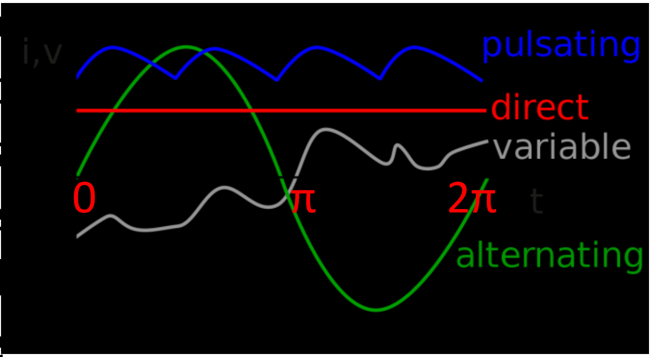
Application of Diode: Rectifiers

BPT: 401: Electronics and Modern Physics

Tutorial – 6+7

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

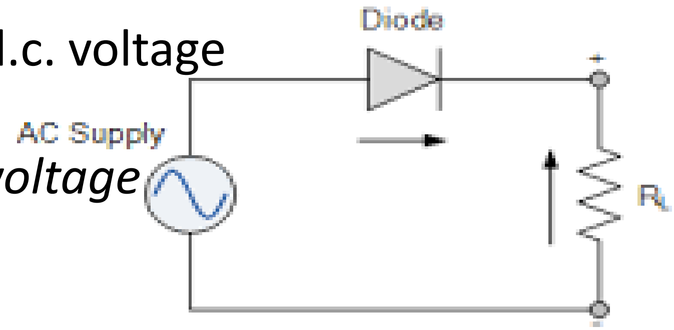
A circuit that converts a.c. voltage of main supply into pulsating d.c. voltage (unidirectional) using one or more PN junction diodes.

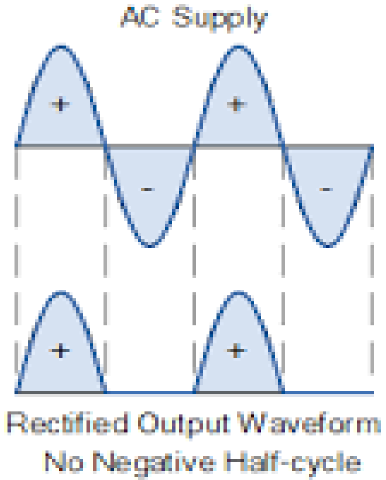
(i) *Half Wave Rectifier – Rectifies only one half cycle of the AC voltage*

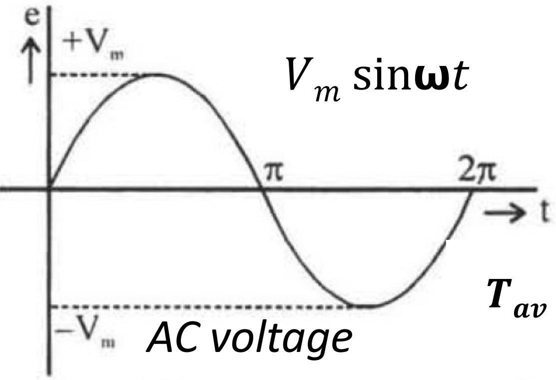
(ii) *Full Wave Rectifier – Rectifies full cycle of AC voltage*

Center tap Rectifier

Bridge Rectifier

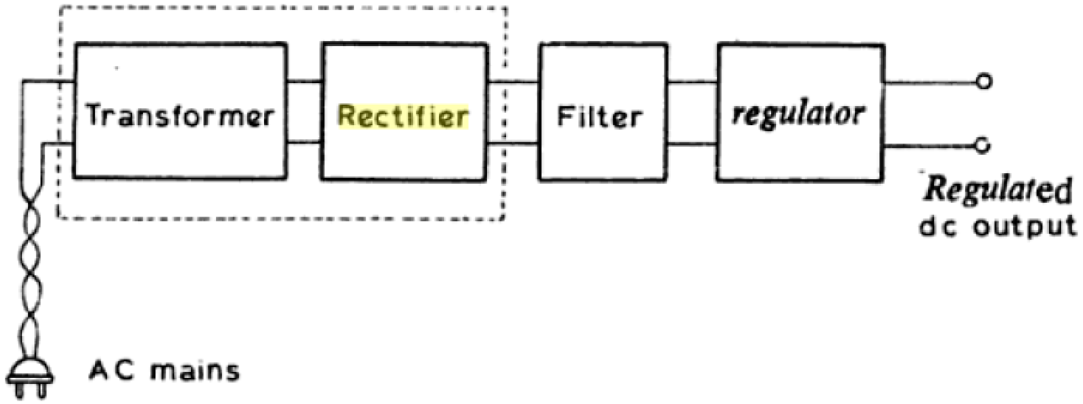






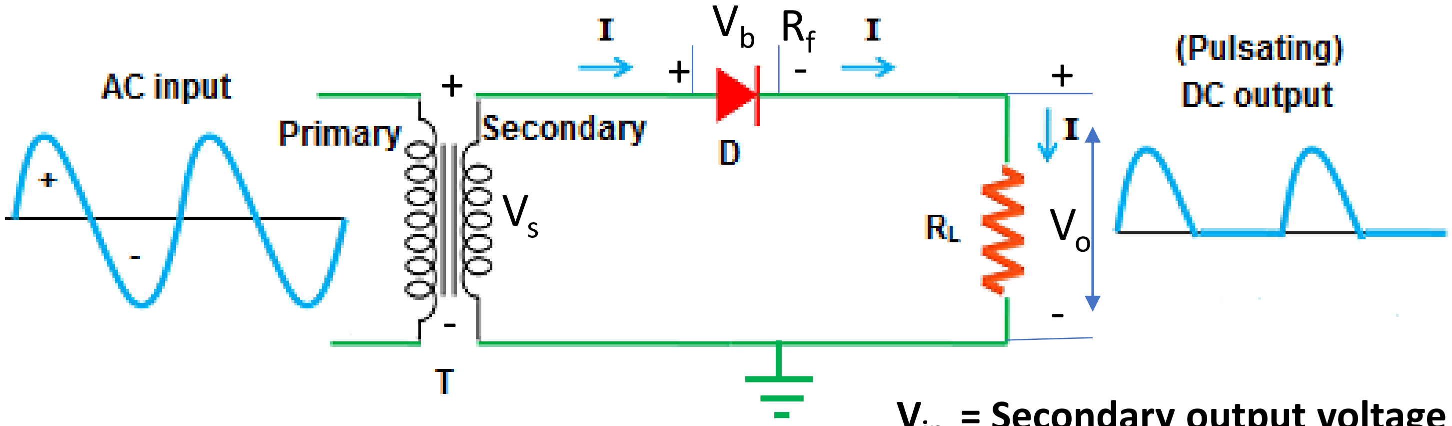
$$T_{av} = \frac{1}{2\pi}\int_0^{2\pi} V_m \sin\omega t$$

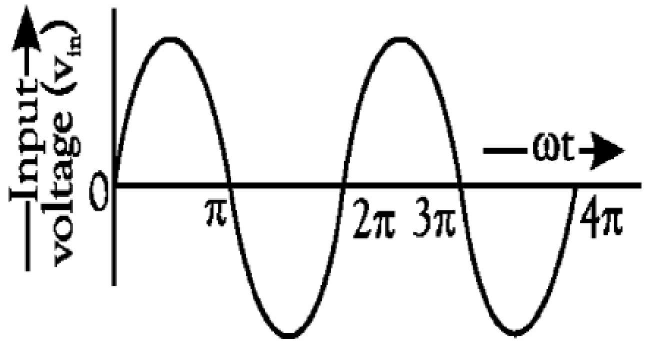
Block Diagram of DC Power Supply



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.





Input AC 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

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

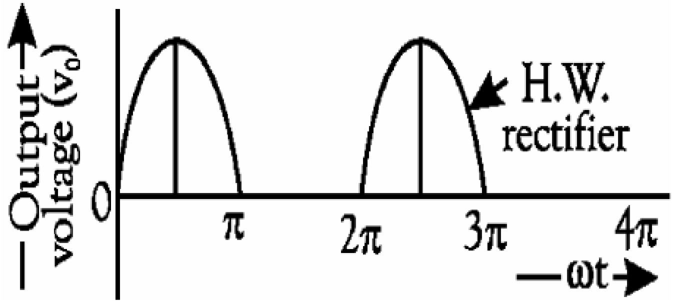
$V_O = V_{in} - V_b$ (for $0 \leq \omega t \leq \pi$)

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

$V_O = V_{in} - V_b$

$$IR_L = Vi_n - IRf$$

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



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:

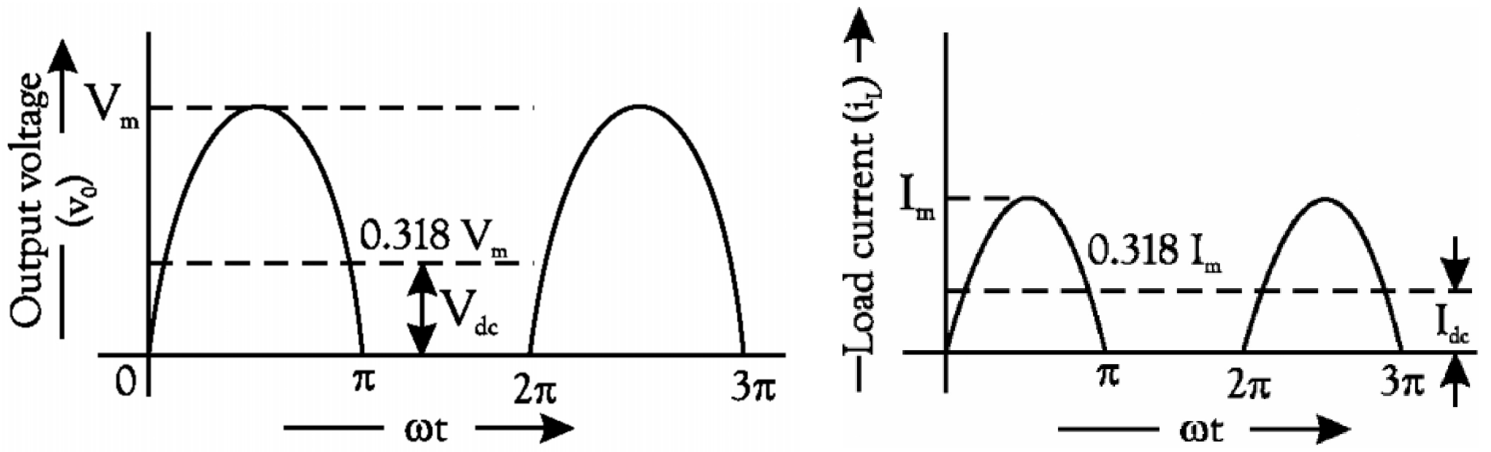
The instantaneous value of the sinusoidal a.c. input voltage is given by the relation, $v = V_m \sin \omega t = V_m \sin\theta$

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:

RMS = Square root of mean square

zero

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 RMS value of a.c component and 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_{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 $\boxed{1.21}$

The output current has both ac and dc part

$$I_{out} = I_{ac} + I_{dc}$$

$$I_{ac} = I_{out} - I_{dc}$$

Let I'_{RMS} be the RMS value of I_{ac}

$$I'_{RMS} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} I^2_{ac}\, d\omega t}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi} (I_{out} - I_{dc})^2 d\theta}$$

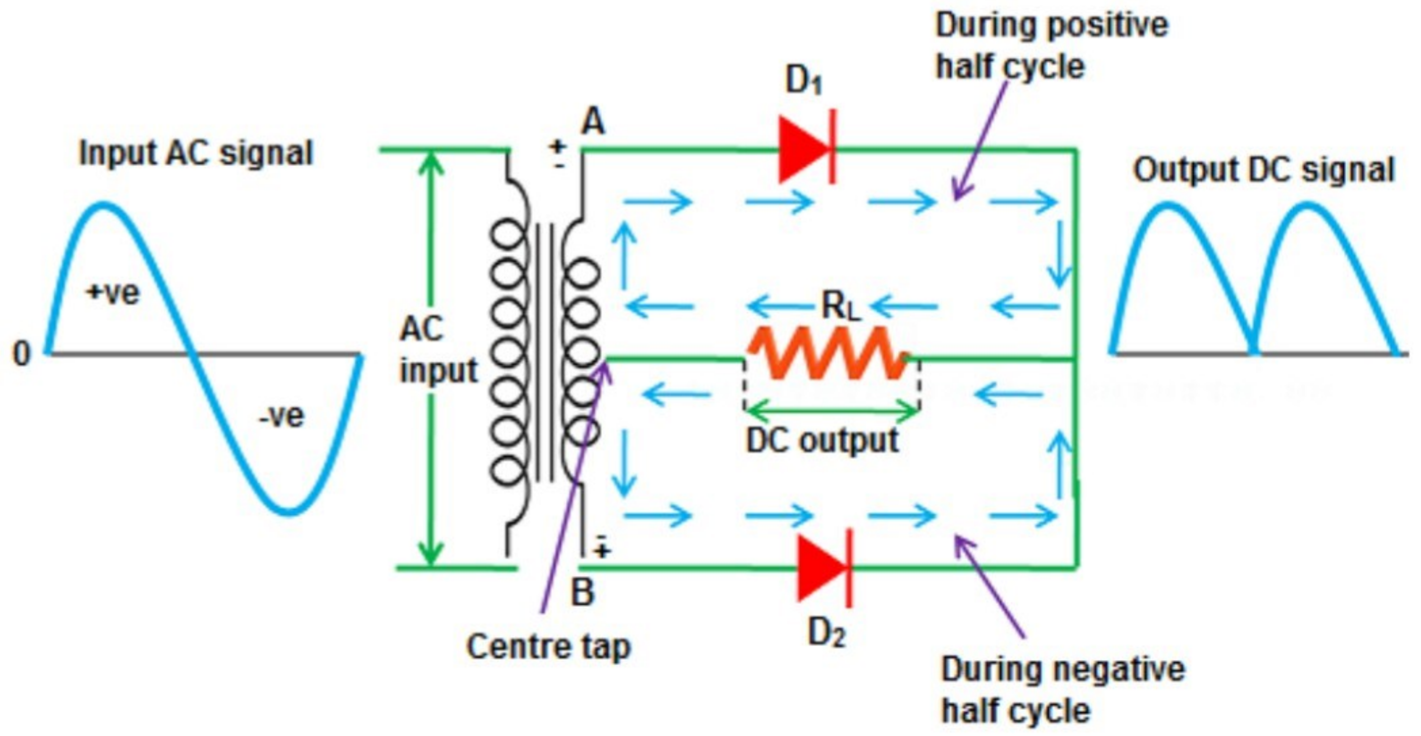
$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi} (I_{out} - I_{dc})^2 d\theta}$$

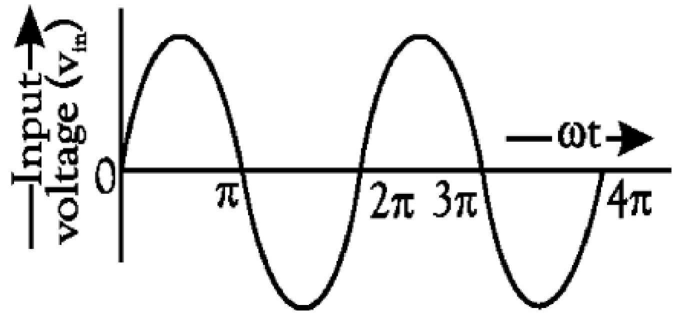
$$I'_{RMS} = I_{RMS} - I_{dc}$$

Full Wave Rectifier

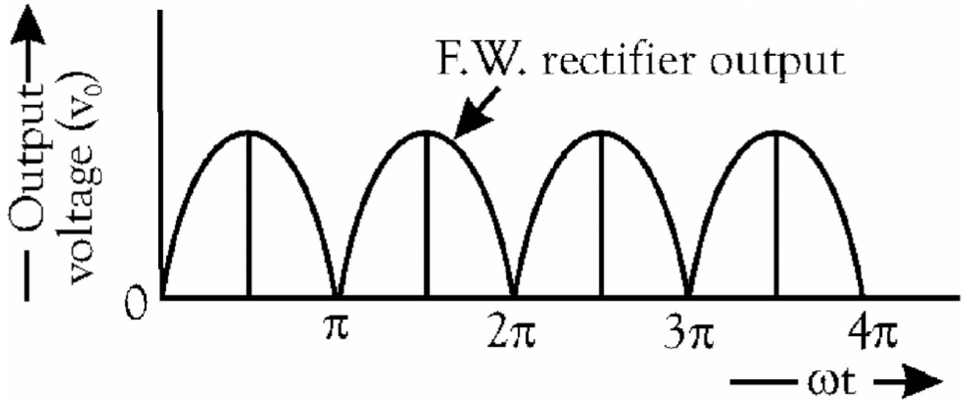
- A Full Wave Rectifier rectifies or converts both the positive and negative half cycle of the input AC signal into unidirectional pulsating DC output signal.
- It is of two types (i) Center Tapped Rectifier and (ii) Bridge Rectifier

Full Wave Center Tapped Rectifier





Input AC Voltage

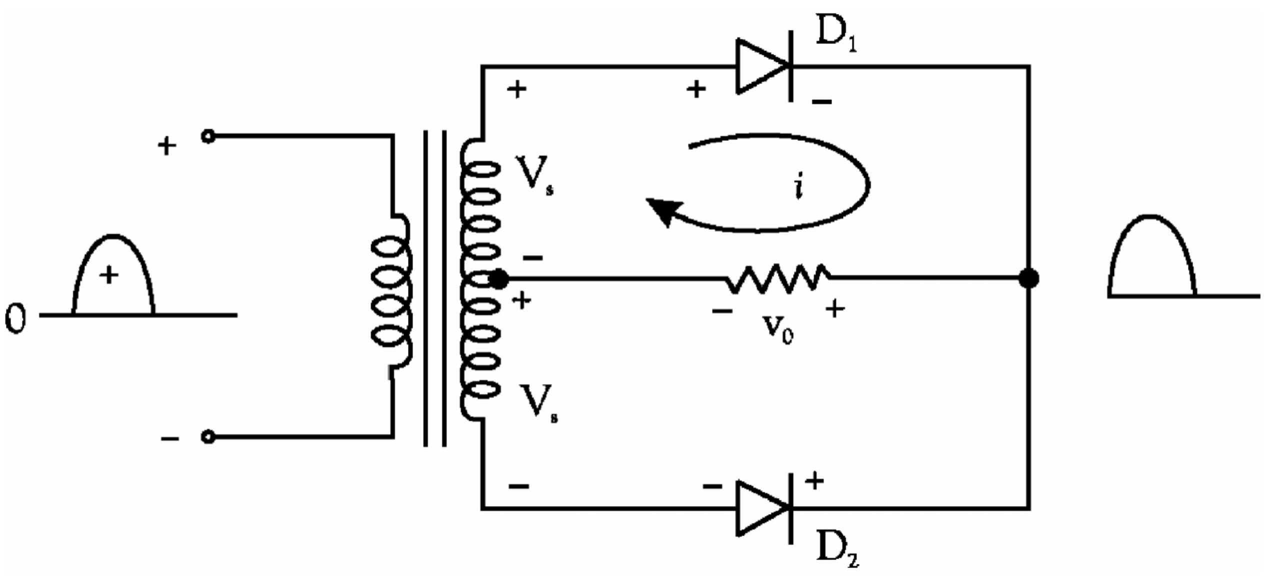


Rectified Pulsating Output Voltage

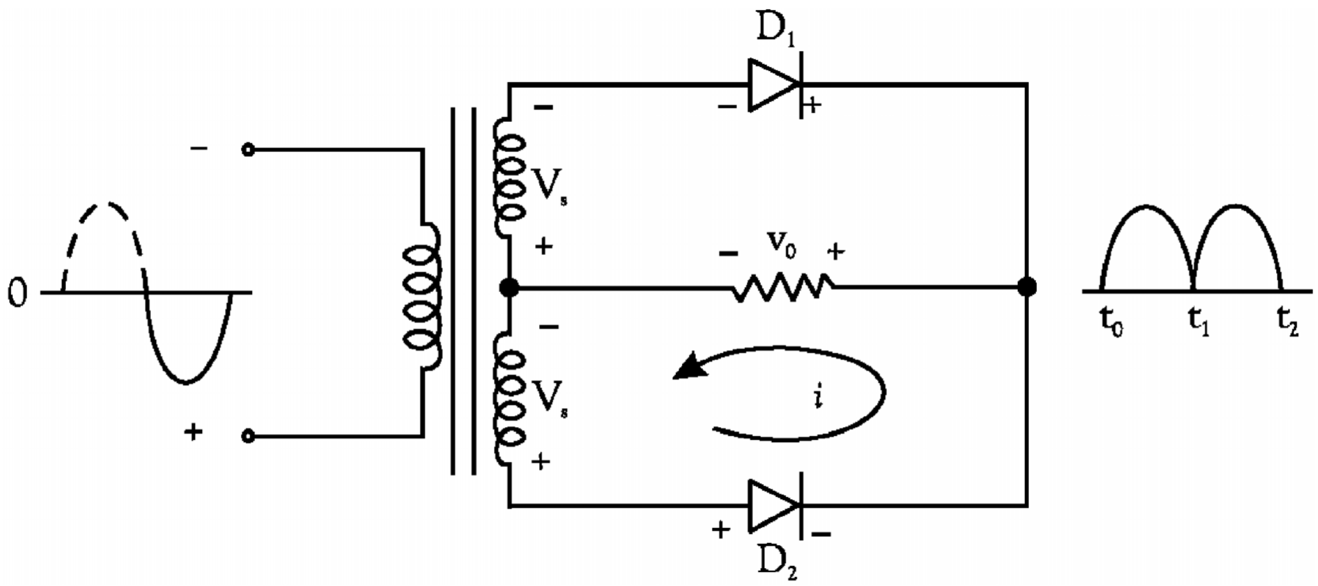
Full Wave Center Tapped Rectifier

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 Center Tapped 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,

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

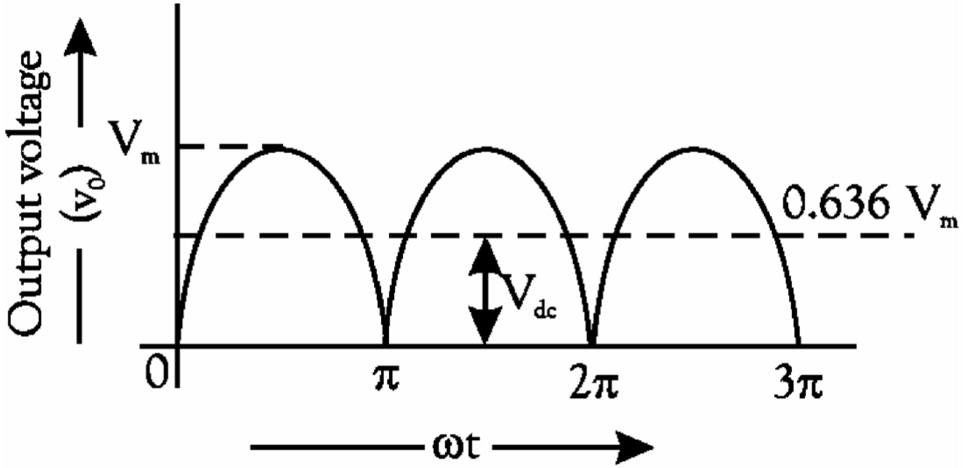
where V_S = Instantaneous value of the voltage across each half of the secondary winding.

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

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

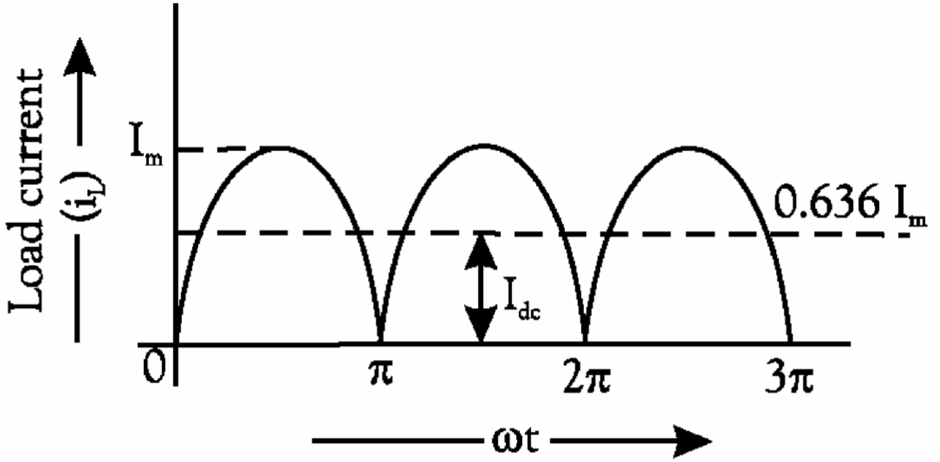
$$V_{dc} = \frac{V_m}{\pi} \left| (-\cos \theta) \right|_0^\pi = \frac{V_m}{\pi} \left[+1 - (-1) \right] = \frac{2 V_m}{\pi} = 0.636 \, V_m$$



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 Center Tapped 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 Center Tapped 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.

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

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 Center Tapped 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 γ 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

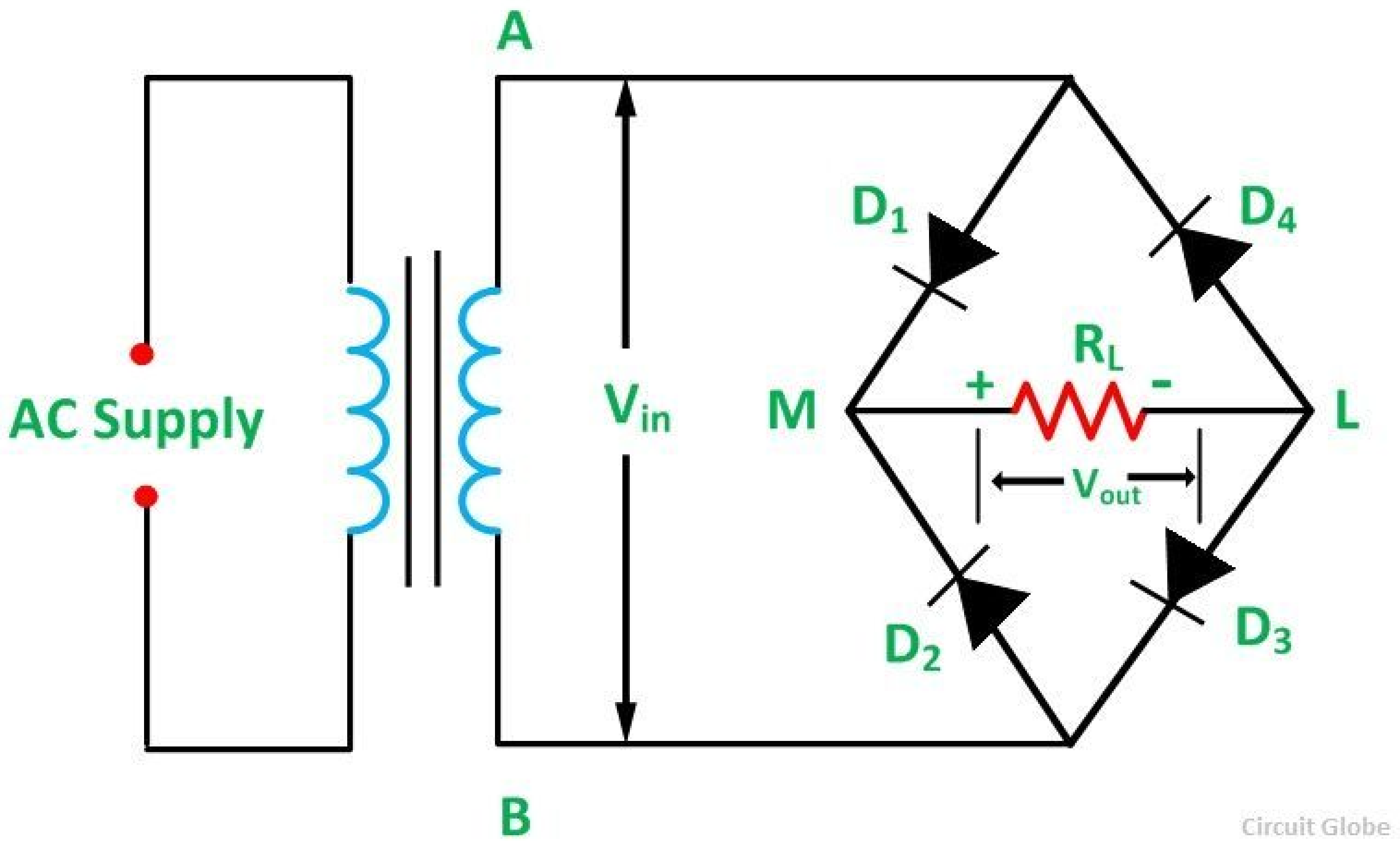
Advantages

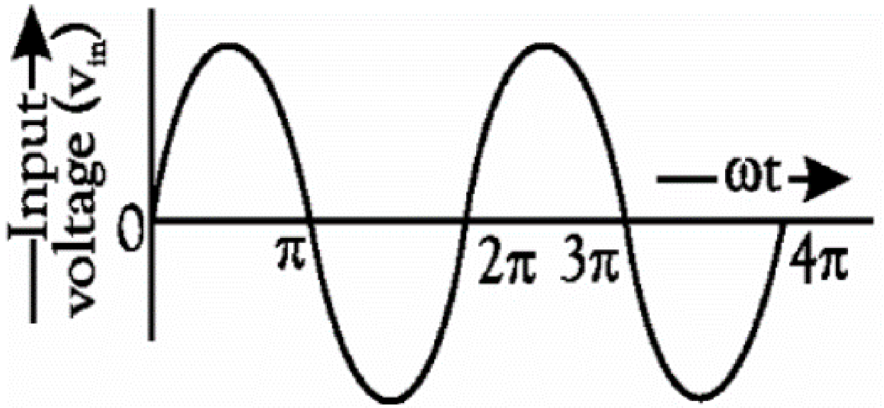
- ❖ The d.c. output voltage and load current values are twice than those of a half-wave rectifier.
- ❖ The ripple factor is much less (0.482) than that of half-wave rectifier.
- ❖ The efficiency is twice that of half-wave rectifier. For a full-wave rectifier, the maximum possible value of efficiency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

Disadvantages

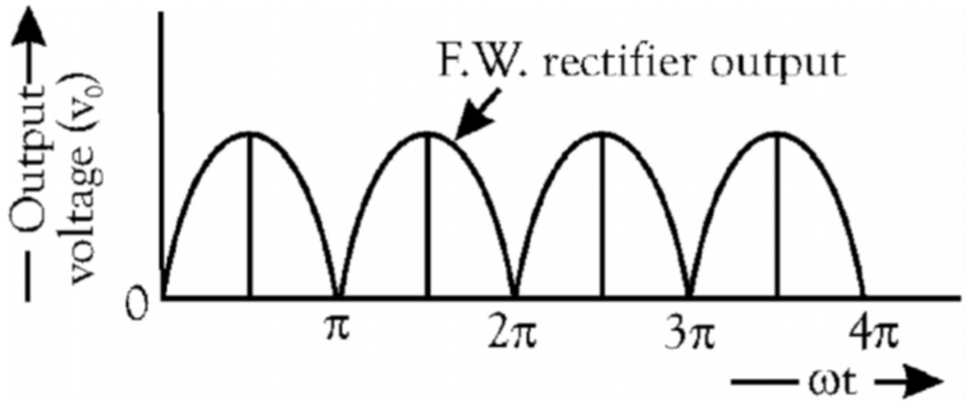
- ❖ The output voltage is half of the secondary voltage.
- ❖ The peak-inverse voltage (PIV) of a diode is twice that of the diode used in the half-wave rectifier.
- ❖ It is expensive to manufacture a center-tapped transformer, which produces equal voltages on each half of the secondary winding.

Full Wave Bridge Rectifier





Input AC Voltage

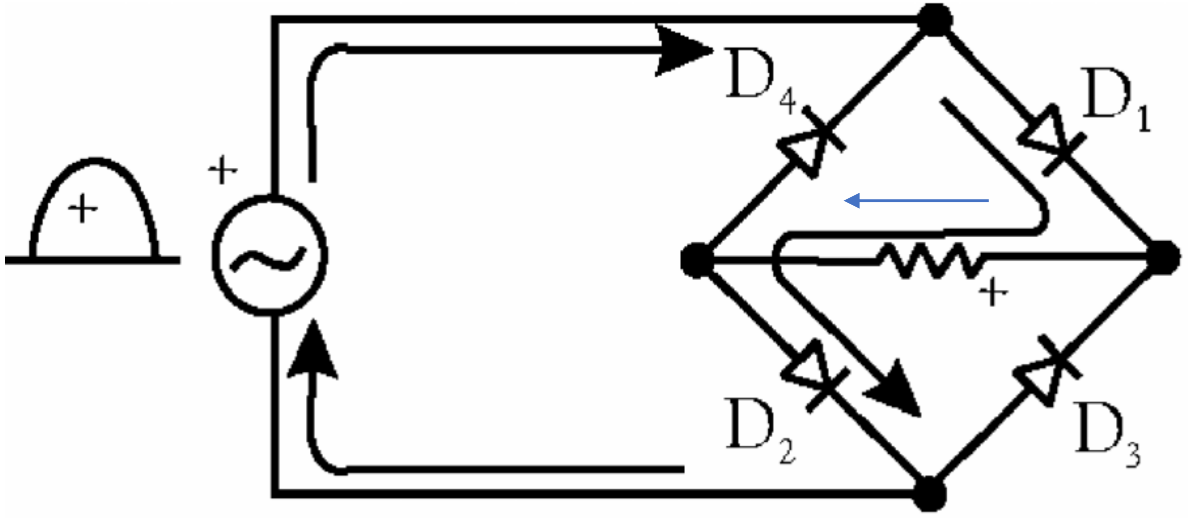


Rectified Pulsating Output Voltage

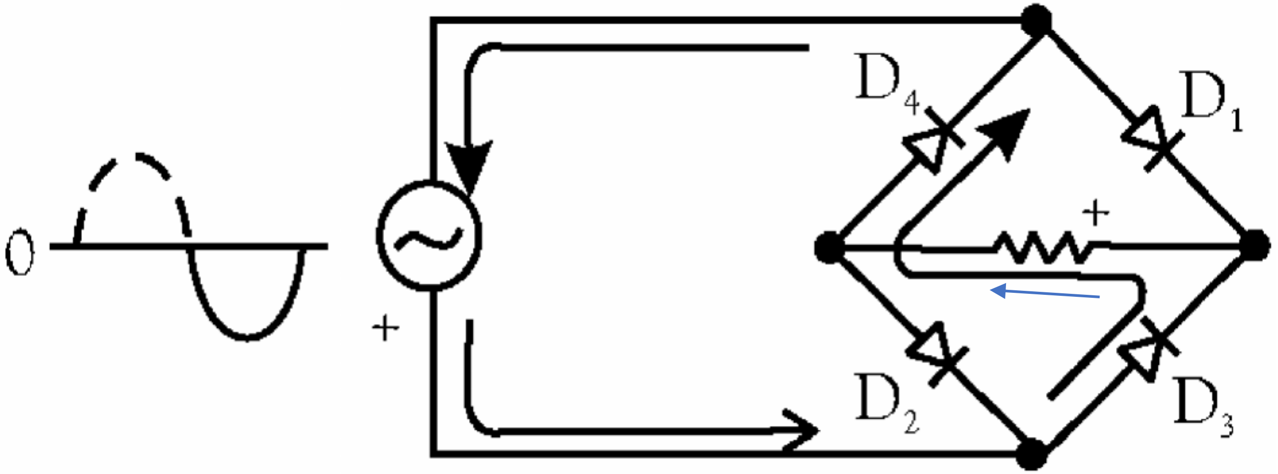
Full Wave Bridge Rectifier

Working

(i) During positive half-cycle of input voltage, the diodes D_1 and D_2 are forward biased and conduct some current in the direction as indicated in the figure. A voltage is developed across the resistor R_L due to the current flow through it. The voltage waveform looks like the positive half of the input cycle. At this time the diodes D_3 and D_4 are reverse biased.

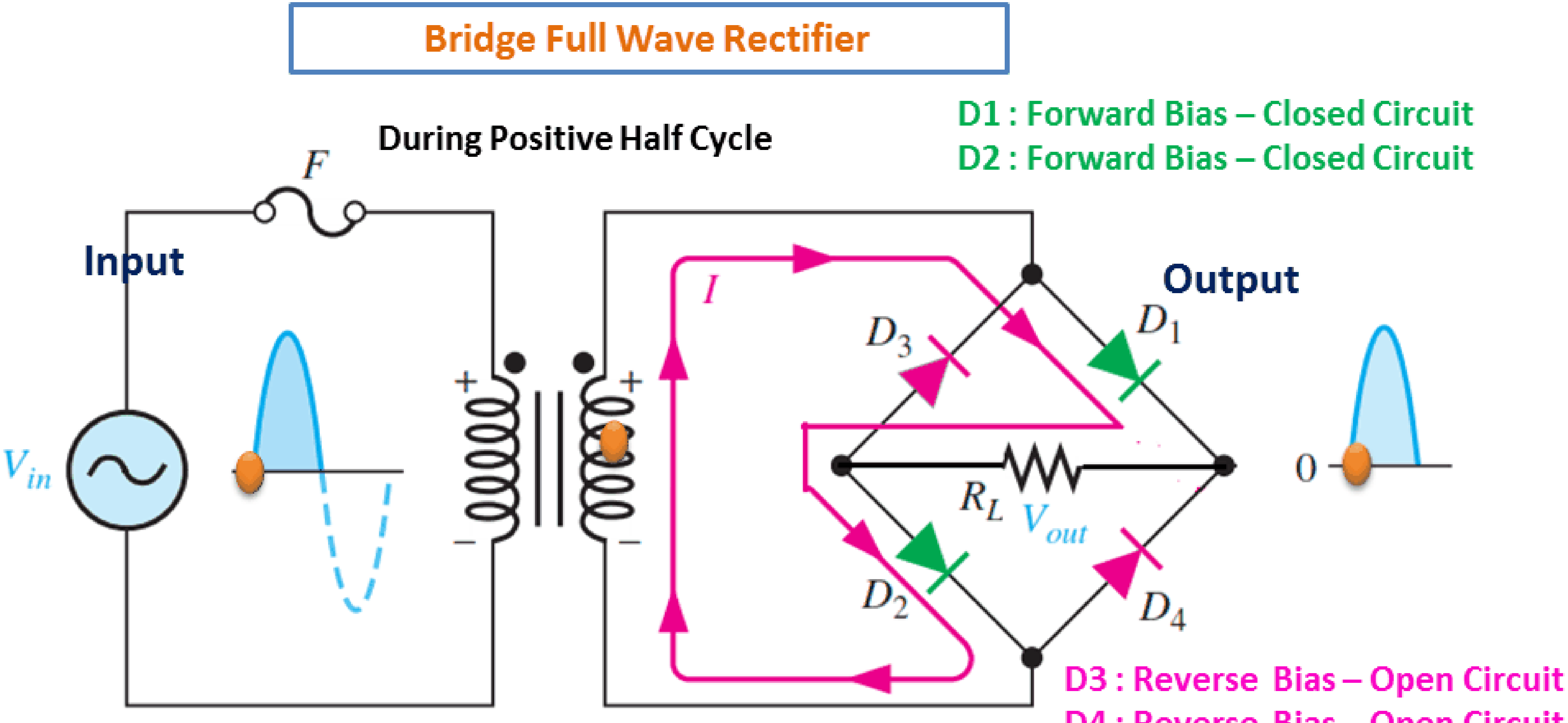


(i) When the input voltage is negative, the diodes D_3 and D_4 are forward biased and conduct some current in the same direction through R_L. During this time, the diodes D_1 and D_2 are reverse biased. As a result of this action, a full-wave rectified output voltage is developed across the resistance R_L.



Full Wave Bridge Rectifier

Working



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Full Wave Bridge Rectifier – Device Parameter

The device parameter are same as that of Full Wave Center Tapped Rectifier except the Peak Inverse Voltage (PIV) of diode. At a given half-cycle, two diodes are reverse biased and have a maximum reverse voltage equal to the maximum secondary voltage (V_m). Thus, peak-inverse voltage of a diode in a full wave bridge rectifier, is PIV= V_m

Comparison of Rectifiers

S. No.	Item	Half-wave	Full-wave	
			Center-tapped	Bridge
1.	Number of diodes	1	2	4
2.	Peak-inverse voltage of diode	V_m	$2\ V_m$	V_m
3.	D.C. Output voltage	$0.318\ V_m$	$0.636\ V_m$	$0.636\ V_m$
4.	Ripple factor	1.21	0.482	0.482
5	Efficiency (%)	40.6%	81.2%	81.2%

Advantages

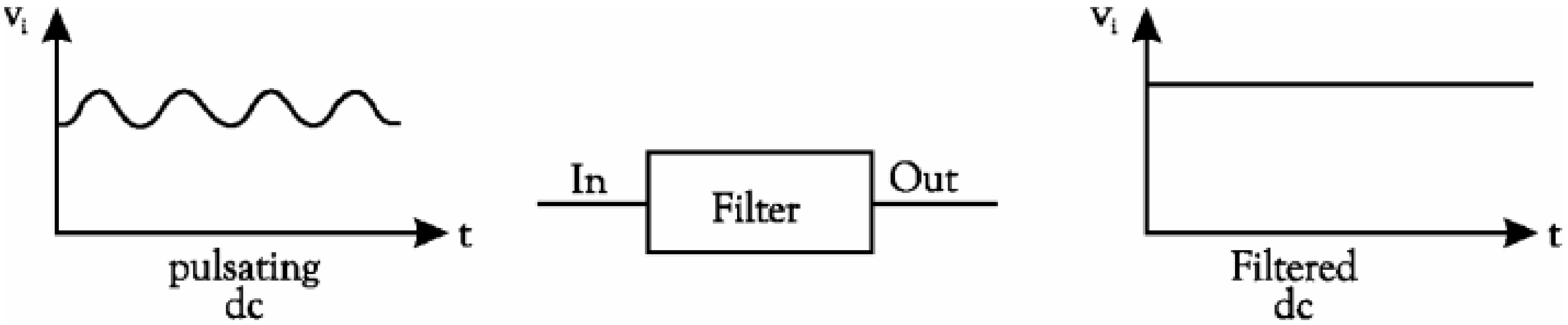
1. It can be used in applications allowing floating output terminals i.e., no output terminal is grounded.
2. No center-tap is required on the transformer. So cost is less.
3. PIV rating required of the diodes, is only half of that for a center-tapped full-wave rectifier. This is a great advantage.

Disadvantages

It has only one disadvantage that it uses four diodes as compared to two diodes for center-tapped full wave rectifier.

Filter Circuits

- Filter is an electronic circuit used to minimize the ripple content in rectified output of a rectifier.
- The output of various rectifier circuits is pulsating. It has a dc value and some ac variations called **ripples**.
- This type of output is not useful for driving sophisticated electronic circuits/devices. The sophisticated circuits require a very steady dc output.
- A circuit that converts a pulsating output from a rectifier into a steady dc level is known as **filter** because it filters out the pulsations in the signal



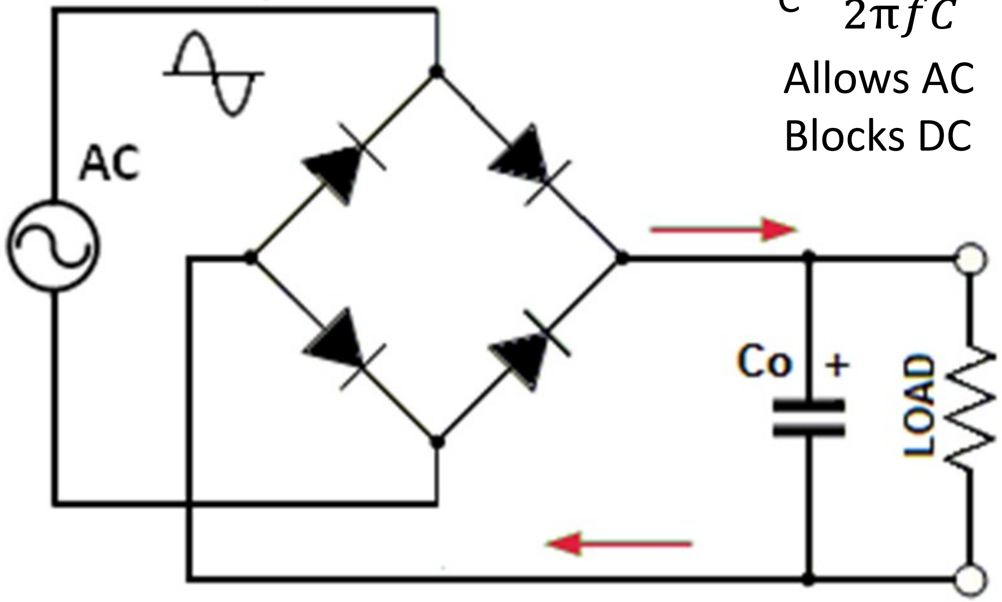
There are different types of filters popularly used in practice. They are :

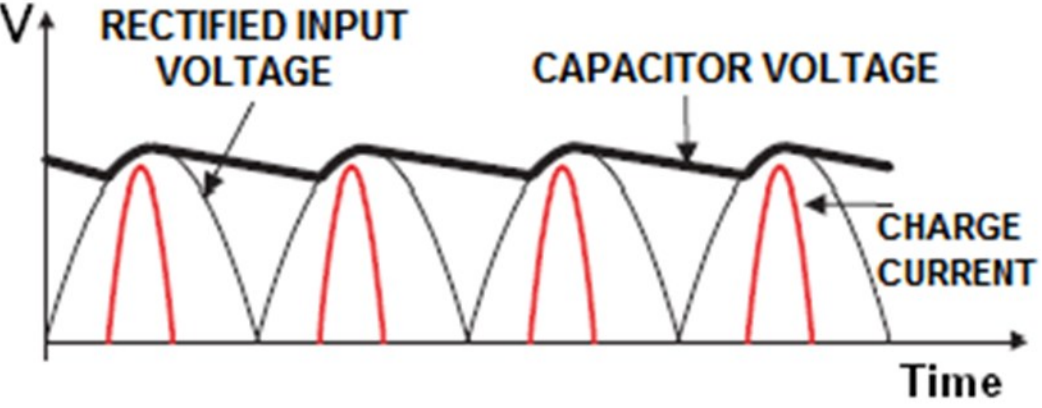
(i) Series inductor filter, (ii) Shunt capacitor filter,
(iii) LC filter (or L-type filter) (iv) π-filter

Full Wave Shunt capacitor Filter

$$X_C = \frac{1}{2\pi f C}$$

Allows AC
Blocks DC

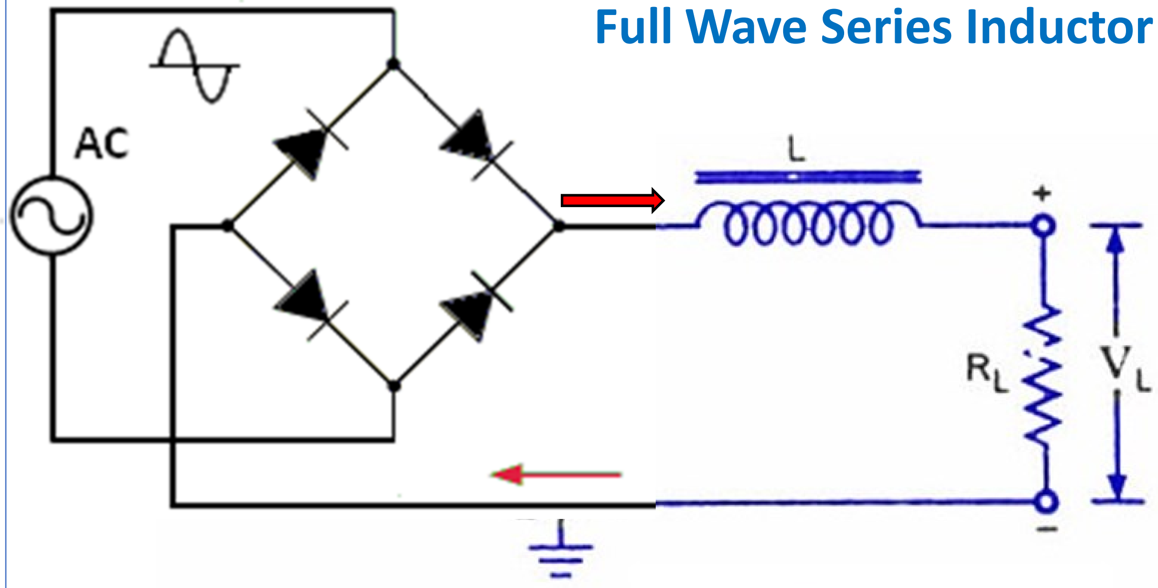




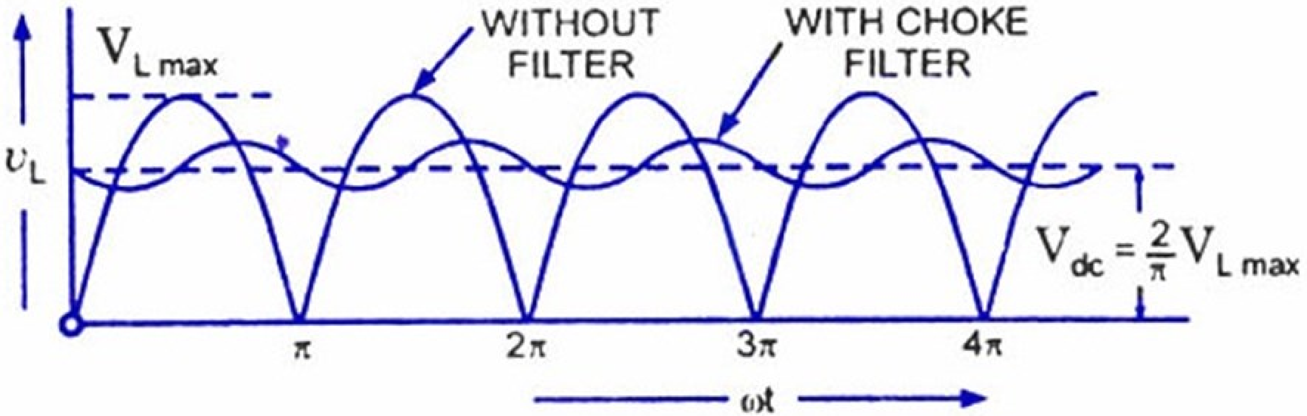
Full Wave Series Inductor Filter

$$X_L = 2\pi f L$$

Allows DC
Blocks AC



Circuit Diagram



Output Voltage Waveforms www.CircuitsToday.com