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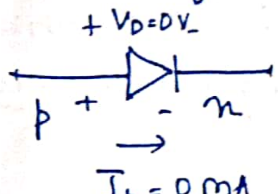
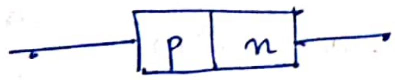
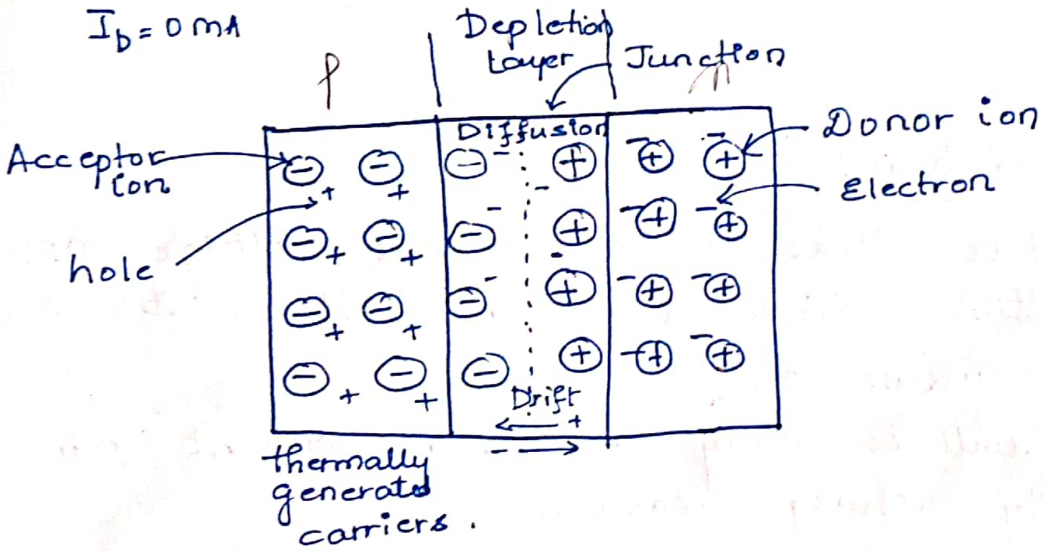
SEMICONDUCTOR DIODES

A diode is a two terminal device. It conducts only in one direction. It is formed when p and n material are joined back to back. It is symbolically represented as follows.







At the instant the two materials are joined the electrons and holes in the region of the junction will combine, resulting in lack of free carriers in the region near the junction. This region of immobile positive and negative zone is called depletion region. Due to depletion of free carriers in this region

Diode working can be analyzed using the three operational states.

1) No applied bias [V = 0V]
2) Reverse bias condition [V < 0V]
3) Forward bias condition [V > 0V]

The term 'bias' refers to the application of an external voltage across the two terminals of the device to obtain the required output response.

1) <u>No applied bias</u> :-

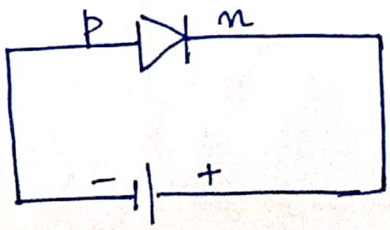
Here there is no external voltage applied across the diode terminals. Hence the net output current = 0A.

→ There will be only a small current due to minority charge carriers.

2) <u>Reverse bias condition</u> [$V_D < 0V$]

If an external voltage is applied across the diode such that +ve terminal is connected to n-type and -ve terminal is connected to p type, a reverse bias condition is established.

← I_s minority carrier flow



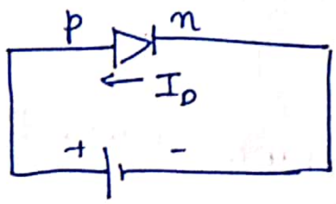
Hence under this condition, the depletion region increases, then the majority carriers fail to acquire sufficient kinetic energy to cross through the depletion region.

Thus here the diode conducts in a small current from cathode to anode. The current that exists under reverse bias condition is due to the minority charge carriers.

The current in reverse bias condition is known as Reverse saturation current and it is represented as I_s.

It is called as saturation current because it reaches its maximum value quickly and it does not change significantly with increase in the reverse bias potential.

3) Forward Bias condition $[V_D > 0V]$



It is established by applying +ve ~~potential~~ terminal to p type and -ve terminal to n-type.

This will pressurize the electrons in the n-type material and the holes in the ptype material to recombine with ions near boundary.

Thus it reduces the width of the depletion region. Hence it leads to heavy majority flow across the junction, leading to conduction heavily from anode to cathode.

It results is an exponential raise in the current.

Diode current equation [Shockley's Equation].

The diode current equation is defined using Shockley's equation, it is given by

$$I_D = I_S\left(e^{V_D/\eta V_T} - 1\right) \quad \text{—— (1)}$$

$I_D \rightarrow$ diode current

$V_D \rightarrow$ voltage applied across diode

$I_S \rightarrow$ reverse saturation factor

$\eta \rightarrow$ ideality factor [1 or 2]

$V_T \rightarrow$ thermal voltage.

$$V_T = \frac{kT}{q}$$

$k \rightarrow$ Boltzmann Constant $= 1.38 \times 10^{-23}$ J/k.

$T \rightarrow$ absolute temparature in Kelvin

$q \rightarrow$ magnitude of electronic charge $= 1.6 \times 10^{-19}$ C

For the given room temparature = 27°c. Determine the thermal voltage V_T

$$T = 273 + 27 = 300k$$

$$V_T = \frac{kT}{q} = \frac{(1.38 \times 10^{-23} J/k)(300)}{1.6 \times 10^{-19} c}$$

$$V_T = 26mV.$$

b) $t = 100$

$$T = 273 + 100 = 373\,k.$$

$$V_T = \frac{kT}{q} = \frac{1.38 \times 10^{-23} \times 373}{1.6 \times 10^{-19}}$$

$$V_T = 32.17\,mV$$

under forward bias condition,

consider Eqn ①

$$I_D = I_S[e^{V_D/\eta V_T} - 1]$$

$$I_D = I_S e^{V_D/\eta V_T} - I_S \quad \text{—— (2)}$$

if V_D is +ve I_D increases exponentially,

∴ Eqn (2) can be approximated as,

$$\boxed{I_D \approx I_S e^{V_D/\eta V_T}}$$

under reverse bias condition :-

for -ve values of V_D Eqn (2) drops very quickly below I_S

∴ I_D can be approximated as,

$$\boxed{I_D \approx -I_S}$$

Avalanche Breakdown :-

The width of the depletion region increases in reverse bias condition and offers huge barrier to the flow of majority carriers. Hence the current is only due to the minority charge carriers.

On increasing the reverse bias potential, the velocity of the minority charge carriers increases. and also and also there will be sudden rise in the reverse current.

The electrons acquire a very high kinetic energy and they break co-valent bond and become free. These free electrons will further collide with the electrons and free them, this process continues like a chain reaction.

This process is known as impact ionization which leads to a high avalanche current and further it results in avalanche breakdown.

The voltage at which avalanche breakdown occurs is known as Reverse Breakdown voltage [V_{BV} or V_{BR} or V_{BD}].

In this region the diode current increases sharply with the diode voltage remaining constant at V_{BD}.

The diode must not be operated in avalanche breakdown, hence each diode has a specified PIV or PRV

PIV [Peak Inverse Voltage]

The maximum reverse bias voltage which can be applied across the diode before it enters the breakdown region.

V-I characteristics of Diode :-

The diode current equation is given by,

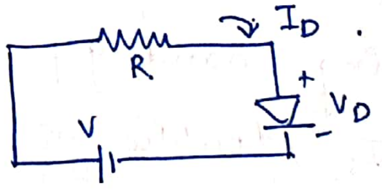
$$I_D = I_S\left[e^{V_D/\eta V_T} - 1\right]$$

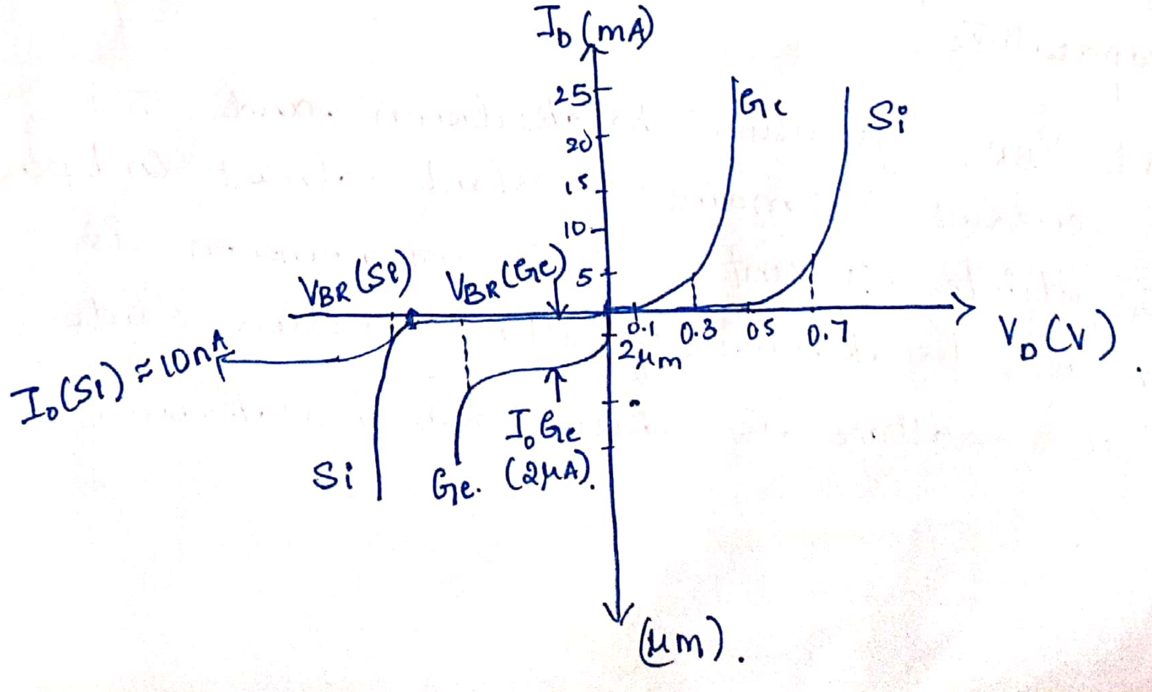
$I_D \rightarrow$ diode current

$I_S \rightarrow$ saturation current

$\eta \rightarrow$ ideality factor 1 for Ge, 2 for Si

Consider a simple diode circuit. The variation of diode current I_D wrt V_D (diode voltage) is as shown in figure.





The following observations can be made,

1) for Si, I_D is very small upto $V_D = V_\gamma = 0.7V$, $\boxed{V_D / V_\gamma / V_k}$ is known as the transition or threshold or knee voltage. It is the voltage at which the forward current of the diode begins to increase exponentially will the applied forward voltage.

Beyond V_D, I_D increase exponentially will V_D.

|||ly for Ge, $V_\gamma = 0.3V$

2) During reverse bias condition, there exists only a small value of current due to the minority charge carriers. This is known as reverse saturation current.
I_s is dependent on temparature, I_s increases with increasing temparature and decreases with increasing band gap.
Approximately I_s double for every $10°C$ rise in temparature.

3) Beyond V_{BR}, junction breakdown and the diode current remains constant almost independ of the diode current. This phenomenon is known as breakdown of the junction diode and the voltage is known as breakdown voltage.

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Diode Resistance levels :-

- The forward characteristics of the diode is non-linear since the diode current changes exponentially with the applied forward voltage.

Hence diode resistance changes when the operating point moves from one region to another. Based on this the resistance of the diode can be analyzed in three different levels.

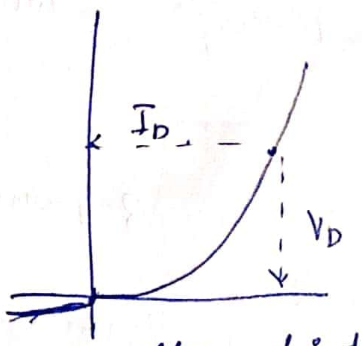
1) DC or static resistance
2) AC or dynamic resistance
3) Average AC resistance.

1) DC or static resistance :-

When a dc voltage is applied to a semiconductor diodes, the operating point lies on the characteristics curve and it will not change with time.

The resistance of the diode then is known as DC or static resistance. It is given by

$$\boxed{R_D = \frac{V_D}{I_D}}$$



here " higher the current through the diode, the lower is the dc resistance level ".

Observations :
1) $R < V_K$ is high
2) In reverse bias $I \approx 0$ $\therefore$ $R \gg$ high.

AC or dynamic resistance:

On applying a sinusoidal voltage, the varying input will result in variation of the operating point up and down in the characteristic curve, hence it defines a specific change in current and voltage.

When the sinusoidal signal = 0; the point of operating point of the curve is termed as QUIESCENT POINT 'Q' point.

To find the dynamic ac resistance; Dynamic resistance refers to AC resistance of PN junction.

Draw a straight line tangent to the curve through Q point.

The peak to peak value of V_D can be used to determine the specific voltage & current change.

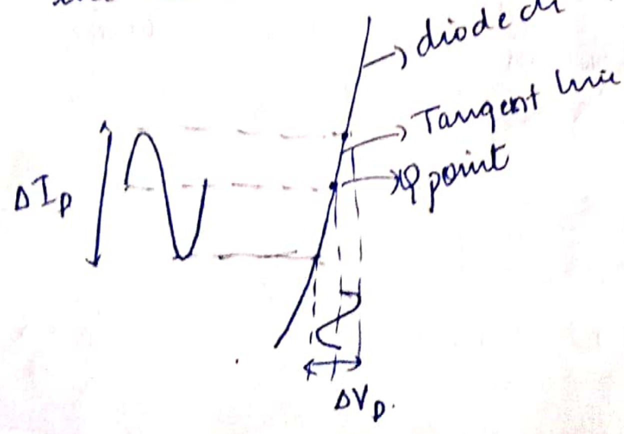
$$\therefore \quad r_d = \frac{\Delta V_d}{\Delta I_D}$$

$\Delta \rightarrow$ signifies a finite change.

here steeper the slope $\rightarrow$ low $\Delta V_D, \Delta I_D \Rightarrow$ low r_d.

Viceversa

$\therefore$ the lower the Q-point of operation, the higher is the ac resistance.



Average AC resistance:-

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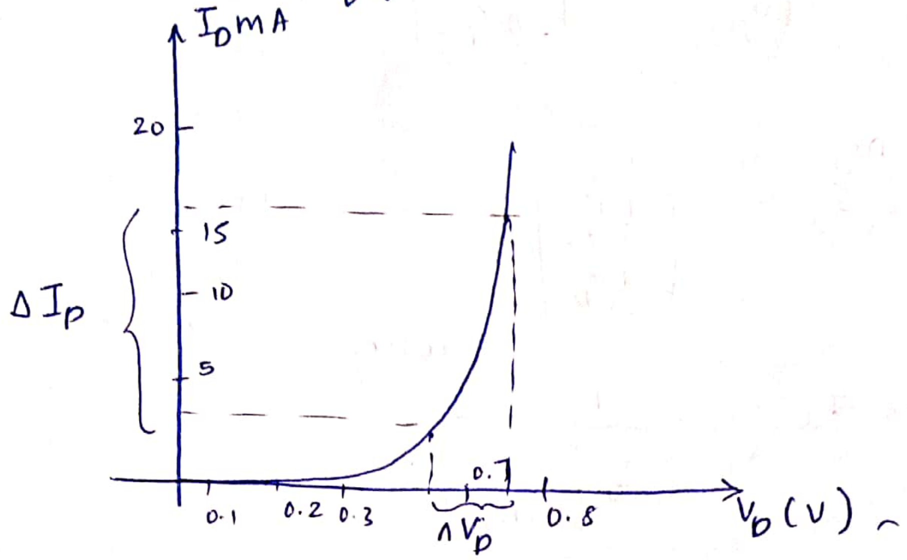
The average ac resistance is the resistance determined by a straight line drawn between the two intersections established by the max & min values of i/p voltage. It is as shown in figure below



dynamic resistance was measured for small signal operation ie., when Q point produces a narrow swing.

The resistance associated with the device under large signal operation is called average ac resistance. Q point produces a broader swing. $r_{av} = \left.\frac{\Delta V_d}{\Delta I_d}\right|_{pt\ to\ pt}$

Analytical expression for dynamic resistance of diode:

from laws of differential calculus,

$r_d = \frac{\partial V_D}{\partial I}$

$$r_d = \left.\frac{dV_D}{dI_D}\right|_{Q\ point} \quad \text{——} (1)$$

wkt $I_D = I_S\left[e^{\frac{V_D}{nV_T}} - 1\right]$

$$I_D \simeq I_S e^{V_D/nV_T} \quad \text{——} (2)$$

differentiating w.r.t V_D we get,

$$\frac{dI_D}{dV_D} = \left[I_S e^{\frac{V_D}{nV_T}}\right] \cdot \frac{1}{nV_T}$$

$$\frac{dI_D}{dV_D} = I_D\left[\frac{1}{nV_T}\right] \quad \text{---} \; (3)$$

But $$\frac{dV_D}{dI_D} = \frac{1}{\left[\frac{dI_D}{dV_D}\right]} \quad \text{---} \; (4)$$

using (3) in (4)

$$r_d = \frac{1}{I_D\left[\frac{1}{nV_T}\right]}$$

$$\boxed{r_d = \frac{nV_T}{I_D}} \quad \text{---} \; (5)$$

taking $n=1$ & $V_T = 26mV$ (at room temp) in Eqn 5. we get,

$$\boxed{r_d = \frac{26mV}{I_D}}$$

The above eqn. gives accurate results only for values of I_D in the vertical rise section of the curve for lower values of I_D $n=2 \Rightarrow r_d = 2r_d$.

Bulk resistance :

Temparature effects

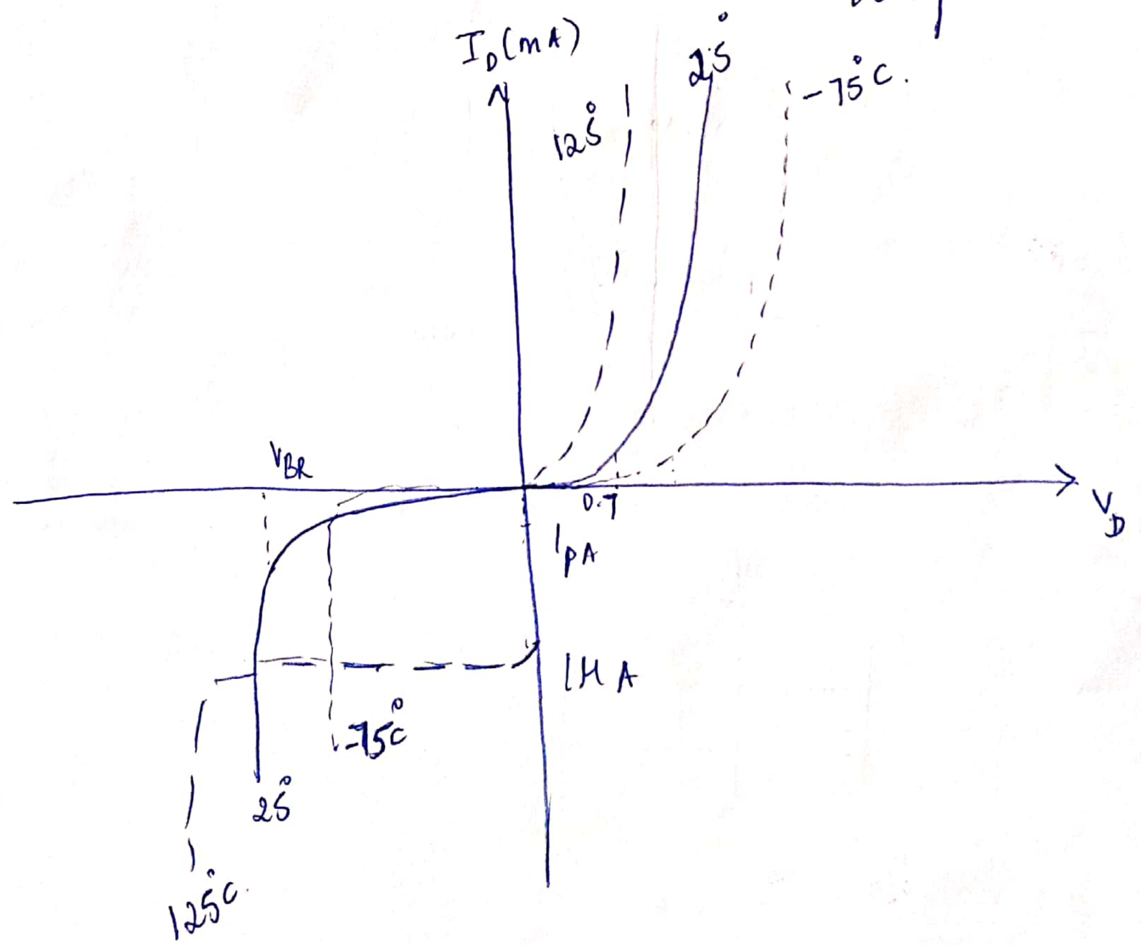
~~During~~ In forward bias region the characteristics of Si diode shifts to the left at a rate of 2.5 mV / °C increase in temparature

[ie., the knee voltage of the diode reduces]

~~During~~ In reverse bias region, the reverse saturation current doubles for every 10°C rise in temparature

The reverse breakdown voltage of a semiconductor will increase or decrease with temparature depending on the zener potential.

[If zener potential is less than 5V, → breakdown decreases the temparature]



Diffusion capacitance or storage capacitance [C_D].

During FB holes move from p to n and electrons move from n to p and it depends on the applied bias. There is an excess in the minority charge carriers due to the diffusion of majority charge carriers across the junction.

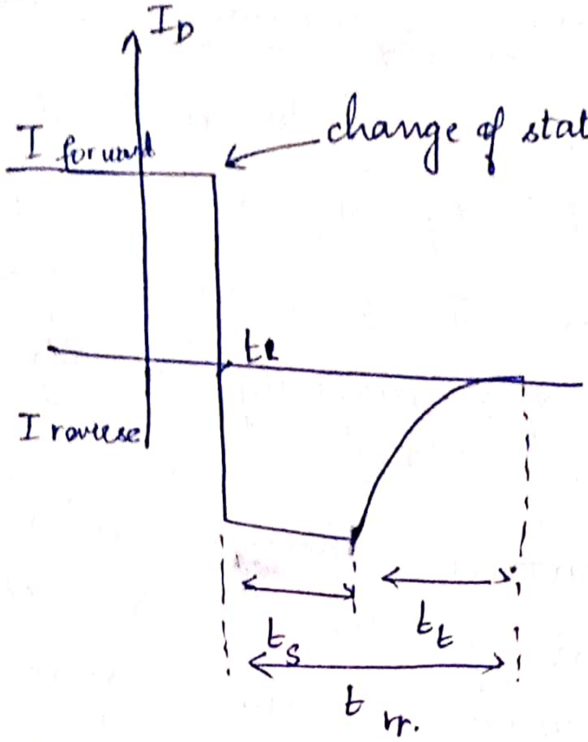
The excess minority carrier change with the applied potential, giving rise to a voltage dependent charge storage or capacitance. This capacitance is known as diffusion capacitance

Charge storage and reverse recovery time

During FB, holes move from p region to n region and electrons move from n to p.. Hence it leads to an increase of holes in n region & electrons in p regions. These excessive minority carriers are called as stored charges and the process is known as charge storage.

If the diode is suddenly reverse biased the diode changes from conducting to non-conducting mode after a time t_{rr} called as reverse recovery time.

The reverse recovery time is the time required by the excessive minority carriers [holes in n & electrons in p] to return to their majority carrier state in the opposite material.



$\therefore\ t_{rr} = t_s + t_t$

$t_s \rightarrow$ storage time $\rightarrow$ the time during which the diode current stays in its measurable level under reverse bias.

$t_t \rightarrow$ transition-time $\rightarrow$ the time during which the diode current decays to 0.

Rectifiers :-

→ Rectifiers convert AC to DC.

→ Diodes conduct current when forward biased and block current when reverse biased, this property is used for performing rectification.

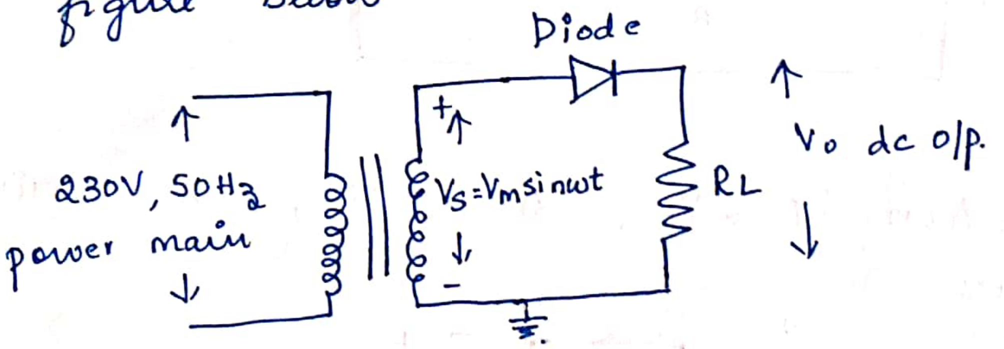
→ Rectifiers are necessary because most of the electronic systems operate using a dc voltage [5V to 30V]

→ Rectifiers can be categorized as

* Half wave rectifier
* Full wave rectifier.

Half wave Rectification :-

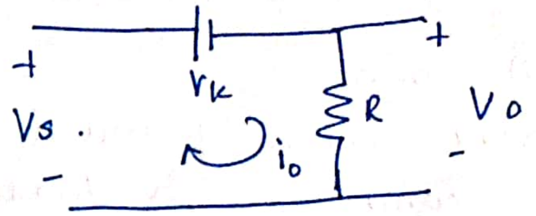
→ converts one half of AC signal into DC. A simple HWR circuit is as shown in the figure below



where V_s → input signal

$V_s = V_m \sin \omega t$.

Case1 :- During +ve cycle, Diode conducts when $V_i \geq V_K$. The equivalent circuit is as shown.



applying KVL,

$$V_S - V_K - V_o = 0$$

$$V_o = V_S - V_K \quad \text{—(1)}$$

when $V_S = V_m$,

$$V_o = V_m - V_K \quad \text{—(2)}$$

Eqn (1) can be written as,

$$\boxed{V_o = (V_m - V_K) \sin\omega t} \quad \text{—(3)}$$

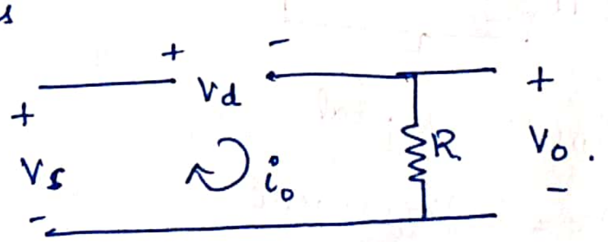
the o/p current is given by

$$i_o = \frac{V_o}{R} \quad \text{—(4)}$$

$$\therefore \boxed{i_o = \frac{(V_m - V_K)}{R} \sin\omega t} \quad \text{—(5)}$$

case 2 :-

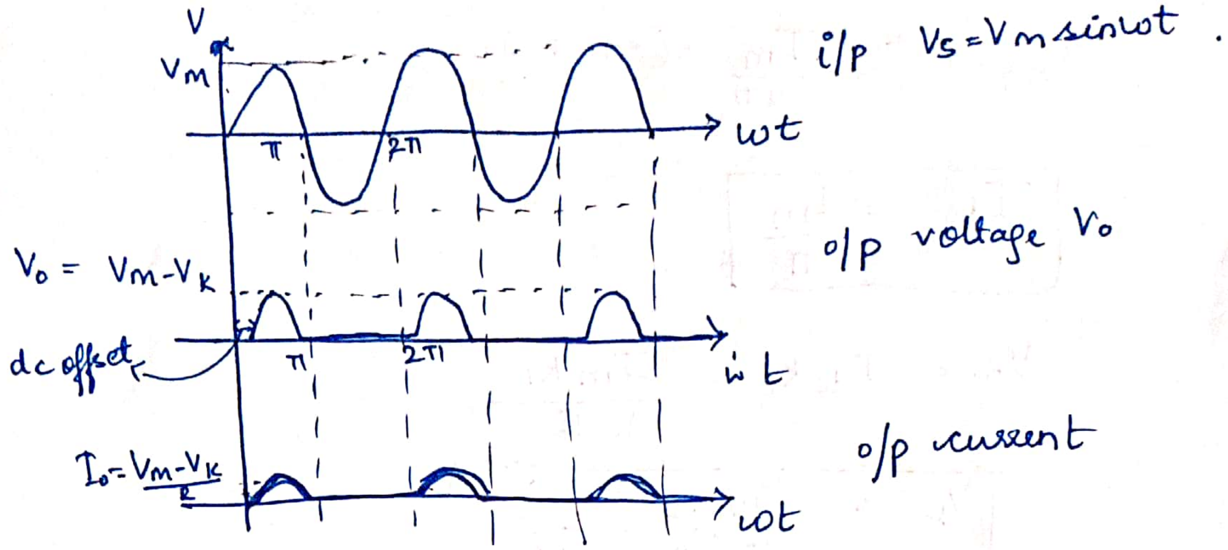
when $V_i \leq V_K$, D is off, the equivalent circuit is



from fig, $i_o = 0$ and $V_o = i_o R = 0$

ie., $\boxed{i_o = 0mA \quad V_o = i_o R = 0V}$

The output waveform is as below,



Performance of half wave rectifier :

1) Average or DC value of current.

wkt $V_S = V_m \sin\omega t$

from waveforms,

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

$i_L = 0$ for $\pi < \omega t \le 2\pi$

where $I_m = \dfrac{V_m}{R_S + r_d + R_L}$

where $R_L \rightarrow$ load resistance

$r_d \rightarrow$ diode forward resistance

$R_S \rightarrow$ resistance of transformer secondary winding.

$$\therefore \quad I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} I_m \sin\omega t \, d\omega t$$

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

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

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

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

$$\therefore \quad V_{DC} = I_{dc} R_L = \frac{I_m R_L}{\pi}$$

$$\boxed{V_{DC} = \frac{V_m R_L}{\pi (R_s + r_d + R_L)}}$$

RMS value of current I_{rms}.

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

$$I_{rms}^2 = \frac{1}{2\pi} \int_0^{\pi} I_m^2 \sin^2 \omega t \, d\omega t + \int_{\pi}^{2\pi} \cancel{0} \, d\omega t$$

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

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

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

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

$$\boxed{I_{rms} = \frac{I_m}{2}} \quad \text{——} \quad (A)$$

$$\text{||}^{ly} \quad V_{rms} = I_{rms} R_L = \frac{I_m R_L}{2}$$

Eqn (A) represents RMS value of total current [DC + AC]

$\therefore$ The instantaneous value of AC components is given by $i_L - i_{dc}$

ie, total current — dc value of current

I'_{rms} = rms value of AC current

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

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

tokt

$$\left.\begin{aligned} \frac{1}{2\pi}\int_0^{2\pi} i_L^2 \, d\omega t &= I_{rms} \\ \frac{1}{2\pi}\int_0^{2\pi} i_L \, d\omega t &= I_{dc} \end{aligned}\right\} \text{— (C)}$$

using (C) in (B).

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

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

Ripple factor :

Pulsations observed in the rectified output voltage is known as ripples.
Hence ripple factor is used to define how smooth the output is, smaller the ripple factor - closer is the output to pure DC

$$\text{ripple factor} = \frac{\text{rms value of ac}}{\text{avg dc value}}$$

$$= \frac{I'_{rms}}{I_{dc}}$$

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

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

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

WKT $I_{rms} = \frac{I_m}{2}$ and $I_{dc} = \frac{I_m}{\pi}$

$$\therefore \gamma = \sqrt{\left(\frac{\frac{\cancel{I_m}}{2}}{\frac{\cancel{I_m}}{\pi}}\right)^2 - 1} = \sqrt{(1.57)^2 - 1}$$

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

$\therefore$ the rectified o/p contains 121% of AC component.

Rectifier efficiency :-

It is used as a measure of merit to compare rectifier. It is defined as the ratio of o/p dc power to input ac power.

$$\eta = \frac{\text{DC power delivered to load}}{\text{AC input power}} = \frac{P_{DC}}{P_{AC}}$$

$$\text{Power} = VI = I^2R.$$

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

$$P_{AC} = I_{rms}^2 R = \left(\frac{I_m}{2}\right)^2 \times (R_L + R_s + r_d) \quad \text{where } R = (R_L + R_s + r_d)$$

$$\therefore \eta = \frac{P_{DC}}{P_{AC}} = \frac{\left(\frac{\cancel{I_m}}{\pi}\right)^2 R_L}{\left(\frac{\cancel{I_m}}{2}\right)^2 \times (R_L + R_s + r_d)}.$$

$$\eta = \frac{4}{\pi^2} \times \frac{R_L}{R_L + R_s + r_d}$$

$$\eta = \frac{0.405 R_L}{R_s + r_d + R_s}$$

$$\text{ie. } \boxed{\eta = \left[40.5\left[\frac{R_L}{R_s + r_d + R_L}\right]\right]\%}$$

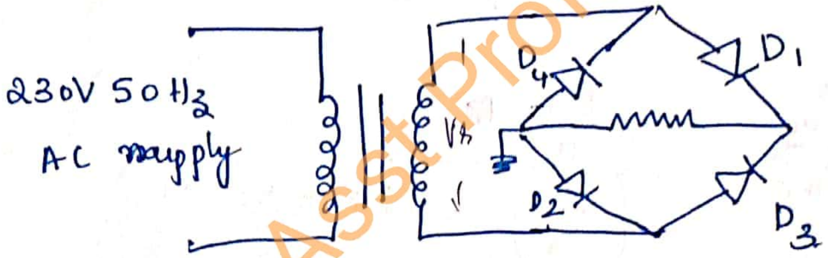
Full wave Rectifier

It converts both +ve and −ve half cycles of AC signal into DC. There are two types of full wave rectifier.

1) Center tapped FWR
2) Bridge rectifier.

Bridge Rectifier :-

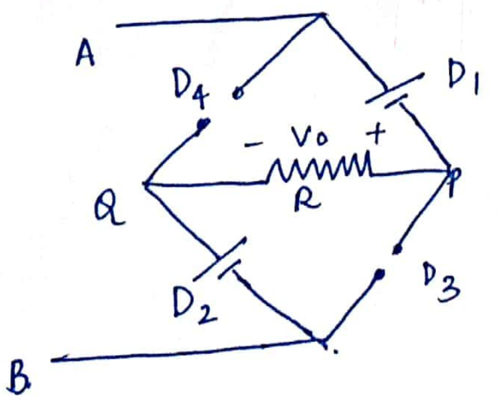
It is known as bridge rectifier because of the similarity of the configuration to that of wheatstone's bridge. The circuit diagram is as shown below,



During +ve cycle :-

D_1 and D_2 are forward biased, [ie., D_1, D_2 on]
D_3 and D_4 are reverse biased. [D_3, D_4 off].

The equivalent circuit is



The current flow path is
A D_1 P Q D_2 B A

applying KVL,

$$V_S - V_K - V_o - V_K = 0$$

$$\therefore V_o = V_S - 2V_K$$

when $V_S = V_m$ then,

$$\boxed{V_o = V_S - 2V_K}$$

the above equation can be generalized as,

$$\boxed{V_0 = (V_m - 2V_k)\sin\omega t} \qquad 0 \leq \omega < \pi$$

III^ly

$$i_0 = \frac{V_0}{R} = \frac{(V_m - 2V_k)\sin\omega t}{R}$$

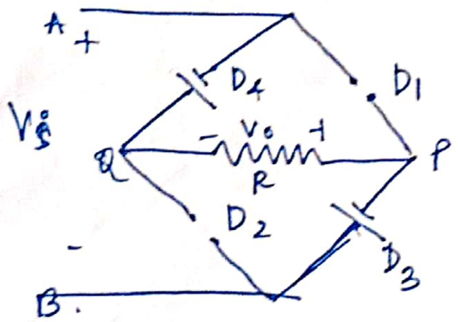
ie.,

$$\boxed{i_0 = \frac{V_m - 2V_k}{R}\sin\omega t}$$

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

During -ve half cycle, the diodes D_3 and D_4 are forward biased [D_3, D_4 on]. The diodes D_1, D_2 are reverse biased [D_1, D_2 off]

∴ the equivalent circuit is as shown,



The current path is $B\,D_3\,P\,Q\,D_4\,A\,B$.

applying KVL to the network,

$$-V_S + V_K + V_0 + V_K = 0$$

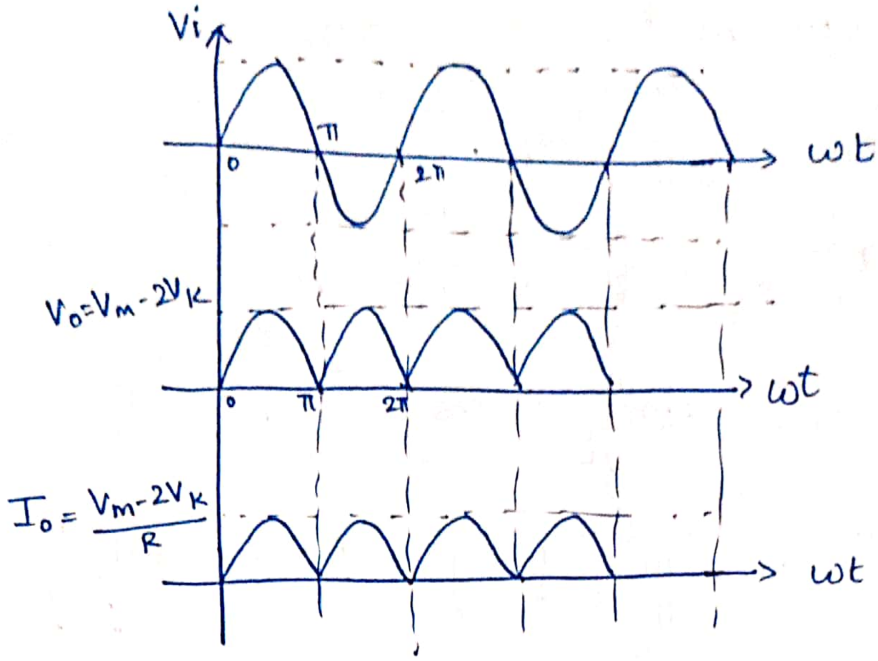
$$\therefore \quad V_0 = V_S - 2V_K$$

when $V_S = V_m$ then,

$$V_0 = V_m - 2V_K$$

the above equation can be generalized as,

$$\boxed{V_0 = (V_m - 2V_K)\sin\omega t}$$



Performance of Bridge Rectifier :-

1) Average or DC value of current

$$I_{dc} = \cancel{\frac{q}{t}}$$

wkt $V_s = V_m \sin\omega t$.

from waveform,

$$i_L = I_m \sin\omega t \qquad 0 \leq \omega t \leq \pi$$

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

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

$$I_{dc} = \frac{I_m}{\pi}\left[1+1\right]$$

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

RMS Value of Current :-

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

$$I^2_{rms} = \frac{1}{\pi}\int_0^{\pi} I_m^2 \sin^2\omega t \, d\omega t$$

$$I^2_{rms} = \frac{I_m^2}{\pi}\int_0^{\pi}\left[\frac{1-\cos 2\omega t}{2}\right] d\omega t$$

$$I^2_{rms} = \frac{I_m^2}{\pi}\left[\left(\frac{1}{2}\omega t\right)_0^{\pi} - \frac{1}{2}\left(\frac{\sin 2\omega t}{2}\right)_0^{\pi}\right]$$

$$I^2_{rms} = \frac{I_m^2}{\pi}\left[\frac{\pi}{2} - \frac{1}{4}\left[\cancel{\sin 2\pi}^{\,0} - \cancel{\sin 0}^{\,0}\right]\right]$$

$$I^2_{rms} = \frac{I_m^2}{2}$$

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

Ripple factor :-

$$\gamma = \frac{I_{ac}}{I_{dc}} = \frac{\sqrt{I^2_{rms} - I^2_{dc}}}{I_{dc}}$$

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

$$\gamma = \sqrt{\frac{\left(\frac{\cancel{I_m}}{\sqrt{2}}\right)^2}{\left(\frac{2\cancel{I_m}}{\pi}\right)^2} - 1}$$

$$\gamma = \sqrt{\frac{\pi^2}{8} - 1} = 0.483$$

$$\boxed{\gamma = 0.483}$$

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Rectifier Efficiency :-

It is used as a measure of merit to compare rectifier. It is defined as the ratio of o/p DC power to input AC power

$$\eta = \frac{\text{DC power delivered to load}}{\text{AC input power}} = \frac{P_{DC}}{P_{AC}}.$$

$$P = VI = I^2 R$$

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

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

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

$$P_{AC} = \frac{I_m^2}{2} (R_L + R_S + r_d)$$

$$\eta = \frac{P_{DC}}{P_{AC}} = \frac{\frac{4 \cancel{I_m^2}}{\pi^2} R_L}{\frac{\cancel{I_m^2}}{2} (R_L + R_S + r_d)}$$

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

$$\eta = .812 \left(\frac{R_L}{R_L + R_S + r_d}\right)$$

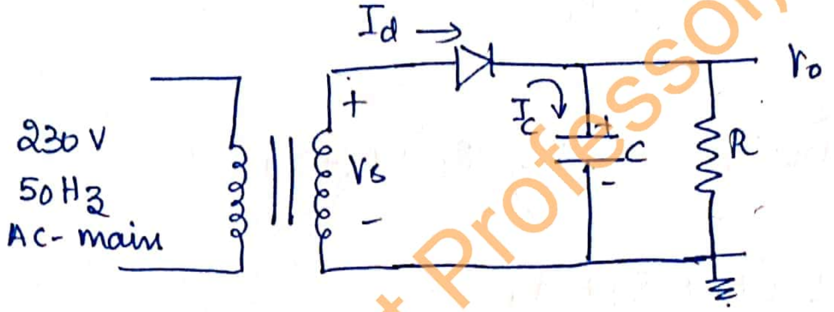
$$\boxed{\eta = \left(81.2 \frac{R_L}{R_L + R_S + r_d}\right) \%}$$

Rectifier with Shunt Capacitance filter.

Pulsating DC o/p of rectifiers (ripples) is not suitable as DC supply for electronic circuits. Filter circuits are used to reduce ripples in rectifier output. This is achieved by using LC components across the load R_L

Half wave Rectification with capacitor filter

A simple HWR with shunt capacitance filter is as shown in figure below



During +ve cycle

→ Diode conducts and capacitor charges to peak value of V_s $\quad V_s = V_m \sin\omega t$

→ After V_m, V_s starts reducing and the diode does not conduct as C is charged to V_m.

→ The capacitor discharges slowly through R_L

→ At time $T+t_1$, $V_i > V_c$ hence diode conducts and charges capacitor to the peak value.

→ V_c follows V_s between t_1 to t_2

→ The rate of discharge of capacitor is dependent on the time constant $R_L C$

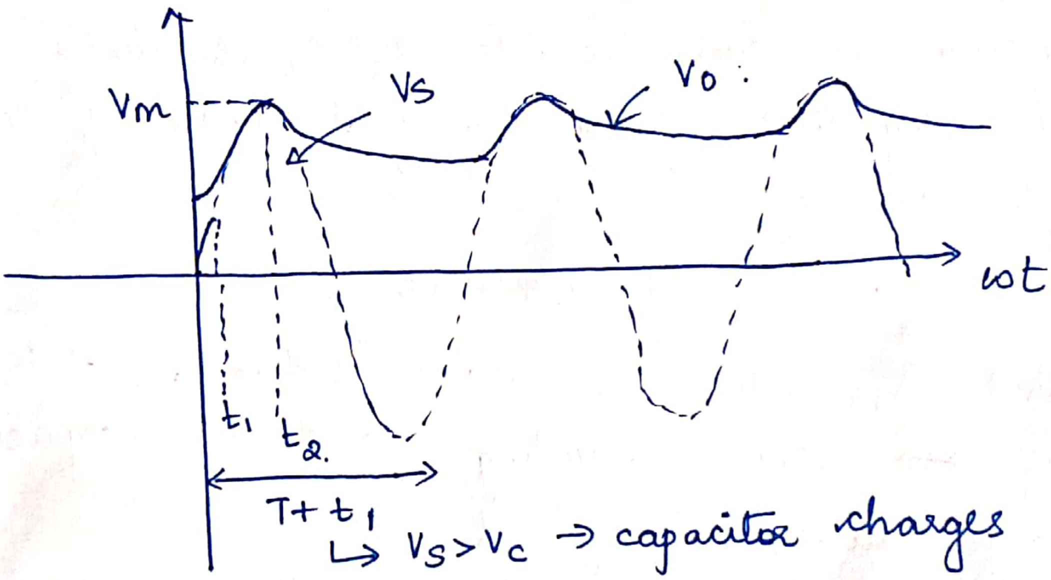
→ select C such that the time constant is large enough so that the capacitor will discharge slowly during the entire interval.

→ The output waveform is as shown in the figure below, the output voltage will be nearly constant and the ripples will be low.

→ The ripple factor is given by,

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

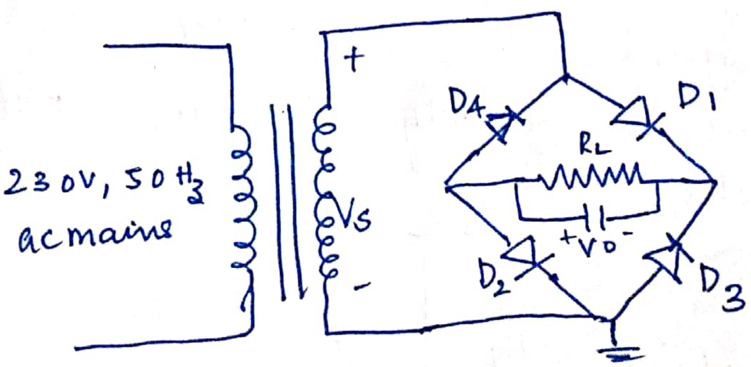
where f is the frequency



↳ $V_s > V_c$ → capacitor charges.

FWR with shunt capacitance :-

A simple FWR with shunt capacitance filter is as shown in the figure below



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During +ve cycle, diode D_1 and D_2 conducts and the capacitor charges to peak value of V_s [D_3, D_4 off]

$$V_s = V_m \sin\omega t$$

→ ~~when~~ Beyond V_m, the V_s starts reducing, ~~and~~ the diodes D_3 and D_4 ~~are~~ stops conducting as C is charged to V_m. The capacitor discharges slowly through R_L.

→ At time $T/2 + t_1$, $V_i > V_c$, hence diode conducts and charges capacitor to peak value

→ V_c follows V_s between t_1 to t_2.

→ During -ve cycle, diode D_3, D_4 conducts and the capacitor charges to peak value of $-V_s$. D_1 and D_2 are off.

$$V_s = -V_m \sin\omega t$$

→ Beyond $-V_m$ the V_s starts reducing, the diodes D_2, D_3 ~~are~~ stop conducting and the capacitor discharges slowly through R_L

→ The rate of discharge of capacitor is dependent on time constant $R_L C$

→ select C such that the time constant is large enough so that the capacitor will discharge slowly during the interval.

→ The voltage waveform is as shown. The output voltage will be nearly constant with very less ripples.

$$\boxed{\gamma = \frac{1}{4\sqrt{3} f C R_L}}$$

Zener Diode :-

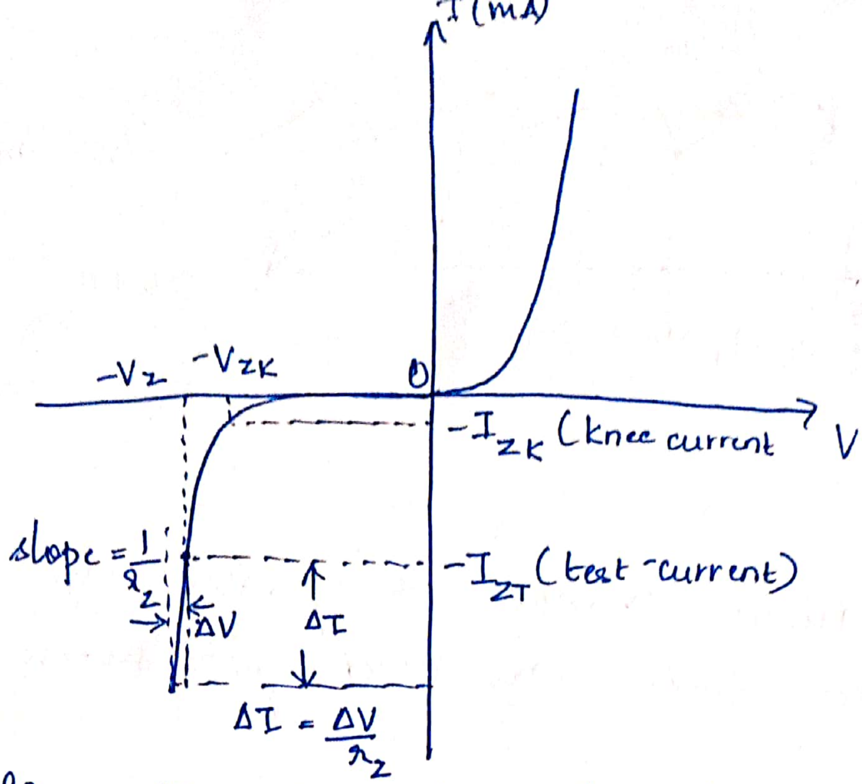
Rectifier diodes cannot be operated in breakdown region. Zener diode are used for reverse breakd-own.

Zener breakdown is due to ionisation of covalent bonds due to high density electric field. This is possible if depletion layer is very thin and electric feild is high. The thin depletion region is obtained by heavily doping both the p and n regions of the diode.

Zener diodes are used in voltage regulation. It helps in maintaining a constant voltage across varying load.

Zener breakdown is achieved much earlier than normal lightly doped diodes.
The breakdown is initiated by direct rupture of covalent bonds because of high electric field.

The VI characteristics of the Zener is as follows.



from fig, the following observations can be made,

→ There is a steep current for almost constant voltage drop, hence zener can be used in the design of voltage regulator.

→ The reverse current I_{ZK} is small for a small reverse voltage.

→ The characteristics is straight for current greater than I_{ZK} in breakdown region.

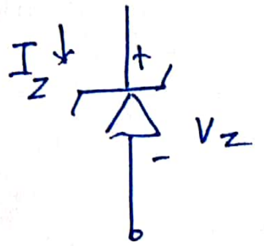
→ Large breakdown current may destroy diode because of excessive heating. Hence to avoid this the current should be limited and proper heat dissipation must be provided.

→ Therefore a test current (I_{ZT}) is defined as the maximum current sustainable by Zener diode for the given V_Z.

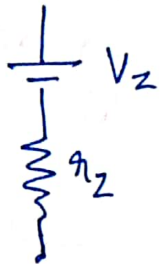
→ If I_{ZT} is reached, the voltage across it will slightly change ie., $\Delta V = r_Z \Delta I$

where $r_Z \rightarrow$ incremental resistance of ZD at operating point Q [dynamic resistance].

Circuit symbol



Equivalent ckt



∴ from fig,

$$\boxed{V_0 = V_Z + I_Z r_Z}$$

Zener as Shunt Regulator

Regulation :- provide output voltage that remains constant and stable irrespective of the variation in V_S and I_L.

The performance of a regulator can be measured using the parameters.

1) Line regulation.
2) Load regulation.

Line regulation:- change in V_o corresponding to a 1V change in V_S.

$$= \frac{\Delta V_o}{\Delta V_S} \quad (mV/V)$$

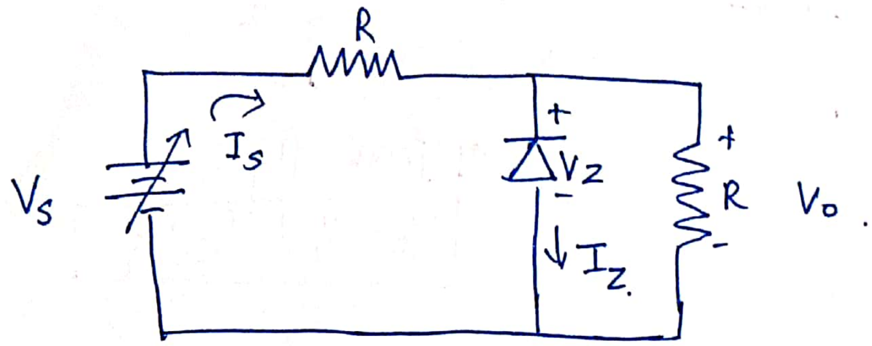
load regulation:- change in V_o corresponding to a 1mA change in i_L

$$= \frac{\Delta V_o}{\Delta V_L}$$

wkt $V_0 = V_Z + r_Z I_Z$

hence it is clear that both line and load regulation depends on r_Z.

A voltage regulator circuit using zener diode is as shown in figure



It is known as shunt regulator because zener diode is connected in parallel to load R_L

When variable supply V_s is fed to the zener diode, there exists large ripple component in the output. The function of zener diode is to keep the output voltage fairly constant over a wide variation of load current. This can be achieved by operating zener in the breakdown region.

→ The resistance R known as the current limiting resistor is used to limit the value of zener current in permissible range.

from figure, the source current divides into two components namely zener current and load current (I_Z and I_L)

ie., $I_{in} = I_Z + I_L$

as long as zener remains in breakdown region. it behaves as a regulator i.e.,

V_Z = constant and

$$I_m = \frac{V_S - V_Z}{R}$$

where R → current limiting resistor.

If R_L is large then I_L is small & I_Z is large

If R_L is small then I_L is large and I_Z is huge

∴ If zener has to be operated as a regulator Then the resistance R_L is chosen such that, I_Z remains within the range

$$I_{ZK} < I_Z < I_{ZT}$$

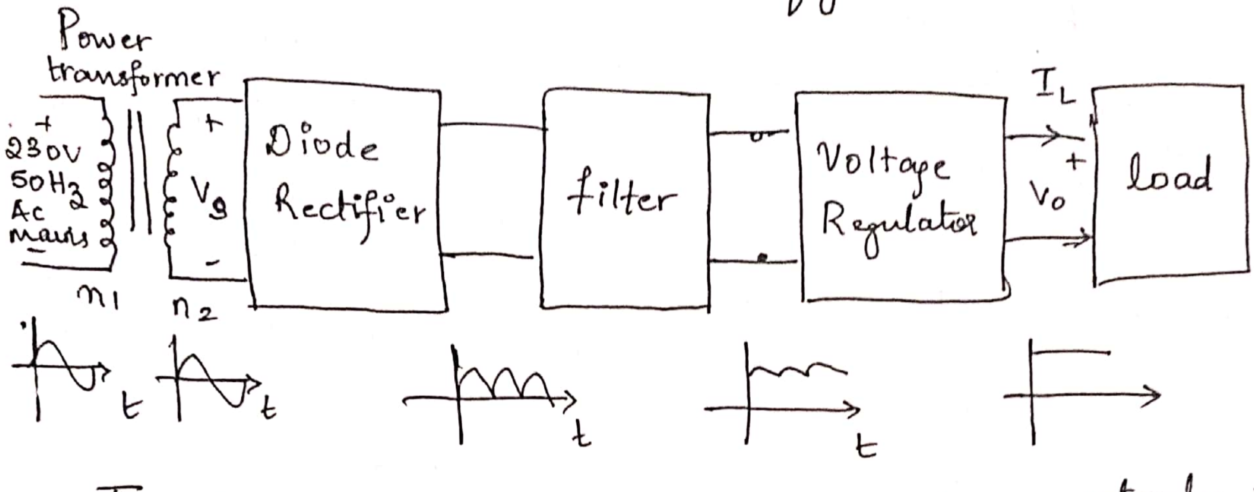
where I_{ZK} → zener knee current

I_Z → zener current

I_{ZT} → zener test current

DC power supply :-

The block diagram of a regulated DC power supply is as shown in the figure below



The DC power supply must generate a steady voltage in spite of variations in ac line voltage and in the current drawn by the load. The above block diagram is used to generate a steady DC voltage as output. It consists of

a) Power transformer :-

consists of 2 separate coils wound around an iron core magnetically coupling the two windings. 230V ac mains is applied to the primary of the transformer. The voltage is stepped down to the desired DC voltage range by adjusting the turns ratio (n_2/n_1). The transformer also provides electrical isolation.

b) Diode rectifier :-

Converts the input ac into pulsating dc output. If half wave rectifier is used, then one half of the i/p signal is rectified.
In case of full wave rectifier both the half of the input signal is rectified.

c) <u>filter</u> :

The rectifier output is known as pulsating dc. It consists of ripples which is around 121% if HWR is used and 48.3% if FWR is used. Hence filter circuits are used to reduce the variations in the rectified o/p. ie., it reduces the ripples. Filter circuits use energy storage capabilities of capacitors and inductors to smooth out the pulsations, thus reduce the amount of ripples.

d) <u>Voltage Regulator</u>

The filter o/p still consists of a small amount of ripples. The filter output is fed into a voltage regulator. The voltage regulator reduces ripples and stabilizes the magnitude of the dc output voltage against variations caused by changes in load current. Zener Shunt regulator is used for voltage regulation.

The output of the zener shunt regulator is a steady dc voltage.