UNIT - II

Rectifiers and Filters.

Introduction:

All Electronic circuits needs dc power supply Either directly or from battery. Some of the electronic ckts operates at fixed dc voltages.

So we have to design a electronic ckt which converts the Ac supply voltage in to dc voltage at the required level.

There are two types of conversion of power supply.

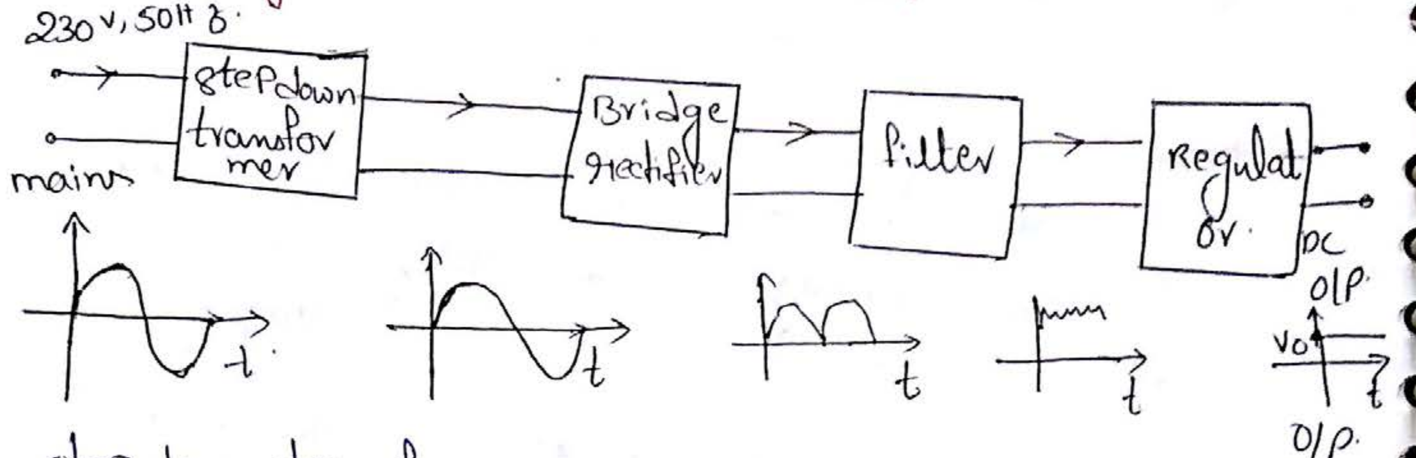
1. Ac to dc — linear mode Power supply. LMPS

If the electronic ckt converts Ac power supply in to 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 ckts is known as switched mode power supply.

Block diagram of linear 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 in to 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 ckts (Amplifer) requires 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 A.C and so the output signal will be amplified AC signal without biasing with DC supply the ckt will not work.

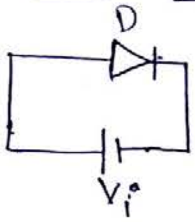
So more or less all electronic A.C instruments require DC Power. To get dc powersupply we can use batteri[es] but they will get dried quickly and replacing them every time is a costly affair.

Hence it is economical to convert AC power supply in t[o] DC.

P-n junction as a Rectifier:

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

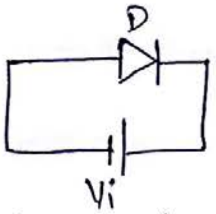
In forward bias:



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 what ever the input given it will appears at the O/P.

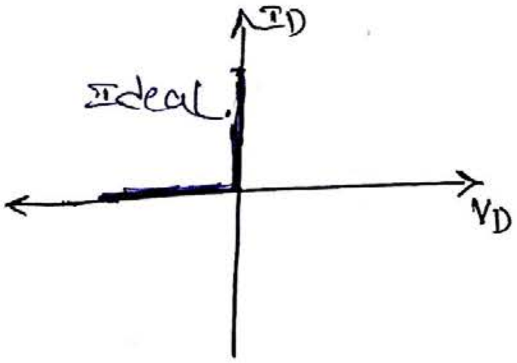
In Reverse bias



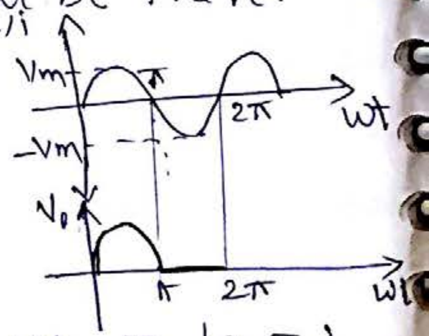
As we know that in Reverse bias the diode will be acted as ~~a rever~~ open ckt.

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

Ideal diode characteristics



$V_i = V_m \sin \omega t$



$V_i = V_m \sin \omega t \quad \omega t = \pi \cdot (0 - \pi)$

$V_i = -V_m \sin \omega t \quad \omega t = (\pi - 2\pi)$

$0-\pi$ Peak is +ve, diode is shorted we get the O/P what ever the i/p value is there.

$\pi - 2\pi$ Peak is −ve diode is opened O/P will be zero.

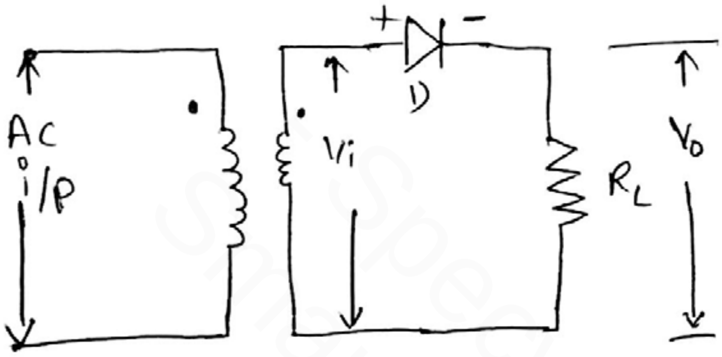
So diode converts bidirectional signal into a unidirectional so diode acts as a rectifier.

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

Or

Rectifier is defined as an electronic device used for converting Bidirectional voltage in to unidirectional voltage.

So rectifier uses the unidirectional devices they are P-N diode, vaccum diodes.



ckt diagram of Halfwave rectifier.

AC input is normally the AC main supply (house hold 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 vaccum tubes should be used.

Operation:

let vi be the voltage to the Primary of the transformer and it can be represented by mathamatical Equation as

$V_i = V_m \sin\omega t \quad V_m >> V_\gamma$.

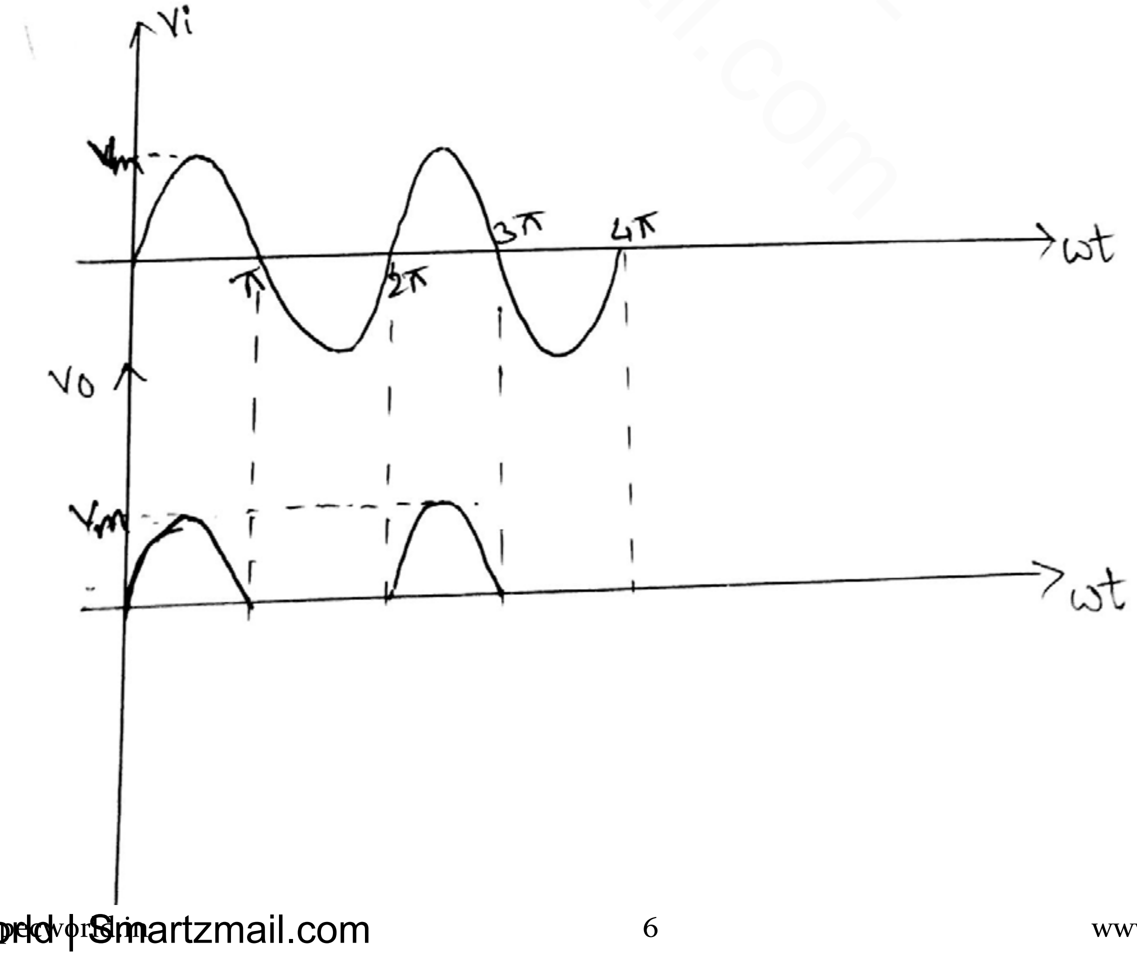
For +ve half cycle:

where V_γ is the cutin voltage of the diode, If i/p voltage is greater than V_γ the diode conducts since during the +ve halfcycle of i/p signal the anode (+ve) of the diode becomes positive with respect 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 i/p will appear across the load Resistance R_L.

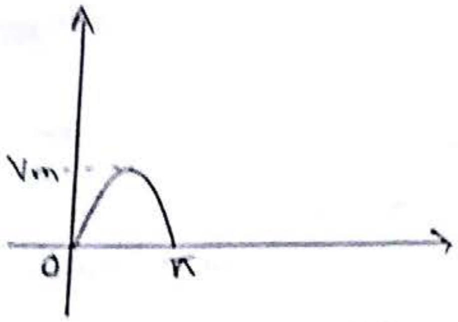
For -ve half cycle:

In the -ve halfcycle of the input signal anode of the diode becomes negative w.r.t cathode and hence D doesnot conduct (for an Ideal diode in reverse bias R=∞ so I is zero) so no voltage across the R_L voltage is zero.



Calculations :
Maximum or Peak current or Peak voltages

$V = V_m \sin\omega t \quad 0 \leq \omega t < \pi$
$= 0 \quad \pi \leq \omega t \leq 2\pi$



$I = V_m / (R_f + R_S) + R_L$

R_f = 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.

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

Average value or V_{avg}

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

for halfwave rectifier

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

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

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

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

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

$$\boxed{V_{dc} = \frac{V_m}{\pi}} \qquad \boxed{I_{dc} = \left(\frac{V_m}{\pi \cdot R_L}\right)}$$

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

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.

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

Vrms voltage or Reading of Ac meter or V_{AC} AC voltage.

An Ac ammeter is constructed such that the needle deflection indicates the effective Rms voltage or current Passing through it w.r.t Peak voltage. (Vrms & Vac almost same) what is meant by Vrms value. It is the value of DC which Produces the same heating effect as the AC quantity, The magnitude of the this equivalent DC is called the Rms of AC.

$$V_{ac} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} V_m^2 \sin^2\omega t \, d\omega t + \int_{\pi}^{2\pi} 0 \cdot d\omega t}$$

$$\because \boxed{V_{rms} = \sqrt{\frac{1}{T}\int_0^{T} V^2 \cdot dt}}$$

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

$$= \sqrt{\frac{V_m^2}{2\pi}\int_0^{\pi} \frac{1 - \cos 2\omega t}{2} \, d\omega t} = \sqrt{\frac{V_m^2}{4\pi}\int_0^{\pi} 1 - \cos 2\omega t \, d\omega t}$$

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

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

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

$$\boxed{V_{rms} = \frac{V_m}{2}} \rightarrow V_{ac}$$

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

Ratio of Rectification or Efficiency η

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

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

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

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

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

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

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

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

Ripplefactor: 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 γ

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

$$\boxed{\gamma = \frac{I'_{rms}}{I_{DC}}} = \frac{V'_{rms}}{V_{DC}}$$

I'_{rms} and V'_{rms} denote the value of the AC component of current or voltage in the o/p 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 $\qquad I_{DC}$ is the DC current
I = total current

$I' = (I - I_{DC}) \qquad$ i.e AC current = total current − DC cur

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

Since in halfwave rectifier $T = 2\pi$

$$I' = \sqrt{\frac{1}{T}\int_0^T (I - I_{DC})^2\, d\omega t}$$

$$I' = \sqrt{\left(\frac{1}{T}\int_0^T I^2 - 2 I . I_{DC} + I_{DC}^2\right) d\omega t}$$

$$I' = \sqrt{\frac{1}{T}\int_0^T I^2 d\omega t - \frac{2 I_{DC}}{T}\int_0^T I\, d\omega t + \frac{1}{T}\int_0^T I_{DC}^2\, d\omega t}$$

$$I' = \frac{1}{T}\int_0^T I^2 d\omega t = (I_{rms})^2 \; ; \; \frac{1}{T}\int_0^T I\, d\omega t = I_{dc} \text{ or } I_{avg}$$

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

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

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

If I take in terms of voltage then ripple factor is

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

Ripple factor of Halfwave is :

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

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

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

Transformer utilization Factor :

Transformer utilization factor TUF ;

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

In the Halfwave rectifer 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 of faltor 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:

$$\text{Formfactor} = \frac{\text{rms value}}{\text{Average value}} = \frac{\left(\frac{V_m}{2}\right)}{\left(\frac{V_m}{\pi}\right)} = \pi/2$$

$$= 1.57$$

Peak factor:

$$\text{Peakfactor} = \frac{\text{Peak value}}{\text{rms value}} = \frac{V_m}{\frac{V_m}{2}} = 2.$$

Disadvantages of HWR

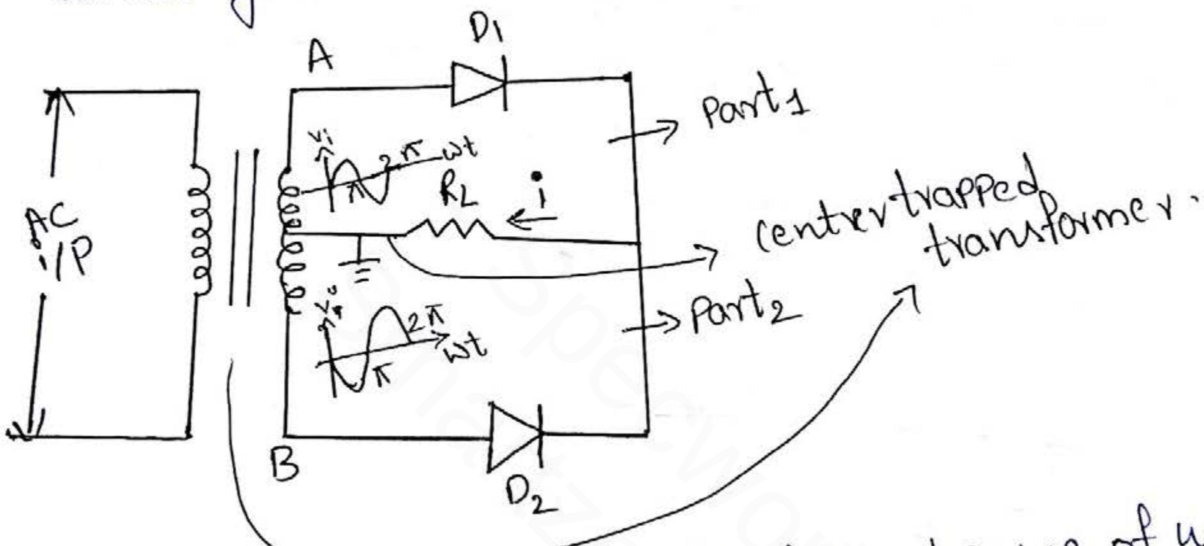
1. Ripple factor is 1.21 ($r>1$)
2. low ratio of rectification ie efficiency (0.406)
3. Low TUF (0.287)
4.

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.

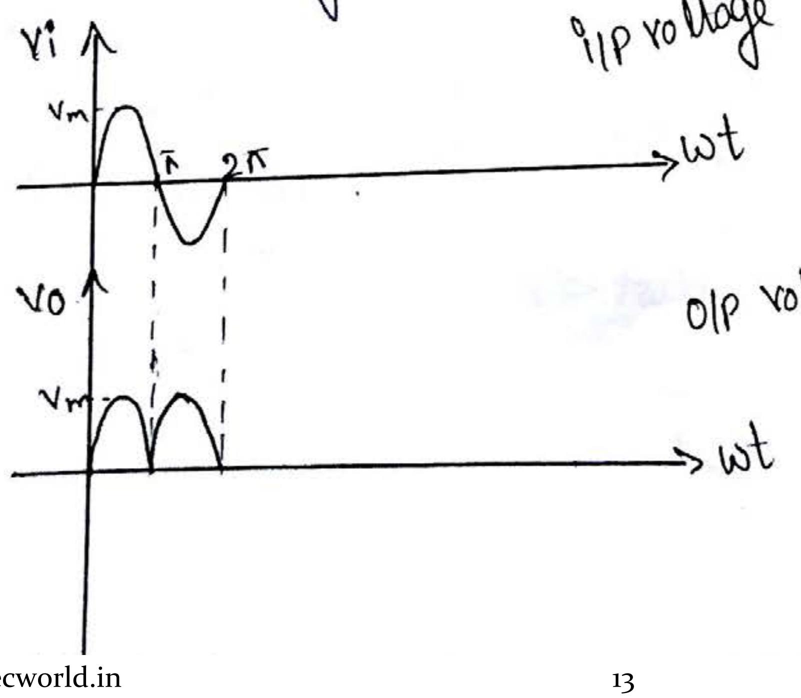
And efficiency of HWR is less since it is conducting only one half cycle (we get o/p voltage in only one half cycle) as i/p is in two cycles.

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



In Part 2 there is a phase shift of 180° because of using center trapped.

A center trapped transformer is essential to get full wave rectification. So there is a phase shift of 180° because of center trapping.



Operation:

Since center trapped transformer is used there is a phase shift of 180° in (phase-2) Part2.

For +ve halfcycle $0-\pi$

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 reversebiased. So the O/P appears occurs R_L

For -ve halfcycle $\pi-2\pi$

During the -ve halfcycle 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 occurs 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

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

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

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

$$\boxed{V_{dc} = \frac{2V_m}{\pi}} \qquad I_{dc} = \frac{2V_m}{\pi R_L} \qquad \because I_{dc} = \frac{V_{dc}}{R_L}$$

AC voltage or rms voltage

$$V_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} V_m^2 \sin^2\omega t\, d\omega t}$$

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

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

$$\because V_{rms} = \frac{1}{T}\int_0^{T} V^2\, dt$$

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

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

$$\int \tfrac{1}{2}\, d\omega t = \omega t/2$$

$$= \sqrt{\frac{V_m^2}{\pi}\left[\frac{\omega t}{2} - \frac{\sin 2\omega t}{4}\right]_0^{\pi}} \quad \because \int \cos 2\omega t = \frac{\sin 2\omega t}{2}$$

$$= \sqrt{\frac{V_m^2}{\pi}\left[\frac{\omega t}{2} - \frac{\sin 2\omega t}{4}\right]_0^{\pi}} \Rightarrow \sqrt{\frac{V_m^2}{\pi}\left[\left[\frac{\pi}{2} - \frac{\sin 2\pi}{4}\right] - \left[\frac{0}{2} - \frac{\sin 2(0)}{4}\right]\right]}$$

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

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

Efficiency η

η = o/p power / i/p power

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

$$\eta = \frac{\text{dc o/p power}}{\text{ac i/p power}} = \frac{P_{dc}}{P_{ac}} = \frac{V_{dc} \times I_{dc}}{V_{rms} \times I_{rms}}$$

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

$$= \frac{4 \times 2}{\pi^2} = 8/\pi^2 = 0.812 \qquad \eta\% = 81.2\%$$

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

Ripplefactor:

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

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

$$= \sqrt{\frac{\pi^2}{4 \times 2} - 1} = \sqrt{\frac{\pi^2}{8} - 1} = 0.482$$

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

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

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

$P_{ac}\ Sec = V_{rms} I_{rms}$ $\qquad TUF = P_{dc} / P_{acsec}$

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

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

Form factor:

$$\text{Form factor} = \frac{\text{rms value of the o/p voltage}}{\text{Average value of the o/p voltage}}$$

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

Peak factor:

$$\text{Peak factor} = \frac{\text{Peak value of the output voltage}}{\text{rms value of the output voltage}}$$

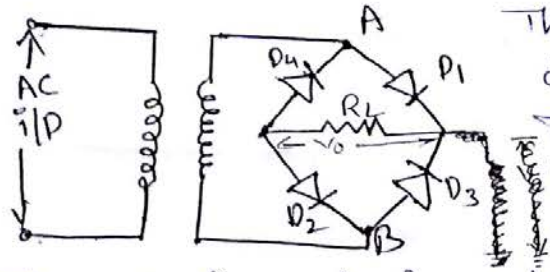
Disadvantages of FWR

1. Center trapped is very costly
2. Both dc an AC is Present at O/P. (voltages)

Advantages!

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

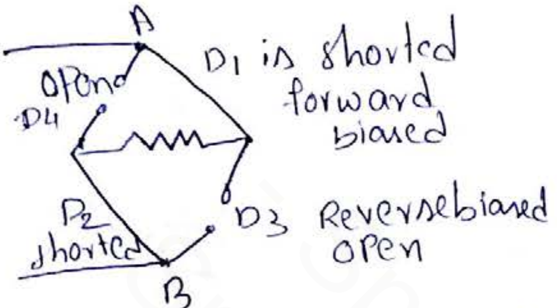
Bridge rectifier



The AC i/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 need of center tapped transformer in full wave rectifier is eliminated in the Bridge rectifier.

for +ve half cycle;



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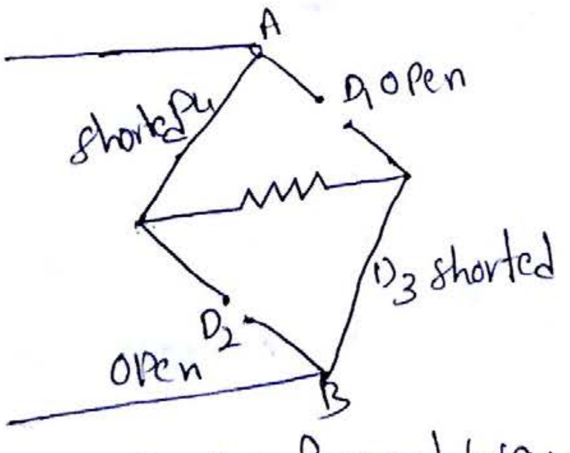
During +ve half cycle D_1 & D_2 is forward biased. D_3 and D_4 is open

So the current will flow through D_1 first and then through R_L and then through D_2 back to the ground. So there is voltage drop across R_L i.e maximum voltage drop occurs.

−ve half cycle



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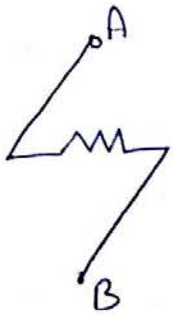


During −ve half cycle D_4 & D_3 are forward biased, D_1 & D_2 are open

D_4 & D_3 are forward biased and they conduct, the current flows from D_3 through R_L to D_4. So In the −ve half cycle also there is voltage drop across R_L.

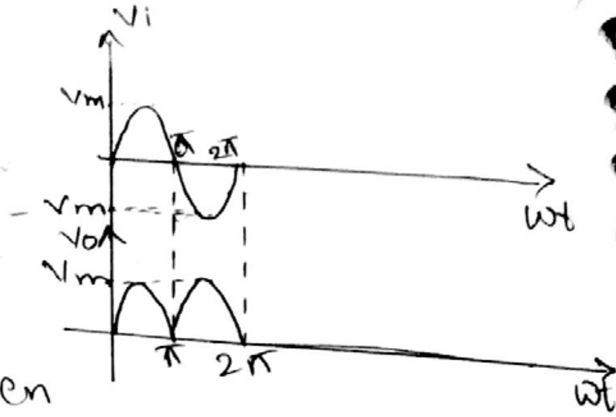
So the o/p will be same as fullwave rectifier.

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 Rs, Rf, RL then

$$I_{dc} = \frac{2V_m}{\pi(R_s + 2R_f + R_L)}$$ ∵ Here 2 Diodes come in to picture for each half cycle.

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

$$V_{ac} \text{ or } V_{rms} = \frac{V_m}{\sqrt{2}} \qquad I_{rms} = \frac{V_{rms}}{R_L} = \frac{V_m}{\sqrt{2} \cdot R_L}$$

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

Advantages:

1. The Peak inverse voltage (PIV) across each diode is Vm and not 2Vm as in the case of FWR.
2. center trapped transformer is not ~~reat~~ required

Disadvantages:

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

Harmonic components in a rectifier circuits:

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

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

The lowest angular frequency present in this expression is that of the primary source of AC power. ie Basic power frequency that occours 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 halfwave 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

$$i = i_1 + i_2$$

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

The fundamental angular frequency ω has been eliminated from the equation, the lowest frequency in the output being 2ω 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 is 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 rectifer and the load inorder to attenuate these ripple components.

<u>Comparision of Rectifier.</u>

Particulars	Type of rectifier: Halfwave	Fullwave	Bridge
No. of diodes	1	2	4
Maximum Efficiency	40.6%	81.2%	81.2%
Vdc (no load)	V_m/π	$\frac{2V_m}{\pi}$	$\frac{2V_m}{\pi}$
Ripple factor	1.21	0.48	0.48
Peak Inverse voltage	V_m	$2V_m$	V_m
output frequency	f	2f	2f
Transformer utilisation factor	0.287	0.693	0.812
Form factor	1.57	1.11	1.11
Peak factor	2	$\sqrt{2}$	$\sqrt{2}$

Filters:

The output of a rectifier contains DC component aswellas Accomponent.

Filters are used to minimize the undesirable A.c ie ripples 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 (fluctulations) up & downs 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 occuring suddenchanges 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 ⇒ frequency $f=0$

$$\boxed{X_L = 2\pi f L} \quad f=0 \Rightarrow X_L = 2\pi(0)L = 2\pi(0)L = 0$$

⇒ short for DC it allows dc

For AC voltage

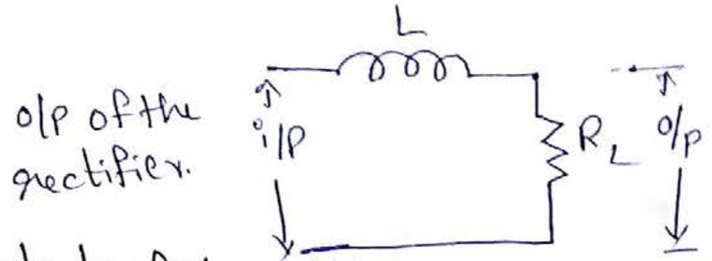
frequency $f \neq 0$ or $f = \infty$

$X_L = 2\pi fL \Rightarrow X_L \neq 0$ that it offers some impedance.

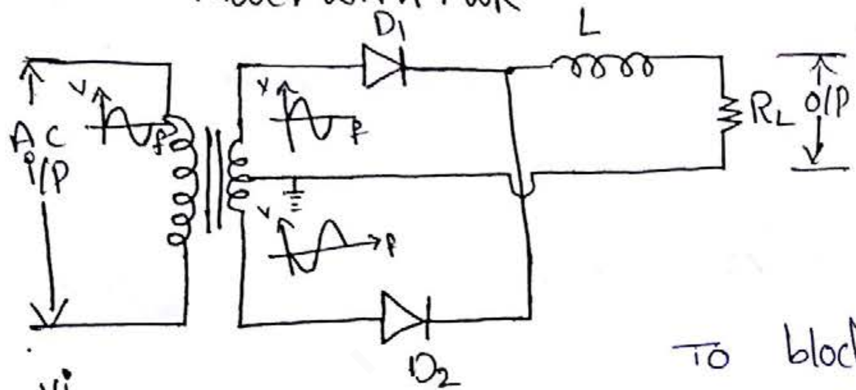
$f = \infty \Rightarrow X_L = \infty$ — open for AC. — it blocks AC.

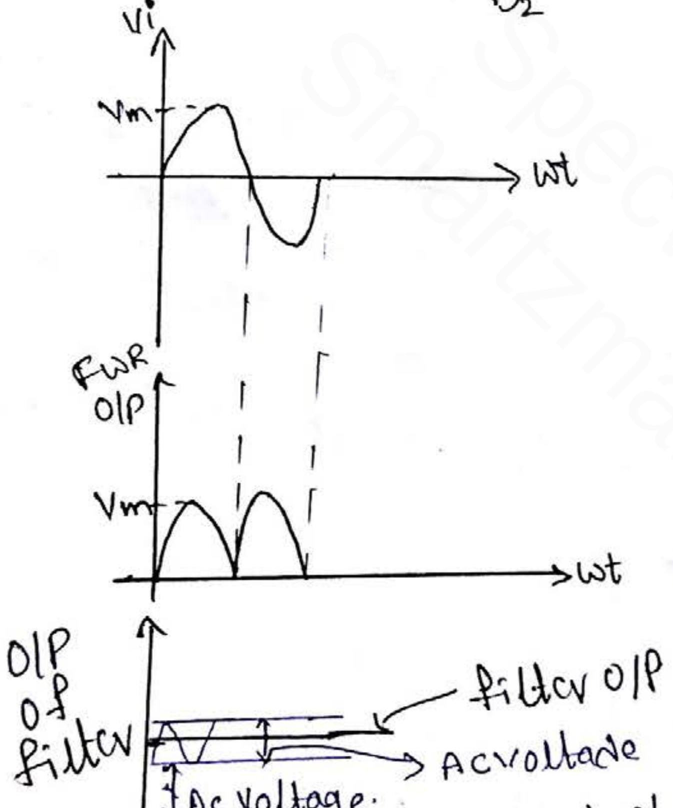
At the o/p of the filter we want only dc not AC, since Inductor is allowing the DC (ie $X_L = 0$ for DC) so it should be in series across the R_L.

If the Inductor is in series across R_L it allows DC or restricts AC. So at O/P of filter almost all the AC will be blocked.



Inductor filter with FWR





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 or product of two signals mathamatical operations on signals will be better or Easy in freq. domain than

In time domain.

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 signal & periodic

If we apply fourier series for the FWR will be

$$V_0 = \frac{2V_m}{\pi} - \frac{4V_m}{\pi}\left[\tfrac{1}{3}\cos 2\omega t + \tfrac{1}{15}\cos 4\omega t + \cdots\right]$$

The higher harmonic terms can be neglected ie $\frac{1}{15}\cos 4\omega t$.

so $V_0 = \frac{2V_m}{\pi} - \frac{4V_m}{\pi}\left[\tfrac{1}{3}\cos 2\omega t\right]$

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

$\frac{2V_m}{\pi}$ = DC voltage ∵ There is no cos & sin terms

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

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

since we are using Inductance we have to change in terms of current:

we ⇒ $Z = \sqrt{(R_L)^2 + (X_L)^2}$ $X_L = \omega L$ 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:

$\omega = 0$

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

$|Z| = \sqrt{R_L^2 + 4(0)^2 L^2} = \sqrt{R_L^2} = R_L$

For AC voltage

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

∵ In inductance current lags by angle $\phi = \tan^{-1}\left(\frac{Imag}{real}\right)$

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

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

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

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

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

$$r = \frac{V_{rms}}{V_{dc}} \text{ or } \frac{I_{rms}}{I_{dc}}$$

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

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

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

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

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

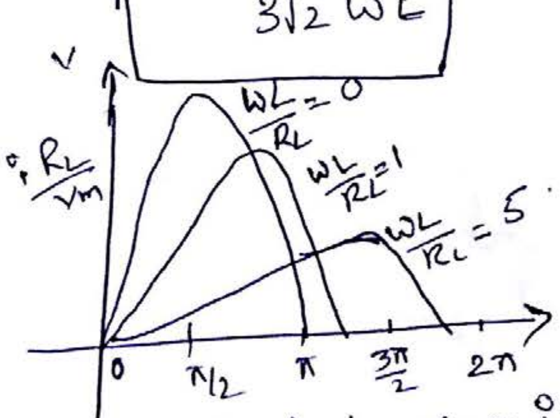
$$= \frac{2}{3\sqrt{2}} \cdot \frac{1}{\sqrt{\frac{R_L^2}{R_L^2} + \frac{4\omega^2 L^2}{R_L^2}}} = \frac{2}{3\sqrt{2}} \cdot \frac{1}{\sqrt{1 + \frac{4\omega^2 L^2}{R_L^2}}}$$

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

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

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

$r \propto R_L \quad r \propto 1/L$



RL is const.

The effect of changing inductance value on the wavefo[rm] with an inductor filter.

Capacitor filter

capacitor

$$C = dq/dv$$

The capacitor will not allow the sudden changes of voltages. (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.

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

for dc voltage $w = 0$ or $f = 0$

$$X_C = \frac{1}{2\pi(0).C} = \frac{1}{0} = \infty \quad X_C = \infty \quad X_C \text{ open for dc}$$

That it is blocks DC voltage i.e it is not allows DC voltages

For AC voltage $w \neq 0$; $f = \infty$ $\quad X_C = 0 \quad X_C \Rightarrow$ ~~open~~ short for AC

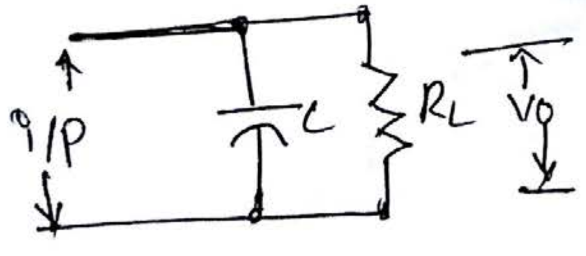
$$X_C = 1/wC \Rightarrow X_C = \frac{1}{\infty C} = 0$$

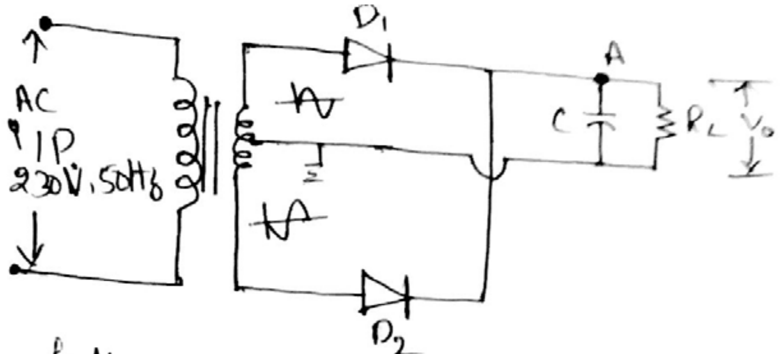
That It is blocks DC voltage i.e it is not allows dc voltages

That it offers some impedance for AC voltages. The impedance will dependent frequency and capacitor value since $X_C = 1/wC$.

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 u it ground AC voltages, 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.

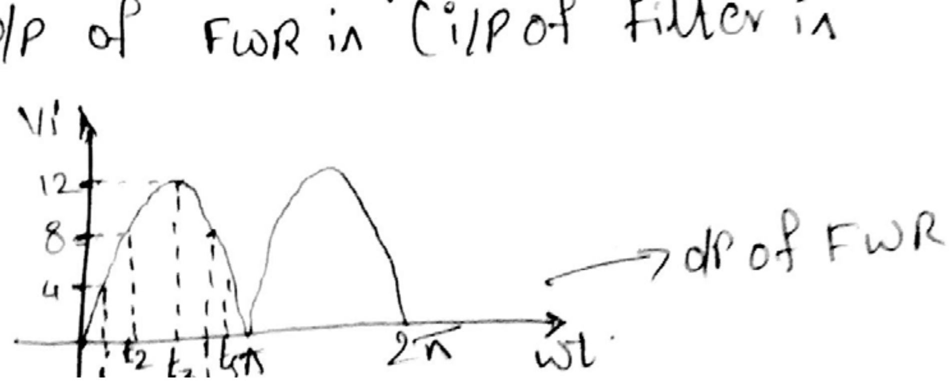
For DC The capacitor will acts as open ($\because \frac{1}{j\omega c} = \frac{1}{0}$) for dc so then dc components will not be grounded. So the dc term flows in the R_L and appears in the O/P V_0.

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

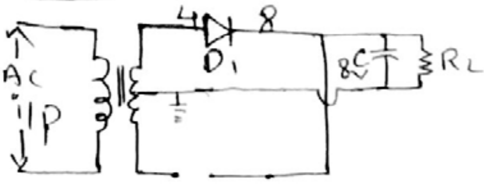
0-π cycle
Assume that capacitor (It is already charged to 8v) having 8v as the i/p is given of 12 at the secondary transformer. Since the capacitor voltage is 8v, Depending on this voltages Diode may be forward biased or Reverse baised.

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

O/P of FWR is (i/p of filter is

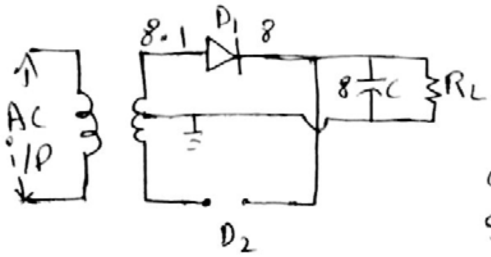


$0-\pi \rightarrow t=1$



At anode of D_1 - 4
cathode of D_1 = 8
cathode having higher voltage than anode. so D_1 is reverse bias a no output voltage across R_L

$0-\pi \rightarrow t=2$ (i.e. i/p voltage > 8V)

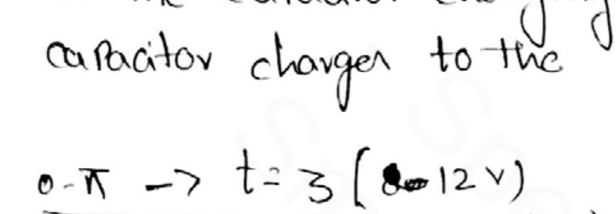


At anode of D_1 voltage = 8.1
at cathode of D_1 voltage = 8
cathode having less voltage than the anode so D_1 will get forward biased.

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.

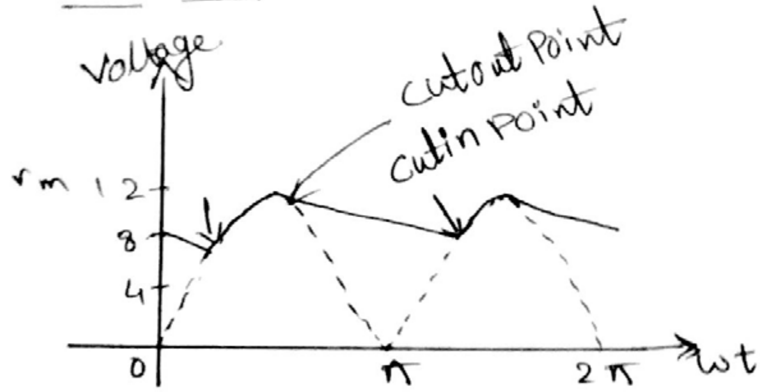
$0-\pi \rightarrow t=4$
capacitor voltage (cathode voltage of D_1) = 12
i/p Anode voltage <12 (less than 12) (since i/p decreased)
So the D_1 diode is Reverse biased opened.



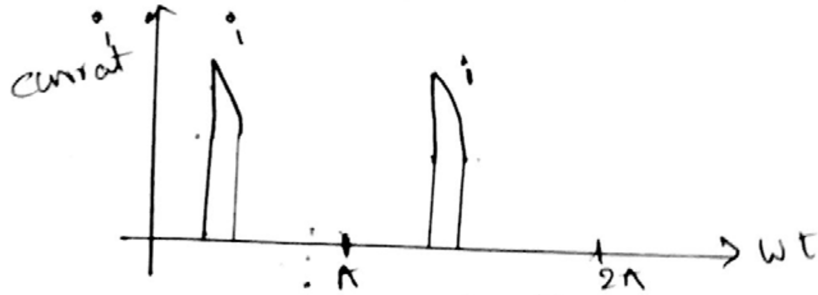
$D_1 \rightarrow$ off capacitor discharges through the load resistor with a time constant CR_L. So capacitor voltage $V_0 = A\,EXP(-t/CR_L)$
$\therefore A = V_m \sin\omega t\, EXP(t_1/CR_L)$.

The capacitor does not allow the sudden changes of voltage. so it takes time to decrease the voltage.
The i/p goes not decreases up to t=6 the capacitor voltage will be greater than that of i/p so D_1 will be opened. capacitor voltage slowly decreases

For $\pi - 2\pi$
In the second cycle i/p goes increase assume capacitor voltage is 8 then for i/p voltage >8 then D_1 conductor a capacitor charges the previous operation



$V = V_i - V_0$



$$I = \left[\frac{1}{R_L} + j\omega C\right] V$$

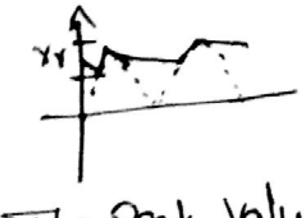
$$= \left[\sqrt{\left(\frac{1}{R_L}\right)^2 + \omega^2 C^2} \angle \tan^{-1}\omega C R_L\right] V$$

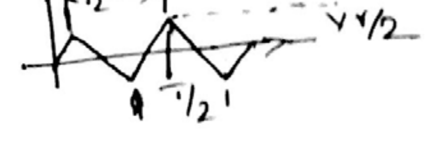
Since V has a peak value V_m then the instantaneous current is

$$i = V_m \sqrt{\omega^2 C^2 + \frac{1}{R_L^2}} \sin(\omega t + \psi)$$

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

Approximation of analysis of capacitor filter.





The peak value is V_m. The capacitor discharge voltage is denoted by V_r. Then the Avg value of voltage $V_{dc} = V_m - \frac{V_r}{2}$

From triangular $V_{rms} = V_r/2\sqrt{3}$

In T_2 represents non conducting, 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 $V_r = \frac{I_{dc}T_2}{C}$ V

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

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

$$\gamma = \text{ripple factor} = \frac{V'_{rms}}{V_{dc}} = \frac{I_{dc}}{4\sqrt{3}fCV_{dc}} \Rightarrow \boxed{\gamma = \frac{1}{4\sqrt{3}fCR_L}}$$

$$V_{dc} = V_m - \frac{I_{dc}}{4fC}.$$

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

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.

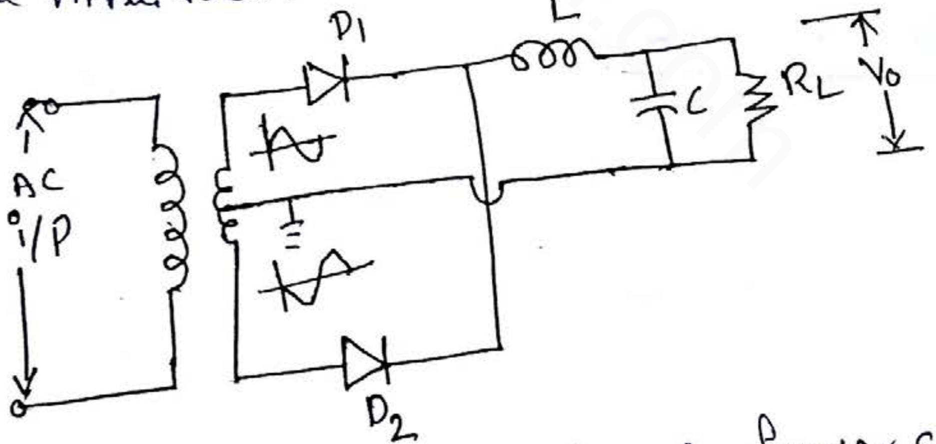
L filter is $r = R_L / 3\sqrt{2}\,\omega L \Rightarrow r \propto R_L$ If Resistance value is more than Inductor ripples will be more. So to reduce the ripple factor we have to use large value of L than R_L

In capacitor filter $r = \dfrac{1}{4\sqrt{3} f C R_L}$ ie $r \propto \dfrac{1}{R_L}$ 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 $\rightarrow r \propto R_L$

capacitor filter $\rightarrow r \propto 1/R_L$

So then the combination of Inductor as capacitor as LC filter the ripple factor will be independent of R_L.



The o/p will be expressed as in fourier series

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

$$V_{dc} = \frac{2V_m}{\pi} \qquad V_{ac} = \frac{4V_m}{3\pi} = V_m$$

$$I_{dc} = 2V_m \qquad I_{ac} = \frac{4V_m}{\;}\cdot\frac{1}{X}$$

$$I_{rms} = \frac{I_{ac}}{\sqrt{2}} = \frac{4V_m}{3\pi\sqrt{2}} \cdot \frac{1}{X_L} = \frac{2}{3\sqrt{2}} \frac{2V_m}{\pi} \cdot \frac{1}{X_L}$$

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

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

The voltage across capacitor is

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

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

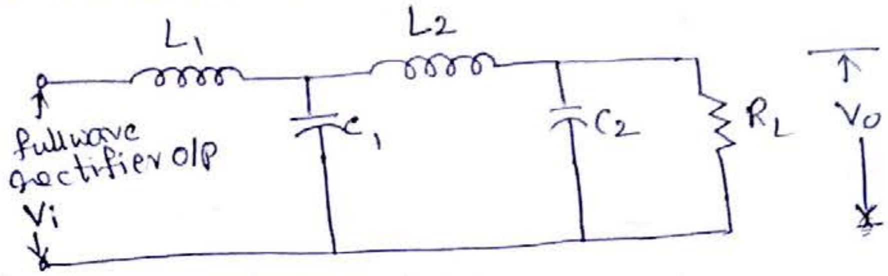
ripple factor $\gamma = \frac{\frac{\sqrt{2}}{3} V_{dc} \cdot \frac{X_C}{X_L}}{V_{dc}}$

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

$X_L = 2\omega L \qquad X_C = 1/2\omega C \qquad \because \cos 2\omega t \Rightarrow \omega = 2\omega.$

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

multiple LC filter:



single LC $r = \frac{\sqrt{2}}{3} \frac{X_C}{X_L}$

multiple LC $r = \frac{\sqrt{2}}{3} \frac{X_{C_1}}{X_{L_1}} \cdot \frac{X_{C_2}}{X_{L_2}}$.

π-section filter or CLC filter:

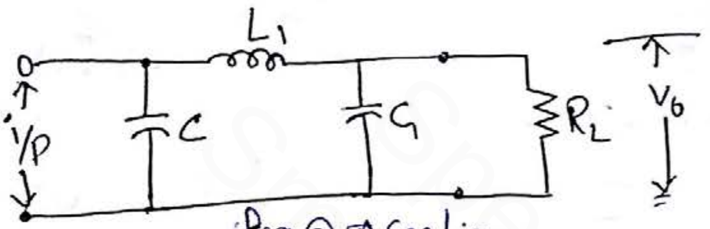


fig ⓐ π section.

A very smooth output may be obtained by using a filter that consists of two capacitors seperated 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 π 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 C_1 followed by a LC filter. The o/p of capacitor filter is feed to the LC filter.

As we know the o/p of capacitor filter will be the triangular wave form.

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

The ripple voltage can be calculated by analyzing the triangular wave (ie o/p of capacitor filter) in to a fourier series and the multiplying each component by $\frac{X_{C_1}}{X_{L_1}}$ for this harmonic.

Fourier analysis of this waveform is given by

$$V = V_{dc} - \frac{V_r}{\pi}\left(\sin 2\omega t - \frac{\sin 4\omega t}{2} + \frac{\sin 6\omega t}{3} + \dots\right)$$

From capacitor filter

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

The rms second harmonic voltage is

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

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.

$V'_{rms} = \frac{V_r}{2\sqrt{3}}$

$V_r = \frac{I_{dc} T_2}{C}$

$T_2 = \frac{T}{2} = \frac{1}{2f}$

$V_r = I_{dc}/2fC$

<u>Second Method</u>

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

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

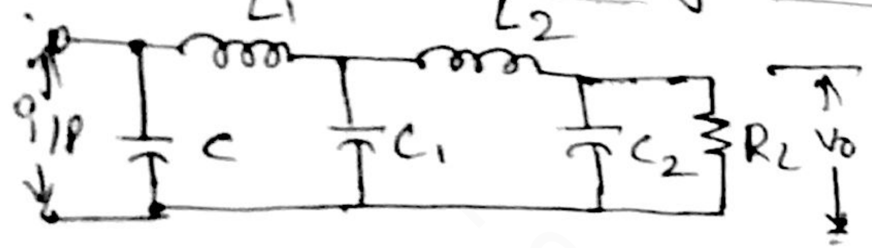
The current is in the form of pulses near the peak value of the cosine curve hence not too great an error is made by replacing $\cos 2\alpha$ by unity. Since the maximum value of cosine curve is unity, This will give the maximum possible value of I_2'.

$$\sqrt{2}\;I_2' \le \frac{1}{\pi}\int_0^{2\pi} i\, d\alpha = 2I_{dc}$$

By definition

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

by L section



$$r = \sqrt{2}\ \frac{X_C}{R_L} \cdot \frac{X_{C_1}}{X_{L_1}} \cdot \frac{X_{C_2}}{X_{L_2}}$$

Comparison of filter:

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

Voltage Regulation using zener diode:

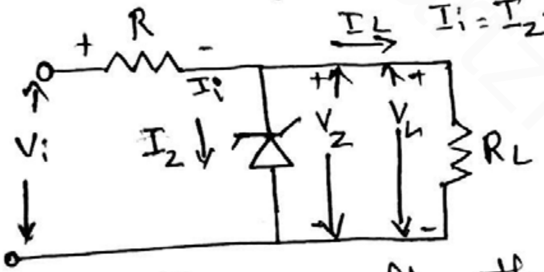
zener diodes specially designed p-n junction diodes with adequate power dissipation capabilities to operate in the breakdown region which can be employed as voltage reference or constant voltage devices in the electronic circuits.

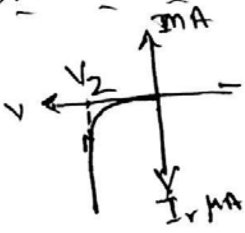
A zener diode maintains a constant output voltage in its breakdown region even though the current flowing through it is varied in its operating current range.

This is 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.

Ref.





$I_i = I_L + I_Z$ flow through resistor. R.

$V_L = I_L \cdot R_L$ $V_Z = I_Z \cdot R_Z$

$V_i = I_i R + V_Z$

$V_L = V_Z = I_L \cdot R_L = I_Z R_Z$.

The circuit consists of a full wave rectifier followed by a π 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 = 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

$$V_0 = V_m - \frac{I_L}{4fC}$$

$\because V_d = V_m - \frac{I_{dc}}{4fC}$ from capacitor filter

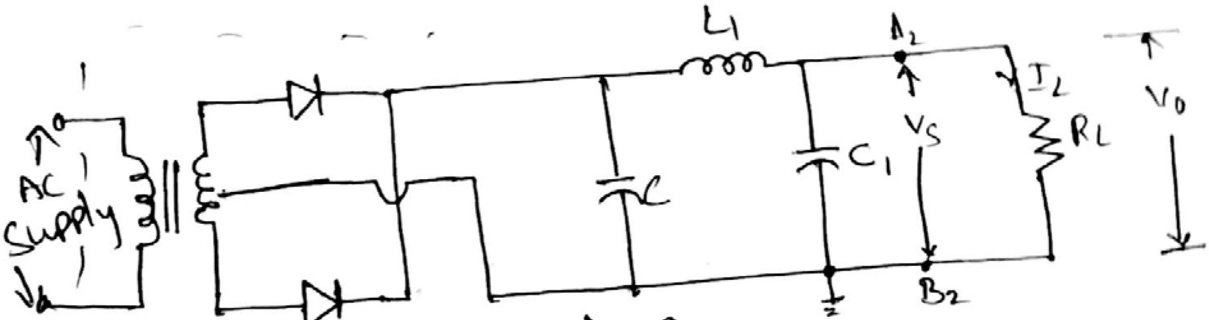


fig (a)

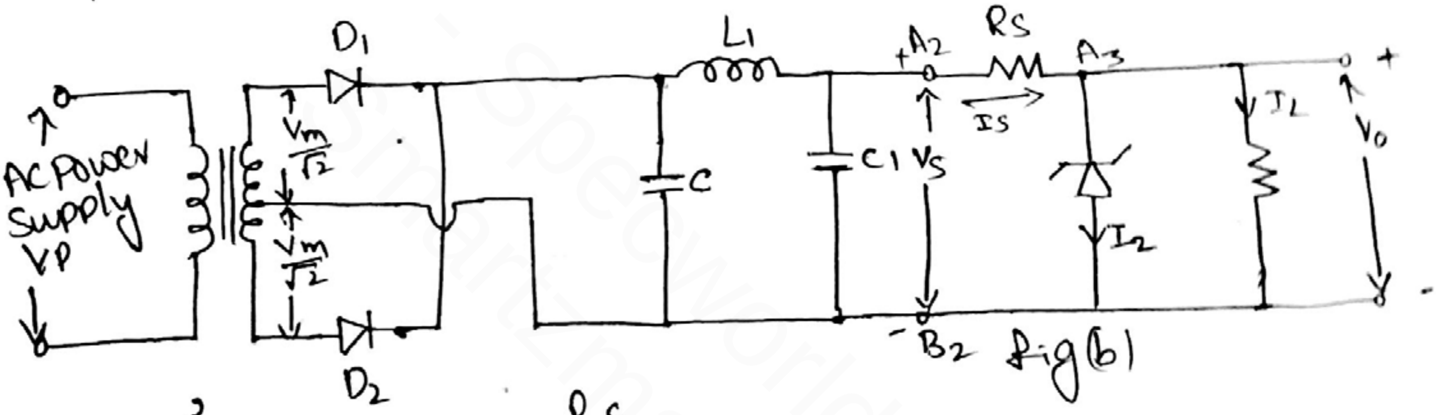


fig (b)

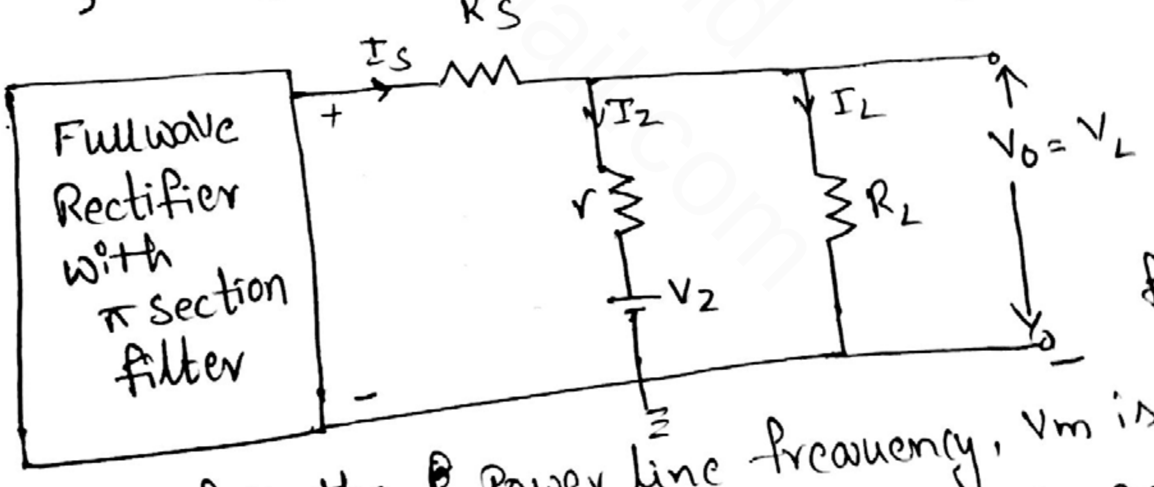


fig c

where f is the power line frequency, Vm is the peak of the transformer secondary with respect to the centertap of C capacitor shown.

must be maintained constant to operate

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

clearly if we maintain

$$V_L = V_0 = V_m - \frac{I_L}{4fc}$$ 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 $\frac{2V_m}{\sqrt{2}}$ where $2V_m$ 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) ckt will operate satisfactorily all the time.

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

Suppose that V_m varries between V_{smin} & V_{smax} corresponding minimum & maximum voltage the power line voltage applied to the Primary winding of the transformer

If the breakdown V_Z is choosen to be equal the desired Voltage V_L across the cht with load impedance R_L such that $V_{Smin} > V_Z = V_L$ 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_Z are current passing through R_L R_S & zener diode.

The current flowing through the load resistance given by

$$I_L = \frac{V_L}{R_L} \quad -① \qquad \text{where } V_L = V_Z + r I_Z \quad -②$$

(If zener diode is operated in breakdown region)

The current flowing through the series resistance R_S

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

$\because$ $I_S = I_L + I_Z$, the zener current

$$I_Z = I_S - I_L \quad -④$$

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

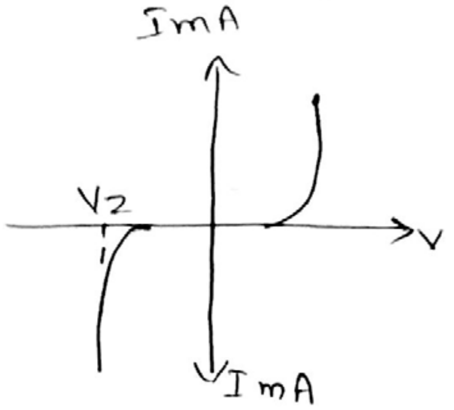
by rearranging term ② & ④, we obtain

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

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

$$I_Z \cong \left(\frac{V_S - V_Z}{R_S}\right) - \frac{V_Z}{R_L}$$

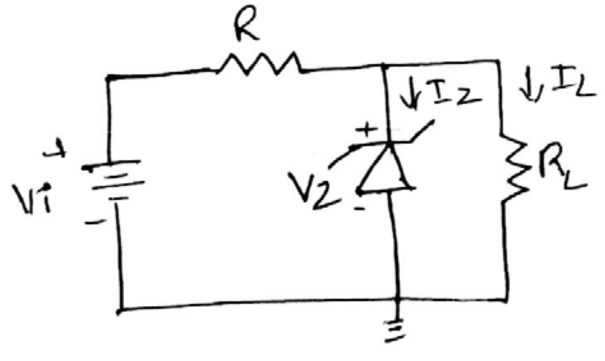
Zener Diode (voltage regulation using zener diode)



V_Z – zener Breakdown voltage

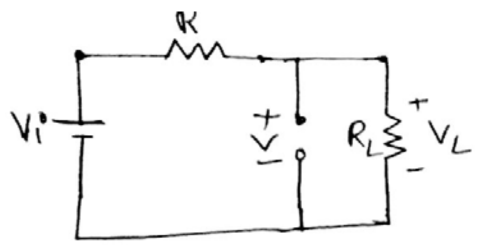
In forward bias zener characteristics same as P-n junction.
In the reverse bias zener characteristics occurs. In Breakdown region zener diode will have constant voltage.
(In breakdown condition is that for small changes of voltage we can get large changes of current. small change of voltage is called as const voltage.)
so that zener diode can be used as a regulator.

vi and R fixed:



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

1. Determine the state of the zenerdiode by removing it from the network and calculating the voltage across the resulting open circuit.

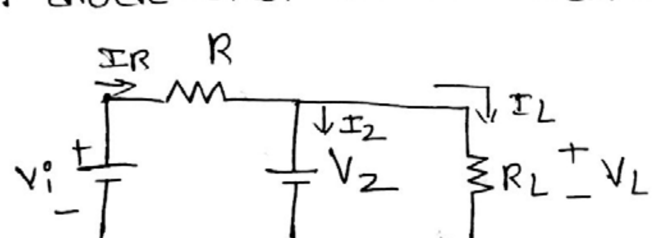


$$I = \frac{V_i}{R+R_L}$$

$$\boxed{V = V_L = \frac{R_L V_i}{R+R_L}} \quad \text{—— (1)}$$

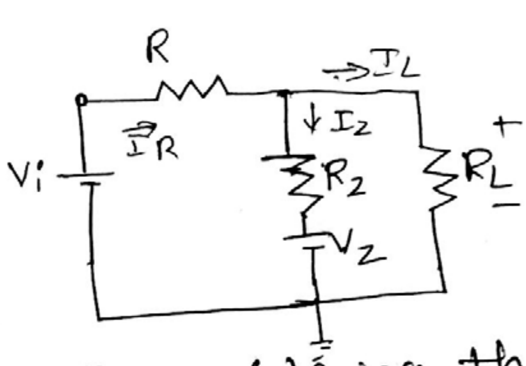
If $V \gg V_Z$ the zener diode is ~~on and~~ + Breakdown condition and appropriate Equivalent model can be substituted.

If diode zener is in breakdown condition then



Neglecting internal resistance of zener diode

fig (a)



By considering the internal resistance of zenerdiode.

fig (b)

By considering the fig a)

$$V_L = V_Z$$

$$I_R = I_Z + I_L$$

$$I_L = \frac{V_L}{R_L} \qquad I_R = \frac{V_R}{R} = \frac{V_i - V_L}{R}$$

$$\boxed{P_Z = V_Z \cdot I_Z} \quad \text{—— (2)}$$

fixed Vi, variable R_L:

Too small a load resistance R_L will result in a voltage V_L 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 use checking condition.

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

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

for solving of R_L

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

$$V_Z R_L + V_Z R = R_L V_i$$

$$V_Z R = R_L V_i - V_Z R_L$$

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

$$\boxed{R_{L\,min} = \frac{V_Z R}{V_i - V_Z}} \quad \text{— (3)}$$

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

$$\boxed{I_{L\,max} = \frac{V_L}{R_L} = \frac{V_Z}{R_{L\,min}}} \quad \text{— (4)}$$

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

$$V_R = V_i - V_Z \quad \text{— (5)}$$

$$I_R = V_R / R$$

$$I_Z = I_R - I_L \quad \text{— (6)}$$

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

ly

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 ma...

$R_{L max} = \frac{V_2}{I_{L min}}$ $\boxed{R_{l max} = \frac{V_2}{I_{l min}}}$

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 $V_i = V_{i min}$

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

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

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

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

$$\boxed{I_{R max} = I_{Z max} + I_L}$$

$$V_{i max} = V_{R max} + V_Z$$

$$\boxed{V_{i max} = I_{R max} R + V_Z}$$

$$V_{i max} = I_{R max} \cdot R + V_Z$$