IES/GATE

Electronics & Telecommunication Engineering

VOLUME-IV

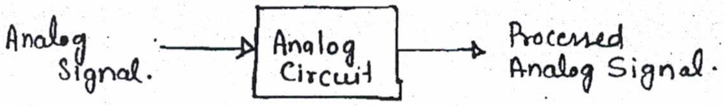
Analogue Electronic Circuits
Digital Electronics

Contents

Introduction

Analog Electronic Circuit:-

A circuit which can process analog signals.



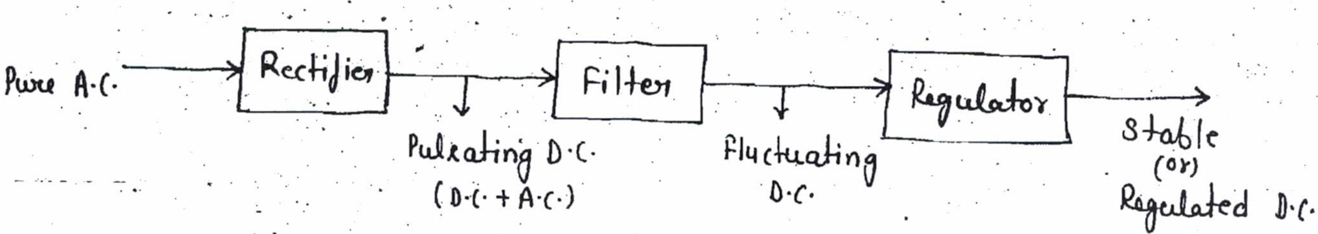
→ Since majority of real time signals are analog in nature so they can be directly processed using analog circuit where as digital processing required analog to digital and digital to analog conversion.

→ An analog circuit can also operate at higher power levels.

Power Supply:-

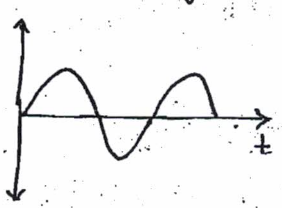
It is an electronic system which converts A.C. Power into D.C. Power.

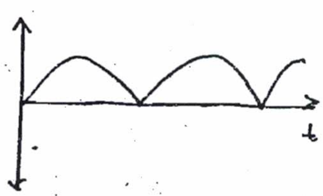
A.C. to D.C. conversion is required because majority of electronic appliances operate with DC power. A regulated power supply is an interconnection of rectifier, filter and regulator.



Rectifier:-

A circuit which can convert a pure A.C. signal into pulsating D.C. signal (or) A circuit which converts a bidirectional signal into unidirectional signal.





Pure A.C.:-

→ It has periodic variations.

→ It is bidirectional.

→ It has zero avg. or D.C. value.

→ No higher harmonics except fundamental frequency (f_0).

Pulsating D.C.:-

→ It has periodic variations.

→ It is unidirectional.

→ It has non zero average or D.C. value.

→ It has higher harmonics.

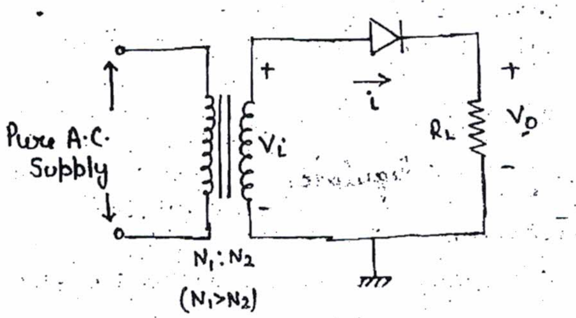
Periodic variation of pulsating D.C. signal indicates presence of A.C. component and non zero avg. indicates presence of D.C. component therefore Pulsating D.C. is considered to be combination of A.C. and D.C.

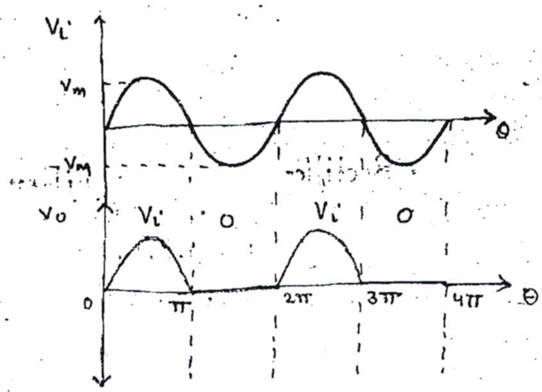
Rectifier

- Low Voltage Rectifier
  - → Provide Low D.C. o/p voltage.
  - → Formed using Diode
  - Half Wave Rectifier
  - Full Wave Rectifier
    - Centre tapped Full Wave Rectifier
    - Bridge Rectifier.
- High Voltage Rectifier.
  - → Formed using SCR

HALF WAVE RECTIFIER:-

Step down transformer is used in all low voltage rectifiers. It converts pure A.C. voltage having higher R.M.S value into pure A.C. voltage having smaller R.M.S. value.





let $V_i = V_m \sin \omega_0 t = V_m \sin \alpha$

V_m = Peak A.C. input.

$\frac{V_m}{\sqrt{2}}$ = R.M.S A.C. i/p.

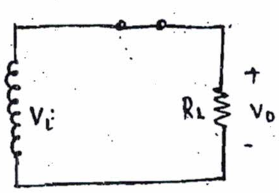
ω_0 or f_0 = Line Frequency or frequency of A.C. supply.

Operation:-

Let V_i be +ve $(0 < \alpha < \pi)$

When V_i is +ve diode is F.B. ≡ S.C.

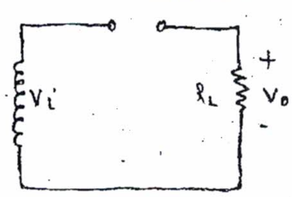
$V_0 = V_i$



Let V_i be -ve $(\pi < \alpha < 2\pi)$

When V_i is -ve diode is R.B. ≡ O.C.

$V_0 = 0$



V_i appears across the diode in O.C. condition only.

Analysis of Half wave Rectifier :-

① Instantaneous o/p Current :- (i)

* $0 < \alpha < \pi$:- Diode is F.B. $\equiv R_F$ (A few ohm)

By KVL in secondary Loop

$$-V_i + iR_F + iR_L = 0$$

$$i = \frac{V_i}{R_F + R_L}$$

$$i = \frac{V_m \sin\alpha}{R_F + R_L}$$

Let $\boxed{\frac{V_m}{R_F + R_L} = I_m}$ Peak o/p Current

$$\boxed{i = I_m \sin\alpha}$$

* $\pi < \alpha < 2\pi$:- Diode is R.B $\boxed{i \approx 0}$

Silicon diode is a better rectifying device because it has much smaller reverse current (nA).

Thus

$$\boxed{i = \begin{cases} I_m \sin\alpha & ; 0 < \alpha < \pi \\ 0 & ; \pi < \alpha < 2\pi \end{cases}}$$

② D.C. output Current :- (I_{DC})

$$I_{DC} = \text{Avg. value of } i = \frac{\text{Area}}{\text{Period}}$$

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

$$= \frac{I_m}{2\pi}\int_0^{\pi} \sin\alpha \, d\alpha$$

$$\boxed{I_{DC} = \frac{I_m}{\pi}}$$ D.C. Load Current. Avg. Load Current.

③ R.M.S. o/p Current :- (I_{rms})

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

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

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

④ R.M.S A.C. o/p Current :- (I'_{rms})

The o/p of rectifier is a combination of A.C. and D.C components therefore

$$i = \text{D.C.} + \text{A.C. component}$$

$$i = I_{DC} + i'$$

$$i' = i - I_{DC}$$

$$I'_{rms} = \text{R.M.S value of } i' = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i'^2 \, d\alpha}$$

$$I'_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi}(i - I_{DC})^2\,d\alpha} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i^2\,d\alpha + \int_0^{2\pi} I_{DC}^2\,d\alpha - 2\int_0^{2\pi} i\,I_{DC}\,d\alpha}$$

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

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

&

I_{rms} is also called reading of A.C. Ametter because an A.C. ametter connected in series with R_L records I'_{rms}.

Ripple Factor:-

Ripple factor refers to the unwanted A.C. component present in the output of rectifier.

Ripple factor is a measure of the amount of A.C. components of ripple.

Since A.C. component is unwanted, ripple factor should be smaller and ideally it should be zero.

Mathematically it is defined as:-

$$\gamma = \frac{\text{R.M.S. A.C. Component}}{\text{D.C. component}}$$

$$= \frac{V'_{rms}}{V_{DC}} \text{ or } \frac{I'_{rms}}{I_{DC}}$$

$$\boxed{= \frac{\sqrt{I_{RMS}^2 - I_{DC}^2}}{I_{DC}} = \sqrt{\frac{I_{rms}^2}{I_{DC}^2} - 1}}$$

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

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

In the o/p. of half wave rectifier A.C. component is greater than D.C. component.

Input Power (P_i):-

It is the avg. of product of instantaneous voltage across secondary winding and instantaneous current through secondary winding.

$$P_i = \text{Avg. value of } \{V_i \times i\}$$

$$= \frac{1}{2\pi}\int_0^{2\pi} V_i \times i\,d\alpha$$

$$= \frac{1}{2\pi}\int_0^{2\pi} (R_F + R_L)\,i^2\,d\alpha$$

$$\boxed{P_i = I_{rms}^2 (R_F + R_L)}$$

Efficiency (η):-

Efficiency is a measure of the ability of a rectifier to convert input power into D.C. power.

Mathematically,

$$\eta = \frac{\text{D.C. o/p power}}{\text{i/p power}}$$

$$\eta = \frac{I_{DC}^2 R_L}{I_{rms}^2 (R_F + R_L)} \times 100\%$$

$$\eta = \frac{(I_m^2/\pi^2) R_L}{(I_m^2/4)\ R_F + R_L} \times 100 = \frac{400}{\pi^2}\ \frac{R_L}{R_F+R_L}\ \%$$

$$\boxed{\eta = 40.528 \frac{R_L}{R_F+R_L}\ \%} \qquad \boxed{\eta = 40.528 \frac{R_L}{R_F+R_L+R_s}\ \%}$$

R_s = Secondary Resistance.

If diode is ideal or $R_F = 0$ then maximum efficiency of 40.53% is obtained.

⑧ D.C. Diode Voltage :- ($V_{diode,DC}$)

It is the avg. value of the instantaneous voltage across the diode.

$0 < \alpha < \pi$ Diode is in F.B.

$V_{Diode} = i R_F \simeq 0$ [∵ R_F is small]

$\pi < \alpha < 2\pi$ Diode is in R.B.

V_i appears across diode.

$V_{Diode} = V_i = V_m \sin\alpha$

$$V_{Diode} = \begin{cases} 0 & ;\ 0 < \alpha < \pi \\ V_m \sin\alpha & ;\ \pi < \alpha < 2\pi \end{cases}$$

D.C. Diode voltage is

$V_{Diode,DC}$ = Avg. of V_{Diode}

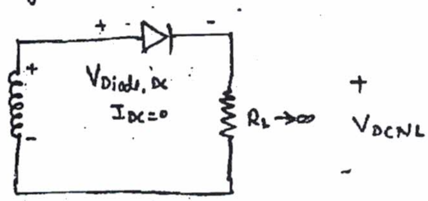
$$= \frac{1}{2\pi}\int_0^{2\pi} V_{Diode}\, d\alpha = \frac{1}{2\pi}\int_0^{\pi} 0\, d\alpha + \frac{1}{2\pi}\int_{\pi}^{2\pi} V_m \sin\alpha\, d\alpha$$

$$\boxed{V_{Diode,DC} = -\frac{V_m}{\pi}}$$

⑨ No Load D.C. o/p Voltage :- (V_{DCNL}) :-

It is the D.C. o/p voltage of a rectifier when load current is zero.

$V_{DCNL} = V_{DC}\big|_{I_{DC}=0}$



$V_{Diode,DC} + V_{DCNL} = 0$

$V_{DCNL} = -V_{Diode,DC}$

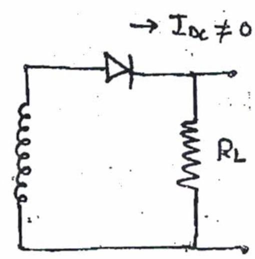
$$\boxed{V_{DCNL} = \frac{V_m}{\pi}}$$

V_{DCNL} is also called maximum o/p D.C. voltage.

⑩ Full Load D.C. o/p Voltage :- (V_{DCFL}) :-

It is the o/p voltage of a rectifier when load current is not zero.

When load current flows D.C. voltage drop takes place in D.C. resistance of secondary winding and across the diode.



$V_{DCFL} = V_{DCNL}$ − Internal voltage Drop

$$V_{DCFL} = \frac{V_m}{\pi} - I_{DC} R$$ where $R = R_{SW} + R_F$

or

$$V_{DCFL} = I_{DC} \cdot R_L$$

Nb: If $R_L \downarrow$ then $I_{DC} \uparrow \rightarrow I_{DC} \times R \uparrow \rightarrow V_{DCFL} \downarrow$

- D.C. o/p voltage of a rectifier decreases with increase in load current.

) Regulation Factor:-

It is a measure of the change in D.C. o/p voltage due to change in load current.

∴ Mathematically,

$$\%\ \text{Regulation} = \frac{V_{DCNL} - V_{DCFL}}{V_{DCFL}} \times 100\%$$

$$= \frac{(V_m/\pi) - \{(V_m/\pi) - I_{DC} R\}}{I_{DC} R_L} \times 100\%$$

$$\%\ \text{Regulation} = \frac{R}{R_L} \times 100\%$$ where $R = R_{SW} + R_F$

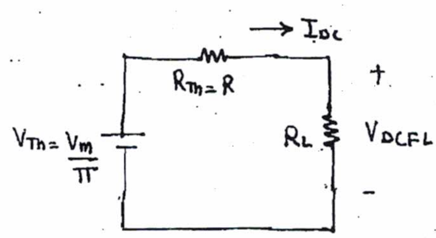
Nb:

- If winding and diode are ideal then %age regulation becomes zero.
- For a power supply %age regulation should be zero ideally.

) Thevenin's Equivalent Circuit:-

$$V_{DCFL} = \frac{V_m}{\pi} - I_{DC} R$$

$\frac{V_m}{\pi} \downarrow V_{Th}$, $R \downarrow R_{Th}$



Peak Inverse voltage (or) PIV:-

It is the maximum voltage which appears across diode in non conducting state i.e. in reverse bias in a rectifier.

PIV = Max. Diode voltage when diode is R.B.

$= |V_m \sin\alpha|_{max}$

$$PIV = V_m$$

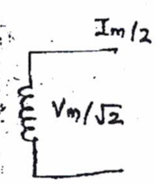
Diode will be safe if PIV is less than breakdown voltage.

Transformer Utilization Factor (TUF):-

It is the ratio of D.C. o/p power and A.C. rating of the transformer secondary winding.

For any winding A.C. rating is the product of R.M.S voltage across the winding and R.M.S current through the winding.

A.C. rating is expressed in volt-Ampere.



$$TUF = \frac{P_{DC}}{\text{A.C. rating of secondary}}$$

$$= \frac{I_{DC}^2 R_L}{(V_m/\sqrt{2})(I_m/2)}$$

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

$$= \frac{2\sqrt{2}}{\pi^2} \frac{I_m^2 R_L}{I_m^2 (R_F + R_L)}$$

$$\boxed{TUF = \cdot 286 \frac{R_L}{R_F + R_L}}$$

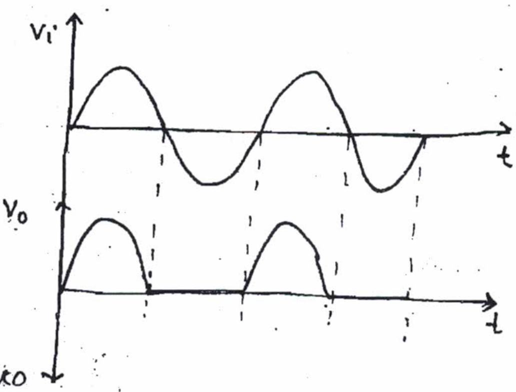
Maximum TUF = ·286 or 28·6%.

TUF is useful in calculation of D.C. o/p power if A.C. rating of secondary winding is known.

$$\boxed{P_{DC} = TUF \times A \cdot C \cdot \text{ Rating}}$$

(15) Frequency of o/p:- (Ripple Frequency):-

Since time period of i/p and o/p waveform is equal there frequencies will be the same



$$\boxed{\text{Ripple frequency} = f_0}$$

where f_0 = Line frequency or A.C. supply frequency.

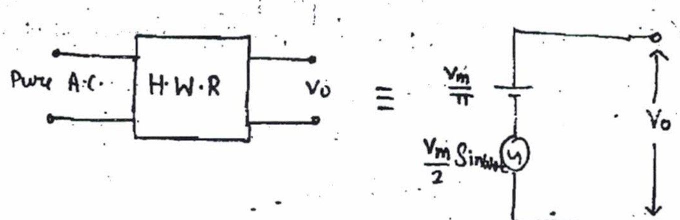
Output waveform is non sinusoidal therefore it also has higher harmonics which can be found in the trigonometric fourier series of Vo.

$$\boxed{V_0 = \frac{V_m}{\pi} + \frac{V_m}{2} \sin \omega_0 t - \frac{2V_m}{\pi} \sum_{k = \text{even}} \frac{\cos k\omega_0 t}{(k+1)(k-1)}}$$

D.C. Component — A.C. Component — A.C. Components (Harmonics)

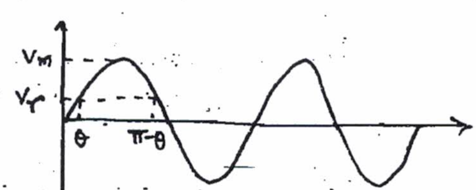
If higher harmonics are neglected then

$$V_0 = \frac{V_m}{\pi} + \frac{V_m}{2} \sin \omega_0 t$$



(16) Angle of Conduction:-

It is the duration for which diode conducts in a rectifier. If diode is ideal conduction takes place from 0 to π therefore angle of conduction will be 180°.



If diode has cut-in voltage V_r, conduction occurs when i/p voltage exceeds cut in voltage therefore a non ideal diode conducts from θ to $\pi-\theta$ and conduction angle becomes $180^\circ - 2\theta$.

At $\alpha = \theta$

$$V_i = V_m \sin\theta = V_r$$

$$\sin\theta = \frac{V_r}{V_m}$$

hence,

$$\boxed{\theta = \sin^{-1}\left\{\frac{V_r}{V_m}\right\}}$$

i) Form Factor:-

It is the ratio of R.M.S value and average value.

$$F.F = \frac{I_{rms}}{I_{avg}} = \frac{I_{rms}}{I_{DC}}$$

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

$$= \pi/2$$

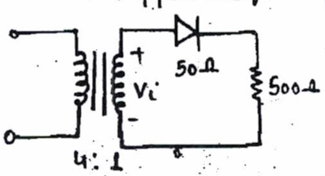
$$\boxed{F.F = 1.57}$$

F.F. is a measure of smoothness in the waveform. Smaller F.F. indicates greater smoothness.

$$\boxed{\gamma = \sqrt{(F.F)^2 - 1}}$$

Q:- A half wave rectifier uses a 4:1 transformer and a diode with $R_F = 50\Omega$. If load resistance is 500Ω and primary voltage is 220 V rms, 50 Hz. Calculate
(i) D.C. o/p current and voltage (ii) A.C. o/p current and voltage
(iii) DC diode current and voltage (iv) RMS o/p current and voltage
(v) PIV and Ripple frequency (vi) I/p power and D.C. o/p power (vii) % efficiency & Regulation.

Soln:-



$$V_i = \frac{220}{4} = 55V \text{ rms}$$

$$\frac{V_m}{\sqrt{2}} = 55$$

$$V_m = 55\sqrt{2} = 77.78 \text{ volts}$$

$$I_m = \frac{V_m}{R_F + R_L} = 141.42 mA$$

Since Diode and R_L are connected in series D.C. diode current will be same as D.C. o/p current.

(i) D.C. o/p current & D.C. o/p voltage

$$I_{DC} = \frac{I_m}{\pi} = \frac{141.42}{\pi} = 45.02 mA$$

$$V_{DC} = \frac{V_m}{\pi} = \frac{77.78}{\pi} = 22.510 = I_{DC} R_L$$ } Ans

(ii) $I'_{rms} = \gamma I_{DC} = \sqrt{I_{rms}^2 - I_{DC}^2} = 1.21 \times 45.02$

$I'_{rms} = 54.47 mA$ Ans

$V'_{rms} = I'_{rms} \times R_L = 54.47 \times 10^{-3} \times 500$

$V'_{rms} = 27.24$ Volt Ans

(iii) $I_{Diode, DC} = I_{DC} = 45 mA$ Ans

$V_{Diode, DC} = -\frac{V_m}{\pi} = -24.75$ Volts. Ans

(iv) $I_{rms} = \frac{I_m}{2} = \frac{141.42}{2} = 70.71 mA$ Ans

$V_{rms} = \frac{V_m}{2} = 38.89$ Volts Ans

(v) PIV = V_m = 77.78 Volts, f_0 = 50 Hz } Ans

(vi) $P_{i/p} = I_{rms}^2 (R_F + R_L) = 2.75$ watts

$P_{o/p\,DC} = I_{DC}^2 R_L = 1.0134$ watts.

(vii) $\% \eta = 40.5 \frac{R_L}{R_F + R_L} = 36.81\%$ Ans

% Regulation = $\frac{R}{\ }\times 100\% = \frac{50}{\ } \times 100 = 10\%$ Ans

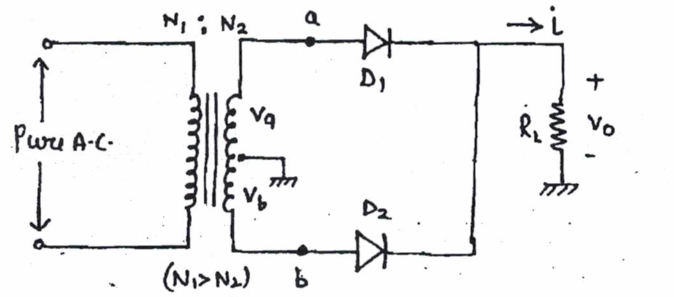
FULL WAVE RECTIFIER:-

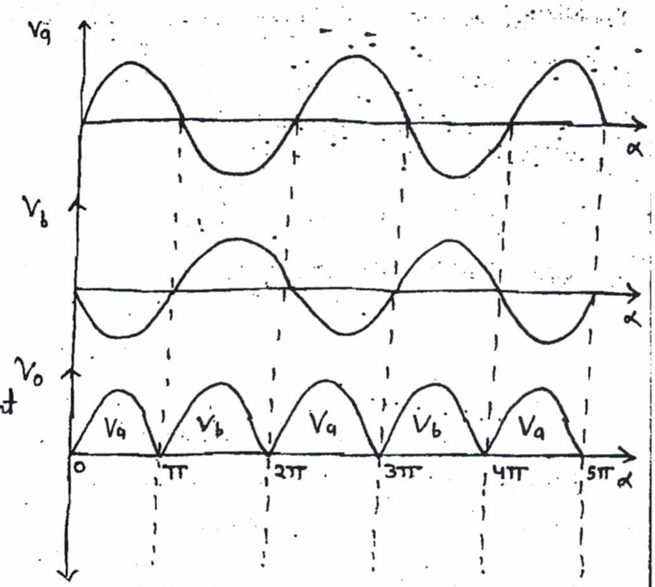
Center Tapped Full Wave Rectifier:-

* Secondary winding of transformer is center tapped i.e. winding is divided into two halves and each half has equal no. of turns.
* If primary winding has N_1 turns then each half of secondary winding has N_2 turns.
* V_a and V_b are equal in magnitude but opposite in sign i.e. $\boxed{V_b = -V_a}$

If $V_a = V_m \sin\alpha$

then $V_b = -V_m \sin\alpha$





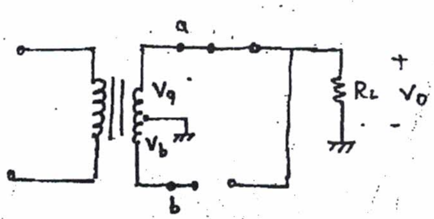
* A Full wave rectifier is functionally equivalent to two half wave rectifiers.
* D_1 performs rectification of V_a and D_2 performs rectification of V_b.

Operation:-

1- $0 < \alpha < \pi$:-

V_a is +ve ⇒ D_1 is F.B. ≡ S/C

V_b is −ve ⇒ D_2 is R.B ≡ O/C



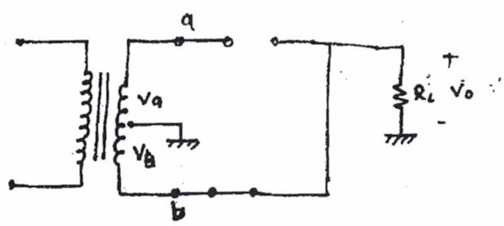
As node a is connected to R_L so V_a appears across R_L.

$\boxed{V_o = V_a}$

2- $\pi < \alpha < 2\pi$:-

V_a is −ve ⇒ D_1 is R.B. ≡ O/C

V_b is +ve ⇒ D_2 is F.B ≡ O/C



As node b is connected to R_L so V_b appears across R_L.

$\boxed{V_o = V_b}$

Analysis of Full Wave Rectifier:-

(1) Instantaneous o/p Current:-

$0 < \alpha < \pi$:-

D_1 is F.B. ≡ R_F

By KVL

$$V_a = iR_F + iR_L$$

$$i = \frac{V_a}{R_F + R_L}$$

$$i = \frac{V_m \sin\alpha}{R_F + R_L} = I_m \sin\alpha$$

$\pi < \alpha < 2\pi$:-

D_2 is in F.B. ≡ R_F

By KVL

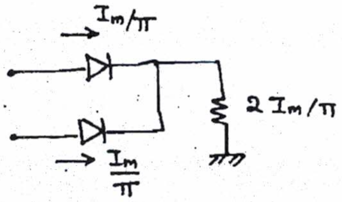
$$V_b = i(R_F + R_L)$$

$$i = \frac{V_b}{R_F + R_L} = -\frac{V_m \sin\alpha}{R_F + R_L}$$

$$i = -I_m \sin\alpha$$

Thus,

$$i = \begin{cases} I_m \sin\alpha & ; 0 < \alpha < \pi \\ -I_m \sin\alpha & ; \pi < \alpha < 2\pi \end{cases}$$



1) D.C. o/p Current :-

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

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

2). R.M.S o/p Current :-

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

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

4) R.M.S A.C o/p Current :-

$$I'_{rms} = \text{rms value of } i' = \text{rms value of } (i - I_{DC})$$

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

5) Ripple Factor :-

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

$$\gamma = \sqrt{\left(\frac{I_m/\sqrt{2}}{2I_m/\pi}\right)^2 - 1} = \sqrt{\frac{\pi^2}{8} - 1}$$

$$\gamma = .483$$

In the o/p of Full wave rectifier A.C. component is less than D.C. component.

6) Input Power (P_i):-

$$P_i = \frac{1}{2\pi}\left[\int_0^{\pi} V_a \cdot i \, d\alpha + \int_{\pi}^{2\pi} V_b \, i \, d\alpha\right]$$

$$= (R_F + R_L)\cdot\frac{1}{2\pi}\int_0^{2\pi} i^2 \, d\alpha$$

$$P_i = I_{rms}^2 (R_F + R_L)$$

7) Efficiency (η):-

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

$$= \frac{I_{DC}^2 R_L}{I_{rms}^2 (R_F + R_L)} \times 100\%$$

$$= \frac{4I_m^2 \times 2}{\pi^2 I_m^2}\,\frac{R_L}{R_F + R_L} \times 100\%$$

$$= \frac{800}{\pi^2}\,\frac{R_L}{R_F + R_L} \times 100\%$$

$$\%\eta = 81\,\frac{R_L}{\ldots}\,\%$$

⑧ D.C. Diode voltage:-

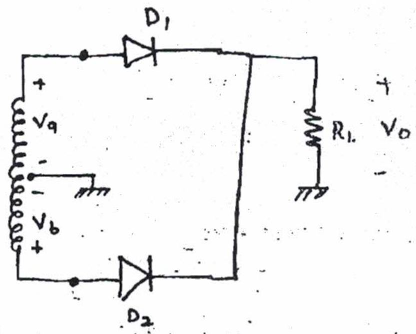
Consider diode D_1

Let V_{Diode} be the instantaneous voltage across D_1

$0 < \alpha < \pi$:-

D_1 is F.B

$V_{Diode} = i R_F \simeq 0$



$\pi < \alpha < 2\pi$:-

D_2 is in F.B.

By KVL

$$V_b - V_a + V_{Diode} = 0$$

$$V_{Diode} = V_a - V_a$$

$$V_{Diode} = 2V_m \sin\alpha$$

Thus

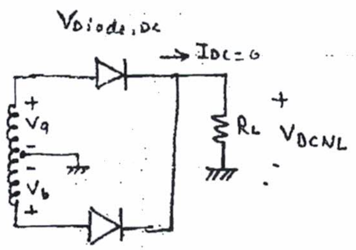
$$V_{Diode} = \begin{cases} 0 & ; 0 < \alpha < \pi \\ 2V_m \sin\alpha & ; \pi < \alpha < 2\pi \end{cases}$$

DC Diode voltage is

$$V_{Diode, DC} = \frac{1}{2\pi} \int_0^{2\pi} V_{Diode}\, d\alpha$$

$$V_{Diode, DC} = -\frac{2V_m}{\pi}$$

⑨ No Load D.C. o/p voltage (V_{DCNL}):-



$$V_{DCNL} = V_{DC}\Big|_{I_{DC}=0}$$

By KVL

$$-0 + V_{Diode,DC} + V_{DCNL} = 0$$

$$V_{DCNL} = +\frac{2V_m}{\pi}$$

⑩ Full Load DC o/p Voltage (V_{DCFL}):-

$$V_{DCFL} = V_{DC}\Big|_{I_{DC} \neq 0}$$

$V_{DCFL} = V_{DCNL} -$ Internal voltage drop

$$V_{DCFL} = \frac{2V_m}{\pi} - I_{DC} R$$

where $R = \frac{R_{SW}}{2} + R_F$

or

$$V_{DCFL} = I_{DC} \cdot R_L$$

⑪ Regulation factor:-

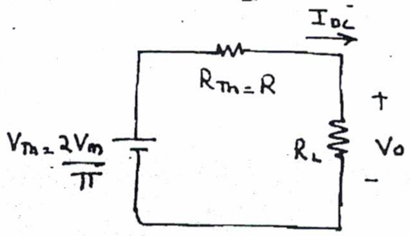
$$\%\text{Regulation} = \frac{V_{DCFL} - V_{DCNL}}{V_{DCFL}} \times 100\%$$

$$\%\text{Regulation} = \frac{R}{R_L} \times 100\%$$

⑫ **Thevenin's Equivalent :-**

$$V_{OCFL} = \frac{2V_m}{\pi} - I_{DC} R$$

($\frac{2V_m}{\pi} \rightarrow V_{Th}$, $R \rightarrow R_{Th}$)



⑬ **Peak Inverse Voltage :-**

$$PIV = |V_{Diode}|_{max} \quad \text{when diode is in Reverse bias}$$

$$= |2V_m \sin\alpha|_{max}$$

$$\boxed{PIV = 2V_m}$$

⑭ **Transformer Utilization Factor (or) TUF :-**

Secondary circuit in full wave rectifier is combination of two half wave rectifiers therefore the value of TUF with respect to secondary winding is two times the T.U.F In half wave rectifier.

$$\text{Max } T.U.F_{SW} = 2 \times .286$$

$$\boxed{TUF_{SW,max} = .57}$$

TUF with respect to primary is defined as

$$TUF_{PW} = \frac{D.C \text{ o/p power}}{A.C \text{ rating of primary winding}}$$

$$= \frac{I_{DC}^2 \cdot R_L}{\frac{V_{m_1}}{\sqrt{2}} \cdot \frac{I_{m_1}}{\sqrt{2}}}$$

$$\because V_{m_1} I_{m_1} = V_m \cdot I_m = I_m^2 (R_F + R_L)$$

$$TUF_{PW} = \frac{2 I_{DC}^2 R_L}{I_m^2 \, R_F + R_L} = \frac{2 \times 4}{\pi^2} \frac{R_L}{R_F + R_L}$$

$$= \frac{8}{\pi^2} \times \frac{R_L}{R_F + R_L} \times 100\%$$

$$\boxed{TUF_{PW} = 81 \frac{R_L}{R_F + R_L} \%}$$

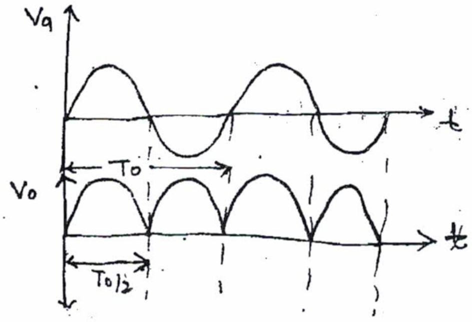
$$\text{Avg. TUF} = \frac{TUF_{PW} + TUF_{SW}}{2} = \frac{.57 + .81}{2}$$

$$\boxed{\text{Avg. TUF} = .69}$$

⑮ **Ripple Frequency or Frequency of o/p :-**

As time period of o/p is $T_o/2$, frequency of o/p will be two times the frequency of input.

$$\boxed{\text{Ripple frequency} = 2f_o}$$



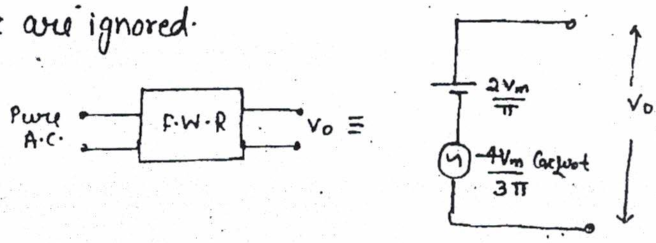
Trigonometric fourier series for signal voltage V_o is

$$\boxed{V_o = \frac{2V_m}{\pi} - \frac{4V_m}{\pi} \sum \frac{\cos k\omega_o t}{\ldots}}$$

A.C. componente has even harmonice i.e. $2\omega_0$, $4\omega_0$, $6\omega_0$ etc. It does not have fundamental frequency ω_0. Due to this filtering process will be relatively easier in F.W.R

If higher frequency harmonice are ignored.

$$V_0 = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi}\cos 2\omega_0 t$$



(16) Angle of Conduction:-

If diodes are ideal then each diode conducte for 180° and net conduction angle will become 360°.

If diodes are non ideal then each diode conducte for 180-2θ and overall conduction angle becomes 360°- 4θ.

D_1 conducte from θ to $\pi-\theta$

D_2 conducte from $\pi+\theta$ to $2\pi-\theta$

where $\theta = \sin^{-1}\left[\frac{V_r}{V_m}\right]$

(17) Form Factor:-

$$F.F = \frac{I_{rms}}{I_{DC}} = \frac{I_m/\sqrt{2}}{2I_m/\pi}$$

$$= \frac{\pi}{2\sqrt{2}}$$

$$\boxed{F.F = 1.11}$$

Advantages:-

1- Small Ripple Factor.
2- Larger efficiency.
3- larger T.U.F.
4- Larger D.C. o/p voltage & current.
5- Filtering of A.C. component is easier.

Disadvantages:-

1- Higher Peak Inverse voltage (PIV).
2- It is necessary to use center tapped transformere which is costlier and bigger in size.

Pb:- A Full wave rectifier uses a 2:1 center tapped transformer and diodes with internal resistance 50Ω. If load resistance is 1kΩ and primary voltage is 120V R.M.S and 60Hz. Calculate

a) DC & AC Load current b) DC & AC Load voltage c) DC diode voltage & current.
d) PIV & Ripple Factor e) Efficiency & regulator factor.

Soln:-

$$\frac{V_P}{V_S} = \frac{2}{1} \Rightarrow V_S = 60\ V_{rms}$$

$$V_m = 60\sqrt{2}\ \text{volts}$$

$$I_m = \frac{V_m}{R_f + R_L} = \frac{60\sqrt{2}}{1050} = 80.81\,mA$$

a) $I_{DC} = \frac{2I_m}{\pi} = 51.442\,mA$, $I_{rms} = \gamma \times I_{DC} = .483 \times 51.42 = 24.83\,mA$. Ans

b) $V_{DC} = I_{DC} R_L = 51.42$ Volts.

$V'_{RMS} = \gamma \times V_{DC} = 24.83$ Volts. Ans

c) $V_{Diode,dc} = -\frac{2V_m}{\pi} = -54$ Volts.

$I_{Diode,dc} = \frac{I_m}{\pi} = 25.7 mA$ Ans

d) $PIV = 2V_m = 169.7$ Volts

$\because f_0 = 60 Hz$

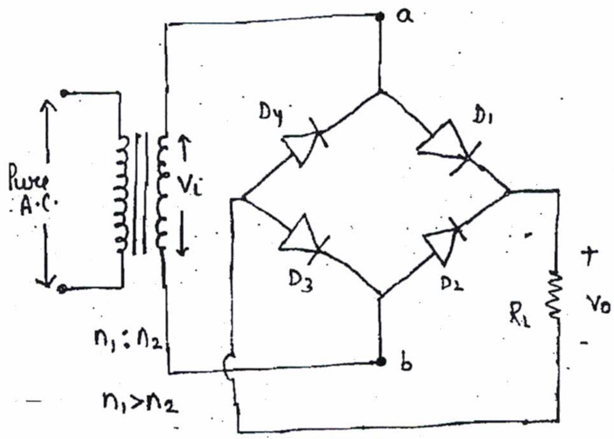
Ripple frequency $= 2f_0 = 120 Hz$. Ans

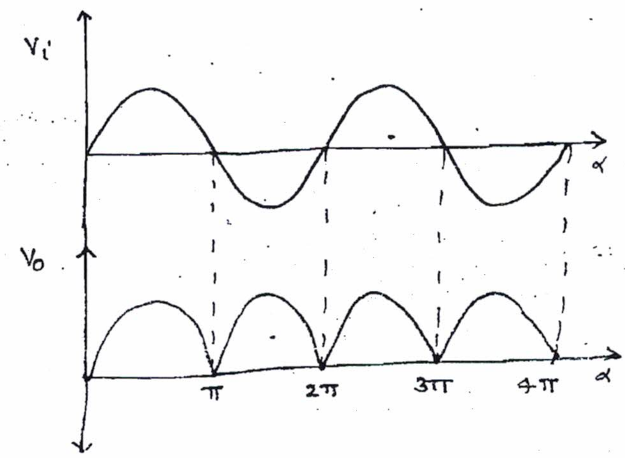
e) $\% \eta = 81 \times \frac{R_L}{R_F + R_L} = 77.14\%$

$\%$ regulation $= \frac{R}{R_L} \times 100 = 5\%$. Ans

Bridge Rectifier:-

It uses a normal step down transformer and 4 diodes connected in the form of bridge network.





Operation:-

V_i is pure A.C. voltage of smaller R.M.S. values

Let $V_i = V_m \sin\alpha$

(i) $0 < \alpha < \pi$:-

V_i is +ve node a is +ve w.r.t node b.
Diode D_1 and D_3 are ON and diode D_2 & D_4 are OFF.
Current flow takes place in the loop consisting D_1, R_L, D_3 and secondary winding.

$D_1 \rightarrow R_L (\downarrow) \rightarrow D_3 \rightarrow$ Secondary $(\uparrow)$

(ii) $\pi < \alpha < 2\pi$:-

V_i is -ve node a is -ve w.r.t node b.
Diode D_2 & D_4 are ON and diode D_1 & D_3 are OFF.
Current flow takes place in the loop consisting of D_2, R_L, D_4 & Secondary winding.

$D_2 \rightarrow R_L (\downarrow) \rightarrow D_4 \rightarrow$ Secondary $(\downarrow)$

→ Current through the secondary winding is bidirectional.

→ Current through R_L is unidirectional or pulsating D.C. because it flows in downward direction.

Analysis of Bridge Rectifier:-

① **Instantaneous o/p Current:-**

$$i = \begin{cases} I_m \sin\alpha & ; 0 < \alpha < \pi \\ -I_m \sin\alpha & ; \pi < \alpha < 2\pi \end{cases}$$

where,

$$I_m = \frac{V_m}{2R_F + R_L}$$

② $$I_{DC} = \frac{2I_m}{\pi}$$

③ $$I_{rms} = \frac{I_m}{\sqrt{2}}$$

④ $$I'_{rms} = \sqrt{I_{rms}^2 - I_{DC}^2}$$

⑤ $$\gamma = .483$$

⑥ $$P_i = I_{rms}^2 (2R_F + R_L)$$

⑦ $$\%\eta = \frac{81 R_L}{2R_F + R_L}\%$$

⑧ **DC Diode Voltage:-**

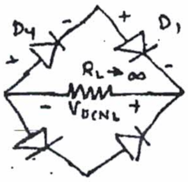
Considering D_1

$$V_{Diode} = \begin{cases} 0 & ; 0 < \alpha < \pi \\ V_m \sin\alpha & ; \pi < \alpha < 2\pi \end{cases}$$

$$V_{Diode,DC} = \frac{1}{2\pi}\int_0^{2\pi} V_{Diode}\, d\alpha$$

$$V_{Diode,DC} = \frac{-V_m}{\pi}$$

⑨ **No load DC o/p Voltage (V_{DCNL}):-**



By KVL in loop $D_1 D_4 R_L$

$$V_{Diode,DC} + V_{DCNL} + V_{Diode,DC} = 0$$

$$V_{DCNL} = -2V_{Diode,DC}$$

$$V_{DCNL} = +\frac{2V_m}{\pi}$$

⑩ **Full Load DC o/p Voltage (V_{DCFL}):-**

$$V_{DCFL} = \frac{2V_m}{\pi} - I_{DC} R$$

where,

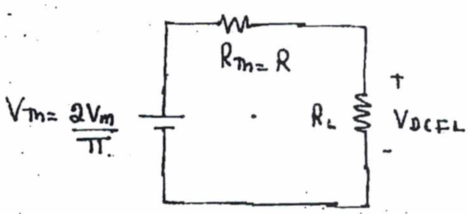
$$R = R_{sw} + 2R_F$$

$$V_{DCFL} = I_{DC} \times R_L$$

⑪ **% Regulation:-**

$$\%\ \text{Regulation} = \frac{R}{R_L} \times 100\%$$

⑫ **Thevenin's Equivalent Circuit:-**



⑬ **Peak Inverse Voltage:-**

$PIV = |V_{Diode}|_{max}$ when diode is in R.B.

$= |V_m \sin\alpha|_{max}$

$$PIV = V_m$$

⑭ **Transformer Utilization factor:-**

$$TUF = \frac{\text{D.C. o/p power}}{\text{A.C. Rating of Secondary winding}}$$

$$= \frac{I_{DC}^2 R_L}{\frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}}} = \frac{2 \times 4 I_m^2 R_L}{\pi^2 (R_L + 2R_F) I_m^2}$$

$$TUF = \frac{.81 R_L}{2R_F + R_L}$$

$$TUF|_{max} = 81\%$$

Imp

If transformer of similar secondary AC ratings are used in the three rectifiers then maximum D.C. o/p power is the highest in the bridge rectifier.

⑮ **Ripple Frequency = $2f_0$**

⑯ **Angle of Conduction = $360° - 4\theta$**

$$\theta = \sin^{-1}\left[\frac{2V_r}{V_m}\right]$$

⑰ $$F.F = 1.11$$

* Advantages:-

Bridge rectifier has following advantages over center tapped full wave rectifier

- Smaller PIV.
- It does not require center tapped transformer.
- Larger TUF.
- Bridge rectifier can be used as high voltage rectifier also if A.C. voltage is directly applied to the diode bridge without any transformer.

When it is used as high voltage rectifier diode should have high breakdown voltage.

FILTER:-

- It is a frequency selective network which passes desired range of frequencies and stops unwanted frequencies.
- Filters are used in power supply to eliminate the A.C. component or ripple present in the output of rectifier.
- Filter should eliminate frequencies ω_0, $2\omega_0$, $4\omega_0$ -- etc in half wave rectifiers and $2\omega_0$, $4\omega_0$, $6\omega_0$ --- etc in full wave and bridge rectifier.
- Filters are formed using reactive elements i.e. inductors and capacitors.

Filters used in power supplies consist of large inductors (a few henry) and large capacitances (μF).

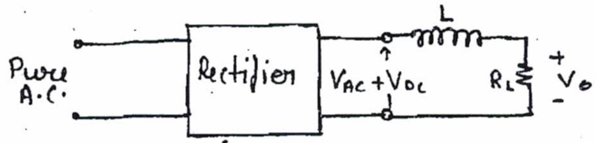
Large inductor offer high reactance and large capacitor offer low reactance to A.C. component.

Filters used in power supplies are:-

- Inductor Filter.
- Capacitor Filter.
- L-C Filter.
- C-L-C Filter.

1) Inductor Filter:-

A large inductor is connected in series with R_L can eliminate the A.C. component.



→ For proper filtering operation inductor should be selected such that $|X_L| >> R$ for half wave rectifier.

$$\rightarrow \omega_0 L >> R_L \text{ for Half wave Rectifier.}$$

$$\rightarrow 2\omega_0 L >> R_L \text{ for bridge and full wave rectifier.}$$

→ The A.C. component V_{AC} of rectifier output appears almost across L and a negligible A.C. voltage appears across R_L because $|X_L| >> R_L$.

→ D.C. component V_{DC} appears across R_L because inductor is a short circuit for D.C. Thus an inductor connected in series with R_L can reduce A.C.