PHS 316

RECTIFICATION

What is a Rectifier?

- A rectifier is an electrical component that converts alternating current (AC) to direct current (DC). A rectifier is analogous to a one-way valve that allows an electrical current to flow in only one direction. The process of converting AC current to DC current is known as rectification.

TYPES OF RECTIFIERS

The rectifiers are mainly classified into two types:

- Half wave rectifier
- Full wave rectifier

- **Half wave rectifier**

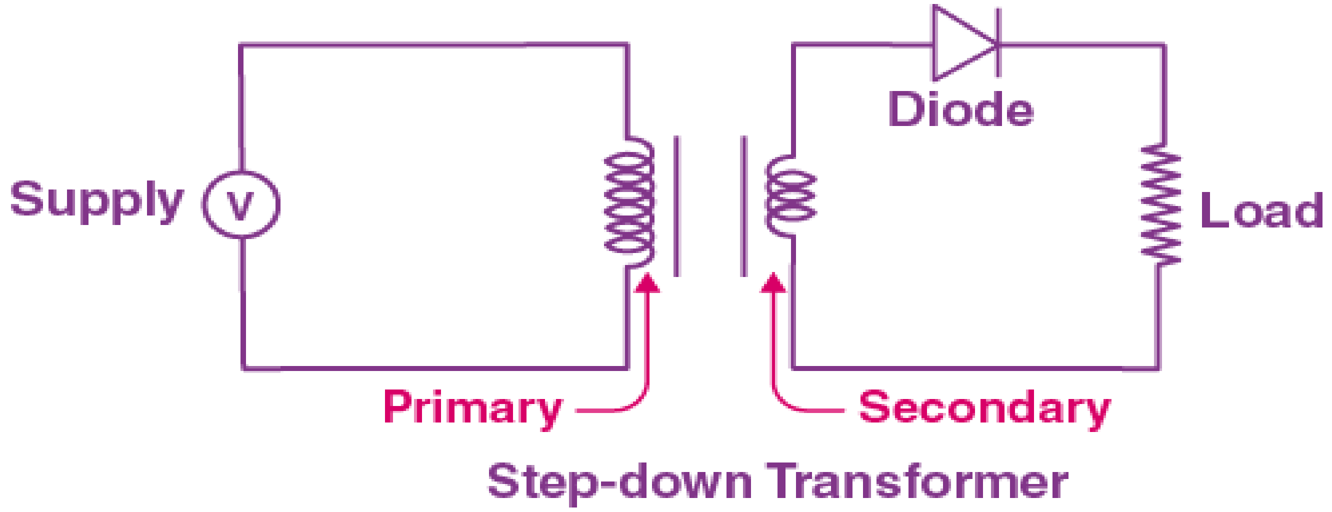
As the name suggests, the half wave rectifier is a type of rectifier which converts half of the AC input signal (positive half cycle) into pulsating DC output signal and the remaining half signal (negative half cycle) is blocked or lost. In half wave rectifier circuit, we use only a single diode.

- **Full wave rectifier**

The full wave rectifier is a type of rectifier which converts the full AC input signal (positive half cycle and negative half cycle) to pulsating DC output signal. Unlike the half wave rectifier, the input signal is not wasted in full wave rectifier. The efficiency of full wave rectifier is high as compared to the half wave rectifier.

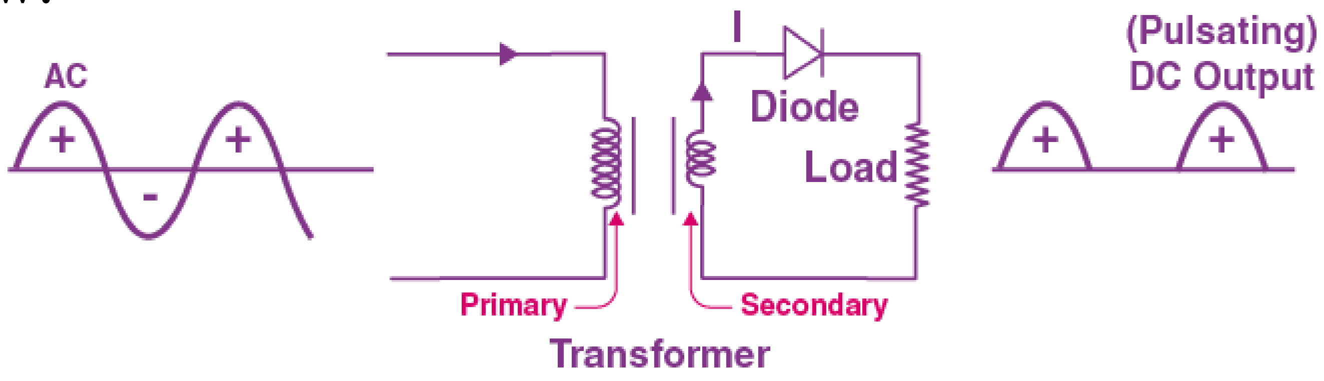
HALF-WAVE RECTIFIER

- 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

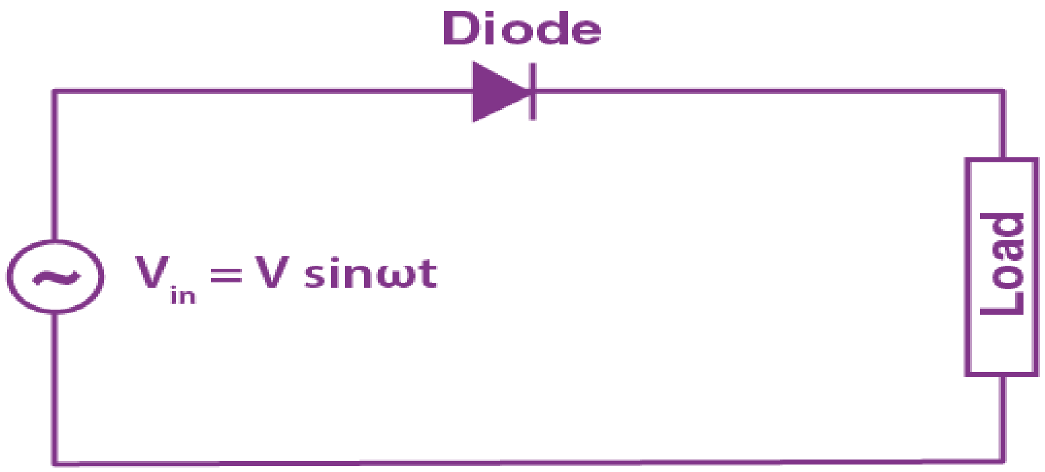


- Working of Half Wave Rectifier
- In this section, let us understand how a half-wave rectifier transforms AC into DC.
- A high AC voltage is applied to the primary side of the step-down transformer. The obtained secondary low voltage is applied to the diode.
- The diode is forward biased during the positive half cycle of the AC voltage and reverse biased during the negative half cycle.

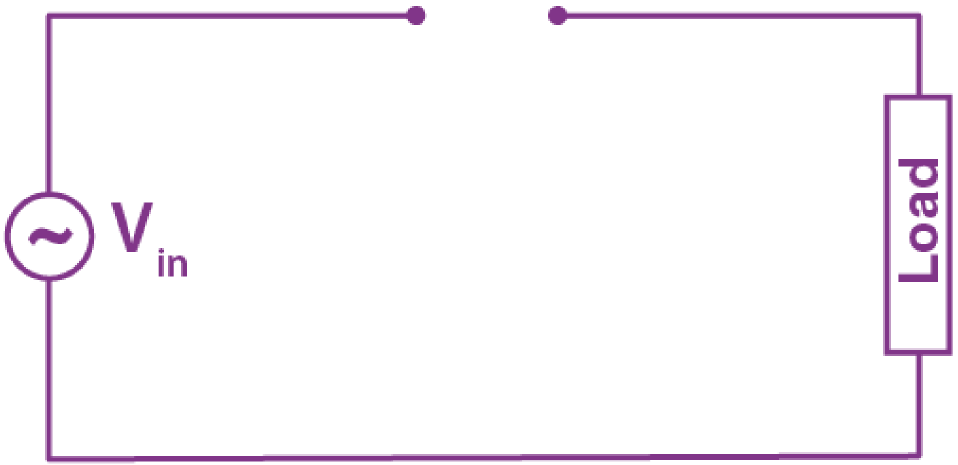
The final output voltage waveform is as shown in the figure below:



For better understanding, let us simplify the half-wave circuit by replacing the secondary transformer coils with a voltage source as shown below:



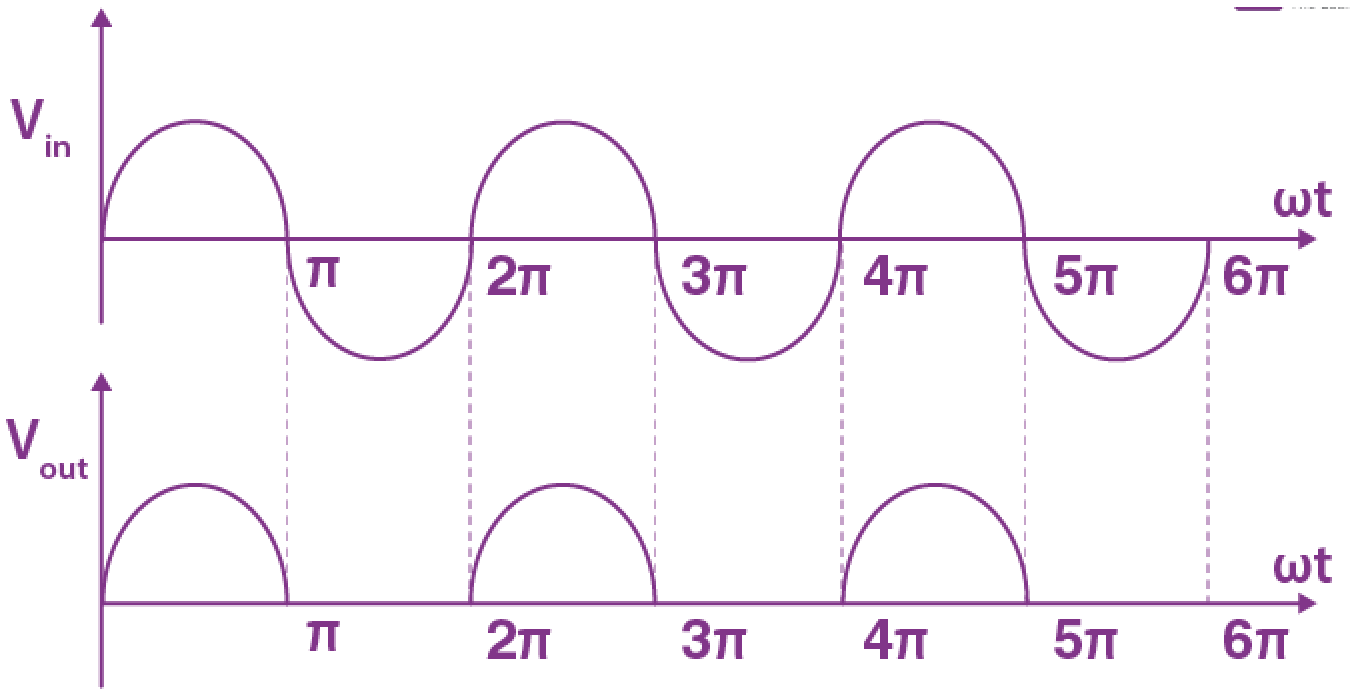
For the positive half cycle of the AC source voltage, the circuit effectively becomes as shown below in the diagram:



When a diode is reverse biased, it acts as an open switch. Since no current can flow to the load, the output voltage is equal to zero.

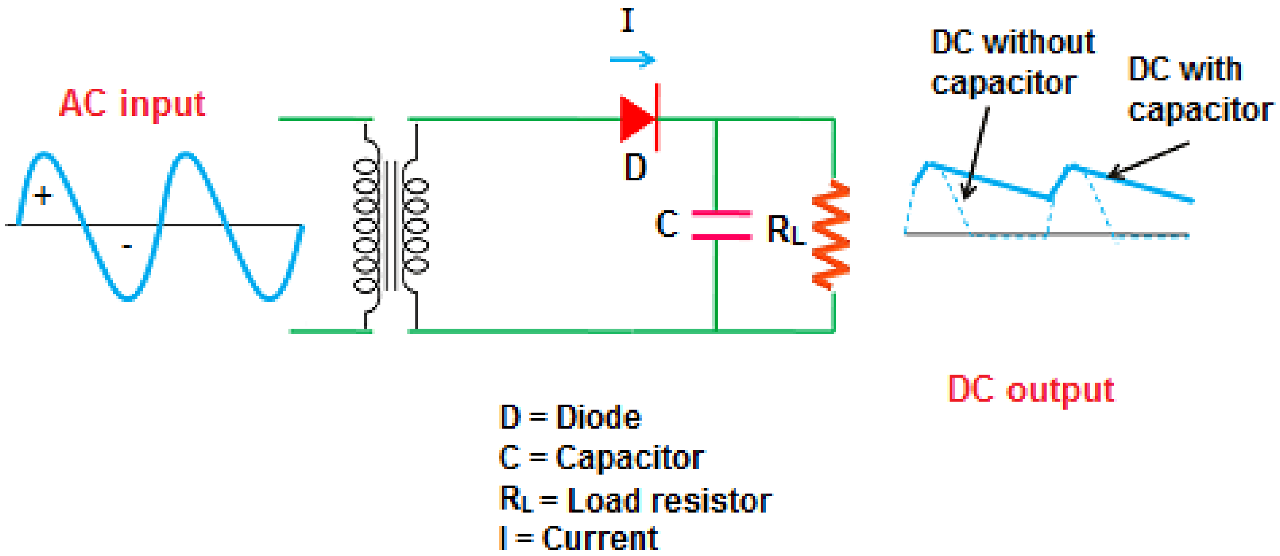
Half Wave Rectifier Waveform

- The halfwave rectifier waveform before and after rectification is shown below in the figure.



Half Wave Rectifier Capacitor Filter

- The output waveform of a halfwave rectifier is a pulsating DC waveform. Filters in halfwave rectifiers are used to transform the pulsating waveform into constant DC waveforms. A capacitor or an inductor can be used as a filter.
- The circuit diagram below shows how a capacitive filter is used with halfwave rectifier to smoothen out a pulsating DC waveform into a constant DC waveform. In the below circuit diagram, the capacitor C is connected in shunt with load resistor (R_L).



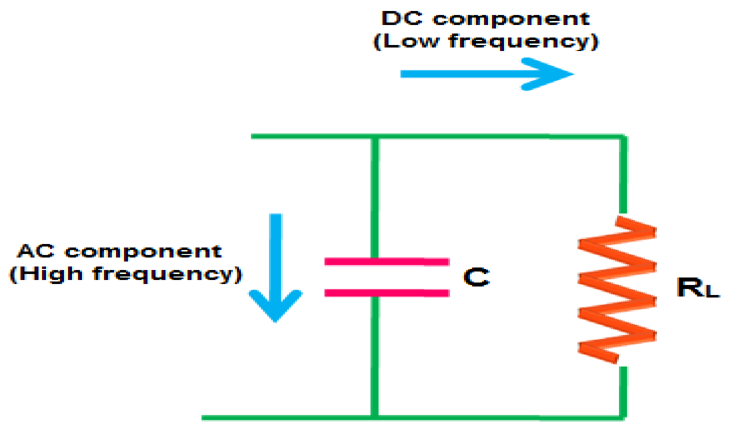
Half wave rectifier with capacitor filter

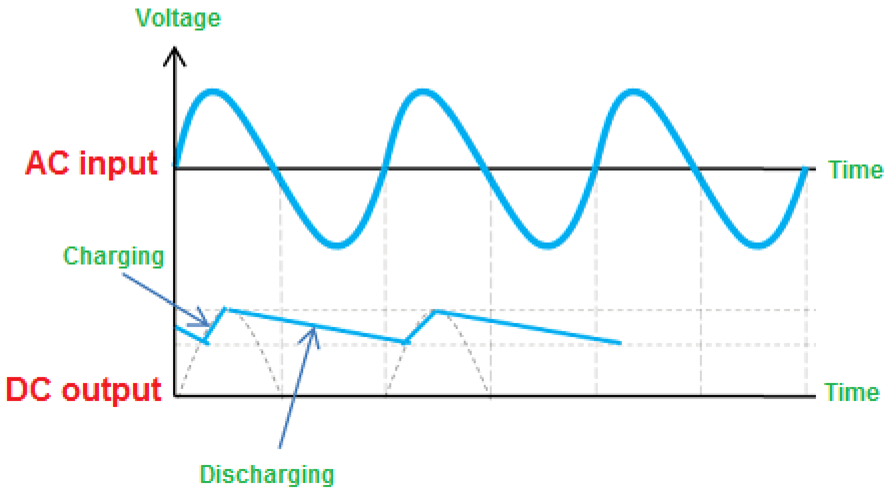
NOTE: The filter is made up of a combination of components such as capacitors, resistors, and inductors. The capacitor allows the ac component and blocks the dc component. The inductor allows the dc component and blocks the ac component.

When AC voltage is applied, during the positive half cycle, the diode D is forward biased and allows electric current through it.
As we already know that, the capacitor provides high resistive path to dc components (low-frequency signal) and low resistive path to ac components (high-frequency signal).

Electric current always prefers to flow through a low resistance path. So when the electric current reaches the filter, the dc components experience a high resistance from the capacitor and ac components experience a low resistance from the capacitor.

The dc components does not like to flow through the capacitor (high resistance path). So they find an alternative path (low resistance path) and flows to the load resistor (RL) through that path.





Half wave rectifier with filter o/p waveforms

On the other hand, the ac components experience a low resistance from the capacitor. So the ac components easily passes through the capacitor. Only a small part of the ac components passes through the load resistor (R_L) producing a small ripple voltage at the output.
The passage of ac components through the capacitor is nothing but charging of the capacitor. During the conduction period, the capacitor charges to the maximum value of the supply voltage. When the voltage between the plates of the capacitor is equal to the supply voltage, the capacitor is said to be fully charged.

Half Wave Rectifier Formula

Ripple Factor of Half Wave Rectifier

- Ripple factor determines how well a halfwave rectifier can convert AC voltage to DC voltage.
- Ripple factor can be quantified using the following formula:

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

The ripple factor of a halfwave rectifier is 1.21.

Efficiency of Halfwave rectifier

The efficiency of a halfwave rectifier is the ratio of output DC power to the input AC power.

The efficiency formula for halfwave rectifier is given as follows;

$$\eta = \frac{P_{DC}}{P_{AC}}$$

RMS value of Half Wave Rectifier

The RMS value of the load current for a half-wave rectifier is given by the formula:

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$

Form factor of a Halfwave Rectifier

The form factor is the ratio between RMS value and average value and is given by the formula:

$$\text{Form Factor} = \frac{\text{RMS value}}{\text{Average Value}}$$

Applications of Half Wave Rectifier

- They are used for signal demodulation purpose
- They are used for rectification applications
- They are used for signal peak applications

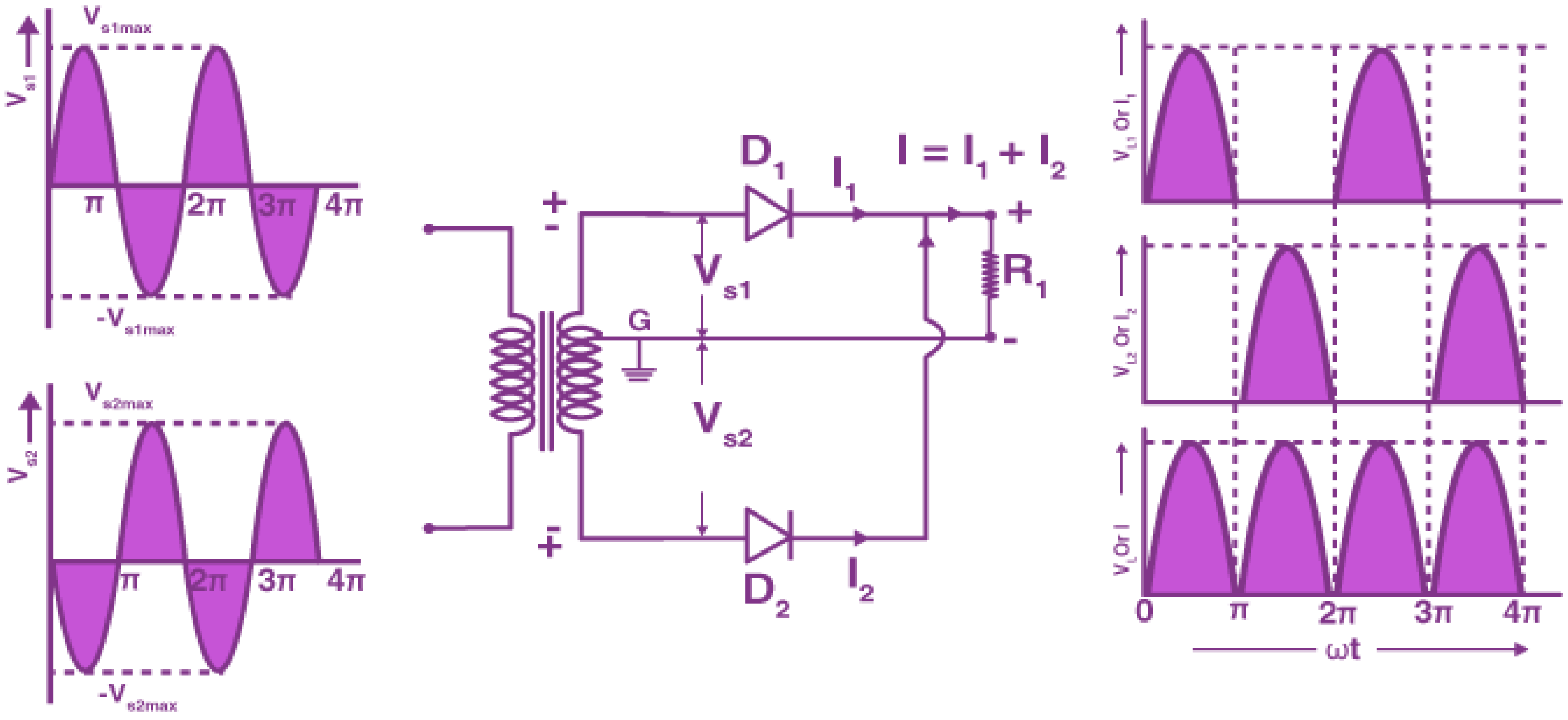
Disadvantages of Half Wave Rectifier

- Power loss
- Low output voltage
- The output contains a lot of ripples

Full Wave Rectifiers

- A full wave rectifier is defined as a rectifier that converts the complete cycle of alternating current into pulsating DC. Unlike halfwave rectifiers that utilize only the halfwave of the input AC cycle, full wave rectifiers utilize the full cycle. The lower efficiency of the half wave rectifier can be overcome by the full wave rectifier.
- The circuit of the full wave rectifier can be constructed in two ways. The first method uses a centre tapped transformer and two diodes. This arrangement is known as a centre tapped full wave rectifier. The second method uses a standard transformer with four diodes arranged as a bridge. This is known as a bridge rectifier.

CENTRE TAPPED FULL WAVE RECTIFIER



Input voltage waveform

Output voltage waveform

The circuit of the full wave rectifier consists of a step-down transformer and two diodes that are connected and centre tapped. The output voltage is obtained across the connected load resistor.

Working of Full Wave Rectifier

- The input AC supplied to the full wave rectifier is very high. The step-down transformer in the rectifier circuit converts the high voltage AC into low voltage AC. The anode of the centre tapped diodes is connected to the transformer’s secondary winding and connected to the load resistor. During the positive half cycle of the alternating current, the top half of the secondary winding becomes positive while the second half of the secondary winding becomes negative.
- During the positive half cycle, diode D_1 is forward biased as it is connected to the top of the secondary winding while diode D_2 is reverse biased as it is connected to the bottom of the secondary winding. Due to this, diode D_1 will conduct acting as a short circuit and D_2 will not conduct acting as an open circuit
- During the negative half cycle, the diode D_1 is reverse biased and the diode D_2 is forward biased because the top half of the secondary circuit becomes negative and the bottom half of the circuit becomes positive. Thus in a full wave rectifiers, DC voltage is obtained for both positive and negative half cycle.

Full Wave Rectifier Formula

Peak Inverse Voltage

Peak inverse voltage is the maximum voltage a diode can withstand in the reverse-biased direction before breakdown. The peak inverse voltage of the full-wave rectifier is double that of a half-wave rectifier. The PIV across D_1 and D_2 is $2V_{max}$.

- **DC Output Voltage**
- The following formula gives the average value of the DC output voltage:

$$V_{dc} = I_{av}R_L = \frac{2}{\pi} I_{max}R_L$$

- **RMS Value of Curre...**
- The RMS value of the current can be calculated using the following formula:

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

- **Form Factor:** Form Factor of an ac waveform is the ratio of the RMS value to the average value. For a full wave rectifier is calculated using the formula:

$$K_f = \frac{RMS\ value\ of\ current}{Average\ value\ of\ current} = \frac{I_{rms}}{I_{dc}} = \frac{I_{max}/\sqrt{2}}{2I_{max}/\pi} = \frac{\pi}{2\sqrt{2}} = 1.11$$

Average (or) DC Output Voltage (Vav or Vdc) Derivation

The most important question of **Rectifiers and Filters** in Electronic Devices and Circuits; **Derive Average (or) DC Output Voltage (V_{av} or V_{dc}) of the half-wave rectifier?** is being answered here.

Average (or) DC Output Voltage (V_{av} or V_{dc}) Derivation

The average dc voltage is given by

$$V_{dc} = I_{dc} \times R_L = \frac{I_m}{\pi} \times R_L = \frac{V_m R_L}{\pi \ R_f + R_L}$$

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

If $R_L >> R_f$ then $V_{dc} = \frac{V_m}{\pi} = 0.318 \ I_m$ $\quad \therefore V_{dc} = \frac{V_m}{\pi}$

- **Peak Factor: t**he peak factor is the peak amplitude of the waveform divided by the RMS value of the waveform.
- The following formula gives the peak factor of the full wave rectifier:

$$K_p = \frac{Peak\ value\ of\ current}{RMS\ value\ of\ current} = \frac{I_{max}}{I_{max}/\sqrt{2}} = \sqrt{2}$$

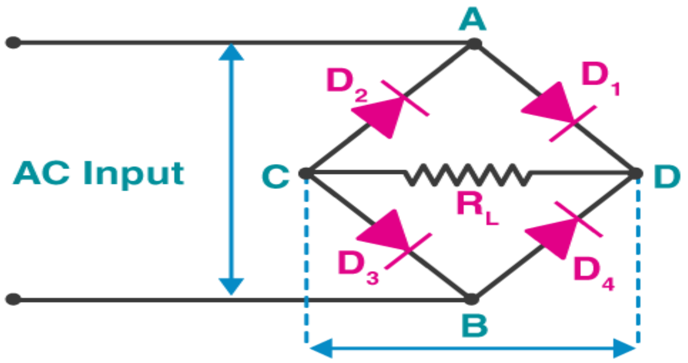
- **Rectification Efficiency**
- The rectification efficiency of the full-wave rectifier can be obtained using the following formula:
- The efficiency of the full wave rectifiers is 81.2%.

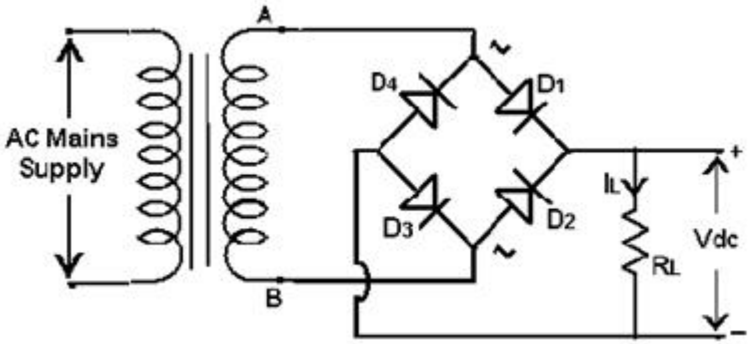
$$\eta = \frac{DC\ Output\ Power}{AC\ Output\ Power}$$

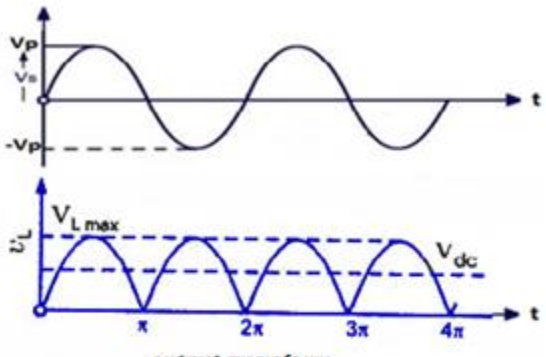
- **Advantages of Full Wave Rectifier**
- The rectification efficiency of full wave rectifiers is double that of half wave rectifiers. The efficiency of half wave rectifiers is 40.6% while the rectification efficiency of full wave rectifiers is 81.2%.
- The ripple factor in full wave rectifiers is low hence a simple filter is required. The value of ripple factor in full wave rectifier is 0.482 while in half wave rectifier it is about 1.21.
- The output voltage and the output power obtained in full wave rectifiers are higher than that obtained using half wave rectifiers.
- The only disadvantage of the full wave rectifier is that they need more circuit elements than the half wave rectifier which makes, making it costlier.

Bridge Rectifier

A bridge rectifier circuit can be built with four diodes which are used to change both input AC half-cycle to DC output. So, in this kind of rectifier, the four diodes are mainly connected in an exact form. In the positive half cycle of the bridge rectifier, the two diodes like D_1 & D_2 will become forward bias whereas diodes D_3 & D_4 will become reverse bias. From a closed loop, the diodes D_1 & D_2 will provide a +Ve output voltage across the R_L (load resistor).

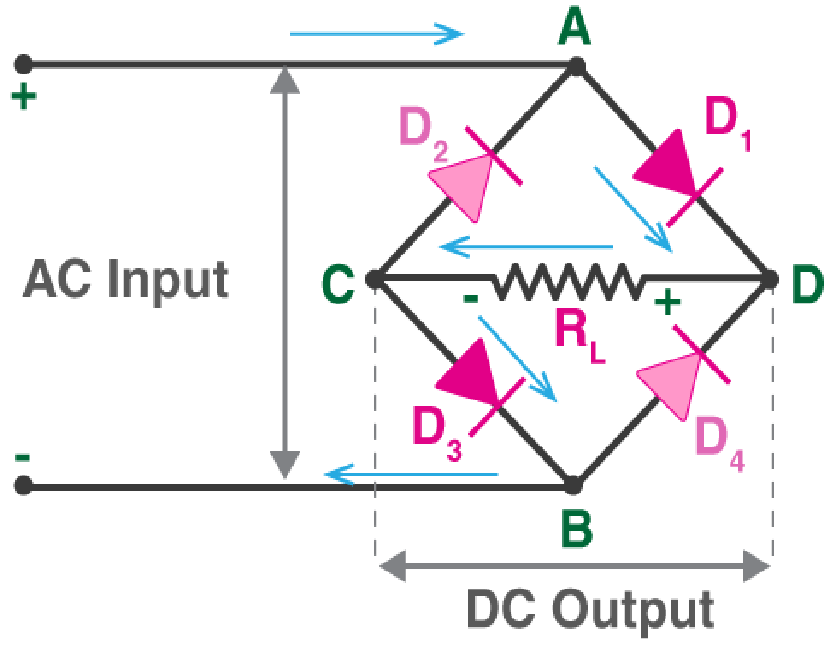






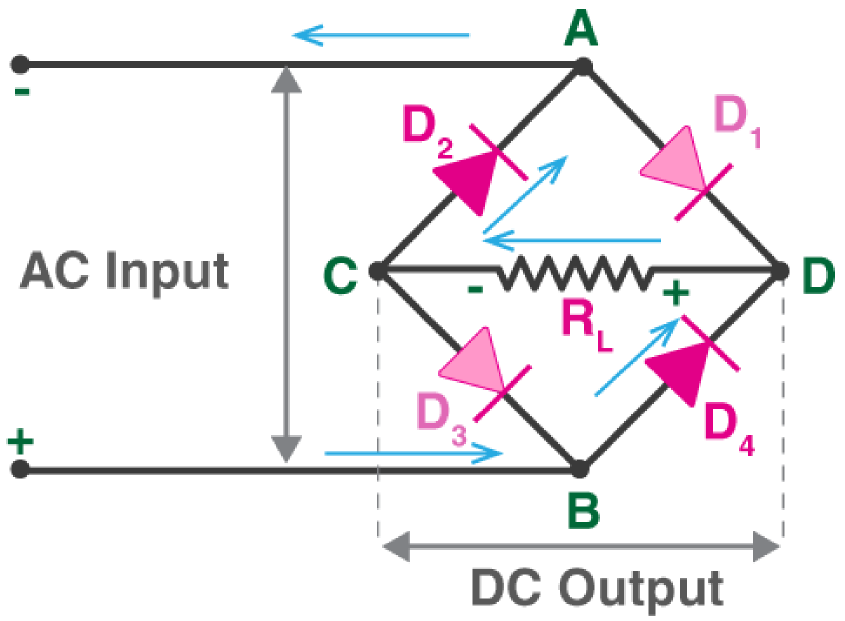
- **Working**

When an AC signal is applied across the bridge rectifier, terminal A becomes positive during the positive half cycle while terminal B becomes negative. This results in diodes D_1 and D_3 becoming forward biased while D_2 and D_4 becoming reverse biased. The current flow during the positive half-cycle is shown in the figure below:

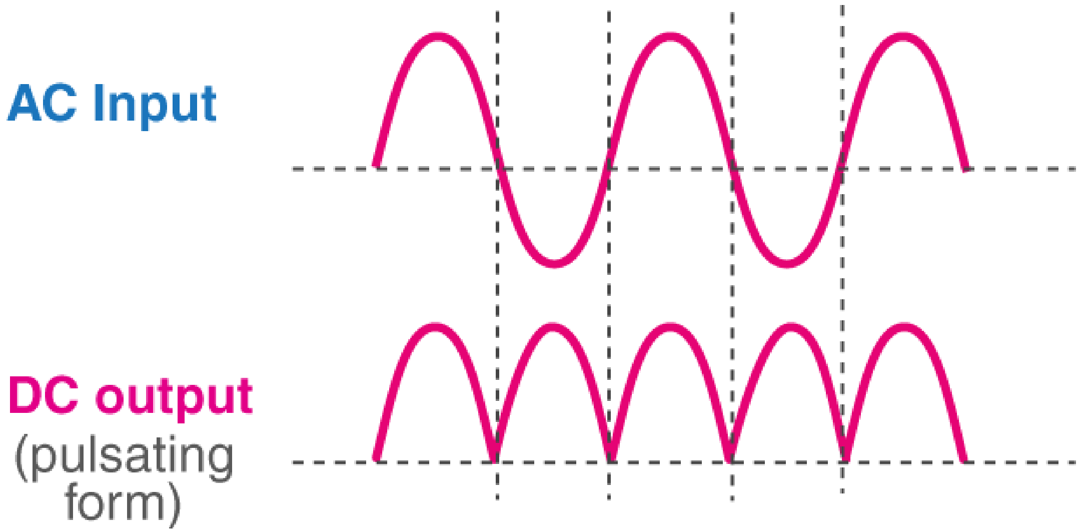


During the negative half-cycle, terminal B becomes positive while terminal A becomes negative. This causes diodes D_2 and D_4 to become forward biased and diode D_1 and D_3 to be reverse biased.

The current flow during the negative half cycle is shown in the figure below:



- From the figures given above, we notice that the current flow across load resistor R_L is the same during the positive and negative half-cycles. The output DC signal polarity may be either completely positive or negative. In our case, it is completely positive. If the diodes' direction is reversed, we get a complete negative DC voltage.
- Thus, a bridge rectifier allows electric current during both positive and negative half cycles of the input AC signal.
- The output waveforms of the bridge rectifier are shown in the below figure.



Characteristics of Bridge Rectifier

- **Ripple Factor**

The smoothness of the output DC signal is measured by a factor known as the ripple factor. The output DC signal with fewer ripples is considered a smooth DC signal while the output with high ripples is considered a high pulsating DC signal.

- Mathematically, the ripple factor is defined as the ratio of ripple voltage to pure DC voltage.
- The ripple factor for a bridge rectifier is given by

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

- For bridge rectifiers, the ripple factor is 0.48.
- **Peak Inverse Voltage**

The maximum voltage that a diode can withstand in the reverse bias condition is known as a peak inverse voltage. During the positive half cycle, the diodes D_1 and D_3 are in the conducting state while D_2 and D_4 are in the non-conducting state. Similarly, during the negative half cycle, diodes D_2 and D_4 are in the conducting state, and diodes D_1 and D_3 are in the non-conducting state.

- **Efficiency**
- The rectifier efficiency determines how efficiently the rectifier converts Alternating Current (AC) into Direct Current (DC). Rectifier efficiency is defined as the ratio of the DC output power to the AC input power. The maximum efficiency of a bridge rectifier is 81.2%.

$$\eta = \frac{DC\ Output\ Power}{AC\ Output\ Power}$$

- **Advantages**
- The efficiency of the bridge rectifier is higher than the efficiency of a half-wave rectifier. However, the rectifier efficiency of the bridge rectifier and the centre-tapped full-wave rectifier is the same.
- The DC output signal of the bridge rectifier is smoother than the output DC signal of a half-wave rectifier.
- In a half-wave rectifier, only half of the input AC signal is used, and the other half is blocked. Half of the input signal is wasted in a half-wave rectifier. However, in a bridge rectifier, the electric current is allowed during both positive and negative half cycles of the input AC signal. Hence, the output DC signal is almost equal to the input AC signal.
- **Disadvantages**
- The circuit of a bridge rectifier is complex when compared to a half-wave rectifier and centre-tapped full-wave rectifier. Bridge rectifiers use 4 diodes while half-wave rectifiers and centre-tapped full wave rectifiers use only two diodes.
- When more diodes are used more power loss occurs. In a centre-tapped full-wave rectifier, only one diode conducts during each half cycle. But in a bridge rectifier, two diodes connected in series conduct during each half cycle. Hence, the voltage drop is higher in a bridge rectifier.

Applications and Uses of Rectifiers

- The primary application of the rectifier is to derive DC power from AC power. Rectifiers are used inside the power supplies of almost all electronic equipment. In power supplies, the rectifier is normally placed in series following the transformer, a smoothing filter, and possibly a voltage regulator. Below, we have discussed a few rectifier applications:
- **A rectifier is used for powering appliances**
- As we know, all electrical appliances use a DC power supply to function. Using a rectifier in the power supply helps in converting AC to DC power supply. Bridge rectifiers are widely used for large appliances, which can convert high AC voltage to low DC voltage.
- **These are used with transformers**
- Using a half-wave rectifier can help us achieve the desired dc voltage by using step-down or step-up transformers. Full-wave rectifiers are even used for powering up the motor and led, which works on DC voltage.
- **Uses of rectifier while soldering**
- A half-wave rectifier is used in soldering iron types of circuits and is also used in mosquito repellent to drive the lead for the fumes. In electric welding, bridge rectifier circuits are used to supply steady and polarized DC voltage.

- **It is also used in AM radio**
- A half-wave rectifier is used in AM radio as a detector because the output consists of an audio signal. Due to the less intensity of the current, it is of very little use to the more complex rectifier.
- **Uses of Rectifier in circuits**
- A half-wave rectifier is used in firing circuits and pulse generating circuits.
- **It is used for modulation**
- A half-wave rectifier is used to demodulate the amplitude of a modulated signal. In a radio signal, a full-wave bridge rectifier is used to detect the amplitude of a modulating signal.
- **It is used in the voltage multiplier**
- For the purpose of the voltage multiplier, a half-wave rectifier is used.

Other Applications

- The rectifier diodes have many applications. Here are a few of the typical applications of diodes include:
- Rectifying a voltage, such as turning the AC into DC voltages
- Isolating signals from a supply
- Voltage Reference
- Controlling the size of a signal
- Mixing signals
- Detection signals
- Lighting systems

Example1

- **The applied input a.c. power to a half-wave rectifier is 100 watts. The d.c. output power obtained is 40 watts.**
  (i) What is the rectification efficiency ?
  (ii) What happens to remaining 60 watts ?

Solution 1

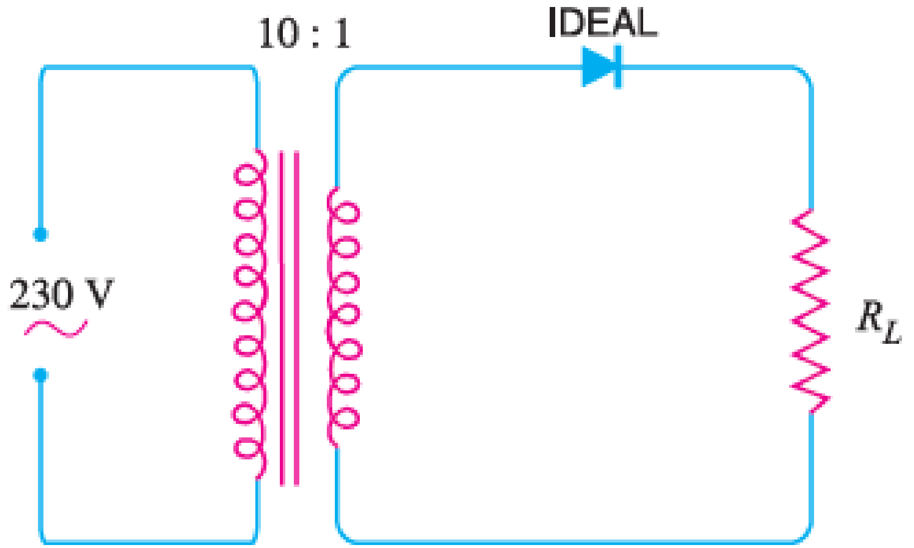
$$\text{Rectification efficiency} = \frac{\text{d.c. output power}}{\text{a.c. input power}} = \frac{40}{100} = 0.4 = 40\%$$

(ii) 40% efficiency of rectification does not mean that 60% of power is lost in the rectifier circuit.
The 100 W a.c. power is contained as 50 watts in positive half-cycles and 50 watts in negative half-cycles.
The 50 watts in the negative half-cycles are not supplied at all.
Only 50 watts in the positive half-cycles are converted into 40 watts.

$$\therefore \quad \text{Power efficiency} = \frac{40}{50} \times 100 = 80\%$$

Example 2

- **An a.c. supply of 230 V is applied to a half-wave rectifier circuit through a transformer of turn ratio 10 : 1. Find (i) the output d.c. voltage and (ii) the peak inverse voltage. Assume the diode to be ideal.**



Solution 2

$$\frac{N_1}{N_2} = 10$$

R.M.S. primary voltage

$$= 230 \text{ V}$$

$\therefore$ Max. primary voltage is

$$V_{pm} = (\sqrt{2}) \times \text{r.m.s. primary voltage}$$

$$= (\sqrt{2}) \times 230 = 325.3 \text{ V}$$

$$V_{sm} = V_{pm} \times \frac{N_2}{N_1} = 325.3 \times \frac{1}{10} = 32.53 \text{ V}$$

$$I_{d.c.} = \frac{I_m}{\pi}$$

$$V_{dc} = \frac{I_m}{\pi} \times R_L = \frac{V_{sm}}{\pi} = \frac{32.53}{\pi} = \mathbf{10.36 \text{ V}}$$

(ii) During the negative half-cycle of a.c. supply, the diode is reverse biased and hence conducts no current. Therefore, the maximum secondary voltage appears across the diode.

$$\therefore \quad \text{Peak inverse voltage} = \mathbf{32.53\ V}$$

Example 3

- **A crystal diode having internal resistance r_f = 20Ω is used for half-wave rectification. If the applied voltage v = 50 sin ω t and load resistance R_L= 800 Ω, find : (i) I_m, I_{dc}, I_{rms} (ii) a.c. power input and d.c. power output (iii) d.c. output voltage (iv) efficiency of rectification.**

Solution 3

$$v = 50 \sin \omega t$$

$$\therefore \quad \text{Maximum voltage, } V_m = 50 \text{ V}$$

(i)

$$I_m = \frac{V_m}{r_f + R_L} = \frac{50}{20 + 800} = 0.061 \text{ A} = \mathbf{61\ mA}$$

$$I_{dc} = I_m/\pi = 61/\pi = \mathbf{19.4\ mA}$$

$$I_{rms} = I_m/2 = 61/2 = \mathbf{30.5\ mA}$$

(ii)

$$\text{a.c. power input} = (I_{rms})^2 \times (r_f + R_L) = \left(\frac{30.5}{1000}\right)^2 \times (20 + 800) = \mathbf{0.763\ watt}$$

$$\text{d.c. power output} = I_{dc}^2 \times R_L = \left(\frac{19.4}{1000}\right)^2 \times 800 = \mathbf{0.301\ watt}$$

(iii)

$$\text{d.c. output voltage} = I_{dc} R_L = 19.4\,\text{mA} \times 800\,\Omega = \mathbf{15.52\ volts}$$

(iv)

$$\text{Efficiency of rectification} = \frac{0.301}{0.763} \times 100 = \mathbf{39.5\%}$$

Example 4

- **A half-wave rectifier is used to supply 50V d.c. to a resistive load of 800 Ω. The diode has a resistance of 25 Ω. Calculate a.c. voltage required.**

Solution4

$$\text{Output d.c. voltage, } V_{dc} = 50\text{ V}$$

$$\text{Diode resistance, } r_f = 25\ \Omega$$

$$\text{Load resistance, } R_L = 800\ \Omega$$

Let V_m be the maximum value of a.c. voltage required.

$$\therefore \quad V_{dc} = I_{dc} \times R_L$$

$$= \frac{I_m}{\pi} \times R_L = \frac{V_m}{\pi(r_f + R_L)} \times R_L \qquad \left[\because I_m = \frac{V_m}{r_f + R_L}\right]$$

or

$$50 = \frac{V_m}{\pi(25 + 800)} \times 800$$

$$\therefore \quad V_m = \frac{\pi \times 825 \times 50}{800} = \mathbf{162\ V}$$

Hence a.c. voltage of maximum value 162 V is required.

Example 5

- **A full-wave rectifier uses two diodes, the internal resistance of each diode may be assumed constant at 20 Ω. The transformer r.m.s. secondary voltage from centre tap to each end of secondary is 50 V and load resistance is 980 Ω. Find : (i) the mean load current (ii) the r.m.s. value of load current.**

Solution 5

$$r_f = 20\ \Omega, \quad R_L = 980\ \Omega$$

$$\text{Max. a.c. voltage, } V_m = 50 \times \sqrt{2} = 70.7\ \text{V}$$

$$\text{Max. load current, } I_m = \frac{V_m}{r_f + R_L} = \frac{70.7\ \text{V}}{(20 + 980)\ \Omega} = 70.7\ \text{mA}$$

(i)

$$\text{Mean load current, } I_{dc} = \frac{2\,I_m}{\pi} = \frac{2 \times 70.7}{\pi} = \mathbf{45\ mA}$$

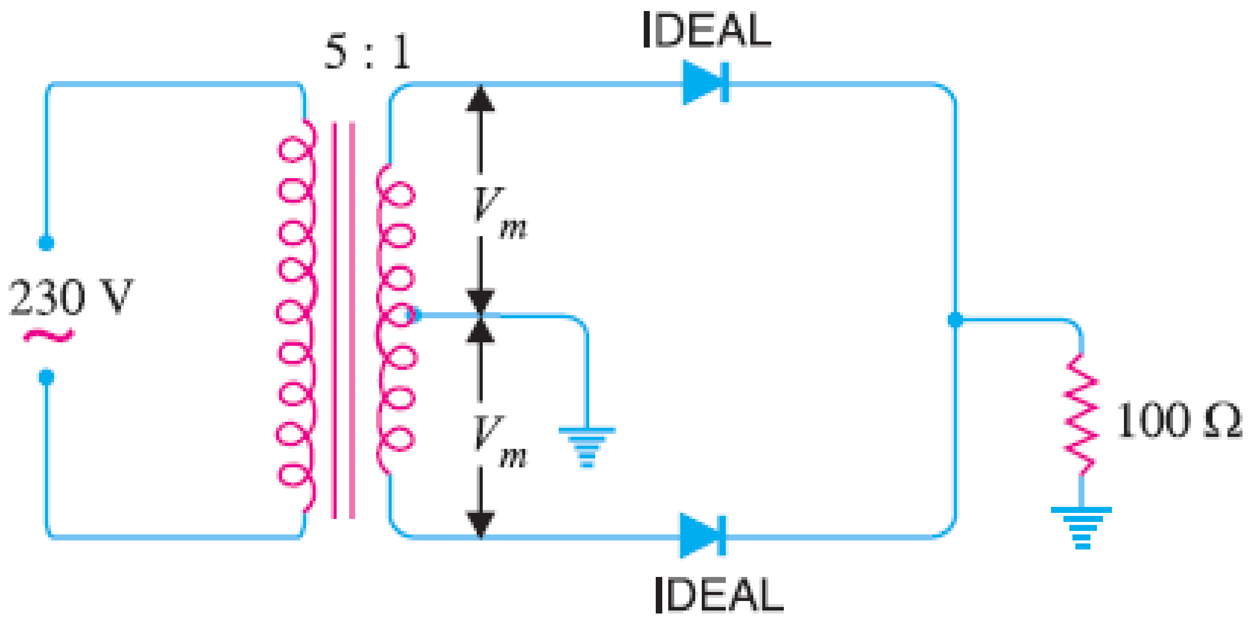
(ii)

R.M.S. value of load current is

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{70.7}{\sqrt{2}}\overrightarrow{AB} = \mathbf{50\ mA}$$

Example 6

- **In the centre-tap circuit shown in Fig. 2, the diodes are assumed to be ideal i.e. having zero internal resistance. Find :(i) d.c. output voltage(ii) peak inverse voltage (iii) rectification efficiency.**



Solution 6

Primary to secondary turns, $N1 / N2 = 5$

R.M.S. primary voltage = 230 V

$\therefore$ R.M.S. secondary voltage

$$= 230 \times (1/5) = 46\text{ V}$$

Maximum voltage across secondary

$$= 46 \times \sqrt{2} = 65\text{V}$$

Maximum voltage across half secondary winding is

$$V_m = 65/2 = 32.5\text{ V}$$

(i) Average current, Idc =

$$\frac{2V_m}{\pi R_L} = \frac{2 \times 32.5}{\pi \times 100} = 0.207 \text{ A}$$

(ii) The peak inverse voltage is equal to the maximum secondary voltage, i.e

$$PIV = \mathbf{65\ V}$$

(iii)

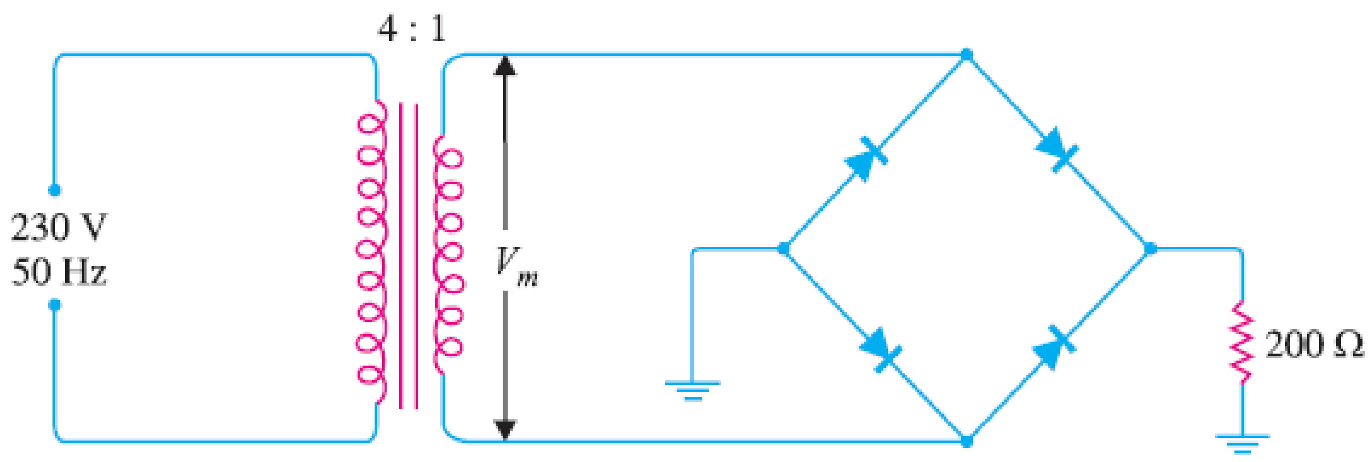
$$\text{Rectification efficiency} = \frac{0.812}{1 + \frac{r_f}{R_L}}$$

$$\text{Since } r_f = 0$$

$$\text{Rectification efficiency} = \mathbf{81.2\ \%}$$

Example 7

- **In the bridge type circuit shown in Fig. 3, the diodes are assumed to be ideal. Find : (i) d.c. output voltage (ii) peak inverse voltage (iii) output frequency. Assume primary to secondary turns to be 4.**



Solution 7

Primary/secondary turns, $N_1/N_2 = 4$

$$\text{R.M.S. primary voltage} = 230 \text{ V}$$

$$\therefore \quad \text{R.M.S. secondary voltage} = 230\,(N_2/N_1) = 230 \times (1/4) = 57.5 \text{ V}$$

Maximum voltage across secondary is

$$V_m = 57.5 \times \sqrt{2} = 81.3 \text{ V}$$

(*i*) $$\text{Average current, } I_{dc} = \frac{2V_m}{\pi R_L} = \frac{2 \times 81.3}{\pi \times 200} = 0.26 \text{ A}$$

$$\therefore \quad \text{d.c. output voltage, } V_{dc} = I_{dc} \times R_L = 0.26 \times 200 = \mathbf{52\ V}$$

(*ii*) The peak inverse voltage is equal to the maximum secondary voltage *i.e.*

$$PIV = \mathbf{81.3\ V}$$

(*iii*) In full-wave rectification, there are two output pulses for each complete cycle of the input a.c. voltage. Therefore, the output frequency is twice that of the a.c. supply frequency *i.e.*

$$f_{out} = 2 \times f_{in} = 2 \times 50 = \mathbf{100\ Hz}$$