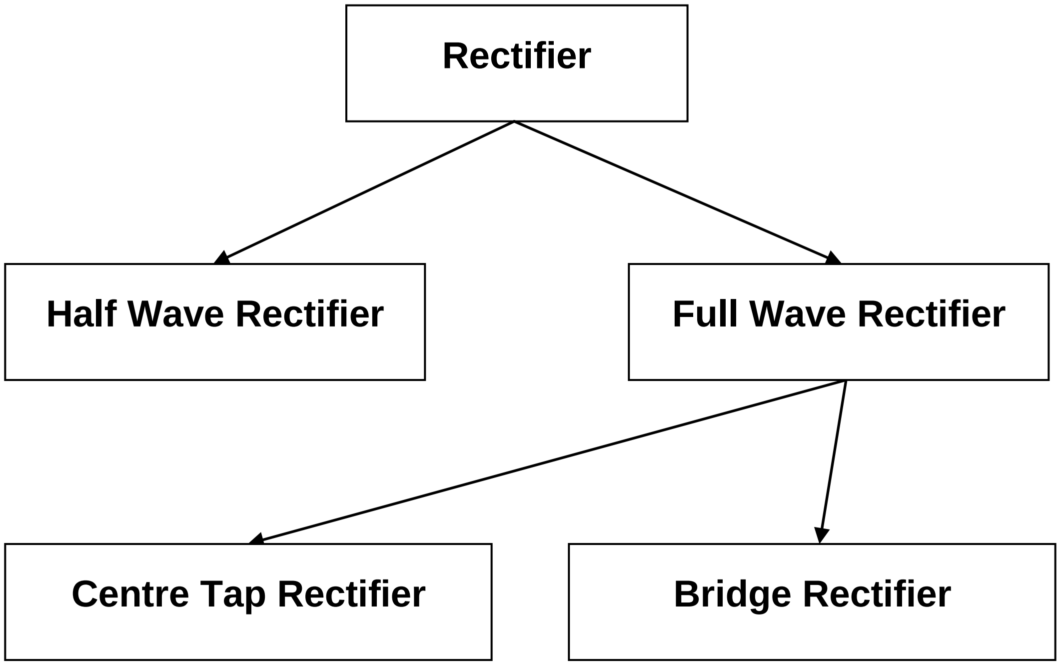
Rectifiers

A diode is used to pass current in a single direction. Alternating current is a current which flows in both directions. In some applications we need dc (direct current) power supply. A method to obtain dc supply is by using batteries. But it is not economical at all times. It is possible to obtain dc from ac supply .That process is known as rectification. Rectification is of two types:

1. Half wave rectification
2. Full wave rectification

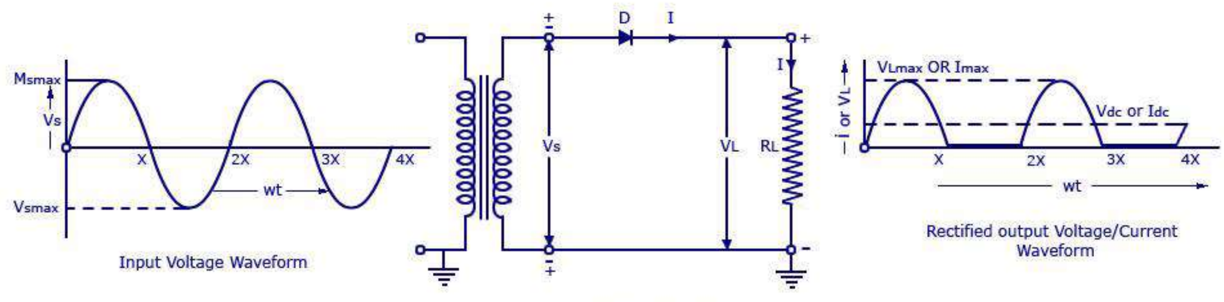
In a half wave rectifier only one half cycle of ac voltage is used. Unlike a half wave rectifier, a full wave rectifier conducts in both half cycles of ac voltage. A full wave rectifier can be implemented in two ways

1. Full wave centre tap rectifier
2. Full wave bridge rectifier



Half Wave Rectifier

The half rectifier consist a step down transformer, a diode connected to the transformer and a load resistance connected to the cathode end of the diode. The circuit diagram of half wave transformer is shown below:



Half-Wave Rectifier

The main supply voltage is given to the transformer which will increase or decrease the voltage and give to the diode. In most of the cases we will decrease the supply voltage by using the step down transformer here also the output of the step down transformer will be in AC. This decreased AC voltage is given to the diode which is connected serial to the secondary winding of the transformer, diode is electronic component which will allow only the forward bias current and will not allow the reverse bias current. From the diode we will get the pulsating DC and give to the load resistance R_L.

Working of Half Wave Rectifier

The input given to the rectifier will have both positive and negative cycles. The half rectifier will allow only the positive half cycles and omit the negative half cycles. So first we will see how half wave rectifier works in the positive half cycles.

Positive Half Cycle

- In the positive half cycles when the input AC power is given to the primary winding of the step down transformer, we will get the decreased voltage at the secondary winding which is given to the diode.

- The diode will allow current flowing in clock wise direction from anode to cathode in the forward bias (diode conduction will take place in forward bias) which will generate only the positive half cycle of the AC.
- The diode will eliminate the variations in the supply and give the pulsating DC voltage to the load resistance R_L. We can get the pulsating DC at the Load resistance.

Negative Half Cycle

- In the negative half cycle diode will go in to the reverse bias. In the reverse bias the diode will not conduct so, no current flow through diode from anode to cathode, and we cannot get any power at the load resistance.

Half Wave Rectifier Circuit Analysis

1. Peak Inverse Voltage (PIV)

Peak Inverse Voltage (PIV) rating of a diode is important in its design stages. It is the maximum voltage that the rectifying diode has to withstand, during the reverse biased period.

When the diode is reverse biased, during the negative half cycle, there will be no current flow through the load resistor R_L. Hence, there will be no voltage drop through the load resistance R_L which causes the entire input voltage to appear across the diode. Thus V_{SMAX}, the peak secondary voltage, appears across the diode. Therefore,

$$PIV = V_{Smax}$$

2. Average and Peak Currents in the diode

By assuming that the voltage across the transformer secondary be sinusoidal of peak values V_{SMAX}, instantaneous value of the voltage given to the rectifier can be written as

$$V_S = V_{Smax} \sin \omega t$$

For Instantaneous value of voltage applied to Half Wave Rectifier, assuming that the diode has a forward resistance of R_F ohms and infinite reverse resistance value, the current flowing through the output load resistance R_L is

$$i = I_{max} \sin \omega t \qquad for\ 0 \leq \omega t \leq \pi$$

$$i = 0 \qquad for\ \pi \leq \omega t \leq 2\pi$$

Maximum current flowing through the diode

$$I_{max} = \frac{V_{Smax}}{(R_F + R_L)}$$

3. DC Output Current

The dc output current is given as

$$I_{dc} = \frac{1}{2\pi} \int_0^{2\pi} i\ d(\omega t)$$

$$I_{dc} = \frac{1}{2\pi} \left[\int_0^{\pi} i\ d(\omega t) + \int_{\pi}^{2\pi} i\ d(\omega t) \right]$$

$$I_{dc} = \frac{1}{2\pi} \left[\int_0^{\pi} i\ d(\omega t) + 0 \right]$$

$$I_{dc} = \frac{1}{2\pi} \int_0^{\pi} I_{max} \sin \omega t\ \ d(\omega t)$$

$$I_{dc} = \frac{I_{max}}{2\pi} \int_0^{\pi} \sin \omega t\ \ d(\omega t)$$

$$I_{dc} = \frac{I_{max}}{2\pi} [-\cos(\omega t)]_0^{\pi}$$

$$I_{dc} = \frac{I_{max}}{2\pi} [-(\cos \pi - \cos 0)]$$

$$I_{dc} = \frac{I_{max}}{2\pi} [-(-1 - 1)]$$

$$I_{dc} = \frac{I_{max}}{2\pi} [2]$$

$$I_{dc} = \frac{I_{max}}{\pi}$$

$$I_{dc} = 0.318 I_{max}$$

Substituting the value of I_{MAX} for the equation $I_{MAX} = V_{SMAX}/(R_F + R_L)$, we have

$$I_{dc} = \frac{V_{Smax}}{(R_F + R_L)\pi}$$

if $R_L >> R_F$ $$I_{dc} = \frac{V_{Smax}}{\pi R_L}$$

4. DC Output Voltage

Dc value of voltage across the load is given by

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

$$V_{dc} = \frac{V_{Smax}}{(R_F + R_L)\pi} R_L$$

$$V_{dc} = \frac{V_{Smax}}{R_L\left(\frac{R_F}{R_L} + 1\right)\pi} R_L$$

$$V_{dc} = \frac{V_{Smax}}{\left(\frac{R_F}{R_L} + 1\right)\pi}$$

if $R_L >> R_F$

$$V_{dc} = \frac{V_{Smax}}{\pi}$$

5. Root Mean Square (RMS) Value of Current

RMS value of current flowing through the diode is given as

$$I_{rms} = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} i^2 \, d(\omega t)}$$

$$I_{rms} = \sqrt{\frac{1}{2\pi} \left[\int_0^{\pi} i^2 \, d(\omega t) + \int_{\pi}^{2\pi} i^2 \, d(\omega t)\right]}$$

$$I_{rms} = \sqrt{\frac{1}{2\pi} \left[\int_0^{\pi} i^2 \, d(\omega t) + 0\right]}$$

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

$$I_{rms} = \sqrt{\frac{I_{max}^2}{2\pi} \int_0^{\pi} \sin^2 \omega t \, d(\omega t)}$$

$$I_{rms} = \sqrt{\frac{I_{max}^2}{2\pi} \int_0^{\pi} \left(\frac{1-\cos 2\omega t}{2}\right) d(\omega t)}$$

$$I_{rms} = \sqrt{\frac{I_{max}^2}{4\pi} \left[\int_0^{\pi} 1\, d(\omega t) - \int_0^{\pi} \cos 2\omega t\ d(\omega t)\right]}$$

$$I_{rms} = \sqrt{\frac{I_{max}^2}{4\pi} [\pi - 0]}$$

$$I_{rms} = \sqrt{\left(\frac{I_{max}}{2}\right)^2}$$

$$I_{rms} = \frac{I_{max}}{2}$$

Substituting the value of I_{max}

$$I_{rms} = \frac{V_{Smax}}{2(R_F + R_L)}$$

6. Root Mean Square (RMS) Value of Output Voltage

RMS value of voltage across the load is given as

$$V_{Lrms} = I_{rms} R_L$$

$$V_{Lrms} = \frac{V_{Smax}}{2(R_F + R_L)} R_L$$

$$V_{Lrms} = \frac{V_{Smax}}{2\left(\frac{R_F}{R_L} + 1\right) R_L} R_L$$

if $R_L >> R_F$

$$V_{Lrms} = \frac{V_{Smax}}{2}$$

7. Rectification Efficiency

Rectification efficiency is defined as the ratio between the output power to the ac input power.

$$\eta = \frac{\text{DC power delivered to the load}}{\text{AC input power from the transformer}} = \frac{P_{dc}}{P_{ac}}$$

DC power delivered to the load,

$$P_{dc} = I_{dc}^2 R_L$$

$$P_{dc} = \left[\frac{I_{max}}{\pi}\right]^2 R_L$$

AC power input to the transformer,

P_{ac} = Power dissipated in diode junction + Power dissipated in load resistance (R_L)

$$P_{ac} = I_{rms}^2 R_F + I_{rms}^2 R_L$$

$$P_{ac} = \left(\frac{I_{max}}{2}\right)^2 R_F + \left(\frac{I_{max}}{2}\right)^2 R_L$$

$$P_{ac} = \frac{I_{max}^2}{4}(R_F + R_L)$$

So, Rectification Efficiency,

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

$$\eta = \frac{\frac{I_{max}^2}{\pi^2} R_L}{\frac{I_{max}^2}{4}(R_F + R_L)}$$

$$\eta = \frac{4}{\pi^2} \frac{R_L}{(R_F + R_L)}$$

$$\eta = \frac{0.406}{\left(1 + \frac{R_F}{R_L}\right)}$$

if $R_L >> R_F$

$$\eta = 0.406$$

$$\eta = 40.6\%$$

The maximum efficiency that can be obtained by the half wave rectifier is 40.6%. This is obtained if R_F is neglected.

8. Ripple Factor

Ripple factor is a measure of the remaining alternating components in a filtered rectifier output. It is the ratio of the effective value of the ac components of voltage (or current) present in the output from the rectifier to the dc component in output voltage (or current).

The effective value of the load current is given as

$$I^2 = I_{dc}^2 + I_1^2 + I_2^2 + I_4^2 + \cdots = I_{dc}^2 + I_{ac}^2$$

Where, I_1,I_2, I_4 and so on are the rms values of fundamental, second, fourth and so on harmonics and I^2_{ac} is the sum of the squares if the rms values of the ac components.

So, ripple factor,

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

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

$$\gamma = \sqrt{K_f^2 - 1}$$

Where K_f is the form factor of the input voltage. For half wave rectifier, form factor is given as

$$K_f = \frac{I_{rms}}{I_{dc}} = \frac{I_{max}/2}{I_{max}/\pi} = \frac{\pi}{2} = 1.57$$

So, ripple factor,

$$\gamma = \sqrt{K_f^2 - 1} = \sqrt{1.57^2 - 1} = 1.21$$

$$\gamma = 1.21$$

Disadvantages of Half wave rectifier

1. The output current in the load contains, in addition to dc component, ac components of basic frequency equal to that of the input voltage frequency. Ripple factor is high and an elaborate filtering is, therefore, required to give steady dc output.

2. The power output and, therefore, rectification efficiency is quite low. This is due to the fact that power is delivered only during one half cycle of the input alternating voltage.

3. Transformer utilization factor is low.

4. DC saturation of transformer core resulting in magnetizing current and hysteresis losses and generation of harmonics.