UNIT-3

RECTIFIERS AND FILTERS

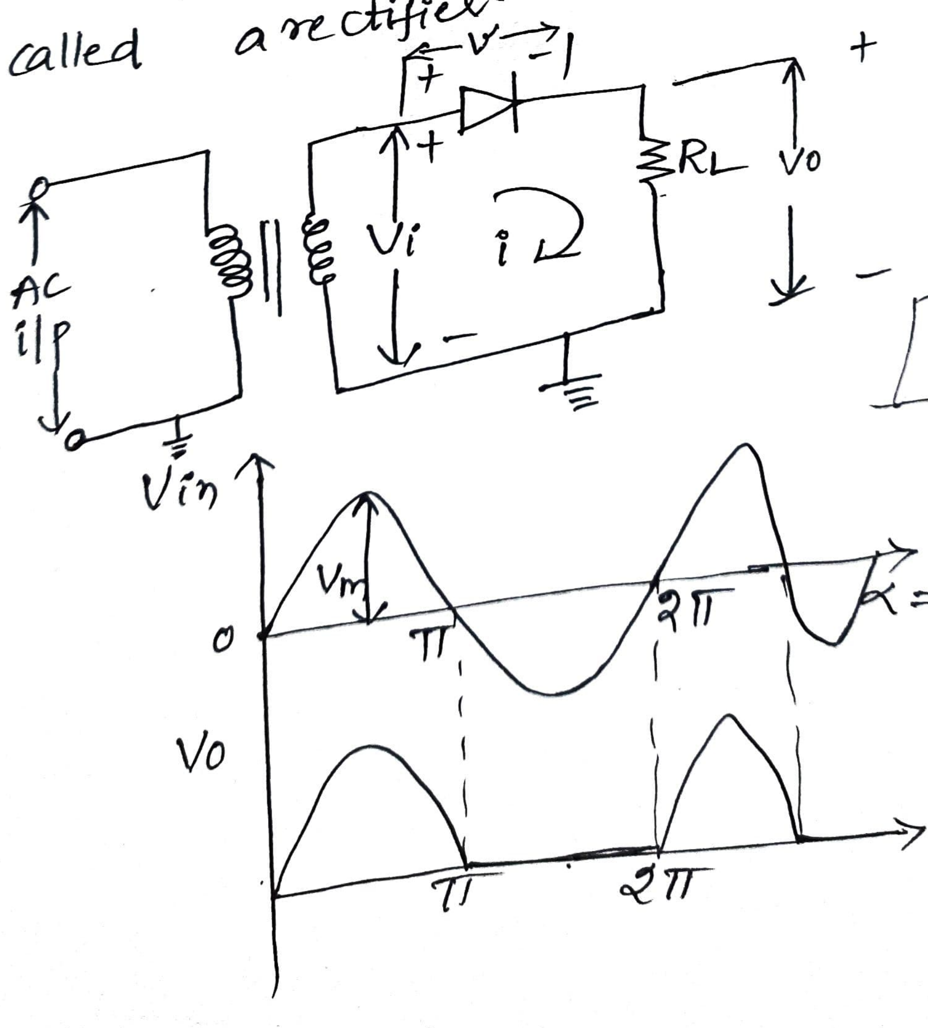
Rectifier:-

It is a device which can convert an ac input into (pulsating) dc output. The o/p will have always some ac components. filtering will be used to obtain a more accurate dc o/p.

Rectifier (or) large signal diodes have larger junction area ⇒ C_T is high & power rating high

Halfwave Rectifier:-

Any electrical device which offers a low resistance to the current in one direction but a high resistance to I in opposite direction is called a rectifier.

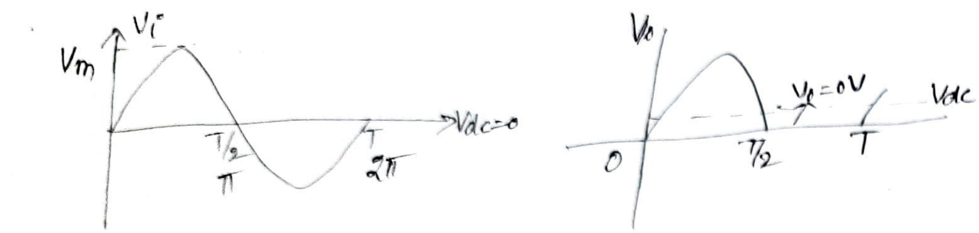


$$\boxed{V_i = V_m \sin \omega t}$$

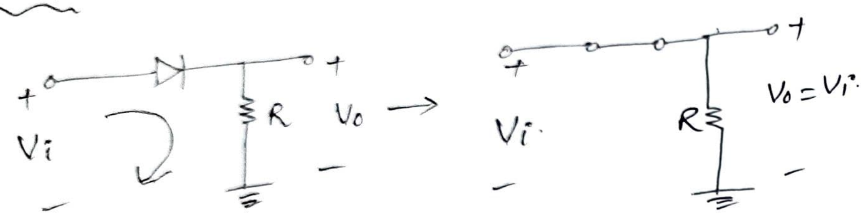
$V_m >> V_r$

During +ve half cycle → diode conducts (FB) (short cut)
-ve " " → " RB (open ckt) → o/p = 0

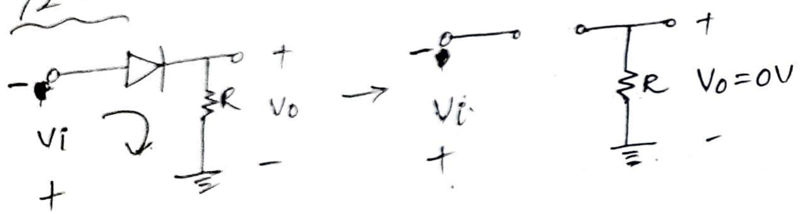
So a.c. will be converted to pulsating DC.



$0 \to T/2$:-



$T/2$ to T :-

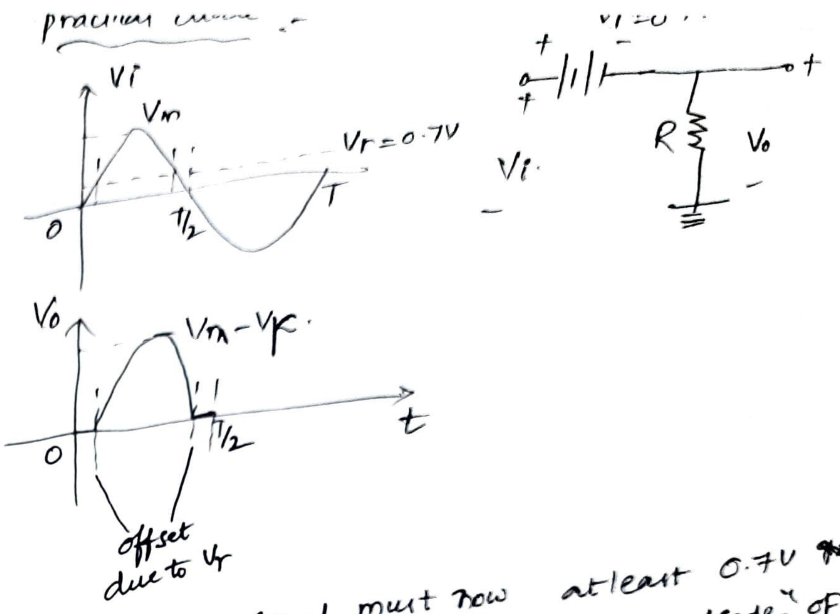


for V_{in}, $V_{dc} = 0 \Rightarrow$ avg. value = 0.

for V_o, $\boxed{V_{dc} = 0.318\, V_m}$ half-wave (∵ for a full period it has net +area above axis)

The process of removing one half the I/P signal to establish a dc level is called half wave rectification

practical ...



The applied signal must now atleast 0.7V greater for the diode to turn out. $V_i < 0.7V \to$ diode "off". $\Rightarrow V_o = 0V$

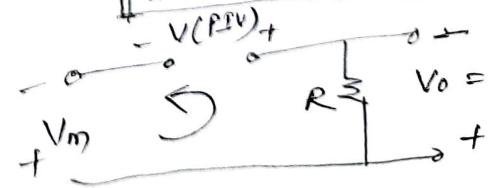
$V_i > 0.7V \Rightarrow V_o = V_i - V_r$

$$\boxed{V_{dc} \cong 0.318\,(V_m - V_r)}$$

PIV (PRV) :-

Peak inverse voltage (or) Peak reverse voltage. It decides the max. reverse vol. that can be applied to the diode so that it can't enter zener / avalanche break down region. It is generally peak of -ve half cycle (V_m)

$\boxed{\text{PIV rating} \geq V_m}$ | half wave



Ripple factor:-

A rectifier converts alternating current into unidirectional current but the o/p still has periodically varying components. A measure of fluctuating components is given by ripple factor r,

$$r = \frac{\text{rms value of alternating components of a wave}}{\text{average value of wave}}$$

(or)

$$r = \frac{\text{rms value of ac component}}{\text{dc value of component}}$$

$$r = \frac{V_{r,rms}}{V_{dc}} = \frac{I_{r,rms}}{I_{dc}}$$

where $V_{r,rms} = \sqrt{V_{rms}^2 - V_{dc}^2}$

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

Now..,

V_{av} (or) V_{dc} content of voltage across load

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

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

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

If diode forward resistance (r_f) and transformer secondary winding resistance (r_s) are considered

$$V_{dc} = \frac{V_m}{\pi} - I_{dc}(r_s + r_f)$$

$$I_{dc} = \frac{V_{dc}}{(r_s + r_f) + R_L} = \frac{V_m}{\pi(r_s + r_f + R_L)}$$

Now..,

$$V_{rms} = \left[\frac{1}{2\pi}\int_0^{\pi} V_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

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

$$= V_m\left[\frac{1}{4\pi}\int_0^{\pi}(1-\cos 2\omega t)\, d(\omega t)\right]^{1/2}$$

$$= V_m\left[\frac{1}{4\pi}[\pi]\right]^{1/2} = \frac{V_m}{2}$$

$$r = \sqrt{\left[\frac{V_m/2}{V_m/\pi}\right]^2 - 1} = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1} = \underline{\underline{1.21}}$$

Efficiency:-

$$\eta = \frac{\text{dc o/p power to load}}{\text{ac i/p power to load}} = \frac{P_{dc}}{P_{ac}}$$

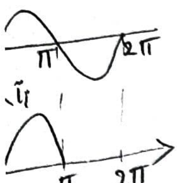
$$= \frac{(V_{dc})^2/R_L}{(V_{rms})^2/R_L} = \frac{(V_m/\pi)^2}{(V_m/2)^2} = 0.406 = \underline{\underline{40.6\%}}$$

max. efficiency of half wave rectifier = 40.6%

Transformer utilisation factor :- (TUF)

In the design of any power supply, the rating of the transformer should be determined.

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



$$= \frac{P_{dc}}{P_{ac\ rated}}$$

In half-wave rectifier, the rated voltage of the transformer secondary is $V_m/\sqrt{2}$ but actual rms current flowing through winding is only $\frac{I_m}{2}$ but not $I_m/\sqrt{2}$

$$TUF = \frac{\frac{I_m^2}{\pi^2} R_L}{\frac{V_m}{\sqrt{2}} \times \frac{I_m}{2}} = \frac{(V_m^2/\pi^2)\frac{1}{R_L}}{\left(\frac{V_m}{\sqrt{2}}\right)\left(\frac{V_m}{2R_L}\right)} = \frac{2\sqrt{2}}{\pi^2} = 0.287$$

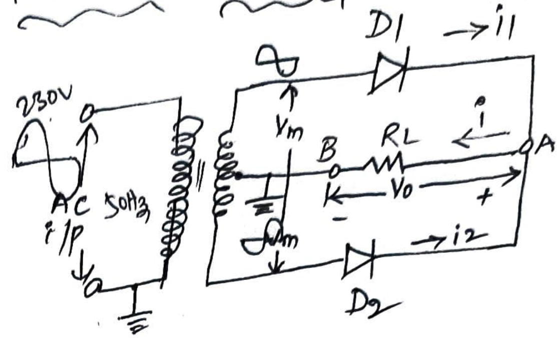
Form factor :-

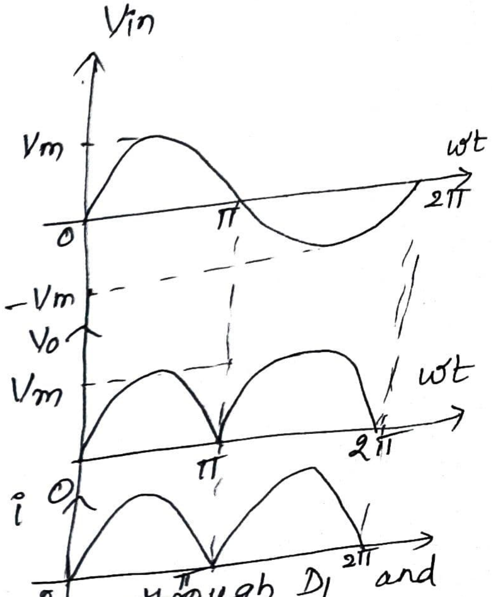
$$\text{Form factor} = \frac{\text{rms value}}{\text{avg value}} = \frac{V_{rms}}{V_{dc}} = \frac{V_m/2}{V_m/\pi} = \frac{\pi}{2} = 1.57$$

Peak factor

$$\text{Peak factor} = \frac{\text{Peak value}}{\text{rms value}} = \frac{V_m}{V_m/2} = 2$$

Full wave rectifier :-





* It converts ac voltage into a pulsating dc voltage using both half cycles of applied ac voltage
* During +ve half, D1 is FB (Anode of D1 is +ve) and D2 is RB (Anode of D2 is -ve). hence D1 conducts and D2 doesn't conduct. The load current flows through D1 and voltage drop occurs at RL
* During -ve half, D1 → RB, D2 → FB. voltage drop across RL because of current through D2.

Ripple factor :-

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

(i) $V_{dc} = \frac{1}{\pi}\int_0^{\pi} V_m \sin\omega t \, d(\omega t)$

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

since avg. value of periodic fn is given by

avg. value $= \frac{\text{area of one cycle of curve}}{\text{base}}$

$I_{dc} = \frac{V_{dc}}{R_L} = \frac{2V_m}{\pi R_L} = \frac{2I_m}{\pi}$, $I_{rms} = \frac{I_m}{\sqrt{2}}$

If diode resistance (r_f) and transformer secondary winding resistance (r_s) are included

$V_{dc} = \frac{2V_m}{\pi} - I_{dc}(r_s + r_f)$

$I_{dc} = \frac{V_{dc}}{(r_s + r_f) + R_L} = \frac{2V_m}{\pi(r_s + r_f + R_L)}$

Now

$V_{rms} = \sqrt{\left[\frac{1}{\pi}\int_0^{\pi} V_m^2 \sin^2\omega t \, d(\omega t)\right]} = \frac{V_m}{\sqrt{2}}$

$r = \sqrt{\left(\frac{V_m/\sqrt{2}}{2V_m/\pi}\right)^2 - 1} = \sqrt{\frac{\pi^2}{8} - 1} = 0.482$

TUF is seperate for primary & secondary

secondary

$TUF = \frac{(V_{dc})^2/R_L}{V_{rms} \cdot I_{rms}} = \frac{\frac{4V_m^2}{\pi^2} \cdot \frac{1}{R_L}}{\frac{V_m}{\sqrt{2}} \cdot \frac{V_m}{\sqrt{2}R_L}} = \frac{8}{\pi^2} = 0.812$

primary is serving two HWR independently

primary TUF $= 2 \times 0.287$

$Avg = \frac{0.574 + 0.812}{2} = 0.693$

efficiency :-

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

$= \frac{(V_{dc})^2/R_L}{(V_{rms})^2/R_L} = \frac{\left(\frac{2V_m}{\pi}\right)^2}{(V_m/\sqrt{2})^2} = \frac{8}{\pi^2} = 81.2\%$

TUF :- $= 0.693$

form factor :-

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

Peak factor :-

$PF = \frac{\text{Peak value of o/p voltage}}{\text{rms " " "}} = \frac{V_m}{V_m/\sqrt{2}} = \sqrt{2}$

PIV $= 2V_m$ because entire secondary voltage appears across the non-conducting diode while $D_1 \rightarrow$ conducting, apply KVL at outer loop, total $2V_m$ at transformer secondary drops at D_2.

Regulation :-

Variation of dc o/p voltage as a fn of dc load current is called regulation

$\%\text{ regulation} = \frac{V_{no\,load} - V_{full\,load}}{V_{full\,load}} \times 100\%$

Half

$V_{no\,load} = \frac{V_m}{\pi}$

$V_{full\,load} = \frac{V_m}{\pi} - I_{dc}R_f$

$\%\text{ reg} = \frac{\frac{V_m}{\pi} - \left(\frac{V_m}{\pi} - I_{dc}R_f\right)}{I_{dc}R_L} \times 100$

$\boxed{\%\text{ reg} = \frac{R_f}{R_L} \times 100}$

full

$V_{no\,load} = \frac{2V_m}{\pi}$

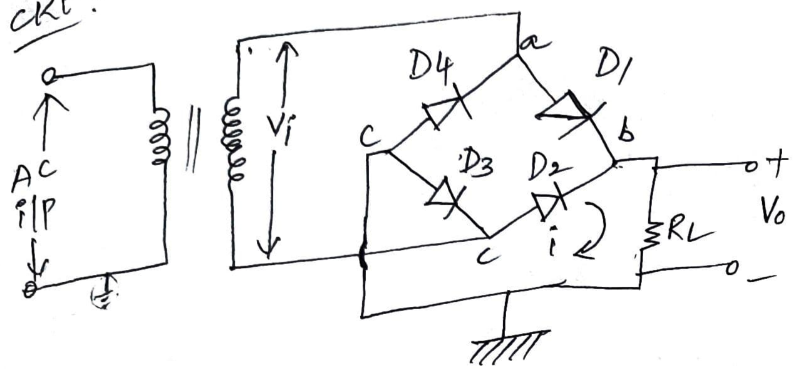
$V_{full\,load} = \frac{2V_m}{\pi} - I_{dc}R_f$

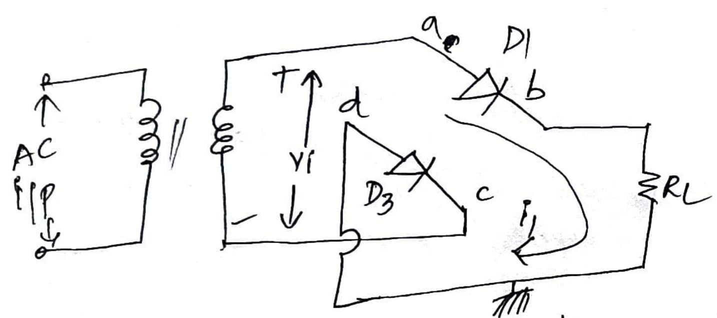
$\%\text{ reg} = \frac{\frac{2V_m}{\pi} - \left(\frac{2V_m}{\pi} - I_{dc}R_f\right)}{I_{dc}R_L} \times 100$

$\boxed{\%\text{ reg} = \frac{R_f}{R_L} \times 100}$

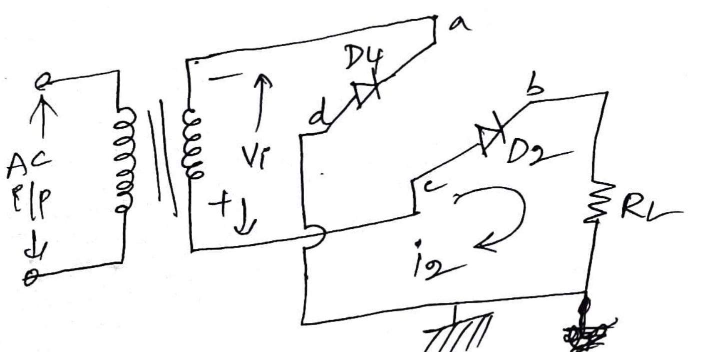
Bridge Rectifier:-

ckt:-

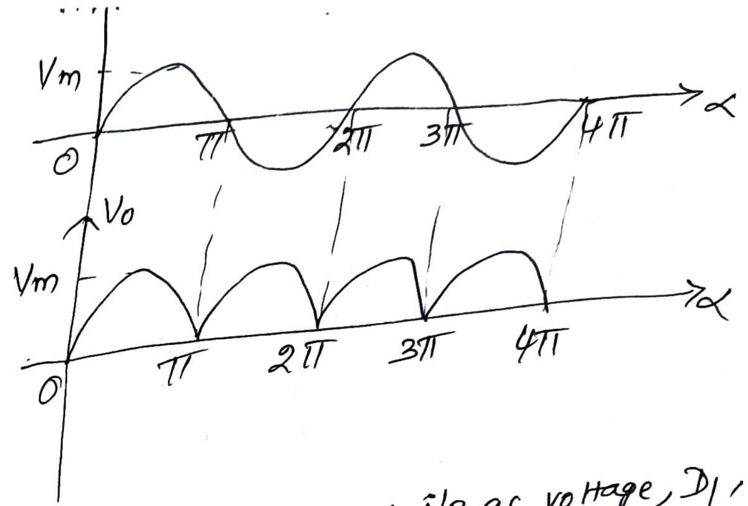




(b) eq. ckt for +ve half cycle.



(c) eq. ckt for -ve half cycle



* For +ve half-cycle of i/p ac voltage, $D_1, D_3 \rightarrow FB$
  $D_2, D_4 \rightarrow RB$
* for -ve, $D_1, D_3 \rightarrow RB$, $D_2, D_4 \rightarrow FB$. hence current flows in same direction in both half cycles.
* PIV = Vm since each diode has only transformer voltage across it on the inverse cycle.

Advantages:-

1. PIV is less (half of Centre tapped)
2. bulky center tapped transformer not required
3. TUF is high
4. No need to ground o/p

doubt

FILTERS

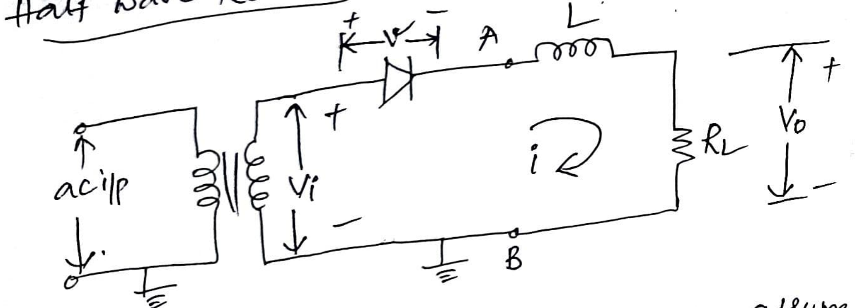
INDUCTOR FILTER

* fourier series representation of o/p wave in a halfwave rectifier contains "harmonics" (multiples of fundamental angular freq. ω i.e. $\omega, 2\omega, 3\omega$ - -). These are undesirable. 'ω' is eliminated in full wave o/p i.e. eliminated ~~random~~ first harmonic. so filtering the o/p of rectifying is advantageous in removing harmonics since full wave is meritorious than half wave rectifier.

Inductor filter :-

* inductor opposes sudden changes in "current". so any sudden changes that might occur in a ckt without an inductor are smoothed out by the presence of it.

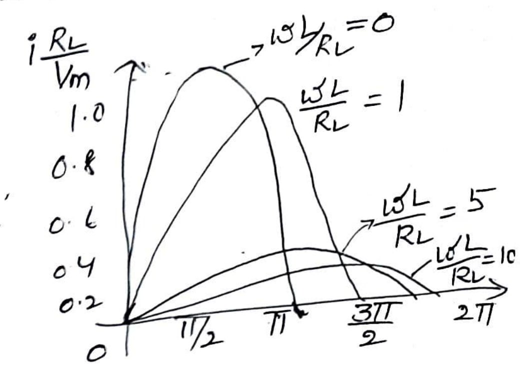
Half wave Rectifier



* inductor (or choke filter is placed. assume diode & choke resistances are negligible.

$V_i = V_m \sin\omega t = L\frac{di}{dt} + R_L i$.

The time at which I falls to zero is called cut out - point.

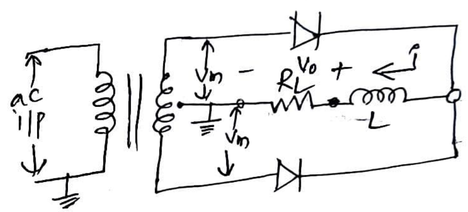


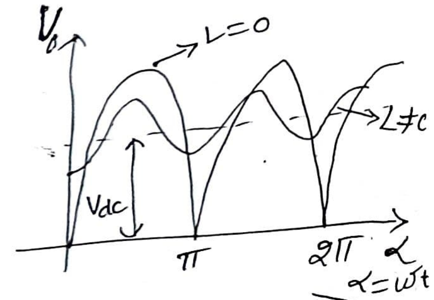
from graph., at constant R_L.

$L\uparrow \rightarrow$ fluctuation $\downarrow$.

($\downarrow$ of ac) more dc

Full wave :-





* Because of 'L', a dc level is established. since the impedance of 'L' ($X_L = \omega L$) $\uparrow$ with $\uparrow$ in freq, better filtering can be done for higher harmonics since inductor has ~~high dc resistance~~ voltage drop - o/p voltage also $\downarrow$

$$V_o = \underbrace{\frac{2V_m}{\pi}}_{dc} - \frac{4V_m}{\pi}\left[\frac{1}{3}\cos 2\omega t + \frac{1}{15}\cos 4\omega t + \frac{1}{35}\cos 6\omega t + \cdots\right]$$

neglecting higher terms and third

$$V_o = \underbrace{\frac{2V_m}{\pi}}_{dc} - \underbrace{\frac{4V_m}{3\pi}\cos 2\omega t}_{a.c.}$$

The total impedance is series of L and R_L at 2ω

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

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

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

The resulting current 'i'

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

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

(current lags voltage in inductor)

ripple factor →

$$r = \frac{\text{rms value of ac}}{\text{dc value}}$$

$$= \frac{\dfrac{4V_m}{\left(3\pi\sqrt{R_L^2 + 4\omega^2 L^2}\right)\sqrt{2}}}{\left(\dfrac{2V_m}{\pi R_L}\right)}$$

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

* If $\dfrac{4\omega^2 L^2}{R_L^2} >> 1$, $\boxed{r = \dfrac{R_L}{3\sqrt{2}\,\omega L}}$ —①

* If $R = \infty$ (no load / open circuit)

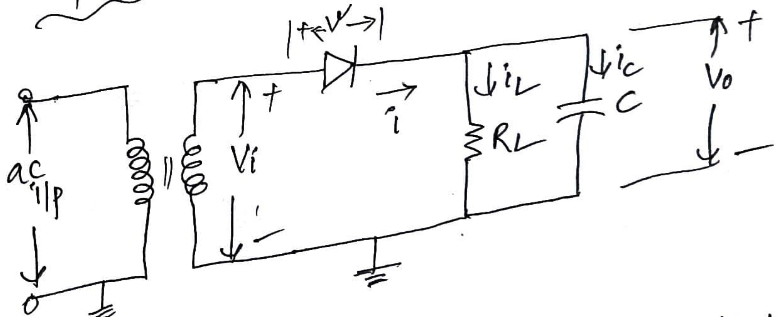
$$r = \frac{2}{3\sqrt{2}} = 0.471 \quad (< 0.482 \text{ normal full wave})$$

From ① → $r \downarrow$ when $L \uparrow$ and R_L should be small and constant to use inductor filter. The $\downarrow$ in 'r' is because of elimination of higher harmonics.

$$i = \frac{V_m}{\sqrt{R_L^2 + \omega^2 L^2}} \left[\sin(\omega t - \phi) + e^{-R_L t/L} \sin\phi\right]$$

where $\tan\phi = \dfrac{\omega L}{R_L}$

Capacitor filter:-



* Capacitor stores energy during the conduction period and delivers this energy to the load during non-conducting period. In this way, the time during which the current passes through load is prolonged, and the ripple is considerably decreased.

* If $R_L = \infty$, capacitor will charge to the potential V_m the transformer max. value. The capacitor will maintain this potential, for no path exists by which this charge is permitted to leak off, since diode will not pass -ve current. hence filtering is perfect, the capacitor voltage V_o remains constant at its peak value $= V_m$.

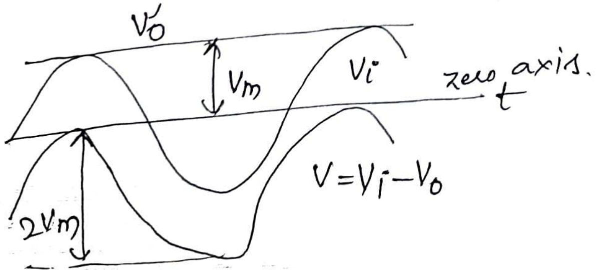
Diode voltage, $v = V_i - V_o$.

From above v is always -ve and $PIV = 2V_m$. hence
$(v = -V_m - V_m = -2V_m)$

the presence of capacitor causes PIV ~~~~ to increase from V_m to $2V_m$.

* R_L = finite. without 'C', the load I and V during the conduction period are sinusoidal. when 'C' is present, capacitor charges in step with the applied voltage. Also it must discharge through R_L only since diode doesn't allow. The diode acts as a switch which permits charge to flow into the capacitor when transformer voltage exceeds the capacitor vol. and then off's when the transformer vol. falls below that of capacitor (disconnects)

Voltages at no load



(a) Diode conducting:

* Consider diode drop is negligible. V_i directly applies across R_L. The point at which diode starts to conduct is called the cut in point and that at which it stops conducting is called cut out point.

since V_i is sine and is impressed across ||el R_L and 'c', the diode current (on phasor current

$$I = \underbrace{\left(\frac{1}{R_L} + j\omega c\right)}_{\text{admittance}} V$$

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

Since 'V' has a peak value V_m, then instantaneous current

$$i = V_m\left[\sqrt{\omega^2 c^2 + \frac{1}{R_L^2}}\right] \sin(\omega t + \phi) \qquad \phi = \tan^{-1}(\omega C R_L)$$

(I leads V in 'c')

when $C\uparrow$, peak diode $I \uparrow$. The conduction period will $\downarrow$ as the capacitance is made larger

The cut out time t_1 is found by equating diode current to zero

$$\sin(\omega t_1 + \phi) = 0.$$

$$\omega t_1 + \phi = n\pi$$

$n=1$ $\quad \omega t_1 = \pi - \tan^{-1}(\omega C R_L)$

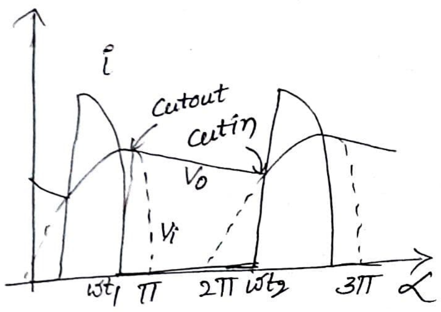


fig: diode current i and o/p voltage V_o in a half wave capacitor filtered rectifier

Diode Non-conducting:-

B/W cutout time t_1 and cutin time t_2, the diode is effectively out of the ckt and 'C' discharges through the load R_L with time const = $R_L C$

Capacitor Voltage :-

$$V_o = A \exp(-t/CR_L)$$

at $t = t_1$, the cutout time from fig :-

$$V_o = V_i = V_m \sin \omega t_1$$

when

$$A = (V_m \sin \omega t_1) \exp(t_1/R_L C)$$

$$\Rightarrow V_o = (V_m \sin \omega t_1) \exp(-(t_1 - t_1)/CR_L)$$

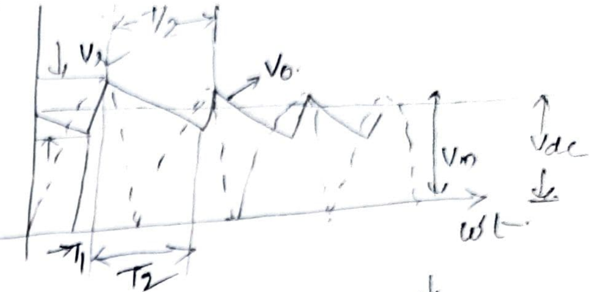
The exponential curve in the graph intersects sine wave $V_m \sin \omega t$ is the cutin point t_2. When time $> t_2$, the transformer vol. $V_i >$ cap. vol. V_o. Since the diode vol. is $V = V_i = V_o$, then "V" will be +ve beyond t_2 and diode will be conducting. Thus t_2 is cutin point.

* For Full wave cut-in point lies b/w π and 2π. Where exponential curve of V_o intersects this line. The cutout point is same as like half wave

Approximate Analysis:-

* V_o of full wave is indicated in graph of Capacitor discharge Vol. is V_r

$$V_{dc} = V_m - \frac{V_r}{2} \quad \text{(from diag.)}$$



A

rms value of triangular wave is independent of slopes from lengths of st. lines and depends on only peak value.

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

* If T_2 is non-conducting time, the capacitor, when discharging at const. rate I_{dc}, will lose charge $= I_{dc} T_2$

hence Capacitor vol.

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

for better filtering :-

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

$f \to$ fundamental power line freq.

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

$$r = \frac{V'_{rms}}{V_{dc}} = \frac{I_{dc}}{4\sqrt{3} f C V_{dc}} = \frac{1}{4\sqrt{3} f C R_L}$$

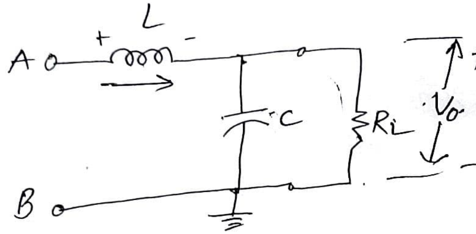
$$V_{dc} = V_m - \frac{I_{dc}}{4fC}$$

$\boxed{r \propto \frac{1}{LC}}$

'r' for half wave approx. double of fullwave. we need high 'C' for better regulation. It has disadvantages of poor regulation and high ripple at large impedance loads. (It means drawing large currents (power) - value of R_L is small)

L-Section filter:-

* This filter combines the ↓ ripple with ↑ load of series inductor with the ↑ ripple with ↑ load of shunt capacitor.



* The inductor offers a high series impedance to the harmonic terms, and the capacitor offers a low shunt impedance to them. The resulting current through R_L is smoothed out much more effectively than single 'L' (or) 'C' ckt

Regulation:-

Fourier series representation of o/p of voltage of the rectifier

$$V = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi}\cos 2\omega t \quad \text{—①}$$

→ two diodes replaced by battery in series with ac source having twice f

If the sum of the diode, transformer and choke resistances is 'R', then

$$V_{dc} = \frac{2V_m}{\pi} - I_{dc} R \quad \text{—②}$$

Ripple factor:-

* filter is to supress harmonics. so the reactance of choke must be large compared to ||el impedance of capacitor & resistor. The latter combination is made small by making the reactance of 'C' small when compared to R_L

* Assume entire ac (alternating current) passes through 'C' and none through R_L under these conditions, the net impedance across AB is approx.

$\Rightarrow X_L = 2\omega L$, (reactance of 'L' at second harmonic freq.)

The alternating I through ckt., (∵ from ①)

$$I'_{rms} = \frac{4V_m}{3\sqrt{2}\pi} \cdot \frac{1}{X_L}$$

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

when 'R' is neglected in eqn ②. The ac voltage across the load is the voltage across capacitor.

$$V'_{rms} = I'_{rms} X_C = \frac{\sqrt{2}}{3} V_{dc} \frac{X_C}{X_L}$$

where $X_C = \frac{1}{2\omega C}$ (reactance of capacitor at second harmonic)

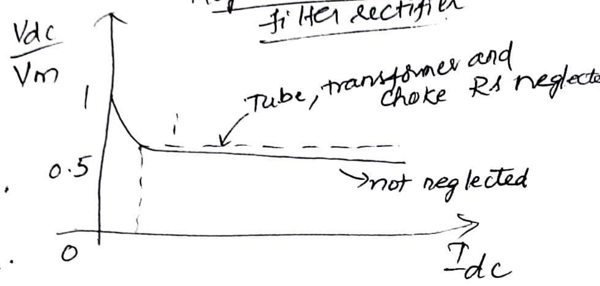
ripple factor

$$r = \frac{V'_{rms}}{V_{dc}} = \frac{\sqrt{2}}{3} \frac{X_C}{X_L}$$

$$\boxed{r = \frac{\sqrt{2}}{3} \cdot \frac{1}{2\omega C} \cdot \frac{1}{2\omega L}}$$

Thus the effect of combining the ↓ ripple because of simple L-filter and the ↑ ripple because of simple C-filter for ↑ loads is a constant ripple independent of load

Reg. curve of L-section filter rectifier



Critical Inductance :-

* Assume current flows through ckt at all times. If cutout points exist this analysis is invalid.

* When L is not present, Capacitor charges to V_m in each cycle. Now 'L' is made to present in ckt. Although the time over which the diode I will exist is some what lengthened, cutout may still occur. As 'L' is ↑, after a value of 'L' the diode continuously supplies to R_L and no cutout occurs. This value is called Critical Inductance L_c'

* To have current through entire cycle,

peak $\sqrt{2}\, I'_{rms}$ of ac of current must not exceed direct current

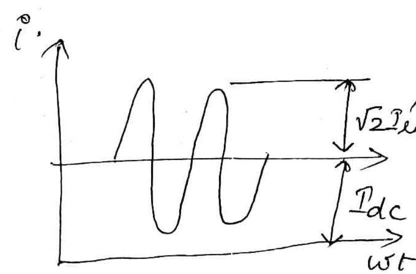


Fig: Diode current in a full wave ckt with L-section

$$\frac{V_{dc}}{R_L} \geq \sqrt{2}\, I'_{rms} = \frac{2V_{dc}}{3} \cdot \frac{1}{X_L}$$

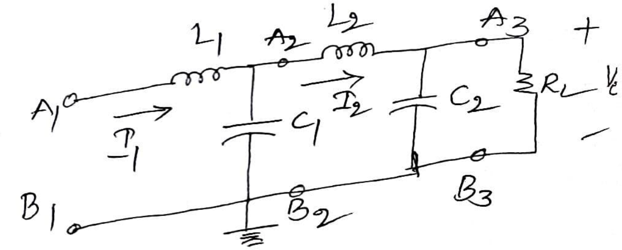
$$X_L \geq \frac{2R_L}{3}$$

$$\boxed{L_c = \frac{R_L}{3\omega}}$$

From graph of Regulation for constant 'L' and a varying load I. When $I = 0$ ($R_L = \infty$). The filter is of Capacitor type and o/p vol. V_m. With ↑ load I, the voltage falls, until at $I = I_c$ (current at $L = L_c$) the o/p potential is that corresponding to simple 'L' filter with no cutout ($\frac{2}{\pi}$/ $0.636\, V_m$). For values of $I > I_c$, the change in potential results from effects of resistance of elements in ckt.

Multiple L-section:

* Two L-sections are in cascade to have better filtering.



* Assume that reactances of all chokes > reactances of the capacitors and reactance of last capacitor is small compared with the resistance of load.

* Impedance b/w A_3 and B_3 is X_{C_2},
A_2 and B_2 is X_{C1}
A_1 and B_1 is X_{L1}

* The ac current $I_1 \approx \frac{\sqrt{2}\, V_{dc}}{3} \cdot \frac{1}{X_{L1}}$

ac voltage across C_1

$$V_{A_2B_2} = I_1 X_{C1}$$

$\left\{ \left(\because \text{from L-section } I'_{rms} = \frac{\sqrt{2}}{3} V_{dc} \cdot \frac{1}{X_L} \right. \right.$ for I_1 in previous page)

(ii) $$I_2 = \frac{V_{A_2B_2}}{X_{L2}}$$

ac voltage across C_2 and hence across R_L is approx

$$I_2 X_{C2} = I_1 \frac{X_{C2} X_{C1}}{X_{L2}} = \frac{\sqrt{2} V_{dc}}{3} \frac{X_{C2}}{X_{L2}} \frac{X_{C1}}{X_{L1}}$$

ripple factor

$$r = \frac{\sqrt{2}}{3} \frac{X_{C1}}{X_{L1}} \cdot \frac{X_{C2}}{X_{L2}}$$ ($\because$ divide above with V_{dc})

for 'n' similar section of multiple 'L' filter

$$r = \frac{\sqrt{2}}{3}\left(\frac{X_C}{X_L}\right)^n = \frac{\sqrt{2}}{3} \cdot \frac{1}{(16\pi^2 f^2 LC)^n}$$

At 60 HZ → from above →

$$LC = 1.76\left(\frac{0.471}{r}\right)^{1/n}.$$

($\because$ Assume imp. b/w A_1 and B_1 is X_{L1}, L_c is same for single section and first Inductor of multiple L-section)