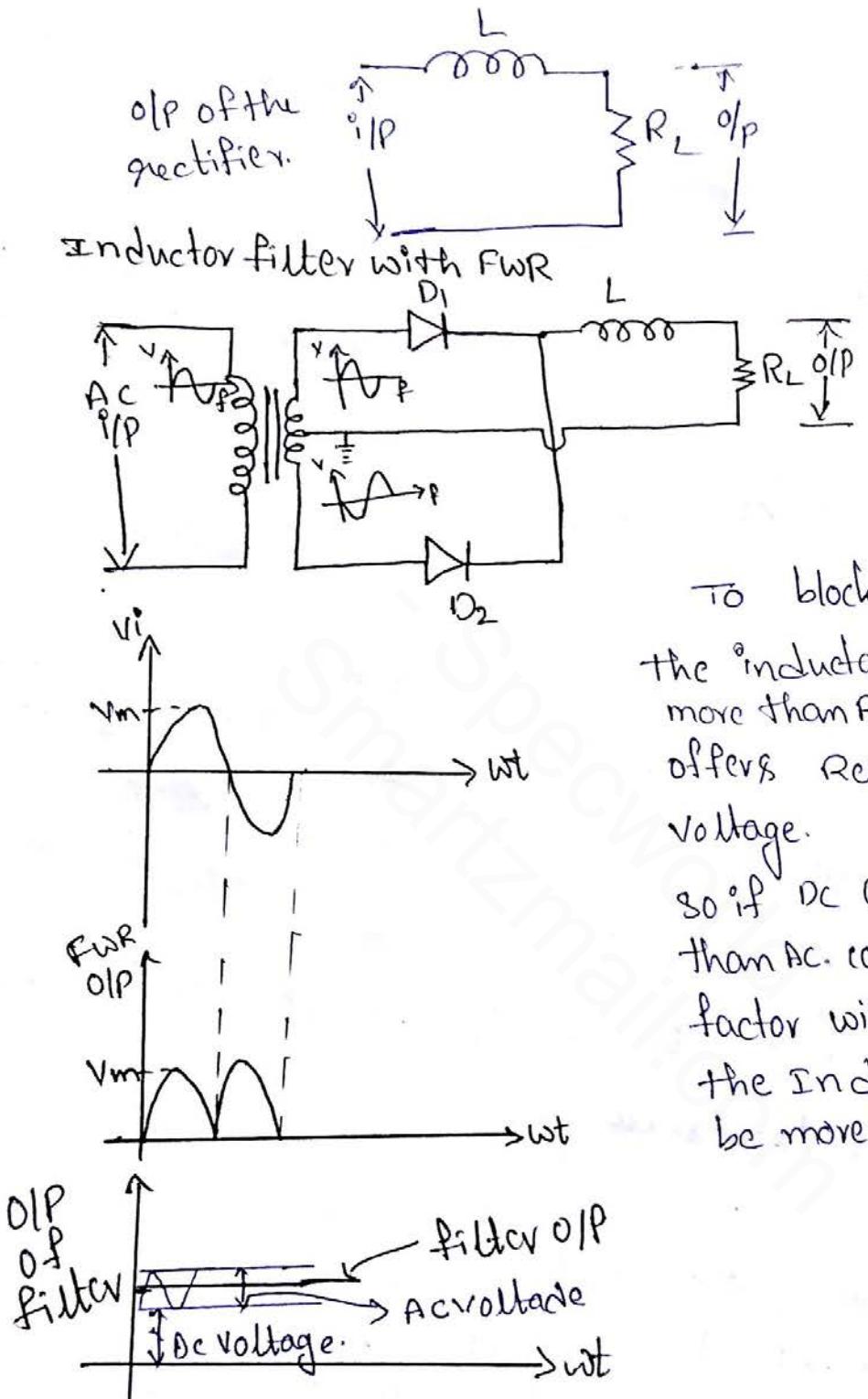
frequency  $f \neq 0$  or  $f = \infty$

$$X_L = j2\pi fL \Rightarrow X_L \neq 0 \quad \text{that it offers some impedance.}$$

$$f = \infty \Rightarrow X_L = \infty \quad \text{— open for AC. — it blocks AC.}$$

At the O.P of the filter we want only DC not AC, since inductor is allowing the DC (ie  $X_L = 0$  for DC) so it should be in series across the  $R_L$ .

The inductor is in series across  $R_L$ . So at O/P of filter almost all the AC will be blocked.



To block the AC components, the inductance value should be more than  $R_L$ . Since the inductance offers resistance for the AC voltage.

So if DC component is more than AC component the ripple factor will be less. So then the inductance value should be more than  $R_L$ .

For Reference

To study of any signals, it is better to take frequency domain. If we take signals in frequency domain we will get more information of the signal (summation is product of two signals mathematical operations on signals will be better & easier in freq-domain than

To convert the signal from time domain to frequency domain, we have to apply Fourier analysis. In Fourier analysis there are two types

1. Fourier Series
2. Fourier Transform.

Fourier series will be applied for periodic signals.

Fourier transform will be applied for nonperiodic signals.

If we apply Fourier series for the FWR will be

$$V_0 = \frac{2V_m}{\pi} - \frac{4V_m}{\pi} \left[ Y_3 \cos 2\omega t + Y_{15} \cos 4\omega t + \dots \right]$$

The higher harmonic terms can be neglected i.e.  $Y_{15} \cos 4\omega t$ .

$$V_0 = \frac{2V_m}{\pi} - \frac{4V_m}{\pi} [Y_3 \cos 2\omega t]$$

$$V_0 = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi} \cos 2\omega t$$

$\frac{2V_m}{\pi}$  = DC voltage

∴ There is no  $\cos 4\omega t$  term  
it is AC voltage

$\frac{4V_m}{3\pi} \cos 2\omega t$  AC voltage ∵ It is having cos term

$$V_{DC} = \frac{2V_m}{\pi} \quad \text{of ac signal} \quad V_m = \frac{4V_m}{3\pi} \quad \text{at } \omega = 2\omega,$$

Since we are using inductance we have to change in terms of current:

$$V_C \Rightarrow Z = \sqrt{(R_L)^2 + (X_L)^2} \quad X_L = \omega L \quad \text{at } \omega = 2\omega \\ X_L = (2\omega L)$$

$$|Z| = \sqrt{R_L^2 + (2\omega L)^2} = \sqrt{R_L^2 + 4\omega^2 L^2}$$

For DC voltage:

$$|Z| = \sqrt{R_L^2 + X_L^2} \quad X_L = \omega L \quad \text{at } \omega = 0$$

$$|Z| = \sqrt{R_L^2 + u(0)^2 L^2} = \sqrt{R_L^2} = R_L$$

For AC voltage

$$|Z| = \sqrt{R_L^2 + 4\omega^2 L^2}$$

$$I_0 = \frac{2V_m}{\pi R_L} = \frac{4V_m}{3\pi |Z|} \cos(2\omega t - \phi)$$

$$\phi = \tan^{-1}\left(\frac{2\omega L}{R_L}\right)$$

$$I_0 = \frac{2V_m}{\pi R_L} = \frac{4V_m}{3\pi \sqrt{R_L^2 + 4\omega^2 L^2}} \cdot \cos(2\omega t - \phi)$$

$$f = \frac{V_{rms}}{V_{DC}} \text{ or } \frac{I_{rms}}{I_{DC}}$$

$$\sqrt{f} = \frac{4V_m}{3\pi\sqrt{2}} \cdot \frac{1}{\sqrt{R_L^2 + 4\omega^2 L^2}} \cdot \frac{2V_m}{\pi R_L}$$

$$= \frac{4V_m}{3\pi\sqrt{2}} \cdot \frac{1}{\sqrt{R_L^2 + 4\omega^2 L^2}} \cdot \frac{\pi R_L}{2V_m} = \frac{2}{3\sqrt{2}} \cdot \frac{R_L}{\sqrt{R_L^2 + 4\omega^2 L^2}}$$

$$= \frac{2}{3\sqrt{2}} \cdot \sqrt{\frac{1}{R_L^2} + \frac{4\omega^2 L^2}{R_L^2}}$$

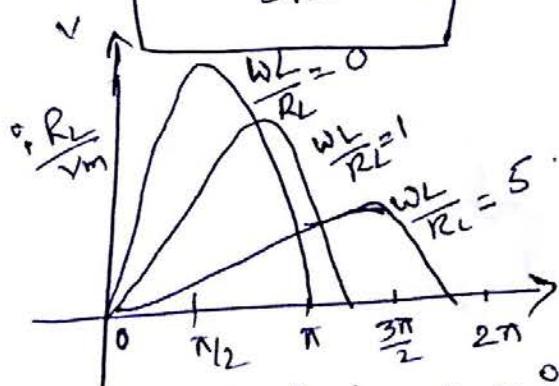
$$= \frac{2}{3\sqrt{2}} \cdot \sqrt{1 + \frac{4\omega^2 L^2}{R_L^2}}$$

As we know that  $L > R_L$  then  $\frac{4\omega^2 L^2}{R_L^2} \gg 1$  so  $I$  can neglected

$$= \frac{2}{3\sqrt{2}} \cdot \sqrt{\frac{1}{\frac{4\omega^2 L^2}{R_L^2}}} = \frac{2}{3\sqrt{2}} \cdot \frac{1}{2\omega L} \cdot \frac{R_L}{R_L} = \frac{2}{3\sqrt{2}} \cdot \frac{R_L}{2\omega L}$$

$$\boxed{Y = \frac{R_L}{3\sqrt{2}\omega L}}$$

$$Y \propto R_L$$



$R_L$  is const.

The effect of changing inductance value on the waveforms in  $RLC$  with an inductor filter.

∴ in inductor current lags by angle  $\phi = \tan^{-1}\left(\frac{Imaginary}{Real}\right)$

$$\phi = \tan^{-1}\left(\frac{Imaginary}{Real}\right)$$

$$I_{DC} = \frac{2V_m}{\pi R_L}$$

$$I_{QPP} = \frac{4V_m}{3\pi \sqrt{R_L^2 + 4\omega^2 L^2}}$$

$$I_{rms} = \frac{I_{DC}}{\sqrt{2}}$$

$$I_{rms} = \frac{4V_m}{3\pi\sqrt{2}} \times \frac{1}{\sqrt{R_L^2 + 4\omega^2 L^2}}$$

$$\frac{R_L}{\sqrt{R_L^2 + 4\omega^2 L^2}}$$

$$= \frac{2}{3\sqrt{2}} \cdot \sqrt{1 + \frac{4\omega^2 L^2}{R_L^2}}$$

capacitor

$$C = \frac{dQ}{dv}$$

The capacitor will not allow the sudden changes of voltage.  
(The capacitor maintains a constant voltage) if the sudden changes of voltage taken in the ckt can be avoided that sudden changes by using capacitor.

$$X_C = \frac{1}{2\pi f C} = \frac{1}{\omega C}$$

for DC voltage  $\omega = 0$  or  $f = 0$

$X_C = \frac{1}{2\pi(0)C} = \frac{1}{0} = \infty$   $X_C = \infty$   $X_C$  open for DC  
That it is blocks DC voltage i.e. it is not allows DC voltage

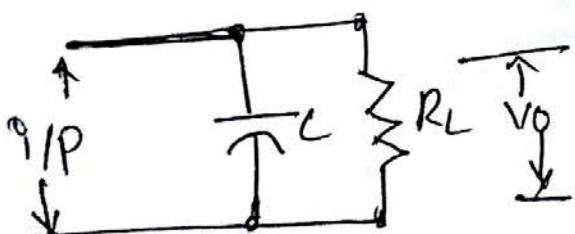
For AC voltage  $\omega \neq 0$ ;  $f \neq 0$   $X_C = \infty$   $X_C = 0$   $X_C \Rightarrow$  short for AC

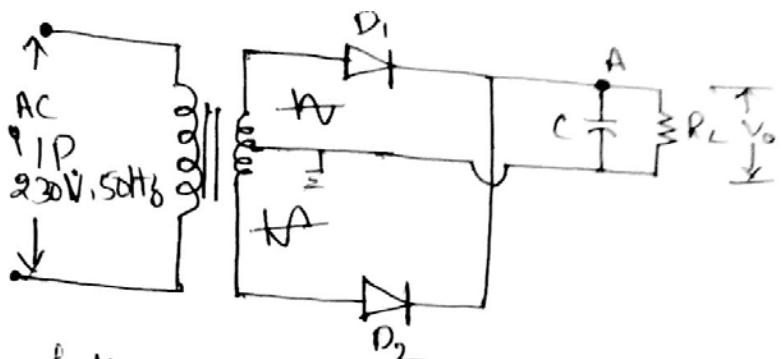
$X_C = \frac{1}{\omega C} \Rightarrow X_C = \frac{1}{(0)C} = 0$   $X_C = 0$   $X_C \Rightarrow$  open for AC

That it is blocks DC voltage i.e. it is not allows DC voltage.  
That it offers some impedance for AC voltage. The impedance will dependent frequency and capacitor value since  $X_C = \frac{1}{\omega C}$ .

At o/p of filters we want DC only, but capacitor is not allowing DC, so it should be kept in parallel.  
If we keep capacitor parallel to  $R_L$  i.e. it avoids DC to be ground in it ground AC voltage, so we get DC voltage at o/p.

so capacitor should be kept in parallel across  $R_L$





fullwave rectifier with capacitor filter.

### At Point A

The FWR have both AC and DC components, so that Point A will have both AC and DC components.

### For DC

The capacitor will acts as open ( $\sim \infty$ ) for DC so then DC components will not be grounded. So the DC term flows in the  $R_L$  and appears in the O/P.  $V_o$ .

### For AC

The capacitor offers some resistance depending on frequency and capacitor value. (For AC capacitor  $\approx 0$  ie it act like as short for AC) So the AC term all gets grounded. So that no AC term across the  $R_L$ .

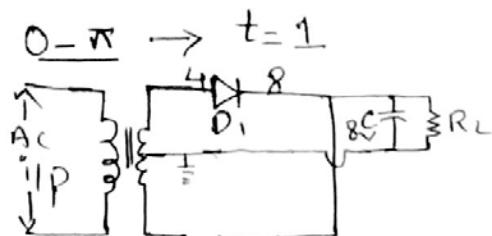
### 0- $\pi$ cycle

Assume that capacitor (it is already charged to 8v) having 8v at the i/p is given of 12 at the secondary transformer. Since the capacitor voltage is 8v, depending on this voltage diode may be forward biased or reverse biased.

The capacitor voltage is 8v at i/p of the capacitor is 12v.

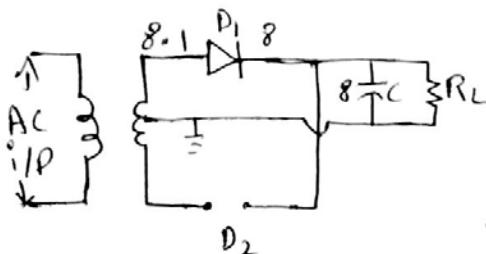
O/P of FWR in C/i/p of filter is





At anode of  $D_1 = 4$   
cathode of  $D_1 = 8$   
cathode having higher voltage than  
anode. So  $D_1$  is reverse biased  
w/ no output voltage across  $R_L$

$0-\pi \rightarrow t=2$  (i.e.  $i_{IP}$  voltage  $> 8V$ )



At anode of  $D_1$  voltage =  $8.1$   
at cathode of  $D_1$  voltage =  $8$   
cathode having less voltage than the anode  
so  $D_1$  will get forward biased.

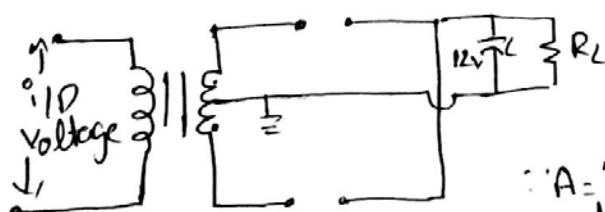
So the capacitor charging takes place after  $8V$ . The capacitor charges to the peak voltage of  $12V$ .

$0-\pi \rightarrow t=3$  ( ~~$8=12V$~~ )  
It (capacitor) charges up to  $12V$ .

$0-\pi \rightarrow t=4$

capacitor voltage (cathode voltage of  $D_1$ ) =  $12$   
 $\therefore i_{IP}$  Anode voltage  $< 12$  (less than  $12$ ) (since  $i_{IP}$   
decreased)

so the  $D_1$  diode is Reverse biased opened.



$D_1 \rightarrow$  off capacitor discharges  
through the load resistor w/ a time constant  $cR_L$ . So capacitor

voltage  $V_o = A \exp(-t/cR_L)$   
 $\because A = V_m \sin \omega t \exp(t_1/cR_L)$ .

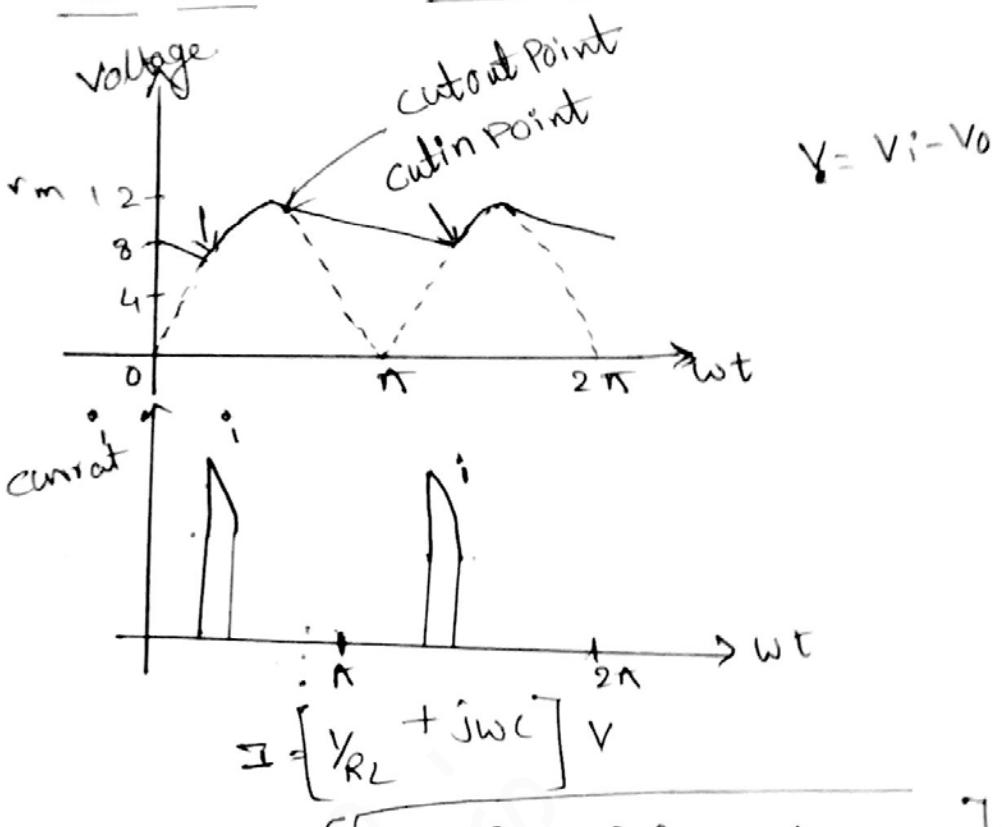
The capacitor does not allow the sudden change of voltage.

So it takes time to decrease the voltage.

The  $i_{IP}$  goes not decreases up to  $t=6$  the capacitor voltage will be greater than that of  $i_{IP}$  so  $D_1$  will be opened. capacitor voltage slowly decreases

For  $\pi-2\pi$

In the second cycle  $i_{IP}$  goes increase assume capacitor voltage is  $8$  then for  $i_{IP}$  voltage  $> 8$  then  $D_1$  conduction w/ capacitor charge the previous operation

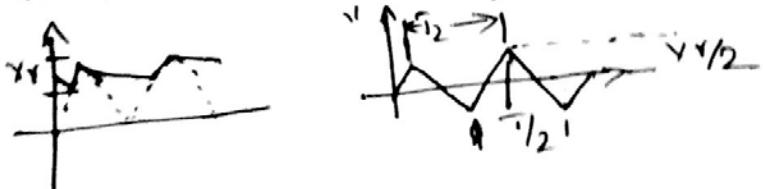


since  $V$  has a peak value  $V_m$  then the instantaneous current is

$$i = V_m \sqrt{\omega^2 C^2 + Y_{RL}^2} \sin(\omega t + \psi)$$

$$\psi = \tan^{-1} \omega C R_L$$

Approximation of analysis of capacitor filter.



The peak value is  $V_m$ . Then the avg value of voltage  $V_{DC} = V_m - \frac{V_r}{2}$

$$\text{From triangular } V_{DC} = \frac{V_r}{2\sqrt{3}}$$

In  $T_2$  represents nonconducting, the capacitor discharges at the constant rate  $I_{DC}$  will loose an amount of charge  $I_{DC}T_2$ . Hence change in capacitor voltage  $I_{DC}T_2/C$  or  $\Delta V = \frac{I_{DC}T_2}{C} \cdot V$

The smaller will be conduction time  $T_1$ , w/  $T_2$  discharge time is longer. (so neglect  $T_1$ )  $\tau_2$  will approach the time half cycle  
Hence  $\tau_2 = T/2 = 1/2f$

$$V_r = \frac{Idc}{2fc}$$

$$\gamma = \text{ripple factor} = \frac{V_{rms}}{V_{dc}} = \frac{Idc}{4\sqrt{3}fcV_{dc}} \Rightarrow R = \frac{1}{4\sqrt{3}fcR_L}$$

$$V_{dc} = V_m - \frac{Idc}{4fc}$$

The ripple is seen vary inversely with the load resistance & with the capacitor.

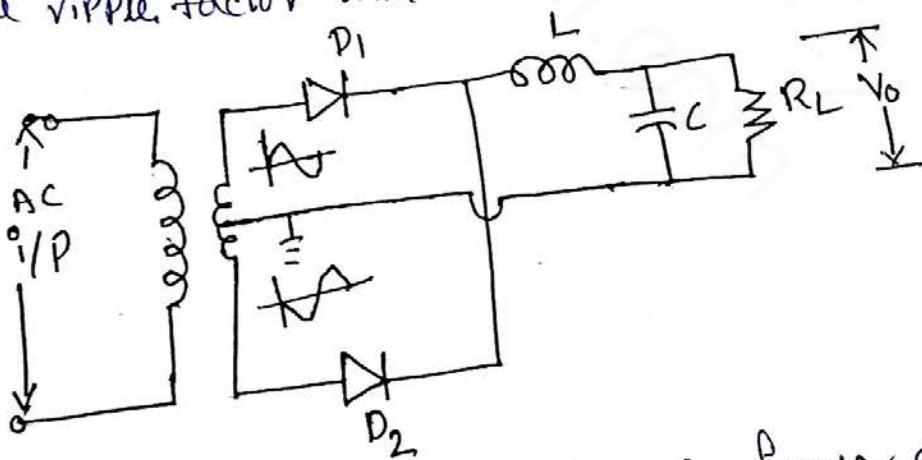
### L section filter or Lc filter:

The inductor offers a high series impedance to the harmonic terms, and the capacitor offers a low shunt impedance to them. The resulting current through the load is smoothed out much more effectively than with either L or C alone in the circuit.

L filter is  $v = R_L / 3\sqrt{2}WL \Rightarrow v \propto \sqrt{dR_L}$  if  
Resistance value is more than inductor ripple will be  
more, so to reduce the ripple factor we have to use large  
value of L than  $R_L$

In capacitor filter  $v = \frac{1}{4\sqrt{3}fCR_L}$  ie  $v \propto \frac{1}{R_L}$  so the  
ripple factor dependent of resistance. If the value  
of  $R_L$  is more than capacitance the ripples will be less.

In inductor filter  $\rightarrow v \propto R_L$   
capacitor filter  $\rightarrow v \propto \frac{1}{R_L}$   
so then the combination of inductor or capacitor as Lc filter  
the ripple factor will be independent of  $R_L$ .



The o/p will be expressed as in Fourier series

$$V_o = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi} \cos 2\omega t \quad I_d = \frac{2V_m}{\pi R_L} - \frac{4V_m}{3\pi X_L} \cos(2\omega t - \phi)$$

$$V_{dc} = \frac{2V_m}{\pi} \quad I_{dc} = \frac{4V_m}{3\pi} = V_m$$

$$I_{d1} = 2V_m$$

$$I_{ac} = \frac{4V_m}{\pi}$$

$$I_{rms} = \frac{I_{ac}}{\sqrt{2}} = \frac{U_{Vm}}{3\pi\sqrt{2}} \cdot \frac{1}{X_L} = \frac{2}{3\sqrt{2}} \frac{2U_{Vm}}{\pi} \cdot \frac{1}{X_L}$$

$$I_{rms} = \frac{2}{3\sqrt{2}} \cdot \frac{X_{ac}}{X_L} = \frac{\sqrt{2}}{3} \frac{V_{dc}}{X_L}$$

ripple factor  $\gamma = \frac{V_{rms}}{V_{dc}}$

The voltage across capacitor is

$$V_{rms} = I_{rms} \cdot X_C = \frac{\sqrt{2}}{3} \frac{V_{dc}}{X_L} \cdot X_C$$

$$V_{rms} = \frac{\sqrt{2}}{3} \cdot V_{dc} \cdot \frac{X_C}{X_L}$$

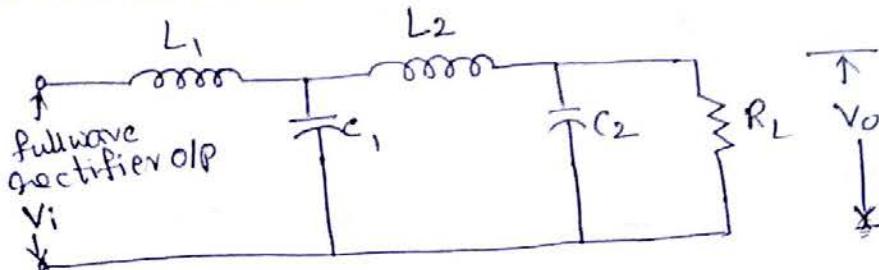
ripple factor  $\gamma = \frac{\sqrt{2}}{3} \frac{V_{dc} \cdot X_C}{X_L}$

$$= \frac{\sqrt{2}}{3} \frac{X_C}{X_L} \frac{V_{dc}}{X_{dc}} \cdot \frac{1}{X_{dc}} = \frac{\sqrt{2}}{3} \frac{X_C}{X_L}$$

$$X_L = 2\omega L \quad X_C = \frac{1}{2\omega C} \quad \therefore \cos 2\omega t \Rightarrow \omega = 2\omega$$

$$\gamma = \frac{\sqrt{2}}{3} \cdot \frac{X_C}{X_L}$$

multiple Lc filter:



$$\text{single Lc } r = \frac{\sqrt{2}}{3} \frac{x_c}{x_L}$$

$$\text{multiple Lc } r = \frac{\sqrt{2}}{3} \frac{x_{c_1}}{x_{L_1}} \cdot \frac{x_{c_2}}{x_{L_2}}$$

$\Pi$ -section filter or CLC filter:

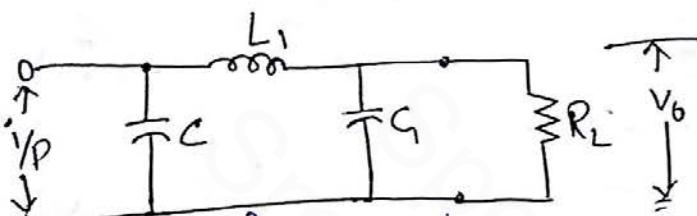


fig @  $\Pi$  section.

A very smooth output may be obtained by using a filter that consists of two capacitors separated by an inductor. As shown in above fig.

In order to get lower ripples than obtained from simple capacitor or inductor and Lc filter by using CLC filter.

The  $\Pi$  section filter can be analyzed by considering the inductor and the second capacitor as an L section filter that acts upon the triangular output voltage wave from first capacitor.

As first capacitor filter consider it followed by a LC filter. The OLP of capacitor filter is feed to the LC filter.

As we know the OLP of capacitor filter will be the triangular wave form.

The triangular wave feed to the LC filter. The ripples contained in the o/p of a capacitor will be reduced by the L-Section filter.

The ripple voltage can be calculated by analysing the triangular wave (i.e. o/p of capacitor filter) into a Fourier series and multiplying each component by  $\frac{X_C}{X_L}$  for this harmonic.

Fourier analysis of this waveform is given by

$$V = V_{DC} - \frac{V_r}{\pi} \left( \frac{\sin 2\omega t}{2} - \frac{\sin 4\omega t}{4} + \frac{\sin 6\omega t}{6} + \dots \right)$$

From capacitor filter

$$V_r = \frac{I_{DC}}{2fC}$$

The rms second harmonic voltage is

$$V_2' = \frac{V_r}{\sqrt{2}} = \frac{I_{DC}}{2\pi f C \sqrt{2}} = \sqrt{2} \cdot I_{DC} \cdot X_C$$

where  $X_C$  is the reactance of  $C$  at the second harmonic frequency.

from capacitor filter

$$V_{DC} = V_m - \frac{V_r}{2}$$

$V_m$  is peak voltage

$V_r$  is capacitor discharge voltage.

$$V_{rms} = \frac{V_r}{2\sqrt{3}}$$

$$V_r = \frac{I_{DC} I_2}{C}$$

$$I_2 = \frac{I}{2} = \frac{V_r}{2f}$$

$$V_r = I_{DC} / 2fC$$

### Second Method

The instantaneous current to the filter is  $i$  then the rms second harmonic current  $I_2'$  is given by the Fourier component

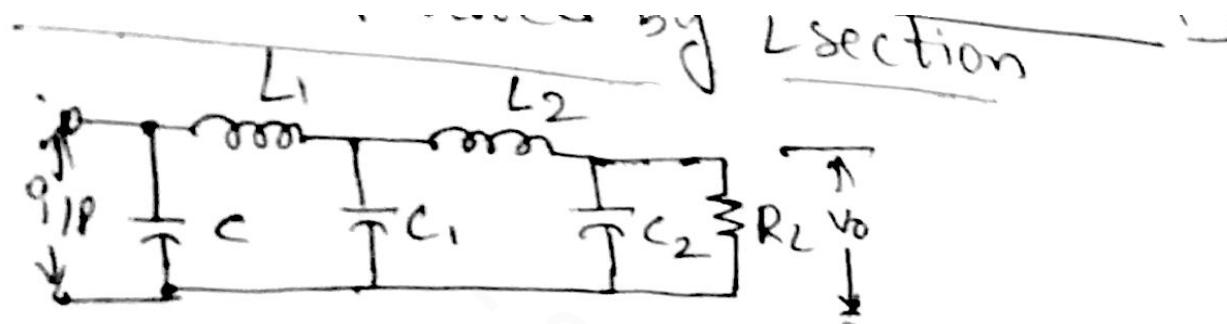
$$\sqrt{2} I_2' = \frac{1}{\pi} \int_0^{2\pi} i \cos 2\alpha d\alpha$$

The current is in the form of pulses near the peak value of the cosine curve hence not too great an error is made by replacing  $\cos 2\alpha$  by unity. Since the maximum value of cosine curve is unity, this will give the maximum possible value of  $I_2'$ .

$$\sqrt{2} I_2' \leq \frac{1}{\pi} \int_0^{2\pi} i d\alpha = 2 I_{DC}$$

By definition

$$I_{DC} = \frac{1}{2\pi} \int_0^{2\pi} i d\alpha$$



$$Y = \sqrt{2} \cdot \frac{x_C}{R_L} \cdot \frac{x_{C_1}}{x_{L_1}} \cdot \frac{x_{C_2}}{x_{L_2}}$$

Comparison of filter:

The comparison of various type of filter when used with fullwave circuits. In these filters, the resistances of diodes, transformer and filter elements are considered negligible in 60Hz power line assumed.

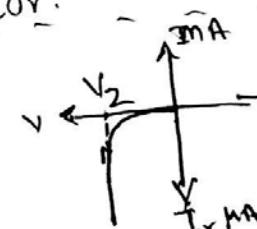
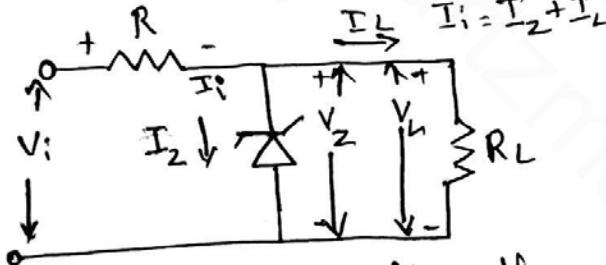
## Voltage Regulation using zener diode:

Zener diode specially designed P-n junction diode with adequate power dissipation capability to operate in the breakdown region which can be employed as voltage reference or constant voltage devices in the electronic circuits.

A zener diode maintains a constant output voltage in its breakdown region even though the current flowing through it is varied in its operating current range.

This important property of the zener diode is used to minimize the voltage fluctuation of a dc power supply obtained by the rectifier filter combination.

That is the reason zener diode is sometimes called a voltage regulator diode and the diode circuit in which the zener diodes are used as voltage regulator is called a zener voltage regulator or zener regulator.



$$I_i = I_L + I_2 \text{ flow through resistor } R.$$

$$V_i = I_i \cdot R + V_z$$

$$V_L = I_L \cdot R_L \quad V_z = I_2 \cdot R_z$$

$$V_L = V_z = I_L \cdot R_L = I_2 \cdot R_z$$

The circuit consists of a full wave rectifier followed by a  $\pi$  section filter whose output is applied to a load resistance  $R_L$ .

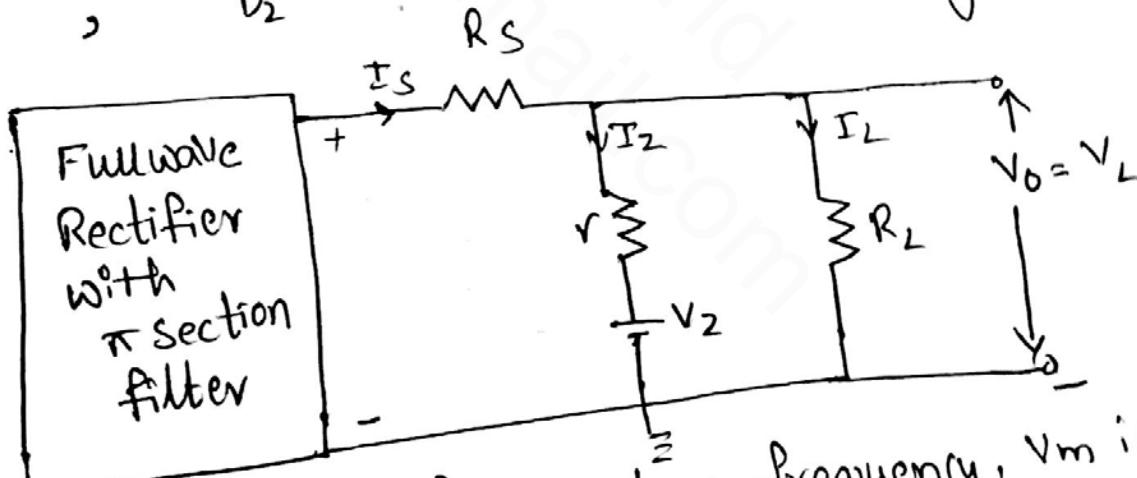
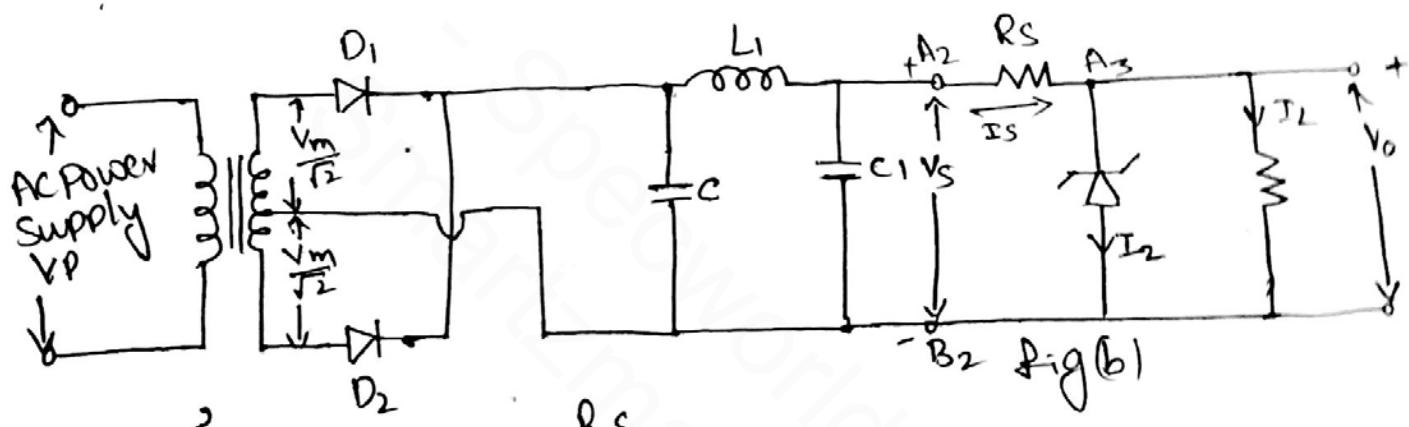
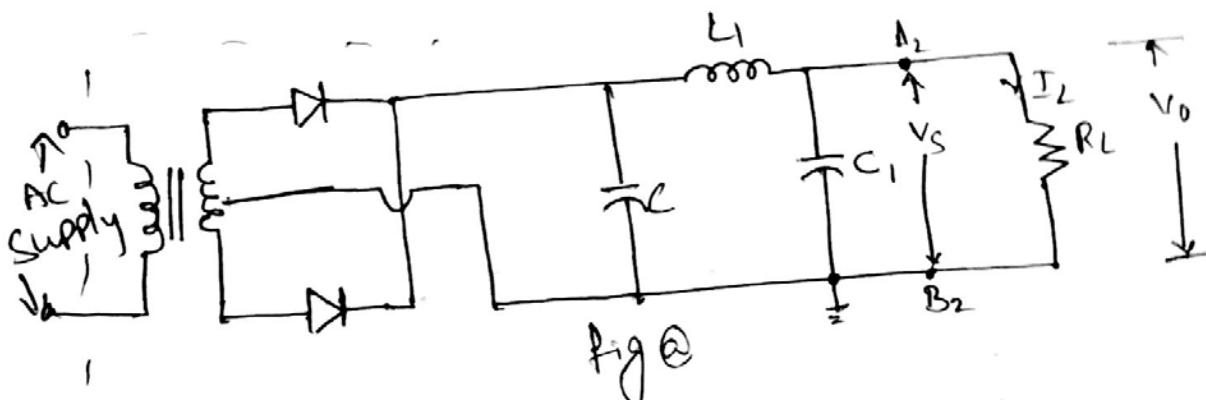
If  $R_L = \infty$  (under open condition) no current flows through the load  $I_L = 0$ . and dc voltage of the filter output is  $V_S = V_m$ .

$R_L = \text{finite}$ 

A DC current must flow through  $R_L$  and hence  $I_L \neq 0$  then through  $R_L$ , discharging will take place through and output voltage across load becomes

$$V_o = V_m - \frac{I_L}{4fC}$$

$\therefore V_d = V_m - \frac{I_L}{4fC}$   
From capacitor filter



where  $f$  is the Power line frequency,  $V_m$  is the peak of the transformer secondary with respect to the center tap &  $C$  capacitor shown.

$I_L = \frac{V_L}{R_L}$  must be maintained constant to operate satisfactorily.

clearly if we maintain

$$V_L = V_0 = V_m - \frac{T_L}{4fc} \quad \text{as constant.}$$

To get constant  $V_L$  by fixing the values of  $V_m$ ,  $c$  and  $f$ .

$f$  is power line frequency it is a constant parameter for all the time.  $c$  is also const for all time.  $V_m$  is not a constant to the desired value for all the time since it depends on the input voltage  $V_p$  of the power line of the transformer Primary winding.

A transformer with  $n_1$  and  $n_2$  as the number of turns in the Primary and Secondary windings respectively let  $V_p$  be the rms voltage of the ac power line which is applied to the transformer Primary.

Total rms voltage of the transformer secondary is  $\left(\frac{n_2}{n_1}\right)V_p$  which again equal to  $\frac{\epsilon_m}{\sqrt{2}}$  where  $\epsilon_m$  is the peak value of the total transformer secondary voltage. Thus the Peak voltage is  $V_m = \left(\frac{n_2}{n_1}\right) \frac{V_p}{\sqrt{2}}$ . Since the powerline voltage  $V_p$  may fluctuate from its desired value due to a number of uncontrolled reasons, there is always a possibility exists that suggests a possible fluctuation in  $V_m$ . So fig(a) does not guarantee desired (instrument) but will operate satisfactorily all the time.

The difficulties of the circuit can be removed by connecting a zener diode with breakdown voltage  $V_z$  and series resistance  $R_s$  in fig(b).

SUPPOSE that  $V_m$  varies between  $V_{min}$  &  $V_{max}$  corresponding minimum w maximum voltage the power line voltage applied to the Primary winding of the transformer

If the breakdown  $V_Z$  is chosen to be equal the desired voltage  $V_L$  across the load with load resistance  $R_L$  such that  $V_S \geq V_Z = V_L$ . The filter output voltage  $V_S$ , reverse biases the zener diode for all the time, and hence the diode must operate in the breakdown region.

Zener diode behaves as a battery in reverse bias where  $r$  is the dynamic resistance of the zener diode.

$I_L, I_S, I_2$  are current passing through  $R_L, R_S$  w/ zener diode.

The current flowing through the load resistance given by

$$I_L = \frac{V_L}{R_L} \quad \text{--- (1)} \quad \text{where } V_L = V_Z + r I_2 \quad \text{--- (2)}$$

(If zener diode is operated  
in breakdown region)

The current flowing through the series resistance  $R_S$

$$I_S = \frac{V_S - V_L}{R_S} \quad \text{--- (3)}$$

$\therefore I_S = I_L + I_2$ , the zener current

$$I_2 = I_S - I_L \quad \text{--- (4)}$$

$$= \left( \frac{V_S - V_L}{R_S} \right) - \frac{V_L}{R_L}$$

by rearranging term (2) in (4), we obtain

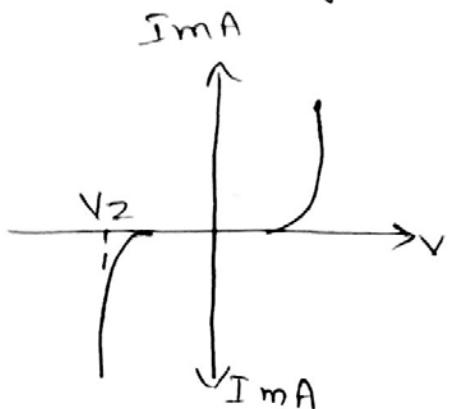
$$I_2 = \frac{\left( \frac{V_S - V_Z}{R_S} \right) - \frac{V_Z}{R_L}}{1 + \left( \frac{r}{R_S} + \frac{r}{R_L} \right)}$$

In most of the practical circuits  $r \ll R_S$  and  $R_L$  w/ hence  $1 + \left( \frac{r}{R_S} + \frac{r}{R_L} \right) \approx 1$ . Thus zener current can be approximately given by

$$I_2 \approx \left( \frac{V_S - V_Z}{R_S} \right) - \frac{V_Z}{R_L}$$

# Zener Diode (voltage regulation using zener diode)

www.jntuworldupdates.org



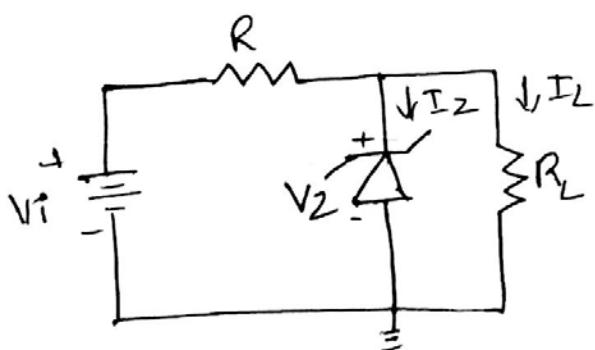
$V_2$  - zener Breakdown voltage

In forward bias zener characteristics same as P-n junction.

In the reverse bias zener characteristics occurs. In Breakdown region zener diode will have constant voltage.

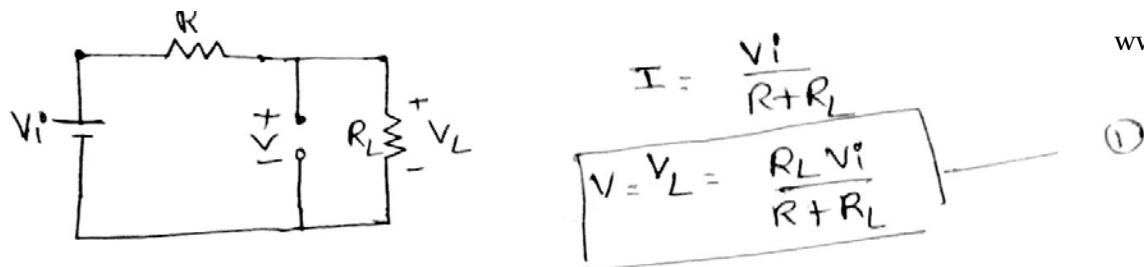
(In breakdown condition is that for small changes of voltage we can get large changes of current. Small change of voltage is called as const voltage.)  
so that zener diode can be used as a regulator.

$v_i$  and  $R$  fixed:



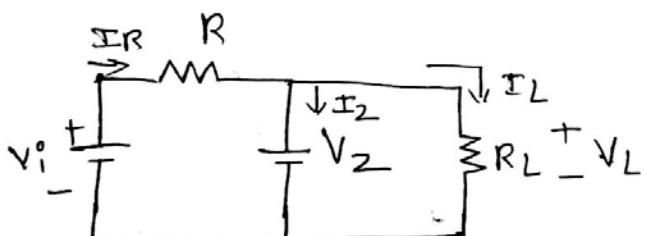
To steps to find that zener diode is in breakdown condition or not.

- Determine the state of the zener diode by removing it from the network and calculating the voltage across the resulting open circuit.



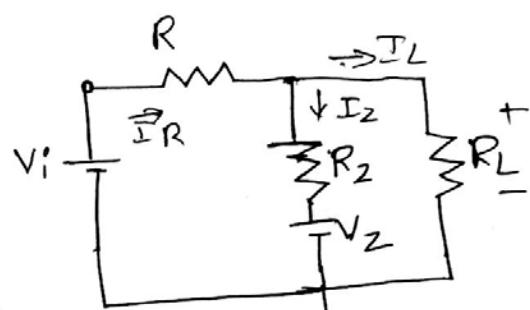
If  $V >> V_z$  the zener diode is on and + Breakdown condition and appropriate equivalent model can be substituted.

If diode zener is in breakdown condition then



Neglecting Internal resistance of zener diode

fig (a)



By considering the internal resistance of zener diode.  
fig (b)

By considering the fig (a)

$$VL = V_z$$

$$IR = I_z + I_L$$

$$I_L = \frac{VL}{RL}$$

$$IR = \frac{VR}{R} = \frac{Vi - VL}{R}$$

$P_z = V_z \cdot I_z$

— ②

fixed  $Vi$ , variable  $R_L$ :

Too small a load resistance  $R_L$  will result in a voltage  $VL$  across the load resistor less than  $V_z$  then the zener diode will be in f.B forward bias.

To determine the minimum load resistance we have to check condition.

$$I = V_i / (R + R_L) \quad (\text{Zener open})$$

$$V_L = V_2 = \frac{R_L V_i}{R_L + R}$$

for solving of  $R_L$

$$V_2(R_L + R) = R_L V_i$$

$$V_2 R_L + V_2 R = R_L V_i$$

$$V_2 R = R_L V_i - V_2 R_L$$

$$V_2 R = R_L (V_i - V_2)$$

$$R_{L\min} = \frac{V_2 R}{V_i - V_2}$$

— (3)

The condition defined by eq (3) establishes the minimum  $R_L$  but in turn specifies the maximum  $I_L$  as

$$I_{L\max} = \frac{V_L}{R_L} = \frac{V_2}{R_{L\min}} \quad — (4)$$

Once the diode is in breakdown condition the voltage across  $R$  remains fixed at

$$V_R = V_i - V_2 \quad — (5)$$

$$I_R = V_R / R$$

$$I_Z = I_R - I_L \quad — (6)$$

By above eq (6) resulting in a minimum  $I_Z$  when  $I_L$  maximum.

4

Maximum  $I_Z$  when  $I_L$  is a minimum value.  
Since  $I_R$  is a constant.

$$I_{L\min} = I_R - I_{Z\max}$$

$$I_{L\min} = I_R - I_{Z\max}$$

$$R_{L\max} = \frac{V_2}{I_{L\min}} \quad R_{I\max} = \frac{V_2}{I_{I\min}} \quad \text{www.jtuworldupdates.org}$$

fixed  $R_L$ , variable  $V_i$

For fixed values of  $R_L$  the voltage  $V_i$  must be sufficiently large to turn the zener breakdown condition. The minimum turn voltage  $V_i = V_{i\min}$ .

$$V_L = V_2 = \frac{R_L V_i}{R_L + R}$$

$$V_{i\min} = \frac{(R_L + R)V_2}{R_L}$$

The maximum value of  $V_i$  is limited by the maximum zener current  $I_{2M}$  since  $I_{2M} = I_R - I_L$ .

In breakdown condition for small variation voltage results large change in current ( $I_{2max}$ )

$$I_R = I_{2max} + I_L$$

$$V_{i\max} = V_R + V_2$$

$$V_{i\max} = I_R \cdot R + V_2$$

$$V_{i\max} = I_R \cdot R + V_2$$