In this section, you have learned about practical diode model. Now, let's discuss the application of the p-n junction diode as a rectifier.

Using the Diode as a Rectifier

The p-n junction semiconductor diode can be used for the following different applications:

- Rectifier circuits
- Clipper circuits
- Clamper circuits
- Voltage multiplier circuits

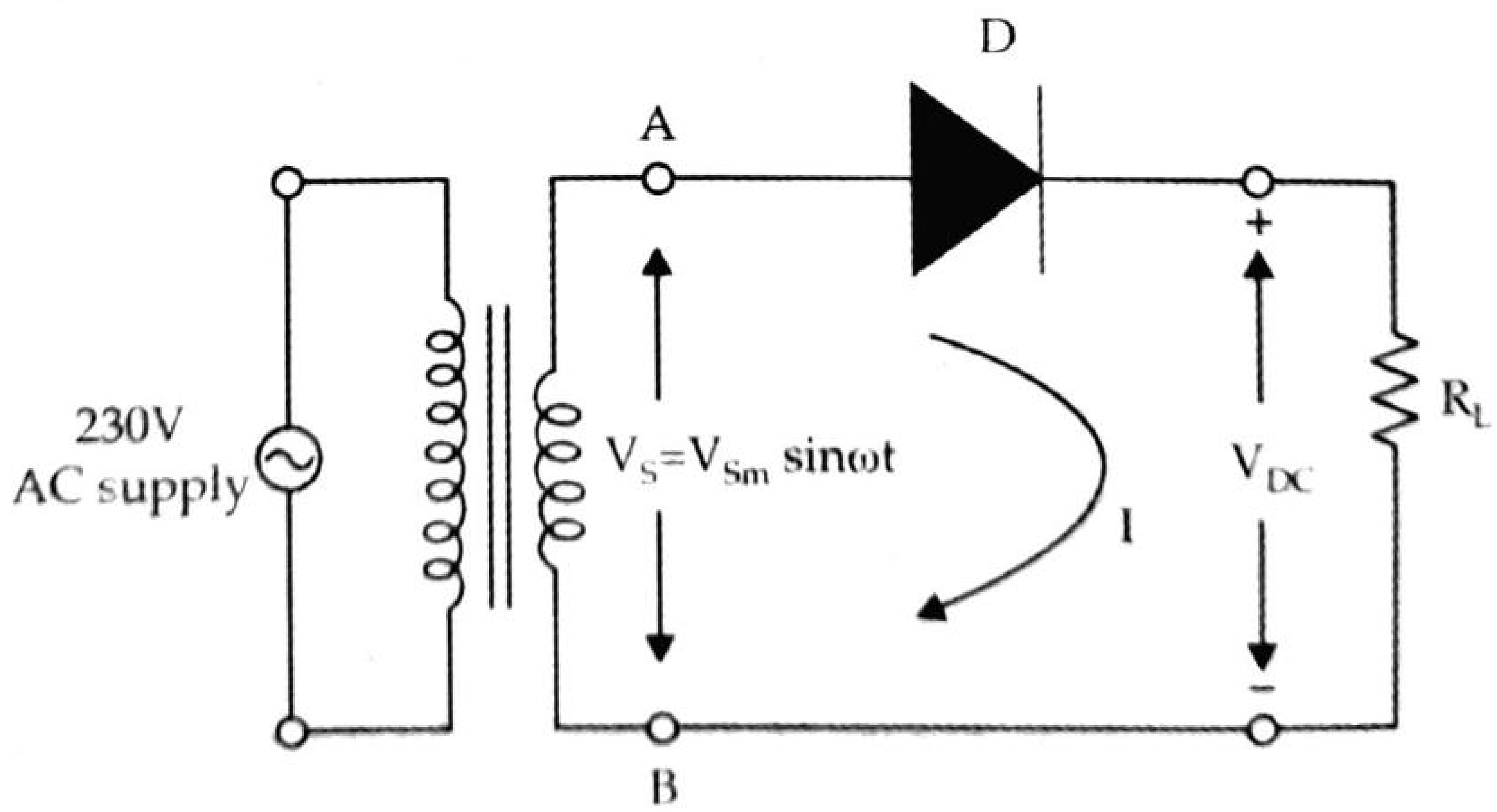
Out of these four applications of diodes, we discuss the use of diodes only in rectifier circuits. A rectifier is a device that converts AC to DC, and the process of converting AC to DC is called rectification. A rectifier circuit contains diodes which offer low resistance to the current in forward direction and a high resistance to the current in opposite (reverse) direction. As diode passes the current in forward bias as a short circuit and do not conduct in reverse bias as a open circuit so they are using for the rectification purpose of an AC signal. There are three types of rectifier circuits mostly used for commercial as well as in domestic purpose, and they are as follows:

- Half-wave rectifier (HWR)
- Full-wave rectifier (FWR)
- Full-wave bridge rectifier (FWBR)

Now, let's discuss about each of these rectifier circuits in detail one by one in the following sections.

Half-Wave Rectifier

An HWR consists of a rectifying element (diode) in series with the load resistor (R_L). This circuit is coupled to a transformer, which is connected across an AC supply. In HWR, rectifying element i.e. diode conducts during the positive half cycle of input AC supply only and not in the negative half cycle. An HWR circuit is shown in Figure 27:



▲ **Figure 27: Displaying the Circuit Diagram of an HWR**

From Figure 27, we get the following equations:

$$\frac{N_2}{N_1} = \frac{V_{SM}}{V_{PM}}$$

where:

$N2$ = secondary coil turns

$N1$ = primary coil turns

V_{SM} = secondary voltage (peak value)

V_{PM} = primary voltage (peak value).

The secondary voltage of the transformer can be written as:

$$V_s = V_{SM} \sin \omega t$$

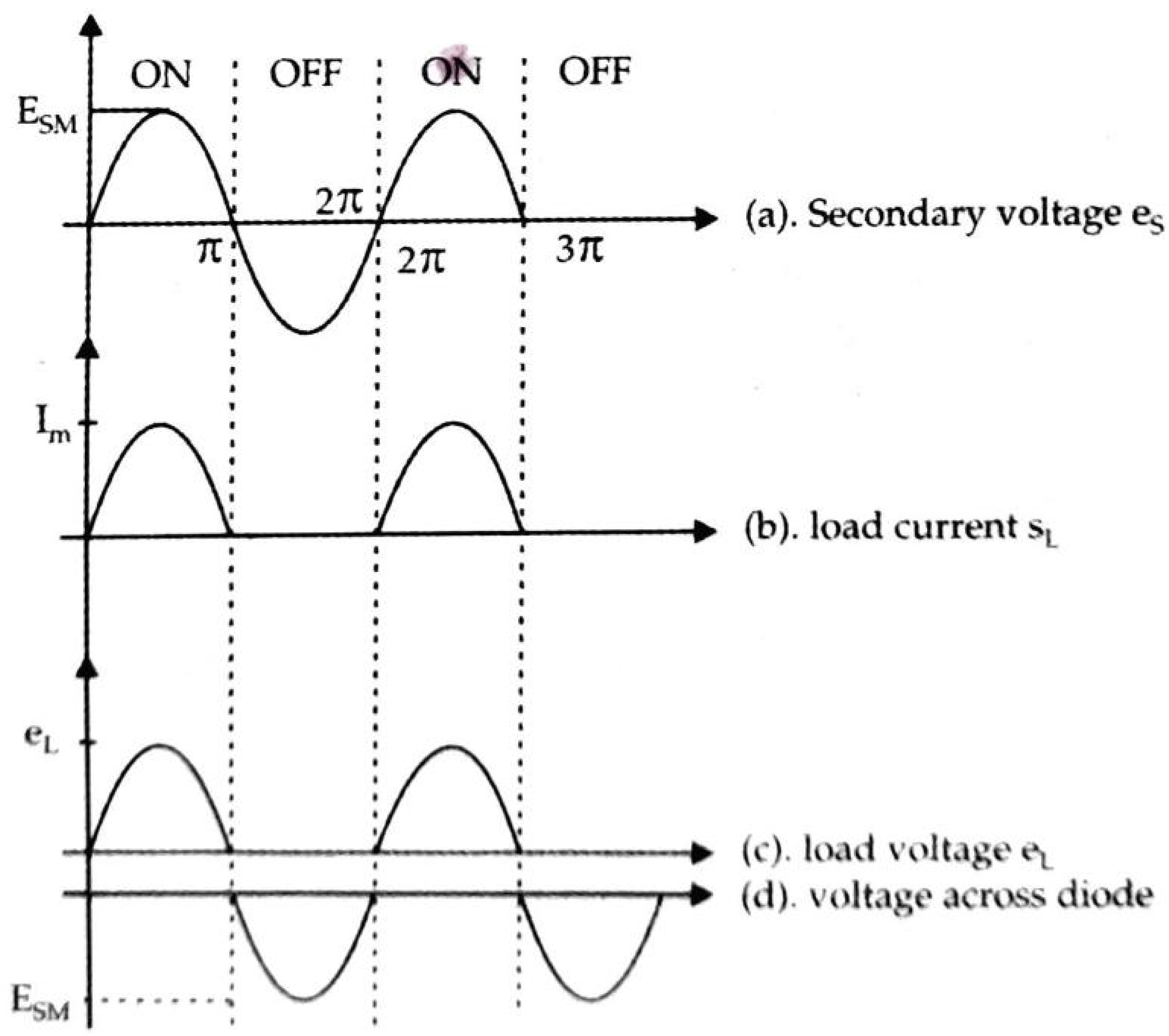
where:

$\omega = 2\pi f$

f = supply frequency (50 HZ).

In the positive half cycle of the AC voltage supply, point A becomes positive and point B becomes negative. Therefore, the diode D conducts and the output nearly equals to the applied input voltage. In the negative half cycle, point A becomes negative and point B becomes positive. At this point, the diode (D) does not conduct, which means that it is reverse biased and acts as an open circuit. Therefore, no current flows through the load resistance (R_L) and the output is zero. Thus the negative half cycles of AC supply are eliminated from the output.

Figure 28 shows the input and output waveforms during the operation of HWR:



▲ **Figure 28: Displaying the Waveforms of HWR**

The DC output waveform is expected to be a straight line, but the HWR gives output in the form of positive sinusoidal pulses. Therefore, the output is called pulsating DC, and it is discontinuous in nature.

In the following discussions, we will analyze the HWR and derive various equations that govern the operation HWR.

Let's derive the equation for average voltage load current (I_{DC}).

The average or DC value of an AC is obtained by integrating the area under the curve over one complete cycle between the limits, from 0 to 2π, and then dividing it by the base (2π).

Now, we have:

$$i_L = I_M \sin\omega t\,, \quad \text{for } 0 \le \omega t \le \pi$$

$$i_L = 0\,, \quad \text{for } \pi \le \omega t \le 2\pi$$

where I_M = peak value of the load current.

The average DC load current is written by the following equation:

$$I_{DC} = \frac{1}{2\pi}\int_0^{2\pi} i_L\, d(\omega t)$$

$$= \frac{1}{2\pi}\int_0^{2\pi} I_M \sin(\omega t)\, d(\omega t)$$

As no current flows during the negative half cycle of the AC input voltage between π and 2π, we have to change the limits of integration; then, the preceding equation can be written as:

$$I_{DC} = \frac{1}{2\pi}\int_0^{\pi} I_M \sin(\omega t)\, d(\omega t)$$

$$= \frac{I_M}{2\pi}\left[-\cos\omega t\right]_0^{\pi}$$

$$= -\frac{I_M}{2\pi}\left[\cos\pi - \cos 0\right]$$

$$= -\frac{I_M}{2\pi}\left[-1-1\right]$$

$$= \frac{I_M}{\pi}$$

$$\therefore I_{DC} = \frac{I_M}{\pi} \qquad (3)$$

By applying KVL in the circuit shown in Figure 27, we get:

$$I_M = \frac{V_{SM}}{R_F + R_L + R_S} \qquad (4)$$

where:

R_S = resistance of the secondary winding of transformer

R_F = forward resistance of the diode

R_L = load resistance

Normally, the values of R_s and R_F are very small as compared to R_L. Therefore, neglecting the value of R_s and R_F in equation (4), we get:

$$I_M = \frac{V_{SM}}{R_L} \qquad (5)$$

Now, let's derive the equation for average DC load voltage (V_{DC}).

V_{DC} is the product of average DC load current I_{DC} and load resistance R_L, i.e.

$$\therefore\ V_{DC} = I_{DC} \times R_L \qquad (6)$$

Putting the value of I_{DC} from equation (3) into equation (6), we get:

$$V_{DC} = \frac{I_M R_L}{\pi}$$

$$= \frac{V_{SM}}{\pi(R_F + R_L + R_S)} \times R_L \quad \text{(Putting the value of } I_m \text{ from equation) (5)}$$

$$= \frac{V_{SM}}{\pi\left[\frac{R_F + R_S}{R_L} + 1\right]} \qquad (7)$$

Given that R_F and R_S are very small as compared to R_L, therefore $(R_F + R_S)/R_L$ is very small and can be neglected.

$$\therefore \frac{R_F + R_S}{R_L} + 1 \approx 1$$

From equation (7), we get:

$$V_{DC} \approx \frac{V_{SM}}{\pi}$$

Now, let's derive the equation for root mean square (RMS) value of the load current (I_{RMS}).

The RMS value is the square root of arithmetic mean of the squares of original values. The RMS value of the load current is expressed as follows:

$$I_{RMS} = \sqrt{\frac{1}{2\pi}\int_0^{\pi}(I_M \sin \omega t)^2 d(\omega t)}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi}(I_M{}^2 \sin^2 \omega t) d(\omega t)}$$

$$= I_M\sqrt{\frac{1}{2\pi}\int_0^{\pi}\frac{[1 - \cos(2\omega t)]d(\omega t)}{2}} \qquad \left[\text{Putting} \quad \sin^2 \omega t = \frac{1 - \cos 2\omega t}{2}\right]$$

$$= I_M\sqrt{\frac{1}{2\pi}\left\{\frac{\omega t}{2} - \frac{\sin(2\omega t)}{4}\right\}_0^{\pi}}$$

$$= I_M\sqrt{\frac{1}{2\pi}\left\{\frac{\pi}{2} - 0\right\}}$$

$$= I_M\sqrt{\frac{1}{2\pi}\left(\frac{\pi}{2}\right)}$$

$$\therefore\ I_{RMS} = \frac{I_M}{2} \qquad (8)$$

Now, let's derive the equation for the RMS value of the load voltage (V_{LRMS}).

The RMS value of the load voltage is the RMS value of the total output voltage, which includes DC output as well as the AC ripples. As the load is resistive, the RMS value of the load voltage is given by:

$$V_{L(RMS)} = I_{RMS}R_L$$

Putting the value of I_{RMS} from equation (8) in the preceding equation, we get:

$$V_{L(RMS)} = \frac{I_M}{2}\times R_L \qquad (9)$$

Putting the value of I_M from equation (5) into equation (9), we get:

$$V_{L(RMS)} = \frac{V_{SM}}{2(R_F + R_L + R_S)}\times R_L$$

$$= \frac{V_{SM}}{2[1+(R_F + R_S)/R_L]}$$

$$\text{If } R_L >> R_F + R_L, \text{ then } 1+\left[\frac{R_F + Rs}{R_L}\right] \approx 1$$

$$\therefore V_{L(RMS)} = \frac{V_{SM}}{2}$$

Now, let's derive the equation for DC power output (P_{DC}).

P_{DC} is the product of DC voltage (V_{DC}) and current (I_{DC}), which is given by:

$$P_{DC} = V_{DC}I_{DC} = I^2_{DC}R_L \qquad (\text{Putting } V_{DC} = I_{DC}\ R_L)$$

$$= \left[\frac{I_M}{\pi}\right]^2 \times R_L \qquad \left(\text{Putting } I_{DC} = \frac{I_M}{\pi}\right) \qquad (10)$$

$$\therefore P_{DC} = \frac{V^2_{SM}R_L}{\pi^2[R_F + R_L + R_S]^2} \qquad \left(\text{Putting } I_M = \frac{V_{SM}}{R_F + R_L + R_S}\right)$$

If $R_L >> R_F + R_S$, we have:

$$P_{DC} = \frac{V^2_{SM}\ R_L}{\pi^2 \times {R_L}^2}$$

$$\therefore\ P_{DC} = \left(\frac{V_{SM}}{\pi}\right)^2 \times \frac{1}{R_L}$$

Now, let's derive the equation for AC power output (P_{AC}).

The power input taken from the secondary side of the transformer is the power supplied to three resistances, such as load resistance (R_L), the diode resistance (R_F), and winding resistance (R_s), and is given by:

$$P_{AC} = I_{RMS}^2 [R_F + R_L + R_S]$$

$$\therefore P_{AC} = \frac{I_M^2}{4}[R_F + R_L + R_S] \qquad \left(\text{Putting } I_{RMS} = \frac{I_M}{2}\right) \qquad (11)$$

Now, let's derive the equation for rectifier efficiency (η).

The rectifier efficiency (η) is defined as the ratio of output DC power to input AC power, which is expressed in percentage, and is mathematically expressed as:

$$\eta = \frac{P_{DC}}{P_{AC}} \times 100$$

Substituting the values of P_{DC} and P_{AC} from equation (10) and (11) into the preceding equation, we get:

$$\eta = \frac{\dfrac{I_M^2}{\pi^2} R_L}{\dfrac{I_M^2}{4}[R_F + R_L + R_S]} \times 100$$

$$= \frac{4}{\pi^2} \times \frac{R_L}{[R_F + R_L + R_S]} \times 100$$

$$= \frac{0.406}{1 + \left(\dfrac{R_F + R_S}{R_L}\right)} \times 100 \qquad \left(\text{Putting } \frac{4}{\pi^2} = 0.406\right)$$

If $R_F + R_S << R_L$, then the maximum theoretical efficiency of HWR $\eta = 0.406$ or $\eta = 40.6\%$.

From the preceding equation, it can be concluded that in HWR, a maximum 40.6% of AC power gets converted to DC power in the load. The remaining 59.4% power is present in terms of ripples, which are fluctuating in nature and are undesirable. The lesser is the rectification efficiency, the more is the ripple contents in the output and vice versa.

Now, let's derive the equation for ripple factor (γ).

The output of HWR is not pure DC, but it is a pulsating DC. Ideally, there should not be any type of ripples present in the rectifier output. The measurement of such type of ripples present in the output is done with the help of a physical quantity called as ripple factor (γ). Ripple factor indicates that how effectively the circuit converts the applied AC input to pure DC output. The value of ripple factor should be as small as possible.

A ripple factor is defined as the ratio of RMS value of the AC component present in the output to DC component present in the output, simultaneously. Therefore, ripple factor can be written as:

$$\therefore \gamma = \frac{V_{RMS}}{V_{DC}} \quad \text{Or} \quad \frac{I_{AC}}{I_{DC}}$$

The output current is composed of AC component as well as DC component. Therefore, the RMS current is given by the following equation:

$$I_{RMS} = \sqrt{I_{AC}^2 + I_{DC}^2}$$

$$\therefore I_{AC} = \sqrt{I_{RMS}^2 - I_{DC}^2}$$

Dividing the previous equation by I_{DC}, we get:

$$\gamma = \frac{I_{AC}}{I_{DC}} = \frac{\sqrt{I_{RMS}^2 - I_{DC}^2}}{I_{DC}}$$

$$\text{or} \quad \gamma = \sqrt{\left(\frac{I_{RMS}}{I_{DC}}\right)^2 - 1}$$

$$\therefore \gamma = 1.21 \qquad \left(\text{Putting } I_{RMS} = \frac{I_M}{2} \text{ and } I_{DC} = \frac{I_M}{\pi}\right)$$

The preceding equation indicates that the ripple contents in the output are 1.21 times the DC component. Hence, it can be concluded that the ripple factor for HWR is very high, which indicates that the HWR circuit is a poor converter of AC into DC. The ripple factor can possibly, minimized by the use of filters in the circuit along with the rectifiers. Now, let's discuss the transformer utilization factor (TUF).

TUF is represented by the ratio of DC power to the AC power rating of the secondary coil of the transformer used in front of the rectifier circuit. The utilization factor for HWR is given by:

$$\text{TUF} = \frac{\text{DC power delivered to the load}}{\text{RMS value of the AC input voltage}}$$

$$\text{TUF} = \frac{I_{DC}^2 \times R_L}{V_{RMS} \times I_{RMS}}$$

By substituting the corresponding values of I_{DC}, V_{RMS}, and I_{RMS} in the preceding equation, we get:

$$\text{TUF} = 0.287$$

This indicates that only 40.6% of the transformer is put to use and the rest is unused. This decreases the efficiency of the circuit.

The advantages of HWR are as follows:

- Very simple in construction
- Single diode is required this will make it cheaper
- Size is small, so easily can be used in small devices

The disadvantages of HWR are as follows:

- Ripple factor is very high (i.e. $\gamma = 1.21$)
- Rectification efficiency is very less, as power is delivered for only the half-cycle
- Transformer utilization factor is low i.e. TUF = 0.287
- Low DC output voltage and current

- The transformer core may get saturated due to the unidirectional flow of current, which may led to magnetizing current and hysteresis losses in the transformer i.e. low power at the input of rectifier.
- Large values of filter components will be required as the ripple factor is more, which means that the size of the capacitor increases

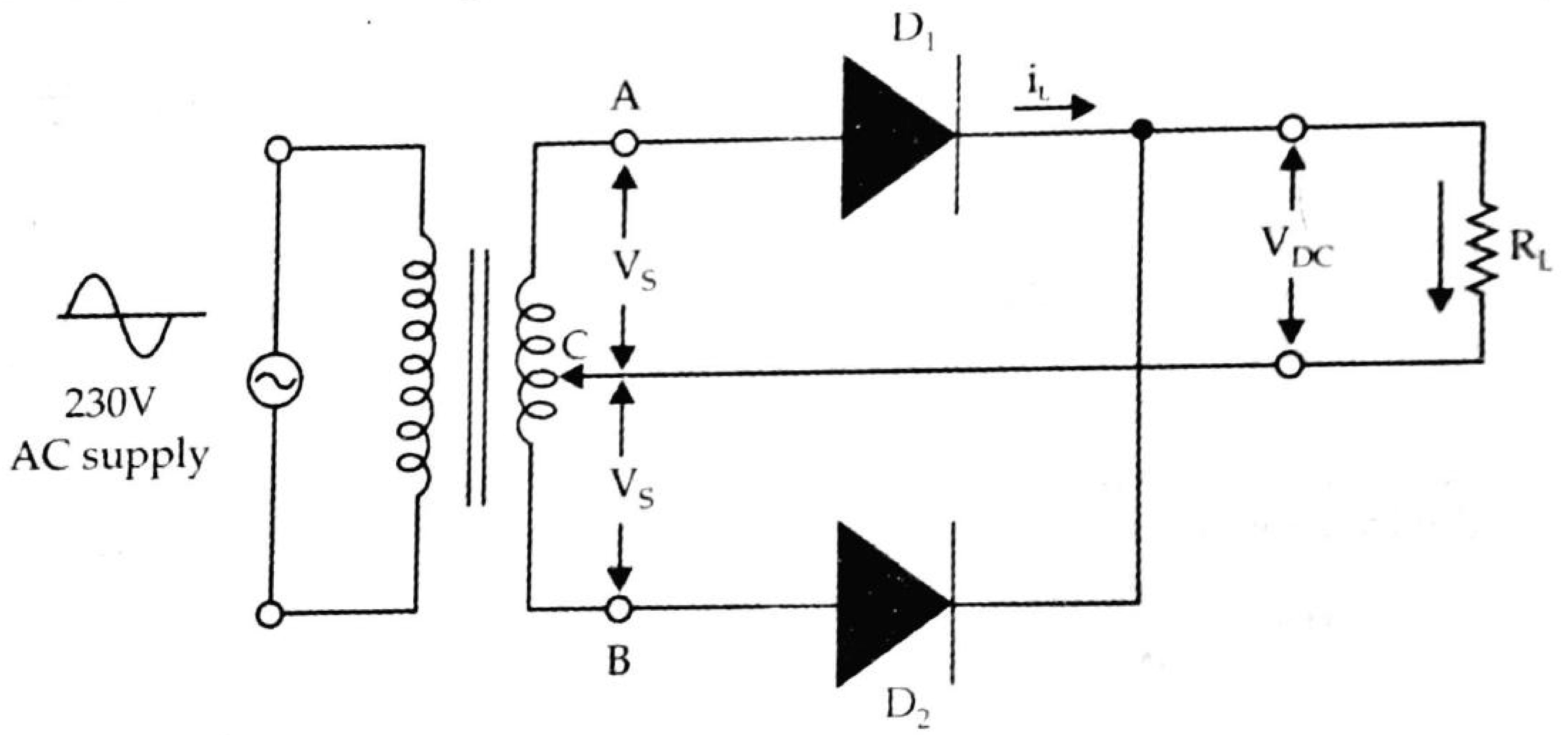
HWR is used in low-cost power supplier such as:

- Battery charger
- Charger adapter for walkman type devices

Full-Wave Rectifier

An FWR conducts electricity in both the positive and negative half cycles of the input AC power supply. It uses two diodes to rectify in both the cycles of an AC power input.

Figure 29 shows the circuit diagram of an FWR:

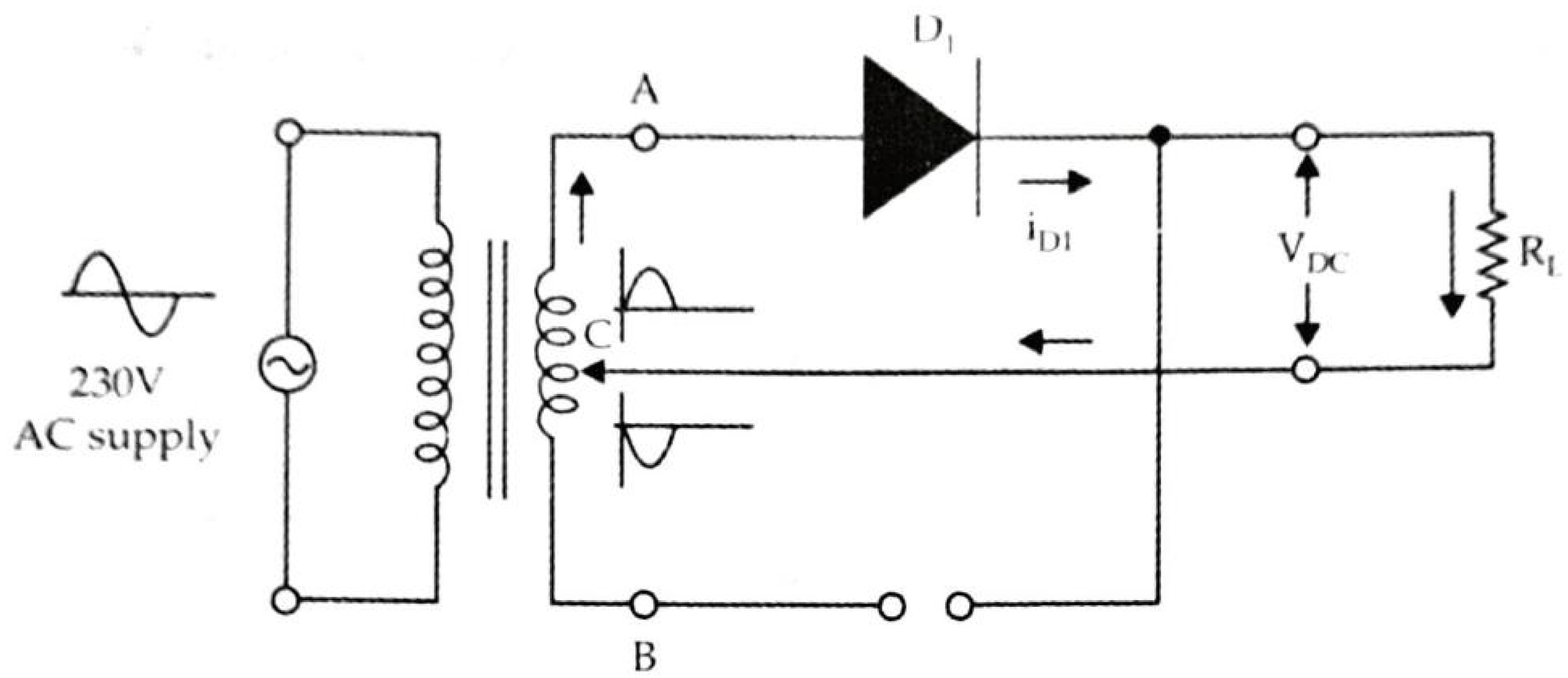


▲ **Figure 29: Displaying the Circuit Diagram of an FWR**

In Figure 29, it can be seen that the diodes D_1 and D_2 feed a common load resistance R_L with the help of a center-tap transformer. The secondary winding of a center-tap transformer is connected by wire called as tap, so that it can be fixed on the secondary coil to get the half of the voltage along the coil, corresponding to both the ends of a secondary coil. The center-tap transformer, usually have three output wire used in combination of two output power supply from the secondary coil in relation to low voltage with high current. It has a common center-tapped connection (C). Each part of the transformer provides source voltage to the diodes D_1 and D_2.

Consider the positive half cycle of the AC input voltage in which terminal A is at positive potential with respect to terminal B. The diode D_1 is in forward biased conducts electric current in positive cycle, while the diode D_2 is in reverse biased will act as an open circuit and does not conduct the electric current.

Figure 30 shows the circuit diagram of an FWR during the positive half cycle of the AC input voltage:

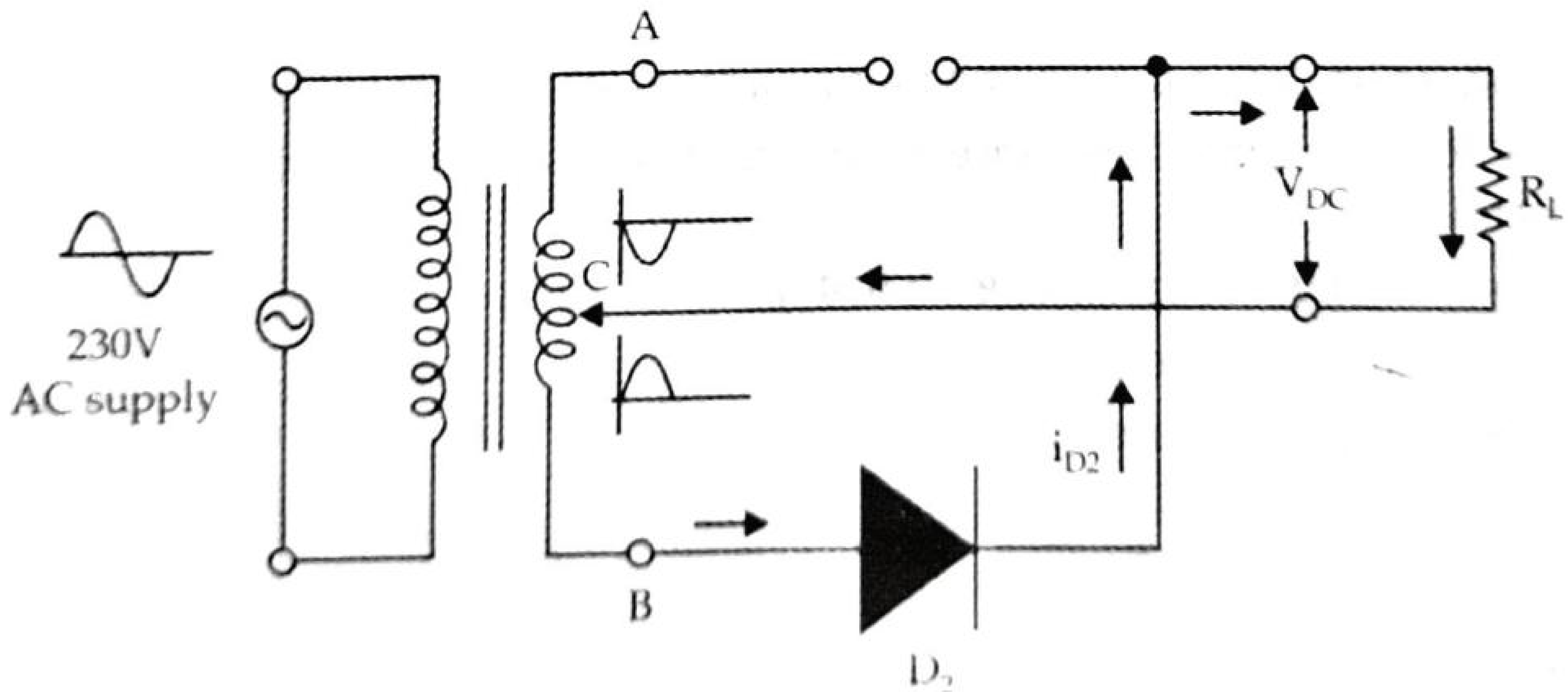


▲ **Figure 30: Displaying Equivalent Circuit of an FWR during the Positive Half Cycle of the AC Input Voltage**

In Figure 30, it can be seen that the diode D_1 supplies the load current where $i_L = i_{D1}$. The current flowing through the half of secondary winding of the transformer connected to load through the diode D_1, while the other half of secondary winding of the transformer carries no current as the diode D_2 connected in reverse bias in the positive cycle, acts as an open circuit.

In the next half cycle of the AC input voltage, polarity reverses, which means that the terminal A becomes negative and terminal B becomes positive with respect to each other. The diode D_2 conducts as it is forward biased, which supplies the load current to the resistor. Now, the other half of the secondary coil carries the current, but the upper half does not conducts because of the open circuit in the negative cycle.

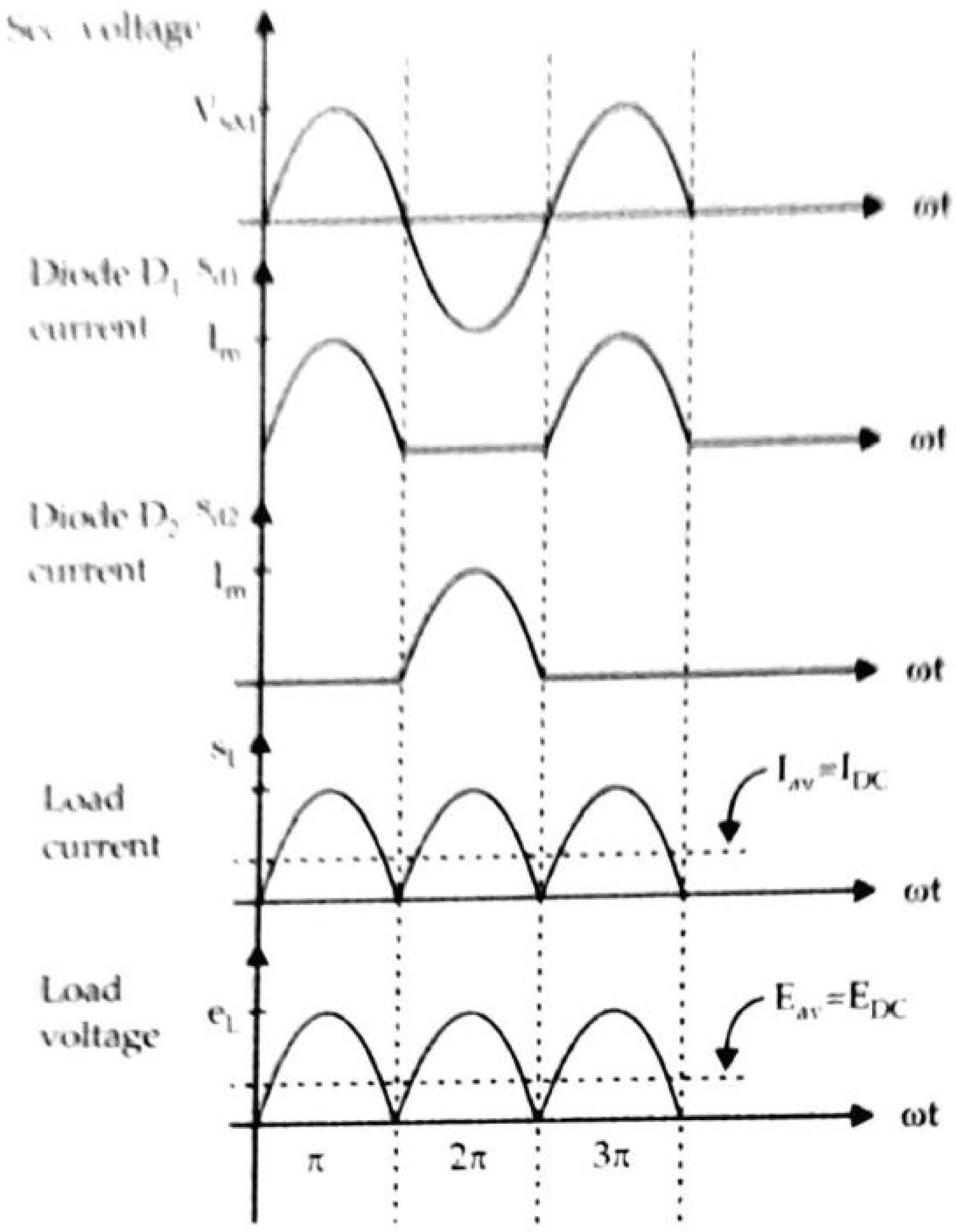
Figure 31 shows the circuit diagram of an FWR during the negative half cycle of the AC input voltage:



▲ **Figure 31: Displaying Equivalent Circuit of an FWR during the Positive Half Cycle of the AC Input Voltage**

It is observed that the load current flowing in both of the half cycles of AC voltage supply in the same direction through the load resistance. Therefore, we get rectified output across the load. The load current at the output resistance i.e. load resistance is the collected amount of individual current flowing from the diode in the corresponding positive and negative half cycles. The two diodes D_1 and D_2 do not conduct at same instance, because only one diode remains in the circuit in their corresponding cycle and other one acted as an open circuit. They both are conducting in alternate half cycles one after other to make the output, always be a positive wave dc.

Figure 32 shows the different voltage and current waveforms of an FWR:



▲ **Figure 32: Displaying Voltage and Current Waveforms of an FWR**

The FWR circuit essentially consists of two HWR circuits, which work independently of each other, but feed a common load. The output load current is still a pulsating DC and not a pure DC.

Now, let us derive the equation for maximum load current (I_M) of an FWR.

Let R_f = forward resistance of the diodes (assuming that $R_{F1} = R_{F2} = R_F$, i.e. diodes are identical)

R_s = winding resistance of each half of the secondary side of the transformer

R_L = load resistance

∴ Maximum load current is given by:

$$I_M = \frac{V_{SM}}{R_F + R_L + R_S}$$

where V_{SM} is the maximum value of the AC input voltage.

Now, let us derive the equation for average DC load current (I_{DC}).

Consider one cycle of the load current i_L from 0 to π to obtain the value of I_{DC}.

The load current i_L can be expressed as follows:

$$i_L = I_M \sin \omega t, \qquad \text{for } 0 \le \omega t \le \pi$$

Now, the average DC load current is given by:

$$I_{Avg} = I_{DC} = \frac{1}{\pi}\int_0^{\pi} i_L\, d(\omega t) = \frac{1}{\pi}\int_0^{\pi} I_M \sin \omega t\, d\omega t$$

$$= \frac{I_M}{\pi}[-\cos\omega t]_0^\pi$$

$$\therefore \quad I_{DC} = \frac{2\,I_M}{\pi}$$

For HWR, $I_{DC} = \frac{I_M}{\pi}$; as FWR is the combination of two HWR circuits acting alternately in two half cycles of input, therefore the value of I_{DC} for FWR is $\frac{2\,I_M}{\pi}$

Now, let's derive the equation for average DC load voltage (V_{DC}).

The average DC load voltage V_{DC} for a FWR can be calculated by the following equation:

$$V_{DC} = I_{DC}R_L = \frac{2I_M}{\pi} \times R_L \qquad \left(\text{putting } I_{DC} = \frac{2I_M}{\pi}\right)$$

$$= \frac{2V_{SM} \times R_L}{\pi[R_F + R_L + R_S]} \qquad \left(\text{putting } I_M = \frac{V_{SM}}{(R_F + R_L + R_S)}\right)$$

$$= \frac{2V_{SM}}{\pi\left[1 + \frac{R_F + R_S}{R_L}\right]}$$

If $R_F + R_S << R_L$, then $\frac{R_F + R_S}{R_L}$ is very small, so it can be taken as $1 + \frac{R_F + R_S}{R_L} \approx 1$.

$$\therefore V_{DC} = \frac{2V_{SM}}{\pi}$$

Now let us derive the equation for RMS value of the load current (I_{RMS}).

The RMS value of the load current I_{RMS} of a FWR is written as:

$$I_{RMS} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i_L^2\,d\omega t}$$

$$= \sqrt{\frac{2}{2\pi}\int_0^{\pi} [I_M \sin\omega t]^2\,d\omega t}$$

$$= I_M\sqrt{\frac{1}{\pi}\int_0^{\pi}\left[\frac{1-\cos 2\omega t}{2}\right]d\omega t}$$

$$= I_M\sqrt{\frac{1}{2\pi}\left[[\omega t]_0^\pi - \left[\frac{\sin 2\omega t}{2}\right]_0^\pi\right]}$$

$$= I_M\sqrt{\frac{1}{2\pi}[\pi - 0]}$$

$$I_{RMS} = \frac{I_M}{\sqrt{2}}$$

Now, let us derive the equation for RMS value of the load voltage (V_{RMS}).

The variable V_{RMS} is the product of load resistance and RMS value of the current is given by:

$$V_{L(RMS)} = I_{RMS} \times R_L = \frac{I_M}{\sqrt{2}} \times R_L$$

The equation for DC power output (P_{DC}).

P_{DC} can be expressed as:

$$\begin{aligned} P_{DC} &= V_{DC} \times I_{DC} \\ &= I_{DC}^2 \times R_L \\ &= \left(\frac{2I_M}{\pi}\right)^2 \times R_L \\ &= \frac{4}{\pi^2} \times I_M^2 \times R_L \\ &= \frac{4}{\pi^2} \frac{V_{SM}^2}{(R_S + R_F + R_L)^2} \times R_L \end{aligned}$$

The equation for AC input power (P_{AC}) can be expressed as follows:

$$P_{AC} = I_{RMS}^2 (R_F + R_S + R_L) = \left(\frac{I_M}{\sqrt{2}}\right)^2 (R_F + R_S + R_L)$$

$$= \frac{I_M^2}{2}(R_F + R_S + R_L)$$

$$= \frac{V_{SM}^2}{2(R_F + R_S + R_L)}$$

Now, the equation for rectifier efficiency (η) of a FWR is as:

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

By putting the values of P_{DC} and P_{AC} in the preceding equation, we get:

$$\eta = \frac{\dfrac{4}{\pi^2} \dfrac{V_{SM}^2}{(R_S + R_F + R_L)^2} \times R_L}{\dfrac{V_{SM}^2}{2(R_F + R_S + R_L)}}$$

$$= \frac{8R_L}{\pi^2 (R_F + R_S + R_L)}$$

If $R_L >> R_S + R_F$, then (R_s + R_F) can be neglected, so we get the following equation:

$$\eta = \frac{8R_L}{\pi^2 \times R_L}$$

$$= \frac{8}{\pi^2}$$

$$=0.812$$

$$=0.812\%$$

The expression for ripple factor (γ) of a FWR is as:

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

Putting $I_{RMS} = \frac{I_M}{\sqrt{2}}$ and $I_{DC} = \frac{2I_M}{\pi}$ in the preceding equation, we get the following result:

$$\gamma = \sqrt{\frac{\pi^2}{8} - 1}$$

$$= 0.48$$

Therefore, from the preceding discussion, it is clear that the value of ripple factor for a FWR is less than that for an HWR.

Now, let us find the expression for peak inverse voltage (PIV), which is the maximum value of applied reverse bias voltage along the ends of the diode before breakdown. It is the maximum instantaneous voltage that occurs in negative half cycle. The PIV for a FWR is given by:

$$PIV = 2V_{SM}$$

Now, let's find the expression for TUF. The TUF for a FWR is given by:

$$TUF = \frac{\text{DC power Delivered to the load}}{\text{RMS value of AC power input}}$$

$$TUF = \frac{I_{DC}^2 \times R_L}{V_{RMS} \times I_{RMS}}$$

Putting, $I_{RMS} = \frac{I_M}{\sqrt{2}}$, $V_{RMS} = \frac{I_M}{\sqrt{2}} \times R_L$, and $I_{DC} = \frac{2I_M}{\pi}$ in the previous equation, we get:

$$TUF = 0.812$$

The expression for voltage regulation (R), which is given by the varying DC output voltage as a function of the DC load current can be written as.

$$\text{Voltage Regulation} = \frac{\text{No Load Voltage} - \text{Full Load}}{\text{No Load Voltage}}$$

$$R = \frac{V_{NL} - V_{FL}}{V_{NL}} \times 100\%$$

Where:

$$V_{NL} = \text{No load voltage} = \frac{2V_M}{\pi}$$

$$V_{FL} = \text{Full load voltage} = I_{DC} \times R_L = \frac{2V_M}{\pi} \times \left(\frac{R_L}{R_S + R_F + R_L} \right)$$

$$\therefore R = \frac{\frac{2V_M}{\pi} - \frac{2V_M}{\pi}\left(\frac{R_L}{R_S + R_F + R_L} \right)}{\frac{2V_M}{\pi}}$$

$$= \frac{\frac{2V_M}{\pi}\left[1 - \frac{R_L}{R_S + R_F + R_L} \right]}{\frac{2V_M}{\pi}}$$

$$= \frac{R_S + R_F + R_L - R_L}{R_S + R_F + R_L}$$

$$= \frac{R_S + R_F}{R_S + R_F + R_L}$$

As R_S and R_F are very small as compared to R_L, so we can take:

$$R_S + R_F + R_L \approx R_L$$

$$\therefore R = \frac{R_S + R_F}{R_L}$$

From the above equation, it is observed that the voltage regulation depends on the following parameters:

- Resistance of the secondary coil of transformer(R_S)
- Forward resistance of the diode(R_F)
- Load resistance(R_L)

For a given circuit, the values of R_S and R_F are constant, and therefore, the regulation will be decided by the load resistance (R_L) only.

The advantages of FWR are as follows:

- The value of ripple factor is very less compared to the HWR
- Higher values of load voltage and current
- As current flows in both the half cycles, so there is no possibility of transformer core saturation
- Better value of TUF as compared to HWR
- Better efficiency compared to HWR

The disadvantages of FWR are as follows:

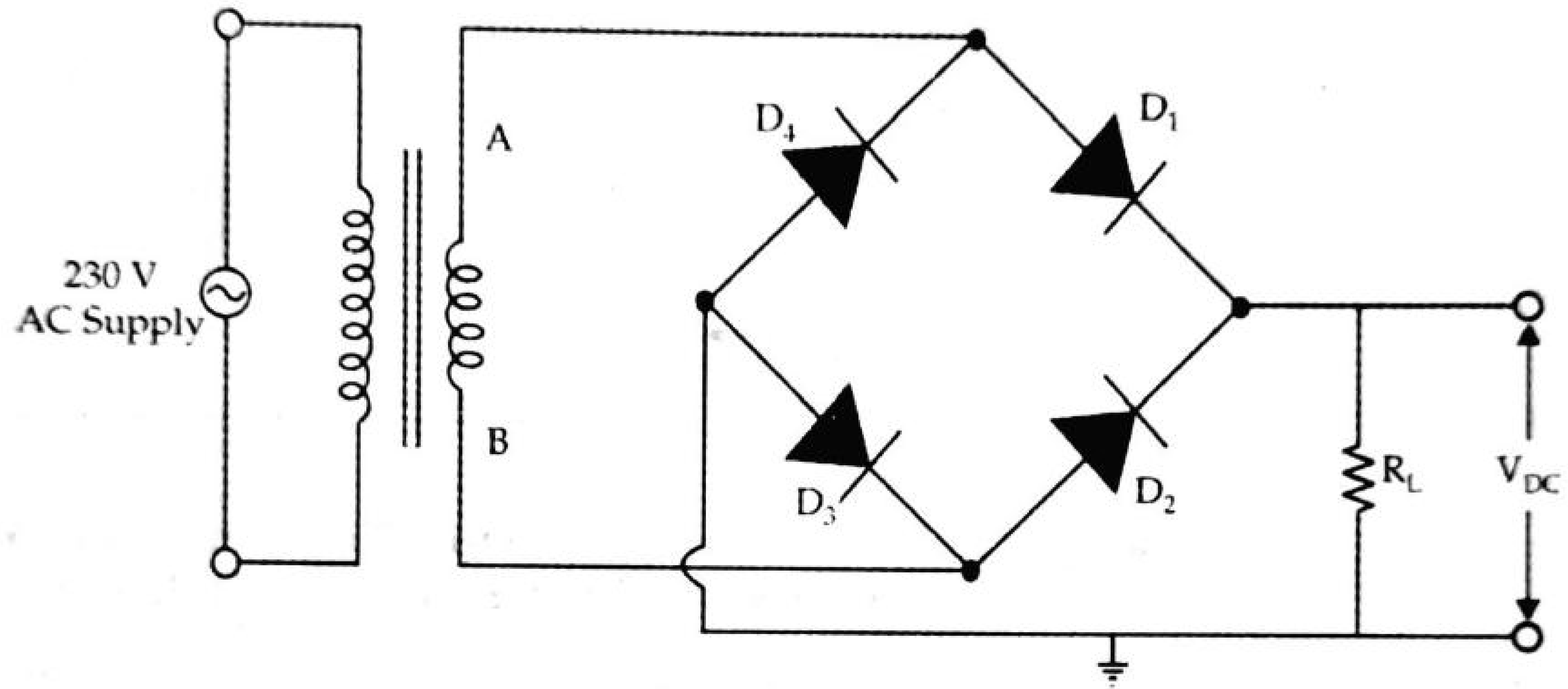
- The circuit becomes bulky due to the center-tap transformer

- The use of center-tap transformer in the circuit increases the cost as it is very expensive
- The peak voltage delivered by the FWR is less

Full-Wave Bridge Rectifier

As the secondary winding of the FWR is center tapped, the peak voltage delivered by this rectifier is half the peak voltage in the HWR. Moreover, the cost of a center-tap transformer is very high. These shortcomings of the FWR can be overcome by using the FWBR circuit.

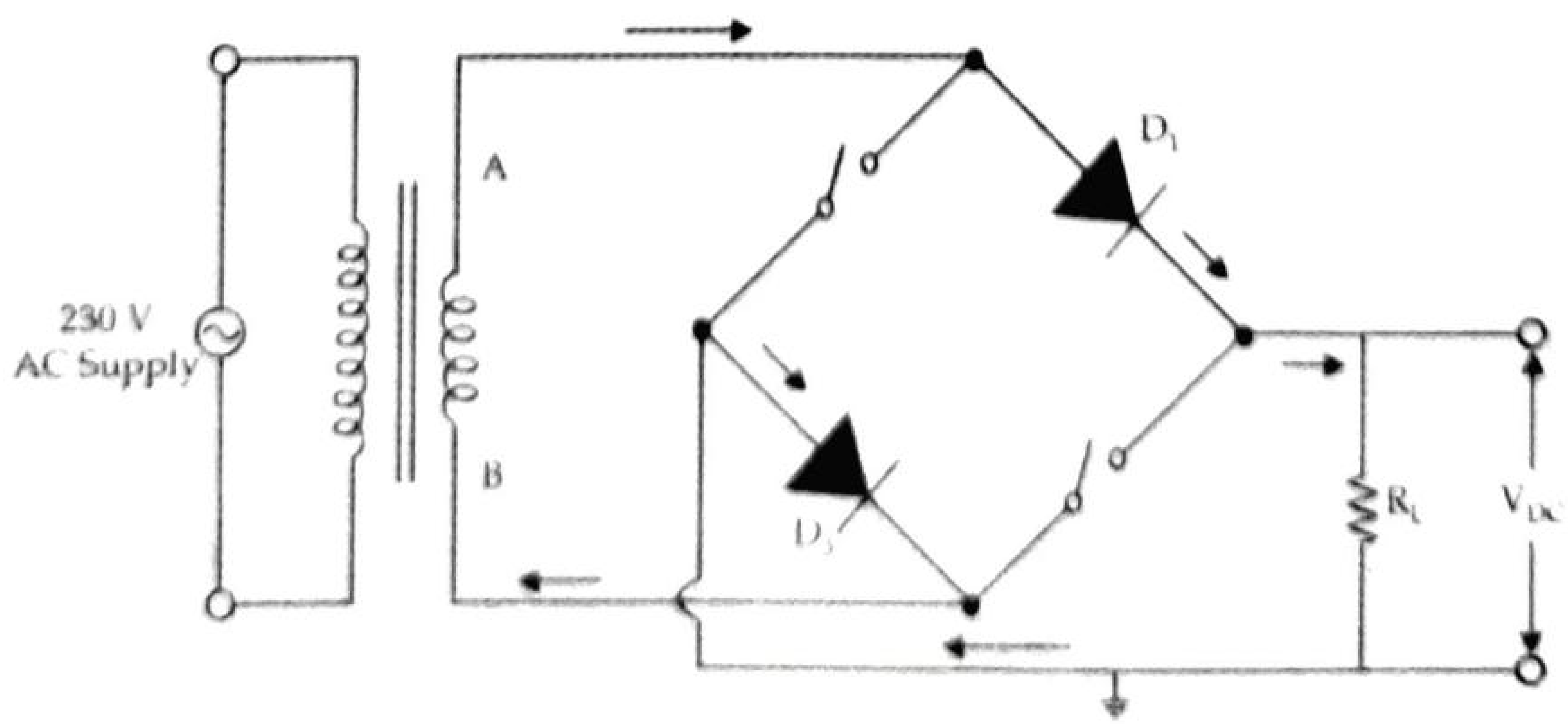
Figure 33 shows the circuit diagram of an FWBR:



▲ **Figure 33: Displaying the Circuit Diagram of an FWBR**

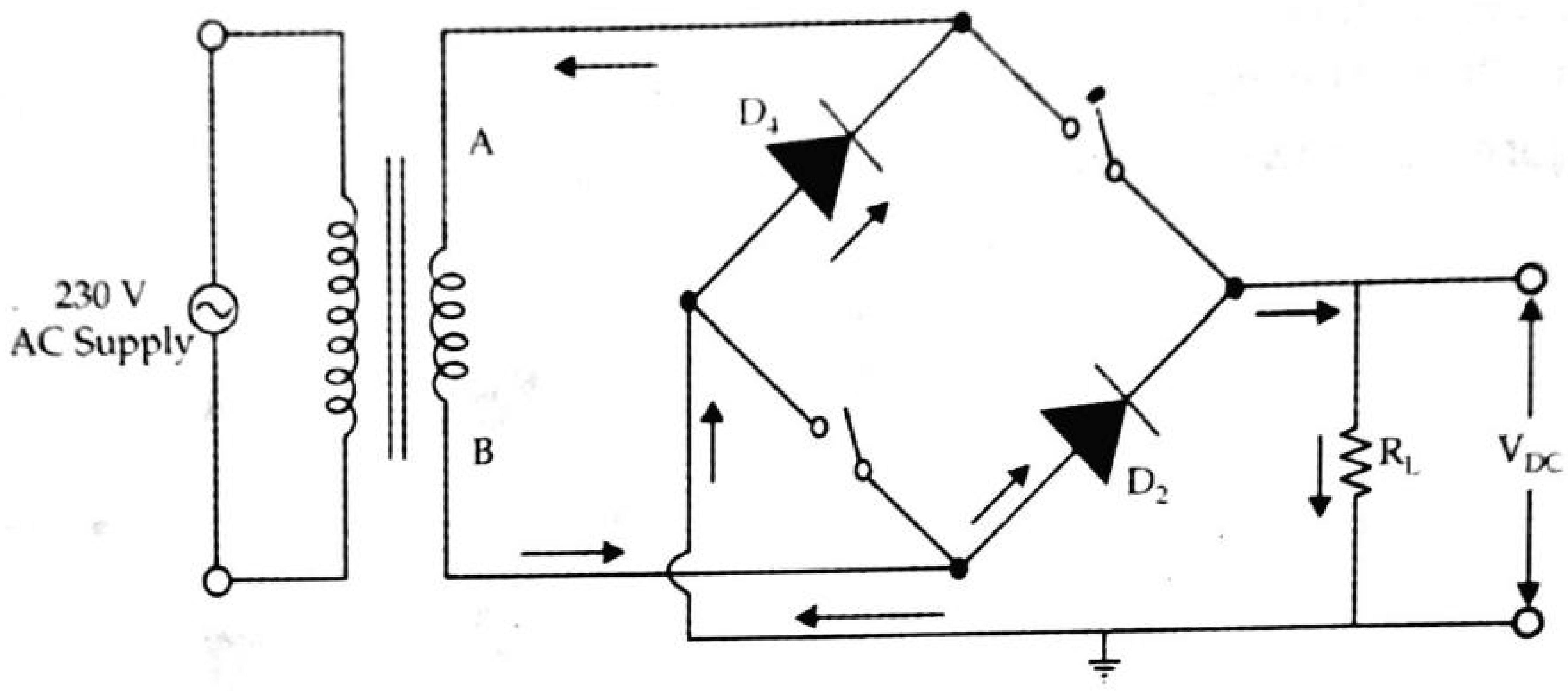
Figure 33 shows that an FWBR consists of four diodes, which are connected in bridge configuration. The diodes conduct electricity in pairs, which means that during a positive half cycle, diodes D_1 and D_3 conducts, whereas during a negative half cycle, diodes D_2 and D_4 conducts electricity.

During the positive half cycle of the AC input voltage supply, the secondary coil voltage is positive (i.e. point A is at positive potential and point B is at negative potential). Therefore, diodes D_1 and D_3 are in forward biased and acted as a short circuit while the diodes D_2 and D_4 are in reverse biased and acted as an open circuit. As a result, the current in the load resistor R_L is supplied by the conducting diodes D_1 and D_3. This will induce a positive voltage across the load resistor. The equivalent circuit diagram of a FWBR in positive half cycle is shown in Figure 34:



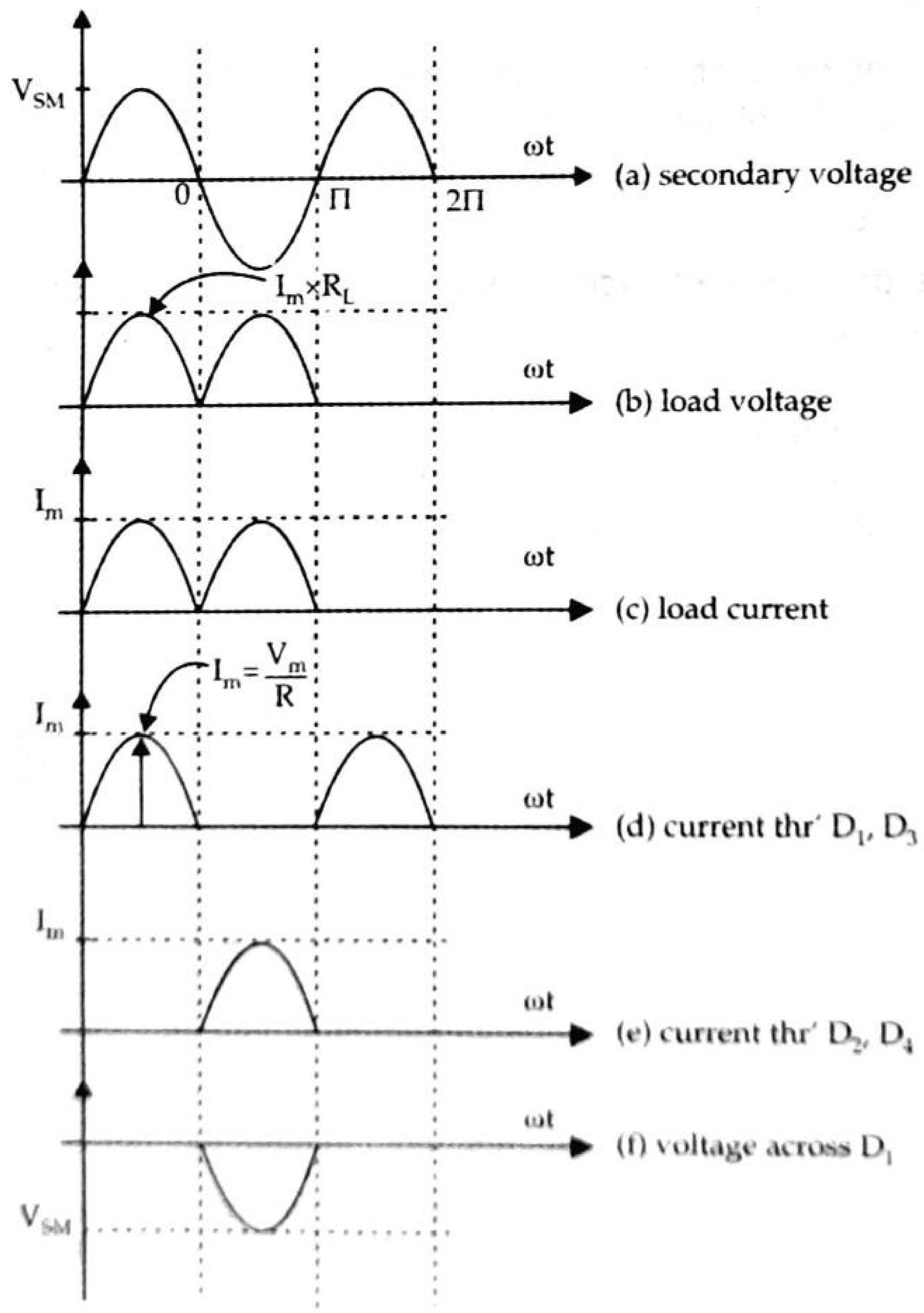
▲ **Figure 34: Displaying the Circuit Diagram of an FWBR Current Flow in Positive Half Cycle**

During the negative half cycle of the AC input voltage supply, the secondary coil voltage is negative (i.e. point A is at negative potential and point B is at positive potential). Therefore, diodes D_2 and D_4 are in forward biased and acted as a short circuit, while the diodes D_1 and D_3 are in reverse biased and acted as an open circuit. The conducting diodes supply current in the load resistor. It can be seen that in both the cases (i.e. positive half cycle and negative half cycle), the current flows through the load resistor is in one direction. The equivalent circuit diagram of a FWBR in the negative half cycle is shown in Figure 35:



▲ **Figure 35: Displaying Circuit Diagram of an FWBR Current Flow during Negative Half Cycle**

Different types of waveforms of current and voltage for a FWBR are shown in Figure 36:



▲ **Figure 36: Displaying Waveforms of an FWBR**

Let us now discuss the performance parameters of the FWBR.

As the output of a FWBR is similar to that of a FWR, therefore the equations for V_{LDC}, V_{LRMS}, I_{LDC}, and I_{LRMS} of a FW bridge rectifier are similar to the earlier derived equations for V_{LDC}, V_{LRMS}, I_{LDC}, and I_{LRMS} of a FWR.

In case of a FWBR, the two diodes conduct at a same time so the equation for peak load current I_m will be modified and is given by:

$$I_M = \frac{V_{SM}}{(R_S + 2R_F + R_L)}$$

The advantages of a FWBR circuit are as follows:

- Size of a FWBR is smaller, as compared to center-tap transformer
- FWBR can generate double voltage with the same size of center-tap transformer rectifier.
- Most suitable for high-voltage and high-current applications
- Core saturation is not possible, as equal and opposite currents flow through the transformer during each half cycle
- Efficiency is high
- TUF is high

The disadvantages of a FWBR circuit are as follows:

- As more diodes are required thereby increasing the cost
- Simultaneous conduction of two diodes increases the voltage drop and decreases the output voltage

Table 1 lists the comparison among the HWR, FWR (center-tap), and FWBR:

Table 1: Comparison among HWR, FWR, and FWBR

S. No.	Parameter	HWR	FWR	FWBR
1.	Number of diodes required	one	two	four
2.	DC/average load current (I_{LDC})	$\frac{I_M}{\pi}$	$\frac{2I_M}{\pi}$	$\frac{2I_M}{\pi}$
3.	Average load voltage (V_{LDC})	$\frac{V_M}{\pi}$	$\frac{2V_M}{\pi}$	$\frac{2V_M}{\pi}$
4.	RMS load current (I_{LRMS})	$\frac{I_M}{2}$	$\frac{I_M}{\sqrt{2}}$	$\frac{I_M}{\sqrt{2}}$
5.	RMS load voltage (V_{LRMS})	$\frac{V_M}{2}$	$\frac{V_M}{\sqrt{2}}$	$\frac{V_M}{\sqrt{2}}$
6.	DC load power P_{DC}	$\left(\frac{I_M}{\pi}\right)^2 R_L$	$4\left(\frac{I_M}{\pi}\right)^2 R_L$	$4\left(\frac{I_M}{\pi}\right)^2 R_L$
7.	Peak load current	$I_M = \frac{V_M}{R_S + R_F + R_L}$	$I_M = \frac{V_M}{R_S + R_F + R_L}$	$I_M = \frac{V_M}{R_S + 2R_F + R_L}$

Table 1: Comparison among HWR, FWR, and FWBR

S. No.	Parameter	HWR	FWR	FWBR
8.	Rectification efficiency	40%	81.2%	81.2%
9.	TUF	28.7%	81.2%	81.2%
10.	Ripple factor	1.21	0.48	0.48
11.	Ripple frequency (Hz)	50	100	100
12.	Transformer core Saturation	Possible	not possible	not possible
13.	Center tap Transformer	Not required	required	Not required
14.	PIV	V_M	$2V_M$	V_M
15.	Voltage regulation	good	better	good

Specifications of Rectifier Diode

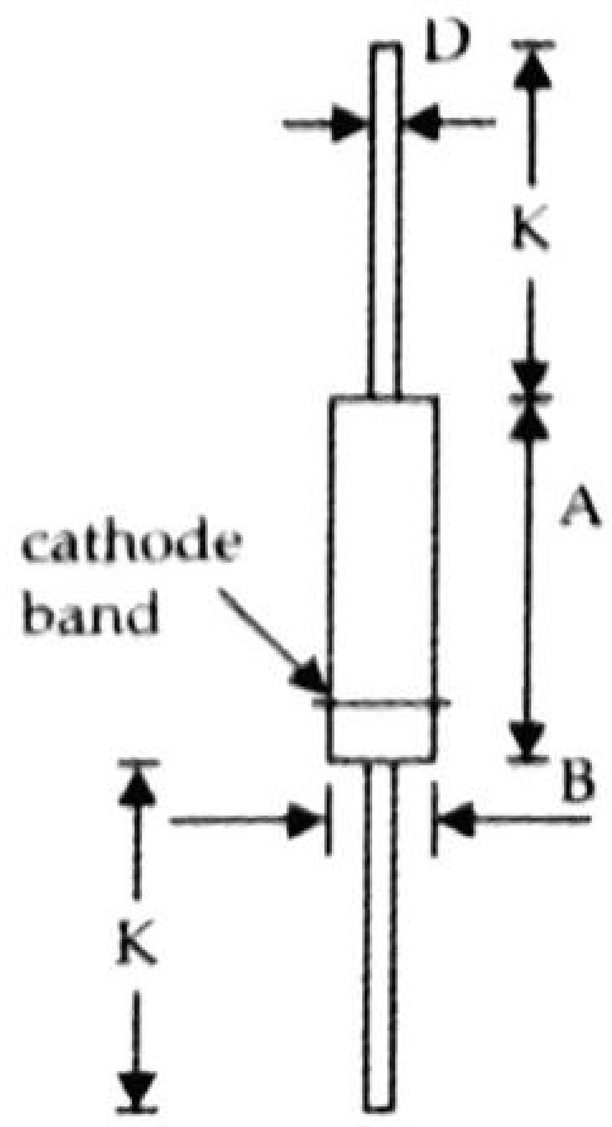
Specifications for rectifier diodes are established by the Joint Electronic Devices Engineering Council (JEDEC) of the Electronic Industries Association (EIA). The JEDEC specifications include the following:

- Standard set of symbols for diode ratings
- Electrical characteristics
- Test circuits

Specification sheet of rectifier diode covers the following points:

- **General description and mechanical characteristics**: Specifies the forward current rating, reverse voltage rating, and the type of package used in a diode. The mechanical characteristics constitute the dimensions of the diode, such as lead length, diameter, and material length. This information is extremely useful while designing a printed circuit board (PCB).

  Figure 37 shows dimensions of a diode:



▲ **Figure 37: Displaying the Dimensions of a Diode**