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Education and Scientific Research
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POWER ELECTRONIC

المرحلة الثالثة

(المحاضرة الخامسة)

Half Wave Rectifier

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Chapter 5

Half Wave Rectifier

Half Wave Rectifier is a diode circuit which is used to transform **Alternating Voltage (AC Supply)** to **Direct Voltage (DC Supply)**. A single diode is used in the HWR circuit for the transformation of AC to DC.

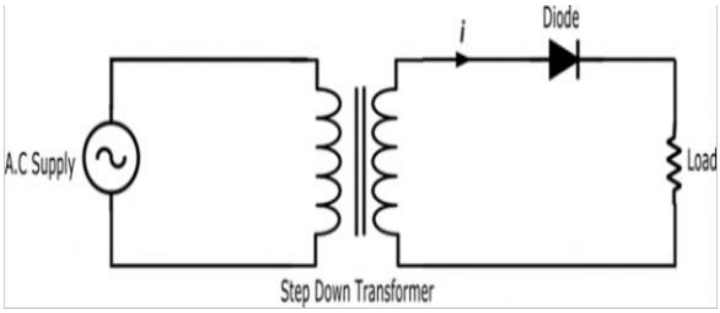
Half Wave Rectifier circuit allows the one – half cycle of the AC Supply waveform to pass and blocks the other half cycle.half wave rectifier circuit diagram

The circuit of HwR consists of following three main components −

a .diode

a .transformer

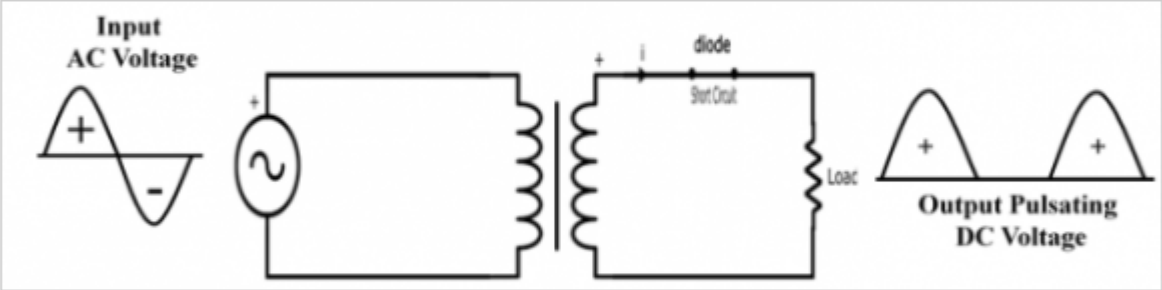
a. load(may be a resistance)



Working of HWR Circuit

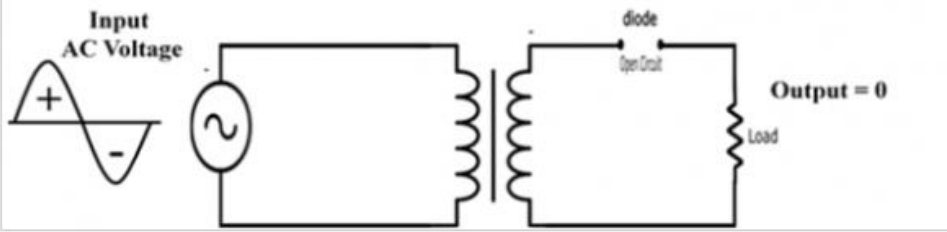
Positive Half Cycle

The AC high voltage is applied to the primary of step down transformer and the obtained secondary low voltage is applied to the diode, the diode is forward biased during positive half cycle and act as a short circuit.

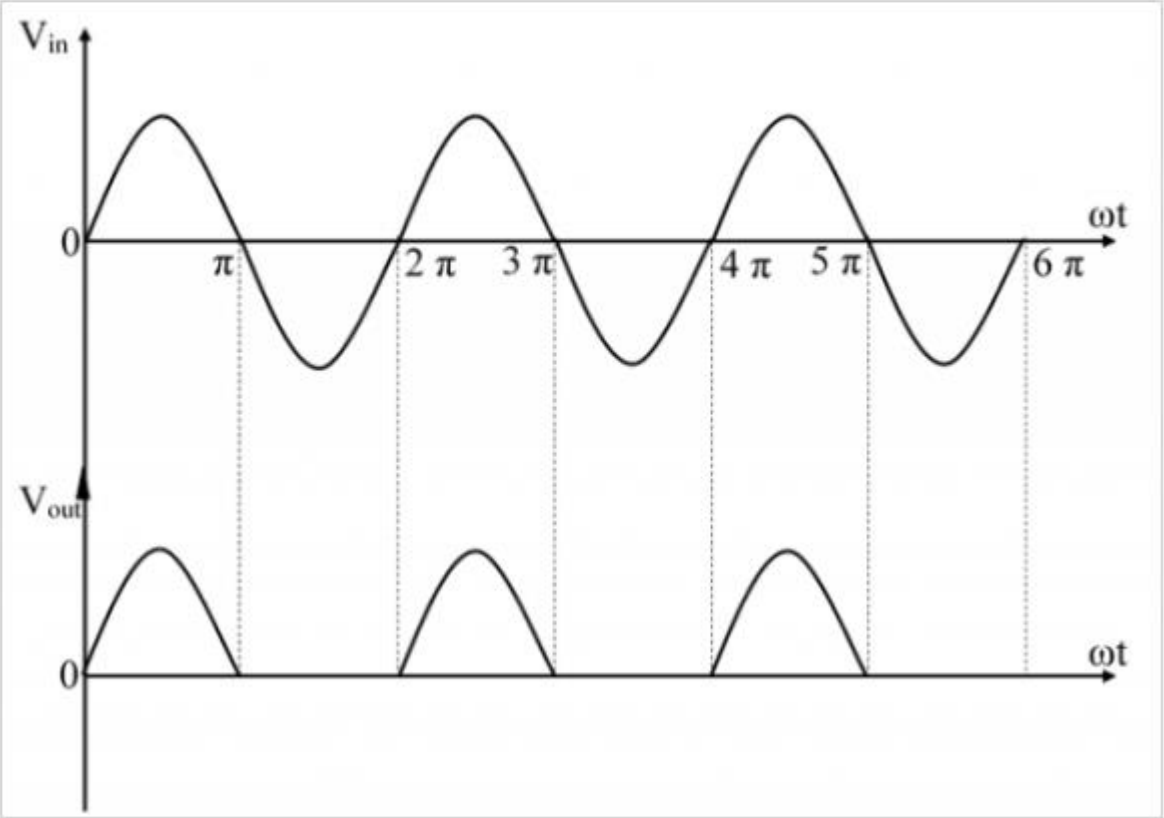


Negative Half Cycle

During the negative half cycle, the P – terminal of the diode is connected with the negative supply which reverse biases the diode, the diode behaves like an open circuit and does not produces the output across the load.



Half Wave Rectifier Waveform



A dc voltmeter is constructed to read the average values

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

$$V_{DC} = \frac{1}{2\pi}\int_0^{\pi} V_m \sin\alpha d\alpha$$

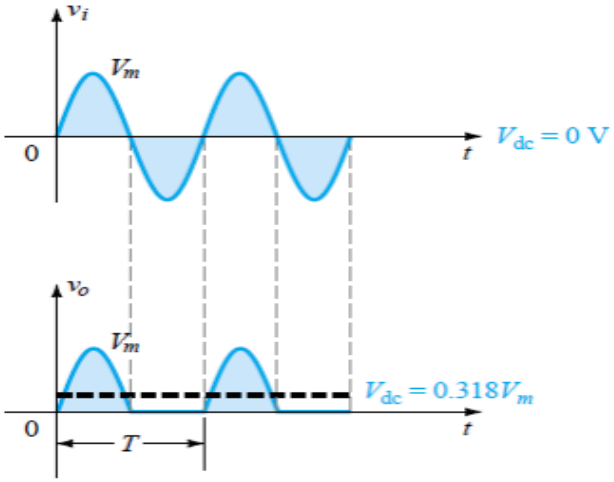
$$V_{DC} = \frac{V_m}{2\pi}\left(-\cos\alpha\right)_0^{\pi}$$

$$V_{DC} = \frac{V_m}{2\pi}\left(-\cos\pi + \cos 0\right) = \frac{V_m}{2\pi}\left(-(-1)+1\right) = \frac{V_m}{\pi}$$

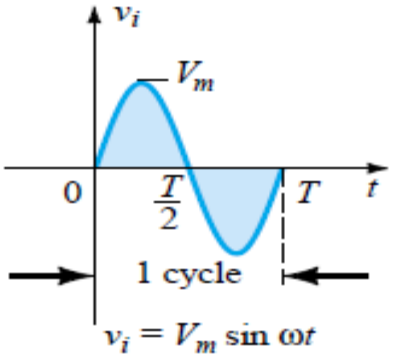
$$V_{DC} = 0.318 V_m$$

DIODE CIRCUIT APPLICATIONS

design of an AC to DC converter.



Sinusoidal inputs:



Half Wave Rectifier Formulae

Efficiency of HWR

The efficiency of HWR is defined as the ration output DC power to the input AC power.

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

The maximum efficiency of half wave rectifier is 40.6%.

Peak Inverse Voltage of HWR

The peak inverse voltage of a HWR is the maximum voltage that can a diode withstand without destruction when reverse bias is applied to it.

$$\mathrm{PIV} = V_m$$

RMS Value of Load Current of HWR

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

Example :1

A diode having internal resistance R_d = 10Ω is used for half wave rectification. If the applied voltage is v = 50 sin (ωt) and load resistance R_L = 1KΩ. Find the following −

- I_m, I_{dc}, I_{rms}
- AC power input and DC power output
- DC output voltage
- Efficiency of rectification

Solution

Maximum voltage, $V_m = 50\,V$

(a) $I_m = \frac{v_m}{R_d + R_L} = \frac{50}{10+1000} = 0.0495 = 49.5\,mA$

$$I_{dc} = I_{avg} = \frac{I_m}{\pi} = \frac{49.5}{\pi} = 15.76\,mA$$

$$I_{rms} = \frac{I_m}{2} = \frac{49.5}{2} = 24.75\,mA$$

(b) $P_{ac} = (I_{rms})^2 (R_d + R_L)$

$$\Rightarrow P_{ac} = (24.75 \times 10^{-3})^2 \times (10 + 1000) = 0.618\,Wat$$

(c) DC output voltage

$$= I_{dc} \times R_L$$

$$= (15.76 \times 10^{-3}) \times 1000 = 15.76\,V$$

(d) Efficiency$(\eta) = \frac{P_{dc}}{P_{ac}} = \frac{0.248}{0.618} \times 100 = 40.12$

Half Wave Rectifier Formulae

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$$\text{PIV} = V_m$$

RMS Value of Load Current of HWR

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

Average Value of Load Current of HWR

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

Form Factor of HWR

$$\text{Form Factor} = \frac{\text{RMS Value}}{\text{Avg. Value}} = \frac{V_{\text{rms}}}{V_{\text{avg}}}$$

For HWR the form factor equals to 1.57

Ripple Factor of HWR

Ripple Factor gives the information about how a HWR can transform input AC voltage to output DC voltage. It is given by

$$\text{Ripple Factor} = \sqrt{((\text{Form Factor})^2 - 1)}$$

The ripple factor for half wave rectifier is 1.21.

Full Wave Rectifier

Full Wave Rectifier is a diode circuit which is used to transform the complete cycle of Alternating Voltage (AC Supply) to Direct Voltage (DC Supply).

In full wave rectification, current flows through the load in the same direction for the complete cycle of input AC Supply.

Types of Full Wave Rectifiers

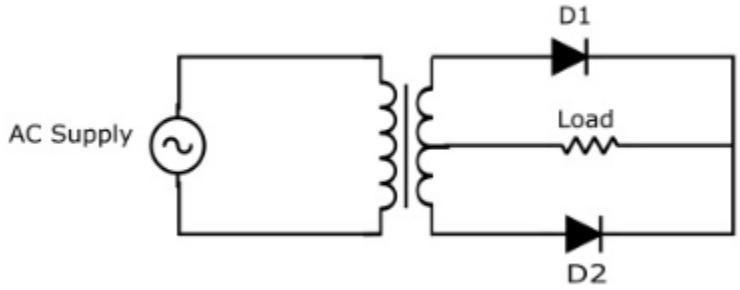
- Centre Tap Full Wave Rectifier
- Full Wave Bridge Rectifier

Centre Tap Full Wave Rectifier

The circuit of centre tap full wave rectifier consists of following main components

Two Diodes:

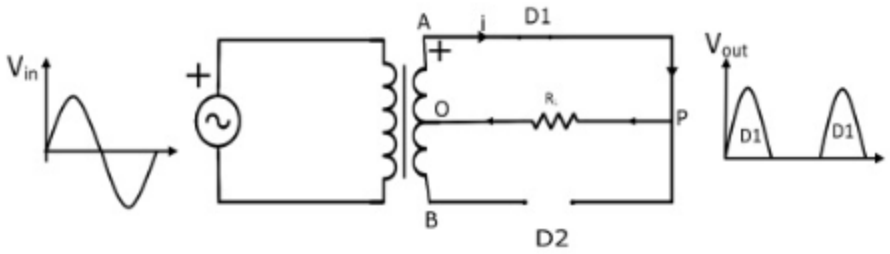
- A centre-tapped transformer
- A load resistance



Working of Centre – Tap FWR Circuit

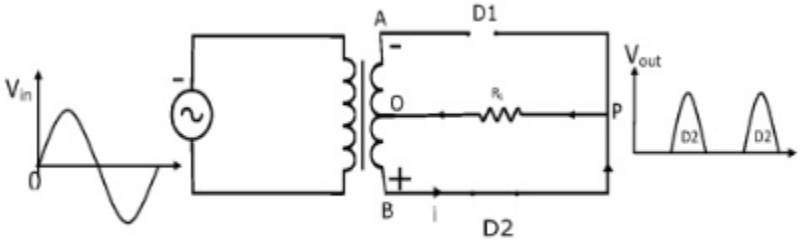
Positive Half Cycle

During the positive half cycle of input AC voltage, the end A of secondary winding becomes positive and the end B negative. This makes the diode D1 forward biased (acts as closed switch) and diode D2 reverse biased (acts as open switch). Therefore, current flows through the load (RL) from P to O.



Negative Half Cycle

During the negative half cycle of input AC supply, the end B of secondary winding becomes positive and the end A negative. This makes the diode D2 forward biased (acts like closed switch) and the diode D1 reverse biased (acts as open switch). Therefore, the current will flow from B to O through diode D2, load RL and lower half of the secondary winding.



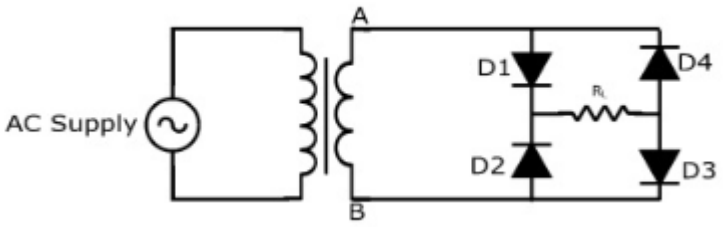
Full Wave Bridge Rectifier

The full wave bridge rectifier eliminates the need of centre tapped transformer. It contains four diodes connected to form bridge.

Circuit Diagram of Bridge FWR

The circuit of full wave bridge rectifier consists of following main components –

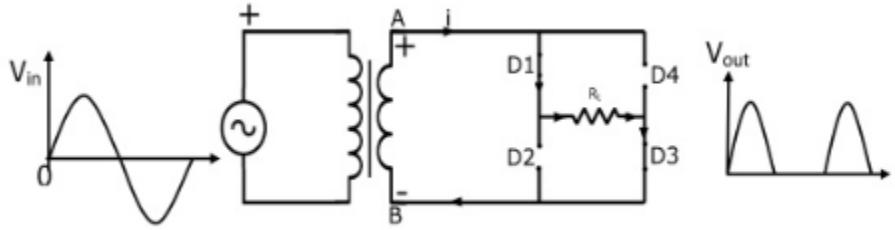
- Four Diodes
- A step down transformer
- A load resistance



Working of Bridge FWR

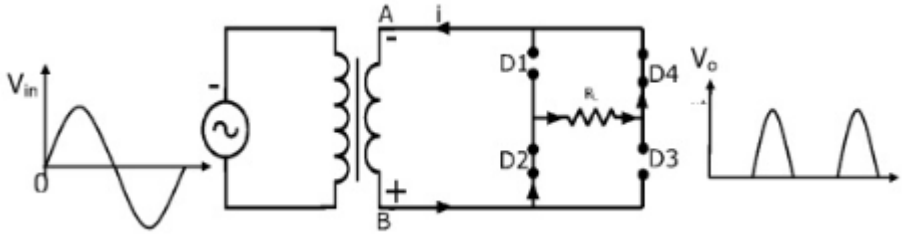
Positive Half Cycle

During positive half cycle, the end A of secondary winding becomes positive and the end B negative. This makes diodes D1 and D3 forward biased (acts like closed switch) and diodes D2 and D4 reverse biased (acts like open switch). The current flows from A to B through diode D1, load RL and diode D3.



Negative Half Cycle

During Negative half cycle, the end A of secondary winding becomes negative and the end B positive. This makes diodes D1 and D3 reverse biased (acts like open switch) and diodes D2 and D4 forward biased (acts like closed switch). The current flows from B to A through diode D2, load RL and diode D4.



Full wave rectifier

A full wave rectifier converts both halves of each cycle of an alternating wave (AC signal) into pulsating DC signal. Figure 3 shows the input AC voltage waveform, the circuit diagram and the final output voltage waveform of a center tapped full wave rectifier.

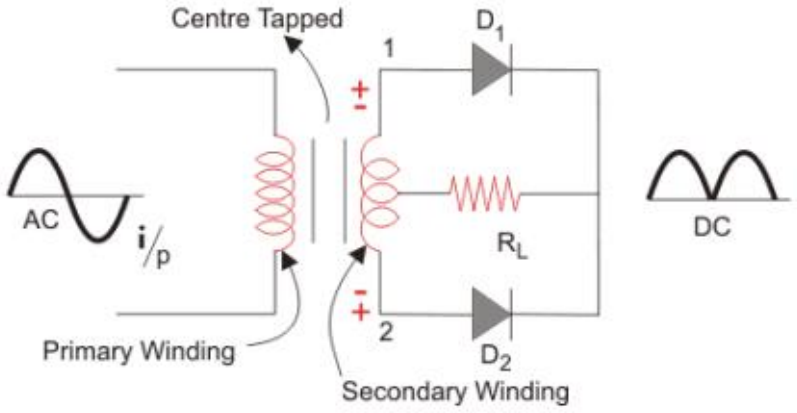


Figure : Center tapped full wave rectifier circuit diagram and waveform [electrical4u.com].

For an AC voltage given by (1) the waveform of the output voltage of a full wave rectifier can be written as (for an ideal diode)

$$V_o(t) = \begin{cases} V_m \sin(\omega t), & 0 \le t \le T/2 \\ V_m \sin(\omega t - \pi), & T/2 \le t \le T \end{cases}$$

Average output voltage of a full wave rectifier

$$\begin{aligned} V_{dc} &= \frac{1}{T}\int_0^T V_o(t)\mathrm{d}t \\ &= \frac{1}{T/2}\int_0^{T/2} V_m \sin(\omega t)\mathrm{d}t \\ &= \frac{2V_m}{T}\int_0^{T/2} \sin(\omega t)\mathrm{d}t \\ &= \frac{2V_m}{\pi}. \end{aligned}$$

RMS value of the output voltage of a full wave rectifier

$$\begin{aligned} V_{\text{rms}} &= \left[\frac{1}{T}\int_0^T V_{\text{o}}^2(t)\mathrm{d}t\right]^{1/2} \\ &= \left[\frac{V_m^2}{T/2}\int_0^{T/2}\sin^2(\omega t)\mathrm{d}t\right]^{1/2} \\ &= \left[\frac{V_m^2}{T}\int_0^{T/2}2\sin^2(\omega t)\mathrm{d}t\right]^{1/2} \\ &= \frac{V_m}{\sqrt{2}}. \end{aligned}$$

Ripple factor of full wave rectifier

$$\begin{aligned} \gamma &= \sqrt{\left(\frac{V_{\text{rms}}}{V_{\text{dc}}}\right)^2 - 1} \\ &= \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1} \\ &\approx 0.48 \end{aligned}$$

Efficiency of full wave rectifier

$$\begin{aligned}\eta &= \frac{P_{\text{dc}}}{P_{\text{dc}}} \\ &= \left(\frac{V_{\text{dc}}}{V_{\text{rms}}}\right)^2 \times \left(1 + \frac{r_f}{R_L}\right) \\ &\approx 0.8106 \left(1 + \frac{r_f}{R_L}\right)\end{aligned}$$

In reality r_f is much smaller then R_L. If we neglect r_f compare to R_L then the efficiency of the rectifier is maximum. Therefore,

$$\boxed{\eta_{\text{max}} \approx 0.8106 = 81.06\%.}$$

Form factor of full wave rectifier

$$\text{Form factor} = \frac{V_{\text{rms}}}{V_{\text{dc}}} = \frac{\pi}{2\sqrt{2}} \approx 1.11.$$

A comparison of different parameters related to the half and full wave rectifiers are given below:

Parameters	Half wave rectifier	Full wave rectifier
Number of diodes	1	2 or 4
Maximum efficiency	40.53%	81.06 %
Peak inverse voltage	V_m	V_m or $2V_m$
Average voltage no load	V_m/π	$2V_m/\pi$
V_{rms} no load	$V_m/2$	$V_m/\sqrt{2}$
Ripple factor	1.21	0.48
Form factor	1.57	1.11
Output frequency	f	$2f$

Full Wave Rectifier Formula

Efficiency of FWR

The efficiency of FWR is defined as the ration output DC power to the input AC power.

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

The maximum efficiency of Full wave rectifier is 81.2%.

Peak Inverse Voltage of FWR

"The PIV is the maximum voltage that a diode can withstand without destruction when it is reverse biased"

- For the centre – tap full wave rectifier, the PIV is twice of the maximum secondary winding voltage.

$$PIV = 2V_m$$

- For Bridge FWR, the PIV of each diode is equal to the maximum secondary voltage.

$$\mathrm{PIV} = \mathrm{V_m}$$

RMS Value of Load Current of FWR

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

Average Value of Load Current of FWR

$$\mathrm{I_{RMS}} = \frac{2\mathrm{I_m}}{\pi}$$

DC Output Voltage of FWR

$$\mathrm{V_{dc}} = \mathrm{V_{dc}R_L} = \mathrm{V_{avg}R_L}$$

Form Factor of FWR

Form Factor of FWR

$$\text{Form Factor} = \frac{\text{RMS Value}}{\text{Avg. Value}} = \frac{\mathrm{V_{rms}}}{\mathrm{V_{avg}}}$$

For FWR the form factor equals to 1.11

Ripple Factor of FWR

Ripple Factor gives the information about how a FWR can transform input AC voltage to output DC voltage. It is given by

$$\text{Ripple Factor} = \sqrt{(\text{Form Factor})^2 - 1}$$

The ripple factor for full wave rectifier is 0.482.

Example #3

In a centre tapped full wave rectifier, the internal resistance of each diode is . The transformer secondary RMS voltage from centre tap to each end of secondary is 60 V and load resistance is . Find –

- The average load current
- RMS value of load current
- DC output voltage
- Peak Inverse Voltage

Solution

RMS voltage across half secondary winding, V_{rms}=60V

Maximum voltage across half secondary winding, $V_m = 60 \times \sqrt{2} = 84.84V$

$$(\because \mathrm{V_m} = V\mathrm{V_{rms}} \times \sqrt{2})$$

$$\mathrm{I_m} = \frac{\mathrm{V_m}}{\mathrm{R_d} + \mathrm{R_L}} = \frac{84.84}{(10 + 870)} = 96.41\mathrm{mA}$$

(a) The average load current

$$\mathrm{I_{avg}} = \frac{2\mathrm{l_m}}{\pi} = \frac{2 \times 96.41}{\pi} = 61.41\mathrm{mA}$$

(b) The RMS value of load current

$$\mathrm{I_{rms}} = \frac{\mathrm{l_m}}{\sqrt{2}} = \frac{96.41}{\sqrt{2}} = 68.18\mathrm{mA}$$

(c) DC output voltage

$$V_{dc} = I_{avg} R_L = 61.41 \times 870 = 53.43V$$

(d) Peak Inverse Voltage

$$PIV = 2V_m = 2 \times 84.84 = 169.68V$$

Example #4

In a full wave bridge rectifier circuit, each diode have forward resistance of 2Ω and an infinite reverse resistance. The alternating supply voltage is 230 V RMS and resistive load is 50Ω. Calculate

- (a) Average load current
- (b) Rectifier Efficiency

Solution

The RMS value of supply voltage

$$V_{rms} = 230V$$

The maximum value of supply voltage

$$V_m = 230 \times \sqrt{2} = 325.22V$$

Maximum value of load current

$$I_m = \frac{V}{2R_d + R_L} = \frac{325.22}{(4 + 50)} = 6.02A$$

(a) Average load current

$$I_{avg} = \frac{2l_m}{\pi} = \frac{2 \times 6.02}{\pi} = 3.83A$$

(b) RMS value of load current

$$I_{rms} = \frac{l_m}{\sqrt{2}} = \frac{6.02}{\sqrt{2}} = 4.26A$$

Rectifier efficiency,

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{I_{avg^2 \times RL}}{(I_{rms})^2 \times (2R_d + R_L)} = \frac{3.83^2 \times 50}{4.26^2 \times 54} \times 100 = 74.84\%$$

Advantages of Bridge FWR

- The output is twice that of the centre tap full wave rectifier for the same secondary voltage.
- No need of centre tapped transformer.
- For same DC output, PIV of full wave bridge rectifier is half that of Centre-Tap FWR.

Disadvantages of Bridge FWR

- It requires four diodes.
- During each half cycle of AC input, the two diodes that conduct are in series which causes voltage drop in internal resistance of diodes.

TUTORIAL PROBLEMS

Q1. An A.c. supply of 230 V is applied to a half-wave rectifier circuit through a transformer of turn ratio 10 : 1. Find (i) the output d.c. voltage and (ii) the peak inverse voltage. Assume the diode to be ideal.

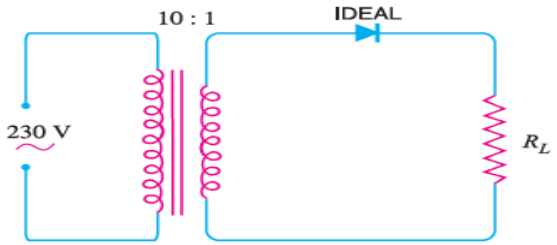


Fig. 1

ans(10.36V,32.53V)

Q2:A crystal diode having internal resistance rf = 20Ω is used for half-wave rectification. If the applied voltage v = 50 sin ω t and load resistance RL= 800 Ω, find :
(i) Im, Idc, Irms (ii) a.c. power input and d.c. power output (iii) d.c. output voltage (iv) efficiency of rectification.

Ans (i)61mA ,19.4mA,30.5mA(ii)0.763w,0.301w (iii)15.53v(iv)39.5%

Q 3Fig. 4(i) and Fig. 4 (ii) show the centre-tap and bridge type circuits having the same load resistance and transformer turn ratio. The primary of each is connected to 230V, 50 Hz supply. (i) Find the d.c. voltage in each case. (ii) PIV for each case for the same d.c. output. Assume the diodes to be ideal.

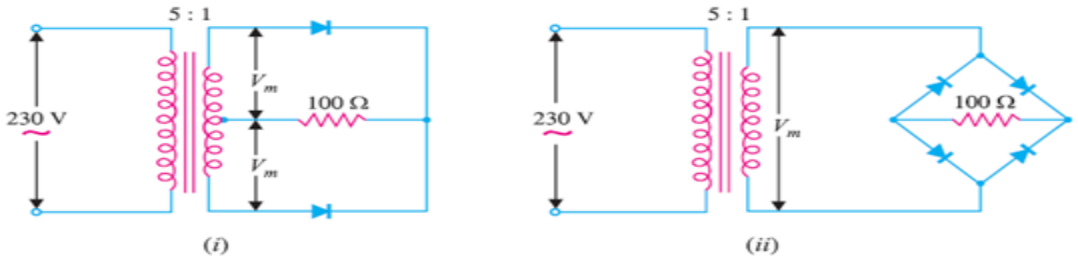


Fig. 4

Ans(20.7V,41.4V)