

Rectifiers and Filters

3.1 INTRODUCTION

All electronic circuits need dc power supply either from battery or power-pack units. Transformers, rectifiers and filters form the basic building blocks of a linear power supply. A transformer supplies ac voltage at the required level. This bidirectional ac voltage is converted into a unidirectional pulsating dc using a rectifier. The unwanted ripple contents of this pulsating dc are removed by a filter to get pure dc voltage. The output of the filter is fed to a regulator which gives a **steady dc output independent of load variations and input supply fluctuations**. This chapter mainly discusses the operation and characteristics of different types of rectifiers and filters.

3.2 RECTIFIERS

Rectifier is defined as an electronic circuit used for converting ac voltage into unidirectional voltage. A rectifier utilizes unidirectional conduction device like a vacuum diode or *PN* junction diode. Rectifiers are classified depending upon the period of conduction as half-wave rectifier and full-wave rectifier.

3.2.1 Half-wave Rectifier

It converts an ac voltage into a pulsating dc voltage using only one half of the applied ac voltage. The rectifying diode conducts only during one half of the ac cycle. Figure 3.1 shows the basic circuit and waveforms of a half-wave rectifier (HWR).

Let v_i be the voltage applied to the primary of the transformer and given by the equation

$$v_i = V_m \sin \omega t; V_m \gg V_\gamma$$

where V_γ is the cut-in voltage of the diode. During the positive half cycle of the input signal, the anode of the diode becomes more positive with respect to the cathode and hence, the diode D conducts. For an ideal diode, the forward voltage drop is zero. So, the whole input voltage will appear across the load resistance, R_L .

During negative half cycle of the input signal, the anode of the diode becomes negative with respect to the cathode and hence, diode D does not conduct. For an ideal diode, the impedance offered by the diode is infinity. So the whole input voltage appears across diode D . Hence, the voltage drop across R_L is zero.

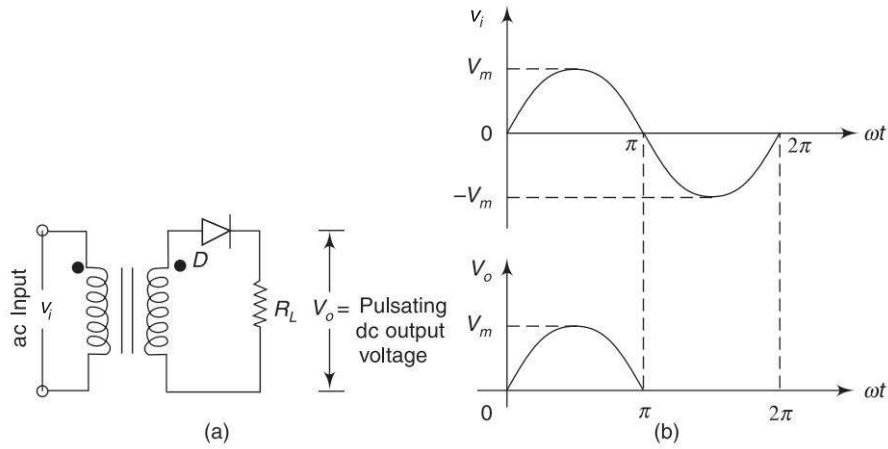


Fig. 3.1 (a) Basic structure of a half-wave rectifier (b) Input output waveforms of half-wave rectifier

Ripple Factor (Γ) The ratio of rms value of ac component to the dc component in the output is known as ripple factor (Γ).

$$\Gamma = \frac{\text{rms value of ac component}}{\text{dc value of component}} = \frac{V_{r, \text{rms}}}{V_{\text{dc}}}$$

where $V_{r, \text{rms}} = \sqrt{V_{\text{rms}}^2 - V_{\text{dc}}^2}$.

Therefore,

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

The rms value of a continuous-time periodic waveform is the square root of the ratio of the square of that waveform function to the time period T , as given by

$$\begin{aligned} V_{\text{rms}} &= \sqrt{\frac{\text{Square of the area under the curve for one cycle}}{\text{Time period}}} \\ &= \sqrt{\frac{1}{T} \int_0^T [x(t)]^2 dt} \end{aligned}$$

The average or the dc content of the voltage across the load is given by

$$\begin{aligned} V_{\text{av}} = V_{\text{dc}} &= \frac{1}{2\pi} \left[\int_0^{\pi} V_m \sin \omega t d(\omega t) + \int_{\pi}^{2\pi} 0 \cdot d(\omega t) \right] \\ &= \frac{V_m}{2\pi} [-\cos \omega t]_0^{\pi} = \frac{V_m}{\pi} \end{aligned}$$

Therefore,

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

If the values of diode forward resistance (r_f) and the transformer secondary winding resistance (r_s) are also taken into account, then

$$V_{dc} = \frac{V_m}{\pi} - I_{dc} (r_s + r_f)$$

$$I_{dc} = \frac{V_{dc}}{(r_s + r_f) + R_L} = \frac{V_m}{\pi(r_s + r_f + R_L)}$$

The rms voltage at the load resistance can be calculated as

$$V_{rms} = \left[\frac{1}{2\pi} \int_0^\pi V_m^2 \sin^2 \omega t d(\omega t) \right]^{\frac{1}{2}}$$

$$= V_m \left[\frac{1}{4\pi} \int_0^\pi (1 - \cos 2\omega t) d\omega t \right]^{\frac{1}{2}} = \frac{V_m}{2}$$

Therefore,

$$\Gamma = \sqrt{\left[\frac{V_m/2}{V_m/\pi} \right]^2} - 1 = \sqrt{\left(\frac{\pi}{2} \right)^2} - 1 = 1.21$$

From this expression, it is clear that the amount of ac present in the output is 121% of the dc voltage. So the half-wave rectifier is not practically useful in converting ac into dc.

Efficiency (η) The ratio of dc output power to ac input power is known as rectifier efficiency (η).

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

$$= \frac{\frac{(V_{dc})^2}{R_L}}{\frac{(V_{rms})^2}{R_L}} = \frac{\left(\frac{V_m}{\pi} \right)^2}{\left(\frac{V_m}{2} \right)^2} = \frac{4}{\pi^2} = 0.406 = 40.6\%$$

The maximum efficiency of a half-wave rectifier is 40.6%.

Peak Inverse Voltage (PIV) It is defined as the maximum reverse voltage that a diode can withstand without destroying the junction. The peak inverse voltage across a diode is the peak of the negative half cycle. For half-wave rectifier, PIV is V_m .

Transformer Utilization Factor (TUF) In the design of any power supply, the rating of the transformer should be determined. This can be done with a knowledge of the dc power delivered to the load and the type of rectifying circuit used.

$$\text{TUF} = \frac{\text{dc power delivered to the load}}{\text{ac rating of the transformer secondary}}$$

$$= \frac{P_{dc}}{P_{ac \text{ rated}}}$$

3.4 Electronic Devices and Circuits

In the half-wave rectifying circuit, the rated voltage of the transformer secondary is $V_m/\sqrt{2}$, but the actual rms current flowing through the winding is only $\frac{I_m}{2}$, not $I_m/\sqrt{2}$.

$$\text{TUF} = \frac{\frac{I_m^2}{\pi^2} R_L}{\frac{V_m}{\sqrt{2}} \times \frac{I_m}{2}} = \frac{\frac{V_m^2}{\pi^2} \frac{1}{R_L}}{\frac{V_m}{\sqrt{2}} \frac{V_m}{2 R_L}} = \frac{2\sqrt{2}}{\pi^2} = 0.287$$

The TUF for a half-wave rectifier is 0.287.

▪ **Form Factor**

$$\text{Form factor} = \frac{\text{rms value}}{\text{average value}} = \frac{V_m/2}{V_m/\pi} = \frac{\pi}{2} = 1.57$$

▪ **Peak Factor**

$$\text{Peak factor} = \frac{\text{peak value}}{\text{rms value}} = \frac{V_m}{V_m/2} = 2$$

EXAMPLE 3.1

A half-wave rectifier, having a resistive load of 1000Ω , rectifies an alternating voltage of 325 V peak value and the diode has a forward resistance of 100Ω . Calculate (a) peak, average and rms values of current (b) dc power output (c) ac input power and (d) efficiency of the rectifier.

Solution

(a) Peak value of current, $I_m = \frac{V_m}{r_f + R_L} = \frac{325}{100 + 1000} = 295.45 \text{ mA}$

Average current, $I_{dc} = \frac{I_m}{\pi} = \frac{295.45}{\pi} \text{ mA} = 94.046 \text{ mA}$

RMS value of current, $I_{rms} = \frac{I_m}{2} = \frac{295.45}{2} = 147.725 \text{ mA}$

(b) The dc power output, $P_{dc} = I_{dc}^2 \times R_L$
 $= (94.046 \times 10^{-3})^2 \times 1000 = 8.845 \text{ W}$

(c) The ac input power, $P_{ac} = (I_{rms})^2 \times (r_f + R_L)$
 $= (147.725 \times 10^{-3})^2 (1100) = 24 \text{ W}$

(d) Efficiency of rectification, $\eta = \frac{P_{dc}}{P_{ac}} = \frac{8.845}{24} = 36.85\%$.

EXAMPLE 3.2

A half-wave rectifier is used to supply 24 V dc to a resistive load of 500Ω and the diode has a forward resistance of 50Ω . Calculate the maximum value of the ac voltage required at the input.

Solution Average value of load current,

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{24}{500} = 48 \text{ mA}$$

Maximum value of load current, $I_m = \pi \times I_{dc} = \pi \times 48 \text{ mA} = 150.8 \text{ mA}$

Therefore, maximum ac voltage required at the input,

$$V_m = I_m \times (r_f + R_L) = 150.8 \times 10^{-3} \times 550 = 82.94 \text{ V}$$

EXAMPLE 3.3

An ac supply of 230 V is applied to a half-wave rectifier circuit through transformer of turns ratio 5:1. Assume the diode is an ideal one. The load resistance is 300 Ω . Find (a) dc output voltage, (b) PIV, (c) maximum, and (d) average values of power delivered to the load.

Solution

(a) The transformer secondary voltage = $\frac{230}{5} = 46 \text{ V}$

Maximum value of secondary voltage, $V_m = \sqrt{2} \times 46 = 65 \text{ V}$

Therefore, dc output voltage, $V_{dc} = \frac{V_m}{\pi} = \frac{65}{\pi} = 20.7 \text{ V}$

(b) PIV of a diode $V_m = 65 \text{ V}$

(c) Maximum value of load current, $I_m = \frac{V_m}{R_L} = \frac{65}{300} = 0.217 \text{ A}$

Therefore, maximum value of power delivered to the load,

$$P_m = I_m^2 \times R_L = (0.217)^2 \times 300 = 14.1 \text{ W}$$

(d) The average value of load current, $I_{dc} = \frac{V_{dc}}{R_L} = \frac{20.7}{300} = 0.069 \text{ A}$

Therefore, average value of power delivered to the load,

$$P_{dc} = I_{dc}^2 \times R_L = (0.069)^2 \times 300 = 1.43 \text{ W}$$

EXAMPLE 3.4

An HWR has a load of 3.5 k Ω . If the diode resistance and secondary coil resistance together have a resistance of 800 Ω and the input voltage has a signal voltage of peak value 240 V. Calculate

- peak, average and rms values of current flowing
- dc power output
- ac power input
- efficiency of the rectifier

Solution Load resistance in an HWR, $R_L = 3.5 \text{ k}\Omega$

Diode resistance and secondary coil resistance, $r_f + r_s = 800 \Omega$

Peak value of input voltage = 240 V

3.6 Electronic Devices and Circuits

(a) Peak value of current,
$$I_m = \frac{V_m}{r_s + r_f + R_L} = \frac{240}{4300} = 55.81 \text{ mA}$$

Average value of current,
$$I_{dc} = \frac{I_m}{\pi} = \frac{55.81 \times 10^{-3}}{\pi} = 17.77 \text{ mA}$$

The rms value of current,
$$I_{rms} = \frac{I_m}{2} = \frac{55.81 \times 10^{-3}}{2} = 27.905 \text{ mA}$$

(b) The dc power output is

$$P_{dc} = (I_{dc})^2 R_L = (17.77 \times 10^{-3})^2 \times 3500 = 1.105 \text{ W}$$

(c) The ac power input is

$$P_{ac} = (I_{rms})^2 \times (r_f + R_L) = (27.905 \times 10^{-3})^2 \times 4300 = 3.348 \text{ W}$$

(d) Efficiency of the rectifier is

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{1.105}{3.348} \times 100 = 33\%$$

EXAMPLE 3.5

An HWR circuit supplies 100 mA dc to a 250 Ω load. Find the dc output voltage, PIV rating of a diode and the rms voltage for the transformer supplying the rectifier.

Solution Given $I_{dc} = 100 \text{ mA}$, $R_L = 250 \Omega$

(a) The dc output voltage,

$$V_{dc} = I_{dc} \times R_L = 100 \times 10^{-3} \times 250 = 25 \text{ V}$$

(b) The maximum value of secondary voltage,

$$V_m = \pi \times V_{dc} = \pi \times 25 = 78.54 \text{ V}$$

(c) PIV rating of a diode, $V_m = 78.54 \text{ V}$

(d) The rms voltage for the transformer supplying the rectifier,

$$V_{rms} = \frac{V_m}{2} = \frac{78.54}{2} = 39.27 \text{ V}$$

EXAMPLE 3.6

A voltage of $200 \cos \omega t$ is applied to HWR with load resistance of 5 k Ω . Find (a) the maximum dc current component, (b) rms current, (c) ripple factor, (d) TUF, and (e) rectifier efficiency,

Solution Given applied voltage = $200 \cos \omega t$, $V_m = 200 \text{ V}$, $R_L = 5 \text{ k}\Omega$

(a) To find dc current:

$$I_m = \frac{V_m}{R_L} = \frac{200}{5 \times 10^3} = 40 \text{ mA}$$

Therefore,
$$I_{dc} = \frac{I_m}{\pi} = \frac{40 \times 10^{-3}}{\pi} = 12.73 \text{ mA}$$

(b) To find rms current:

$$I_{\text{rms}} = \frac{I_m}{2} = \frac{40 \times 10^{-3}}{2} = 20 \text{ mA}$$

(c) Ripple factor:

$$\Gamma = \sqrt{\left(\frac{I_{\text{rms}}}{I_{\text{dc}}}\right)^2} - 1 = \sqrt{\left(\frac{20 \times 10^{-3}}{12.73 \times 10^{-3}}\right)^2} - 1 = 1.21$$

(d) To determine TUF:

$$\text{TUF} = \frac{P_{\text{dc}}}{P_{\text{ac}(\text{rated})}}$$

$$P_{\text{dc}} = I_{\text{dc}}^2 R_L = (12.73 \times 10^{-3})^2 \times 5 \times 10^3 = 0.81 \text{ W}$$

$$P_{\text{ac}(\text{rated})} = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{2} = \frac{200}{\sqrt{2}} \times \frac{40 \times 10^{-3}}{2} = 2.828$$

Therefore,

$$\text{TUF} = \frac{P_{\text{dc}}}{P_{\text{ac}(\text{rated})}} = \frac{0.81}{2.828} = 0.2863$$

(e) Rectifier efficiency:

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

$$P_{\text{dc}} = 0.81 \text{ W}$$

$$P_{\text{ac}} = I_{\text{rms}}^2 R_L = (20 \times 10^{-3})^2 \times 5 \times 10^3 = 2 \text{ W}$$

Therefore,

$$\eta = \frac{P_{\text{dc}}}{P_{\text{ac}}} \times 100 = \frac{0.81}{2} \times 100 = 40.5\%$$

EXAMPLE 3.7

A diode has an internal resistance of 20Ω and $1,000 \Omega$ load from a 110 V rms source of supply. Calculate (a) the efficiency of rectification and (b) the percentage regulation from no load to full load.

Solution Given $r_f = 20 \Omega$, $R_L = 1,000 \Omega$ and $V_{\text{rms}}(\text{secondary}) = 110 \text{ V}$

(a) The half-wave rectifier uses a single diode.

Therefore,

$$V_m = \sqrt{2} V_{\text{rms}}(\text{secondary}) = \sqrt{2} \times 110 = 155.56 \text{ V}$$

$$I_m = \frac{V_m}{r_f + R_L} = \frac{155.56}{20 + 1000} = 0.1525 \text{ A}$$

$$I_{\text{dc}} = \frac{I_m}{\pi} = \frac{0.1525}{\pi} = 0.04854 \text{ A}$$

$$V_{\text{dc}} = I_{\text{dc}} R_L = 0.04854 \times 1000 = 48.54 \text{ V}$$

$$P_{\text{dc}} = V_{\text{dc}} I_{\text{dc}} = 48.54 \times 0.04854 = 2.36 \text{ W}$$

$$P_{\text{ac}} = I_{\text{rms}}^2 (r_f + R_L) = \left(\frac{I_m}{2}\right)^2 (r_f + R_L) \quad \left(\text{since } I_{\text{rms}} = \frac{I_m}{2} \text{ for half-wave}\right)$$

$$= \left(\frac{0.1525}{2} \right)^2 (20 + 1000) = 5.93 \text{ W}$$

$$\text{Efficiency, } \eta = \frac{P_{dc}}{P_{ac}} \times 100 = \frac{2.36}{5.93} \times 100 = 39.7346\%$$

$$\begin{aligned} \text{(b) Percentage of line regulation} &= \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100 = \frac{\frac{V_m}{\pi} - V_{dc}}{V_{dc}} \times 100 \\ &= \frac{\frac{155.56}{\pi} - 48.54}{48.54} \times 100 = 2\% \end{aligned}$$

EXAMPLE 3.8

Show that maximum dc output power $P_{dc} = V_{dc} \times I_{dc}$ in a half-wave single-phase circuit occurs when the load resistance equals diode resistance r_f .

Solution For a half-wave rectifier,

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

$$I_{dc} = \frac{I_m}{\pi} = \frac{V_m}{\pi(r_f + R_L)}$$

and

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

$$\text{Therefore, } P_{dc} = V_{dc} \times I_{dc} = I_{dc}^2 R_L = \frac{V_m^2 R_L}{\pi^2 (r_f + R_L)^2}$$

For this power to be maximum,

$$\begin{aligned} \frac{dP_{dc}}{dR_L} &= 0 \\ \frac{d}{dR_L} \left[\frac{V_m^2 R_L}{\pi^2 (r_f + R_L)^2} \right] &= \frac{V_m^2}{\pi^2} \left[\frac{(r_f + R_L)^2 - R_L \times 2(r_f + R_L)}{(r_f + R_L)^4} \right] = 0 \\ (r_f + R_L)^2 - 2R_L(r_f + R_L) &= 0 \\ r_f^2 + 2r_f R_L + R_L^2 - 2r_f R_L - 2R_L^2 &= 0 \\ r_f^2 - R_L^2 &= 0 \\ R_L^2 &= r_f^2 \end{aligned}$$

Thus, the power output is maximum if $R_L = r_f$

EXAMPLE 3.9

The transformer of a half-wave rectifier has a secondary voltage of $30 V_{rms}$ with a winding resistance of 10Ω .

The semiconductor diode in the circuit has a forward resistance of $100\ \Omega$. Calculate (a) no load dc voltage (b) dc output voltage at $I_L = 25\text{ mA}$ (c) % regulation at $I_L = 25\text{ mA}$ (d) ripple voltage across the load (e) ripple frequency (f) ripple factor (g) dc power output and (h) PIV of the semiconductor diode.

Solution

$$V_{\text{rms}} (\text{secondary}) = 30\text{ V}, r_s = 10\ \Omega, r_f = 100\ \Omega$$

$$V_m = \sqrt{2} \times V_{\text{rms}} = \sqrt{2} \times 30 = 42.4264\text{ V}$$

$$(a) \quad V_{\text{dc}} = \frac{V_m}{\pi} = \frac{42.4264}{\pi} = 13.5047\text{ V}$$

$$(b) \quad I_L = I_{\text{dc}} = 25\text{ mA}$$

$$V_{\text{dc}} = I_{\text{dc}} R_L = \frac{I_m}{\pi} R_L = \frac{V_m}{\pi(r_f + r_s + R_L)} \times R_L$$

$$\text{Here,} \quad R_L = \frac{V_{\text{dc}}}{I_{\text{dc}}}$$

$$\text{Therefore,} \quad V_{\text{dc}} = \frac{V_m}{\pi \left(r_f + r_s + \frac{V_{\text{dc}}}{I_{\text{dc}}} \right)} \times \frac{V_{\text{dc}}}{I_{\text{dc}}}$$

$$V_{\text{dc}} = \frac{42.426 V_{\text{dc}}}{\pi \left(100 + 10 + \frac{V_{\text{dc}}}{25 \times 10^{-3}} \right)} \times \frac{1}{25 \times 10^{-3}}$$

$$V_{\text{dc}} (110 + 40V_{\text{dc}}) = 540.1897 V_{\text{dc}}$$

$$V_{\text{dc}} = \frac{540.1897 - 110}{40} = 10.7547\text{ V}$$

$$(c) \quad \text{Percentage of regulation} = \frac{V_{\text{dc}}(NL) - V_{\text{dc}}(FL)}{V_{\text{dc}}(FL)} \times 100 = \frac{13.5047 - 10.7547}{10.7547} \times 100 = 25.569\%$$

$$(d) \quad I_m = \frac{V_m}{r_f + r_s + R_L}, \text{ where } R_L = \frac{V_{\text{dc}}}{I_{\text{dc}}} = \frac{10.7547}{25 \times 10^{-3}} = 430.188\ \Omega$$

$$\text{Therefore,} \quad I_m = \frac{42.4264}{100 + 10 + 430.188} = 0.07854\text{ A}$$

$$I_{\text{rms}} = \frac{I_m}{2} = 0.03927\text{ A}$$

$$\Gamma = \sqrt{\left(\frac{I_{\text{rms}}}{I_{\text{dc}}} \right)^2} - 1 = \sqrt{\left(\frac{0.03927}{25 \times 10^{-3}} \right)^2} - 1 = 1.21$$

$$\text{Ripple voltage} \quad \Gamma \times V_{\text{dc}} = 1.21 \times 10.7547 = 13.02791\text{ V}$$

$$(e) \quad \text{Ripple frequency,} \quad f = 50\text{ Hz}$$

- (f) $\Gamma = \text{ripple factor} = 1.21$
(g) $P_{dc} = V_{dc} I_{dc} = 10.7547 \times 25 \times 10^{-3} = 0.2688 \text{ W}$
(h) $PIV = V_m = 42.4264 \text{ V}$

3.2.2 Full-wave Rectifier

It converts an ac voltage into a pulsating dc voltage using both half cycles of the applied ac voltage. It uses two diodes of which one conducts during one half-cycle while the other diode conducts during the other half-cycle of the applied ac voltage. There are two types of full-wave rectifiers, viz., (i), full-wave rectifier with centre tapped transformer, and (ii) full-wave rectifier without transformer (bridge rectifier).

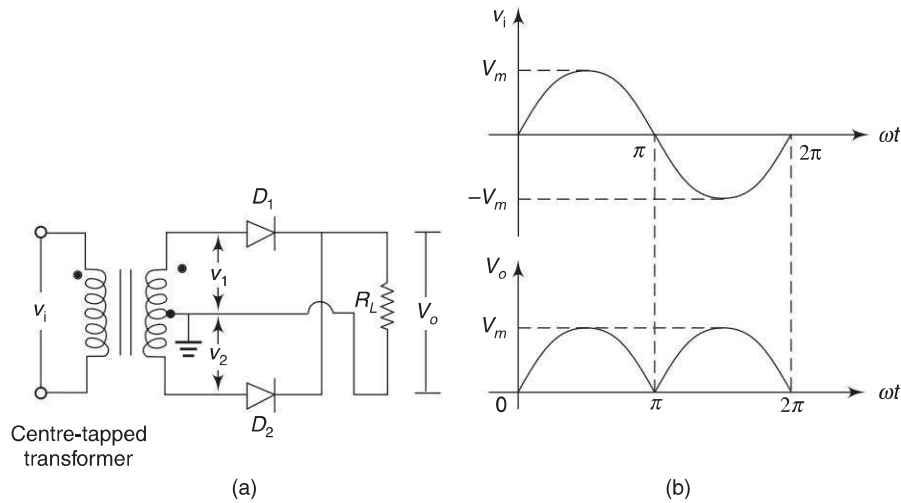


Fig. 3.2 Full-wave rectifier

Figure 3.2 shows the basic circuit and waveforms of full-wave rectifier with a center tap transformer. During positive half of the input signal, the anode of the diode D_1 becomes positive and at the same time, the anode of diode D_2 becomes negative. Hence, D_1 conducts and D_2 does not conduct. The load current flows through D_1 and the voltage drop across R_L will be equal to the input voltage.

During the negative half-cycle of the input, the anode of D_1 becomes negative and the anode of D_2 becomes positive. Hence, D_1 does not conduct and D_2 conducts. The load current flows through D_2 and the voltage drop across R_L will be equal to the input voltage.

Ripple Factor (Γ)

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

The average voltage or dc voltage available across the load resistance is

$$\begin{aligned}
 V_{dc} &= \frac{1}{\pi} \int_0^{\pi} V_m \sin \omega t \, d(\omega t) \\
 &= \frac{V_m}{\pi} [-\cos \omega t]_0^{\pi} = \frac{2V_m}{\pi} \\
 I_{dc} &= \frac{V_{dc}}{R_L} = \frac{2V_m}{\pi R_L} = \frac{2I_m}{\pi} \text{ and } I_{rms} = \frac{I_m}{\sqrt{2}}
 \end{aligned}$$

If the diode forward resistance (r_f) and the transformer secondary winding resistance (r_s) are included in the analysis, then

$$\begin{aligned}
 V_{dc} &= \frac{2V_m}{\pi} - I_{dc} (r_s + r_f) \\
 I_{dc} &= \frac{V_{dc}}{(r_s + r_f) + R_L} = \frac{2V_m}{\pi (r_s + r_f + R_L)}
 \end{aligned}$$

The rms value of the voltage at the load resistance is

$$\begin{aligned}
 V_{rms} &= \sqrt{\left[\frac{1}{\pi} \int_0^{\pi} V_m^2 \sin^2 \omega t \, d(\omega t) \right]} = \frac{V_m}{\sqrt{2}} \\
 \Gamma &= \sqrt{\left(\frac{V_m/\sqrt{2}}{2V_m/\pi} \right)^2} - 1 = \sqrt{\frac{\pi^2}{8}} - 1 = 0.482
 \end{aligned}$$

Therefore,

Efficiency (η) The ratio of dc output power to ac input power is known as rectifier efficiency (η).

$$\begin{aligned}
 \eta &= \frac{\text{dc output power}}{\text{ac input power}} = \frac{P_{dc}}{P_{ac}} \\
 &= \frac{(V_{dc})^2 / R_L}{(V_{rms})^2 / R_L} = \frac{\left[\frac{2V_m}{\pi} \right]^2}{\left[\frac{V_m}{\sqrt{2}} \right]^2} \\
 &= \frac{8}{\pi^2} = 0.812 = 81.2\%
 \end{aligned}$$

The maximum efficiency of a full-wave rectifier is 81.2%.

Transformer Utilization Factor (TUF) The average TUF in a full-wave rectifying circuit is determined by considering the primary and secondary windings separately and it gives a value of 0.693.

▪ **Form Factor**

$$\text{Form factor} = \frac{\text{rms value of the output voltage}}{\text{average value of the output voltage}} = \frac{V_m/\sqrt{2}}{2V_m/\pi} = \frac{\pi}{2\sqrt{2}} = 1.11$$

▪ **Peak Factor**

$$\text{Peak factor} = \frac{\text{peak value of the output voltage}}{\text{rms value of the output voltage}} = \frac{V_m}{V_m/\sqrt{2}} = \sqrt{2}$$

Peak inverse voltage for full-wave rectifier is $2V_m$ because the entire secondary voltage appears across the non-conducting diode.

EXAMPLE 3.10

A 230 V, 60 Hz voltage is applied to the primary of a 5:1 step-down, centre-tap transformer use in a full-wave rectifier having a load of $900\ \Omega$. If the diode resistance and secondary coil resistance together has a resistance of $100\ \Omega$, determine (a) dc voltage across the load, (b) dc current flowing through the load, (c) dc power delivered to the load, (d) PIV across each diode, (e) ripple voltage and its frequency and (f) rectification efficiency.

Solution

The voltage across the two ends of secondary = $\frac{230}{5} = 46\text{ V}$

Voltage from centre tapping to one end, $V_{\text{rms}} = \frac{46}{2} = 23\text{ V}$

(a) The dc voltage across the load, $V_{\text{dc}} = \frac{2V_m}{\pi} = \frac{2 \times 23 \times \sqrt{2}}{\pi} = 20.7\text{ V}$

(b) The dc current flowing through the load, $I_{\text{dc}} = \frac{V_{\text{dc}}}{(r_s + r_f + R_L)} = \frac{20.7}{1000} = 20.7\text{ mA}$

(c) The dc power delivered to the load,

$$P_{\text{dc}} = (I_{\text{dc}})^2 \times R_L = (20.7 \times 10^{-3})^2 \times 900 = 0.386\text{ W}$$

(d) PIV across each diode

$$= 2V_m = 2 \times 23 \times \sqrt{2} = 65\text{ V}$$

(e) Ripple voltage,

$$V_{r,\text{rms}} = \sqrt{(V_{\text{rms}})^2 - (V_{\text{dc}})^2}$$

$$= \sqrt{(23)^2 - (20.7)^2} = 10.05\text{ V}$$

Frequency of ripple voltage

$$= 2 \times 60 = 120\text{ Hz}$$

(f) Rectification efficiency,

$$\eta = \frac{P_{\text{dc}}}{P_{\text{ac}}} = \frac{(V_{\text{dc}})^2/R_L}{(V_{\text{rms}})^2/R_L} = \frac{(V_{\text{dc}})^2}{(V_{\text{rms}})^2}$$

$$= \frac{(20.7)^2}{(23)^2} = \frac{428.49}{529} = 0.81$$

Therefore, percentage of rectification efficiency = 81%

EXAMPLE 3.11

A full-wave rectifier has a centre-tap transformer of 100-0-100 V and each one of the diodes is rated at $I_{\text{max}} = 400\text{ mA}$ and $I_{\text{av}} = 150\text{ mA}$. Neglecting the voltage drop across the diodes, determine (a) the value of load resistor that gives the largest dc power output, (b) dc load voltage and current, and (c) PIV of each diode.

Solution

- (a) We know that the maximum value of current flowing through the diode for normal operation should not exceed 80% of its rated current.

Therefore, $I_{\max} = 0.8 \times 400 = 320 \text{ mA}$

The maximum value of the secondary voltage,

$$V_m = \sqrt{2} \times 100 = 141.4 \text{ V}$$

Therefore, the value of load resistor that gives the largest dc power output

$$R_L = \frac{V_m}{I_{\max}} = \frac{141.4}{320 \times 10^{-3}} = 442 \Omega$$

- (b) The dc (load) voltage, $V_{\text{dc}} = \frac{2V_m}{\pi} = \frac{2 \times 141.4}{\pi} = 90 \text{ V}$

The dc load current, $I_{\text{dc}} = \frac{V_{\text{dc}}}{R_L} = \frac{90}{442} = 0.204 \text{ A}$

- (c) PIV of each diode $= 2V_m = 2 \times 141.4 = 282.8 \text{ V}$

EXAMPLE 3.12

A full-wave rectifier delivers 50 W to a load of 200 Ω . If the ripple factor is 1%, calculate the ac ripple voltage across the load.

Solution

The dc power delivered to the load,

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

Therefore, $V_{\text{dc}} = \sqrt{P_{\text{dc}} \times R_L} = \sqrt{50 \times 200} = 100 \text{ V}$

The ripple factor, $\Gamma = \frac{V_{\text{ac}}}{V_{\text{dc}}}$

i.e., $0.01 = \frac{V_{\text{ac}}}{100}$

Therefore, the ac ripple voltage across the load, $V_{\text{ac}} = 1 \text{ V}$

EXAMPLE 3.13

In a full-wave rectifier, the transformer rms secondary voltage from centre tap to each end of the secondary is 50 V. The load resistance is 900 Ω . If the diode resistance and transformer secondary winding resistance together has a resistance of 100 Ω , determine the average load current and rms value of load current?

Solution

Voltage from centre tapping to one end, $V_{\text{rms}} = 50 \text{ V}$

Maximum load current, $I_m = \frac{V_m}{r_s + r_f + R_L} = \frac{V_{\text{rms}} \times \sqrt{2}}{r_s + r_f + R_L} = \frac{70.7}{1000} = 70.7 \text{ mA}$

Average load current, $I_{\text{dc}} = \frac{2I_m}{\pi} = \frac{2 \times 70.7 \times 10^{-3}}{\pi} = 45 \text{ mA}$

RMS value of load current, $I_{\text{rms}} = \frac{I_m}{\sqrt{2}} = \frac{70.7 \times 10^{-3}}{\sqrt{2}} = 50 \text{ mA}$

EXAMPLE 3.14

A full-wave rectifier circuit uses two silicon diodes with a forward resistance of 20Ω each. A dc voltmeter connected across the load of $1 \text{ k}\Omega$ reads 55.4 V . Calculate

- I_{rms}
- average voltage across each diode
- ripple factor and
- transformer secondary voltage rating

Solution Given $V_{\text{dc}} = 55.4 \text{ V}$ and $R_L = 1 \text{ k}\Omega$

$$(a) \quad I_{\text{dc}} = \frac{V_{\text{dc}}}{(r_f + R_L)} = \frac{55.4}{20 + 1000} = 54.31 \text{ mA}$$

We know that $I_{\text{dc}} = \frac{2I_m}{\pi}$ and $I_{\text{rms}} = \frac{I_m}{\sqrt{2}}$

$$I_m = I_{\text{dc}} \times \frac{\pi}{2} = 54.31 \times 10^{-3} \times \frac{\pi}{2} = 85.31 \text{ mA}$$

$$I_{\text{rms}} = \frac{I_m}{\sqrt{2}} = \frac{85.31 \times 10^{-3}}{\sqrt{2}} = 60.32 \text{ mA}$$

- The average voltage across each silicon diode will be 0.72 V .
- To find ripple factor Γ

$$\Gamma = \sqrt{\left(\frac{I_{\text{rms}}}{I_{\text{dc}}}\right)^2 - 1} = \sqrt{\left(\frac{60.32 \times 10^{-3}}{54.31 \times 10^{-3}}\right)^2 - 1} = 0.4833$$

To find transformer secondary voltage rating

We know that, $V_{\text{dc}} = \frac{2V_m}{\pi} - I_{\text{dc}}(r_s + r_f)$

where r_f is the diode forward resistance and r_s is the transformer secondary winding resistance.

$$55.4 = \frac{2V_m}{\pi} - 54.31 \times 10^{-3} \times 20 = \frac{2V_m}{\pi} - 1.086$$

$$56.49 = \frac{2V_m}{\pi}$$

Therefore, $V_m = 56.49 \times \frac{\pi}{2} = 88.73 \text{ V}$

$$V_{\text{rms}} = \frac{V_m}{\sqrt{2}} = \frac{88.73}{\sqrt{2}} = 62.74 \text{ V}$$

Hence, transformer secondary voltage rating is 65 V .

3.2.3 Bridge Rectifier

The need for a centre-tapped transformer in a full-wave rectifier is eliminated in the bridge rectifier. As shown in Fig. 3.3, the bridge rectifier has four diodes connected to form a bridge. The ac input voltage is applied to the diagonally opposite ends of the bridge. The load resistance is connected between the other two ends of the bridge.

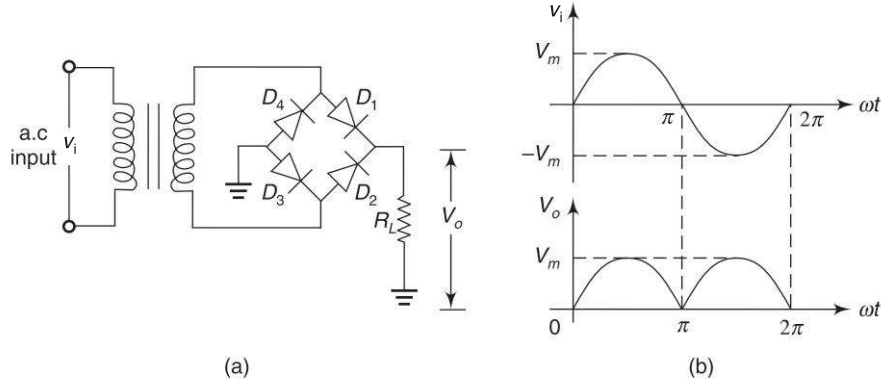


Fig. 3.3 Bridge rectifier

For the positive half-cycle of the input ac voltage, diodes D_1 and D_3 conduct, whereas diodes D_2 and D_4 do not conduct. The conducting diodes will be in series through the load resistance R_L . So the load current flows through R_L .

During the negative half-cycle of the input ac voltage, diodes D_2 and D_4 conduct, whereas diodes D_1 and D_3 do not conduct. The conducting diode D_2 and D_4 will be in series through the load R_L and the current flows through R_L in the same direction as in the previous half-cycle. Thus, a bidirectional wave is converted into an unidirectional one.

The average values of output voltage and load current for bridge rectifier are the same as for a centre-tapped full-wave rectifier. Hence,

$$V_{dc} = \frac{2V_m}{\pi} \quad \text{and} \quad I_{dc} = \frac{V_{dc}}{R_L} = \frac{2V_m}{\pi R_L} = \frac{2I_m}{\pi}$$

If the values of the transformer secondary winding resistance (r_s) and diode forward resistance (r_f) are considered in the analysis, then

$$V_{dc} = \frac{2V_m}{\pi} - I_{dc} (r_s + r_f)$$

$$I_{dc} = \frac{2I_m}{\pi} = \frac{2V_m}{\pi (r_s + r_f + R_L)}$$

The maximum efficiency of a bridge rectifier is 81.2% and the ripple factor is 0.48. The PIV is V_m .

▪ **Advantages of the Bridge Rectifier** In the bridge rectifier, the ripple factor and efficiency of the rectification are the same as for the full-wave rectifier. The PIV across either of the non-conducting diodes is equal to the peak value of the transformer secondary voltage, V_m . The bulky centre-tapped transformer is

not required. Transformer utilization factor is considerably high. Since the current flowing in the transformer secondary is purely alternating, the TUF increases to 0.812, which is the main reason for the popularity of a bridge rectifier. The bridge rectifiers are used in applications allowing floating output terminals, i.e., no output terminal is grounded.

The bridge rectifier has only one disadvantage that it requires four diodes as compared to two diodes for centre-tapped full-wave rectifier. But the diodes are readily available at cheaper rate in the market. Apart from this, the PIV rating required for the diodes in a bridge rectifier is only half of that for a centre tapped full-wave rectifier. This is a great advantage, which offsets the disadvantage of using extra two diodes in a bridge rectifier.

Comparison of Rectifiers The comparison of rectifiers is given in Table 3.1.

Table 3.1 A comparison of rectifiers

Particulars	Type of rectifier		
	Half-wave	Full-wave	Bridge
No. of diodes	1	2	4
Maximum efficiency	40.6%	81.2%	81.2%
V_{dc} (no load)	V_m/π	$2V_m/\pi$	$2V_m/\pi$
Average current/diode	I_{dc}	$I_{dc}/2$	$I_{dc}/2$
Ripple factor	1.21	0.48	0.48
Peak inverse voltage	V_m	$2V_m$	V_m
Output frequency	f	$2f$	$2f$
Transformer utilisation factor	0.287	0.693	0.812
Form factor	1.57	1.11	1.11
Peak factor	2	$\sqrt{2}$	$\sqrt{2}$

EXAMPLE 3.15

A 230 V, 50 Hz voltage is applied to the primary of a 4:1 step-down transformer used in a bridge rectifier having a load resistance of 600 Ω . Assuming the diodes to be ideal, determine (a) dc output voltage, (b) dc power delivered to the load, (c) PIV, and (d) output frequency.

Solution

- (a) The rms value of the transformer secondary voltage,

$$V_{\text{rms (secondary)}} = \frac{V_{\text{rms(primary)}}}{\text{Turns ratio}} = \frac{230}{4} = 57.5$$

The maximum value of the secondary voltage

$$V_m = \sqrt{2} \times 57.5 = 81.3 \text{ V}$$

Therefore, dc output voltage,

$$V_{dc} = \frac{2V_m}{\pi} = \frac{2 \times 81.3}{\pi} = 52 \text{ V}$$

- (b) The dc power delivered to the load,

$$P_{dc} = \frac{V_{dc}^2}{R_L} = \frac{52^2}{600} = 2.704 \text{ W}$$

- (c) PIV across each diode = $V_m = 81.3 \text{ V}$

- (d) Output frequency = $2 \times 50 = 100 \text{ Hz}$

EXAMPLE 3.16

In a bridge rectifier, the transformer is connected to 200 V, 60 Hz mains and the turns ratio of the step down transformer is 11:1. Assuming the diode is ideal, find (a) V_{dc} (b) I_{dc} and (c) PIV.

Solution Given in a bridge rectifier, input voltage = 200 V, 60 Hz and turns ratio = 11:1

- (a) To find the voltage across load, V_{dc}

$$V_{dc} = \frac{2V_m}{\pi}$$

where

$$V_m = \sqrt{2} V_{\text{rms(secondary)}}$$

$$V_{\text{rms(secondary)}} = \frac{V_{\text{rms(primary)}}}{\text{Turns ratio}} = \frac{200}{11} = 18.18 \text{ V}$$

Therefore, $V_m = 18.18 \times \sqrt{2} = 25.7 \text{ V}$

Hence, $V_{dc} = \frac{2 \times 25.7}{\pi} = 16.36 \text{ V}$

- (b) To find I_{dc}

Assuming that $R_L = 600 \Omega$, then

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{16.36}{600} = 27.26 \text{ mA}$$

- (c) To find PIV

$$PIV = V_m = 25.7 \text{ V}$$

EXAMPLE 3.17

A bridge rectifier uses four identical diodes having forward resistance of 5Ω and the secondary voltage is 30 V(rms). Determine the dc output voltage for $I_{dc} = 200 \text{ mA}$ and value of the output ripple voltage.

Solution Given, transformer secondary resistance = 5Ω

Secondary voltage $V_{\text{rms}} = 30 \text{ V}$, $I_{dc} = 200 \text{ mA}$

Since only two diodes of the bridge rectifier circuit will conduct during positive or negative half cycle of the input signal, the diode forward resistance, $r_f = 2 \times 5 \Omega = 10 \Omega$.

We know that,

$$V_{dc} = \frac{2V_m}{\pi} - I_{dc} (r_f + r_s) \text{ where } V_m = \sqrt{2}V_{rms} = \sqrt{2} \times 30 \text{ V}$$

Therefore,
$$V_{dc} = \frac{2 \times \sqrt{2} \times 30}{\pi} - 200 \times 10^{-3} (10 + 5) = 24 \text{ V}$$

$$\text{Ripple factor} = \frac{\text{rms value of ripple at the output}}{\text{average value of output voltage}}$$

Therefore,
$$0.48 = \frac{\text{rms value of ripple at the output}}{24}$$

Hence, rms value of ripple at the output = $0.48 \times 24 = 11.52 \text{ V}$

EXAMPLE 3.18

In a full-wave rectifier, the required dc voltage is 9 V and the diode drop is 0.8 V. Calculate ac rms input voltage required in centre-tapped full-wave rectifier and bridge rectifier circuits.

Solution

(a) The dc voltage across the load of the center tapped full-wave rectifier circuit,

$$V_{dc} = 9 = \frac{2V_m}{\pi} - 0.8 = \frac{2\sqrt{2} \times V_{rms}}{\pi} - 0.8$$

where V_{rms} is the rms input voltage from centre tapping to one end. That is,

$$9.8 = \frac{2\sqrt{2} V_{rms}}{\pi}$$

Therefore,
$$V_{rms} = \frac{9.8 \pi}{2\sqrt{2}} = 10.885 \text{ V}$$

Hence, the voltage across the two ends of the secondary = $2 \times 10.885 = 21.77 \text{ V}$

(b) In the bridge rectifier,
$$V_{dc} = 9 = \frac{2\sqrt{2}V_{rms}}{\pi} - 2 \times 0.8$$

Therefore, the voltage across two ends of secondary,
$$V_{rms} = \frac{10.6 \pi}{2\sqrt{2}} = 11.77 \text{ V}$$

3.3 HARMONIC COMPONENTS IN A RECTIFIER CIRCUIT

The term *harmonic* is defined as “a sinusoidal component of a periodic waveform or quantity possessing a frequency, which is an integral multiple of the fundamental frequency.” By definition, a perfect sine wave has no harmonics, except fundamental component at one frequency. Harmonics are present in waveforms that are not perfect sine waves due to distortion from nonlinear loads. The French mathematician Fourier discovered that a distorted waveform can be represented as a series of sine waves, with each being an integer multiple of the fundamental frequency and each with a specific magnitude.

That is, the harmonic frequencies are integer multiples [2, 3, 4,...] of the fundamental frequency. For example, the second harmonic on a 50 Hz system is 2×50 or 100 Hz. The sixth harmonic in a 50 Hz system, or the fifth harmonic in a 60 Hz system is 300 Hz. There are a number of different types of equipment that may experience faulty operations or failures due to high harmonic voltage and/ or current levels. The amount of the harmonic voltage and current levels that a system can tolerate is dependent on the equipment and the source.

The sum of the fundamental and all the harmonics is called the **Fourier series**. This series can be viewed as a spectrum analysis where the fundamental frequency and the harmonic component are identified.

The result of such an analysis for the current waveform of a half-wave rectifier circuit using a single diode is given by

$$i = I_m \left[\frac{1}{\pi} + \frac{1}{2} \sin \omega t - \frac{2}{\pi} \sum_{k=2,4,6} \frac{\cos k\omega t}{(k+1)(k-1)} \right]$$

The angular frequency of the power supply is the lowest angular frequency present in the above expression. All the other terms are the even harmonics of the power frequency.

The full-wave rectifier consists of two half-wave rectifier circuits, arranged in such a way that one circuit conducts during one half cycle and the second circuit operates during the second half cycle. Therefore, the currents are functionally related by the expression $i_1(\alpha) = i_2(\alpha + \pi)$. Thus, the total current of the full-wave rectifier is $i = i_1 + i_2$ as expressed by

$$i = I_m \left[\frac{2}{\pi} - \frac{4}{\pi} \sum_{\substack{k=\text{even} \\ k \neq 0}} \frac{\cos k\omega t}{(k+1)(k-1)} \right]$$

From the above equation, it can be seen that the fundamental angular frequency is eliminated and the lowest frequency is the second harmonic term 2ω . This is the advantage that the full-wave rectifier presents in filtering of the output. Additionally, the current pulses in the two halves of the transformer winding are in such directions that the magnetic cycles formed through the iron core is essentially that of the alternating current. This avoids any dc saturation of the transformer core that could give rise to additional harmonics at the output.

3.4 FILTERS

The output of a rectifier contains dc component as well as ac component. Filters are used to minimise the undesirable ac, i.e., ripple leaving only the dc component to appear at the output.

The ripple in the rectified wave being very high, the factor being 48% in the full-wave rectifier; majority of the applications which cannot tolerate this, will need an output which has been further processed.

Figure 3.4 shows the concept of a filter, where the full-wave rectified output voltage is applied at its input. The output of a filter is not exactly a constant dc level. But it also contains a small amount of ac component. Some important filters are

- (i) Inductor filter
- (ii) Capacitor filter
- (iii) LC or L-section filter
- (iv) CLC or π -type filter

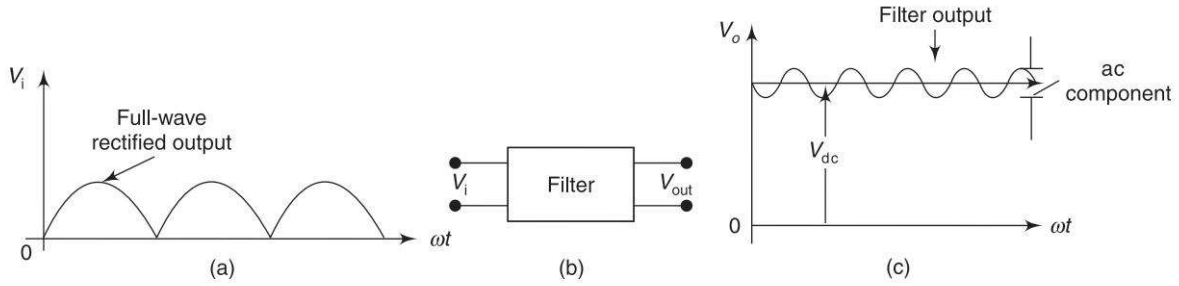


Fig. 3.4 Concept of a filter

3.5 INDUCTOR FILTER

Figure 3.5 shows the inductor filter. When the output of the rectifier passes through an inductor, it blocks the ac component and allows only the dc component to reach the load.

The ripple factor of the inductor filter is given by

$$\Gamma = \frac{R_L}{3\sqrt{2} \omega L}$$

It shows that the ripple factor will decrease when L is increased and R_L is decreased. Clearly, the inductor filter is more effective only when the load current is high (small R_L). The larger value of the inductor can reduce the ripple and at the same time the output dc voltage will be lowered as the inductor has a higher dc resistance.

The operation of the inductor filter depends on its well known fundamental property to oppose any change of current passing through it.

To analyse this filter for a full-wave, the Fourier series can be written as

$$V_o = \frac{2V_m}{\pi} - \frac{4V_m}{\pi} \left[\frac{1}{3} \cos 2\omega t + \frac{1}{15} \cos 4\omega t + \frac{1}{35} \cos 6\omega t + \dots \right]$$

The dc component is $\frac{2V_m}{\pi}$.

Assuming the third and higher terms contribute little output, the output voltage is

$$V_o = \frac{2V_m}{2\pi} - \frac{4V_m}{3\pi} \cos 2\omega t$$

The diode, choke and transformer resistances can be neglected since they are very small as compared with R_L . Therefore, the dc component of current $I_m = \frac{V_m}{R_L}$. The impedance of series combination of L and R_L at 2ω is

$$Z = \sqrt{R_L^2 + (2\omega L)^2} = \sqrt{R_L^2 + 4\omega^2 L^2}$$

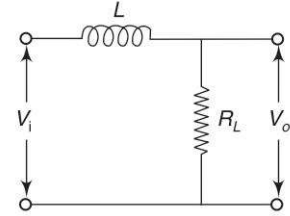


Fig. 3.5 Inductor filter

Therefore, for the ac component,

$$I_m = \frac{V_m}{\sqrt{R_L^2 + 4\omega^2 L^2}}$$

Therefore, the resulting current i is given by,

$$i = \frac{2V_m}{\pi R_L} - \frac{4V_m}{3\pi} \frac{\cos(2\omega t - \varphi)}{\sqrt{R_L^2 + 4\omega^2 L^2}}$$

where $\varphi = \tan^{-1} \left(\frac{2\omega L}{R_L} \right)$.

The ripple factor, which can be defined as the ratio of the rms value of the ripple to the dc value of the wave, is

$$\Gamma = \frac{\frac{4V_m}{3\pi\sqrt{2} \sqrt{R_L^2 + 4\omega^2 L^2}}}{\frac{2V_m}{\pi R_L}} = \frac{2}{3\sqrt{2}} \cdot \frac{1}{\sqrt{1 + \frac{4\omega^2 L^2}{R_L^2}}}$$

If $\frac{4\omega^2 L^2}{R_L^2} \gg 1$, then a simplified expression for Γ is

$$\Gamma = \frac{R_L}{3\sqrt{2} \omega L}$$

In case, the load resistance is infinity, i.e., the output is an open circuit, then the ripple factor is

$$\Gamma = \frac{2}{3\sqrt{2}} = 0.471$$

This is slightly less than the value of 0.482. The difference being attributable to the omission of higher harmonics as mentioned. It is clear that the inductor filter should only be used where R_L is consistently small.

EXAMPLE 3.19

Calculate the value of inductance to use in the inductor filter connected to a full-wave rectifier operating at 60 Hz to provide a dc output with 4% ripple for a 100 Ω load.

Solution

We know that the ripple factor for inductor filter is $\Gamma = \frac{R_L}{3\sqrt{2} \omega L}$

Therefore,
$$0.04 = \frac{100}{3\sqrt{2} (2\pi \times 60 \times L)} = \frac{0.0625}{L}$$

$$L = \frac{0.0625}{0.04} = 1.5625 \text{ H}$$

3.6 CAPACITOR FILTER

An inexpensive filter for light loads is found in the capacitor filter which is connected directly across the load, as shown in Fig. 3.6(a). The property of a capacitor is that it allows ac component and blocks the dc component. The operation of a capacitor filter is to short the ripple to ground but leave the dc to appear at the output when it is connected across a pulsating dc voltage.

During the positive half-cycle, the capacitor charges up to the peak value of the transformer secondary voltage, V_m , and will try to maintain this value as the full-wave input drops to zero. The capacitor will discharge through R_L slowly until the transformer secondary voltage again increases to a value greater than the capacitor voltage (equal to the load voltage). The diode conducts for a period which depends on the capacitor voltage. The diode will conduct when the transformer secondary voltage becomes more than the 'cut-in' voltage of the diode. The diode stops conducting when the transformer voltage becomes less than the diode voltage. This is called cut-out voltage.

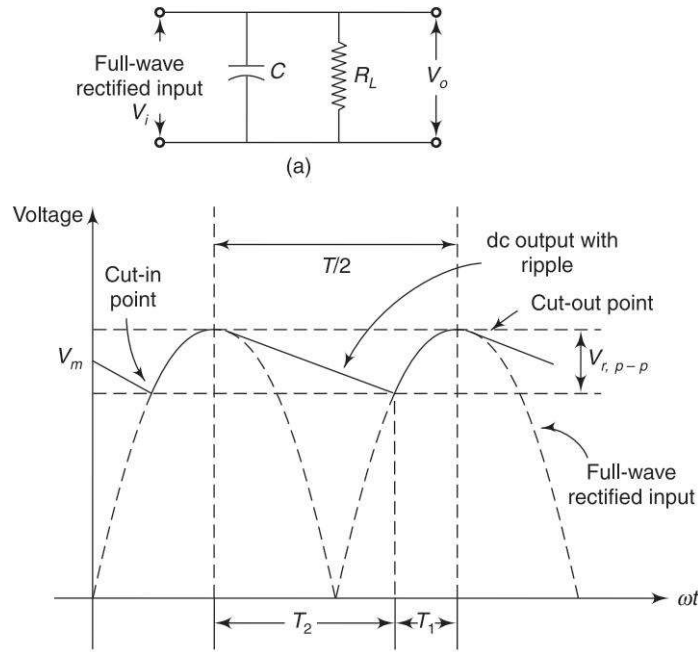


Fig. 3.6 (a) Capacitor filter (b) Ripple voltage triangular waveform

Referring to Fig. 3.6(b) with slight approximation, the ripple voltage waveform can be assumed as triangular. From the cut-in point to the cut-out point, whatever charge the capacitor acquires is equal to the charge the capacitor has lost during the period of non-conduction, i.e., from cut-out point to the next cut-in point.

The charge it has acquired = $V_{r, p-p} \times C$

The charge it has lost = $I_{dc} \times T_2$

Therefore, $V_{r, p-p} \times C = I_{dc} \times T_2$

If the value of the capacitor is fairly large, or the value of the load resistance is very large, then it can be assumed that the time T_2 is equal to half the periodic time of the waveform,

i.e.,
$$T_2 = \frac{T}{2} = \frac{1}{2f}, \text{ then } V_{r,p-p} = \frac{I_{dc}}{2fC}$$

With the assumptions made above, the ripple waveform will be triangular in nature and the rms value of the ripple is given by

$$V_{r, \text{rms}} = \frac{V_{r,p-p}}{2\sqrt{3}}$$

Therefore, from the above equation, we have

$$\begin{aligned} V_{r, \text{rms}} &= \frac{I_{dc}}{4\sqrt{3} fC} \\ &= \frac{V_{dc}}{4\sqrt{3} fCR_L}, \text{ since } I_{dc} = \frac{V_{dc}}{R_L} \end{aligned}$$

Therefore, ripple factor $\Gamma = \frac{V_{r, \text{rms}}}{V_{dc}} = \frac{1}{4\sqrt{3} fCR_L}$

The ripple may be decreased by increasing C or R_L (or both) with a resulting increase in dc output voltage.

If $f = 50$ Hz, C in μF and R_L in Ω , $\Gamma = \frac{2890}{CR_L}$.

EXAMPLE 3.20

Calculate the value of capacitance to use in a capacitor filter connected to a full-wave rectifier operating at a standard aircraft power frequency of 400 Hz, if the ripple factor is 10% for a load of 500 Ω .

Solution We know that the ripple factor for capacitor filter is

$$\Gamma = \frac{1}{4\sqrt{3} fCR_L}$$

Therefore,
$$0.01 = \frac{1}{4\sqrt{3} \times 400 \times C \times 500} = \frac{0.722 \times 10^{-6}}{C}$$

$$C = \frac{0.722 \times 10^{-6}}{0.01} = 72.2 \mu\text{F}$$

EXAMPLE 3.21

A 15-0-15 volt (rms) 50 Hz ideal transformer is used with a full-wave rectifier circuit with diodes having forward drop of 1 volt. The load is a resistance of 100 Ω and a capacitor of 10,000 μF is used as a filter across the load resistance. Calculate the dc load current and voltage.

Solution Given transformer secondary voltage = 15-0-15 V (rms);

Diode forward drop = 1 V; $R_L = 100 \Omega$; $C = 10,000 \mu\text{F}$

We know that,
$$V_{dc} = V_m - \frac{V_{r,p-p}}{2} = V_m - \frac{I_{dc}}{4fC}$$

Therefore,
$$V_{dc} = V_m - \frac{V_{dc}}{R_L 4fC}, \left[\text{since } I_{dc} = \frac{V_{dc}}{R_L} \right]$$

Simplifying, we get
$$V_{dc} = \left[\frac{4f R_L C}{4f R_L C + 1} \right] V_m$$

We know that
$$V_m = V_{rms} \times \sqrt{2} = 15 \times \sqrt{2}$$

Therefore,
$$V_{dc} = \left[\frac{4 \times 50 \times 100 \times 10000 \times 10^{-6}}{4 \times 50 \times 100 \times 10000 \times 10^{-6} + 1} \right] \times 15 \times \sqrt{2} = 21.105 \text{ V}$$

Considering the given voltage drop of 1 volt due to diodes,

$$V_{dc} = 21.105 - 1 = 20.105 \text{ V}$$

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{20.105}{100} = 0.20105 \text{ A}$$

EXAMPLE 3.22

A full-wave rectified voltage of 18 V peak is applied across a 500 μF filter capacitor. Calculate the ripple and dc voltages if the load takes a current of 100 mA.

Solution

Given $V_m = 18 \text{ V}$, $C = 500 \mu\text{F}$ and $I_{dc} = 100 \text{ mA}$

$$V_{dc} = V_m - \frac{I_{dc}}{4fC} = 18 - \frac{100 \times 10^{-3}}{4 \times 50 \times 500 \times 10^{-6}} = 17 \text{ V}$$

$$V_{r,rms} = \frac{I_{dc}}{4\sqrt{3}fC} = \frac{100 \times 10^{-3}}{4\sqrt{3} \times 50 \times 500 \times 10^{-6}} = 0.577 \text{ V}$$

Therefore, ripple,
$$\Gamma = \frac{V_{r,rms}}{V_{dc}} = \frac{0.577}{17} \times 100 = 3.39\%$$

EXAMPLE 3.23

A bridge rectifier with capacitor filter is fed from 220 V to 40 V step down transformer. If average dc current in load is 1 A and capacitor filter of 800 μF , calculate the load regulation and ripple factor. Assume power line frequency of 50 Hz. Neglect diode forward resistance and dc resistance of secondary of transformer.

Solution

$V_{rms} \text{ (secondary)} = 40 \text{ V}$, $I_{dc} = 1 \text{ A}$, $C = 800 \mu\text{F}$, and $f = 50 \text{ Hz}$

$$V_m = \sqrt{2} V_{rms} = \sqrt{2} \times 40 = 56.5685 \text{ V}$$

$$V_{dc(FL)} = V_m - \frac{I_{dc}}{4fC} = 56.5685 - \frac{1}{4 \times 50 \times 800 \times 10^{-6}} = 50.3185 \text{ V}$$

On no load, $I_{dc} = 0$

Hence, $V_{dc(NL)} = V_m = 56.5685 \text{ V}$

$$\begin{aligned} \text{Therefore, percentage of regulation} &= \frac{V_{dc(NL)} - V_{dc(NL)}}{I_{dc(NL)}} \times 100 \\ &= \frac{56.5685 - 50.1385}{50.1385} \times 100 = 12.42\% \end{aligned}$$

$$R_L = \frac{V_{dc}}{I_{dc}} = \frac{50.1385}{1} = 50.1385 \Omega$$

$$\Gamma = \frac{1}{4\sqrt{3} f C R_L} = \frac{1}{4\sqrt{3} \times 50 \times 800 \times 10^{-6} \times 50.1385} = 0.0717, \text{ i.e., } 7.17\%$$

3.7 L-SECTION FILTER (LC FILTER)

We know that the ripple factor is directly proportional to the load resistance R_L in the inductor filter and inversely proportional to R_L in the capacitor filter. Therefore, if these two filters are combined as LC filter or L-section filter as shown in Fig. 3.7, the ripple factor will be independent of R_L .

If the value of the inductance is increased, it will increase the time of conduction. At some critical value of inductance, one diode, either D_1 or D_2 in full-wave rectifier, will always be conducting.

From Fourier series, the output voltage can be expressed as

$$V_o = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi} \cos 2\omega t$$

The dc output voltage, $V_{dc} = \frac{2V_m}{\pi}$

Therefore, $I_{rms} = \frac{4V_m}{3\pi\sqrt{2}} \cdot \frac{1}{X_L} = \frac{\sqrt{2}}{3} \cdot \frac{V_{dc}}{X_L}$

This current flowing through X_C creates the ripple voltage ($V_{r, rms}$) in the output.

Therefore, $V_{r, rms} = I_{rms} \cdot X_C = \frac{\sqrt{2}}{3} \cdot V_{dc} \cdot \frac{X_C}{X_L}$

The ripple factor, $\Gamma = \frac{V_{r, rms}}{V_{dc}} = \frac{\sqrt{2}}{3} \cdot \frac{X_C}{X_L}$

$$= \frac{\sqrt{2}}{3} \cdot \frac{1}{4\omega^2 C L}, \text{ since } X_C = \frac{1}{2\omega C} \text{ and } X_L = 2\omega L$$

If $f = 50 \text{ Hz}$, C is in μF and L is in Henry, ripple factor $\Gamma = \frac{1.194}{LC}$.

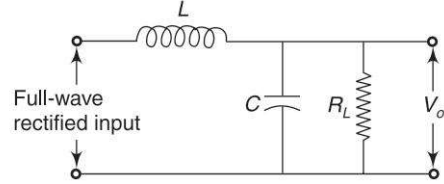


Fig. 3.7 LC filter

Bleeder Resistor It was assumed in the analysis given above that for a critical value of inductor, either of the diodes is always conducting, i.e., current does not fall to zero. The incoming current consists of two components:

(i) $I_{dc} = \frac{V_{dc}}{R_L}$, and (ii) a sinusoidal varying components with peak value of $\frac{4V_m}{3\pi X_L}$. The negative peak of the ac current must always be less than dc, i.e., $\sqrt{2} I_{rms} \leq \frac{V_{dc}}{R_L}$.

We know that for LC filter, $I_{rms} = \frac{\sqrt{2}}{3} \times \frac{V_{dc}}{X_L}$

Hence, $\frac{2V_{dc}}{X_L} \leq \frac{V_{dc}}{R_L}$, i.e., $X_L \geq \frac{2}{3} R_L$

i.e., $L_C = \frac{R_L}{2\omega}$, where L_C is the critical inductance.

It should be noted that the condition $X_L \geq \frac{2}{3} R_L$ cannot be satisfied for all load requirements. At no load, i.e., when the load resistance is infinity, the value of the inductance will also tend to be infinity. To overcome this problem, a bleeder resistor R_B is connected in parallel with the load resistance as shown in Fig. 3.8. Therefore, a minimum current will always be present for optimum operation of the inductor. It improves voltage regulation of the supply by acting as the pre-load on the supply. Also, it provides safety by acting as a discharging path for capacitor.

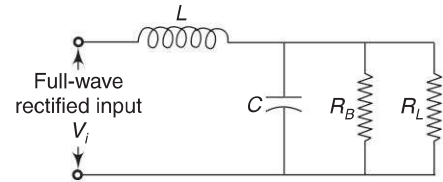


Fig. 3.8 Bleeder resistor connected at the filter output

EXAMPLE 3.24

Design a filter for full-wave circuit with LC filter to provide an output voltage of 10 V with a load current of 200 mA and the ripple is limited to 2%.

Solution The effective load resistance, $R_L = \frac{10}{200 \times 10^{-3}} = 50 \Omega$

We know that the ripple factor,

$$\Gamma = \frac{1.194}{LC}$$

$$\text{i.e., } 0.02 = \frac{1.194}{LC}$$

$$\text{i.e., } LC = \frac{1.194}{0.02} = 59.7$$

$$\text{Critical value of } L = \frac{R_L}{3\omega} = \frac{50}{3 \times 2\pi f} = 53 \text{ mH}$$

Taking $L = 60 \text{ mH}$ (about 20% higher), C will be about $1000 \mu\text{F}$.

EXAMPLE 3.25

A full-wave rectifier (FWR) supplies a load requiring 300 V at 200 mA. Calculate the transformer secondary voltage for (a) a capacitor input filter using a capacitor of 10 mF, and (b) a choke input filter using a choke of 10 H and a capacitance of 10 μ F. Neglect the resistance of choke.

Solution Given $V_{dc} = 300$ V; $I_{dc} = 200$ mA

(a) For the capacitor filter with $C = 10$ μ F,

$$V_{dc} = V_m - \frac{I_{dc}}{4fC}$$

$$300 = V_m - \frac{200 \times 10^{-3}}{4(50)(10 \times 10^{-6})} = V_m - 100$$

Therefore,

$$V_m = 400 \text{ V}_{(p-p)}$$

$$V_{rms} = \frac{V_m}{\sqrt{2}} = 282.84 \text{ V}$$

(b) For the choke, i.e., LC filter with $L = 10$ H; $C = 10$ μ F

$$V_{dc} = \frac{2V_m}{\pi}$$

$$300 = \frac{2V_m}{\pi}$$

Therefore,

$$V_m = 471.23 \text{ V}$$

$$V_{rms} = \frac{V_m}{\sqrt{2}} = 333.21 \text{ V}$$

EXAMPLE 3.26

Determine the ripple factor of a L -type choke input filter comprising a 10 H choke and 8 μ F capacitor used with a FWR. Compare with a simple 8 μ F capacitor input filter at a load current of 50 mA and also at 150 mA. Assume the dc voltage of 50 V.

Solution $V_{dc} = 50$ V, $L = 10$ H, $C = 8$ μ F

Assume $f = 50$ Hz, i.e., $\omega = 2\pi f = 100\pi$ rad/sec.

For LC filter, the ripple factor is

$$\Gamma = \frac{1}{6\sqrt{2}\omega^2 LC} = \frac{1}{6\sqrt{2} \times (100\pi)^2 \times 10 \times 8 \times 10^{-6}} = 0.01492 \text{ i.e., } 1.492\%$$

For the simple capacitor filter, $C = 8$ μ F.

(a) At $I_L = 50$ mA,

$$R_L = \frac{V_{dc}}{I_L} = \frac{50}{50 \times 10^{-3}} = 1000 \Omega$$

$$\Gamma = \frac{1}{4\sqrt{3}fCR_L} = \frac{1}{4\sqrt{3} \times 50 \times 8 \times 10^{-6} \times 1000} = 0.3608, \text{ i.e., } 36.08\%$$

(b) At $I_L = 150 \text{ mA}$,

$$R_L = \frac{V_{dc}}{I_L} = \frac{50}{150 \times 10^{-3}} = 333.33 \Omega$$

$$\Gamma = \frac{1}{4\sqrt{3}fCR_L} = \frac{1}{4\sqrt{3} \times 50 \times 8 \times 10^{-6} \times 333.33} = 1.082, \text{ i.e., } 108.2\%$$

Thus, it is inferred that the LC choke input filter is more effective than capacitor input filter and the ripple factor of LC choke input filter does not depend on the load resistance.

EXAMPLE 3.27

In a full-wave rectifier using an LC filter, $L = 10 \text{ H}$, $C = 100 \mu\text{F}$, and $R_L = 500 \Omega$. Calculate I_{dc} , V_{dc} , and ripple factor for an input of $v_i = 30 \sin(100\pi t) \text{ V}$.

Solution

Comparing the input with $v_i = V_m \sin \omega t$

$$V_m (\text{secondary}) = V_m = 30 \text{ V}$$

$$V_{dc} = \frac{2V_m}{\pi} = \frac{2 \times 30}{\pi} = 19.0985 \text{ V}$$

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{19.0985}{500} = 0.03819 \text{ A} = 38.19 \text{ mA}$$

$$\begin{aligned} \text{Ripple factor} &= \frac{1}{6\sqrt{2}\omega^2 LC} \\ &= \frac{1}{6\sqrt{2} \times (100\pi)^2 \times 10 \times 100 \times 10^{-6}} = 1.194 \times 10^{-3} \end{aligned}$$

3.8 π -SECTION FILTER

Figure 3.9 shows the CLC or π -type filter which basically consists of a capacitor filter followed by an LC section. This filter provided a fairly smooth output, and is characterized by a highly peaked diode currents and poor regulation.

The action of a π -section filter can best be understood by considering the inductor and the second capacitor as an L-section filter that acts upon the triangular output-voltage wave from the first capacitor. The output voltage is then approximately that from the input capacitor, decreased by the dc voltage drop in the inductor. The ripple contained in this output is reduced by the L-section filter.

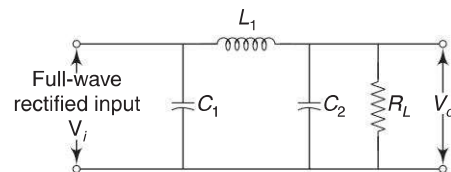


Fig. 3.9 CLC or π -type filter

The ripple voltage can be calculated by analyzing the triangular wave into a Fourier series and then multiplying each component by X_{C2}/X_{L1} for this harmonic. The Fourier analysis of this waveform is given by

$$v = V_{dc} - \frac{V_r}{\pi} \left(\sin 2\omega t - \frac{\sin 2\omega t}{2} + \frac{\sin 6\omega t}{3} - \dots \right)$$

We know that

$$V_r = \frac{I_{dc}}{2fC_1}$$

The rms second-harmonic voltage is

$$V_{rms} = V'_2 = \frac{V_r}{\pi\sqrt{2}} = \frac{I_{dc}}{2\pi fC_1\sqrt{2}} = \sqrt{2}I_{dc}X_{C1}$$

where X_{C1} is the reactance of C_1 at the second-harmonic frequency.

The voltage V'_2 is impressed on an L-section, and the output ripple is V'_2X_{C2}/X_{L1} .

Hence, the ripple factor is

$$\Gamma = \frac{V_{rms}}{V_{dc}} = \frac{\sqrt{2}I_{dc}X_{C1}}{V_{dc}} \frac{X_{C2}}{X_{L1}} = \sqrt{2} \frac{X_{C1}}{R_L} \frac{X_{C2}}{X_{L1}}$$

where all reactance are calculated at the second-harmonic frequency.

For $f = 60$ Hz, the above equation reduces to

$$\Gamma = \frac{3,300}{C_1C_2L_1R_L}$$

3.9 MULTIPLE L-SECTION AND MULTIPLE π -SECTION FILTER

3.9.1 Multiple L-section Filter

The filtering level can be improved by using two or more L-section filters in series, as shown in Fig. 3.10. It is assumed that the reactance of all the inductances are much larger than the reactance of the capacitors and the reactance of the last capacitor is small compared with the resistance of the load. Under these conditions, the impedance between 3 and 3' is X_{C2} , the impedance between 2 and 2' is X_{C1} , and the impedance between 1 and 1' is X_{L1} . The alternating current I_1 through L_1 is, given by

$$I_1 = \frac{\sqrt{2}V_{dc}}{3} \frac{1}{X_{L1}}$$

The ac voltage across C_1 is given by

$$V_{22'} = I_1X_{C1}$$

The alternating current I_2 through L_2 is given by

$$I_2 = \frac{V_{22'}}{X_{L2}}$$

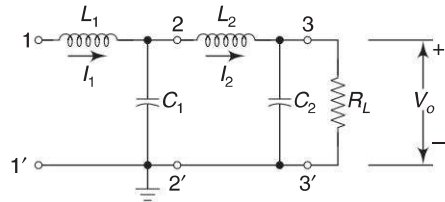


Fig. 3.10 A multiple (two-section) L-section filter

The ac voltage across C_2 and hence, across the load is given by

$$V_{33'} = I_2 X_{C2} = I_1 \frac{X_{C2} X_{C1}}{X_{L2}} = \frac{\sqrt{2} V_{dc}}{3} \frac{X_{C2} X_{C1}}{X_{L2} X_{L1}}$$

The ripple factor is obtained by dividing the above equation by V_{dc} . Hence,

$$\Gamma = \frac{\sqrt{2}}{3} \frac{X_{C1} X_{C2}}{X_{L1} X_{L2}}$$

The generalized expression for any number of sections can be obtained by comparing the above equation with that of a single L-section. For example, the ripple factor of a multiple L-section filter (Γ_n) is given by

$$\Gamma_n = \frac{\sqrt{2}}{3} \left(\frac{X_C}{X_L} \right)^n = \frac{\sqrt{2}}{3} \frac{1}{(16\pi^2 f^2 LC)^n}$$

where n is the number of similar L-sections.

3.9.1 Multiple π -section Filter

In order to obtain pure dc at the output, more number of π -sections may be used in series. Such a filter using more than one π -section, as shown in Fig. 3.11, is called a multiple π -section filter.

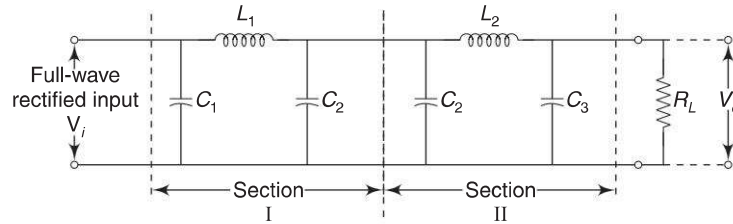


Fig. 3.11 Multiple π -section filter

The ripple factor for multiple π -section filter is given by

$$\Gamma = \frac{X_{C1}}{R_L} \cdot \frac{X_{C2}}{X_{L1}} \cdot \frac{X_{C3}}{X_{L2}} \dots \frac{X_{Cn}}{X_{L(n-1)}}$$

where n is the number of π -sections.

EXAMPLE 3.28

Design a CLC or π -section filter for $V_{dc} = 10$ V, $I_L = 200$ mA, and $\Gamma = 2\%$.

Solution

$$R_L = \frac{10}{200 \times 10^{-3}} = 50 \Omega$$

$$0.02 = \frac{5700}{LC_1 C_2 \times 50} = \frac{114}{LC_1 C_2}$$

If we assume $L = 10 \text{ H}$ and $C_1 = C_2 = C$, we have

$$0.02 = \frac{114}{LC^2} = \frac{11.4}{C^2}$$

$$C^2 = 570; \text{ therefore, } C = \sqrt{570} \approx 24 \mu\text{F}$$

EXAMPLE 3.29

A full-wave single-phase rectifier employs a π -section filter consisting of two $4 \mu\text{F}$ capacitances and a 20 H choke. The transformer voltage to the centre tap is 300 V rms . The load current is 500 mA . Calculate the dc output voltage and the ripple voltage. The resistance of the choke is 200Ω .

Solution

$$C_1 = C_2 = 4 \mu\text{F}, L = 20 \text{ H}$$

$$I_{\text{dc}} = 500 \text{ mA}, R_x = 200 \Omega$$

Maximum value of secondary voltage,

$$V_{s(\text{max})} = \sqrt{2} \times 300 = 424.2 \text{ V}$$

$$R_L = \frac{V_{\text{dc}}}{I_{\text{dc}}} = \frac{270.19}{500 \times 10^{-3}} = 540 \Omega$$

$$V_{\text{dc}} = V_{s(\text{max})} - \frac{V_r}{2} - I_{\text{dc}} R_x$$

Ripple voltage,
$$V_r = \frac{I_{\text{dc}}}{2fC} = \frac{500 \times 10^{-3}}{2 \times 50 \times 4 \times 10^{-6}} = 1.25 \text{ mV}$$

The dc output voltage,
$$V_{\text{dc}} = 424.2 - \frac{1.25 \times 10^{-3}}{2} - (500 \times 10^{-3} \times 200) = 324.19 \text{ V}$$

R-C Filters Consider the CLC filter with the inductor L replaced by a resistor R . This type of filter called RC filter is shown in Fig. 3.12. The expression for the ripple factor can be obtained by replacing X_L by R . Then,

$$\Gamma = \sqrt{2} \frac{X_{C1}}{R_L} \cdot \frac{X_{C2}}{R}$$

Therefore, if resistor R is chosen equal to the reactance of the inductor which it replaces, the ripple remains unchanged.

The resistance R will increase the voltage drop and hence, the regulation will be poor. This type of filters are often used for economic reasons, as well as the space and weight requirement of the iron-cored choke for the LC filter. Such RC filters are often used only for low current power supplies.

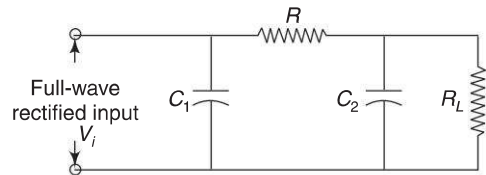


Fig. 3.12 R-C filter

3.10 COMPARISON OF VARIOUS FILTER CIRCUITS

Table 3.2 shows the comparison of various types of filters, when used with full-wave circuits. In all these filters, the resistances of diodes, transformer and filter elements are considered negligible and a 60 Hz power line is assumed.

Table 3.2 Comparison of various types of filters

Particulars	Type of Filter				
	None	L	C	L-Section	π -Section
V_{dc} at no load	$0.636 V_m$	$0.636 V_m$	V_m	V_m	V_m
V_{dc} at load I_{dc}	$0.636 V_m$	$0.636 V_m$	$V_m - \frac{4170 I_{dc}}{C}$	$0.636 V_m$	$V_m - \frac{4170 I_{dc}}{C}$
Ripple factor Γ	0.48	$\frac{R_L}{16000 L}$	$\frac{2410}{C R_L}$	$\frac{0.83}{LC}$	$\frac{3330}{LC_1 C_2 R_L}$
Peak inverse voltage (PIV)	$2 V_m$	$2 V_m$	$2 V_m$	$2 V_m$	$2 V_m$

REVIEW QUESTIONS

- What is a rectifier?
- Show that a PV diode works as rectifier.
- Define the following terms:
 - ripple factor
 - peak inverse voltage
 - efficiency
 - transformer utilization factor
 - form factor
 - peak factor
- Draw the circuit diagram of an half-wave rectifier, and explain its operation.
- Derive expressions for rectification efficiency, ripple factor, transformer utilization factor, form factor, and peak factor of an half-wave rectifier with resistive load.
- A half-wave rectifier has a load of $3.5 \text{ k}\Omega$. If the diode resistance and secondary coil resistance together have a resistance of 800Ω and the input voltage has a signal voltage of peak value 240 V , calculate
 - Peak, average and rms value of current flowing
 - dc power output
 - ac power input
 - Efficiency of the rectifier

[Ans. (i) 55.81 mA, 17.78 mA and 27.9 mA (ii) 1.1 W (iii) 3.35 W (iv) 32.9%]
- Explain the action of a full-wave rectifier and give waveforms of input and output voltages.
- Derive expressions of dc or average value of voltage and rms value of voltage of a full-wave rectifier with resistive load.
- Derive an expression for a ripple factor in a full-wave rectifier with resistive load.
- Determine the value of ripple factor in the full-wave rectifier operating at 50 Hz with a $100 \mu\text{F}$ capacitor filter and 100Ω load.

[Ans. 29%]
- Show that a full-wave rectifier is twice as efficient as a half-wave rectifier.
- Describe the action of a full-wave bridge rectifier.
- What are the advantages of a bridge rectifier?

14. Compare half-wave, full-wave and bridge rectifiers.
15. What is the need for filters in power supplies?
16. Explain the various types of filters used in power supplies.
17. Obtain the ripple factor of a full-wave rectifier with shunt capacitor filter.
18. Derive an expression for the ripple factor in a full-wave rectifier using inductor filter.
19. Compare the performance of inductive, L-section and π -section filters.
20. An L - C filter is to be used to provide a dc output with 1% ripple from a full-wave rectifier operating at 50 Hz. Assuming $L/C = 0.01$, determine the required values of L and C . [Ans. 1.093 H, 109.27 μ F]
21. In a full-wave rectifier using an L - C filter, it is known that $L = 10$ H, $C = 100$ μ F, and $R_L = 500$ Ω . Calculate I_{dc} , V_{dc} , I_{ac} , V_{ac} if $V_m = 30$ V and $f = 50$ Hz. [Ans. 38.2 mA, 19.1 V, 1.43 mA, 22.7 mV]
22. The turns ratio of the transformer used in a half-wave rectifier is 2:1 and the primary is connected to 230 V, 50 Hz power mains. Assuming the diodes to be ideal, determine (i) dc voltage across the load, (ii) PIV of each diode, and (iii) maximum and average values of power delivered to the load having a resistance of 200 Ω . Also find the efficiency of the rectifier and output ripple frequency. [Ans. 51.7 V, 162.2 V, 132.2 W, 13.5 W, 10.21%, 50 Hz]
23. In a full-wave rectifier, the voltage applied to each diode is $240 \sin 377t$, the load resistance is $R_L = 2000$ Ω and each diode has a forward resistance of 400 Ω . Determine the (i) peak value of current, (ii) dc value of current, (iii) rms value of current, (iv) rectifier efficiency, (v) ripple factor, and (vi) output ripple frequency. [Ans. 100 mA, 63.8 mA, 70.7 mA, 67.6%, 0.482, 120 Hz]
24. In a bridge rectifier, the transformer is connected to 220 V, 60 Hz mains and the turns ratio of the step down transformer is 11:1. Assuming the diodes to be ideal, find (i) the voltage across the load, (ii) I_{dc} and (iii) PIV. [Ans. 18 V, 18 mA, 28.28 V]
25. In a full-wave rectifier, the transformer rms secondary voltage from centre tap to each end of secondary is 50 V. The load resistance is 900 Ω . If the diode resistance and transformer secondary winding resistance together has a resistance of 100 Ω . Determine the average load current and rms value of load current. [Ans. 45 mA, 50 mA]

OBJECTIVE-TYPE QUESTIONS

1. A rectifier is used to
 - (a) convert ac voltage to dc voltage
 - (b) convert dc voltage to ac voltage
 - (c) both (a) and (b)
 - (d) convert voltage to current
2. The maximum efficiency of a half-wave rectifier is
 - (a) 40.6%
 - (b) 81.2%
 - (c) 1.12%
 - (d) 48.2%
3. In a full-wave rectifier, the current in each diode flows for
 - (a) whole cycle of the input signal
 - (b) half-cycle of the input signal
 - (c) more than half-cycle of the input signal
 - (d) none of the above
4. In a full-wave bridge rectifier, if V_m is the peak voltage across the secondary of the transformer, the maximum voltage coming across each reverse-biased diode is
 - (a) V_m
 - (b) $2V_m$
 - (c) $\frac{1}{2}V_m$
 - (d) $\frac{V_m}{\sqrt{2}}$
5. The rectifier efficiency is
 - (a) $\frac{P_{dc}}{P_{ac}}$
 - (b) $\frac{\text{rms value}}{\text{average value}}$
 - (c) $\frac{\text{Peak value}}{\text{rms value}}$
 - (d) $\sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$
6. The major advantages of a bridge rectifier is that
 - (a) no centre-tap transformer is required
 - (b) the required peak inverse voltage of each diode is double that for a full-wave rectifier

- (c) peak inverse voltage of each diode is half that for a full-wave rectifier
(d) the output is more smooth
7. The ripple factor decreases with
(a) decrease in C (b) increase in C
(c) increase in frequency (d) decrease in frequency
8. The primary function of a rectifier filter is to
(a) suppress odd harmonics (b) remove ripples
(c) stabilize the output dc level (d) minimize the input ac variations
9. The diode used in voltage regulator is
(a) PN -junction diode (b) varactor diode
(c) Zener diode (d) GUNN diode
10. A bleeder resistor is used in a dc power supply because it
(a) keeps the supply OFF (b) keeps the supply ON
(c) improves filtering action (d) improves voltage regulation
11. The ripple factor of a power supply is given by
(a) $\frac{P_{dc}}{P_{ac}}$ (b) $\sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$ (c) $\sqrt{\left(\frac{I_{dc}}{I_{rms}}\right) - 1}$ (d) $\frac{I_{dc}}{I_{rms}}$
12. For constructing a full-wave rectifier,
(a) at least two diodes are needed (b) more than two diodes are needed
(c) at least four diodes are needed (d) none of the above
13. Ripple factor of an ideal rectifier is
(a) 1 (b) 0 (c) infinity (d) none of the above
14. The bridge rectifier is preferable to a full-wave rectifier with centre-tap connections because it uses four diodes
(a) its transformer has no centre tap (b) it needs much small transformer for the same output
(c) it has higher safety factor (d) both (b) and (c)
15. In a rectifier, larger the value of shunt capacitor filter,
(a) larger the peak current in the rectifying diode
(b) smaller the dc voltage across the load
(c) longer the time that current pulse flows through the diode
(d) all of the above
16. In an LC filter, the ripple factor
(a) increases with the load current (b) increases with the load resistance
(c) remains constant with the load current (d) has the lowest value
17. Consider the following rectifier circuits:
1. Half-wave rectifier without filter
2. Full-wave rectifier without filter
3. Full-wave rectifier with series inductance filter
4. Full-wave rectifier with capacitance filter.
The sequence of these rectifier circuits in decreasing order of their ripple factor is
(a) 1, 2, 3, 4 (b) 3, 4, 1, 2 (c) 1, 4, 3, 2 (d) 3, 2, 1, 4