COURSE CODE: EEE-2121

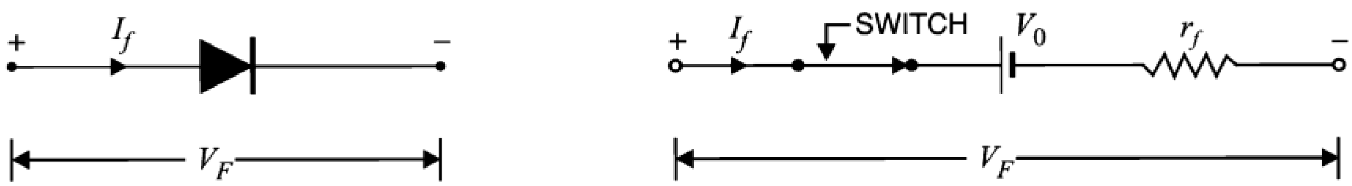
COURSE TITLE: Electronic devices and circuits

(*i*) ***Approximate Equivalent circuit.** When the forward voltage V_F is applied across a diode, it will not conduct till the potential barrier V_0 at the junction is overcome. When the forward voltage exceeds the potential barrier voltage, the diode starts conducting as shown in Fig. 6.7 (*i*). The forward current I_f flowing through the diode causes a voltage drop in its internal resistance r_f. Therefore, the forward voltage V_F applied across the *actual* diode has to overcome :

(*a*) potential barrier V_0

(*b*) internal drop $I_f r_f$

$$\therefore \qquad V_F = V_0 + I_f r_f$$

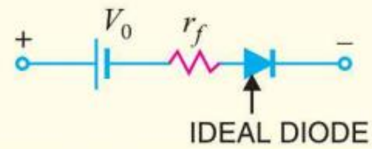
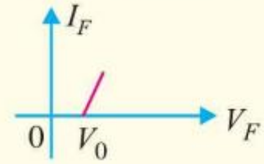
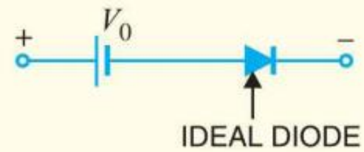
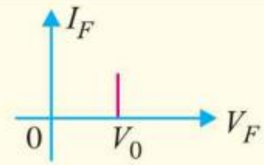
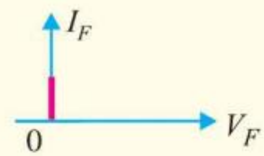


DIODE (*i*)   EQUIVALENT CIRCUIT (*ii*)

(*ii*) **Simplified Equivalent circuit.** For most applications, the internal resistance r_f of the crystal diode can be ignored in comparison to other elements in the equivalent circuit. The equivalent circuit then reduces to the one shown in Fig. 6.8 (*ii*). This simplified equivalent circuit of the crystal diode is frequently used in diode-circuit analysis.

(*i*)   (*ii*)

(*iii*) **Ideal diode model.** An ideal diode is one which behaves as a perfect conductor when forward biased and as a perfect insulator when reverse biased. Obviously, in such a hypothetical situation, forward resistance $r_f = 0$ and potential barrier V_0 is considered negligible. It may be mentioned here that although ideal diode is never found in practice, yet diode circuit analysis is made on this basis. *Therefore, while discussing diode circuits, the diode will be assumed ideal unless and until stated otherwise.*

S.No.	Type	Model	Characteristic
1.	Approximate model		
2.	Simplified model		
3.	Ideal Model		

Example 6.3. *Find the current through the diode in the circuit shown in Fig. 6.10 (i). Assume the diode to be ideal.*

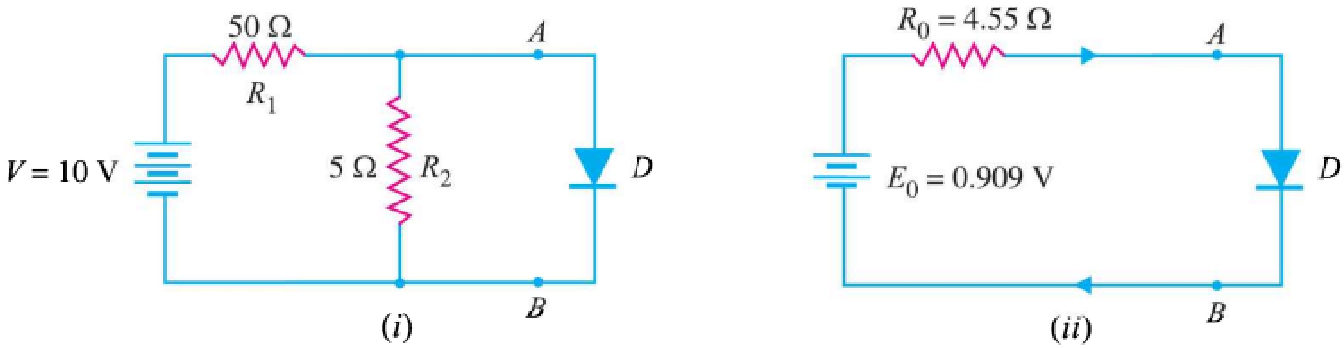


Fig. 6.10

Solution. We shall use Thevenin's theorem to find current in the diode. Referring to Fig. 6.10(*i*),

$$E_0 = \text{Thevenin's voltage}$$
$$= \text{Open circuited voltage across } AB \text{ with diode removed}$$
$$= \frac{R_2}{R_1 + R_2} \times V = \frac{5}{50 + 5} \times 10 = 0.909 \text{ V}$$

$$R_0 = \text{Thevenin's resistance}$$
$$= \text{Resistance at terminals } AB \text{ with diode removed and battery replaced by a short circuit}$$
$$= \frac{R_1 R_2}{R_1 + R_2} = \frac{50 \times 5}{50 + 5} = 4.55\ \Omega$$

Fig. 6.10 (*ii*) shows Thevenin's equivalent circuit. Since the diode is ideal, it has zero resistance.

$$\therefore \quad \text{Current through diode} = \frac{E_0}{R_0} = \frac{0.909}{4.55} = 0.2 \text{ A} = \textbf{200 mA}$$

Example 6.7. *Find V_Q and I_D in the network shown in Fig. 6.14 (i). Use simplified model.*

Solution. Replace the diodes by their simplified models. The resulting circuit will be as shown in Fig. 6.14 (*ii*). By symmetry, current in each branch is I_D so that current in branch *CD* is $2I_D$. Applying Kirchhoff's voltage law to the closed circuit *ABCDA*, we have,

$$-0.7 - I_D \times 2 - 2\,I_D \times 2 + 10 = 0 \qquad (I_D \text{ in mA})$$

or $$6\,I_D = 9.3$$

$\therefore$ $$I_D = \frac{9.3}{6} = \mathbf{1.55\ mA}$$

Also $$V_Q = (2\,I_D) \times 2\ \text{k}\Omega = (2 \times 1.55\ \text{mA}) \times 2\ \text{k}\Omega = \mathbf{6.2\ V}$$

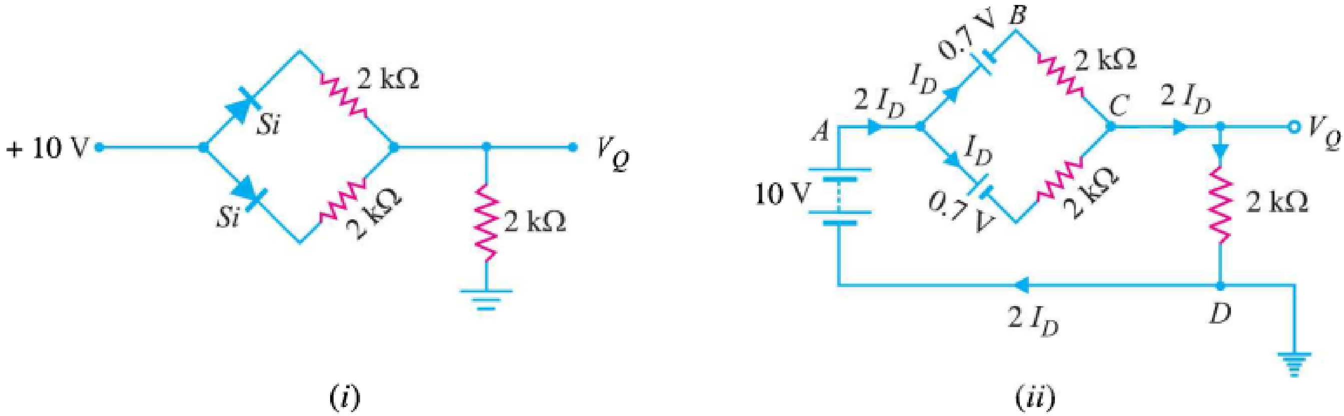


Fig. 6.14

Example 6.9. *Determine the currents I_1, I_2 and I_3 for the network shown in Fig. 6.16(i). Use simplified model for the diodes.*

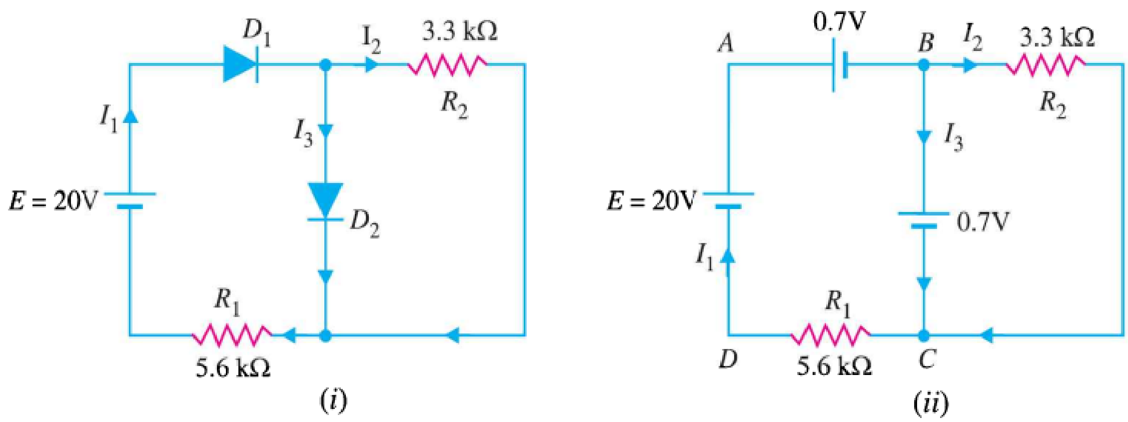


Fig. 6.16

Solution. An inspection of the circuit shown in Fig. 6.16 (*i*) shows that both diodes D_1 and D_2 are forward biased. Using simplified model for the diodes, the circuit shown in Fig. 6.16 (*i*) becomes the one shown in Fig. 6.16 (*ii*). The voltage across R_2 (= 3.3 k Ω) is 0.7V.

$\therefore$ $$I_2 = \frac{0.7\ \text{V}}{3.3\ \text{k}\Omega} = \mathbf{0.212\ mA}$$

Applying Kirchhoff's voltage law to loop *ABCDA* in Fig. 6.16 (*ii*), we have,

$$-0.7 - 0.7 - I_1 R_1 + 20 = 0$$

$\therefore$ $$I_1 = \frac{20 - 0.7 - 0.7}{R_1} = \frac{18.6\ \text{V}}{5.6\ \text{k}\Omega} = \mathbf{3.32\ mA}$$

Now $$I_1 = I_2 + I_3$$

$\therefore$ $$I_3 = I_1 - I_2 = 3.32 - 0.212 = \mathbf{3.108\ mA}$$

(*i*) **Forward current.** It is the current flowing through a forward biased diode. Every diode has a maximum value of forward current which it can safely carry. If this value is exceeded, the diode may be destroyed due to excessive heat. For this reason, the manufacturers' data sheet specifies the maximum forward current that a diode can handle safely.

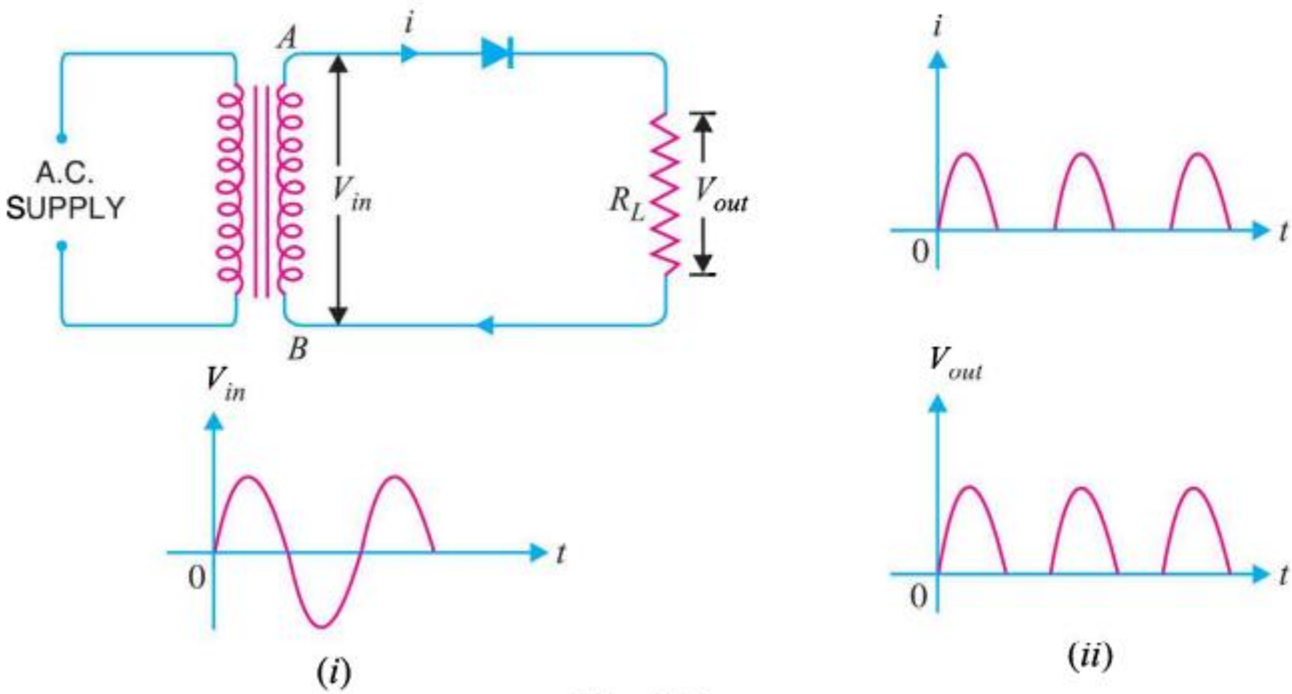
(*ii*) **Peak inverse voltage.** *It is the maximum reverse voltage that a diode can withstand without destroying the junction.*

If the reverse voltage across a diode exceeds this value, the reverse current increases sharply and breaks down the junction due to excessive heat. Peak inverse voltage is extremely important when diode is used as a rectifier. In rectifier service, it has to be ensured that reverse voltage across the diode does not exceed its PIV during the negative half-cycle of input a.c. voltage. As a matter of fact, PIV consideration is generally the deciding factor in diode rectifier circuits. The peak inverse voltage may be between 10V and 10 kV depending upon the type of diode.

(*iii*) **Reverse current or leakage current.** It is the current that flows through a reverse biased diode. This current is due to the minority carriers. Under normal operating voltages, the reverse current is quite small. Its value is extremely small ($< 1\mu$ A) for silicon diodes but it is appreciable ($\simeq$ 100 μA) for germanium diodes.

6.8 Half-Wave Rectifier

In half-wave rectification, the rectifier conducts current only during the positive half-cycles of input a.c. supply. The negative half-cycles of a.c. supply are suppressed *i.e.* during negative half-cycles, no current is conducted and hence no voltage appears across the load. Therefore, current always flows in one direction (*i.e.* d.c.) through the load though after every half-cycle.

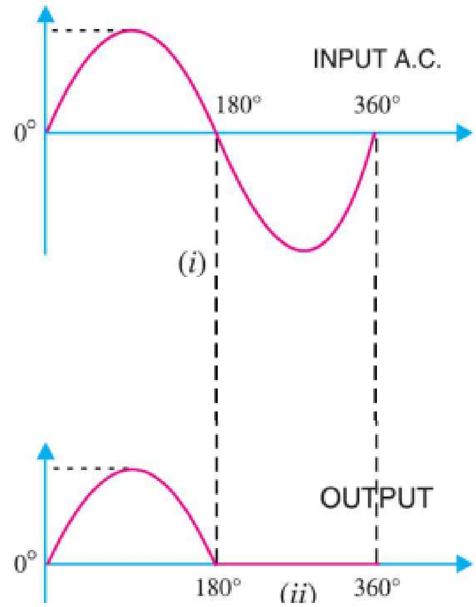


6.9 Output Frequency of Half-Wave Rectifier

The output frequency of a half-wave rectifier is equal to the input frequency (50 Hz). Recall how a complete cycle is defined. A waveform has a complete cycle when it repeats the same wave pattern over a given time. Thus in Fig. 6.21 (*i*), the a.c. input voltage repeats the same wave pattern over 0° – 360°, 360° – 720° and so on. In Fig. 6.21 (*ii*), the output waveform also repeats the same wave pattern over 0° – 360°, 360° – 720° and so on. This means that when input a.c. completes one cycle, the output half-wave rectified wave also completes one cycle. In other words, the output frequency is equal to the input frequency *i.e.*

$$f_{out} = f_{in}$$

For example, if the input frequency of sine wave applied to a half-wave rectifier is 100 Hz, then frequency of the output wave will also be 100 Hz.



6.13 Full-Wave Bridge Rectifier

The need for a centre tapped power transformer is eliminated in the bridge rectifier. It contains four diodes D_1, D_2, D_3 and D_4 connected to form bridge as shown in Fig. 6.26. The a.c. supply to be rectified is applied to the diagonally opposite ends of the bridge through the transformer. Between other two ends of the bridge, the load resistance R_L is connected.

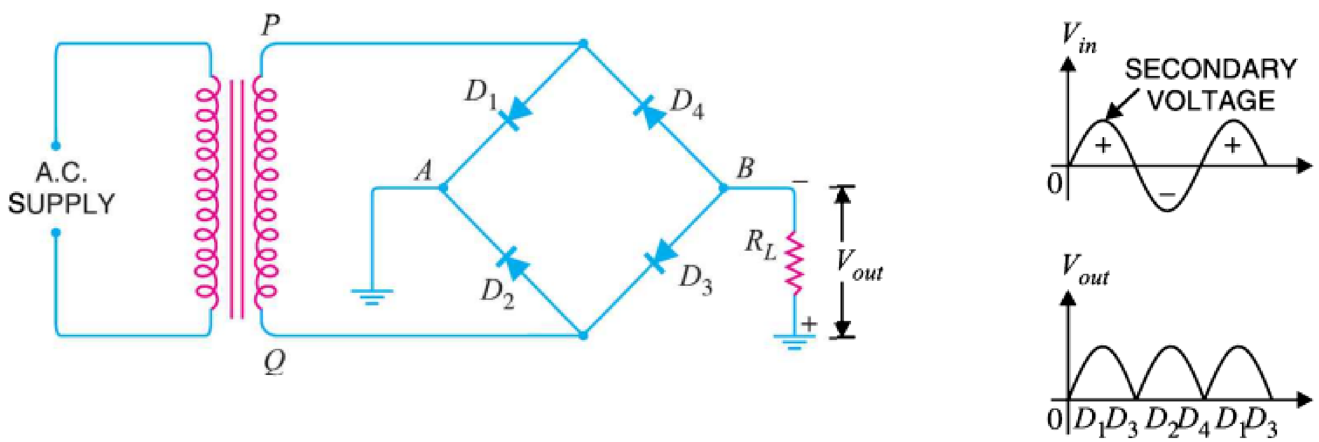
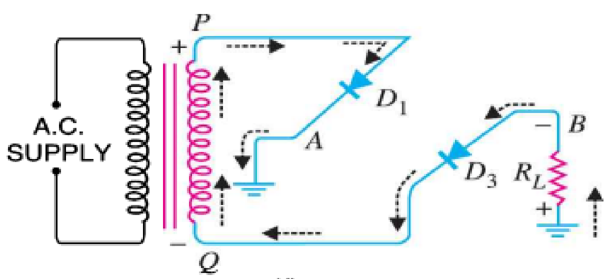


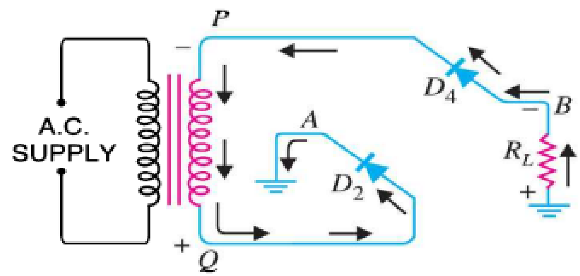
Fig. 6.26

Operation. During the positive half-cycle of secondary voltage, the end P of the secondary winding becomes positive and end Q negative. This makes diodes D_1 and D_3 forward biased while diodes D_2 and D_4 are reverse biased. Therefore, only diodes D_1 and D_3 conduct. These two diodes will be in series through the load R_L as shown in Fig. 6.27 (*i*). The conventional current flow is shown by dotted arrows. It may be seen that current flows from A to B through the load R_L .

During the negative half-cycle of secondary voltage, end P becomes negative and end Q positive. This makes diodes D_2 and D_4 forward biased whereas diodes D_1 and D_3 are reverse biased. Therefore, only diodes D_2 and D_4 conduct. These two diodes will be in series through the load R_L as shown in Fig. 6.27 (*ii*). The current flow is shown by the solid arrows. It may be seen that again current flows from A to B through the load *i.e.* in the same direction as for the positive half-cycle. Therefore, d.c. output is obtained across load R_L.



(*i*)

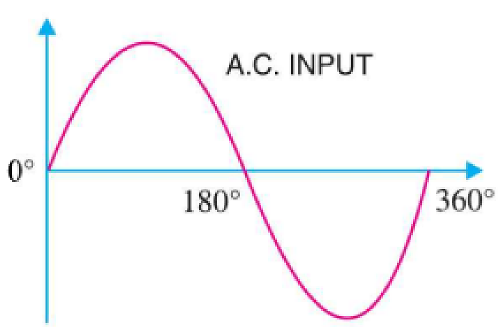


(*ii*)

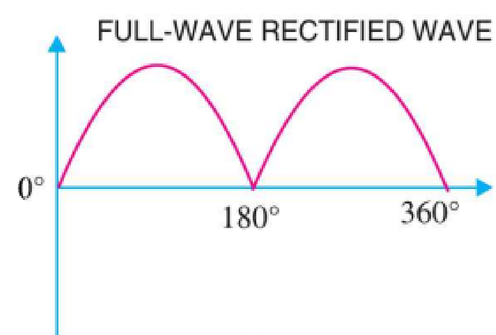
6.14 Output Frequency of Full-Wave Rectifier

The output frequency of a full-wave rectifier is double the input frequency. Remember that a wave has a complete cycle when it repeats the same pattern. In Fig. 6.29 (*i*), the input a.c. completes one cycle from 0° – 360°. However, the full-wave rectified wave completes 2 cycles in this period [See Fig. 6.29 (*ii*)]. Therefore, output frequency is twice the input frequency *i.e.*

$$f_{out} = 2 f_{in}$$



(*i*)



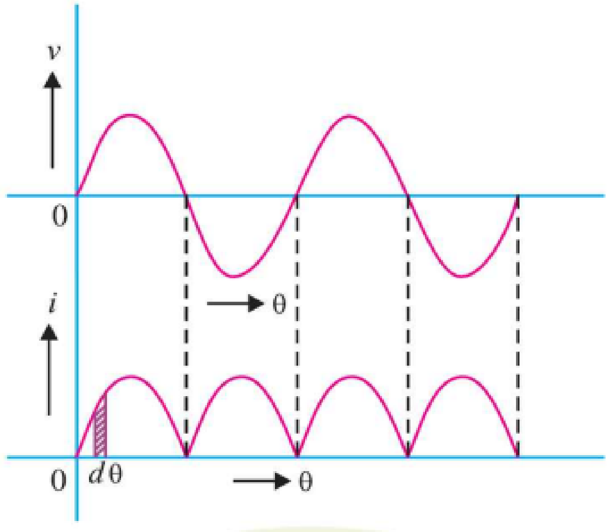
(*ii*)

Fig. 6.29

For example, if the input frequency to a full-wave rectifier is 100 Hz, then the output frequency will be 200 Hz.

Fig. 6.30 shows the process of full-wave rectification. Let $v = V_m \sin\theta$ be the a.c. voltage to be rectified. Let r_f and R_L be the diode resistance and load resistance respectively. Obviously, the rectifier will conduct current through the load in the same direction for both half-cycles of input a.c. voltage. The instantaneous current i is given by :

$$i = \frac{v}{r_f + R_L} = \frac{V_m \sin\theta}{r_f + R_L}$$



d.c. output power. The output current is pulsating direct current. Therefore, in order to find the d.c. power, average current has to be found out. From the elementary knowledge of electrical engineering,

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

$\therefore$ d.c. power output, $P_{dc} = I_{dc}^2 \times R_L = \left(\frac{2 I_m}{\pi}\right)^2 \times R_L$

a.c. input power. The a.c. input power is given by :

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

For a full-wave rectified wave, we have,

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

$$\therefore \quad P_{ac} = \left(\frac{I_m}{\sqrt{2}}\right)^2 (r_f + R_L)$$

$\therefore$ Full-wave rectification efficiency is

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{(2I_m/\pi)^2 R_L}{\left(\frac{I_m}{\sqrt{2}}\right)^2 (r_f + R_L)}$$

$$= \frac{8}{\pi^2} \times \frac{R_L}{(r_f + R_L)} = \frac{0.812\ R_L}{r_f + R_L} = \frac{0.812}{1 + \frac{r_f}{R_L}}$$

The efficiency will be maximum if r_f is negligible as compared to R_L.

$\therefore$ Maximum efficiency = 81.2%

Example 6.16. *A full-wave rectifier uses two diodes, the internal resistance of each diode may be assumed constant at 20 Ω. The transformer r.m.s. secondary voltage from centre tap to each end of secondary is 50 V and load resistance is 980 Ω. Find :*

(*i*) *the mean load current* (*ii*) *the r.m.s. value of load current*

Solution.

$$r_f = 20\ \Omega, \quad R_L = 980\ \Omega$$

$$\text{Max. a.c. voltage, } V_m = 50 \times \sqrt{2} = 70.7\text{ V}$$

$$\text{Max. load current, } I_m = \frac{V_m}{r_f + R_L} = \frac{70.7\text{ V}}{(20 + 980)\ \Omega} = 70.7\text{ mA}$$

(*i*) Mean load current, $I_{dc} = \frac{2I_m}{\pi} = \frac{2 \times 70.7}{\pi} = \mathbf{45\ mA}$

(*ii*) R.M.S. value of load current is

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{70.7}{\sqrt{2}} = \mathbf{50\ mA}$$

Example 6.20. *The four diodes used in a bridge rectifier circuit have forward resistances which may be considered constant at 1Ω and infinite reverse resistance. The alternating supply voltage is 240 V r.m.s. and load resistance is 480 Ω. Calculate (i) mean load current and (ii) power dissipated in each diode.*

Solution.

$$\text{Max. a.c. voltage, } V_m = 240 \times \sqrt{2} \text{ V}$$

(*i*) At any instant in the bridge rectifier, two diodes in series are conducting. Therefore, total circuit resistance $= 2\, r_f + R_L$.

$$\text{Max. load current, } I_m = \frac{V_m}{2\, r_f + R_L} = \frac{240 \times \sqrt{2}}{2 \times 1 + 480} = 0.7 \text{ A}$$

$$\therefore \quad \text{Mean load current, } I_{dc} = \frac{2\, I_m}{\pi} = \frac{2 \times 0.7}{\pi} = \mathbf{0.45\ A}$$

(*ii*) Since each diode conducts only half a cycle, diode r.m.s. current is :

$$I_{r.m.s.} = I_m/2 = 0.7/2 = 0.35 \text{ A}$$

$$\text{Power dissipated in each diode} = I^2_{r.m.s.} \times r_f = (0.35)^2 \times 1 = \mathbf{0.123\ W}$$

6.18 Ripple Factor

The output of a rectifier consists of a d.c. component and an a.c. component (also known as *ripple*). The a.c. component is undesirable and accounts for the pulsations in the rectifier output. The effectiveness of a rectifier depends upon the magnitude of a.c. component in the output ; the smaller this component, the more effective is the rectifier.

The ratio of r.m.s. value of a.c. component to the d.c. component in the rectifier output is known as **ripple factor** *i.e.*

$$\text{Ripple factor} = \frac{\text{r.m.s. value of a.c component}}{\text{value of d.c. component}} = \frac{I_{ac}}{I_{dc}}$$

Therefore, ripple factor is very important in deciding the effectiveness of a rectifier. The smaller the ripple factor, the lesser the effective a.c. component and hence more effective is the rectifier.

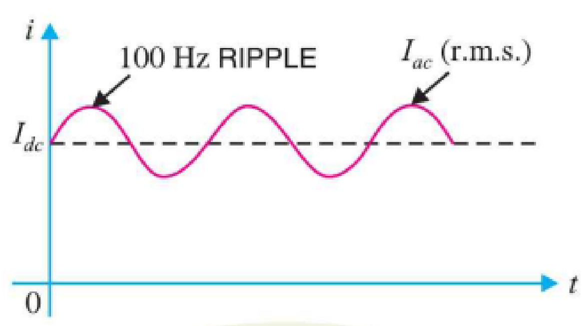


Fig. 6.39

Mathematical analysis. The output current of a rectifier contains d.c. as well as a.c. component. The undesired a.c. component has a frequency of 100 Hz (*i.e.* double the supply frequency 50 Hz) and is called the *ripple* (See Fig. 6.39). It is a fluctuation superimposed on the d.c. component.

By definition, the effective (*i.e.* r.m.s.) value of total load current is given by :

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

or

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

Dividing throughout by I_{dc}, we get,

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

But I_{ac}/I_{dc} is the ripple factor.

$$\therefore \qquad \text{Ripple factor} = \frac{1}{I_{dc}} \sqrt{I_{rms}^2 - I_{dc}^2} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

(*i*) For half-wave rectification. In half-wave rectification,

$$I_{rms} = I_m/2 \qquad ; \qquad I_{dc} = I_m/\pi$$

$$\therefore \qquad \text{Ripple factor} = \sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2 - 1} = 1.21$$

It is clear that a.c. component exceeds the d.c. component in the output of a half-wave rectifier. This results in greater pulsations in the output. Therefore, half-wave rectifier is ineffective for conversion of a.c. into d.c.

(*ii*) For full-wave rectification. In full-wave rectification,

$$I_{rms} = \frac{I_m}{\sqrt{2}} \qquad ; \qquad I_{dc} = \frac{2\,I_m}{\pi}$$

$$\therefore \qquad \text{Ripple factor} = \sqrt{\left(\frac{I_m/\sqrt{2}}{2\,I_m/\pi}\right)^2 - 1} = 0.48$$

i.e. $\dfrac{\text{effective a.c. component}}{\text{d.c. component}} = 0.48$

This shows that in the output of a full-wave rectifier, the d.c. component is more than the a.c. component. Consequently, the pulsations in the output will be less than in half-wave rectifier. For this reason, full-wave rectification is invariably used for conversion of a.c. into d.c.