# Application of Diode: Rectifiers

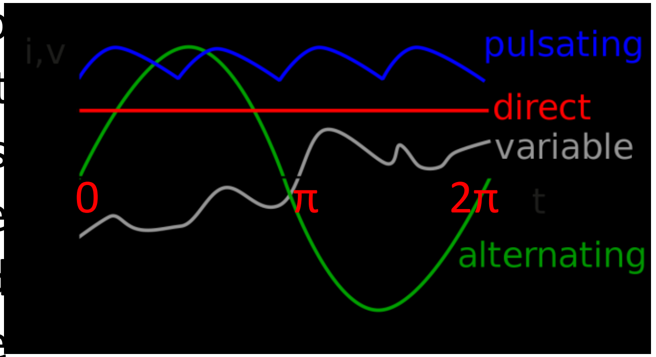
BPT: 401: Electronics and Modern Physics

Tutorial - 6

*Banaras Hindu University 14/04/2021* *Sterlin*

# Rectification

**Rectification** is the process of conversion of an alternating current (AC) or voltage to direct current (DC) or voltage. This involves a device having low resistance to current in one direction and a relatively high resistance to current in the reverse direction. As we have seen, that a semiconductor diode has this feature (low forward resistance and high reverse resistance). Such diodes can be used as rectifiers. The simplest kind of rectifier circuit is the half-wave rectifier with single diode. It only allows only one half cycle of an AC waveform to pass through to the load.




# Rectifier

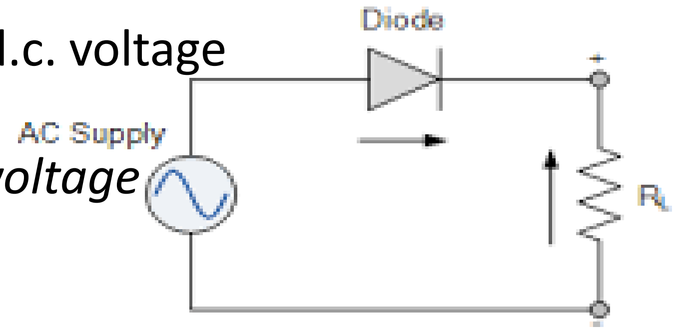
A circuit that converts a.c. voltage of main supply into pulsating d.c. voltage (unidirectional) using one or more PN junction diodes.

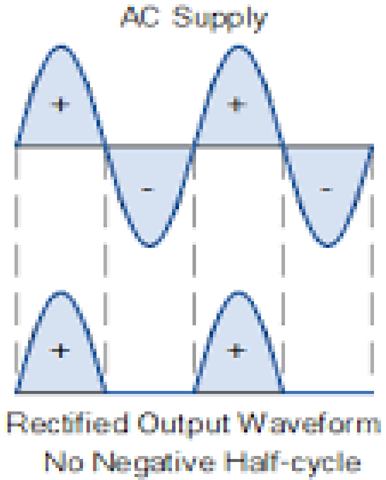
*(i)* *Half Wave Rectifier – Rectifies only one half cycle of the AC voltage*

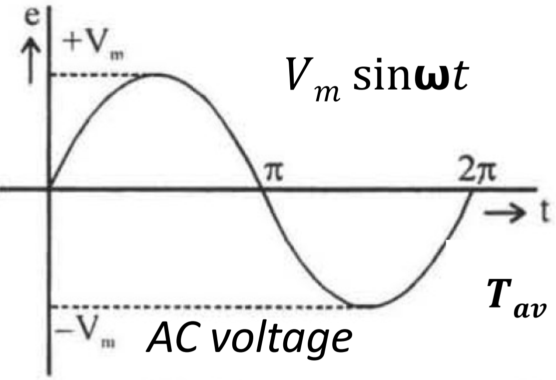
*(ii)* *Full Wave Rectifier – Rectifies full cycle of AC voltage*

*Center tap Rectifier*

*Bridge Rectifier*

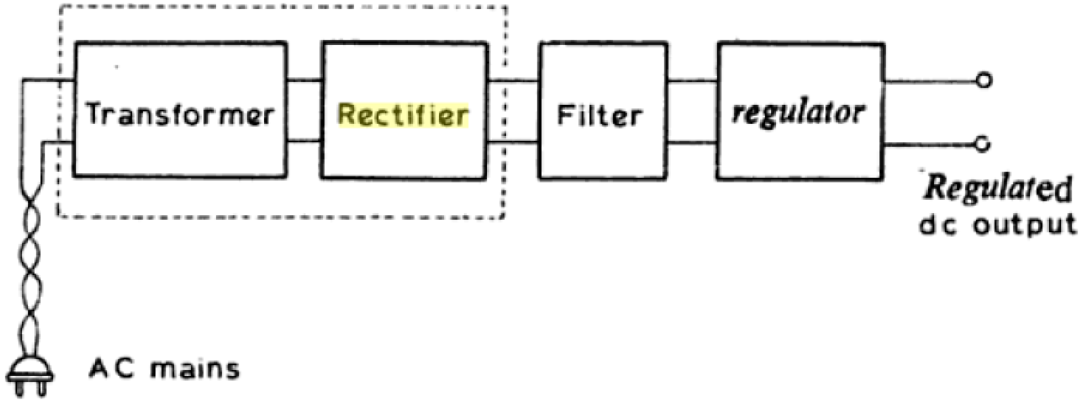


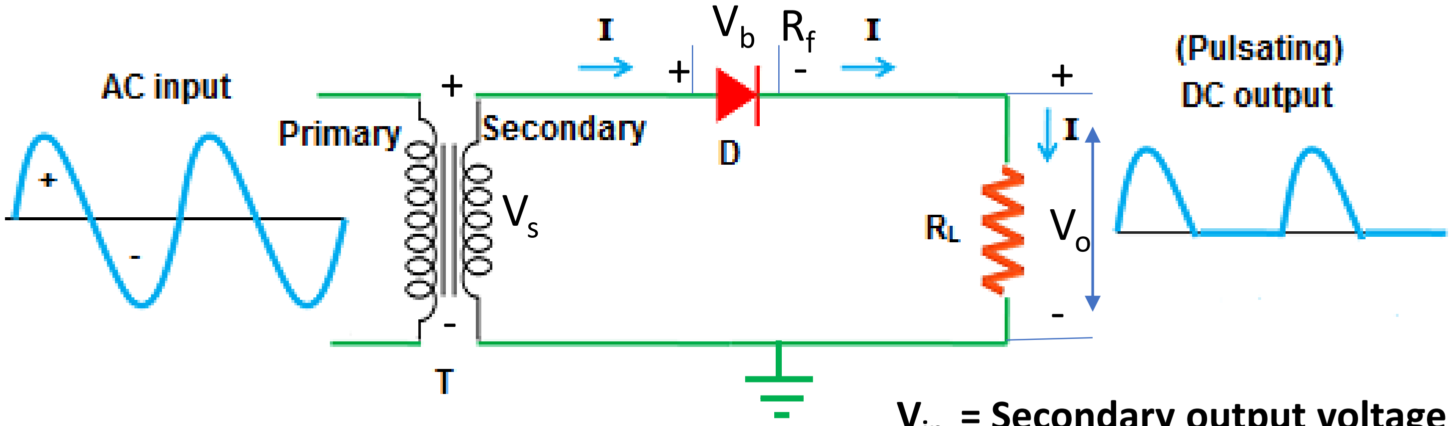

$$T_{av} = \frac{1}{2\pi}\int_0^{2\pi} V_m \sin\omega t$$

**Block Diagram of DC Power Supply**




# Half Wave Rectifier

- We know that a diode allows electric current in one direction and blocks electric current in another direction. This principle is used in rectifier circuit.
- A Half Wave Rectifier rectifies or converts only the positive half cycle of the input AC signal into pulsating DC (Direct Current) output signal.
- In other words, only one half cycle of the input AC signal is rectified by the half wave rectifier. The other half cycle of the input AC signal is blocked or we get zero output voltage.




I = Current
D = Diode
$R_L$ = Load resistor
T = Transformer
\+ = Positive half cycle
\- = Negative half cycle

Half wave rectifier

$V_{in}$ = Secondary output voltage of transformer
$V_b$ = Barrier voltage (0.7 V for Si)
$R_f$ = Diode forward bias resistance
$V_O$ = Output voltage across $R_L$

$V_{in} - V_b - V_O = 0$

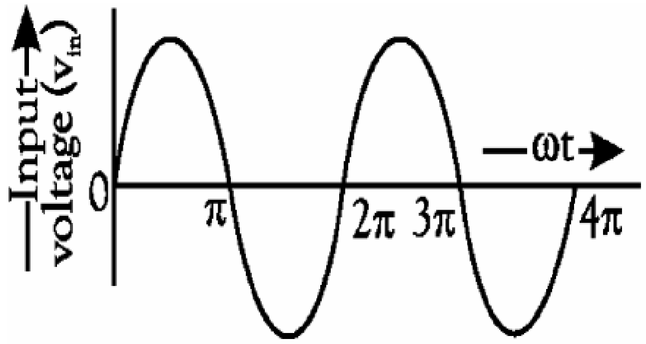
$V_O = V_{in} - V_b$ (for $0 \leq \omega t \leq \pi$)

$V_O = 0$ (for $\pi \leq \omega t \leq 2\pi$)

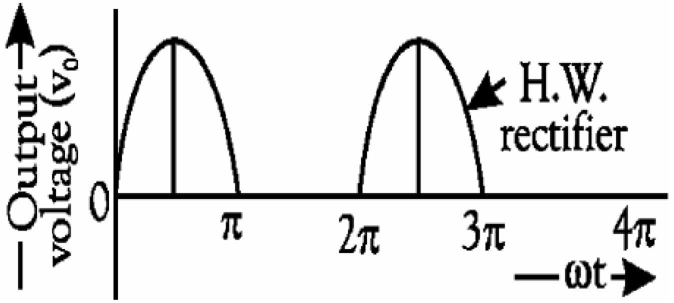
$V_O = V_{in} - V_b$

$$IR_L = V_{in} - IR_f$$

$$I = \frac{V_{in}}{R_L + R_f}$$




*Input AC Voltage*




*Half Rectified Pulsating Output Voltage*

# Half Wave Rectifier

## Working

The working of a half-wave rectifier circuit may be studied by considering the positive and negative half cycles of the a.c. input voltage separately.

(i) During the positive half cycle of the a.c. input voltage, the diode is forward biased and conducts for all instantaneous voltages greater than the offset voltage (0.7 V for silicon and 0.3 V for germanium diodes). However, for all practical purposes, we assume that the diode is forward biased, whenever the a.c. input voltage goes above zero. While conducting, the diode acts as a short-circuit, so that the circuit current flows and produces a voltage across the load resistor ($R_L$). The voltage produced across the load resistor has the same shape as that of the positive input half cycle of a.c. input voltage.

(ii) During the negative half-cycle of the a.c. input voltage, the diode is reverse biased and hence it does not conduct. Thus there is no current flow or voltage drop across load resistor $R_L$ i.e., $I_D= 0$ and $V_O = 0$. The net result is that only the positive half cycle of the a.c. input voltage appears across $R_L$. It means that only the positive half cycle of the a.c. input voltage is utilized for delivering a.c. power. It is evident that the output voltage ($V_O$) is not a steady d.c. but it is a pulsating d.c. wave having a ripple frequency equal to the input voltage frequency.

# Half Wave Rectifier – Device Parameter

## (i) Average Values of Output Voltage and Load Current:

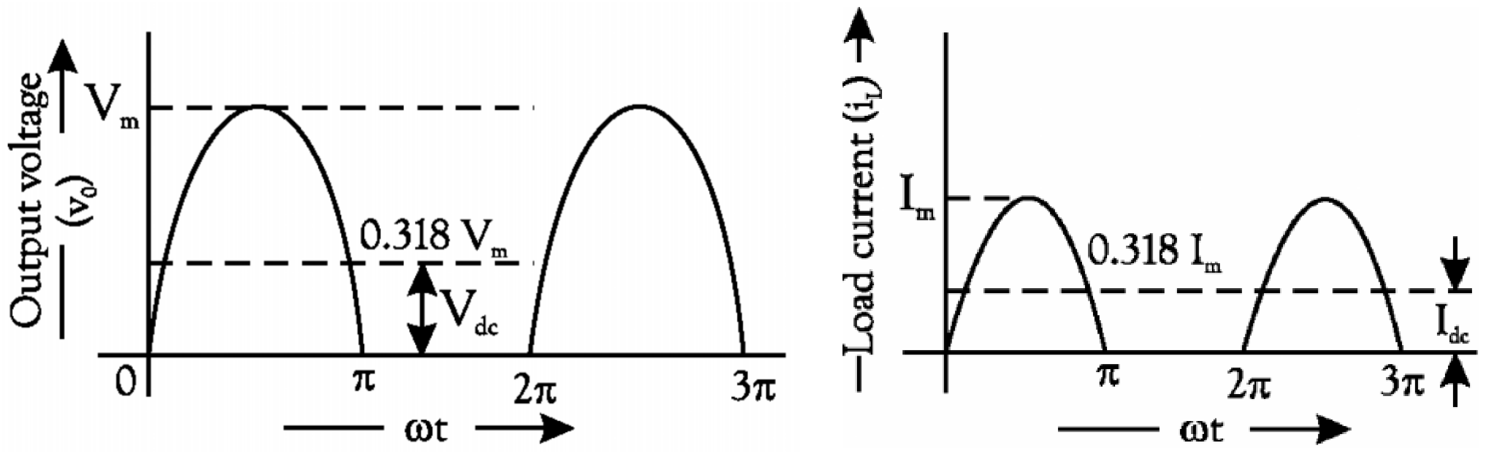
The instantaneous value of the sinusoidal a.c. input voltage is given by the relation, $v = V_m \sin \omega t = V_m \sin\theta$

Let,

$I_m$ & $V_m$= Maximum value of diode current or load current and maximum load voltage respectively. It is the current and voltage through the resistor $R_L$.

$V_{dc}$ = Average or d.c. value of output (or load) voltage across the load resistor, and

$I_{dc}$ = Average or d.c. value of load current.




***Average values of output voltage and load current in a half-wave rectifier***

The average or d.c. value of the output voltage is given by the relation,

$$V_{dc} = \frac{\text{Area under the curve over the full cycle}}{\text{Base}} = \frac{\int_0^{2\pi} V_m \sin\theta \, d\theta}{2\pi - 0} = \frac{\int_0^{\pi} V_m \sin\theta \, d\theta}{2\pi} + \frac{\int_\pi^{2\pi} V_m \sin\theta \, d\theta}{2\pi}$$

zero

$$= \frac{V_m}{2\pi}\left|\left(-\cos\theta\right)_0^{\pi}\right| = \frac{V_m}{2\pi}\left(+1-(-1)\right)$$

We know, $\int \sin\theta \, d\theta = -\cos\theta$ Here, $\theta = \omega t$

$$V_{dc} \boxed{= \frac{V_m}{\pi} = 0.318\, V_m}$$

And

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

# Half Wave Rectifier – Device Parameter

## (ii) Root Mean Square (RMS) Value of Output Voltage and Load Current:

zero

RMS = Square root of mean square

Therefore, $V_{RMS} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} V^2{}_m \sin^2\theta \, d\theta} = \sqrt{\frac{V^2{}_m}{2\pi}\int_0^{\pi} \sin^2\theta \, d\theta} + \sqrt{\frac{V^2{}_m}{2\pi}\int_\pi^{2\pi} \sin^2\theta \, d\theta}$

We know,
$cos2\theta = 1 - 2sin^2\theta$
$sin^2\theta = \frac{1}{2}(1 - cos2\theta)$

$$V_{RMS} = \sqrt{\frac{V^2{}_m}{4\pi}\int_0^{\pi}(1 - cos2\theta)d\theta}$$

$$V_{RMS} = \sqrt{\frac{V^2{}_m}{4\pi}\left[\theta - \frac{sin2\theta}{2}\right]_0^{\pi}} = \sqrt{\frac{V^2{}_m}{4\pi}\pi}$$

$$\boxed{V_{RMS} = \frac{V_m}{2}}$$

Similarly,

$$\boxed{I_{RMS} = \frac{V_m}{2R_L} = \frac{I_m}{2}}$$

# Half Wave Rectifier – Device Parameter

## (iii) Form Factor (F)

It is the ratio of rms value of maximum load current to average value of maximum load current.

$\boxed{F = (\text{rms value of } I_m)/(\text{average value of } I_m)} = 0.5\ I_m\ /\ 0.318\ I_m = \boxed{1.57}$

## (iv) Peak Inverse Voltage (PIV)

It is the maximum voltage across the diode in the reverse direction. Its value in present case is $\boxed{V_m.}$

## (v) Rectification Efficiency (η)

It is the ratio of output power to total input power supplied to the circuit.

$$\boxed{\eta = P_{out}/P_{in}}$$

Here, $P_{out} = I_{dc}^{\ 2}.R_L$; $P_{in} = I_{rms}^{\ 2}\ (R_d + R_L)$ where $R_d$ is forward resistance of the diode.

Then $\eta\ \% = [(I_{dc}^{\ 2}.R_L)\ /\ I_{rms}^{\ 2}\ (R_d + R_L)]\ \times 100$

$I_{dc} = 0.318\ I_m$ $I_{rms} = 0.5\ I_m$

By neglecting $r_d$, $\boxed{\eta = 40.6\ \%}$

Hence, the maximum possible efficiency of half-wave rectifier is 40.6 %.

# Half Wave Rectifier – Device Parameter

## (vi) Ripple Factor (γ)

**Ratio of a.c component in the d.c. output**

It is the ratio of voltage (or ripple current) in output to d.c. voltage component in output (or current) and denoted by γ

Thus $\gamma = V_r(\text{rms}) / V_{dc} = I_{r(\text{rms})} / I_{dc}$

By simplifying the value of $I_{r(\text{rms})}$ in terms of $I_{\text{rms}}$ we can write

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

or

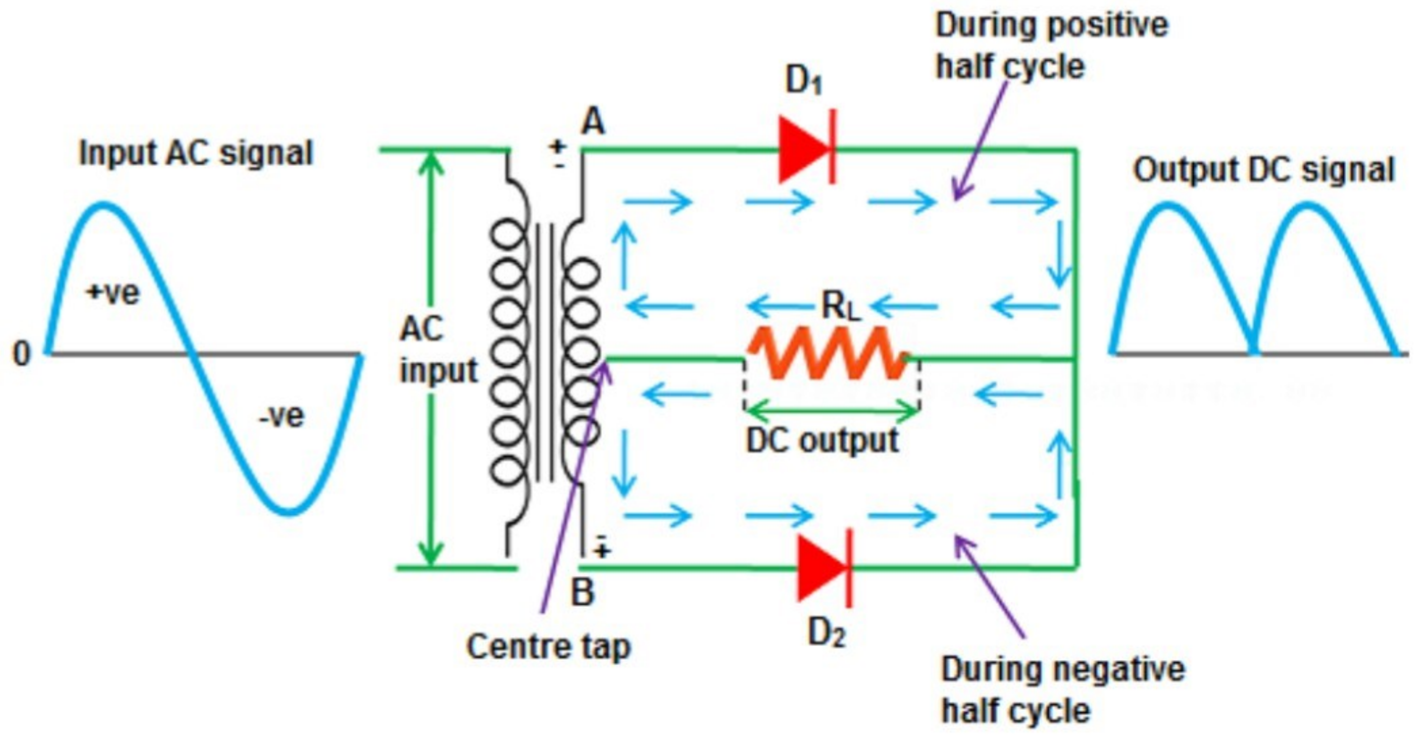
$$\gamma = \sqrt{\left(\frac{I_m / 2}{I_m / \pi}\right)^2 - 1} = 1.21$$

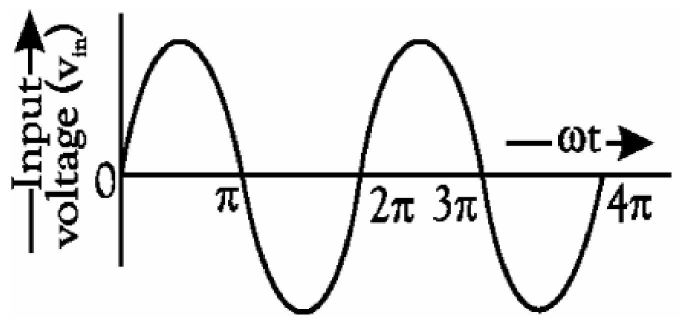
Thus the ripple factor of half-wave rectifier is $\boxed{1.21}$

# Full Wave Rectifier

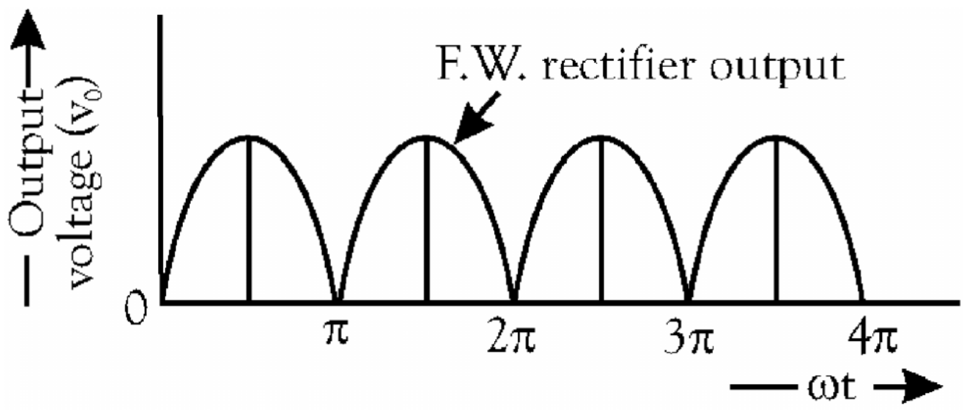
- ❖ A Full Wave Rectifier rectifies or converts both the positive and negative half cycle of the input AC signal into unidirectional pulsating DC output signal.
- ❖ It is of two types (i) Center Tapped Rectifier and (ii) Bridge Rectifier

# Center Tapped  Full Wave Rectifier



*Input AC Voltage*

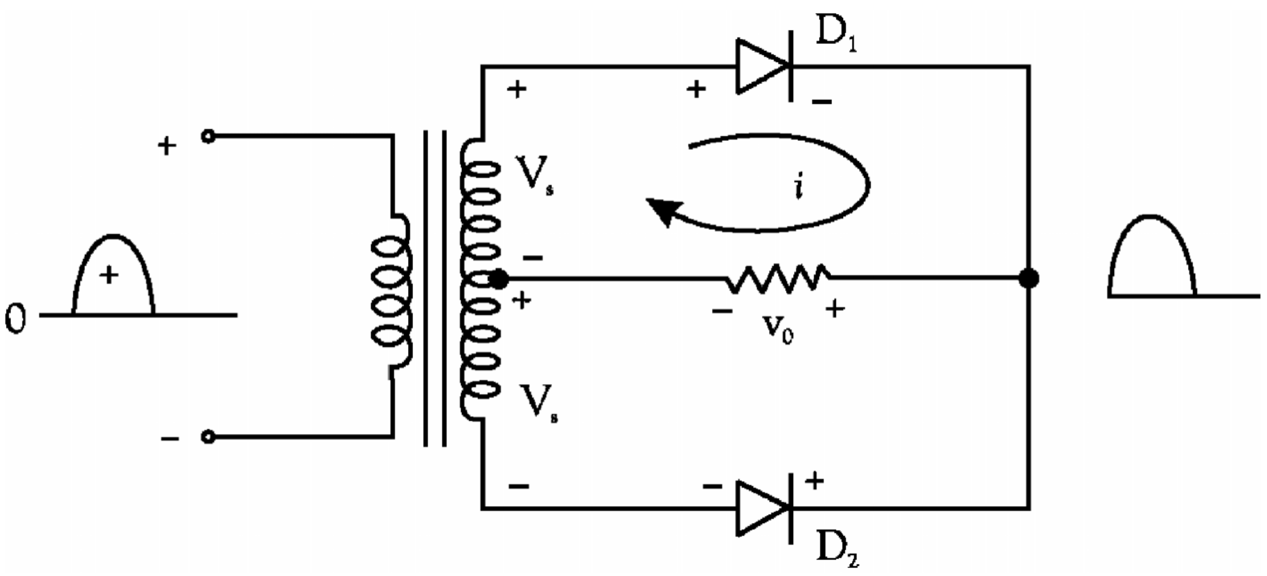


*Rectified Pulsating Output Voltage*

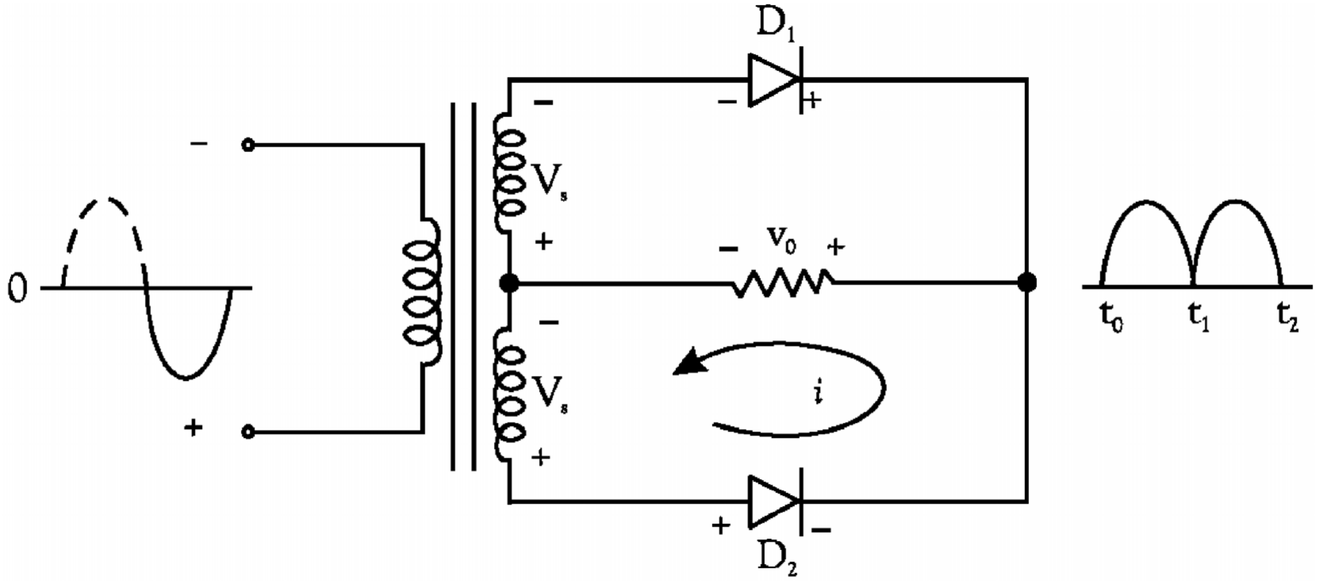
# Full Wave Rectifier

## Working

**(i)** During the positive input half-cycle, it forward biases the diode $D_1$ and reverse-biases the diode $D_2$. As a result of this, the diode $D_1$ conduct some current whereas the diode $D_2$ is OFF. The current through load $R_L$ is indicated as arrow in the figure.




**(ii)** During the negative input half-cycle, it reverse-biases the diode $D_1$ and forward-biases the diode, $D_2$. As a result of this, the diode $D_1$ is OFF and the diode $D_2$ conducts some current. The current through the load $R_L$ is indicated as arrow in the figure.



# Full Wave Rectifier– Device Parameter

## (i) Average Values of Output Voltage and Load Current:

We know that the equation for the voltage across each half of the secondary winding,

$V_S = V_m \sin \omega t = V_m \sin \theta$

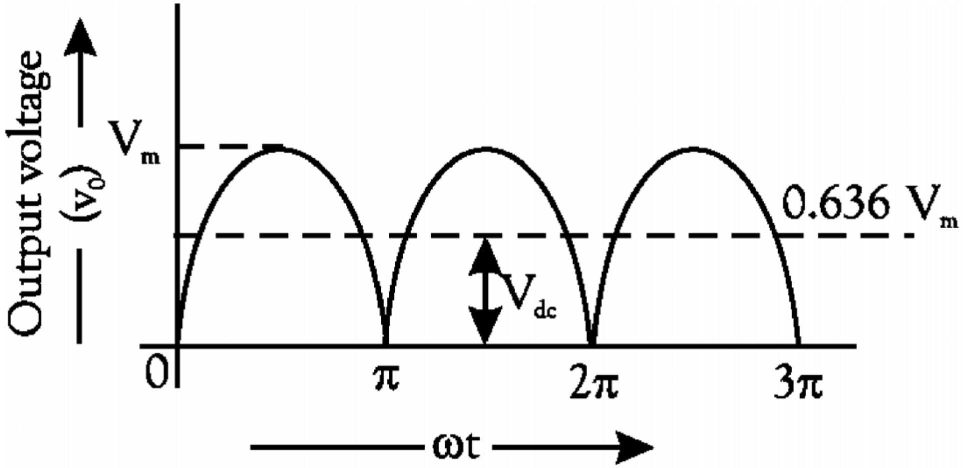
where $V_S$ = Instantaneous value of the voltage across each half of the secondary winding.

We also know that the average or d.c. value of the output voltage,

$V_{dc}$ = (Area under the curve over a half-cycle) / base

$$= \frac{\int_0^\pi v_s \, . d\theta}{\pi} = \frac{\int_0^\pi V_m \sin \theta \, d\theta}{\pi} = \frac{1}{\pi} \int_0^\pi V_m . \sin \theta \, d\theta$$

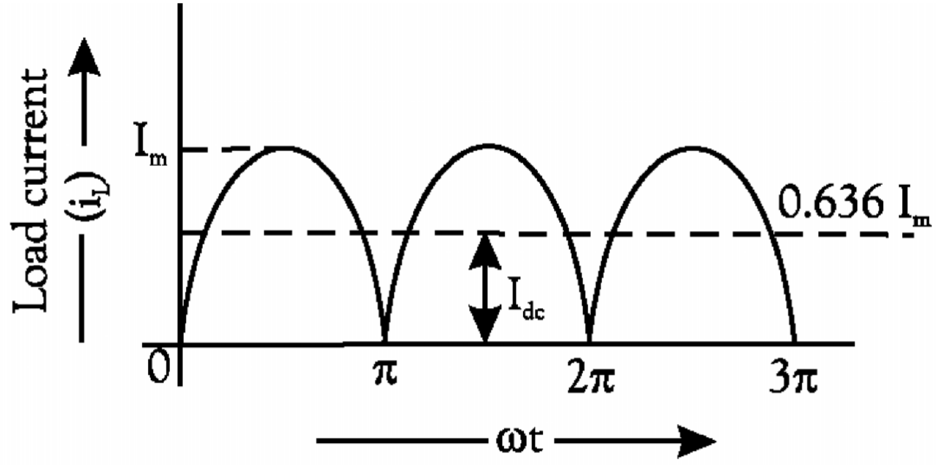
$$V_{dc} = \frac{V_m}{\pi} \left|(-\cos \theta)\right|_0^\pi = \frac{V_m}{\pi} \left[+1 - (-1)\right] = \frac{2 V_m}{\pi} = 0.636 \, V_m$$




***From the above relation it is noted that the average value of a full-wave rectifier is 0.636. This value is twice that of a half-wave rectifier.***

The average or d.c. value of load current is given by,

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{2 V_m}{\pi . R_L} = \frac{2 I_m}{\pi} = 0.636 \, I_m$$



# Full Wave Rectifier– Device Parameter

### (ii) Peak Inverse Voltage of a Diode

The anode voltage of the diode $D_1$ is + $V_m$ (where $V_m$ is the maximum half secondary voltage) and the anode voltage of $D_2$ is $-V_m$. Since $D_1$ is forward biased, its cathode is at the same voltage as its anode (neglecting barrier potential) i.e., + $V_m$. This is also the voltage on the cathode of the diode $D_2$. The total reverse voltage across the diode $D_2$ is : $= V_m - (-V_m) = 2V_m$. Therefore, Peak–inverse voltage of each diode in a center-tapped full-wave rectifier,

$$PIV = 2\,V_m$$

# Full Wave Rectifier– Device Parameter

**(iii) Efficiency**

We know that the efficiency of rectifier $\eta = P_{out}/P_{in}$

Here $P_{out} = I_{dc}^2 . R_L$; $P_{in} = I_{rms}^2 (R_d + R_L)$

$$\eta = \frac{I_{dc}^2 \times R_L}{I_{rms}^2 (R_d + R_L)}$$

where $R_d$ is the forward resistance of diode.

$$\eta = \frac{\left(\frac{2 I_m}{\pi}\right)^2 \times R_L}{\left(\frac{I_m}{\sqrt{2}}\right)^2 \times (R_d + R_L)} = \frac{8}{\pi^2} \times \frac{R_L}{R_d + R_L} = \frac{0.812}{1 + \frac{R_d}{R_L}}$$

Efficiency will be maximum if $R_L >> R_d$. Thus $\eta_{max} = 0.812$ or 81.2%

From the above, it is evident that maximum efficiency of a full-wave rectifier is twice that of half-wave rectifier.

# Full Wave Rectifier– Device Parameter

## (iv) Ripple factor

The average value of load current in a full-wave rectifier is given by the relation, $I_{dc} = 2I_{rms} / \pi$

The r.m.s. value of the load current is given by : $I_{rms} = I_m / \sqrt{2}$

Then the expression for ripple factor $\gamma$ is

$$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} = \sqrt{\left(\frac{I_m / \sqrt{2}}{2I_m / \pi}\right)^2 - 1} = 0.482$$

From the above result it is evident that ripple factor of a full-wave rectifier is 0.482 and is much smaller than that of a half-wave rectifier. Because of this reason, full-wave rectifier is used more commonly in actual practice.

# Advantages and Disadvantages of Center-tapped Full-wave Rectifier

## Advantages

- The d.c. output voltage and load current values are twice than those of a half-wave rectifier.
- The ripple factor is much less (0.482) than that of half-wave rectifier.
- The efficiency is twice that of half-wave rectifier. For a full-wave rectifier, the maximum possible value of efficiency is 81.2%, while that of half-wave rectifier is 40.6%.

## Disadvantages

- The output voltage is half of the secondary voltage.
- The peak-inverse voltage (PIV) of a diode is twice that of the diode used in the half-wave rectifier.
- It is expensive to manufacture a center-tapped transformer, which produces equal voltages on each half of the secondary winding.