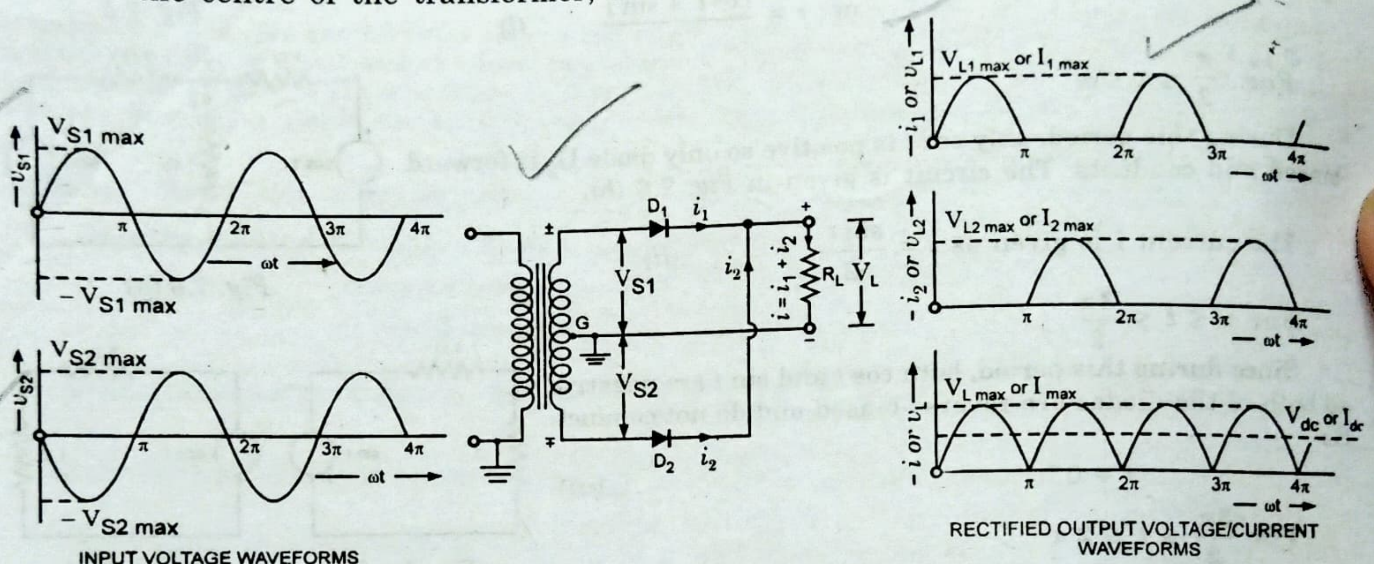
7.3. FULL-WAVE RECTIFIERS

In half-wave rectifiers only one half cycles of the input are utilized but in full-wave rectifiers both half cycles of the input are utilized. Alternate half cycles are inverted to give unidirectional load current. There are two types of full-wave rectifier circuits namely

1. *centre-tap rectifier* and 2. *bridge rectifier*.

7.3.1. Centre-Tap Full-Wave Rectifier. In such a rectifier, the ac input is applied through a transformer, the anodes of the two diodes D_1 and D_2 (having similar characteristics) are connected to the opposite ends of the centre tapped secondary winding and two cathodes are connected to each other and are connected also through the load resistance R_L and back to the centre of the transformer, as shown in fig. 7.8.



Centre-Tap Full-Wave Rectifier
Fig. 7.8

When the top of the transformer secondary winding is positive, say during the first half-cycle of the supply, the anode of diode D_1 is positive w.r.t. cathode, and anode of diode D_2 is negative w.r.t. cathode. Thus only diode D_1 conducts, being forward biased and current flows from cathode to anode of diode D_1, through load resistance R_L and top half the transformer secondary making cathode end of load resistance R_L positive. During the second half-cycle of the input voltage the polarity is reversed, making the bottom of the secondary winding positive w.r.t. centre tap and thus diode D_2 is forward biased and diode D_1 is reverse biased. Consequently during this half-cycle of the input only the diode D_2 conducts and current flows through the load resistance R_L and bottom of the transformer secondary making the cathode end of the load resistance R_L positive. Thus the direction of flow of current through the load resistance R_L remains the same during both halves of the input supply voltage. Thus the circuit shown in fig. 7.8 acts as a full-wave rectifier.

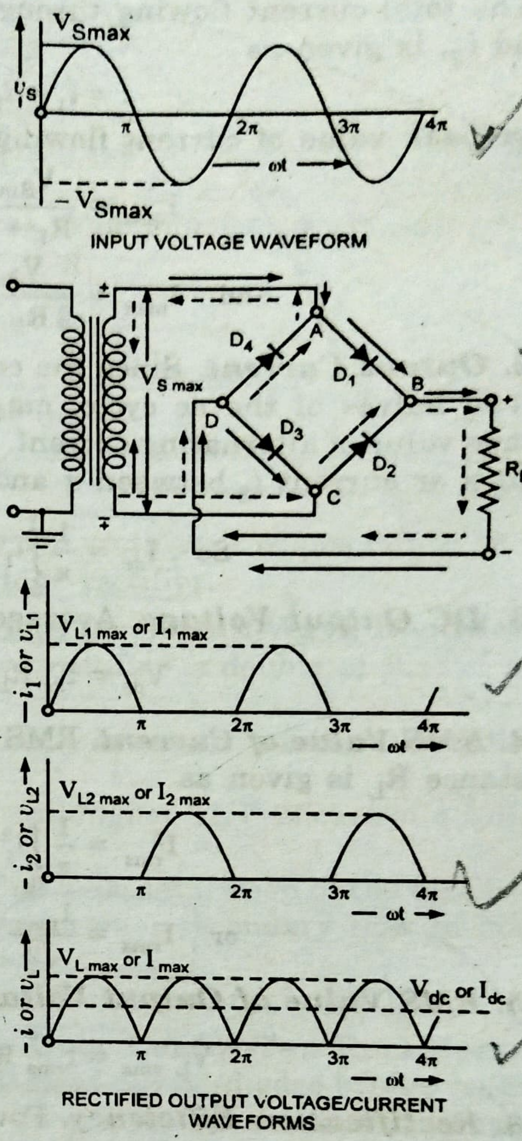
Peak Inverse Voltage. As already mentioned before, peak inverse voltage (PIV) is the maximum possible voltage across a diode when it is reverse-biased. During first half-cycle of the supply *i.e.* when the top of the transformer secondary winding is positive, diode D_1 conducts and offers almost zero resistance. So whole of the voltage $V_{S\,max}$ of the upper half winding is developed across the load resistance R_L. Now voltage across the non-conducting diode D_2 is the sum of voltage across the lower half of the transformer secondary and the voltage across the load resistance R_L.

Thus PIV of diode, $D_2 = V_{S\,max} + V_{S\,max} = 2\,V_{S\,max}$

Similarly PIV of diode $D_1 = 2\,V_{S\,max}$ ...(7.22)

7.3.2. Bridge Rectifier. In the bridge circuit four diodes are connected in the form of a Wheatstone bridge, two diametrically opposite junctions of the bridge are connected to the secondary of a transformer and the other two are connected to the load, as shown in fig. 7.9.

When the upper end of the transformer secondary winding is positive, say during first half-cycles of the input supply, diodes D_1 and D_3 are forward biased and current flows through arm AB, enters the load at positive terminal, leaves the load at negative terminal, and returns back flowing through arm DC. During this half of each input cycle, the diodes D_2 and D_4 are reverse biased and so the current is not allowed to flow in arms AD and BC. The flow of current is indicated by solid arrows in the figure. In the second half of the input cycle the lower end of ac supply becomes positive, diodes D_2 and D_4 become forward biased and current flows through arm CB, enters the load at the positive terminal, leaves the load at negative terminal and returns back flowing through arm DA. Flow of current has been shown by dotted arrows in the figure. Thus the direction of flow of current through the load resistance R_L remains the same during both half cycles of the input supply voltage.



Bridge Rectifier
Fig. 7.9

Peak Inverse Voltage (PIV). Fig. 7.9 shows a bridge rectifier circuit. Let us consider the instant the secondary voltage attains its positive peak value $V_{S\ max}$. Now diodes D_1, and D_3 are conducting whereas diodes D_2 and D_4 are non-conducting being reverse biased. The conducting diodes D_1 and D_3 have almost zero resistance (*i.e.* zero voltage drop across them). Point B has the same potential as point A and similarly point D has the same potential as point C. The entire voltage of the transformer secondary winding, $V_{S\ max}$ is developed across the load resistance R_L. The same voltage *i.e.* $V_{S\ max}$ acts across each of the non-conducting diodes D_2 and D_3. Thus

$$PIV = V_{S\ max} \qquad ...(7.23)$$

7.3.3. Circuit Analysis. The analysis of both of the full-wave rectifier circuits (*i.e.* centre-tap and bridge type) is the same except that (*i*) in a bridge rectifier circuit two diodes conduct during each half cycle and forward resistance becomes double *i.e.* 2 R_F and (*ii*) in a bridge rectifier circuit $V_{S\ max}$ is the maximum voltage across the transformer secondary winding whereas in a centre tap rectifier circuit $V_{S\ max}$ represents the maximum voltage across each half of the secondary winding.

1. ***Peak Current.*** Instantaneous value of voltage applied to the rectifier is given as

$$v_s = V_{S\ max} \sin \omega t \qquad ...(7.24)$$

If the diode is assumed to have a forward resistance of R_F ohms and reverse resistance equal to infinity, then current flowing through the load resistance is given as

$$i_1 = I_{max} \sin \omega t \text{ and } i_2 = 0 \text{ for first half cycle} \qquad ...(7.25)$$

$$\text{and } i_1 = 0 \text{ and } i_2 = I_{max} \sin \omega t \text{ for second half cycle} \qquad ...(7.26)$$

The total current flowing through the load resistance R_L, being the sum of currents i_1 and i_2, is given as

$$i = i_1 + i_2 = I_{max} \sin \omega t \text{ for the whole cycle} \quad ...(7.27)$$

where peak value of current flowing through the load resistance R_L is given as

$$I_{max} = \frac{V_{S max}}{R_F + R_L} \quad ...(7.28) \text{ in case of centre-tap rectifier}$$

$$\text{and } I_{max} = \frac{V_{S max}}{2 R_F + R_L} \quad ...(7.29) \text{ in case of bridge rectifier}$$

2. *Output Current.* Since the current is the same through the load resistance R_L in the two halves of the ac cycle, magnitude of direct current I_{dc}, which is equal to the average value of alternating current, can be obtained by integrating the current i_1 between 0 and π or current i_2 between π and 2π.

$$\text{So } \boxed{I_{dc} = \frac{1}{\pi}\int_0^{\pi} i_1 \, d(\omega t) = \frac{1}{\pi}\int_0^{\pi} I_{max} \sin \omega t \, d(\omega t) = \frac{2 I_{max}}{\pi}} \quad ...(7.30)$$

3. *DC Output Voltage.* Average or dc value of voltage across the load is given as

$$V_{dc} = I_{dc} R_L = \frac{2}{\pi} I_{max} R_L \quad ...(7.31)$$

4. *RMS Value of Current.* RMS or effective value of current flowing through the load resistance R_L is given as

$$I^2_{rms} = \frac{1}{\pi}\int_0^{\pi} i_1^2 \, d(\omega t) = \frac{1}{\pi}\int_0^{\pi} I^2_{max} \sin^2 \omega t \, d(\omega t) = \frac{I^2_{max}}{2}$$

$$\text{or } I_{rms} = \frac{I_{max}}{\sqrt{2}} \quad ...(7.32)$$

5. *RMS Value of Output Voltage.* RMS value of voltage across the load is given as

$$\boxed{V_{L\,rms} = I_{rms} R_L = \frac{I_{max}}{\sqrt{2}} R_L} \quad ...(7.33)$$

6. *Rectification Efficiency.* Power delivered to load,

$$P_{dc} = I^2_{dc} R_L = \left(\frac{2}{\pi} I_{max}\right)^2 R_L = \frac{4}{\pi^2} I^2_{max} R_L \quad ...(7.34)$$

$$\text{AC input power, } P_{ac} = I^2_{rms} (R_L + R_F) = \frac{I^2_{max}}{2} (R_L + R_F) \quad ...(7.35)$$

$$\text{Rectification efficiency, } \eta = \frac{P_{dc}}{P_{ac}}$$

$$= \frac{\frac{4}{\pi^2} I^2_{max} R_L}{\frac{1}{2} I^2_{max} (R_L + R_F)} = \frac{8}{\pi^2} \frac{1}{1 + \frac{R_F}{R_L}} = \frac{0.812}{1 + \frac{R_F}{R_L}} \quad ...(7.36)$$

In case of bridge rectifier, rectification efficiency is given as

$$\boxed{\eta = \frac{0.812}{1 + \frac{2 R_F}{R_L}}} \quad ...(7.37)$$

7. *Ripple Factor.* Form factor of the rectified output voltage of a full-wave rectifier is given as

$$K_f = \frac{I_{rms}}{I_{av}} = \frac{I_{max}/\sqrt{2}}{2\,I_{max}/\pi} = \frac{\pi}{2\sqrt{2}} = 1.11$$

Ripple factor is given as

$$\boxed{\gamma = \sqrt{K_f^2 - 1} = \sqrt{(1.11)^2 - 1} = 0.482} \qquad ...(7.38)$$

8. ***Regulation.*** The dc output voltage is given as, from equation (7.31).

$$V_{dc} = \frac{2}{\pi} I_{max} R_L = \frac{2\,V_{S\,max}\,R_L}{\pi(R_F + R_L)}$$

$$= \frac{2\,V_{S\,max}}{\pi}\left[1 - \frac{R_F}{R_F + R_L}\right] = \frac{2\,V_{S\,max}}{\pi} - I_{dc}\,R_F \qquad ...(7.39)$$

In case of a bridge rectifier, $V_{dc} = \dfrac{2\,V_{S\,max}}{\pi} - 2\,I_{dc}\,R_F$ ...(7.40)

9. ***Transformer Utilisation Factor.*** For full-wave rectifier it comes out to be 0.693 in case centre tap rectifier and 0.812 in case of bridge rectifier.

7.3.4. Merits and Demerits of Full-wave Rectifiers Over Half-Wave Rectifiers.

Merits. 1.The rectification efficiency of full-wave rectifier is double of that of a half-wave rectifier.

2. The ripple voltage is low and of higher frequency in case of a full-wave rectifier so simple filtering circuit is required.
3. Higher output voltage, higher output power and higher TUF in case of a full-wave rectifier.
4. In a full-wave rectifier, there is no problem due to dc saturation of the core because the dc currents in the two halves of the transformer secondary flow in opposite directions.

Demerits. Full-wave rectifier needs more circuit elements and is costlier.

7.3.5. Merits and Demerits of Bridge Rectifiers Over Centre-Tap Rectifiers. With the availability of low-cost, highly reliable and small-sized silicon diodes bridge rectifier is becoming more and more popular in comparison to centre-tap rectifier. It has many advantages over a centre-tap rectifier, as given below.

1. No centre tap is required in the transformer secondary so in case of a bridge rectifier the transformer required is simpler. If stepping up or stepping down of voltage is not required, transformer can be eliminated even.
2. The PIV is one half that of centre-tap rectifier. Hence bridge rectifier is highly suited for high voltage applications.
3. Transformer utilisation factor, in case of a bridge rectifier, is higher than that of a centre-tap rectifier.
4. For a given power output, power transformer of smaller size can be used in case of the bridge rectifier because current in both (primary and secondary) windings of the supply transformer flow for the entire ac cycle.

The main drawback of a bridge rectifier is that it needs four diodes, two of which conduct in alternate half-cycles. Because of this the total voltage drop in diodes becomes double of that in case of centre-tap rectifier, losses are increased and rectification efficiency is somewhat reduced. This poses a problem when low voltages are required. Another drawback of bridge rectifier is that the load resistor R_L and the supply source have no common point which may be earthed.

7.3.6. Comparison Between Half-Wave, Centre-Tap and Bridge Rectifiers.

S.No.	Particulars	Half-Wave Rectifiers	Full-Wave Rectifiers Centre-Tap	Full-Wave Rectifiers Bridge
1.	Number of diodes required	1	2	4
2.	Transformer requirement	not essential	essential	not essential
3	Average value of current, I_{dc}	I_{max}/π	$2\,I_{max}/\pi$	$2\,I_{max}/\pi$
4.	RMS value of current, I_{rms}	$I_{max}/2$	$I_{max}/\sqrt{2}$	$I_{max}/\sqrt{2}$
5.	Peak inverse voltage (PIV)	$V_{S\,max}$	$2\,V_{S\,max}$	$V_{S\,max}$
6.	Peak load current, I_{max}	$\frac{V_{S\,max}}{R_L + R_F}$	$\frac{V_{S\,max}}{R_L + R_F}$	$\frac{V_{S\,max}}{R_L + 2\,R_F}$
7.	DC output voltage, V_{dc}	$\frac{I_{max}}{\pi} R_L$	$\frac{2}{\pi} I_{max}\, R_L$	$\frac{2}{\pi} I_{max}\, R_L$
8.	Rectification efficiency (max)	40.6%	81.2%	81.2%
9.	Ripple factor	1.21	0.482	0.482
10.	Fundamental frequency of ripple	Supply frequency, f	$2\,f$	$2\,f$
11.	Voltage regulation	good	better	good
12.	Transformer utilisation factor	0.286	0.693	0.812

Example 7.6. The load resistance of a centre-tapped full-wave rectifier is 500 Ω and the necessary voltage (end to end) is 60 sin (100 πt). Calculate (i) peak, average and rms values of current; (ii) ripple factor and (iii) efficiency of the rectifier. Each diode has an idealised I-V characteristics having slope corresponding to a resistance of 50 Ω.

[A.M.I.E. Sec B. Electronic Devices & Circuits Winter 1999]

Solution: Maximum value of supply voltage, $V_{S\,max} = 60$ V

Forward resistance, $R_F = 50\ \Omega$

Load resistance, $R_L = 500\ \Omega$

(i) Peak current, $$I_{max} = \frac{V_{S\,max}}{R_L + R_F} = \frac{60}{500 + 50} = 0.109 \text{ A} \quad \textbf{Ans.}$$

Average current, $$I_{dc} = \frac{2\,I_{max}}{\pi} = \frac{2 \times 0.109}{\pi} = 0.0695 \text{ A} \quad \textbf{Ans.}$$

RMS value of current, $$I_{rms} = \frac{I_{max}}{\sqrt{2}} = \frac{0.109}{\sqrt{2}} = 0.077 \text{ A} \quad \textbf{Ans.}$$

(ii) Ripple factor, $$r = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} = \sqrt{\left(\frac{0.077}{0.0695}\right)^2 - 1} = 0.482 \quad \textbf{Ans.}$$

(iii) Efficiency of rectifier, $$\eta = \frac{0.812}{1 + \frac{R_F}{R_L}} \times 100 = \frac{0.812 \times 100}{1 + \frac{50}{500}} = 73.82\% \quad \textbf{Ans.}$$

Example 7.7. A centre-tapped transformer has a 220 V primary winding and a secondary winding rated at 12-0-12 V and is used in a full-wave rectifier circuit with a load of 100 Ω. What is the dc output voltage, dc load current and the PIV rating required for diodes?

[A.M.I.E. Sec B. Electronic Devices & Circuits Winter 1994]

Solution: Peak value of supply voltage, $V_{S\,max} = 12\sqrt{2}$ V

Load resistance, $R_L = 100\ \Omega$

$$\text{DC load current, } I_{dc} = \frac{2}{\pi} I_{max} = \frac{2}{\pi} \frac{V_{S\,max}}{R_L} = \frac{2}{\pi} \times \frac{12\sqrt{2}}{100} = 108 \text{ m A}$$

$$\text{DC output voltage, } V_{dc} = I_{dc}\, R_L = 108 \times 10^{-3} \times 100 = 10.8 \text{ V } \textbf{Ans.}$$

$$\text{PIV rating of diodes} = 2\, V_{S\,max} = 2 \times 12\sqrt{2} = 33.94 \text{ V } \textbf{Ans.}$$

PHASE RECTIFIERS