(vi) The existence of +ve & -ve charges on opposite side of the junction creates a potential (voltage) across the junction.

This potential has fixed polarity & it acts as a barrier to the flow of electrons or holes across the junction. Hence this potential is called as barrier potential or junction potential or cut-in-voltage of a p-n junction. [0.7 V for Si & 0.3 V for germanium]

(vii) The physical distance from one side to other side of the depletion layer is called width of the layer.

[ie, in order of 0.5 to 1 micron where 1 micron is 10^{-6} m]

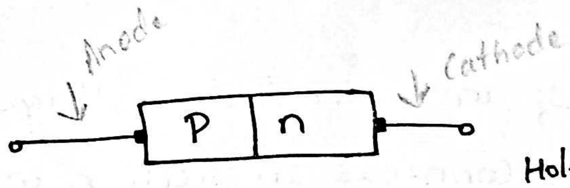


fig (a) Schematic representation

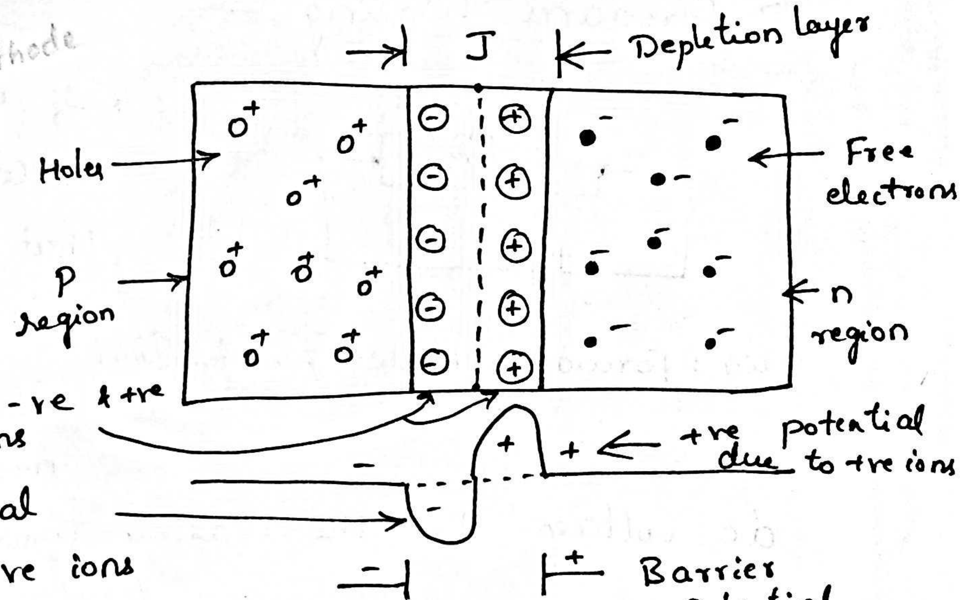


fig (b): Unbiased p-n junction

* Biasing of P-N junction :-

→ Applying external dc voltage to any electronic device is called as biasing.

Depending upon the polarity of the d.c. voltage externally applied to it the biasing is classified as :-

→ Forward biasing

→ Reverse biasing

[For p-n junction under bias condition current flows in one direction]

→ Forward biasing :-

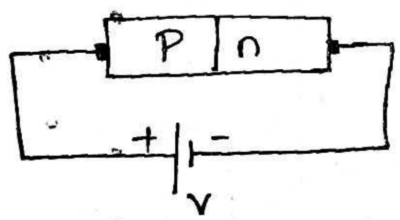


fig : Forward biased p-n junction

* If an external dc voltage is connected in such a way that the p-region terminal is connected to the +ve of the dc voltage & the n-region to the -ve of the dc voltage then the biasing condition is called as forward biasing.

* when the pn junction is forward biased as long as the applied voltage is less than the barrier potential there cannot be any conduction.

* When the applied voltage becomes more than the barrier potential, the -ve terminal of battery pushes the free electrons against barrier potential from n to p region.

Thus holes get repelled by +ve terminal & cross the junction against barrier potential. Thus the applied voltage overcomes the barrier potential.

* As fwd voltage is increased at a particular value the depletion region gets completely collapsed.

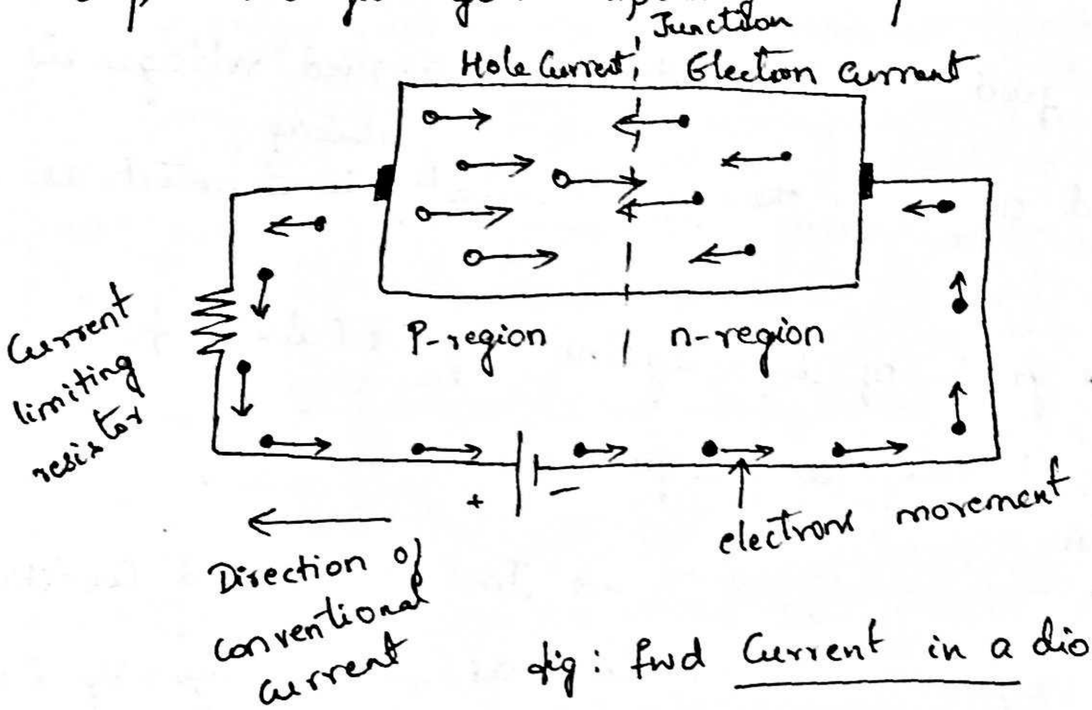


fig: fwd Current in a diode

* A large no of majority carriers can pass through the junction under the influence of applied fwd biased voltage.

The large no of majority carriers constitute a current called fwd current.

* Current in p-region is due to movements of holes & in n-region is due to electrons i.e, the overall fwd current is due to majority charge carriers.

* Forward chara of p-n junction :-

→ The response of p-n junction can be easily understood with help of characteristics called V-I characteristics of p-n junction.

→ Under fwd biased condition, the applied voltage is denoted as V_f & the fwd current flowing is denoted as I_f.

The graph of I_f against V_f is called fwd characteristics of a p-n junction.

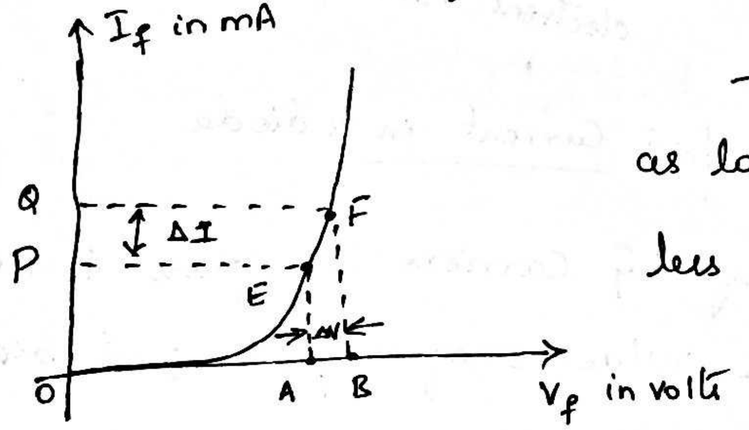


fig: fwd chara

→ In fwd biased condition as long as fwd voltage V_f is less than barrier potential (V_γ) there is no fwd current so I_f is zero.

→ once fwd voltage V_f becomes greater than barrier potential V_γ, the fwd current I_f starts flowing.

→ once the depletion layer collapses at a particular value of V_f, the current I_f increases drastically.

→ The fwd current is the conventional current hence it is treated as +ve & the fwd voltage V_f is also +ve. Hence the fwd chara is plotted in the first quadrant.

→ The resistance offered by the p-n junction is called fwd resistance.

It can be defined into two ways:-

* Static fwd resistance
* Dynamic fwd resistance

→ static fwd resistance :- This is the fwd ~~chara~~ resistance of p-n junction when p-n junction is used in d.c circuit & the applied fwd voltage is d.c.

It is denoted by R_F & defined as " the ratio of the dc voltage applied across the p-n junction to the d.c current flowing through the p-n junction.

$$\text{ie, } R_F = \frac{\text{fwd d.c voltage}}{\text{fwd d.c current}} = \frac{OA}{OP} \text{ @ pt } E$$

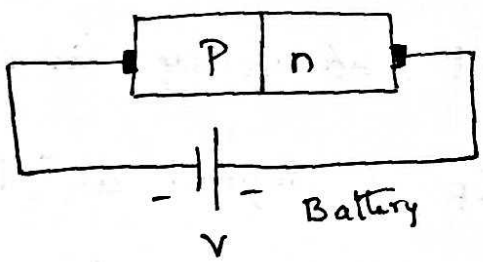
→ Dynamic fwd resistance :- This is the resistance offered by the p-n junction under a.c. conditions is called dynamic resistance denoted as r_f.

It is the reciprocal of the slope of the fwd characteristics. ie, change in applied voltage from pt A to B, denoted as ΔV & corresponding change in fwd current from point P to Q denoted as ΔI.

Thus the slope of the chara is $\frac{\Delta I}{\Delta V}$, the reciprocal slope is dynamic resistance.

ie, $r_f = \frac{\Delta V}{\Delta I} = \frac{1}{\text{slope of fwd chara}}$

* Reverse biasing of p-n junction :-



→ Reverse biasing means connecting P-region to -ve & n-region +ve of the battery.

→ when the p-n junction is connected in such manner then the biasing is called as reverse biasing of a pn junction.

→ when the junction is reverse biased the -ve Terminal attracts the holes in the p-region away from the junction

& +ve terminal attracts the free electrons in the n-region away from the junction.

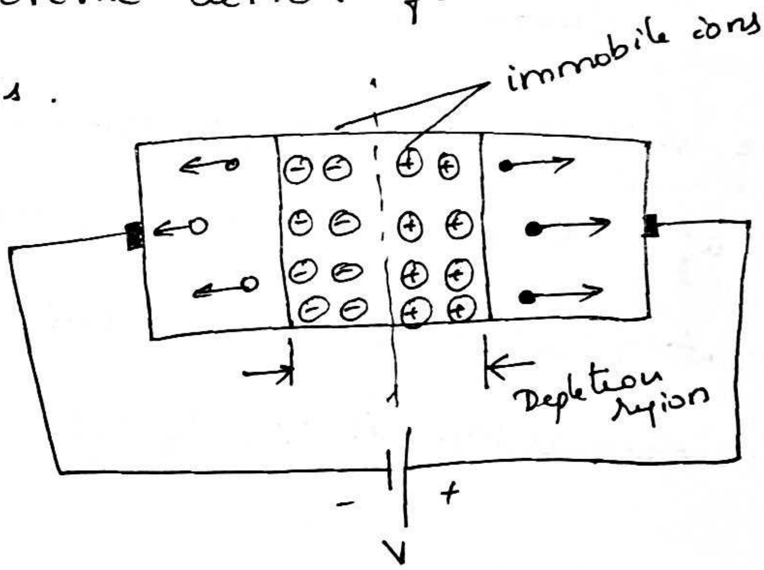
* As a result there is no charge carrier to cross the junct[ion]

∴ depletion region widens.

This creates more +ve charge in the n-region & more -ve charge in the p-region. This is because the applied voltage helps the barrier potential.

* By this electron in p-region are very less & the holes in n-region are also very less. Hence the reverse current is very small.

* The reverse current flows due to minority charge carriers.



* Reverse chara of p-n junction :-

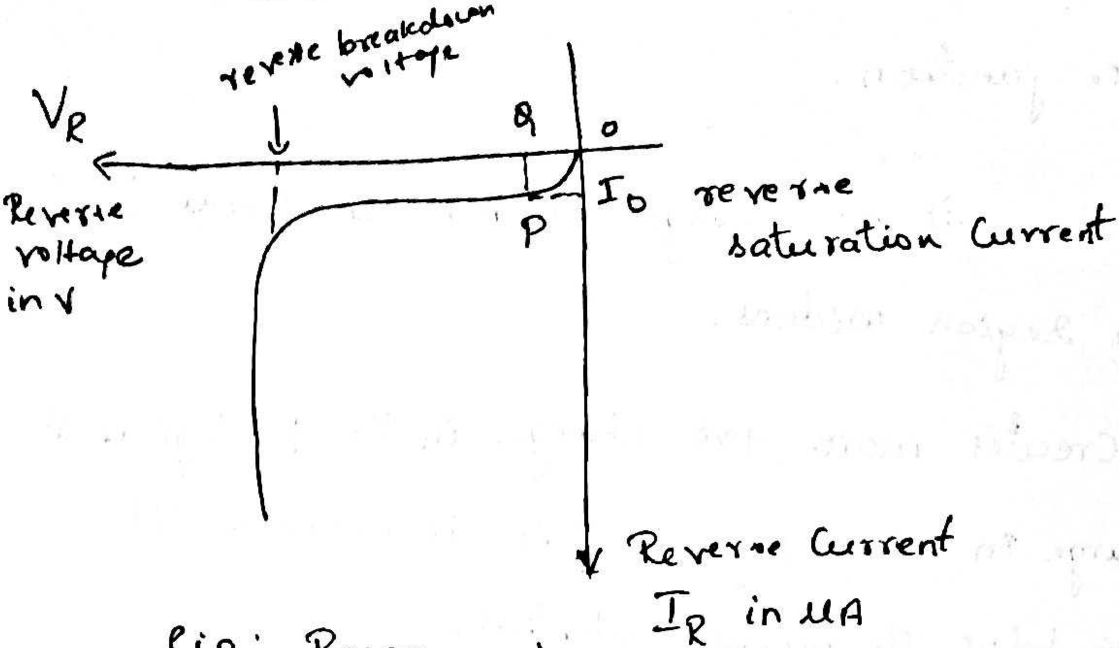


fig: Reverse chara

→ The graph of reverse current against the applied reverse voltage is called reverse chara of p-n junction.

→ Reverse voltage is taken as -ve. Hence it is plotted in 3rd Quadrant.

→ As reverse voltage increases, reverse current ↑ initially but after a certain voltage, the current remains constant equal to reverse saturation current I_0 though reverse voltage is ↑. It offers large resistance.

→ static resistance :- $R_r = \frac{OQ}{I_0} = \frac{\text{applied reverse voltage}}{\text{reverse sat current}}$

→ Dynamic resistance :- $r_r = \frac{\Delta V_R}{\Delta I_R} = \frac{\text{change in reverse voltage}}{\text{change in reverse current}}$

* Diode Approximations :-

Ideal diode characteristics :-

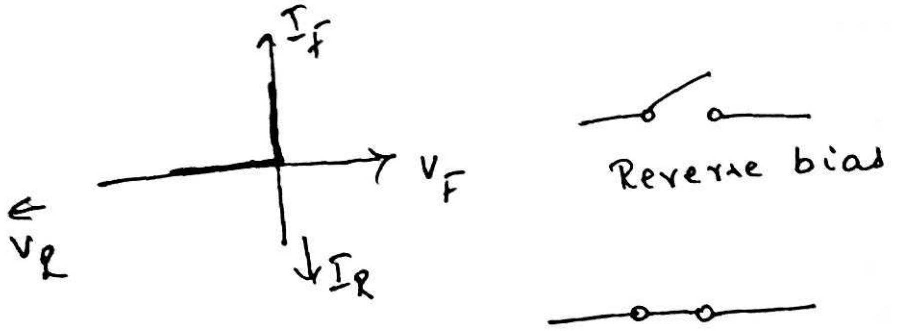
→ An ideal diode exhibits the following features:-

① The cut-in voltage is zero. Since for an ideal diode, there is no barrier potential, any small fwd bias vtg causes conduction through the diode.

② The fwd resistance is zero

③ The reverse resistance is infinity (∞)

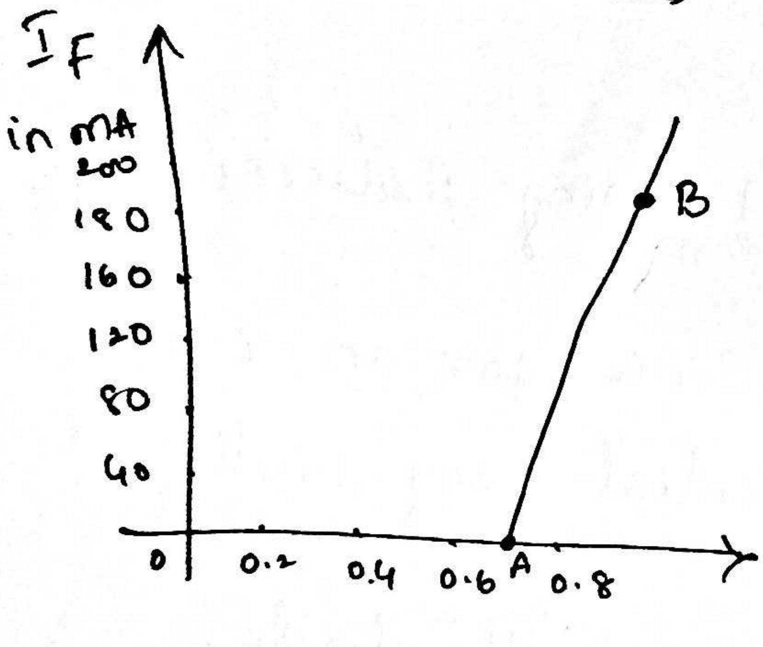
④ The diode readily conducts when fwd biased & it blocks conduction when reverse biased. The reverse saturation current is zero.



(a) Ideal chara

Any ordinary switch has zero resistance when closed & infinite resistance when open.

* Piecewise linear chara :- (straight-line approximation)



→ when a fwd chara of a diode is not available, we may represent the device as a piecewise linear model.

→ The diff distinctly defined Parts of the chara are replaced by straight-line segments joined together.

- there is some Deviation offered → Very high in Rev... Low in fwd ...

→ Mark V_F on horizontal axis & from V_F straight line is drawn with a slope equal to inverse of diode dynamic resistance

[slope

[$1/R_{DD}$]

R_{dc} V_f

Rectifiers :-

A rectifier is a device which converts ac voltage to pulsating dc voltage using one or more p-n junction diodes.

→ It Conducts when fwd biased while practically it doesnot conduct when reverse biased.

Using one or more diodes following rectifiers ckt can be designed into :-

1. Halfwave rectifier
2. Fullwave rectifier
3. Bridge rectifier

1. Halfwave rectifier :-

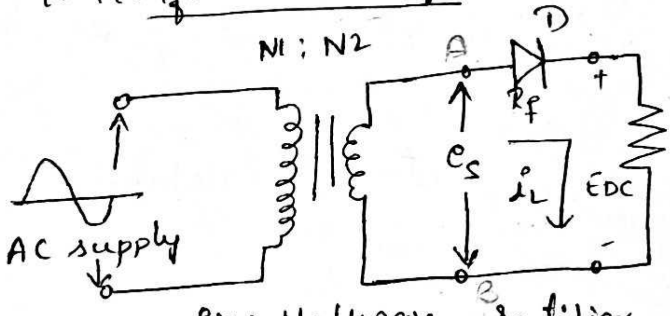


fig: Halfwave rectifier

* In half-wave rectifier, rectifying element conducts only during +ve half cycle of an i/p a.c. supply. The -ve half cycles of a.c. supply are eliminated from the output.

* The rectifier consists of resistive load, rectifying element ie, p-n junction diode & the a.c source connected in series as shown in the above figure.

* usually the rectifier ckts are operated from ac mains supply. To obtain desired dc voltage across the load, the ac vtg is applied to rectifier ckts using suitable step-up or step-down transformer with necessary turns ratio.

* The i/p voltage to the half-wave rectifier is a sinusoidal a.c voltage having a freq, 50Hz. which is the supply freq

* The transformer decides the peak value of the secondary voltage.

If the N_1 are primary number of turns & N_2 are secondary number of turns & E_{pm} is the peak value of the primary voltage then,

$$\frac{N_2}{N_1} = \frac{E_{sm}}{E_{pm}}$$

where E_{sm} is the peak value of the secondary ac voltage.

* As the nature of E_{sm} is sinusoidal the instantaneous value will be,

$$e_s = E_{sm} \sin \omega t$$

$\omega = 2\pi f$

f = supply frequency

$V_i = V_m \sin \omega t$

$V_{max} = V_{rms} \times 1.414$

or $V_{rms} = V_{max} \times 0.707$

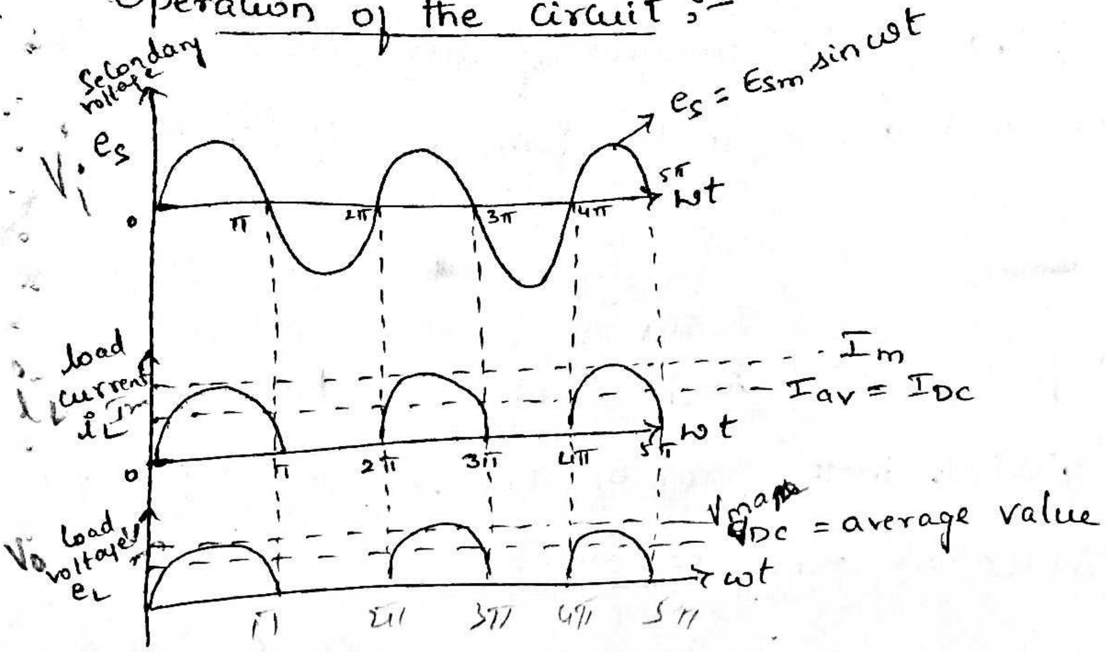
$V_{DC} = 0.45 V_{rms}$

$= 0.45 \times 240$

$= 108V$

or $V_{DC} = 0.318 V_{max} = 10..V$

Operation of the circuit :-



$V_{DC} = \frac{V_{max}}{\pi}$

fig : load current & load voltage w/f's

* During the +ve half cycle of secondary a.c voltage, terminal A becomes +ve w.r.t terminal B.

* The diode is fwd biased & the current flows in the ckt in the clockwise direction.

* The current will flow for almost full +ve half cycle. This current is also flowing through load resistance R_L hence denoted as i_L, the load current.

* During -ve half cycle when terminal A is -ve w.r.t B, diode becomes reverse biased. Hence no current flows in the ckt.

* Thus the ckt current, which is also the load current is in the form of half sinusoidal pulses.

* The load voltage, being the product of load current & load resistance will also be in the form of half sinusoidal pulses.

* The d.c. o/p w/f is expected to be straight line but the half wave rectifier gives o/p in the form of +ve sinusoidal pulses. Hence the o/p is called pulsating dc.

* Hence it is necessary to calculate the average value of load current & average value of o/p voltage.

Average DC load current $[I_{DC}]$:-

* The avg or dc value of alternating current is obtained by integration.

* For finding out the avg value of an alternating w/f we have to determine the area under the curve over one complete cycle ie, from 0 to 2π & then dividing it by the base ie, 2π

* Mathematically, current w/f can be described as,

$$i_L = i_m \sin \omega t \quad \text{for } 0 \leq \omega t \leq \pi$$

$$i_L = 0 \quad \text{for } \pi \leq \omega t \leq 2\pi$$

where i_m = peak value of load current

$$I_{DC} = \frac{1}{2\pi}\int_0^{2\pi} i_L \, d(\omega t) = \frac{\text{area under the o/p over full cycle}}{\text{period of the o/p}}$$

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

As no current flows during -ve half cycle of ac i/p voltage ie, between $\omega t = \pi$ to $\omega t = 2\pi$. [As no curr -ve i/p π to 2π

we change the limits of integration

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

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

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

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

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

$$\therefore I_{DC} = \frac{I_m}{\pi} = \text{average value}$$

Applying KVL we can write,

$$\boxed{I_m = \frac{E_{sm}}{R_f + R_L + R_s}}$$

where R_s = resistance of secondary winding of transformer.

* If R_s is not given it should be neglected while calculating I_m.

Average DC load voltage (E_{DC}) :-

It is the product of average DC load current & the load resistance R_L.

ie, $E_{DC} = I_{DC} R_L$

Substituting value of I_{DC},

$$E_{DC} = \frac{I_m}{\pi} R_L = \frac{E_{sm}}{\pi(R_f + R_L + R_s)} \cdot R_L$$

The winding resistance R_s & fwd diode resistance R_f are praticalły very small compared to R_L.

$$\therefore \quad E_{DC} = \frac{E_{sm}}{\pi\left[\frac{R_f + R_s}{R_L} + 1\right]}$$

$\frac{E_{sm} R_L}{\pi\left[\frac{R_f + R_s + R_L}{R_L}\right]}$

R_f & R_s

but as R_f & R_s are small compared to. R_L, $\frac{R_f + R_s}{R_L}$ is negligibly small compared to 1. So neglecting it we get,

$$\boxed{E_{DC} \simeq \frac{E_{sm}}{\pi}}$$ V_m

E_{DC} or $V_{DC} = 0.318\, V_m$

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

* The R.M.S means squaring, finding mean & then finding square root.

Hence R.M.S value of load current can be obtained as,

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

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

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

$$= I_m \sqrt{\frac{1}{2\pi}\left\{\frac{\omega t}{2} - \frac{\sin 2\omega t}{4}\right\}_0^{\pi}}$$

$$= I_m \sqrt{\frac{1}{2\pi}\left(\frac{\pi}{2}\right)} \quad \text{as } \sin(2\pi) = \sin(0) = 0$$

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

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

D.C power output (P_{DC}):-

The d.c power o/p can be obtained as,

$$P_{DC} = E_{DC} I_{DC} = I_{DC} R_L \cdot I_{DC}$$

$$= I_{DC}^2 \cdot R_L$$

$$\text{D.C power o/p} = I_{DC}^2 \cdot R_L$$

$$= \left[\frac{I_m}{\pi}\right]^2 R_L$$

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

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

where $I_m = \dfrac{E_{sm}}{R_f + R_L + R_s}$

$$\boxed{\therefore P_{DC} = \frac{E_{sm}^2 \cdot R_L}{\pi^2 [R_f + R_L + R_s]^2}}$$

A.C power input (P_{AC}):-

$$P_{AC} = I_{RMS}^2 [R_L + R_f + R_s]$$

but $I_{RMS} = \dfrac{I_m}{2}$ for half wave

$$\boxed{\therefore P_{AC} = \frac{I_m^2}{4} [R_L + R_f + R_s]}$$

Rectifier Efficiency (η):-

The rectifier efficiency is defined as the ratio of o/p dc to i/p a.c power.

$$\eta = \frac{\text{D.C o/p Power}}{\text{A.C i/p power}} = \frac{P_{DC}}{P_{AC}}$$

$$\eta = \frac{\frac{I_m^2}{\pi^2} . R_L}{\frac{I_m^2}{4}\left[R_f + R_L + R_S\right]}$$

$$= \frac{(4/\pi^2) . R_L}{R_f + R_L + R_S}$$

$$\eta = \frac{0.406}{1 + \left[\frac{R_f + R_S}{R_L}\right]}$$

If $(R_f + R_S) << R_L$, we get the max theoretical efficiency of half wave rectifier as,

$$\% \eta_{max} = 0.406 \times 100$$

$$= 40.6 \%$$

Thus in half wave rectifier, max 40.6% a.c. power gets converted to d.c power in the load. The remaining power exits in the form of ripples.

Ripple factor (γ) :- (γ) :

Ideally there should not any ripples in the rectifier o/p. The measure of such ripples present in the o/p is with the help of a factor called ripple factor denoted by γ.

It is defined as the ratio of RMS value of the ac component to the average or d.c component.

$$\therefore \text{Ripple factor } \gamma = \frac{\text{RMS value of ac Component}}{\text{Average or DC Component}}$$

Now the o/p current is composed of ac component as well as d.c component.

Let I_{ac} = rms value of component present in o/p

I_{DC} = d.c component present in o/p

$I_{rms}^2 = I_{ac}^2 + I_{dc}^2$

I_{RMS} = RMS Value of total o/p current

$$\therefore I_{RMS} = \sqrt{I_{ac}^2 + I_{dc}^2}$$

$$I_{ac} = \sqrt{I_{RMS}^2 - I_{DC}^2}$$

$$\therefore \text{Ripple factor} = \frac{I_{ac}}{I_{DC}}$$

$$\gamma = \frac{\sqrt{I_{RMS}^2 - I_{DC}^2}}{I_{DC}}$$

$$\therefore \gamma = \sqrt{\left[\frac{I_{RMS}}{I_{DC}}\right]^2 - 1}$$

This is the general expression for ripple factor & can be used for any rectifier ckt.

Now for half-wave ckt,

$$I_{RMS} = \frac{I_m}{2} \quad \text{while} \quad I_{DC} = \frac{I_m}{\pi}$$

$$\therefore \gamma = \sqrt{\left[\frac{(I_m/2)}{(I_m/\pi)}\right]^2 - 1}$$

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

$$= \sqrt{1.4674}$$

$$\gamma = 1.211$$

This indicates that the ripple factor contents in the o/p are 1.211 times the d.c component.

* The ripple factor for half wave is very high which indicates that the half wave ckt is a poor converter of a.c to d.c.
* The ripple factors is minimized using filter ckts along with rectifiers.

Peak Inverse voltage (PIV) :- It is defined as "the max voltage that appears across the diode during non-conducting condition or under reverse bias". ie, PIV = V_m

PIV of diode $= E_{sm}$

= max value of secondary vtg ∴ PIV = πE

$$\boxed{PIV = \pi E_{DC}}$$

$\because E_{DC} = \frac{E_{sm}}{\pi}$

$PIV = \pi E_{DC}$ / for all $I_{DC} = 0$

[PIV is the peak voltage across the diode in the reverse direction ie, when the diode is reverse biased]

Advantages :-

1. The ckt is simpler & requires only one diode.

2. PIV is only V_m or E_{sm}.

Disadvantages :-

1. Ripple factor $\gamma = 1.21$ or 121%

2. Efficiency is very low about $\eta = 40.6\%$

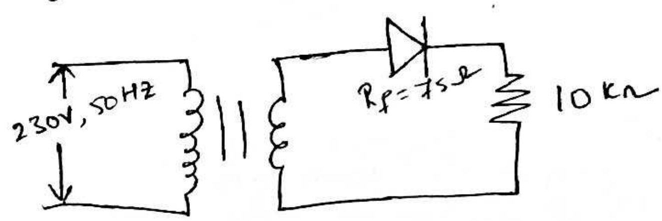
3. The ckt has low transformer ultilization factor, showing that the transformer is not fully utilized.

4. The dc current is flowing through the secondary winding of the transformer which may cause dc saturation of the core of the transformer. To minimize this, transformer size have to be ↑ accordingly. This ↑ the cost.

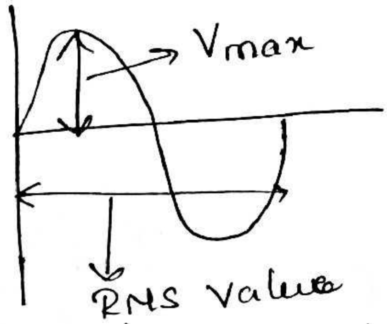
Problems :-

① A ½ wave rectifier ckt is supplied from a 230V, 50Hz supply with a step-down ratio of 3:1 to a resistive load of 10KΩ. The diode fwd resistance is 75Ω ~~white~~ while transfoomer secondary resistance is 10Ω. Calculate max, average RMS values of current, DC o/p voltage, efficiency of rectification & ripple factor.

Soln :-



$N_1 : N_2$ is 3:1



RMS Values
↓
It is square root of the mean of the squares of the values for the one periode of the sine wave

The given values are,

$$R_f = 75\Omega, \; R_L = 10K\Omega, \; R_s = 10\Omega$$

The given supply voltages are always r.m.s values.

$$E_p(RMS) = 230V, \quad \frac{N_1}{N_2} = \frac{3}{1} \quad \text{ie,} \quad \frac{N_2}{N_1} = \frac{1}{3}$$

$$\frac{N_2}{N_1} = \frac{E_s(RMS)}{E_p(RMS)}$$

$$\frac{1}{3} = \frac{E_s(RMS)}{230}$$

$$E_s(RMS) = \underline{76.667V}$$

$\therefore E_{sm} = \sqrt{2}\, \underbrace{E_s(RMS)}$ std for,

max value of secondary v

$$= \sqrt{2} \times 76.667$$

$$= \underline{108.423\,V}$$

$$\therefore I_{sm} = \frac{E_{sm}}{R_s + R_f + R_L}$$

$$= \frac{108.423}{10 + 75 + 10 \times 10^{3}}$$

$$= \underline{10.75\,mA}$$

$$\therefore I_{av} = I_{DC} = \frac{I_m}{\pi} = \frac{10.75m}{\pi}$$

$$= \underline{3.422\,mA}$$

$I_{RMS} = \frac{I_m}{2}$ for half wave

$$= \frac{10.75}{2} = \underline{5.375\,mA}$$

E_{DC} = d.c o/p voltage = $I_{DC} R_L$.

$$= 3.422 \times 10^{-3} \times 10 \times 10^{3}$$

$$= \underline{34.22\,V}$$

P_{DC} = d.c o/p power = $E_{DC} I_{DC}$

$$= 34.22 \times 3.422 \times 10^{-3}$$

$$= \underline{0.1171\,W}$$

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

$$= \frac{(10.75 \times 10^{-3})^2}{\pi^2} \times 10 \times 10^3$$

$$= \underline{0.1171 W}$$

P_{AC} = ac i/p power

$$= I_{RMS}^2 [R_s + R_f + R_L]$$

$$= (5.375 \times 10^{-3})^2 [10 + 75 + 10 \times 10^3]$$

$$= \underline{0.2913 W}$$

$$\% \eta = \frac{P_{DC}}{P_{AC}} \times 100 = \frac{0.1171}{0.2913} \times 100$$

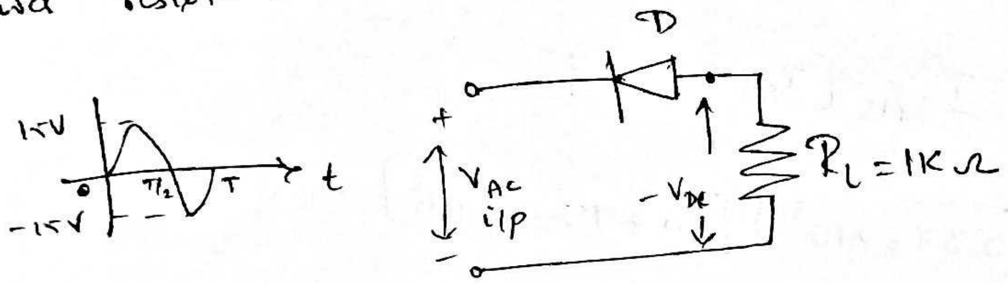
$$= \underline{40.19\%}$$

The ripple factor is constant for half wave rectifier is 1.21

$$\therefore\ \underline{\gamma = 1.21}$$

(5) (a) Assuming ideal diode, calculate the d.c. o/p vtg for the n/w shown in the fig.

(b) Repeat part (a) if the ideal diode is replaced by a Si diode having a cut-in-voltage of 0.7V. Neglect diode fwd resistance.



soln:/ In the ckt, the diode will be fwd biased during -ve half cycle of a.c i/p vtg & dc o/p vtg will be -ve w.r.t. common gnd terminal as shown.

(a) For an ideal diode cut-in-vtg $V_\gamma = 0$, $R_f = 0$

$$\therefore \text{DC o/p vtg} = \frac{-\text{Max value of ac. i/p vtg}}{\pi}$$

$$= \frac{-15}{\pi} = \underline{\underline{-4.77V}}$$

-ve sign indicates that vtg is -ve w.r.t gnd.

(b) for a Si diode, $V_\gamma = 0.7V$, R_f is assumed to be zero

$$\therefore \text{DC o/p vtg} = \frac{-[\text{Max. A.C. Vtg} - V_\gamma]}{\pi}$$

$$= \frac{-(15-0.7)}{\pi} = \underline{\underline{-4.55V}}$$

(2) A HWR with $R_L = 1K\Omega$ is given an i/p of 10V Peak from step down transformer. Calculate DC voltage & load Current for ideal & Si diode.

soln :- $R_L = 1K\Omega$, $V_m = 10V$ peak

Case (i) :- Ideal diode

$V_\gamma = 0V$, $R_f = 0\,\Omega$

$$\therefore E_{DC} = \frac{V_m}{\pi} = \frac{10}{\pi_{3.14}} = \underline{\underline{3.18V}}$$

$$I_{DC} = \frac{E_{DC}}{R_L} = \frac{3.18}{1\times10^3} = \underline{\underline{3.18\,mA}}$$

Case (ii) :- Si diode

$V_\gamma = 0.7$, $R_f = 0$

$$E_{DC} = \frac{V_m - V_\gamma}{\pi} = \frac{10-0.7}{\pi} = \underline{\underline{2.96V}}$$

$$I_{DC} = \frac{E_{DC}}{R_L} = \frac{2.96}{1k} = \underline{\underline{2.96mA}}$$

(3) In a HWR, the i/p is 300 sin 314t, find its avg o/p vtg.

soln :- $E = E_{sm} \sin \omega t$ — general eqn.

$E_{sm} = 300$

$$\therefore \text{Avg o/p vtg is, } E_{DC} = \frac{E_{sm}}{\pi} = \frac{300}{\pi_{3.14}} = \underline{\underline{95.49\,V}}$$

(21)

(4) A voltage $V = 300 \cos 100t$ is applied to a HWR, with $R_L = 5K\Omega$. The rectifier may be represent by ideal diode in series with a resistance of $1K\Omega$. Calculate I_m, DC power, AC power, η, γ.

soln:

$$E = E_m \sin \omega t$$

$$E_{sm} = 300V$$

$$R_L = 5K\Omega, \quad R = 1K\Omega, \quad R_s = R_f = 0\Omega$$

i) $$I_m = \frac{E_{sm}}{R+R_L+R_s+R_f} = \frac{300}{6\times K} = \underline{\underline{50mA}}$$

6×10^3

(ii) $$I_{DC} = \frac{I_m}{\pi} = \frac{50\times10^{-3}}{\pi} = \underline{\underline{15.9154mA}}$$

iii) $$P_{DC} = I_{DC}^2 R_L = 15.9154m \times 5\times10^3$$

$$= \underline{\underline{1.2665\ W}}$$

(iii) $$P_{AC} = I_{RMS}^2 (R+R_L+R_s+R_f)$$

$$= \left(\frac{I_m}{2}\right)^2 (R+R_L+R_s+R_f)$$

$$= \left(\frac{50\times10^{-3}}{2}\right) 6\times10^3$$

$$= \underline{\underline{3.75W}}$$

(iv) $\eta = \frac{P_{DC}}{P_{AC}} \times 100$

$= \frac{1.2665}{3.75} \times 100$

$= \underline{33.77\%}$

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

$= \sqrt{\left(\frac{25 \times 10^{3}}{15.9154 \times 10^{3}}\right)^2 - 1}$

$= \underline{1.211}$

Full-wave rectifier (FWR):-

* The FWR conducts during both +ve & -ve half cycles of i/p a.c supply.

* In order to rectify both the half cycles of a.c i/p, two diodes are used in this ckt.

* The diodes feed a common load R_L with the help of a center-tap transformer.

The a.c voltage is applied through a suitable power transformer with proper turns ratio.

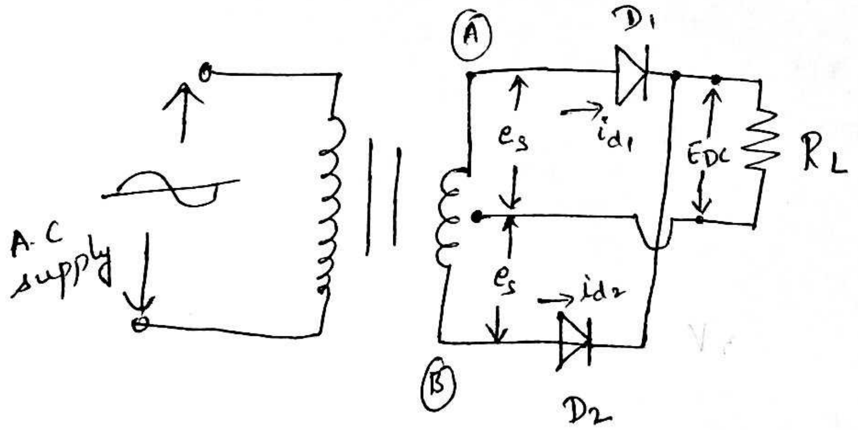


fig: Full-wave rectifier

* For the proper operation of the ckt, a center-tap on the secondary winding of the transformer is essential.

* Operation of the CKt:-

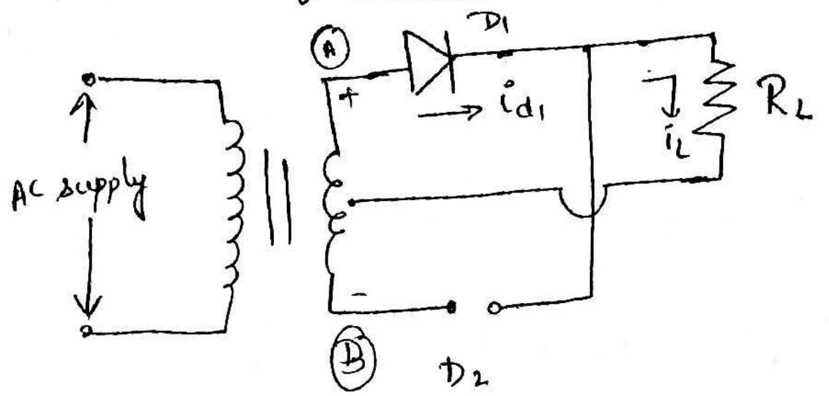


fig: Current flow during +ve half cycle

* Consider the +ve half cycle of ac i/p voltage in which terminal (A) is +ve & terminal (B) is -ve.

* The diode D_1 will be fwd biased & hence will conduct, while diode D_2 will be reverse biased & will act as open CKt & will not conduct as shown in the above fig.

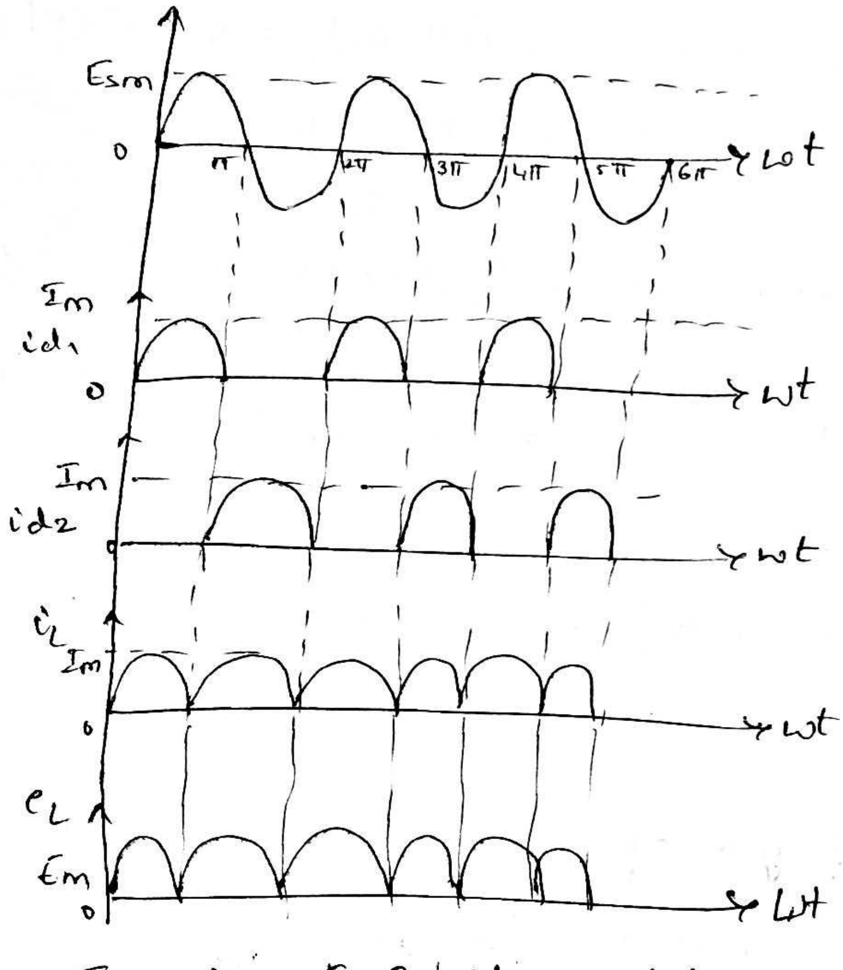
* The diode D_1 supplies the load current ie, $i_L = i_{d_1}$ through upper half on secondary winding while the lower half of secondary winding of the transformer carries no current since diode D_2 is reverse biased & acts as open CKt.

* In the next half cycle of ac voltage, terminal (A) becomes -ve & B +ve. The diode D_2 conducts being fwd biased, while D_1 does not being reverse biased.

* The diode D_2 supplies the load current ie, $i_L = i_{d2}$.
Now the lower half of the secondary winding carries the current but the upper half does not.

* ∴ The load current flows in both half cycles of ac voltage & in the same direction through the load resistance.

Hence we get rectified O/P across the load. The load current is sum of individual diode currents flowing in corresponding half cycles.



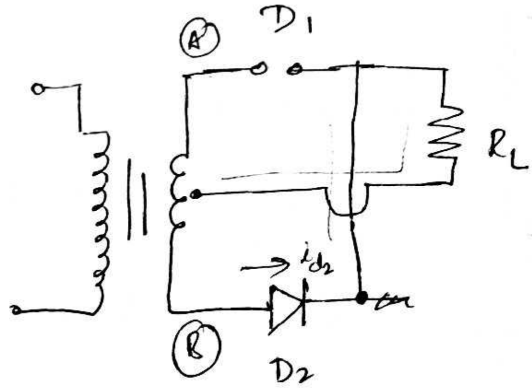


fig: Current flow during -ve half cycle

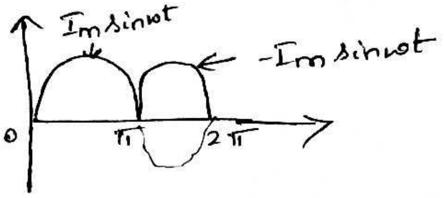
* Thus the FWR ckt essentially consists of two half wave rectifier ckt working independently of each other but feeding a common load. The O/P load current is still pulsating dc & not
(ii) Pure d.c

* Maximum load current :-

$$I_m = \frac{E_{sm}}{R_s + R_f + R_L}$$

where I_m = maximum value of load current i_L.

* Average DC load current I_{DC} :-



→ Consider one cycle of load current i_L from 0 to 2π to obtain the avg value which is d.c value of load current

ie, $i_L = I_m \sin \omega t \quad 0 \le \omega t \le \pi$

But for π to 2π, the current i_L is again +ve while sin ωt term is -ve during π to 2π.

Hence in the region π to 2π the +ve i_L can be represented as -ve of $I_m \sin \omega t$.

ie, $i_L = -I_m \sin \omega t \quad \pi \le \omega t \le 2\pi$

$$\therefore I_{av} = I_{DC} = \frac{1}{2\pi} \int_0^{2\pi} i_L \, d(\omega t)$$

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

$$= \frac{I_m}{2\pi} \left[\int_0^{\pi} \sin \omega t \, . d(\omega t) - \int_{\pi}^{2\pi} \sin \omega t \, . d(\omega t) \right]$$

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

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

$[\cos\pi = -1]$

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

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

* Full-wave rectifier is the combination of two ½ wave rectifiers ckt acting alternately in two half cycles of i/p.

* Average DC load voltage (E_{DC}) :-

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

Substituting value of I_m,

$$E_{DC} = \frac{2E_{sm} \cdot R_L}{\pi\left[R_f + R_s + R_L\right]} = \frac{2E_{sm}}{\pi\left[1 + \frac{R_f + R_s}{R_L}\right]}$$

But as R_f & R_s << R_L hence $\frac{R_f + R_s}{\pi} << 1$

$$\therefore E_{DC} = \frac{2E_{sm}}{\pi}$$

* **RMS load current I_{RMS} :-**

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

$$= \frac{2}{2\pi}\int_0^{\pi} \left[I_m \sin \omega t\right]^2 d(\omega t)$$

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

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

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

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

$$= I_m \sqrt{\frac{1}{2\pi}(\pi)}$$ as $\sin(2\pi) = \sin(0) = 0$

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

* DC power o/p (P_{DC}) :-

$$\text{DC power o/p} = E_{DC} I_{DC} = I^2_{DC} \cdot R_L$$

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

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

$$\text{(or)} \quad P_{DC} = \frac{4}{\pi^2} \frac{E_{sm}^2}{(R_s + R_f + R_L)^2} \cdot R_L$$

* AC power input (P_{AC}) :-

$$P_{AC} = I^2_{RMS} (R_f + R_s + R_L)$$

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

$$= \frac{I_m^2 (R_f + R_s + R_L)}{2}$$

$$= \frac{E_{sm}^2}{(R_f + R_s + R_L)^2} \times \frac{1}{2} (R_f + R_s + R_L)$$

$$\therefore P_{AC} = \frac{E_{sm}^2}{2(R_f + R_s + R_L)}$$

* Rectifier Efficiency (η) :-

$$\eta = \frac{P_{DC} \ o/p}{P_{AC} \ i/p}$$

$$= \frac{\frac{4}{\pi^2} I_m^2 R_L}{\frac{I_m^2 (R_f + R_L + R_s)}{2}}$$

$$\eta = \frac{8 R_L}{\pi^2 (R_f + R_s + R_L)}$$

But if $R_f + R_s << R_L$, neglecting it from denominator

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

$$\therefore \% \eta_{max} = \frac{8}{\pi^2} \times 100$$

$$= 81.2 \%$$

* **Ripple factor (γ) :-**

$$\text{ripple factor} = \sqrt{\left(\frac{I_{RMS}}{I_{DC}}\right)^2 - 1}$$

$$I_{RMS} = \frac{I_m}{\sqrt{2}} \quad \& \quad I_{DC} = \frac{2 I_m}{\pi}$$

$$\therefore \gamma = \sqrt{\left[\frac{I_m/\sqrt{2}}{2 I_m/\pi}\right]^2 - 1}$$

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

$$\therefore \gamma = 0.48$$

* **Peak inverse voltage (PIV) :-**

$$\text{PIV of diode} = 2 E_{sm}$$

$$= \pi E_{DC} \quad \left[\because E_{DC} = \frac{2 E_m}{\pi}\right]$$

* If the diode drop is considered to be 0.7V then the PIV of reverse biased diode is,

$$PIV = 2 E_{sm} - 0.7$$

This is because only one diode conducts at a time.

* Advantages :-

→ Requires only two diodes
→ Efficiency is high $\eta = 81.2\%$
→ lower ripple $\gamma = 48.2\%$

* Disadvantages :-

→ lower DC o/p since each half cycle utilize half the transformer vtg.
→ Increased cost due to center tapped transformer.
→ ~~High PIV (2Vm) or (2Esm) is required~~ . PIV is twice that of HWR ∴ diodes are required of higher rating

Problems:-

① A FWR ckt is fed from a transformer having a center tapped secondary winding. The rms voltage from either end of secondary to center tap is 30V. If the diode fwd resistance is 2Ω & that of the half secondary is 8Ω for a load of 1KΩ calculate,

a> power delivered to load

b> A.C. power i/p

c> Rectifier efficiency

d> Ripple factor

Soln:- $E_{S(RMS)} = 30V$

$\therefore E_{sm} = \sqrt{2} E_{S(RMS)}$

$= \sqrt{2} \times 30 = \underline{42.426 V}$

$I_m = \frac{E_{sm}}{R_f + R_L + R_s}$

$= \frac{42.426}{2 + 1000 + 8}$

$= \underline{42 mA}$

$\therefore I_{DC} = \frac{2 I_m}{\pi} = \underline{26.74 mA}$

a) $P_{DC} = I_{DC}^2 R_L$

$= \cancel{26.74mA} \; 26.74m \times 1K$

$= \underline{0.715W}$

$I_{RMS} = \frac{I_m}{\sqrt{2}} = \frac{42}{\sqrt{2}} = \underline{29.698 mA}$

b) $P_{AC} = I_{RMS}^2 (R_f + R_s + R_L)$

$= \underline{0.8908 W}$

(54)

c) $\% \eta = \frac{P_{DC}}{P_{AC}} \times 100$

$= \frac{0.715}{0.8908} \times 100$

$\% \eta = \underline{80.26\%}$

d) $\gamma = \sqrt{\left[\frac{I_{RMS}}{I_{DC}}\right]^2 - 1}$

$= \sqrt{\left(\frac{29.698}{26.74}\right)^2 - 1}$

$\gamma = \underline{0.48}$

(2) A FWR used a diode with fwd resistance of $1\,\Omega$. The transformer secondary is centre tapped with o/p 10-0-10 Vrms & has resistance of $5\,\Omega$ for each half section. Calculate (i) No-load dc voltage
(ii) DC o/p vtg at 100mA

soln:- $E_{sm} = \sqrt{2}\, E_{s(rms)} = \sqrt{2} \times 10 = \underline{14.1421\text{ V}}$

(i) $E_{DC}(NL) = \frac{2E_{sm}}{\pi} = \frac{2 \times 14.1421}{\pi} = \underline{9.0031\text{V}}$

(ii) $I_{DC} = \frac{2I_m}{\pi}$

$100\text{ m} = \frac{2I_m}{\pi}$

$I_m = \underline{157.079\text{ mA}}$

But $I_m = \dfrac{E_{sm}}{R_s + R_f + R_L}$

$$157.079 \times 10^{-3} = \frac{14.1421}{5 + 1 + R_L}$$

$$\underline{R_L = 84.0317\,\Omega}$$

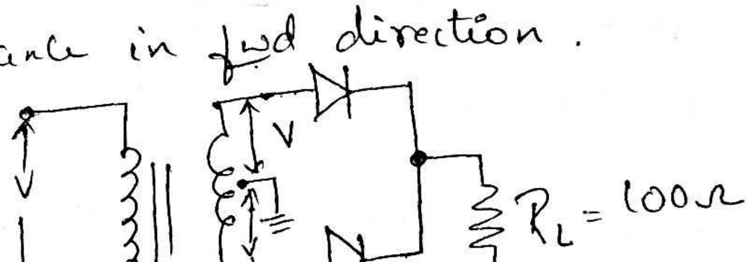
$\therefore\ E_{DC}(\text{load}) = I_{DC} \cdot R_L$

$$= 100\text{m} \times 84.0317$$

$$= \underline{8.4031\,V}$$

(3) For the FWR ckt shown below, V is a sin vtg. if the max allowable avg d.c current in each diode is 1A, Calculate the max allowable peak-to-peak value of V. Assume two diodes to be identical, & neglect diode resistance in fwd direction.

Soln:-



$I_{DC} = 1A$

The avg I_{DC} per HWR diode

$$= \frac{I_m}{\pi} = \frac{1}{\pi}\frac{V_m}{R_L}$$

$$\therefore \; IA = \frac{V_m}{\pi R_L}$$

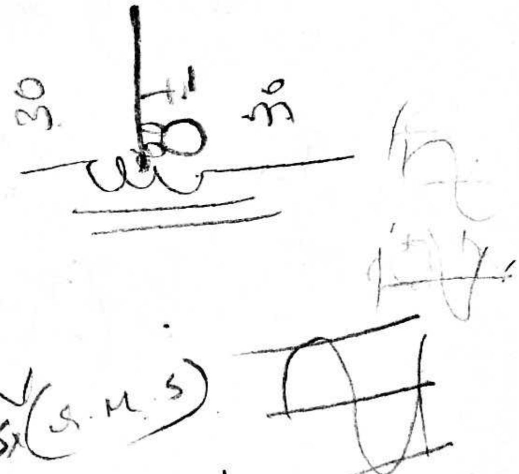
30-0-30

$$V_m = \pi R_L = \pi \times 100 = \underline{314.16V}$$

$$\therefore \; V_{m\,(p-p)} = V_{max} \times 2$$

$$= 314.16 \times 2$$

$$= \underline{628.32V}$$



(4) In a FWR the i/p is from 30-0-30V transformer the load & diode fwd resistance are 100Ω & 10Ω respectively. Calculate the avg voltage & efficiency.

Soln:- It is FWR with i/p from center tap transformer. So rms value of secondary across each half of secondary is 30V.

$$\therefore \; E_{sm} = \sqrt{2} \times 30 = \underline{42.4264\,V}$$

$$I_m = \frac{E_{sm}}{R_f + R_L} = \frac{42.426}{(100+10)} = \underline{0.3856A}$$

$$\therefore \; I_{DC} = \frac{2I_m}{\pi} = \frac{2 \times 0.3856}{\pi} = \underline{0.2455A}$$

$\therefore E_{DC} = I_{DC} \cdot R_L$

$= 0.2455 \times 100$

$= 24.55V$

$P_{DC} = I_{DC}^2 \cdot R_L = 6.027W$

$P_{AC} = I_{rms}^2 [R_f + R_L]$

$= \left(\frac{I_m}{\sqrt{2}}\right)^2 [R_f + R_L]$

$= 8.1778 W$

$\therefore \% \eta = \frac{P_{DC}}{P_{AC}} \times 100 = \frac{6.027}{8.1778} \times 100$

$= 73.69\%$

(5) What is the necessary AC i/p power from the transform secondary used in a HWR to deliver 500W of DC power to the load? what would be the AC i/p power for the same load in a FWR?

Soln:- for HWR, $\% \eta = 40.6\%$.

$40.6 = \frac{P_{DC}}{P_{AC}} \times 100$

$40.6 = \frac{500}{P_{AC}} \times 100$

$$\therefore P_{AC} = \frac{500 \times 100}{40.6}$$

$$= \underline{\underline{1231.527 W}}$$

for the same load, with FWR the max η_{max} is 81.2%

$$\therefore 81.2 = \frac{P_{DC}}{P_{AC}} \times 100$$

$$81.2 = \frac{500}{P_{AC}} \times 100$$

$$P_{AC} = \frac{500 \times 100}{81.2}$$

$$P_{AC} = \underline{615.763 V}$$

* **Bridge Rectifier Circuit :-**

→ The bridge rectifier ckt is essentially a FWR ckt using four diodes forming the four arms of an electrical bridge.

→ The main advantage is that does not require a center tap on the secondary winding of the transformer. Hence wherever possible, ac voltage can be directly applied to the bridge.

Operation of the circuit :-

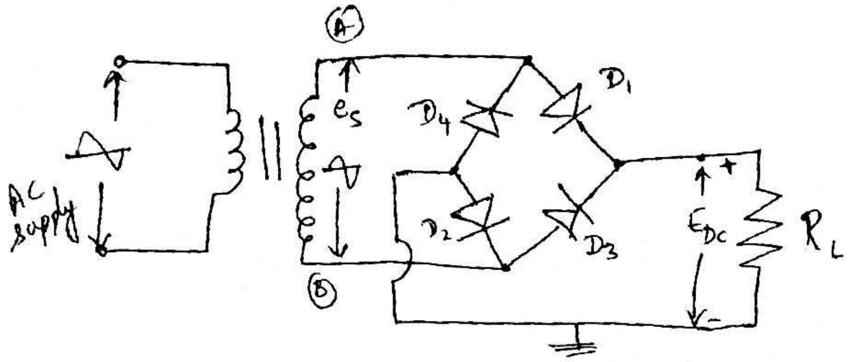


fig : Bridge rectifier ckt

→ The bridge rectifier ckt is as shown in the figure.

→ Consider the +ve half cycle of ac i/p voltage. The pt A of secondary becomes +ve. The diodes D_1 & D_2 will be fwd biased, while D_3 & D_4 reverse biased. The two diodes D_1 & D_2 conduct in series with the load & the current flows as shown in the ckt below:-

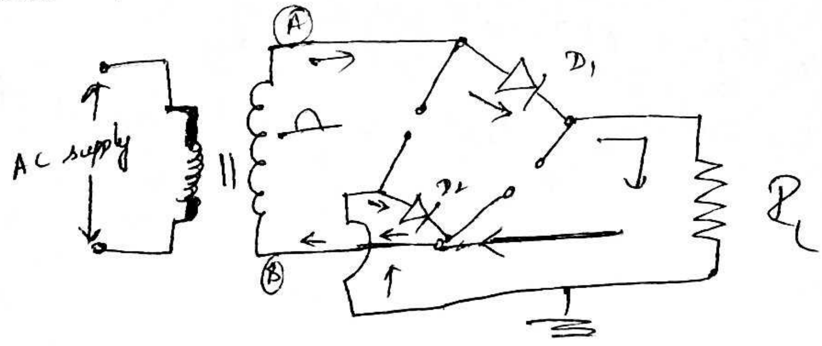


fig : Current flow during +ve half-cycle

→ In the next half cycle, when the polarity of ac voltage reverses hence pt B becomes +ve diodes D_3 & D_4 are fwd biased, while D_1 & D_2 reverse biased.

Now the diodes D_3 & D_4 conducts in series with the load & the current flows as shown below :-

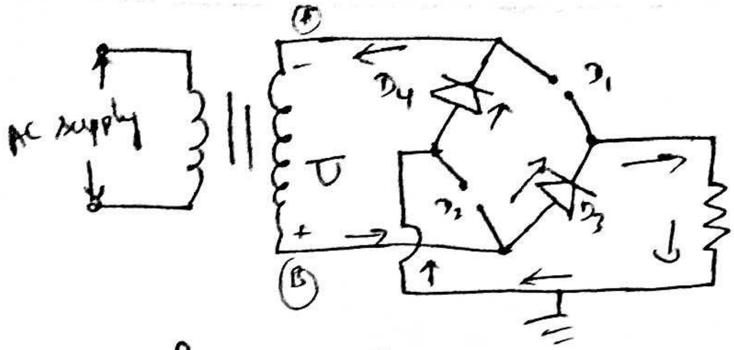


fig: Current flow during -ve half cycle.

→ It is seen that in both cycles of ac, the load current is flowing in the same direction hence we get a full wave rectified o/p.

→ The wf's of load current & voltage remain exactly same as FWR as studied earlier.

* Expressions for various parameters :-

$$I_{DC} = \frac{2 I_m}{\pi} \quad \& \quad I_{rms} = \frac{I_m}{\sqrt{2}}$$

$$I_m = \frac{E_{sm}}{R_s + 2R_f + R_L}$$

[∵ In each half cycle two diodes conducts simultaneously.]

PIV = E_{sm}

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

$$P_{DC} = I_{DC}^2 \cdot R_L$$

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

$$P_{AC} = I_{rms}^2 (R_s + 2R_f + R_L)$$

$$= \frac{I_{m}^2 (2R_f + R_s + R_L)}{2}.$$

$$\eta = \frac{8 R_L}{\pi^2 (R_s + 2R_f + R_L)}$$

$$\% \eta_{max} = 81.2\%$$

$$\gamma = 0.48$$

<u>Advantages</u> :-

* The o/p voltage is twice than that of FWR.

* PIV required is half of FWR

* It does not require center tap transformer.

* Disadvantages :-

→ It requires four diodes.

→ power loss in bridge n/w is high than that of FWR.

→ All the four diodes used should be ~~ind~~ identical.

Problems :-

① The four semiconductor diodes used in a bridge rectifier ckt each having a fwd resistance of 0.1Ω & infinite reverse resistance, feed a d.c current of 10A to a resistive load from a sinusoidally varying alternating supply of 30v (rms). Determine the resistance of the load & the efficiency of the ckt.

soln :-

$$E_{sm} = E_{sm}(rms) \times \sqrt{2}$$

$$= \sqrt{2} \times 30 = 42.4264\,V$$

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

$$\boxed{I_m = \frac{\pi I_{DC}}{2} = \frac{\pi \times 10}{2} = 15.7079\,A}$$

$$\frac{2 E_{sm}}{R_f + R_s}$$

$$I_m = \frac{E_{sm}}{2R_f + R_s + R_L}$$

$$15.7079 = \frac{42.426}{2 \times 0.1 + R_L}$$

$$R_L + 0.2 = 2.7$$

$$\underline{R_L = 2.5\,\Omega}$$

$$\therefore P_{DC} = I_{DC}^2 \cdot R_L$$

$$= 10^2 \times 2.5 = \underline{\underline{250 W}}$$

$$P_{AC} = I_{RMS}^2 (2R_f + R_s + R_L)$$

$$I_{RMS} = \frac{I_m}{\sqrt{2}} = \frac{15.7079}{\sqrt{2}} = \underline{\underline{11.1071 A}}$$

$$\therefore P_{AC} = (11.1071)^2 [2 \times 0.1 + 2.5]$$

$$= \underline{\underline{333.092 W}}$$

$$\% \eta = \frac{P_{DC}}{P_{AC}} \times 100$$

$$= \frac{250}{333.092} \times 100$$

$$= \underline{\underline{75.05 \%}}$$

(2) A 5KΩ load is fed from a bridge rectifier connected across a transformer secondary whose primary is connected to 460V, 50Hz supply. The ratio of no of primary turns to secondary turns is 2:1. Calculate d.c load current, dc load Vtg, ripple voltage & PIV rating of diode.

Soln :-

$$\frac{E_s}{E_p} = \frac{N_2}{N_1} = \frac{1}{2}$$

$$E_S = \frac{E_P}{2} = 230\,V$$

$$E_{sm} = \sqrt{2} \times E_s = \sqrt{2} \times 230 = 325.269\,V$$

$$I_{DC} = \frac{2 I_m}{\pi} \quad \text{where} \quad I_m = \frac{E_{sm}}{R_L} \quad \text{neglecting } R_f$$

$$\therefore\ I_{DC} = \frac{2 E_{sm}}{\pi R_L} = \frac{2 \times 325.269}{\pi \times 5K} = 41.41\,mA$$

$$E_{DC} = I_{DC} \cdot R_L = 41.41 \times 10^{-3} \times 5 \times 10^{3} = 207.072\,V$$

Ripple voltage = Ripple factor × V_{DC}

Ripple factor for bridge rectifier is 0.482

Ripple voltage = 0.482 × 207.072

= 99.8 V

PIV = E_{sm} = 325.27

(3) A FWBR is supplied from 230V, 50Hz & uses a transformer of turns ratio of 15:1. It uses load resistance of 50 Ω. Calculate load voltage & ripple vtg. Assume ideal diode & transformer. Assume std value of ripple factor for FWR.

Soln :-

$$\frac{E_{p\,rms}}{E_{s\,rms}} = \frac{N_1}{N_2}$$

$E_{s\,rms} = \frac{E_{sm}}{\sqrt{2}}$ $\boxed{\therefore E_{sm} = \sqrt{2}\, E_{s\,rms}}$

or

$E_{s(rms)} = E_{sm} \times 0.707$ $\boxed{\therefore E_{sm} = \frac{E_{s\,rms}}{0.707}}$ $\because \frac{1}{\sqrt{2}} = 0.707$

$$E_{s(rms)} = \frac{N_2}{N_1} E_{p(rms)}$$

$$= \frac{1}{15} \times 230 = \underline{15.33V}$$

$$\therefore E_{sm} = \sqrt{2} \times E_{s(rms)} = \sqrt{2} \times 15.33 = \underline{\underline{21.684\,V}}$$

$$\therefore I_m = \frac{E_{sm}}{R_s + 2R_f + R_L} = \frac{21.684}{50} = \underline{\underline{0.4336A}}$$

$$I_{DC} = \frac{2 I_m}{\pi} = \frac{2 \times 0.4336}{\pi} = \underline{\underline{0.276\,A}}$$

$$E_{DC} = I_{DC} \cdot R_L = 0.276 \times 50 = \underline{\underline{13.8\,V}}$$

Ripple factor $= 0.482$

$$= \frac{\text{ac rms o/p}}{\text{dc o/p}} = \frac{\text{ripple voltage}}{E_{DC}}$$

$$0.482 = \frac{\text{ripple vtg}}{13.8}$$

$$\therefore \text{Ripple voltage} = 0.482 \times 13.8 = \underline{\underline{6.6516V}}$$

(4) In FWBR, the transformer secondary vtg is $100 \sin \omega t$. The fwd resistance of each diode is 25Ω & the load resistance is 950Ω. Calculate (i) DC o/p vtg (ii) ripple factor (iii) efficiency of rectification (iv) PIV across non-conducting diode.

Soln :-

$$E_S = 100 \sin \omega t$$

$$\therefore \underline{E_{sm} = 100\,V}$$

[redacted]

(i) $E_{DC} = I_{DC} . R_L$

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

$E_{DC} = \frac{2 V_{sm}}{\pi} = \frac{2 \times 100}{\pi} = 63.$

$$I_m = \frac{E_{sm}}{R_L + 2R_f} = \frac{100}{950 + 2 \times 25} = \underline{0.1A}$$

$$\therefore I_{DC} = \frac{2 \times 0.1}{\pi} = \underline{63.66\,mA}$$

$$\therefore E_{DC} = 63.66m \times 950 = \underline{60.478\,V}$$

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

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

$$\therefore \text{Ripple factor} = \sqrt{\left(\frac{0.0707}{0.06366}\right)^2 - 1} = \underline{0.4831}$$

(iii) $P_{DC} = I_{DC}^2 \cdot R_L$

$$= (0.06366)^2 \times 950$$

$$= \underline{3.849\ W}$$

$$P_{AC} = I_{rms}^2 \left[2R_f + R_L\right]$$

$$= (0.0707)^2 \left[2 \times 25 + 950\right]$$

$$= \underline{4.9984\ W}$$

$$\therefore \ \% \eta = \frac{P_{DC}}{P_{AC}} \times 100 = \frac{3.8499}{4.9984} \times 100$$

$$= \underline{77.022\ \%}$$

(iv) PIV rating $= E_{sm}$ for BR

$$= \underline{100V}$$

Quantity	Halfwave	Full wave: Center tapped	Full wave: Bridge
I_{dc}	I_m/π	$\frac{2I_m}{\pi}$	$2I_m/\pi$
I_{rms}	$I_m/2$	$I_m/\sqrt{2}$	$I_m/\sqrt{2}$
γ	1.21	0.48	0.48
η	$\frac{0.406 R_L}{R_L+R_s+R_f}$	$\frac{0.812 R_L}{R_L+R_s+R_f}$	$\frac{0.812 R_L}{R_s+2R_f+R_L}$
Center tapped Transformer	Not Required	Required	Not Required
No of Diodes	One	Two	Four
PIV	V_m	$2V_m$	V_m

Filter Circuits :-

* It is seen that the o/p of a half wave or full wave rectifier ckt is not pure d.c., it contains fluctuations or ripple which is undesired.

* To minimize the ripple in the o/p, filter ckts are used. These ckts are connected b/n the rectifier & load as shown in the fig below:-

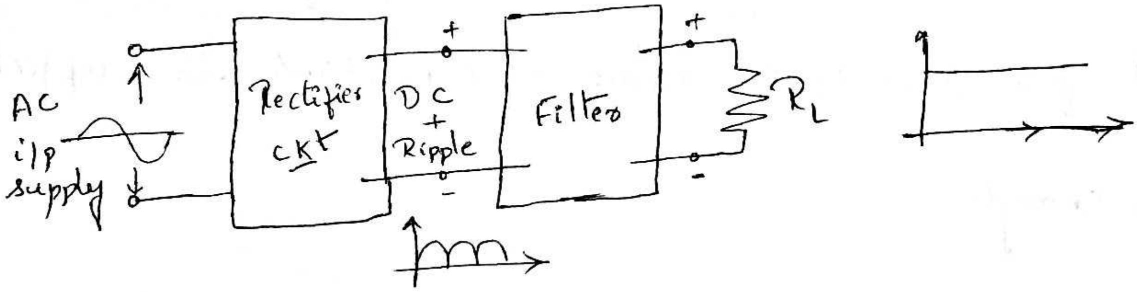


fig: power supply using rectifier & filter

* An AC i/p is applied to the rectifier. At the o/p of the rectifier, there will be DC & ripple voltage present, which is the i/p to the filter.

* Ideally the o/p of the filter should be pure DC. Pratically the filter ckt will try to minimize the ripple at the o/p, as far as possible.

* Basically the ripple is ac ie, varying with time, while DC is a constant w.r.t time.

Hence in order to separate DC from ripple, the filter ckt should ~~be~~ use components which have widely different impedance for ac & dc.

Two such components are inductance & capacitance. Ideally the inductance acts as a short ckt for d.c. but it has a large impedance for a.c.

$\|^{ly}$, The capacitor acts as open for d.c. & almost short for a.c., if the value of capacitance is sufficiently large enough. $X_C = \frac{1}{2\pi f C}$; $X_L = 2\pi f L$

for 'C' $f = 0$; $X_C = \infty \rightarrow$ High reactance for DC.

for 'L' $f = \infty$; $X_L = \infty \rightarrow$ High reactance for AC

* Ideally, inductance acts as short ckt for d.c, it cannot placed in shunt arm across the load, otherwise the d.c. will be shorted.

Hence, in a filter ckt the inductance is always connected in series with the load. The inductance used in filter ckts is also called "Choke".

$\|^{ly}$ since the capacitance is open for d.c ie, it blocks d.c hence it cannot be connected in series with the load. It is always connected in shunt arm $\parallel^{ld}$ to the load.

Thus filter is an electronic ckt composed of C, L or combination of both & connected b/n the rectifier & the load so as to convert pulsating d.c. to pure d.c.

* There are basically two types of filter ckts :-

a) Capacitor i/p filter

b) Choke i/p filter.

[Choke i/p filter is not in use ∵ as inductors are bulky, expensive & consume more power]

* Capacitor i/p filter :-

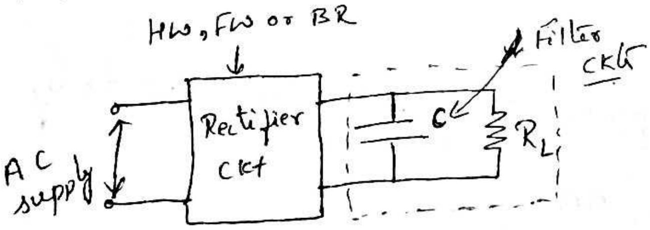


fig: Rectifier with C filter

→ Looking from the rectifier side if the first element in the filter ckt is C, then it is called as capacitor filter.

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

$V_{max} = \sqrt{2} V_{rms}$

$C \nearrow \searrow$

$C \to DC$

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

$C \quad f = 0 \, ; \, X_C = \infty$

$\nearrow DC$

$L \quad f = \infty \, ; \, X_L = \infty$

$\nearrow AC \to dc$

* Halfwave rectifier with C filter :-

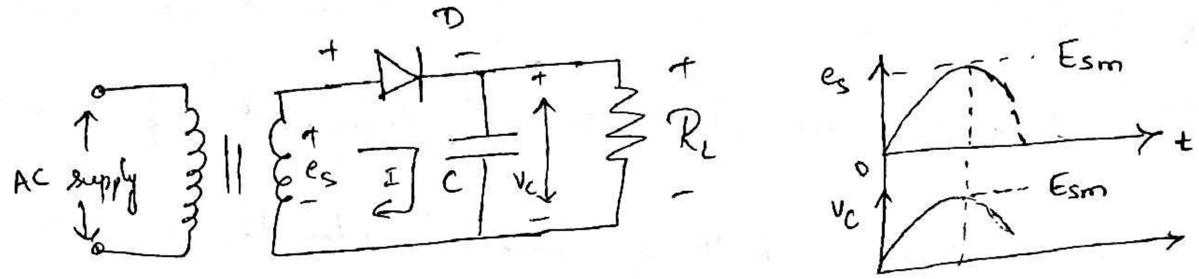


fig: HWR with C filter

→ The above fig shows a HWR with a C i/p filter.

→ The filter uses a single capacitor connected in $\parallel^{el}$ with the load R_L.

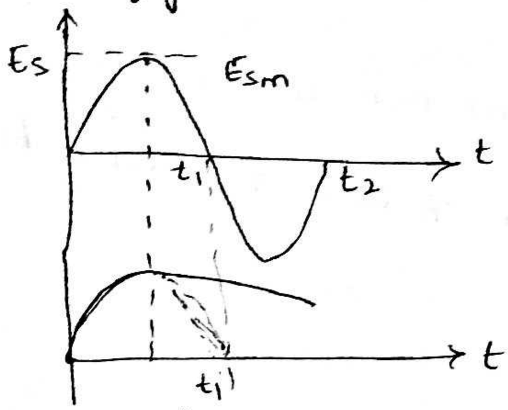
→ During the +ve quarter cycle of the i/p signal e_s the diode is fwd biased.

This charges the capacitor 'C' to peak value of i/p Esm [Pratically C charges to (Esm - 0.7) V due to diode fwd voltage drop].

→ This initial charging happens only once immediately when the power is turned on.

→ When the i/p starts decreasing below its peak value, the capacitor remains charged at Esm & the ideal diode gets reversed biased. This is coz capacitor vtg which is cathode vtg of diode becomes more +ve than that of the anode.

→ So during the entire −ve half cycle & some part of the next +ve half cycle capacitor discharges through R_L as shown in the fig below:-



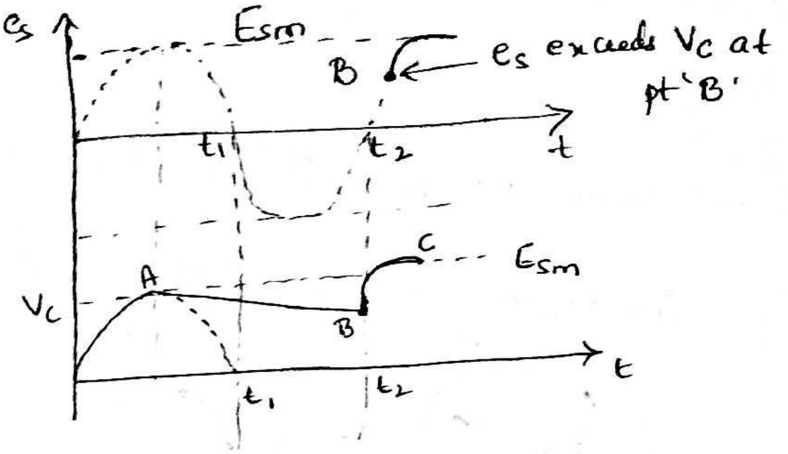


fig (a)

→ Capacitor discharges through load resistance. The discharging of capacitor is decided by $R_L C$ time constant which is very large & hence capacitor discharges very little from E_{sm}.

→ In the next +ve half cycle, when e_s becomes more than capacitor voltage, the diode becomes fwd biased & charges the capacitor C back to E_{sm}.

→ The capacitor starts charging at pt 'B' where e_s exceeds the capacitor voltage which is slightly less than E_{sm}. So from 'B' onwards the capacitor starts charging again & gets charged to E_{sm} as shown in the above fig (b).

→ The discharging of the capacitor is from A to B. The capacitor voltage is same as the o/p vtg as it is in parallel with R_L.

→ From pt A to B the diode remains non-conducting & conducts only for the period from B to C as shown below:-

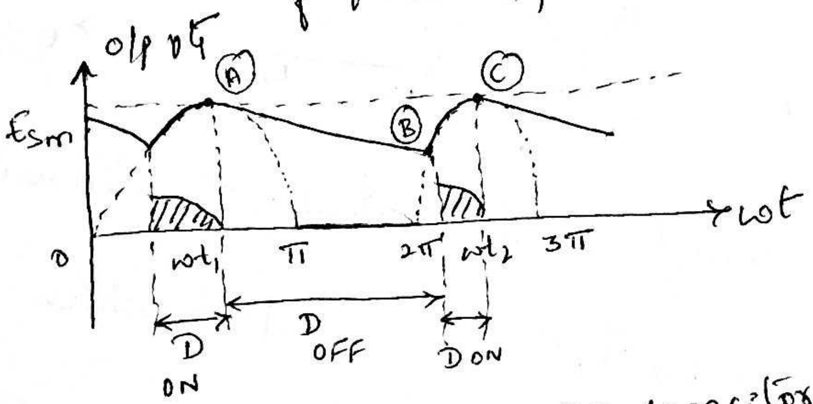
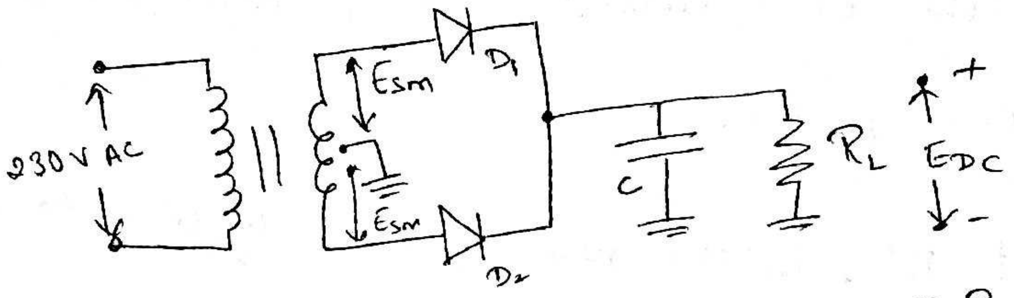


fig: Halfwave rectifier o/p with capacitor filter

→ When the diode is non-conducting the capacitor supplies the load current.

As the time required by the capacitor is very small to charge while its discharging time constant is very large, the ripple in the o/p gets reduced considerably.

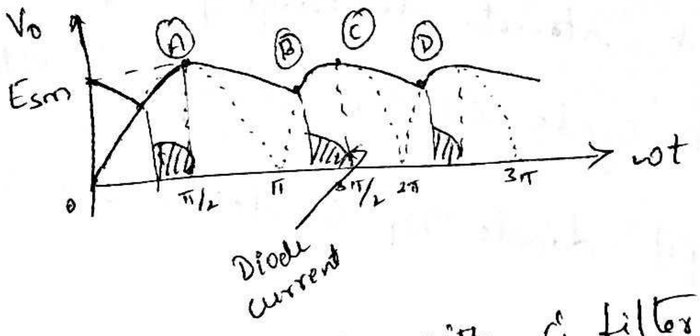
* Fullwave Rectifier with capacitor input filter :-



fig(a): Capacitor i/p filter in FWR

→ The capacitor filter used in FWR is as shown in the above fig.

→ Immediately when power is turned on, the C gets charged through fwd biased diode D_1 to Esm during 1st quarter cycle of the rectified o/p Vtg.



(A) - (B) C discharges

(B) - (C) C recharges

fig (b) : FWR O/P with C filter

→ In the next quarter cycle from π/2 to π, the C starts discharging through R_L. Once capacitor gets charged to Esm, the diode D_1 becomes reverse biased & stops conducting.

→ So during the period $\pi/2$ to π, the capacitor C_1 supplies the load current. It discharges to pt B as shown in fig (b).

→ At pt 'B', in the next quarter cycle π to $3\pi/2$ of rectified o/p vtg, the i/p vtg exceeds capacitor voltages, making D_2 fwd biased. This charges C_1 back to E_{sm} at pt 'C'.

→ The time required by C_1 to charge to E_{sm} is quite small & only for this period diode D_2 is conducting.

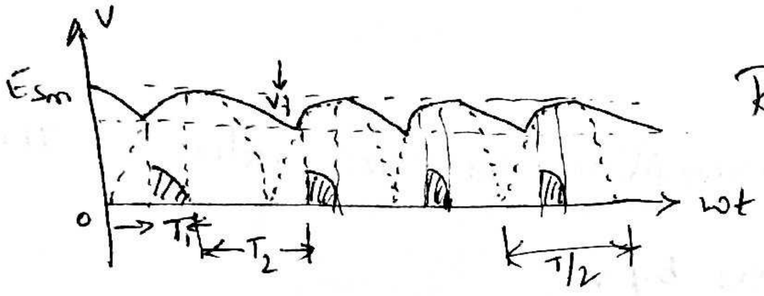
→ Again at pt 'C', diode D_2 stops conducting & C_1 supplies load & starts discharging up to pt 'D' in the next quarter cycle of the rectified o/p vtg.

At this pt diode D_1 conducts to charge capacitor back to E_{sm}.

→ When the capacitor is discharging through the load resistance R_L both the diodes are non-conducting. Hence the C_1 supplies the load current.

* Approximate analysis of Capacitor filter :-

→ Consider an o/p w/f for a FWR ckt using a C i/p filter as shown below :-



$$\text{Ripple factor} = \frac{V_{r(rms)}}{E_{DC}}$$

fig(a) : Derivation of Ripple factor

let T = Time period of the ac i/p vtg

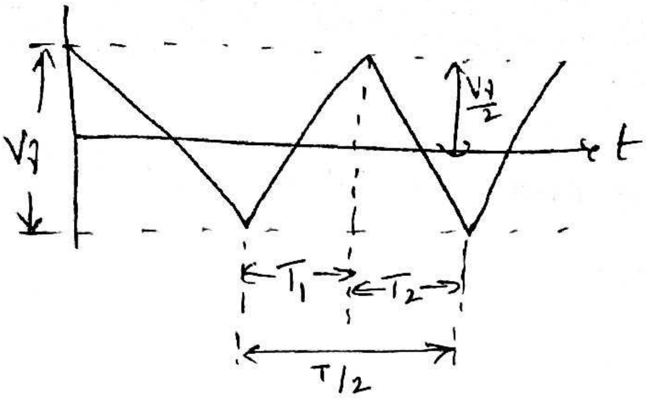
T/2 = Half of the time period

T_1 = Time for which diode is conducting

T_2 = — " — non-conducting

→ During time T_1, C gets charged & the process is quick. During time T_2, C gets discharged through R_L. As the time constant $R_L C$ is very large, discharging process is very slow & hence $T_2 >> T_1$.

→ Let V_r be the peak to peak value of ripple voltage which is assumed to be triangular as shown in the fig (b)



$V_{rms} = \sqrt{\frac{1}{\pi/2}\int_0^{\pi/2}\left(\frac{2}{\pi}V_{pk}\,\theta\right)^2 d\theta}$
$= \frac{1}{\sqrt{3}}V_{pk} \simeq 0.577 V_{pk}$

$T_r = \frac{1}{2f}$

$\frac{V_r C}{I_{dc}} = \frac{1}{2f}$

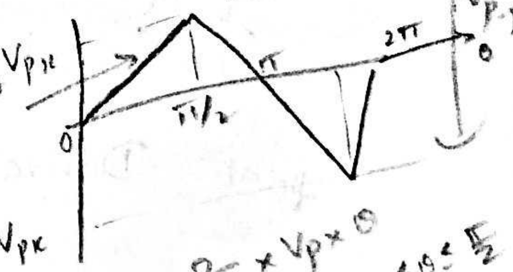
$V_r = \frac{I_{dc}}{2fC}$

$V_r = \frac{E_{DC}}{2fCR_L}$

→ For triangular assumption the rms value of the ripple voltage is given by,

$$V_{r\,(rms)} = \frac{V_r}{2\sqrt{3}}$$

for Δ $V_r/2 = V_{rms}\sqrt{3}$



$V = \frac{2}{\pi} \times V_{pk} \times \theta$

$V = \frac{2}{\pi} \times V_{pk} \times \theta$ for $0 \le \theta \le \frac{\pi}{2}$

→ During the time interval T_2, the capacitor C is discharging through the load resistance R_L. The charge lost is,

$$Q = CV_r$$

But $i = \frac{dQ}{dt}$ hence $Q = \int_0^{T_2} i\,dt = I_{DC}T_2$

gives an average or d.c. value.

→ Hence $I_{DC}T_2 = CV_r$ i.e, $V_r = \frac{I_{DC}T_2}{C}$

Now, $T_1 + T_2 = T/2$ & $T_2 >> T_1$

$\therefore$ $T_1 + T_2 = T_2 = T/2$ where $T = 1/f$

$$\therefore V_r = \frac{I_{DC}}{C}\left[\frac{T}{2}\right]$$

$$= \frac{I_{DC} \times T}{2C} = \frac{I_{DC}}{2fC}$$

But $I_{DC} = \frac{E_{DC}}{R_L}$

$$\therefore V_r = \frac{E_{DC}}{2fCR_L}$$ = Peak to peak ripple voltage for full wave.

$$E_{DC} = \frac{1}{V_r\, 2RCR_L}$$

→ The ripple factor is defined as the ratio of rms value of the a.c. component to the d.c component.

$$\therefore \text{Ripple factor} = \frac{V_r\,(rms)}{E_{DC}} = \frac{V_r}{2\sqrt{3}} \times \frac{1}{V_r\, 2fCR_L}$$

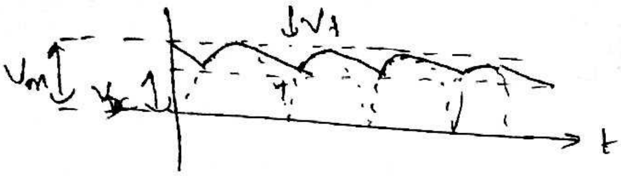
$$= \frac{1}{4\sqrt{3}\, fCR_L}$$

→ For HWR with C filter,

$$\text{Ripple factor} = \frac{1}{2\sqrt{3}\, fCR_L} \quad \left[\because T_1 + T_2 = T\right]$$

→ The d.c o/p vtg from a capacitor filter fed from a FWR is given by, $E_{DC} = E_{Sm} - \frac{V_r}{2}$

$$\therefore E_{DC} = E_{sm} - I_{DC}\left[\frac{1}{4fC}\right]$$



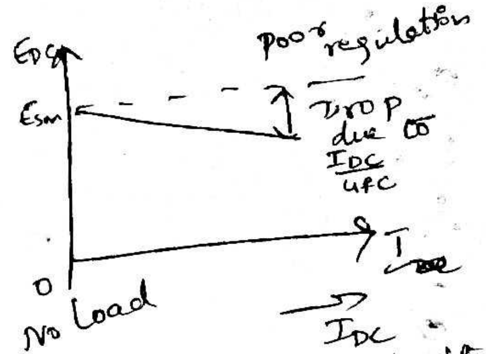


fig: Load Regulation in C i/p filter

& for HWR is given by,

$$E_{DC} = E_{sm} - I_{DC}\left[\frac{1}{2fC}\right] \quad \left(\therefore V_{DC} = V_m - \frac{V_r}{2}\right)$$

From the above expression, it can be seen that as the current drawn by the load ↑ the d.c o/p vtg ↓.

Hence having poor regulation.

$V_{r(rms)}$ = RMS Ripple voltage = $E_{DC} \times$ Ripple factor

$$\therefore V_{r(rms)} = \frac{I_{DC}}{4\sqrt{3}\,fC}\ V \quad \text{for FWR}$$

$$\frac{1}{4\sqrt{3}\,fCR_L} = \frac{V_{r(rms)}}{E_{DC}} = \frac{V_{r(rms)}}{I_{DC}R_L}$$

$$V_{r(rms)} = \frac{I_{DC}}{2\sqrt{3}\,fC}\ V \quad \text{for HWR}$$

$$V_{r(rms)} = \frac{I_{DC}}{4\sqrt{3}fC}\ V\ (FW)$$

$$\frac{V_{r,rms}}{V_{dc}} = r = \frac{1}{4\sqrt{3}\,fR_LC} \quad \text{FWR}$$

$$\frac{V_{r(rms)}}{V_{dc}} = r = \frac{1}{4\sqrt{3}R_LCf}$$

$$V_{r(rms)} = \frac{I_{DC}}{2\sqrt{3}fC}\ V\ (HW)$$

$$\boxed{V_{dc} = V_m - \frac{V_{r(p-p)}}{2}}$$

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

$$\therefore \frac{V_{r(rms)}}{I_{dc} \cdot R_L} = r = \frac{1}{4\sqrt{3}R_LCf}$$

$$\therefore V_{r(rms)} = \frac{I_{dc}}{4\sqrt{3}fC} \quad \text{FWR}$$

$$V_{r(rms)} = \frac{I_{dc}}{2\sqrt{3}fC} \quad \text{HWR}$$

Advantages :-

→ less no of Components

→ low ripple factor hence low ripple voltage

→ Suitable for high voltage at small load currents.

Disadvantages :-

→ Ripple factor depends on load resistance

→ Not suitable for variable loads as ripple content ↑ & R_L ↓

→ Regulation is poor.

Problems :-

① In a HWR Ckt fed from 230V, 50 Hz mains it is desired to have a ripple factor $\gamma \leq 0.005$. Estimate the value of the capacitance needed $I_L = 0.5$ A

Soln :- $E_{s(rms)} = 230V$, $f = 50Hz$, $\gamma = 0.005$

$\therefore E_{sm} = \sqrt{2} \times E_{s\,rms} = \sqrt{2} \times 230 = 325.269\,V$

$\therefore$ for HWR, $\gamma = \dfrac{1}{2\sqrt{3} f C R_L}$

$$0.005 = \frac{1}{2\sqrt{3} \times 50 \times C \times R_L}$$

Now $R_L = \frac{E_{DC}}{I_L}$

$= \frac{E_{sm}}{\pi I_L}$

$= \frac{325.269}{\pi \times 0.5}$

$= 207.072\,\Omega$

$\therefore\ C = \frac{1}{2\sqrt{3} \times 50 \times 0.005 \times 207.072}$

$C = 5.576\text{ mF}$

(2) In a FWR with capacitor filter the load current from the ckt operating from 230V, 50Hz supply is 10mA. Estimate the value of capacitor required to keep the ripplefactor less than 1%.

Soln:- $E_{s(rms)} = 230V$, $f = 50Hz$, $I_L = 10mA$ & $\gamma = 0.01$ (1%)

$\therefore\ E_{sm} = \sqrt{2} \times E_{s(rms)} = \sqrt{2} \times 230 = 325.269V$

$R_L = \frac{E_{DC}}{I_L} = \frac{2E_{sm}}{\pi I_L} = \frac{2 \times 325.269}{\pi \times 10 \times 10^{-3}} = 20.7\,k\Omega$

$\therefore$ Ripple factor for FWR is,

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

$0.01 = \frac{1}{4\sqrt{3} \times 50 \times C \times 20.7 \times 10^{3}}$

$$\therefore C = \frac{1}{4\sqrt{3} \times 50 \times 0.01 \times 20.7 \times 10^{3}}$$

$$= 1.39 \times 10^{-5} F$$

$$= \underline{13.94 \ \mu F}$$

Zener diodes :-

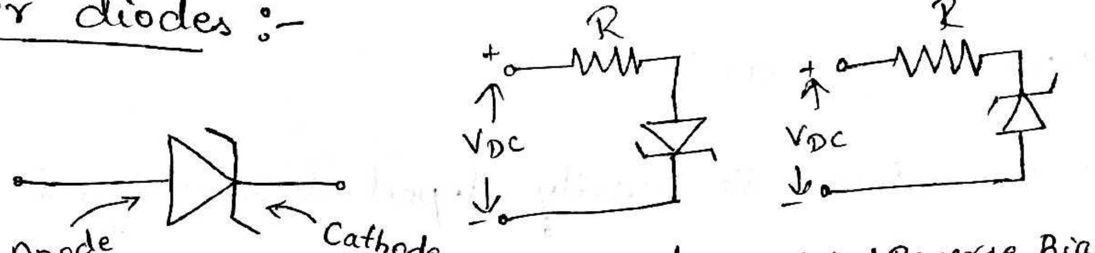


fig (a) Symbol (b) : Forward Biasing (c) : Reverse Biasing

* The zener diode is a p-n junction Si diode which is heavily doped & designed to operate under reverse bias Condition.

* The Zener diode acts $\parallel^{lar}$ to the conventional diode in fwd biased, but in revere biased it is opereated in reverse breakdown region.

* When reverse biased, if the reverse current of zenere diode is limited de using a series resistance then the power dissipation at the junction is limited to such a level which will not damage the diode & the zener diode continues to operate safely in reverse breakdown region.

* In zener diode there are two distinct mechanisms due to which breakdown occurs in reverse biased p-n junction

→ Zenere breakdown
→ Avalanche breakdown

* Zenerbreakdown :-

→ Zenerediode is heavily doped & is designed to operate under reverse bias. Since due to heavy doping of P & n layers the depletion layer becomes very narrow.

→ The electric field strength produced by a reverse bias voltage can be very high in the depletion region.

→ The high-intensity electric field causes electrons to break away from their atoms thus converting the depletion region from an insulating material into a conductor.

→ This is called as ionization by electric field & also called as zener breakdown & it is usually occurs with reverse bias vtg less than 5.6V.

→ Avalanche breakdown :-

* Consider a lightly doped p-n junction under reverse bias the depletion region widens further.

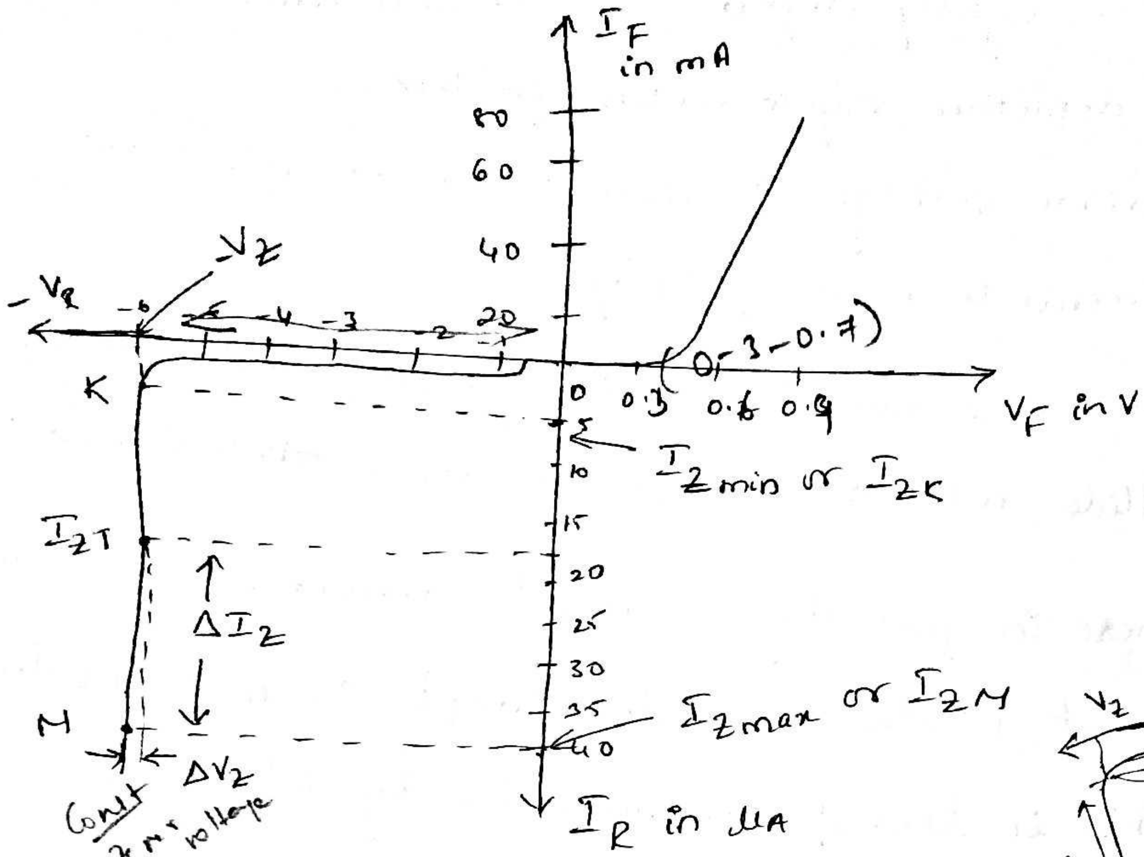
→ When reverse voltage ↑ above 5.6 V it forces the minority carries to move quickly.

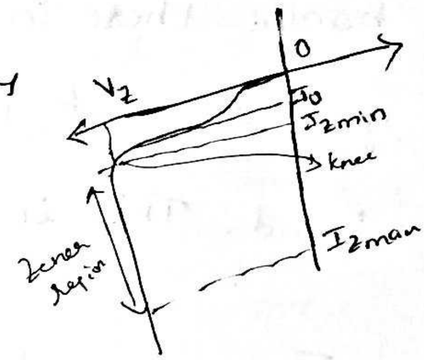
Since these minority carriers get sufficient energy & they collide with atoms & break down ~~covalent~~ covalent bonds these in generating additional carriers, these carriers gain sufficient kinetic energy to disrupt the next covalent bond. This is termed as ionization by collision.

→ Thus in addition to original carriers a new electron-hole pair gets created, these carriers again generate additional more pairs.

This is a cumulative process of multiplication or carrier multiplication & the current ↑ sharply & is known as Avalanche breakdown.

* Zener diode chara & parameters :-





V_Z = Zener breakdown voltage

I_{ZT} = Test Current to measure V_Z

I_{ZM} = Max Zener Current

I_{ZK} = Min —"—

Applications :-

→ voltage regulators

→ protection ckt

→ voltage limiters etc

* Distinguish b/n Zener & Avalanche breakdown:-

Zener diode	Avalanche breakdown
1. Breakdown is due to intense electric field across the junction	1. Breakdown is due to the collision of accelerated charge carriers with the adjacent atoms & due to carrier multiplication.
2. Occurs for zener with zener voltage less than 5.6V	2. Occurs for zener with zener voltage greater than 5.6V
3. The breakdown Vtg ↓ as junction temperature ↑.	3. The breakdown Vtg ↑ as junction tempr ↑.

* Zener diode voltage Regulators:-

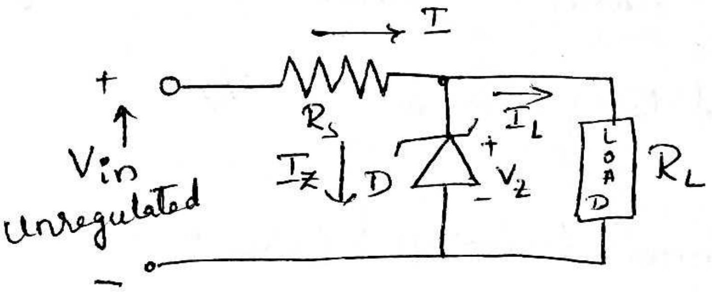


fig: Zener diode as a shunt regulator

→ A Zener diode can be used as a voltage regulator since it maintains a constant o/p Vtg even though the current through zener changes.

→ The ckt of zener regulator is as shown in the above fig consisting of an unregulated voltage source Vi connected to ~~Current limiting~~ series resistor R_S, a zener diode in $\parallel^{el}$ with load resistor R_L.

→ The zener should be selected in such a way that the required regulated o/p voltage V_o should be equal to zener breakdown voltage.

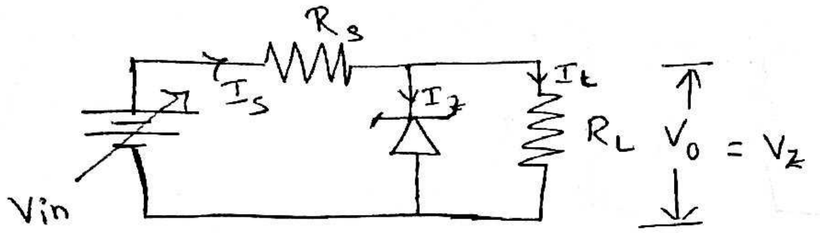
→ In order to work as a regulator the following conditions must be satisfied :-

1. Zener diode must be reverse biased
2. I/p voltage must be greater than zener breakdown voltage.
3. The load current should be less than $I_{Z max}$.
4. The zenere diode has a chara that, as long as the current through it is b/n $I_{Z min}$ & $I_{Z max}$, the voltage across it is constant equal to zenere voltage V_Z.
5. The zener diode is connected in $\parallel^{el}$ (shunt) with the R_L the o/p vtg is equal to the zener vtg.
6. The value of R_S can be obtained as,

$$R_S = \frac{V_{in} - V_Z}{I_S} \quad \text{ie,} \quad I_S = \frac{V_{in} - V_Z}{R_S}$$

$$\& \quad I_S = I_{Z_{max}} + I_L$$

* Regulation with Varying i/p voltage (line regulation) :-



→ It can be seen that the o/p is $V_0 = V_z$ is Constant

$$\therefore I_L = \frac{V_0}{R_L} = \frac{V_z}{R_L} = \text{Constant}$$

$$\& \quad I_s = I_z + I_L$$

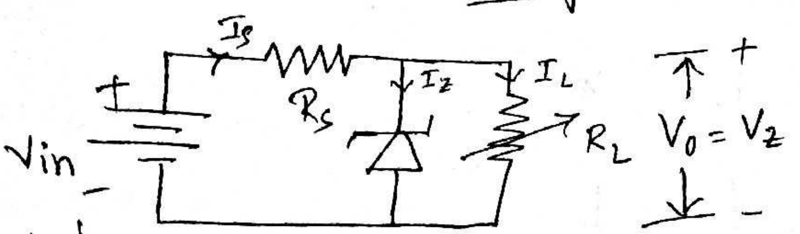
→ Now if Vin ↑, then the total current I_s ↑ but I_L is constant as V_z is Constant, Hence I_z ↑ to keep I_L constant.

→ But as long as I_z is b/n $I_{z\,min}$ & $I_{z\,max}$, o/p vtg V_0 is constant [∵ V_z = constant]

→ Thus the changes in i/p vtg get compensated & o/p is maintained constant.

→ $|||^{ly}$ is Vin ↓, the I_s ↓. But to keep I_L constant I_z ↓. As long as I_z is b/n $I_{z\,max}$ & $I_{z\,min}$, the o/p vtg remains constant.

* Regulation with Varying load (load Regulation) :-



Constant

→ The i/p vtg is constant while the load resistance R_L is Variable.

As Vin is Constant & $V_0 = V_Z$ is also Constant.

Then for Constant R_s the Current I_s is Constant.

$$\therefore \quad I_s = \frac{V_{in} - V_Z}{R_s} \quad \text{Constant} = I_L + I_Z$$

→ Now if $R_L \downarrow$ so $I_L \uparrow$ to keep I_s Constant $I_Z \downarrow$. But as long as it is b/n $I_{Z\,min}$ & $I_{Z\,max}$ O/p vtg V_0 will be constant.

→ IIIly if $R_L \uparrow$ so $I_L \downarrow$ to keep I_s Constant $I_Z \uparrow$. But as long as it is b/n $I_{Z\,min}$ & $I_{Z\,max}$ O/p vtg V_0 will be Constant.

* Designing of R_s :-

Since current through zener diode varies with change in i/p voltage, proper current through R_s has to be taken.

$$R_{s\,min} \leq R_s \leq R_{s\,max}$$

When V_i is maximum, I_Z is max < $I_{Z\,max}$ rating

R_s should be selected such that it is min.

$$\therefore R_s = \frac{V_i - V_o}{I_s} = \frac{V_i - V_o}{I_L + I_Z}$$

$V_i = V_{i\,max}$

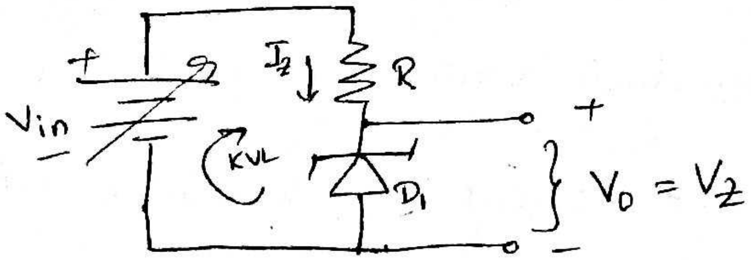
$I_Z = I_{Z\,max}$, $I_L = I_{L\,min}$

$$R_{s\,min} = \frac{V_{i\,max} - V_o}{I_{Z\,max} + I_L} \quad \text{if } I_L \text{ fixed}$$

if I_L is varying, it is $I_{L\,min}$

$$R_{s\,max} = \frac{V_{i\,min} - V_o}{I_{Z\,min} + I_{L\,max}}$$

* Regulator ckt with No load :-



* In the above ckt, the o/p voltage is regulated only with the help of Variable i/p voltage Vin.

* Resistor 'R' limits the zener diode current to the desired level.

∴ By applying KVL to the above ckt we get,

$$-V_{in} + I_Z R + V_Z = 0$$

$$\therefore V_Z = V_{in} - I_Z R$$

$$\& \; I_Z = \frac{V_{in} - V_Z}{R}$$

(3) a. Calculate the ripple voltage of a full wave rectifier with a 120 μF Capacitor connected to a load & load Current of 60 mA, freq of AC source of 50 Hz.

b. If the peak voltage of the rectified wave is 60V. Calculate the DC voltage.

c. Calculate the ripple factor.

soln :-

$$\frac{V_{r(rms)}}{V_{dc}} = r = \frac{1}{4\sqrt{3}R_L f C}$$

$$\therefore V_{r(rms)} = \frac{V_{dc}}{4\sqrt{3} f R_L C}$$

$$= \frac{I_{dc}}{4\sqrt{3} f C} = \frac{60 \times 10^{-3}}{4 \times \sqrt{3} \times 50 \times 120 \times 10^{-6}} = \underline{1.44 V}$$

a. $V_{r(p-p)} = 2\sqrt{3} \times V_{r(rms)}$

$$= 2\sqrt{3} \times 1.44 = \underline{5V}$$

b. $V_{dc} = V_m - \frac{V_{r p-p}}{2}$

$$= 60 - \frac{5}{2} = \underline{57.5V}$$

c. $r = \frac{1}{4\sqrt{3} f R_L C} = \frac{1.44}{V_{dc}} = \underline{2.5\%}$

(4) A FWR has $R_L = 10K\Omega$ & a capacitive filter with a capacitance of $C = 20\mu F$. The applied voltage is $V = 50 \sin 2\pi 50t$, calculate its ripple factor.

soln :-

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

$$= \frac{1}{4\sqrt{3} \times 50 \times 10 \times 10^3 \times 20 \times 10^{-6}}$$

$$= \underline{0.0144}$$

n45