15

Rectifiers and Other Diode Circuits

TOPICS DISCUSSED

- Half-wave and full-wave rectifier circuits
- Analysis of rectifiers
- Filters
- Clipping and clamping circuits

15.1 RECTIFIERS

15.1.1 Introduction

A rectifier is a device that converts ac supply into dc using diodes. Rectification can be done by half-wave or full-wave rectification circuits. All electronic circuits need a dc voltage for their operation. The supply voltage available is from the ac mains which is 230 V, 50 Hz supply. A rectifier will first step down the ac supply voltage to the required level by using a step-down transformer. A single diode can be used to rectify the ac voltage into half-wave rectified dc voltage. Since the rectified voltage is a unidirectionally changing dc, filter circuits are used to get steady dc output.

In this section we will discuss half-wave and full-wave rectifier circuits.

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biased during the positive half cycle of the applied voltage and reverse biased during the negative half cycle.

During the positive half cycle, i.e., from time 0 to π, voltage is positive, and hence terminal A of the transformer, T is positive. Diode is forward biased, and hence current will flow through the diode and through the load resistance, R_L. If a step down transformer is used, the magnitude of output voltage will be reduced. If however, step down of voltage is not required, a transformer having an equal turn ratio, i.e., N_2/N_1 will be used. The function of the transformer will be to electrically isolate the dc output circuit from the input circuit.

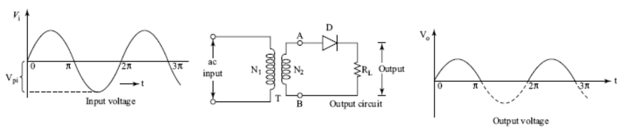

Figure 15.1 Half-wave rectifier circuit with input and output voltage waveforms

During the negative half cycle of the input voltage wave, the terminal A of the transformer will be negative and terminal B will be positive. The diode will be reverse biased and virtually no current will flow through the diode and the load.

This sequence of allowing the positive half cycle of current through the diode and blocking the negative half cycle will continue for each and every cycle of power supply. As a result, a half-wave rectified current will flow through the output circuit. The voltage drop across the load resistance, R_L will be the output voltage, V_o which will be a half-wave rectified voltage. When the diode is reverse biased, the maximum or peak voltage of the negative half cycle of the input will be appearing across the diode terminals. This is the peak of the reverse voltage or peak-inverse voltage (PIV) which is getting applied to the diode in every alternate half cycles.

It is seen that a diode works as a closed switch during the positive half cycle of the input voltage and works as an open switch during the negative half cycle. The output voltage appears across the load during the positive half cycle only. The load voltage and load current although positive all the time (i.e., unidirectional) are fluctuating dc as its magnitudes changing. Our aim will be to obtain steady dc at the output.

The average value of this fluctuating dc as also its RMS values can be calculated as I_m/π and $I_m/2$, respectively.

The performance parameters of a half-wave rectifier output are calculated in terms of the output dc current (i.e., the average value of the rectified wave), the RMS value of the output current, the output voltage, ripple factor, peak inverse voltage, etc.

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$i = I_m \sin \theta$,

where i is the instantaneous value, I_m is the maximum value, and $\theta = \omega t$.

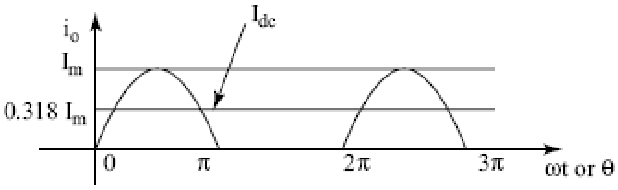

Figure 15.2 Half-wave rectified current

The average value is calculated by integrating the current for a period $\theta = 0$ to $\theta = \pi$ and averaging it for the entire cycle, i.e., $\theta = 0$ to $q = 2\pi$.

I_{dc} is the average value of the rectified current.

$$
\begin{aligned}
I_{dc} = I_{av} &= \frac{1}{2\pi}\int_0^{\pi} i\,d\theta = \frac{1}{2\pi}\int_0^{\pi} I_m \sin\theta\,d\theta \\
&= \frac{I_m}{2\pi}\left[-\cos\theta\right]_0^{\pi} \\
&= \frac{I_m}{2\pi}\left[-(-1)-(-1)\right] \\
&= \frac{I_m}{\pi} = 0.318\ I_m
\end{aligned}
$$

The RMS value, I is calculated by first squaring the current, then taking its mean, and then taking its root as

$$I = \sqrt{\frac{1}{2\pi}\int_0^{\pi} i^2\,d\theta} \quad \text{or,} \quad I^2 = \frac{1}{2\pi}\int_0^{\pi} i^2\,d\theta$$

or,

$$I^2 = \frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\theta\,d\theta$$

or,

$$
\begin{aligned}
I^2 &= \frac{I_m^2}{2\pi}\int_0^{\pi}\left[\frac{1-\cos 2\theta}{2}\right]d\theta = \frac{I_m^2}{4\pi}\left[\theta - \frac{\sin 2\theta}{2}\right]_0^{\pi} \\
&= \frac{I_m^2}{4\pi}\left[\pi - \frac{\sin 2\pi}{2} - \left(0 - \frac{\sin 2\times 0}{2}\right)\right] \\
&= \frac{I_m^2}{4\pi}\times\pi
\end{aligned}
$$

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Ripple Factor: The output of a half-wave rectifier is a pulsating dc. If we analyse, we will see that it has a steady dc component and an ac component. The ac component is called the ripple. Ripple factor is defined as the ratio of the RMS value of ac component to the value of dc component. The ripple factor indicates the level of fluctuation of the output voltage from its steady value. Ripple is an undesired effect and should be minimized. The ripple factor, r for a half-wave rectifier is calculated as

$$\text{Ripple Factor, } r = \frac{\text{RMS value of ac component}}{\text{value of dc component}}$$

$$= \frac{I_{ac}}{I_{dc}}$$

Again, $I_{rms}^2 = I_{dc}^2 + I_1^2 + I_2^2 + I_4^2 + \cdots = I_{dc}^2 + I_{ac}^2$

where I_1, I_2, I_4, etc., are the fundamental and harmonics of the ac component

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

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

where I_{ac} is the RMS value of the ac component of the output current.

I_{dc} is the dc component of the output current and I_{rms} is the RMS value of the output current.

Substituting

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

Considering $I_{rms} = \frac{I_m}{2}$ and $I_{dc} = \frac{I_m}{\pi}$ a half-wave rectifier,

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ripple factor,

$$
\begin{aligned}
r &= \sqrt{\left[\frac{I_m/2}{I_m/\pi}\right]^2 - 1} \\
&= \sqrt{\frac{\pi^2}{4} - 1} \\
&= 1.21
\end{aligned}
$$

Output voltage, V_{dc} across the load is

$$V_{dc} = I_{dc}\, R_L = \frac{I_m}{\pi} R_L = \frac{V_m}{\pi} = 0.318\ V_m$$

Rectifier efficiency: It is calculated as the ratio of output power to input power.

DC output power,

$$P_{dc} = I_{dc}^2\, R_L = \left(\frac{I_m}{\pi}\right)^2 R_L$$

AC input power, P_{ac} = Power dissipated in diode junction + Power dissipated in the load = $I_{rms}^2\ R_f + I_{rms}^2 R_L$

The forward resistance, R_f of the diode is very small, and hence I^2_{rms} R_f can be neglected in comparison with I^2_{rms} R_L.

$$
\begin{aligned}
\text{Therefore, rectifier efficiency } &= \frac{P_{dc}}{P_{ac}} = \frac{I_m^2}{\pi^2} RL \div I_{rms}^2 R_L \\
&= \frac{I_m^2\ RL}{\pi^2\ I_{rms}^2 RL} = \frac{I_m^2}{\pi^2 \cdot \left(\frac{I_m}{2}\right)^2} \\
&= \frac{4}{\pi^2} = 0.406 = 40.6 \text{ per cent}
\end{aligned}
$$

This value of efficiency is considered low and ripple factor is considered very high. A filter circuit has to be used to minimize the ripples.

Peak inverse voltage (PIV): As mentioned earlier, PIV is the maximum value of reverse voltage that appears across the diode when it gets reverse biased. Here

PIV = V_m

Rectifier diodes are specified for their average forward current-car-

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Voltage Regulation of the rectifier is calculated using the relation,

$$\text{Voltage regulation} = \frac{V_{dc} \text{ at no load} - V_{dc} \text{ on full load}}{V_{dc} \text{ on full load}}$$

The difference between no-load voltage and full-load voltage is the voltage drop in the transformer winding and across the diode. The value of voltage regulation, which is generally expressed in percentage should be low.

Example 15.1 A half-wave diode rectifier has a forward voltage drop, i.e., voltage drop across the diode when conducting is 0.7 V. The load resistance is 600 Ω. The RMS value of the ac input is 28.87 V. Calculate I_{dc}, I_{rms}, PIV, and form factor.

Solution:

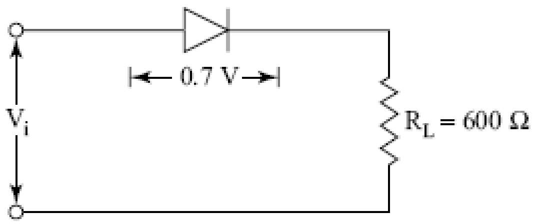

Figure 15.3

$$V_i(\text{RMS}) = 28.27 \text{ V}$$

$$V_i(\max) = \sqrt{2}\, V_i(\text{RMS})$$

$$= 1.414 \times 28.27$$

i.e., $V_m = 40$ V

$$\text{PIV} = V_m = 40 \text{ V}$$

$$I_{dc} = \frac{I_m}{\pi}; \qquad I_m = \frac{V_m - 0.7}{R_L} = \frac{40 - 0.7}{600} = \frac{39.3}{600} \text{ A}$$

$$I_{dc} = \frac{39.3}{600 \times \pi} = 0.0208 \text{ A} = 20.8 \text{ mA}$$

$$I_{rms} = \frac{I_m}{2} \frac{39.3}{600 \times 2} = 0.0327 \text{ A} = 32.7 \text{ mA}$$

$$\text{Form factor} = \frac{\text{RMS value}}{\text{Average value}} = \frac{I_{rms}}{I_{dc}} = \frac{32.7}{20.8}$$

$$= 1.57$$

Example 15.2 A half-wave rectifier produces a maximum load current (peak value) of 50 mA through a 1200 Ω resistor. Calculate the PIV of the diode. The diode is of silicon material.

Solution:

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$$I_m = \frac{V_m - 0.7}{R_L} = \frac{V_m - 0.7}{1200}$$

I_m is given as 40 mA.

Therefore,

$$40 \times 10^{-3} = \frac{V_m - 0.7}{1200}$$

or, $$V_m - 0.7 = 1200 \times 40 \times 10^{-3} = 48\text{ V}$$

or, $$V_m = 48 + 0.7 = 48.7\text{ V}$$

PIV = V_m = 48.7 V

Example 15.3 A half-wave rectifier circuit has been made using a step-down transformer of turn ratio 10:1. The input voltage is v = 325 sin ωt the diode forward resistance is 25 Ω. A load resistance of 1.2 kΩ has been connected in the circuit. Assuming a secondary winding resistance of the transformer as 1Ω, calculate the following: (a) RMS value of load current (b) rectification efficiency, and (c) ripple factor.

Solution:

Input voltage, v = 325 sin ωt

Input, V_m = 325

Transformer has a turn ratio of 10:1

The output $$V_m = \frac{325}{10} = 32.5\text{ V}$$

$$I_m = \frac{V_m}{R_2 + R_F + R_L}$$

where R_2 is the secondary winding resistance, R_F is the forward resistance of the diode and R_L is the load resistance.

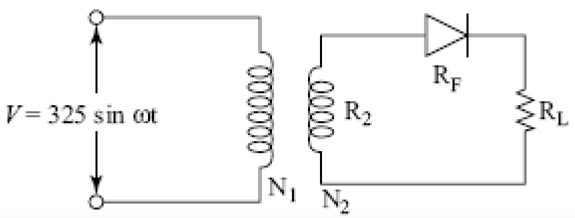

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Figure 15.4 Half-wave rectifier

$$I_m = \frac{32.5}{1+25+1200}$$
$$= \frac{32.5}{1226}\ \text{A}$$
$$= 26.5\ \text{mA}$$

Since it is a half-wave rectifier circuit,

$$I_{rms} = \frac{I_m}{2} = \frac{26.5}{2} = 13.25\ \text{mA}$$

$$I_{dc} = \frac{I_m}{\pi} = \frac{26.5}{3.14} = 8.44\ \text{mA}$$

output dc power = $I^2_{dc} R_L = (8.44 \times 10^{-3})^2 \times 1200$

= 85.48 mW

AC input power = $(I_{rms})^2\ [R_2 + R_F + R_L]$

$= (13.25 \times 10^{-3})^2 \times 1226$

= 0.215 W = 215 mW

$$\text{Rectifier efficiency} = \frac{\text{Output dc power}}{\text{Input ac power}} \times 100$$
$$= \frac{85.48 \times 100}{215} = 39.75 \text{ per cent}$$

$$\text{Ripple factor, } r = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} = \sqrt{\left(\frac{13.25}{8.44}\right)^2 - 1} = 1.21$$

15.1.4 Full-wave Rectifier

Full-wave rectifiers can be made using two diodes and a centre-tapped transformer. Full-wave rectifiers are also made using a two-winding transformer and four diodes. Such rectifiers are called bridge rectifiers. These are discussed as follows.

Two-diode full-wave rectifier: here ac input voltage is supplied from the secondary of a centre-tapped transformer. The circuit consists of the transformer, two diodes and the load resistance. The circuit is essentially the summation of two half-wave rectifiers as shown in Fig. 15.5.

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This way in each half cycle one of the two diodes will conduct and current will flow through the load resistance, R_L. The output current and the output voltage across the load will be a full-wave rectified current and voltage, respectively. The output wave form is a series of consecutive positive half cycles of sinusoidal wave form. The current through the load resistance is unidirectional but its magnitude is fluctuating as shown in Fig. 15.5. The PIV is the maximum voltage that would appear across a diode when it is reverse biased. Here, when D_1 is conducting, D_2 is reverse biased and vice versa. When D_1 is conducting, the voltage that would appear across diode D_2 is the sum of the voltage across the lower half of the transformer secondary winding and the voltage appearing across the load. PIV of the diode is equal to 2 V_m.

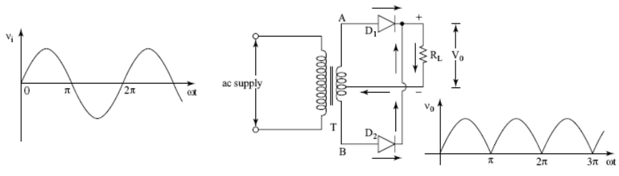
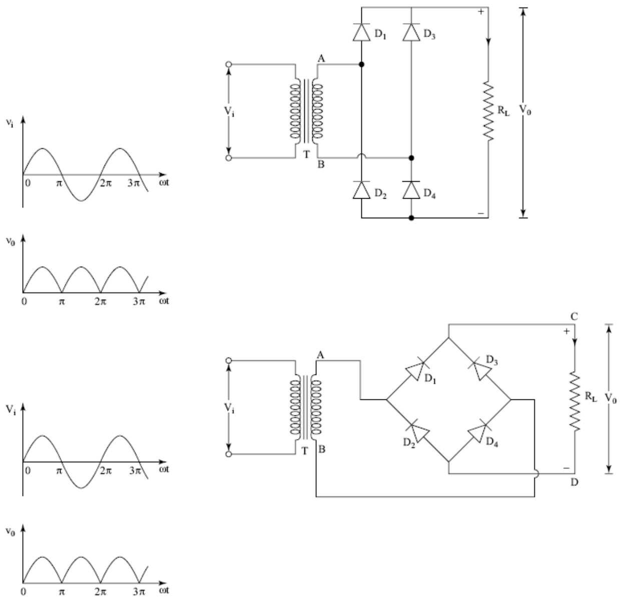


Figure 15.5 Full-wave rectifier using two diodes and a centre-tapped transformer

15.1.5 Full-wave Bridge Rectifier

A bridge rectifier circuit uses four diodes connected in the form of a bridge. The various ways the four diodes in the bridge circuit are drawn have been shown in Fig. 15.6 (a) and (b). As shown in Fig. 15.6 (a), the arrow head symbols of all the diodes are pointing towards the positive terminal of the output, i.e., the load.



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During the positive half cycle of the input voltage, terminal A of the transformer is positive. Current will flow from the positive terminal through diode D_1, load R_L and diode D_4, and back to the negative terminal, B of the transformer. The direction of current through the load has been shown to be from C to D, i.e., from top to bottom. The polarities of the load terminals have been shown. During this period diodes D_2 and D_3 are reverse biased.

During the negative half cycle of the input voltage diodes D_3 and D_2 are forward biased while diodes D_1 and D_4 are reverse biased. Current through the load will flow in the same direction, i.e., from terminal C to D. During both positive and negative half cycles of the input voltage, current will pass through the load in the same direction. The output voltage wave shape is a series of positive half cycles of the sinusoidal voltage. This is dc output but having a varying magnitude. The transformer provides isolation of the dc output from the supply ac input.

The important parameters of a full-wave bridge rectifier are determined as follows.

15.1.6 Analysis of Full-wave Rectifiers

Average value or dc value of load current, I_{dc}: The average value or dc value will be the same if calculated for a period 0 to π or 0 to 2 π

$$
\begin{aligned}
I_{dc} &= \frac{1}{\pi}\int_0^{\pi} I_m \sin\theta \, d\theta \\
&= \frac{I_m}{\pi}\int_0^{\pi} \sin\theta \, d\theta \\
&= \frac{I_m}{\pi}\left[-\cos\theta\right]_0^{\pi} \\
&= \frac{I_m}{\pi}\left[-(-1)-(-1)\right] \\
&= \frac{2I_m}{\pi}
\end{aligned}
$$

RMS value of the laod current, I_{rms}

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$$I_{rms}^2 = \frac{1}{\pi}\int_0^{\pi} I_m^2 \sin^2\theta \, d\theta$$

$$= \frac{I_m^2}{2\pi}\int_0^{\pi}(1-\cos 2\theta)\, d\theta$$

$$= \frac{I_m^2}{2\pi}\left[\theta - \frac{\sin 2\theta}{2}\right]_0^{\pi}$$

$$= \frac{I_m^2}{2\pi} \times \pi = \frac{I_m^2}{2}$$

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

Output voltage, V_{dc}

$$V_{dc} = I_{dc} R_L$$

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

$$= \frac{2\ R_L}{\pi} \frac{V_m}{(R_L + 2R_F + R_2)}$$

where R_L is the load resistance, R_F is the forward resistance of the diode, and R_2 is the secondary winding resistance of the transformer.

Rectifier efficiency, η

$$\eta = \frac{\text{dc power output, } P_{dc}}{\text{ac power input, } P_{ac}}$$

$$= \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_L + 2R_F + R_2)} \qquad \text{(Two diodes being in series)}$$

$$= \frac{(2I_m)^2 R_L}{\pi^2 I_{rms}^2 (R_L + 2R_F + R_2)}$$

$$= \frac{(2\sqrt{2}\ I_{rms})^2 R_L}{\pi^2 I_{rms}^2 (R_L + 2R_F + R_2)}$$

$$= \frac{8\ I_{rms}^2}{\pi^2 I_{rms}^2 \left(1 + \frac{2R_F + R_2}{R_L}\right)}$$

$$= \frac{8}{\pi^2} = 0.812 \ \text{ since } \ (2R_F + R_2) << R_L$$

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Ripple Factor

$$\text{Ripple factor, } r = \frac{\text{RMS value of ac component}}{\text{dc component}}$$

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

$$\text{Substituting, } \quad I_{rms} = \frac{I_m}{\sqrt{2}} = \quad \text{and} \quad I_{dc} = \frac{2I_m}{\pi}$$

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

$$= \sqrt{\frac{\pi^2}{8} - 1}$$

$$= 0.48$$

We had earlier calculated the ripple factor for a half-wave rectifier as 1.21. For a full-wave rectifier, the ripple factor is reduced to 0.48. This indicates that the fluctuation of dc output is reduced. PIV for a bridge rectifier = V_m.

It is now possible to compare the performance parameters of a half-wave rectifier with a bridge rectifier. This has been shown in Table 15.1. Although the performance parameters of a bridge rectifier are superior than a half-wave rectifie, the quality of output voltage is still not acceptable and has ripple content which must be further minimized. This is achieved by using filters. Filters are discussed in the section that follows.

15.1.7 Comparison of Half-wave and Full-wave Rectifiers

The performance of half-wave and full-wave rectifiers with respect to certain parameters has been compared as in Table 15.1.

Table 15.1 Comparison of Half-wave and Full-wave Rectifiers Against Their Salient Parameters

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Parameters	Half-wave rectifier	Full-wave rectifier with centre-tapped transformer	Bridge rectifier
Number of diodes regd.	1	2	4
DC load current, I_{dc}	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
RMS value or load current I_{rms}	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
DC output, P_{dc}	$I_{dc}^2 R_L$ $= \frac{I_m^2}{\pi^2} R_L$	$\frac{4 I_m^2}{\pi^2} R_L$	$\frac{4 I_m^2}{\pi^2} R_L$
AC input, P_{ac}	$I_{rms}^2 (R_L + R_F + R_2)$ $= \frac{I_m^2}{4} (R_L + R_F + R_2)$	$I_{rms}^2 (R_L + 2R_F + R_2)$ $= \frac{I_m^2}{2} (R_L + 2R_F + R_2)$	$I_{rms}^2 (R_L + 2R_F + R_2)$ $= \frac{I_m^2}{2} (R_L + 2R_F + R_2)$
Maximum rectification efficiency	40%	81.2%	81.2%
Ripple factor	1.21	0.48	0.48
PIV	V_m	$2 V_m$	V_m
Ripple frequency	Fr = f	Fr = 2f	Fr = 2f
Centre tap transformer	Not required	Required	Not required
Transformer utilization factor	28.7%	69.2%	81.2%

Example 15.4 The input to a bridge rectifier is through a step-down transformer of turn ratio 10:1. The supply voltage is 230 V at 50 Hz. The load resistance is 1.2 kΩ secondary winding resistance of the transformer is 4 Ω diode forward resistance is 2 Ω. Calculate the efficiency of the bridge rectifier.

Solution:

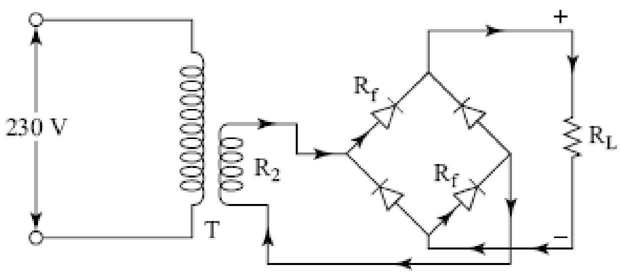

Figure 15.7 Bridge-rectifier circuit

Given V_i (RMS) = 230 V

R_F = 2 Ω, R_2 = 4 Ω, R_L = 1200 Ω

The RMS value of the emf in transformer secondary

$$V_s\,(\mathrm{RMS}) = 230\left(\frac{N_2}{N_1}\right)$$

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Peak secondary voltage, V_m is

$$V_m = \sqrt{2}\, V_s(\text{RMS})$$
$$= \sqrt{2} \times 23$$
$$= 32.5\,\text{V}$$

Current through the load will flow from the transformer secondary via two diodes. Therefore, following the current path during the positive half cycle

$$I_m = \frac{V_m}{R_L + 2\,R_F + R_2} = \frac{32.5}{1200 + 4 + 4} = 26.8\ \text{mA}$$

For a bridge rectifier,

$$I_{dc} = \frac{2I_m}{\pi} = \frac{2 \times 26.8}{3.14} = 17\ \text{mA}$$

DC power output, $P_{dc} = I^2_{dc} R_L = (17 \times 10^{-3})^2 \times 1200$

$= 346.8$ mW

AC power input,

$$P_{ac} = (I_{rms})^2 (R_L + 2R_F + R_S)$$
$$= \left(\frac{I_m}{\sqrt{2}}\right)^2 (R_L + 2R_F + R_S)$$
$$= \left(\frac{26.8 \times 10^{-3}}{2}\right)^2 \times (1200 + 2 \times 2 + 4)$$
$$= 432\ \text{mW}$$

$$\text{Rectifier efficiency}, \eta = \frac{P_{dc}}{P_{ac}} \times 100 = \frac{346.8 \times 100}{432} = 80\ \text{per cent.}$$

Example 15.5 Determine for the bridge circuit the peak value of load current when $V_i = 15$ V, $R_1 = 600\ \Omega$ and the forward voltage drop of the diode is 0.7 V. Also calculate the average value of the output current

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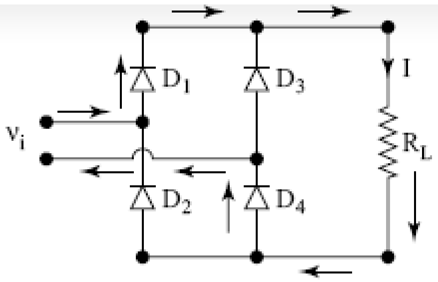

Figure 15.8 Bridge rectifier circuit

Solution:

$$V_i = 15 \text{ V}$$

$$V_i(\max) = \sqrt{2} \times 15 = 21.21 \text{ V}$$

Maximum value of voltage appearing across the load will be V_i (max) – 2 V_F.

This is because two diodes are involved in the current flow through the load at any point of time

$$\begin{aligned} V_0(\max) &= V_i\,(\max) - 2\ V_F \\ &= 21.21 - 2 \times 0.7 \\ &= 19.81 \text{ V} \end{aligned}$$

$$I_0(\max) = \frac{V_0(\max)}{R_L} = \frac{19.81}{600} = 36 \text{ mA}$$

$$I_0(\text{average}) = I_{dc} = \frac{2\,I_m}{\pi} = \frac{2 \times 36}{3.14} = 22.93 \text{ mA}$$

15.2 FILTERS

We have seen that the wave form of the rectified voltage is a series of positive half cycles of the input voltage wave form either of equal or of reduced magnitude. For a half-wave rectifier we get a series of positive half cycles with one missing in between. Our objective is to get a steady-value dc output. To convert the fluctuating output voltage into a steady dc, smoothing circuits called filters must be used. The simplest filter is a capacitor which is connected across the load. Fig. 15.9 shows a capacitor C connected across the load resistance R_L in a half-wave rectifier. The effect of the use of a capacitor on the output voltage wave has been shown.

During the positive half cycle of the input voltage the diode D_1 is for-

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After attaining the pick value, the input voltage starts reducing, its value becoming less and less than V_m. But the capacitor has been charged to a voltage V_m. Thus, the potential of terminal B becomes higher than the potential of terminal A. As a result, diode D_1 gets reverse biased but the capacitor voltage remains close to V_m. With the diode D_1 reverse biased, the changing of the capacitor stops. The capacitor now starts getting discharged through the load resistor R_L. The voltage across the capacitor, V_C starts falling, as has been shown in Fig. 15.9, through a thick horizontally inclined line. The diode, D_1 remains reverse biased throughout the rest of the positive half cycle and also during the negative half cycle, and further to the next positive half cycle until at θ_2 when the input voltage starts becoming higher than the capacitor voltage, V_C once again. At this point the diode becomes conducting supplying current to the load as also charging the capacitor once again. This process of charging and discharging of the capacitor continues in every cycle and an output voltage waveform, as shown by a thick line, is achieved. This wave shape of the output voltage is superior to the wave shape of the output voltage obtained when no capacitor was connected. The ripple of the output voltage is now reduced and a near-steady dc output voltage obtained.

Amplitude of ripple voltage and selection of capacitor

The half-wave rectified voltage with a capacitor filter has been shown again in Fig. 15.10. V_r represents the peak to peak ripple voltage. The time of discharge of the capacitor is represented by t_1 as shown in Fig. 15.10. The output voltage fluctuates between V_0 (min) to V_0 (max).

Peak to peak, $V_r = V_0\text{ (max)} – V_0\text{ (min)}$.

Average value of output voltage, $V_0\text{(average)}=$

$$\frac{V_0(\max) + V_0(\min)}{2}$$

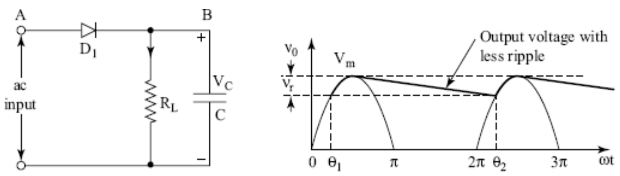
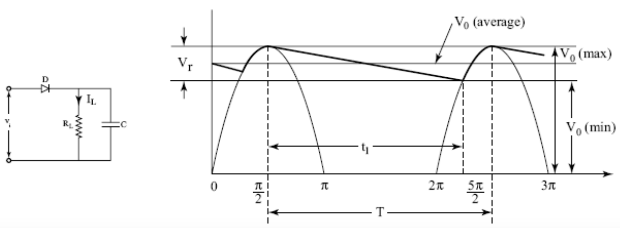


Figure 15.9 Half-wave rectifier circuit with a capacitor filter



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The capacitor C gets discharged during the time t_1 when the voltage across it drops by V_r causing a load current, I_L to flow through the resistance R_L. So we can write

$$Q = C V_r = I_L \times t$$

or, $$C = \frac{I_L \times t}{V_r} \qquad \text{(i)}$$

Calculation of the value of the capacitor to be used depends on the allowable ripple voltage, the average output voltage, the load resistance, and the supply frequency. The approximate value is calculated using the procedure illustrated through an example. The standard manufacture's list is then consulted to select the next higher value of the capacitor available in the market.

Example 15.6 A half-wave capacitor filter rectifier has maintained an average output voltage of 15 V with a peak to peak ripple of not more than 3 V. The load resistance is 100 Ω Calculate the value of the capacitor filter. The ac supply frequency is 50 Hz.

Solution:

$$\text{The load current, } I_L = \frac{V_0(\text{average})}{R_L}$$

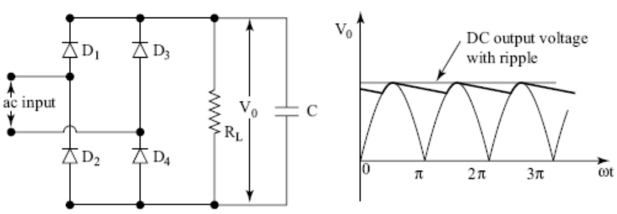
$$= \frac{15}{100} \text{ A} = 150 \text{ mA}$$

$$\text{Time period, } T = \frac{1}{f} = \frac{1}{50} \text{ seconds}$$

$$= \frac{1000}{50} \text{ ms} = 20 \text{ ms}$$

The time of discharge of the capacitor t_1 can approximately by considered equal to T. Therefore,

t_1 = T = 20 ms



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using the relation,

$$C\,V_r = I_L t_1$$

$$C = \frac{I_L t_1}{V_r} = \frac{150\times10^{-3}\times20\times10^{-3}}{3} = 1000\ \mu\text{F}$$

Capacitors of 100 mF are available as can be checked from the manufacturer's list.

Similar to the capacitor filter used in half-wave rectifiers, capacitor filters are used in full-wave rectifier also as shown in Fig. 15.11. The circuit works exactly the same way as has been explained in the case of half-wave rectifier with a capacitor filter. From the dc output voltage wave shape it is observed that the ripple is minimized to a very small level.

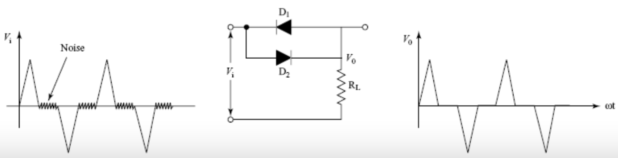
The ripple voltage that appears across the capacitor can further be reduced by use of another resistor and a capacitor. The resistor is connected in series while the capacitors are in parallel making a π formation. Such filters are called R–C filters or simply π filters. Similarly, we can use L–C filters also to further smoothen the output voltage. An inductor in series with the load also works as a filter as the inductor allows dc current to flow and opposes ac current flow.

15.3 APPLICATIONS OF DIODES IN CLIPPING AND CLAMPING CIRCUITS

A clipping circuit removes, i.e., clips off a certain portion of the input voltage wave form. Clipping circuits are used when it becomes necessary to protect a circuit or a device that might get destroyed due to large amplitude signal. In fact, the half-wave rectifier described earlier is a clipper circuit. It clips off the negative half cycle and allows only the positive half cycle. A clipping circuit, or also called a clipper is used to clip off certain unwanted portions of the wave form which may lead to noise, and deteriote the performance of the device through which such currents pass. Let us see one noise clipper circuit as shown in Fig. 15.12. Here the noise level is lower than the forward voltage drop V_F of the diodes i.e., V_F = 0.7 V. Two diodes, D_1 and D_2 clear both the halves of the main signal but do not allow the noise signal to pass.

15.3.1 Negative and Positive Series Clippers

When the input is positive the diode is forward biased, and hence the positive half cycle is passed to the output as shown in Fig. 15.13 (a). During the negative half cycle the diode is reverse biased, and hence the output will remain zero. This way we can say that the circuit cuts off the negative half cycles of the input voltage.



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In Fig. 15.13 (b), the positive half cycles are clipped off as the diode is reverse biased during the positive half cycles of the input. The input voltage wave in these two clippers are sinusoidal. However, the input wave form shapes could be of any other form like square, rectangular, triangular, etc.

15.3.2 Shunt Clippers

Like series clippers, shunt clippers can also clip off the positive half cycle or the negative half cycle of the input.

Figure 15.14 shows a positive shunt clipper circuit where the diode is connected in parallel, i.e., in shunt with the load resistance R_L.

When the input voltage is positive the diode is forward biased and is in conducting mode. The voltage drop across the diode V_F, which is only 0.7 V for a silicon diode will appear across the load. Thus, effectively the positive half cycle of the input voltage is clipped off and the output voltage will be nearly zero. When the input voltage is negative the diode is reverse biased. Current flows through the load resistance R_L and the series resistance R. The voltage drop across R is I_L R which is small as compared to the voltage drop across the load resistance R_L. The output voltage V_0 is nearly equal to the negative input voltage as has been shown. Resistance R is connected in the circuit to limit the diode current when it is forward biased.

A negative shunt clipper can be made by reversing the diode terminal connections.

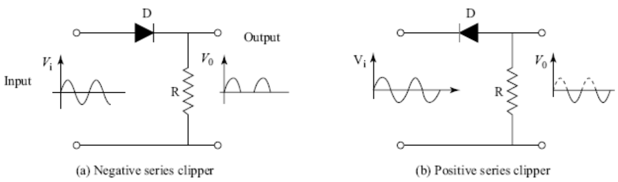

Figure 15.13 Negative and positive series clippers

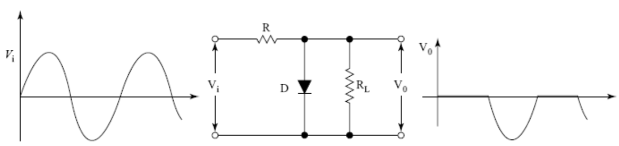

Figure 15.14 Positive shunt clipper

15.3.3 Biased Clippers

The level of clipping can be adjusted by introducing a biased voltage in the circuit. Fig. 15.15 shows a biased positive clipper circuit where a biased voltage, V_B has been connected in series with the diode.

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output current is possible. Thus, the current through the load is restricted by the bias voltage level. A combination biased clipping circuit can be made by using another diode together with a bias voltage. The bias voltage for the two diodes can be made different to achieve the clipping of the positive and negative half cycles at different voltage levels. Biased clipping circuits are used to protect circuits and devices from over voltages. We have also observed that clipper circuits can change the output voltage wave shape also.

15.3.4 Clamping Circuits

A clamping circuit essentially adds a dc component to the ac signal in either direction. As shown in Fig. 15.16 a dc voltage has been added to the sinusoidal voltage. The signal voltage equation is say, $v = v_m \sin \omega t = 5 \sin \omega t$. If we add +5 V dc, the equation of the resultant voltage will be $v = 5 + 5 \sin \omega t$. The clamper circuit has added a dc voltage of +5 V to the signal and pushed the signal upwards without changing its wave shape. This is called a positive clamper. If a negative dc voltage is added, the signal will be brought downwards, and such a clamper will be called a negative clamper. A negative clamper circuit has been explained in Fig. 15.16.

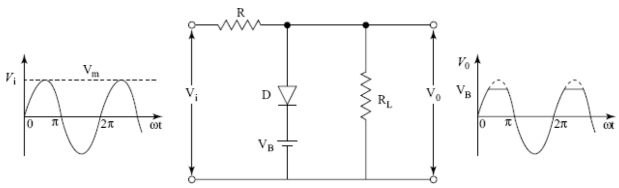

Figure 15.15 Biased shunt clipper

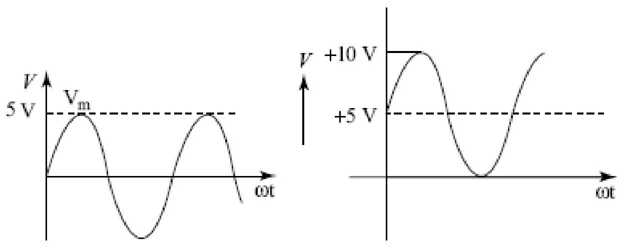

Figure 15.16 Positive clamper's wave shape

Assume that the input voltage is a square one. During the positive half cycle of the input voltage the diode is forward biased and will work like a short circuit (neglecting the forward voltage drop across the diode). The capacitor will be charged to input voltage level. The voltage across the diode, and hence across the load resistor R_L will be zero.

During the negative half cycle of the input the diode will be reverse biased and will be like an open switch (no current through it can

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$$-V_i - V_c - V_0 = 0$$

or, $$V_0 = -V_i - V_i \text{ (as } V_c = V_i)$$

or, $$V_0 = -2V_i$$

This shows that the input signal is negatively clamped by a dc voltage equal to the magnitude of the input voltage.

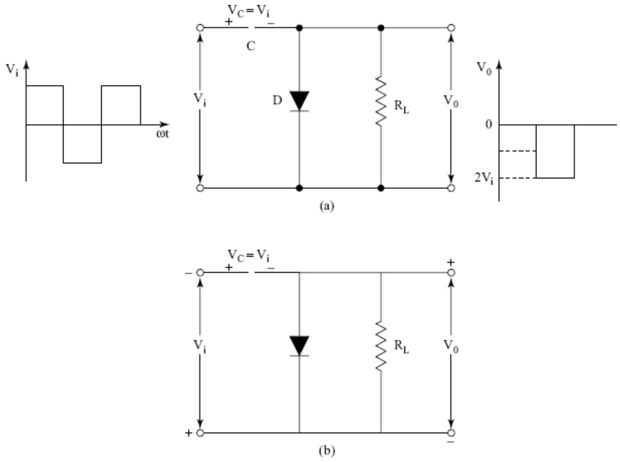

Figure 15.17 A negative clamper circuit

15.4 REVIEW QUESTIONS

A. Short Answer Type Questions

1. Draw a half-wave rectified circuit and show the input and output voltage waveforms.
2. List the performance parameters of a half-wave rectifier and explain this significance.
3. Draw the circuit diagram for a centre-tap full-wave rectifier and explain its operation with the help of input and output voltage wave forms.
4. Draw and explain the circuit for a bridge rectifier and draw the input and output voltage waveforms.
5. Derive the expression for the following in the case of a half-wave rectifier:
    1. rectifier efficiency
    2. ripple factor
    3. average value of output dc current
    4. output voltage, V_{dc}.
6. Compare the performance parameters of a half-wave rectifier and a full-wave bridge rectifier.
7. What is meant by ripple factor and what is its significance. Calculate its value for a half-wave rectifier and a full-wave rectifier.
8. What are the disadvantages of a half-wave rectifier?
9. What is meant by rectifier efficiency? What is its value for a

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12. Sketch the nature of ripple in the output of a capacitor filter used in a full-wave bridge rectifier.
13. Draw and explain the half-wave rectifier circuit with a capacitor filter. Also draw the input and output voltage wave form.
14. Draw and explain a bridge rectifier with a smoothing capacitor. Draw the output voltage wave shape.
15. What is a clipping and a clamping circuit? Where are they used?
16. Draw and explain negative and positive series clipper circuits with their input and output voltage waveforms, respectively.
17. What is a shunt clipper circuit? Draw the input and output voltage waveforms.
18. Draw the circuit for a biased clipper. Also draw the input and output voltage waveforms.
19. What are clamping circuits and what are their applications?
20. Draw and explain positive and negative clamper circuits.

B. Multiple Choice Questions

1. The average or dc value of output current for a half-wave rectifier is
    1. $\frac{2I_m}{\pi}$
    2. $\frac{I_m}{\pi}$
    3. $\frac{I_m}{2\pi}$
    4. $\frac{I_m}{\sqrt{2}}$.
2. The RMS value of load current for a half-wave rectifier is
    1. $\frac{I_m}{\sqrt{2}}$
    2. $\frac{I_m}{\pi}$
    3. $\frac{I_m}{2}$
    4. $\frac{I_m}{2\pi}$.
3. The output voltage V_{dc} for a half-wave rectifier is
    1. $\frac{V_m}{\pi}$
    2. $\frac{V_m}{2\pi}$
    3. $\frac{V_m}{\sqrt{2}}$
    4. $\frac{V_m}{}$.

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2. 20.3% and 81.2%
3. 40.6% and 91.2%
4. 20.3% and 40.6%.

5. Ripple factor for a half-wave and full-wave rectifier circuit, respectively are
    1. 0.48 and 1.21
    2. 0.48 and 0.121
    3. 4.8 and 1.21
    4. 8.21 and 0.48.
6. Peak inverse voltage is defined as the
    1. Minimum voltage that appears across the diode when it is forward biased
    2. Minimum voltage that appears across the diode when it is reverse biased
    3. Maximum voltage that appears across the diode when it is reverse biased
    4. Minimum voltage that appears across the diode when it is reverse biased.
7. In a capacitor filter circuit, a capacitor is connected
    1. In series with the load and it allows dc current to flow through it
    2. In parallel with the load and it allows ac but blocks dc
    3. In parallel with the load and it allows dc but blocks ac
    4. In series with the load and it allows ac and blocks dc.
8. A clamping circuit
    1. adds a dc component to an ac signal in either direction
    2. adds an ac component to a dc signal in either direction
    3. adds a dc component to an ac signal in positive direction only
    4. adds a dc component to an ac signal in negative direction only.

Answers to Multiple Choice Questions

1. (b)
2. (c)
3. (a)
4. (a)
5. (d)
6. (c)
7. (b)
8. (a)

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