Rectifier

The electric power is usually available in a.c supply. The supply voltage varies sinusoidal and has a frequency of 50Hz and used for different purposes such as lightning, heating and electric motors. But there are many applications such as electronics circuit where d.c supply is needed. When such a d.c supply is requiring, the mains a.c supply is rectified. Thus, rectifiers convert sinusoidal a.c to pulse d.c.

There are two types of rectifiers:

1. Half-wave rectifier
2. Full wave rectifier

Half Wave Rectifier

A half-wave rectifier is the simplest form of the rectifier and requires only one diode for the construction of a halfwave rectifier circuit.

A halfwave rectifier circuit consists of three main components as follows:

- A diode
- A transformer
- A resistive load

Half Wave Rectifier | Derivation

The half wave rectifier utilizes alternate half cycles of the input sinusoid. Figure 1 shows the circuit of a half-wave rectifier circuit. The a.c. voltage to be rectified is applied to the input of the transformer and the voltage v_i across the secondary is applied to the rectifier. The circuit consists of the series connection diode D and a resistor R. Assuming sinusoidal waveform, let the input voltage v_i be given by,

$v_i = V_m sin\omega t$ .....(1)

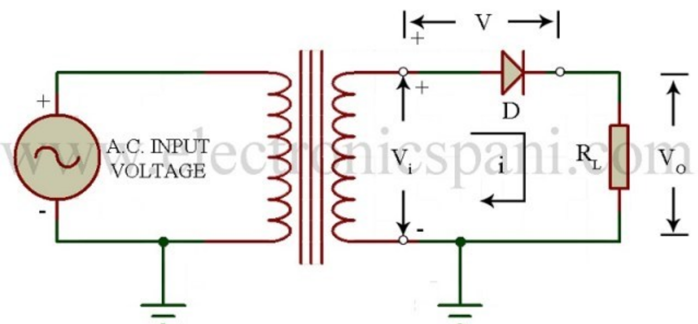


Figure 1: Half Wave Rectifier Circuit

Working of Half Wave Rectifier Circuit

Assume the diode to be ideal. During the positive half-cycle of the input sinusoid, the positive v_i will cause current to flow through the diode in its forward direction. It follows that that diode voltage V_v will be very small – ideally zero. Thus, the circuit will have output voltage V_O will be equal to the input voltage v_i. on the other hand, during the negative half-cycles of v_i, the diode will not conduct. Thus the circuit will have the equivalent and V_O will be zero. Thus, the output voltage will have the waveform shown in figure 2.

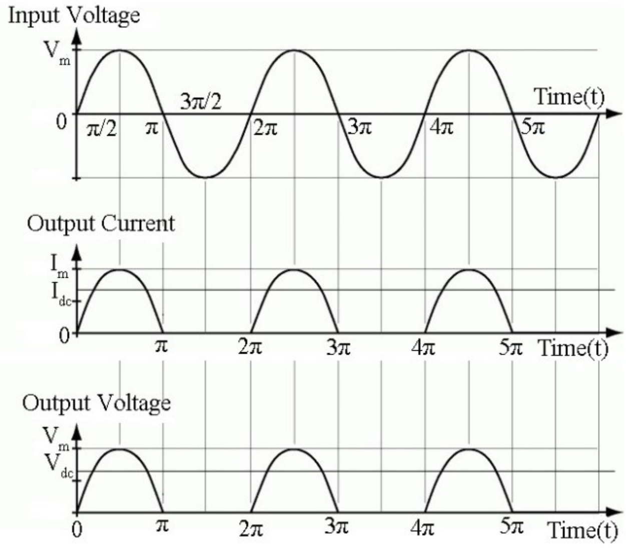


Figure 2: Waveform of Half Wave Rectifier

Let the amplitude V_m>> V_v where V_v is the cutin voltage for the pn diode. Hence, we may assume that $V_v = 0$. Further let the diode be idealized with resistance R_f in the ON state and open circuit ($R_r = \infty$) in the OFF state. Then the current i through the diode and the load resistance R_L is given by,

$i = I_m sin\alpha$ for $0 \leq \alpha \leq \pi$ …..(2)

$i = 0$ for $\pi \leq \alpha \leq 2\pi$ …..(3)

Where $\alpha = \omega t$

And the peak current I_m is given by

$$I_m = \frac{V_m}{R_f + R_L} \quad \text{….(4)}$$

Figure 2. shows the wave forms of voltage v_i fed to the diode, current I through the diode and the output voltage v_0. Current I flows through the diode and the load resistor R_L. only during the positive half of the applied input voltage v_i. this load current I flowing through the load resistor R_L produces the rectifier output voltage v_o.

Average or DC Current I_{dc} | Half Wave Rectifier

Average or DC output current of half wave rectifier is given by

$$I_{dc} = \frac{1}{\pi} \int_0^{2\pi} i d\alpha \quad .....(5)$$

Where i is given by equation (2) and (3). Current i = 0 i.e. no current flows during the period $\pi to 2\pi$ radians. Hence,

$$I_dC = \frac{1}{2\pi} \int_0^{\pi} I_m sin\alpha d\alpha \quad .....(6)$$

Or, $I_{dc} = \frac{I_m}{\pi}$

$$= \frac{V_m}{\pi(R_f + R_1)} \quad ......(7)$$

RMS Current | Half Wave Rectifier

The RMS current I is given by,

$$I = [\frac{1}{2\pi} \int_0^{2\pi} i^2 d\alpha]^{\frac{1}{2}} \quad .....(8)$$

Substituting the value of i from equation (2) and (3) into equation (4) we get,

$$I = [\frac{1}{2\pi} \int_0^{\pi} I_m^2 sin^2\alpha d\alpha]^{\frac{1}{2}}$$

$$= \frac{I_m}{2} \quad .....(9)$$

$$= \frac{V_m}{2(R_f + R_L)} \quad .....(10)$$

Average or DC Output Voltage (V_{dc}) | Half Wave Rectifier

Average or DC output voltage of half wave rectifier is given by

$$V_{dc} = I_{dc}R_L = \frac{I_m R_L}{\pi} \quad .....(11)$$

$$= \frac{V_m}{\pi(1 + \frac{R_f}{R_L})} \quad .....(12)$$

RMS Output Voltage (V_O) | Half Wave Rectifier

RMS value of voltage across the load resistor is given by

$$V_O = IR_L = \frac{I_m R_L}{2} = \frac{V_m}{2(1+\frac{R_f}{R_L})} \quad \text{.....(13)}$$

DC Output Power (P_{dc}) | Half Wave Rectifier

The output dc power across the load resistor R_L forms the useful output power and is given by,

$$P_{dc} = I_{dc}^2 R_L = \frac{I_m^2 R_L}{\pi^2} = \frac{V_m^2}{(R_f+R_L)^2}\frac{R_L}{\pi^2} \quad \text{.....(14)}$$

Total AC Input Power | Half Wave Rectifier

Out of the total a.c. power P_i from the a.c. voltage source, a part P_d is dissipated at the junction of diode and rest of the power P_r is dissipated in the load resistance R_L. Since the rectifier itself is assumed to be ideal, dissipated P_d takes place in the resistance R_f of the conducting diode. Then we get,

$$P_d = I^2 R_f = \frac{I_m^2}{4} R_f \quad \text{.....(15)}$$

$$P_r = I^2 R_L = \frac{I_m^2}{4} R_L \quad \text{.....(16)}$$

Total a.c. input power

$$P_i = P_d + P_r = \frac{I_m^2}{4}(R_f + R_L) \quad \text{.....(17)}$$

Rectifier Efficiency | Half Wave Rectifier

It is defined as the ratio of the dc output power P_{dc} to the a.c. input Power P_i and is, therefore, given by,

Rectifier Efficiency $\eta = \frac{P_{dc}}{P_i}$

$$= \frac{I_m^2 \frac{R_L}{\pi^2}}{I_m^2 \frac{(R_f + R_L)}{4}}$$

$$= (\frac{2}{\pi})^2 \frac{R_L}{R_f + R_L}$$

Or $\eta = \dfrac{0.406}{1 + \dfrac{R_f}{R_L}}$ ……(18)

% rectifier efficiency $= \dfrac{40.6}{1 + \dfrac{R_f}{R_L}}$ …..(19)

From equation (18) we conclude that the rectifier efficiency increases as the ratio $\frac{R_f}{R_L}$ reduces. Further from equation (19) we find that the theoretical maximum value of rectifier efficiency of a half wave rectifier is only 40.6% and this is obtained when $\frac{R_f}{R_L} = 0$.

Frequency Components in the Rectifier Output | Half Wave Rectifier

Analysis shows that current waveform of halfwave rectifier contains

1. dc components $I_{dc} = \frac{I_m}{\pi}$
2. ripple components
3. Component of fundamental frequency f of peak value $\frac{I_m}{2}$. This is the lowest frequency components.
4. Even harmonic components of frequencies 2f, 4f etc.

Harmonic components are found to have progressively diminishing amplitudes.

Ripple Factor | Half Wave Rectifier

(γ)

This is defined as ratio of the effective value of te a.c. components of voltage (or current) to the direct or average value.

The RMS value of the load current is given by,

$I = \sqrt{I_{dc}^2 + I_1^2 + I_2^2 + I_4^2 + ...} = \sqrt{I_{dc}^2 + I_{ac}^2}$ …..(20)

Where I_1, I_2, I_4 etc are the rms values of fundamental, second, fourth etc harmonics and I_{sc}^2 is the sum of the square of the rms values of the ac components.

Hence the ripple factor is,

$$\gamma = \frac{I_{ac}}{I_{dc}} = \frac{\sqrt{I^2 - I_{dc}^2}}{\sqrt{I_{dc}^2}}$$

$$= \sqrt{(\frac{I}{I_{dc}}) - 1} = \sqrt{F^2 - 1} \qquad .....(21)$$

Where F is the form factor.

For half wave rectifier, $I = \frac{I_m}{2} and I_{dc} = \frac{I_m}{\pi}$

Hence $F = \frac{\frac{I_m}{2}}{\frac{I_m}{\pi}} = \frac{\pi}{2} = 1.57$

Hence ripple factor $\gamma = \sqrt{(1.57)^2 - 1} = 1.21$

Peak Inverse Voltage (PIV) | Half Wave Rectifier

It is the maximum reverse voltage which the rectifier is required to withstand during nonconducting period. In half wave rectifier, PIV equals V_m, the peak value of applied voltage. However on using a capacitor filter, the PIV ration of the diode increases to 2 V_m.

Transformer Utilization Factor (TUF) | Half Wave Rectifier

It is defined as the ratio of dc power delivered to the load and ac rating of the transformer secondary winding.

i.e. $TUF = \frac{dc - power - delivered - the - load}{ac - rating - of - the - transformer - secondary}$ .....(22)

Hence, $TUF = \frac{P_{dc}}{P_{ac}(rating)} = \frac{(\frac{I_m}{\pi})^2 R_L}{(\frac{V_m}{\sqrt{2}})(\frac{I_m}{\sqrt{2}})}$ .....(23)

But, $V_m = I_m(R_f + R_L)$

Hence, $TUF = \frac{0.286 R_L}{R_f + R_L}$ .....(24)

If $R_L \gg R_f, TUF = 0.286$

Regulation | Half Wave Rectifier

By regulation is meant variation of output voltage with change in load current. Thus,

Percentage Regulation $= \frac{V_{nL} - V_L}{V_L} \times 100$ .....(25)

Where V_{nL} is the no-load output voltage i.e. voltage with zero load current, and V_L is the output voltage with normal load current.

For half wave rectifier, combining equation (7) and (13) we get,

$$V_{dc} = \frac{V_m R_L}{\pi(R_f + R_L)}$$

$$= \frac{V_m}{\pi}[1 - \frac{R_f}{R_f + R_L}] = \frac{V_m}{\pi} - I_{dc} \times R_f \quad .....(26)$$

Equation (26) indicate that the half wave rectifier functions as if it were a constant voltage source $V(= \frac{V_m}{\pi})$ in series with an internal resistance (output resistance) $R_0 = R_f$ as shown in figure 3. From this model, called Thevenin's model, we note that dc output voltage V_{dc} decreases linearly with the increase of dc output current I_{dc}.

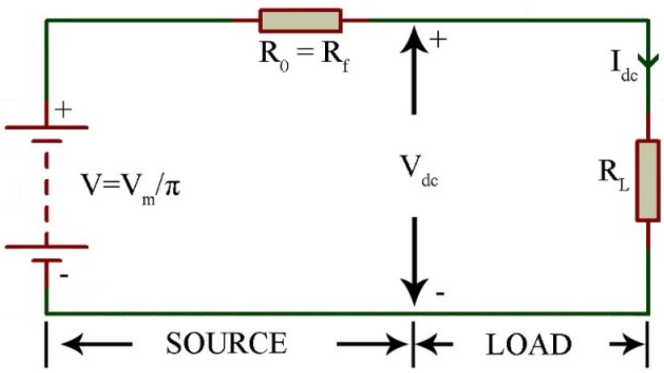


Figure 3: Thevenin's Model for a Half Wave Rectifier

Advantage of Halfwave rectifier

1. Simple Circuit
2. Low Cost

Disadvantage of Halfwave Rectifier

1. Low rectifier efficiency
2. High Ripple Factor
3. Low TUF
4. DC saturation of transformer core results in magnetising current and hysteresis losses and production of harmonics.

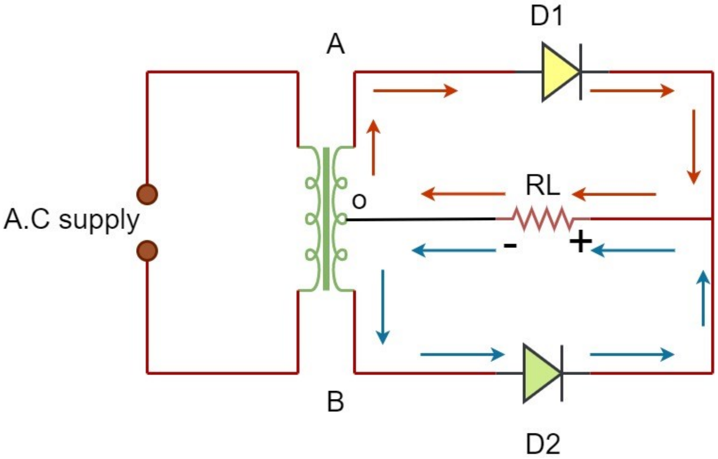
Full wave Rectifier

In full wave rectifier, for the positive half-cycle of input voltage, one diode supplies current to the load and for the negative half-cycle, the other diode does. The current always flows through the load in the same direction for both half-cycles of input a.c voltage. Therefore, a full-wave rectifier utilizes both half-cycles of input a.c voltage to produce the d.c output.

There are mainly two circuits used for full-wave rectification:

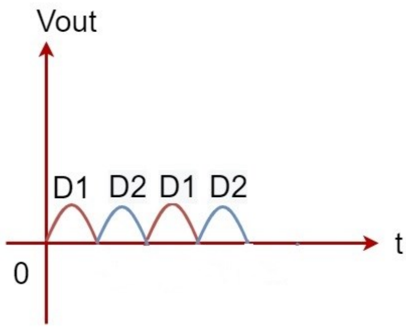
- **Centre-tap full-wave rectifier**
- **Full-wave bridge rectifier**

Centre-tap Full wave Rectifier



The centre-tap full-wave rectifier employs two diodes D1 and D2.A centre tapped secondary winding AB is used with two diodes connected so that each uses one half-cycles of input a.c voltage. Diode D1 utilizes the a.c voltage appearing across the upper half (OA) of secondary winding for rectification while diode D2 uses the lower half winding OB.

During Positive half-cycles of a.c supply, diode D1 is forward biased and diode D2 is reverse biased. During negative half-cycle, diode D2 is forward biased and diode D1 is reverse biased. The current in load RL is in the same direction for both half-cycles of input a.c voltage. Therefore, d.c is obtained across load RL.

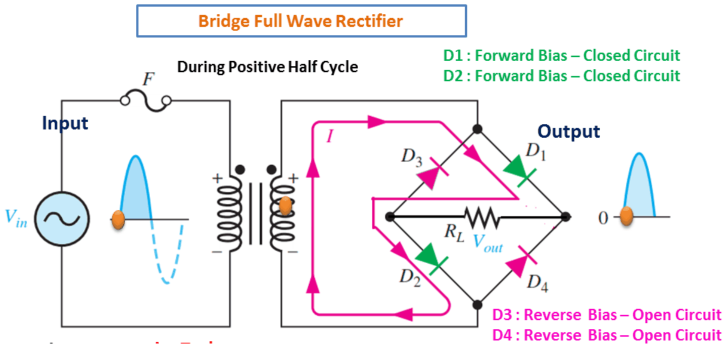


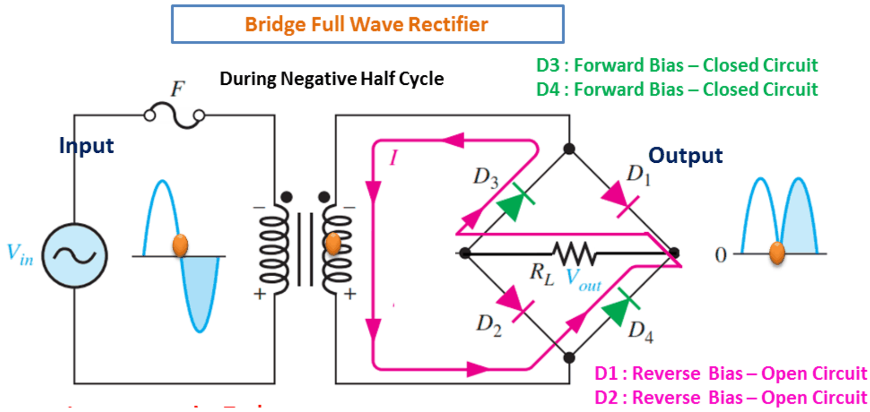
$$Peak\ inverse\ voltage, PIV = 2\ V_m$$

$where,$

V_m = maximum voltage across OA and OB of secondary

Full-wave Bridge Rectifier





Full-wave bridge rectifier contains four diodes D1, D2,D3 and D4 connected to form bridge. The a.c supply to be rectified is applied to the diagonally opposite ends of the bridge through the transformer. Between other ends of the bridge, the load resistance RL is connected.

(i) During positive half-cycle of input a.c voltage, diodes D1 and D2 are forward biased while diodes D3 and D4 are reverse biased. Therefore, positive half of a.c is conducted through load RL via diodes D1 and D2.

(ii) During negative half-cycle of input a.c voltage, diodes D3 and D4 are forward biased while diodes D1 and D2 are reverse biased. Therefore, negative half of a.c is conducted through load RL via diodes D3 and D4.

$$PIV\ of\ each\ diode = V_m = Max.voltage\ across\ secondary$$

Efficiency of Full-wave Rectifier

Suppose v=Vm sinθ be the alternating voltage that is to be rectified. Let rf and RL be the diode resistance and load resistance respectively. The rectifier will conduct current through the load in the same direction for both half-cycles of input a.c voltage. The instantaneous current i is given by:

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

(i)

$$I_{ac} = I_{dc} = 2I_m / \pi$$

(ii)

$$I_{ac} = I_{r.m.s} = {}^{I_m}\!\big/\!\sqrt{2}$$

(iii)

$$P_{dc} = I_{dc}^2 R_L = ({}^{2I_m}\!\big/\!{}_{\pi})^2 R_L$$

(iv)

$$P_{ac} = I_{r.m.s}^2 (r_f + R_L)$$
$$= ({}^{I_m}\!\big/\!\sqrt{2})^2 (r_f + R_L)$$

(v)

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

$$= \frac{(2I_m/\pi)^2 R_L}{(I_m/\sqrt{2})^2 (r_f + R_L)}$$

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

$$= \frac{0.812 R_L}{(r_f + R_L)}$$

$$= \frac{0.812}{1 + \frac{r_f}{R_L}}$$

The efficiency will be maximum when rf is negligible as compared to RL. Neglecting rf/RL, we have, **Maximum efficiency, η_{max}=81.2%**

Ripple Factor

The output of a rectifier consists of a d.c component and a.c component. The a.c component is undesirable and accounts for the pulsations in the rectifier output. The effectiveness of a rectifier depends upon the magnitude of a.c component in the output; the smaller this component, the more effective is the rectifier.

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

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

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

For full-wave rectification:

$$I_{r.m.s} = I_m / \sqrt{2}$$

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

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

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

In the output of a full-wave rectifier, the d.c component is more than the a.c component. The pulsations in the output will be less than in half-wave rectifier. Full-wave rectification is invariably used for conversion of a.c to d.c.

Comparison of Rectifiers

S.N	**Particular**	**Half-wave**	**Centre-tap**	**Bridge type**
1	**No. of diodes**	**1**	**2**	**4**
2	**Transformer necessary**	**No**	**Yes**	**No**
3	**Max. efficiency**	**40.6%**	**81.2%**	**81.2%**
4	**Ripple factor**	**1.21**	**0.48**	**0.48**
5	**Output frequency**	**fin**	**2fin**	**2fin**
6	**Peak inverse voltage**	**Vm**	**2Vm**	**Vm**