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Diode application : Rectifier

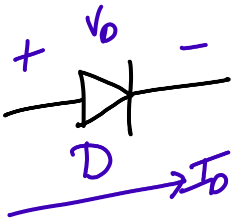
- Half-wave rectifier
- Full-wave center tap rectifier
- Full-wave bridge rectifier

only with 'R' load

+ Filters (Capacitor filter)

1. ckt diagm
2. working
3. I/p - o/p w/fs w.r.t time
4. Analysis :-
   a) $V_{out\,avg}$; $I_{out\,avg}$
   b) $V_{out\,rms}$; $I_{out\,rms}$
   c) Rectificatn eff (η)
   d) Ripple factor (γ)
   e) TUF

Diode basics:-



D. is F.B (ON)

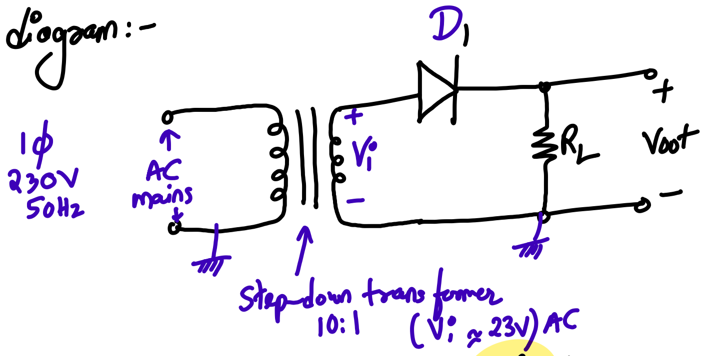
S.c

D is R.B (OFF)

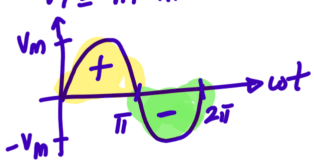
O.C

Half-wave Rectifier with 'R' load:

Circuit diagram :-

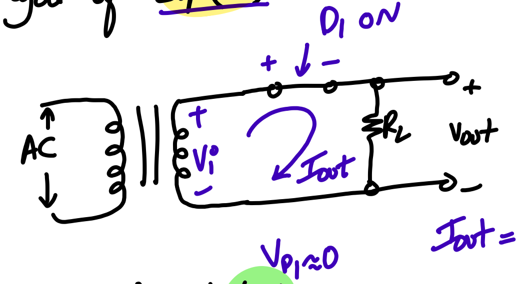


$V_i = V_m \sin\omega t \rightarrow$ Secondary voltage of transformer



Case ①:- During +ve half cycle of I/p (V_i)

D_1 is F.B i.e ON



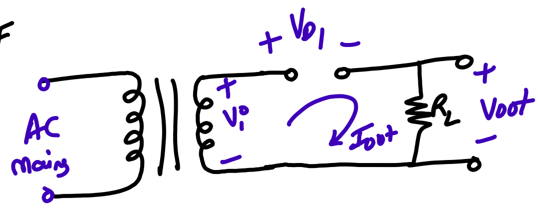
$V_{out} = V_i$

o/p follows I/p voltage

$I_{out} = \frac{V_{out}}{R_L}$

Case ②:- During −ve half cycle of I/p (V_i)

D_1 is R.B i.e OFF



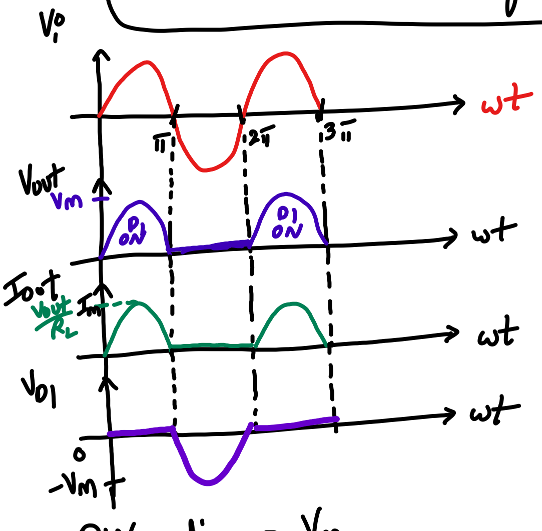
$I_{out} = 0$

$V_{out} = 0$

$V_{D_1} \neq 0$ "PIV rating"

Input-Output w/fs :-

$$\boxed{\begin{aligned} V_{out} &= V_i \ (V_m \sin\omega t) && \text{if } 0 < \omega t < \pi \\ &= 0 && \text{if } \pi < \omega t < 2\pi \end{aligned}} \quad \text{—①}$$



HWR I/p & o/p waveforms.

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

PIV rating $\rightarrow -V_m$

Analysis (HWR):

Derive
a) Expression for $V_{out\,avg}$
b) —"— for $V_{out\,rms}$
c) —"— for rectification efficiency (η)
d) —"— for ripple factor (γ)
e) —"— for TUF

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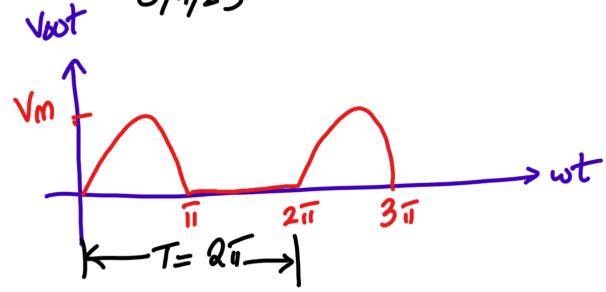


a) $V_{out(avg)} / V_{dc}$:

$$V_{out(avg)} = \frac{1}{T}\int_0^T V_{out}\, d\omega t$$

$V_i = V_m \sin\omega t$

$$V_{out(avg)} = \frac{1}{2\pi}\int_0^{2\pi} V_{out}\, d\omega t$$

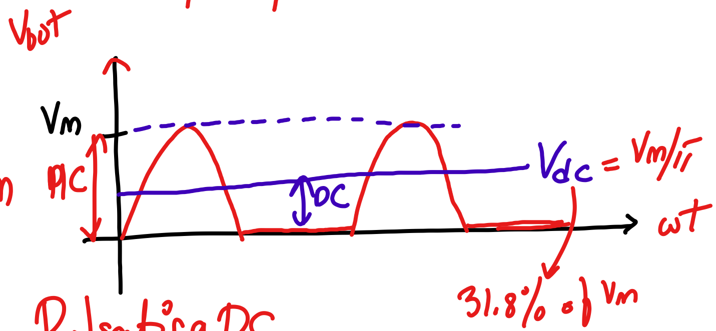
$$V_{out(avg)} = \frac{1}{2\pi}\left[\int_0^{\pi} V_m \sin\omega t\, d\omega t + \int_{\pi}^{2\pi} 0\, d\omega t\right]$$

$$V_{out(avg)} = \frac{V_m}{2\pi}\left[-\cos\omega t\right]_0^{\pi} = -\frac{V_m}{2\pi}\left[\underset{-1}{\cos\pi} - \underset{1}{\cos 0}\right]$$

$$V_{out(avg)} = \frac{V_m}{2\pi}(2)$$

$$\boxed{V_{out(avg)} = \frac{V_m}{\pi}}$$

i.e $V_{dc} = 0.318 V_m$



o/p of HWR : Pulsating DC (AC+DC)

$$I_{out(avg)} = I_{dc} = \frac{V_{out(avg)}}{R_L} = \frac{V_{dc}}{R_L} = \frac{V_m}{\pi R_L}$$

I_m

$$\boxed{I_{out(avg)} = \frac{I_m}{\pi}}$$ where $I_m = \frac{V_m}{R_L}$

b) $V_{out(rms)} \rightarrow$ RMS value of AC component of o/p

$$V_{out(rms)}^2 = \frac{1}{T}\int_0^T V_{out}^2(\omega t)\, d\omega t \quad ; T = 2\pi$$

$V_i = V_m \sin\omega t$

$$V_{out(rms)}^2 = \frac{1}{2\pi}\int_0^{2\pi} V_{out}^2(\omega t)\, d\omega t$$

$$V_{out(rms)}^2 = \frac{1}{2\pi}\int_0^{\pi} V_m^2 \sin^2\omega t\, d\omega t = \frac{V_m^2}{2\pi}\int_0^{\pi}\left(1 - \frac{\cos 2\omega t}{2}\right) d\omega t$$

$$V_{out(rms)}^2 = \frac{V_m^2}{2\pi}\left[\frac{\omega t}{2} - \frac{\sin 2\omega t}{4}\right]_{\omega t = 0}^{\pi}$$

$$V_{out}^2(rms) = \frac{V_m^2}{2\pi}\left\{\left(\frac{\pi}{2}-0\right) - \frac{\cancel{\sin 2\pi}^{\,0}}{4} - \frac{\cancel{\sin 0}^{\,0}}{4}\right\}$$

$$V_{out}^2(rms) = \frac{V_m^2}{2\pi}\times\frac{\pi}{2} = \frac{V_m^2}{4}$$

$$\boxed{V_{out}(rms) = \frac{V_m}{2}}$$

$$I_{out}(rms) = \frac{I_m}{2}$$

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

c) Rectifier efficiency (η): $\rightarrow$ It is the ratio of DC power at the o/p to the applied o/p AC power

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

$$P_{DC} = V_{dc} I_{dc} = \frac{V_{dc}^2}{R_L} = I_{dc}^2 R_L$$

$$P_{AC} = V_{out(rms)} I_{out(rms)} = V_{rms} I_{rms} = \frac{V_{rms}^2}{R_L} = I_{rms}^2 R_L$$

$$P_{DC} = \frac{V_{dc}^2}{R_L} = \frac{\left(\frac{V_m}{\pi}\right)^2}{R_L} = \frac{V_m^2}{\pi^2 R_L} \quad -(a)$$

$$P_{AC} = \frac{V_{rms}^2}{R_L} = \frac{\left(\frac{V_m}{2}\right)^2}{R_L} = \frac{V_m^2}{4R_L} \quad -(b)$$

$$\%\eta = \frac{P_{DC}}{P_{AC}}\times 100 = \frac{\frac{\cancel{V_m^2}}{\pi^2 \cancel{R_L}}}{\frac{\cancel{V_m^2}}{4\cancel{R_L}}}\times 100$$

$$\%\eta = \frac{4}{\pi^2}\times 100$$

$$\boxed{\%\eta = 40.56\,\%}$$ HWR

d) Ripple factor (γ): $\rightarrow$ It is the ratio of rms value of o/p AC component to the DC component of rectifier o/p

$$\gamma = \frac{I_{ac}}{I_{dc}} \qquad I_{ac} = \sqrt{I_{out(rms)}^2 - I_{dc}^2}$$

i.e. $$\frac{I_{ac}}{I_{dc}} = \sqrt{\frac{I_{rms}^2}{I_{dc}^2} - 1}$$

i.e. $$\boxed{\gamma = \sqrt{\frac{I_{rms}^2}{I_{dc}^2} - 1}}$$

For HWR, $I_{rms} = \frac{I_m}{2}$, $I_{dc} = \frac{I_m}{\pi}$

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

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

——x——

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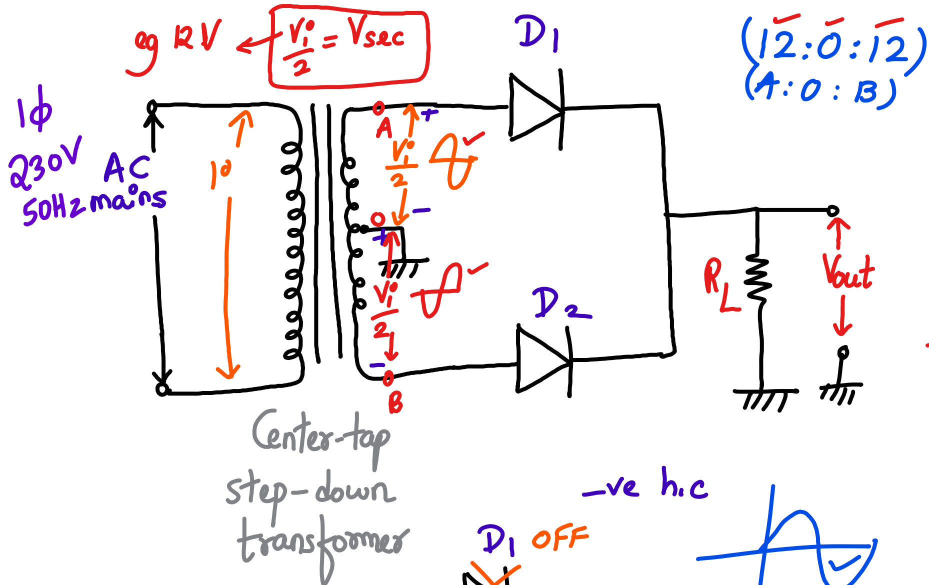
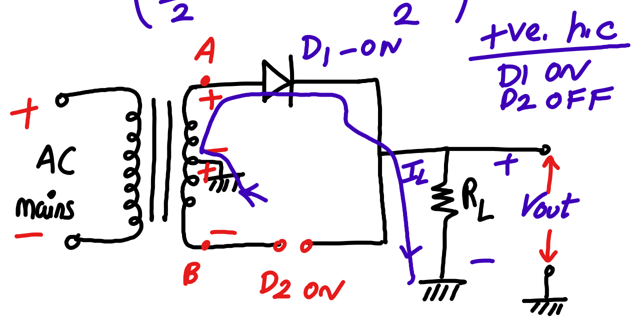
Full-wave "Center tapped" rectifier with 'R' load :

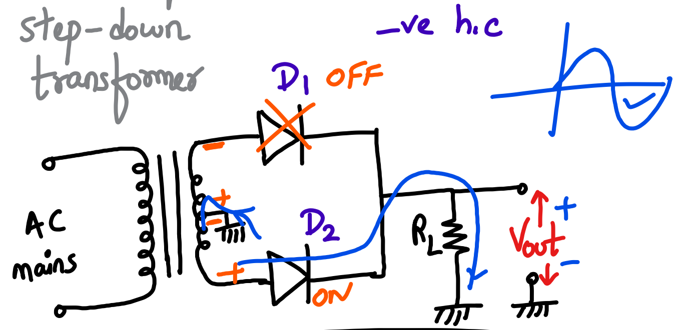
$V_i \Rightarrow$ Secondary voltage of transformer



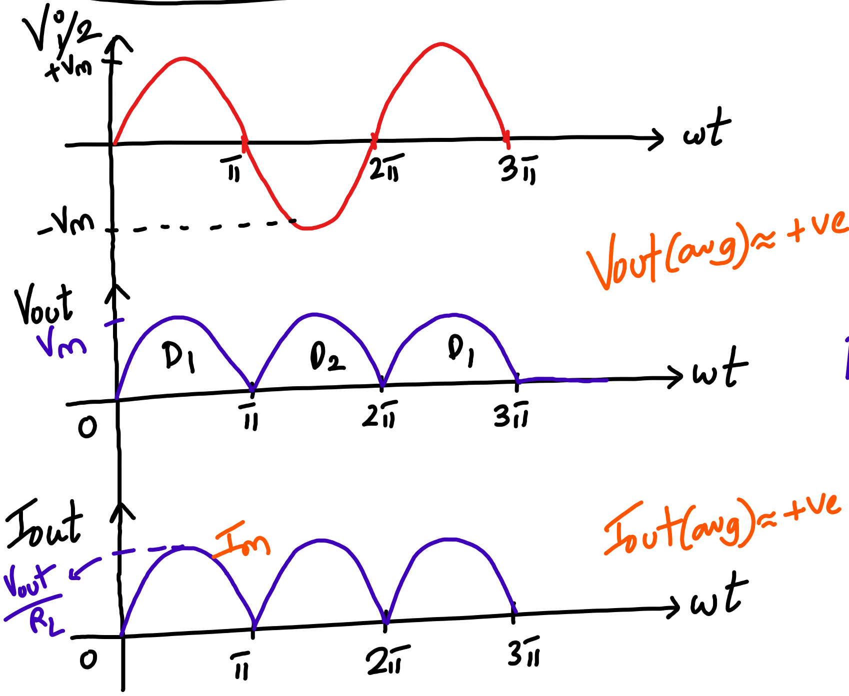
5 – 0 – 5

$\left(\frac{V_i}{2} - 0 - \frac{V_i}{2}\right)$





$$\boxed{\begin{aligned} V_{out} &= \frac{V_i}{2}(V_m \sin\omega t) \text{ if } 0 < \omega t < \pi \\ &= \frac{V_i}{2}(V_m \sin\omega t) \text{ if } \pi < \omega t < 2\pi \end{aligned}} \quad (1)$$



$V_{out} = I_{out} R_L$

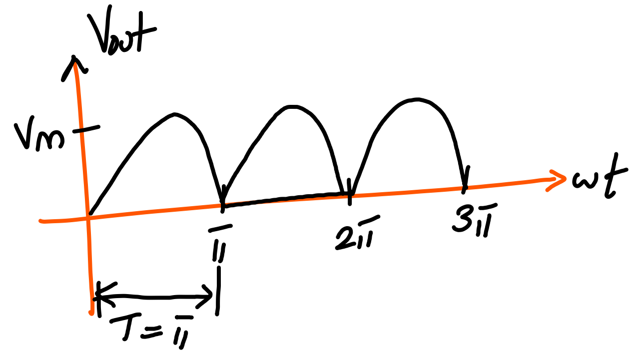
FWR I/p & o/p waveforms

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

FWR with 'R' load analysis:

Derive
a) Expression for rectification efficiency (η)
b) Expression for ripple factor (γ)
c) Expression for TUF

① $V_{out(avg)} = V_{dc} = \frac{1}{T}\int_0^T V_{out}\, d\omega t$



$T = \pi$

i.e $V_{dc} = \frac{1}{\pi}\int_0^{\pi} V_i(\omega t)\, d\omega t$

i.e $V_{dc} = \frac{1}{\pi}\left[\int_0^{\pi} V_m \sin\omega t\, d\omega t\right]$

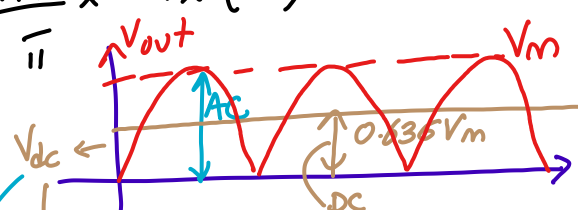
i.e $V_{dc} = \frac{V_m}{\pi}\left[-\cos\omega t\right]_{\omega t=0}^{\pi}$

ie $V_{dc} = \frac{V_m}{\pi} \times \left\{-\left[\underbrace{\cos\pi}_{-1} - \underbrace{\cos 0}_{1}\right]\right\} = \frac{V_m}{\pi} \times -1 \times (-2)$

i.e $\boxed{V_{dc} = \frac{2V_m}{\pi}}$ FWR

$V_{out(avg)}$

i.e $V_{dc} = 0.636\, V_m$



$V_{out(avg)}$

63.6 % of V_m

O/P of FWR : Pulsating DC (AC+DC)

$V_{out(avg)} = V_{dc} = \frac{2V_m}{\pi}$

② $I_{out(avg)} = \dfrac{V_{out(avg)}}{R_L} = \dfrac{V_{dc}}{R_L} = \dfrac{2V_m}{\pi R_L} \rightarrow I_m$ $\left(V_{out(avg)} = I_{out(avg)} R_L\right)$

$$\boxed{I_{out(avg)} = \frac{2I_m}{\pi}}$$ where, $\boxed{I_m = V_m/R_L}$ $\boxed{I_{out(avg)} = I_{dc}}$

③ $V_{out(rms)} \rightarrow$ Rms value of AC component of output

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

$T = \pi$

From eqⁿ ①,

$$\text{i.e } V_{out(rms)} = \left[\frac{1}{\pi}\int_0^{\pi} V_i^2(\omega t)\, d\omega t\right]^{1/2}$$

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

$$\text{i.e } V_{out(rms)} = \left[\frac{V_m^2}{\pi}\left\{\int_0^{\pi}\left(\frac{1-\cos 2\omega t}{2}\right) d\omega t\right\}\right]^{1/2}$$

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

$$\text{ie } V_{out(rms)} = \left[\frac{V_m^2}{2\pi}\left\{\omega t - \frac{\sin 2\omega t}{2}\right\}_{\omega t=0}^{\pi}\right]^{1/2}$$

$$\text{i.e } V_{out(rms)} = \left[\frac{V_m^2}{2\pi}\left\{(\pi - 0) - \cancel{\frac{\sin 2\pi}{2}}^{\,0} - \cancel{\frac{\sin 0}{2}}^{\,0}\right\}\right]^{1/2}$$

$$\text{ie } V_{out(rms)} = \left[\frac{V_m^2}{2\pi}\times\pi\right]^{1/2} = \left(\frac{V_m^2}{2}\right)^{1/2}$$

$$\text{i.e } \boxed{V_{out(rms)} = \frac{V_m}{\sqrt{2}}}\ \text{FWR}$$

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

where, $I_m = \dfrac{V_m}{R_L}$

$V_{out(rms)} = V_{rms}$; $I_{out\,rms} = I_{rms}$

④ Rectification efficiency (η):

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

It is the ratio of DC power at the output to the applied input AC power

$$P_{DC} = V_{dc} I_{dc} = \boxed{\frac{V_{dc}^2}{R_L}} = I_{dc}^2 R_L$$

$$P_{AC} = V_{rms} I_{rms} = \boxed{\frac{V_{rms}^2}{R_L}} = I_{rms}^2 R_L$$

ie $P_{DC} = \frac{V_{dc}^2}{R_L} = \frac{\left(\frac{2V_m}{\pi}\right)^2}{R_L} = \frac{4V_m^2}{\pi^2 R_L}$ — (a)

ie $P_{AC} = \frac{V_{rms}^2}{R_L} = \frac{\left(\frac{V_m}{\sqrt{2}}\right)^2}{R_L} = \frac{V_m^2}{2R_L}$ — (b)

ie $\% \eta = \frac{P_{DC}}{P_{AC}} \times 100 = \frac{\frac{4\cancel{V_m^2}}{\pi^2 \cancel{R_L}}}{\frac{\cancel{V_m^2}}{2R_{\cancel{L}}}} \times 100 = \frac{8}{\pi^2} \times 100$

i.e $\boxed{\% \eta = \frac{8}{\pi^2} \times 100 \approx 81.05\%}$ → Rectification efficiency of FWR with 'R' load

* $\boxed{\eta_{FWR} > \eta_{HWR}}$

⑤ Ripple factor (γ):

It is the ratio of rms value of o/p AC component to the DC component of the rectifier output

Smaller the AC component → more effective is the rectifier

$$\gamma = \frac{I_{ac}}{I_{dc}} = \frac{V_{ac}}{V_{dc}} \; ; \quad \boxed{I_{ac} = \sqrt{I_{out(rms)}^2 - I_{dc}^2}}$$

Remember it!

$$I_{out(rms)}^2 = I_{rms}^2$$

ie $$\frac{I_{ac}}{I_{dc}} = \sqrt{\frac{I_{rms}^2}{I_{dc}^2} - 1}$$

i.e $$\boxed{\gamma = \sqrt{\frac{I_{rms}^2}{I_{dc}^2} - 1}}$$

For FWR, $I_{rms} = \frac{I_m}{\sqrt{2}}$, $I_{dc} = \frac{I_m \times 2}{\pi}$

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

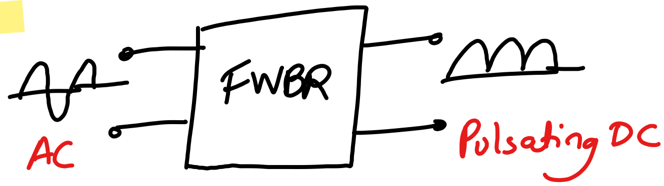
$$\boxed{\gamma = \sqrt{\frac{\pi^2}{8} - 1} \approx 0.483}$$

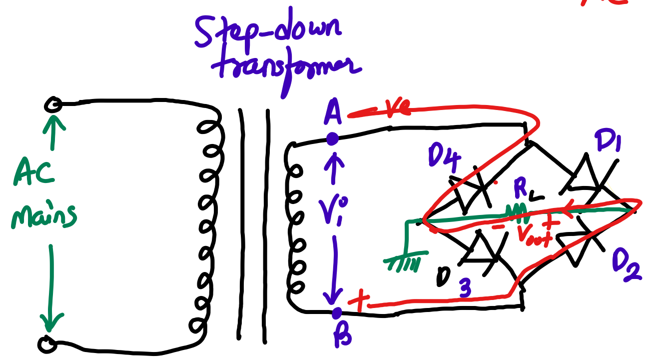
FWCTR

$\gamma_{FWR} < \gamma_{HWR}$

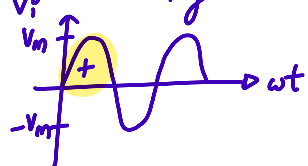
↳ contains smaller ac component

Full-wave Bridge rectifier





V_i : 2° transformer voltage



$V_i = V_m \sin\omega t$

→ F.B → ON →

→ R.B → OFF →

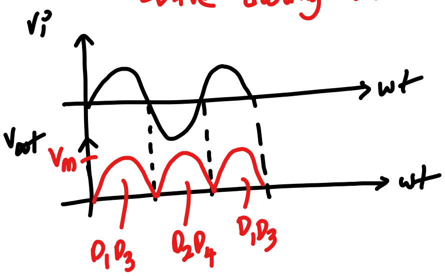
+ve h.c of V_i → D_1 & D_3 → ON

I_{out} → $A - D_1 - R_L - D_3 - B - A$

−ve h.c of V_i → D_2 & D_4 ON

I_{out} → $B - D_2 - R_L - D_4 - A$

↳ +ve during −ve h.c also



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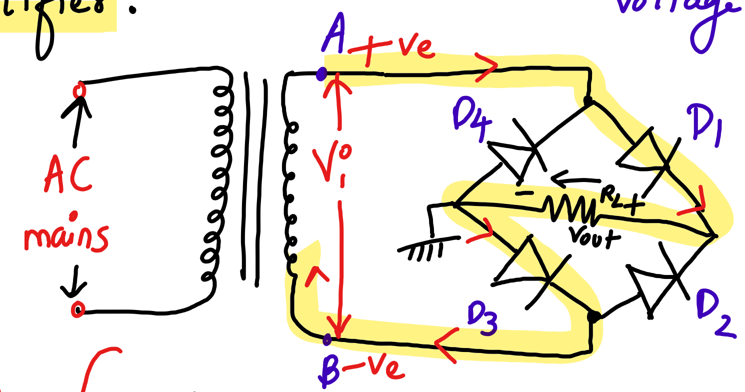
V_i^o : Secondary transformer voltage

Full-wave bridge rectifier :



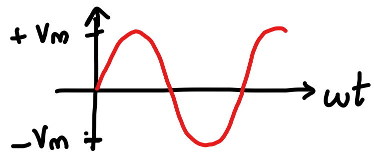
"Two diodes conducts together"

$A^{+ve} - D_1 - R_L - D_3 - B$

↓

Iout path during +ve h.c

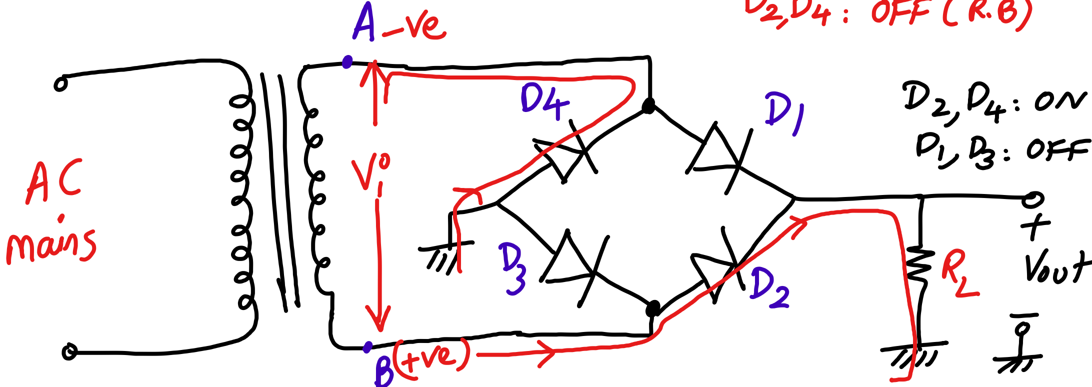
$V_i^o = V_m \sin \omega t$



$V_{out} = I_{out} R_L$

D_1 & D_3 : ON (F.B)

D_2, D_4 : OFF (R.B)



D_2, D_4 : ON (F.B)

D_1, D_3 : OFF (R.B)

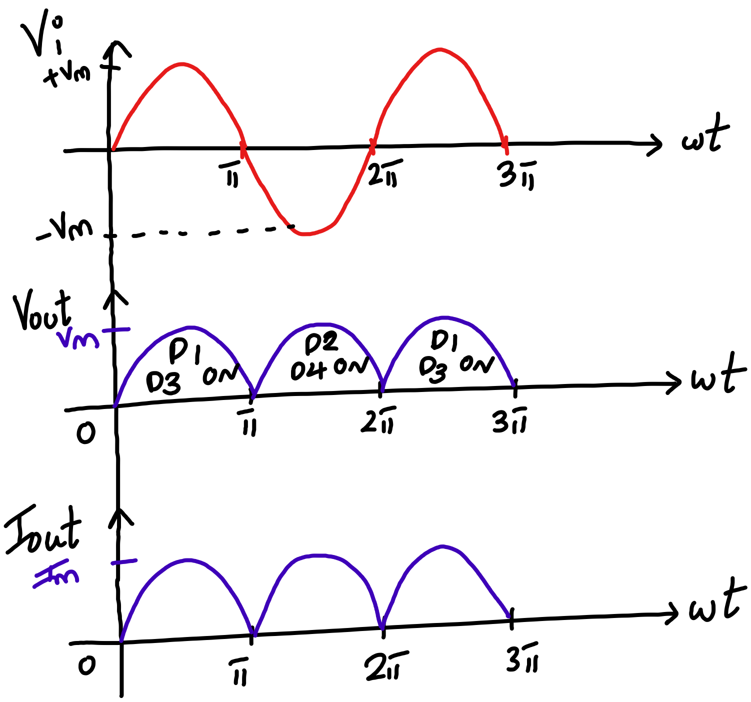
$B - D_2 - R_L - D_4 - A$

↓

Iout path during -ve h.c

$V_{out} = V_i^o \ (V_m \sin \omega t)$ if $0 \leq \omega t \leq \pi$

$= V_i^o \ (V_m \sin \omega t)$ if $\pi \leq \omega t \leq 2\pi$



FWBR I/P - O/P waveform's

Due to 'R' load, nature of Vout & Iout are similar

'B' FWR with 'R' load analysis:

Derive a) Expression for rectification efficiency (η)

b) Expression for ripple factor (γ)

c) Expression for TUF

① $$V_{out(avg)} = V_{dc} = \frac{1}{T}\int_0^T V_{out}\, d\omega t$$

$$\boxed{V_{out(avg)} = V_{dc} = \frac{2V_m}{\pi}}$$ --- FWBR

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

② $I_{out(avg)} = \dfrac{V_{out(avg)}}{R_L}$ $\left(V_{out(avg)} = I_{out(avg)} R_L\right)$

③ $V_{out(rms)} \rightarrow$ Rms value of AC component of output

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

$$\boxed{V_{out(rms)} = V_{rms} = \frac{V_m}{\sqrt{2}}} \qquad \boxed{I_{rms} = \frac{I_m}{\sqrt{2}}}$$

↳ FWBR

④ Rectification efficiency (η):

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

It is the ratio of DC power at the output to the applied input AC power

$$P_{DC} = \frac{V_{dc}^2}{R_L} \qquad V_{dc} \rightarrow \frac{2V_m}{\pi}$$

$$P_{AC} = \frac{V_{rms}^2}{R_L} \qquad V_{rms} \rightarrow \frac{V_m}{\sqrt{2}}$$

$$\%\eta = \frac{\dfrac{4\cancel{V_m^2}}{\pi^2 \cancel{R_L}}}{\dfrac{\cancel{V_m^2}}{2\cancel{R_L}}} \times 100$$

$$\boxed{\%\eta = \frac{8}{\pi^2} \times 100 = 81.05\%}$$

FWBR

⑤ Ripple factor (γ):

It is the ratio of rms value of o/p AC component to the DC component of the rectifier output

Smaller the AC component → more effective is the rectifier

$$\gamma = \frac{I_{ac}}{I_{dc}} \quad ; \quad I_{ac} = \sqrt{I_{out(rms)}^2 - I_{dc}^2}$$

$$I_{out(rms)}^2 = I_{rms}^2$$

ie $$\frac{I_{ac}}{I_{dc}} = \sqrt{\frac{I_{rms}^2}{I_{dc}^2} - 1}$$

i.e $$\boxed{\gamma = \sqrt{\frac{I_{rms}^2}{I_{dc}^2} - 1}}$$

for FWBR,

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

$$\gamma = \sqrt{\frac{\cancel{I_m^2}\pi^2}{2 \times 4\cancel{I_m^2}} - 1} = \sqrt{\frac{\pi^2}{8} - 1} = 0.483$$

$\boxed{\gamma = 0.483}$ FWBR