UNIT II - Diode Applications

Rectifier - Half Wave Rectifier, Full Wave Rectifier, Bridge Rectifier, Rectifiers with Capacitive and Inductive Filters, Clippers-Clipping at two independent levels, Clamper-Clamping Circuit Theorem, Clamping Operation, Types of Clampers.

2.1 Rectifier

- A rectifier is a device which converts a.c. voltage to pulsating d.c. voltage, using one or more p-n junction diode.

2.1.1 Types of Rectifier Circuits

- Using one or more diodes, following rectifier circuits can be designed.
    - Half wave rectifier (HWR)
    - Full wave rectifier (FWR)
    - Bridge rectifier(BR)

2.2 Half Wave Rectifier

- Half wave rectifier circuit uses only one diode.
- During positive half cycle of input a.c. supply, diode conducts and we will get the output at load.
- During negative half cycles of a.c, supply, there is no output at the load.

2.2.1 Construction

- This rectifier circuit consists of a.c. voltage source, rectifying element (p-n junction diode) and resistive load , all are connected in series.
- The circuit diagram is shown in the Fig. 2.1.

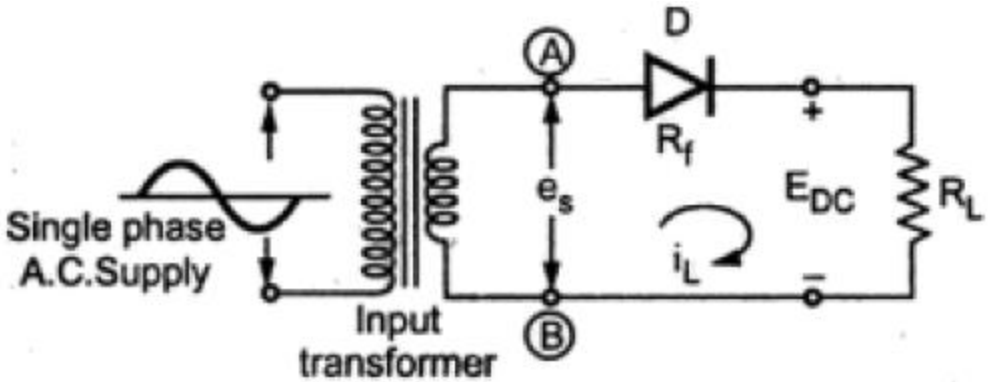


Fig. 2.1 Half wave rectifier

- To obtain the desired d.c voltage across the load, the a.c voltage is applied to rectifier circuit using suitable step-down transformer with necessary turns ratio.
- The input voltage to the half wave rectifier circuit is a sinusoidal a.c voltage, having a supply frequency of 50 Hz and is given by

$$e_s = E_{sm} \sin \omega t$$

Where

$$\omega = 2\pi f$$

$$f = \text{Supply frequency}$$

- The transformer decides the peak value of the secondary voltage.
- If N_1 are the primary number of turns and N_2 are the secondary number of turns and E_{pm} is the peak (or) maximum value of the primary voltage and E_{sm} is the peak (or) maximum value of the secondary voltage then,

$$\frac{N_2}{N_1} = \frac{E_{sm}}{E_{pm}}$$

- R_f represents the forward resistance of the diode.

2.2.2 Operation

- During the positive half cycle of secondary a.c voltage, terminal (A) becomes positive with respect to terminal (B).
- The diode is forward biased and the current flows in the circuit almost full positive half cycle. This current is also flowing through load resistance R_L hence denoted as load current i_L.
- During negative half cycle when terminal (A) is negative with respect to terminal (B), diode becomes reverse biased.
- Hence no current flows in the circuit.

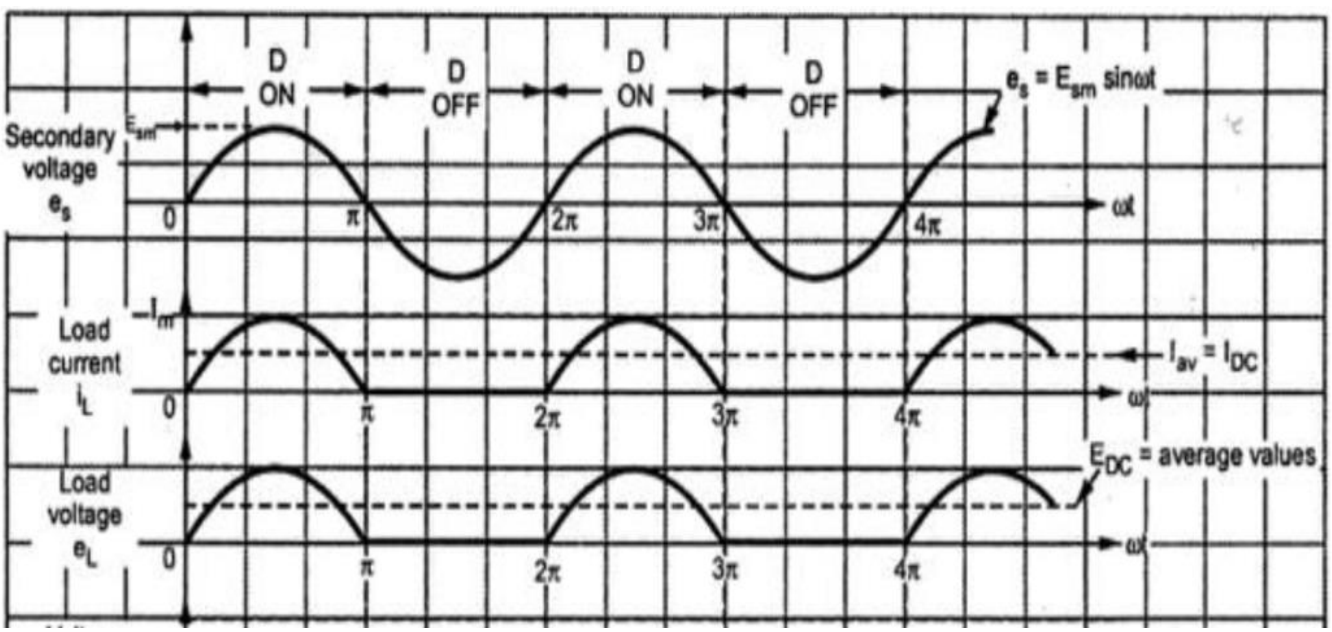


Fig. 2.2 Waveforms of Half wave Rectifier

- Thus the circuit current, which is also the load current, is in the form of half sinusoidal pulses.
- The load voltage, being the product of load current and load resistance, will also be in the form of half sinusoidal pulses.
- The different waveforms are illustrated in Fig. 2.2.

2.2.3 Parameters of Half Wave Rectifier

- Average D.C. Load Current (I_{DC})
- Average D.C. Load Voltage (E_{DC})
- R.M.S. Value of Load Current (I_{RMS})
- D.C. Power Output (P_{DC})
- A.C. Power Input (P_{AC})
- Rectifier Efficiency (η)
- Ripple Factor (ϒ)
- Peak Inverse Voltage (PIV)
- Transformer Utilization Factor (TUF)
- Voltage Regulation

2.2.3.1 Average D.C. Load Current (I_{DC})

- The average d.c value of alternating current is obtained by integration.
- For finding out the average value of an alternating waveform, we have to determine the area under the curve over one complete cycle i.e. from 0 to 2π and then dividing it by the base 2π.
- Mathematically, current waveform can be described as,

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

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

where

$$I_m = \text{Peak value of load current}$$

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

- As no current flows during negative half cycle of a.c, input voltage, i.e. between ωt = π to ωt =2π, we change the limits of integration.

$$I_{DC} = \frac{1}{2\pi}\int_0^{\pi} I_m \sin(\omega t)\, d(\omega t) = \frac{I_m}{2\pi}\left[-\cos(\omega t)\right]_0^{\pi}$$

$$= -\frac{I_m}{2\pi}\left[\cos(\pi) - \cos(0)\right] = -\frac{I_m}{2\pi}[-1-1] = \frac{I_m}{\pi}$$

$$\boxed{I_{DC} = \frac{I_m}{\pi} = \text{Average value}}$$

- Applying Kirchhoff's voltage law we can write,

$$\boxed{I_m = \frac{E_{sm}}{R_f + R_L + R_s}}$$

Where R_S = Resistance of secondary winding of transformer.

2.2.3.2 Average D.C. Load Voltage (E_{DC})

- It is the product of average D.C. load current and the load resistance R_L.

$$E_{DC} = I_{DC} R_L$$

- Substituting value of I_{DC} in the above equation

$$E_{DC} = \frac{I_m}{\pi} R_L$$

$$= \frac{E_{sm}}{(R_f + R_L + R_s)\pi} R_L$$

$$\boxed{E_{DC} = \frac{E_{sm}}{\pi\left[\frac{R_f + R_s}{R_L} + 1\right]}}$$

- The winding resistance R_S and forward diode resistance R_f are practically very small compared to R_L.
- $(R_f + R_S)/R_L$ is negligibly small compared to 1. So we get,

$$\boxed{E_{DC} \approx \frac{E_{sm}}{\pi}}$$

2.2.3.3 R.M.S. Value of Load Current (I_{RMS})

- The R.M.S means squaring, finding mean and then finding square root. Hence R.M.S. value of load current can be obtained as,

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

$$= I_m\sqrt{\frac{1}{2\pi}\int_0^{\pi}\frac{[1-\cos(2\omega t)]\,d(\omega t)}{2}} = I_m\sqrt{\frac{1}{2\pi}\left\{\frac{\omega t}{2} - \frac{\sin(2\omega t)}{4}\right\}_0^{\pi}}$$

$$= I_m\sqrt{\frac{1}{2\pi}\left(\frac{\pi}{2}\right)} \qquad \text{as } \sin(2\pi) = \sin(0) = 0$$

$$= \frac{I_m}{2}$$

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

2.2.3.4 D.C. Power Output (P_{DC})

- The d.c. power output can be obtained as,

$$\boxed{P_{DC} = E_{DC}\, I_{DC} = I_{DC}^2 R_L}$$

- For half wave rectifier, we have $I_{DC} = I_m / \pi$

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

$$= \left[\frac{I_m}{\pi}\right]^2 R_L$$

$$P_{DC} = \frac{I_m^2}{\pi^2} R_L$$

where

$$I_m = \frac{E_{sm}}{R_f + R_L + R_s}$$

$$\therefore \quad \boxed{P_{DC} = \frac{E_{sm}^2 R_L}{\pi^2 [R_f + R_L + R_s]^2}}$$

2.2.3.5 A.C. Power Input (P_{AC})

- The a.c. power is given by,

$$\boxed{P_{AC} = I_{RMS}^2 [R_L + R_f + R_s]}$$

- For half wave rectifier, we have $I_{RMS} = I_m / 2$

$$\boxed{P_{AC} = \frac{I_m^2}{4} [R_L + R_f + R_s]}$$

2.2.3.6 Rectifier Efficiency (η)

- The rectifier efficiency is defined as the ratio of D.C. output power to A.C. input power.

$$\eta = \frac{\text{D.C. output power}}{\text{A.C. input power}} = \frac{P_{DC}}{P_{AC}}$$

$$\eta = \frac{\frac{I_m^2}{\pi^2} R_L}{\frac{I_m^2}{4} [R_f + R_L + R_s]} = \frac{(4/\pi^2) R_L}{(R_f + R_L + R_s)}$$

$$\therefore \quad \boxed{\eta = \frac{0.406}{1 + \left(\frac{R_f + R_s}{R_L}\right)}}$$

- We know that, $(R_f + R_S) \ll R_L$. So we get the maximum theoretical efficiency of half wave rectifier as,

$$\boxed{\% \, \eta_{max} = 0.406 \times 100 = 40.6 \, \%}$$

- If the efficiency of rectifier Is 40 % then what happens to the remaining 60 % power.
- It is present in terms of ripples in the output which is fluctuating component present in the output.

2.2.3.7 Ripple Factor (ɤ)

- It is seen that the output of half wave rectifier is not pure d.c, but a pulsating d.c.
- The output contains pulsating components called ripples.
- The measure of ripples present in the output is with the help of a factor called ripple factor denoted by ɤ.
- Mathematically ripple factor is defined as the ratio of R.M.S. value of the a.c. component in the output to the average or d.c. component present in the output.

$$\text{Ripple factor} \quad \gamma = \frac{\text{R.M.S. value of a.c. component of output}}{\text{Average or d.c. component of output}}$$

- Now the output current is composed of a.c. component as well as d.c. component.

Let

$$I_{ac} = \text{r.m.s. value of a. c. component present in output}$$

$$I_{DC} = \text{d.c. component present in output}$$

$$I_{RMS} = \text{R.M.S. value of total output current}$$

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

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

- As per definition

$$\text{Ripple factor} = \frac{I_{ac}}{I_{DC}}$$

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

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

- This is the general expression for ripple factor and can be used for any rectifier circuit.

2.2.3.7.1 Ripple Factor (ɤ) for half wave rectifier

- Now for a half wave circuit, we have

$$I_{RMS} = \frac{I_m}{2} \quad \text{while} \quad I_{DC} = \frac{I_m}{\pi}$$

$$\gamma = \sqrt{\left[\frac{\left(\frac{I_m}{2}\right)}{\left(\frac{I_m}{\pi}\right)}\right]^2 - 1} = \sqrt{\frac{\pi^2}{4} - 1} = \sqrt{1.4674}$$

$$\gamma = 1.211 \qquad \text{.. Halfwave}$$

- This indicates that the ripple contents in the output are 1.211 times the d.c. component

2.2.3.8 Peak Inverse Voltage (PIV)

- The Peak Inverse Voltage is the peak voltage across the diode in the reverse direction i.e., when the diode is reverse biased.
- In half wave rectifier, the load current is ideally zero when the diode is reverse biased and hence the maximum value of the voltage that can exist across the diode is nothing but E_{sm}.

$$\therefore \quad \boxed{\text{PIV of diode} = E_{sm} = \text{Maximum value of secondary voltage} = \pi\, E_{DC}\big|_{I_{DC}=0}}$$

2.2.3.9 Transformer Utilization Factor (TUF)

- The factor which indicates how much is the utilization of the transformer in the circuit is called Transformer Utilization Factor (TUF)

$$\text{T.U.F.} = \frac{\text{D.C. power delivered to the load}}{\text{A.C. power rating of the transformer}}$$

- A.C. power rating of transformer = $E_{RMS}\, I_{RMS}$

$$= \frac{E_{sm}}{\sqrt{2}} \cdot \frac{I_m}{2}$$

$$= \frac{E_{sm}\, I_m}{2\sqrt{2}}$$

- D.C. power delivered to the load = $I_{DC}^2\, R_L$

$$= \left(\frac{I_m}{\pi}\right)^2 R_L$$

$$\text{T.U.F.} = \frac{\left(\frac{I_m}{\pi}\right)^2 R_L}{\left(\frac{E_{sm} I_m}{2\sqrt{2}}\right)}$$

- Neglecting the drop across R_f and R_S we can write,

$$E_{sm} = I_m R_L$$

$$\text{T.U.F} = \frac{I_m^{\,2}}{\pi^2} \cdot \frac{R_L \cdot 2\sqrt{2}}{I_m^{\,2} R_L}$$

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

$$\boxed{\text{T.U.F} = 0.287}$$

- The value of T.U.F. is low which shows that in half wave rectifier circuit, the transformer is not fully utilized.

2.2.3.10 Voltage Regulation

- The voltage regulation is defined as the change in the d.c output voltage as load changes from no load to full load condition.

$$\text{If } (V_{dc})_{NL} = \text{D.C. voltage on no load}$$
$$(V_{dc})_{FL} = \text{D.C. voltage on full load.}$$

- Then voltage regulation is defined as,

$$\boxed{\text{Voltage regulation} = \frac{(V_{dc})_{NL} - (V_{dc})_{FL}}{(V_{dc})_{FL}}}$$

Where

$$(V_{dc})_{NL} = \frac{E_{sm}}{\pi}$$

$$(V_{dc})_{FL} = I_{DC} R_L = \frac{I_m}{\pi} R_L = \frac{E_{sm}}{\pi[R_f + R_s + R_L]} \times R_L$$

2.2.4 Advantages of Half Wave Rectifier

- Only one diode is required
- Circuit is easy to design
- No centre transformer is necessary

2.2.5 Disadvantages of Half Wave Rectifier

- The ripple factor of half wave rectifier circuit is 1.21, which is quite high
- The maximum theoretical rectification efficiency is found to be 40% which is very low.
- TUF is very low showing that the transformer is not fully utilized.
- To minimize the saturation, transformer size have to be increased which increases the cost

Example : *A half wave rectifier circuit connected to a 230 V, 50 Hz source, through a transformer of turn ratio of 10 : 1. The rectifier circuit is to supply power to a 500 Ω, 1 watt resistor and diode forward resistance is 100 Ω.*

Calculate :

1) Maximum, average and r.m.s. value of current and voltage.

2) Efficiency of rectification.

3) Percentage regulation.

Solution : $E_p(\text{r.m.s.}) = 230$ V, $N_1/N_2 = 10:1$, $R_L = 500\ \Omega$, $R_f = 100\ \Omega$

$$\frac{N_2}{N_1} = \frac{1}{10} = \frac{E_{s(r.m.s.)}}{E_{p(r.m.s.)}}$$

$$\therefore \quad E_{s(r.m.s.)} = \frac{1}{10} \times 230 = 23 \text{ V}$$

$$\therefore \quad E_{sm} = \sqrt{2} \times E_{s(r.m.s.)} = \sqrt{2} \times 23 = 32.5269 \text{ V.}$$

$$1)\ \therefore \quad I_m = \frac{E_{sm}}{R_f + R_L} = \frac{32.5269}{100+500} = \mathbf{54.2115\ mA} \qquad \text{...Maximum current}$$

$$\therefore \quad I_{av} = I_{DC} = \frac{I_m}{\pi} = \mathbf{17.2561\ mA} \qquad \text{...Average current}$$

$$\therefore \quad I_{R.M.S.} = \frac{I_m}{2} \text{ for half wave} = \mathbf{27.1058\ mA}$$

$$\therefore \quad E_{DC} = I_{DC} R_L = \mathbf{8.628\ V}$$

$$2)\ \therefore \quad P_{DC} = I_{DC}^2\, R_L = 0.14888\ W$$

$$P_{AC} = I_{RMS}^2 (R_L + R_f) = 0.44083\ W$$

$$\therefore \quad \%\,\eta = \frac{P_{DC}}{P_{AC}} \times 100 = \frac{0.14888}{0.44083} \times 100 = \mathbf{33.7723\ \%}$$

$$3) \quad (V_{d.c.})_{NL} = \frac{E_{sm}}{\pi} = \frac{32.5269}{\pi} = 10.3536\ V$$

$$(V_{d.c.})_L = E_{DC} = 8.628\ V$$

$$\therefore \quad \%\,R = \frac{(V_{dc})_{NL} - (V_{dc})_L}{(V_{dc})_L} \times 100 = \mathbf{20\ \%}$$

Example *A voltage of 200 cos wt is applied to HWR with the load resistance of 5 kΩ. Find the maximum d.c. current component, r.m.s current, ripple factor, TUF and the rectifier efficiency.*

Solution : Comparing input voltage to $E_{sm} \sin(\omega t + \phi)$, $\phi = 90^\circ$

$$\therefore \quad E_{sm} = 200\ V, \quad R_L = 5\ k\Omega$$

$$\therefore \quad I_m = \frac{E_{sm}}{R_L + R_f + R_s} = \frac{200}{5 \times 10^3} = \mathbf{40\ mA} \qquad \text{... } R_f = R_s = 0$$

$$\therefore \quad I_{RMS} = \frac{I_m}{2} = \frac{40}{2} = \mathbf{20\ mA} \qquad \text{... Half wave}$$

$$\gamma = \sqrt{\left(\frac{I_{RMS}}{I_{DC}}\right)^2 - 1} \quad \text{where} \quad I_{DC} = \frac{I_m}{\pi} = 12.7324\ mA$$

$$= \sqrt{\left(\frac{20}{12.7324}\right)^2 - 1} = \mathbf{1.21}$$

$$TUF = \frac{\text{D.C. power output}}{\text{A.C. power rating of transformer}} = \frac{I_{DC}^2\, R_L}{\left(\frac{E_{sm}}{\sqrt{2}} \frac{I_{sm}}{2}\right)}$$

$$= \frac{(12.7324\times 10^{-3})^2 \times 5\times 10^3}{\left(\frac{200}{\sqrt{2}}\right)\left(\frac{40\times 10^{-3}}{2}\right)} = \mathbf{0.2865}$$

Note that for half wave rectifier $I_{RMS} = \frac{I_m}{2}$

$$P_{AC} = I^2_{RMS}\, R_L = (20\times 10^{-3})^2 \times 5\times 10^3 = 2\text{ W}$$

$$P_{DC} = I^2_{DC}\, R_L = (12.7324\times 10^{-3})^2 \times 5\times 10^3 = 0.8105\text{ W}$$

$$\therefore \quad \%\,\eta = \frac{P_{DC}}{P_{AC}} \times 100 = \frac{0.8105}{2} \times 100 = \mathbf{40.528\ \%}$$

2.3 Full Wave Rectifier

- The full wave rectifier conducts during both positive and negative half cycles of input a.c supply.
- In order to rectify both the half cycles of a.c. input, two diodes are used in this circuit.
- The diodes feed a common load R_L with the help of a centre tap transformer.
- The a.c voltage is applied through a suitable power transformer with proper turns ratio.
- The full wave rectifier circuit is shown in the Fig. 2.3.

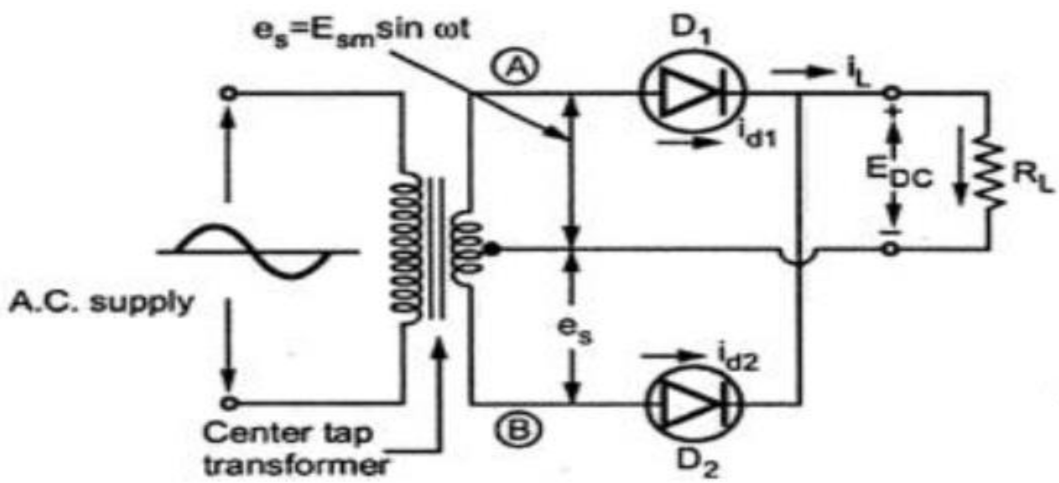


Fig. 2.3 Full wave Rectifier

2.3.1 Operation

- Consider the positive half cycle of a.c input voltage in which terminal (A) is positive and terminal (B) negative.
- The diode D_1 will be forward biased and hence will conduct.
- While diode D_2 will be reverse biased and will act as an open circuit and will not conduct.
- The diode D_1 supplies the load current, i.e. $i_L = i_{d1}$. This current is flowing through upper half of secondary winding.
- The diode current and the load current are illustrated in the Fig. 2.4.

- During negative half cycle of a.c voltage, polarity reverses and terminal (A) becomes negative and (B) is positive.
- The diode D_2 conducts, being forward biased, while D_1 does not, being reverse biased.
- The diode D_2 supplies the load current, i.e. $i_L = i_{d2}$. Now the lower half of the secondary winding carries the current.
- The diode current and the load current are illustrated in the Fig. 2.4.
- It is noted that the load current flows in both the half cycles of a.c voltage and in the same direction through the load resistance.
- Hence we get rectified output across the load.
- The load current is sum of individual diode currents flowing in corresponding half cycles.
- It is also noted that the two diodes do not conduct simultaneously but in alternate half cycles.
- The output load current is still pulsating d.c and not pure d.c.

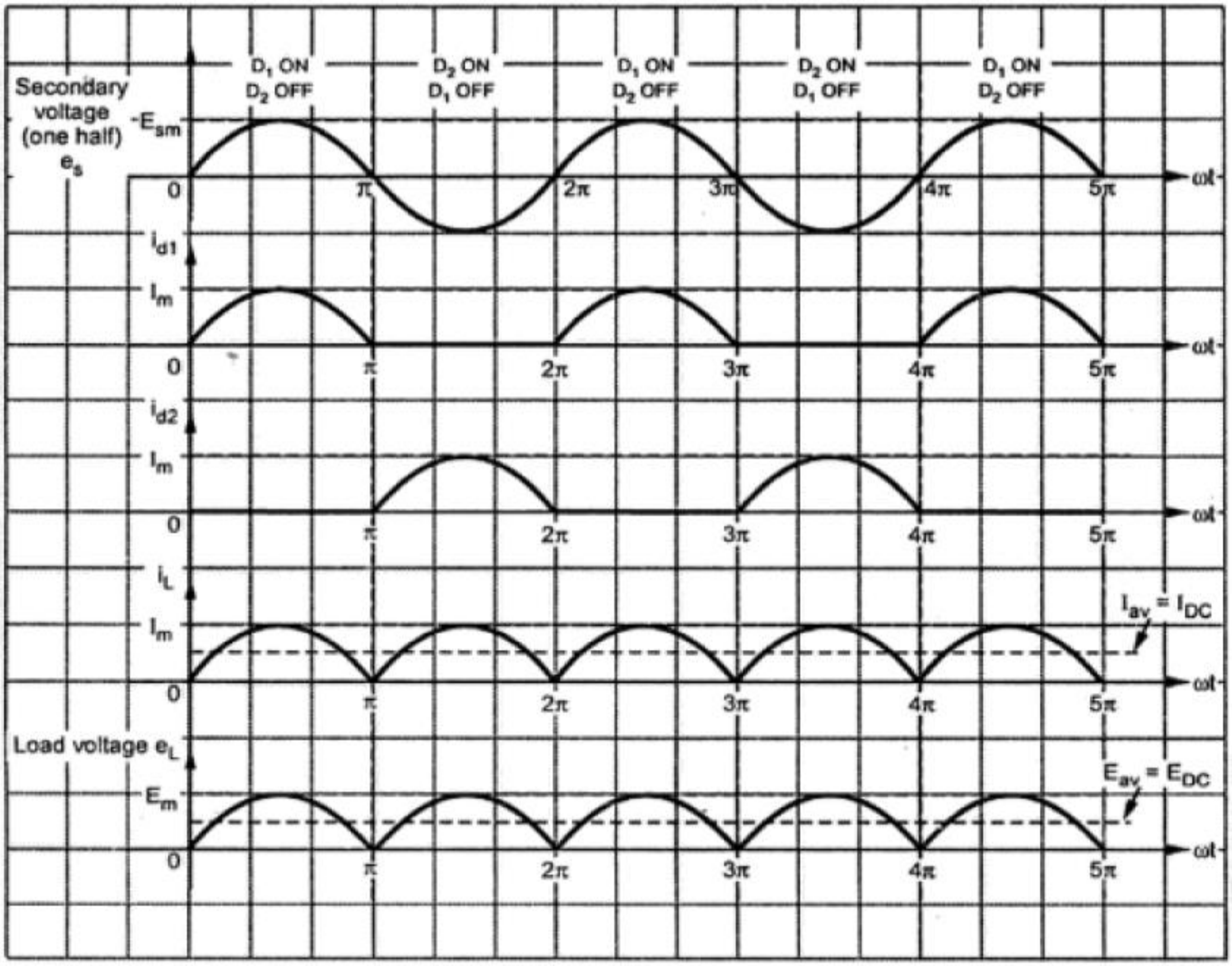


Fig. 2.4 Waveforms for Full wave rectifier

2.3.2 Parameters of FWR

- Average D.C. Load Current (I_{DC})
- Average D.C. Load Voltage (E_{DC})
- R.M.S. Value of Load Current (I_{RMS})
- D.C. Power Output (P_{DC})
- A.C. Power Input (P_{AC})
- Rectifier Efficiency (η)
- Ripple Factor (ϒ)
- Peak Inverse Voltage (PIV)
- Transformer Utilization Factor (TUF)
- Voltage Regulation

2.3.2.1 Average D.C. Load Current (I_{DC})

- The average d.c value of alternating current is obtained by integration.
- For finding out the average value of an alternating waveform, we have to determine the area under the curve over one complete cycle i.e. from 0 to 2π and then dividing it by the base 2π.
- Mathematically, current waveform can be described as,

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

$$i_L = I_m \sin \omega t \qquad \text{for } \pi \le \omega t \le 2\pi$$

where

$$I_m = \text{Peak value of load current}$$

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

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

$$= \frac{1}{\pi}\int_0^{\pi} I_m \sin \omega t \, d\omega t$$

$$= \frac{I_m}{\pi}\left[(-\cos \omega t)_0^{\pi}\right]$$

$$= \frac{I_m}{\pi}[-\cos \pi - (-\cos 0)]$$

$$= \frac{I_m}{\pi}(+1 - (-1)] \qquad \ldots \cos \pi = -1$$

$$\therefore \quad \boxed{I_{DC} = \frac{2I_m}{\pi}} \qquad \text{for full wave rectifier}$$

2.3.2.2 Average D.C. Load Voltage (E_{DC})

- The d,c. load voltage is,

$$E_{DC} = I_{DC} R_L = \frac{2 I_m R_L}{\pi}$$

- Substituting value of I_m in the above equation

$$E_{DC} = \frac{2 E_{sm} R_L}{\pi [R_f + R_s + R_L]}$$

$$= \frac{2 E_{sm}}{\pi \left[1 + \frac{R_f + R_s}{R_L}\right]}$$

- But as R_f & R_S << R_L hence (R_f & R_S)/ R_L << 1

$$\boxed{E_{DC} = \frac{2 E_{sm}}{\pi}}$$

2.3.2.3 R.M.S. Value of Load Current (I_{RMS})

- The R.M.S value of current can be obtained as follows.

$$I_{R.M.S.} = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} i_L^2 d(\omega t)}$$

- Since two half wave rectifier are similar in operation we can write

$$I_{R.M.S.} = \sqrt{2 \frac{1}{2\pi} \int_0^{\pi} [I_m \sin \omega t]^2 d(\omega t)}$$

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

$$\therefore \quad I_{R.M.S.} = I_m \sqrt{\frac{1}{2\pi}\left[[\omega t]_0^{\pi} - \left(\frac{\sin 2\omega t}{2}\right)_0^{\pi}\right]} = I_m \sqrt{\frac{1}{2\pi}[\pi - 0]}$$

$$= I_m \sqrt{\frac{1}{2\pi}(\pi)} \qquad \text{as } \sin(2\pi) = \sin(0) = 0$$

$$\therefore \quad \boxed{I_{R.M.S.} = \frac{I_m}{\sqrt{2}}}$$

2.3.2.4 D.C. Power Output (P_{DC})

- D.C. power output $P_{DC} = E_{DC} I_{DC} = I_{DC}^2 R_L$
- For full wave rectifier, we have $I_{DC} = 2I_m / \pi$

$$P_{DC} = I_{DC}^2 R_L = \left(\frac{2 I_m}{\pi}\right)^2 R_L$$

$$P_{DC} = \frac{4}{\pi^2} I_m^2 R_L$$

- Substituting value of I_m we get,

$$P_{DC} = \frac{4}{\pi^2} \frac{E_{sm}^2}{(R_s + R_f + R_L)^2} \times R_L$$

2.3.2.5 A.C. Power Input (P_{AC})

- The a.c. power input is given by,

$$P_{AC} = I_{RMS}^2 (R_f + R_s + R_L) = \left(\frac{I_m}{\sqrt{2}}\right)^2 (R_f + R_s + R_L)$$

$$P_{AC} = \frac{I_m^2 (R_f + R_s + R_L)}{2}$$

- Substituting value of I_m we get,

$$P_{AC} = \frac{E_{sm}^2}{(R_f + R_s + R_L)^2} \times \frac{1}{2} \times (R_f + R_s + R_L)$$

$$P_{AC} = \frac{E_{sm}^2}{2(R_f + R_s + R_L)}$$

2.3.2.6 Rectifier Efficiency (η)

- The Rectifier Efficiency is given by

$$\eta = \frac{P_{DC} \text{ output}}{P_{AC} \text{ input}}$$

$$\eta = \frac{\frac{4}{\pi^2} I_m^2 R_L}{\frac{I_m^2 (R_f + R_s + R_L)}{2}}$$

$$\eta = \frac{8 R_L}{\pi^2 (R_f + R_s + R_L)}$$

- But $(R_f + R_S) << R_L$,

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

$$\% \eta_{max} = \frac{8}{\pi^2} \times 100$$

$$\% \eta_{max} = 81.2 \%$$

2.3.2.7 Ripple Factor (ɤ)

- As derived earlier, a general expression the ripple factor is given by

$$\text{Ripple factor} = \sqrt{\left[\frac{I_{RMS}}{I_{DC}}\right]^2 - 1}$$

- For full wave rectifier $I_{RMS} = I_m/\sqrt{2}$ and $I_{DC} = 2I_m/\pi$
- Substitute the above values in ripple factor equation

$$\text{Ripple factor} = \sqrt{\left[\frac{I_m/\sqrt{2}}{2I_m/\pi}\right]^2 - 1} = \sqrt{\frac{\pi^2}{8} - 1}$$

$$\boxed{\text{Ripple factor} = \gamma = 0.48}$$

2.3.2.8 Peak Inverse Voltage (PIV)

- The total peak voltage across diode is $2E_{sm}$.

$$\boxed{\text{PIV of diode} = 2\,E_{sm} = \pi E_{DC}|_{I_{DC}=0}}$$

2.3.2.9 Transformer Utilization Factor (TUF)

- In full wave rectifier, the secondary current flows through each half separately in every half cycle while the primary of transformer carries current continuously.
- Hence TUF is calculated for primary and secondary windings separately and then the average TUF is determined.

$$\text{Secondary T.U.F.} = \frac{\text{D.C. power to the load}}{\text{A.C. power rating of secondary}}$$

$$= \frac{I_{DC}^2\,R_L}{E_{RMS}\,I_{rms}} = \frac{\left(\frac{2}{\pi}I_m\right)^2 R_L}{\frac{E_{sm}}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}}}$$

- Neglecting forward resistance R_f of diode, $E_{sm} = I_m R_L$

$$\text{Secondary T.U.F.} = \frac{\frac{4}{\pi^2} \times I_m^2\,R_L}{\frac{I_m^2\,R_L}{2}} = \frac{8}{\pi^2} = 0.812$$

- The primary of the transformer is feeding two half-wave rectifiers separately.

$$\text{T.U.F. for primary winding} = 2 \times \text{T.U.F. of half wave circuit}$$

$$= 2 \times 0.287 = 0.574.$$

- The average T.U.F for full wave rectifier circuit will be

$$\text{Average T.U.F. for full wave rectifier circuit} = \frac{\text{T.U.F. of primary} + \text{T.U.F. of secondary}}{2}$$

$$= \frac{0.574 + 0.812}{2} = 0.693$$

Average T.U.F. for full-wave rectifier = 0.693

2.3.2.10 Voltage Regulation

- For a full wave circuit,

$$(V_{dc})_{NL} = \frac{2E_{sm}}{\pi}$$

$$(V_{dc})_{FL} = I_{DC} R_L$$

- The regulation can be expressed as,

$$\% R = \frac{(V_{dc})_{NL} - (V_{dc})_{FL}}{(V_{dc})_{FL}} \times 100$$

2.3.3 Advantages of Full Wave Rectifier

- The d.c load voltage and current are more than half wave.
- No d.c current through transformer windings hence no possibility of saturation.
- T.U.F. is better as transformer losses are less.
- The efficiency is higher.
- The large d.c power output.
- The ripple factor is less.

2.3.4 Disadvantages of Full Wave Rectifier

- The PIV rating of diode is higher.
- Higher PIV diodes are larger in size and costlier.
- The cost of centre tap transformer is higher.

Example : *A full-wave rectifier circuit is fed from a transformer having a centre-tapped secondary winding. The rms voltage from either end of secondary to center tap is 30 V. If the diode forward resistance is 2 Ω and that of the half secondary is 8 Ω, for a load of 1 kΩ, calculate,*

a) Power delivered to load, b) % Regulation at full load,
c) Efficiency of rectification, d) T.U.F. of secondary.

Solution : Given : $E_s = 30\,V,\ R_f = 2\,\Omega,\ R_s = 8\,\Omega,\ R_L = 1\,k\Omega$

$$E_s = E_{RMS} = 30\ V$$

$$E_{sm} = E_s\sqrt{2} = 30\sqrt{2}\ \text{volt} = 42.426\ V$$

$$I_m = \frac{E_{sm}}{R_f + R_L + R_s} = \frac{30\sqrt{2}}{2+1000+8}\ A$$

$$= 42\ mA$$

$$I_{DC} = \frac{2}{\pi} I_m = 26.74\ mA$$

a) Power delivered to the load $= I_{DC}^2\, R_L = (26.74 \times 10^{-3})^2\ (1k\Omega)$

$$= 0.715\ W$$

b) V_{DC}, no load $= \frac{2}{\pi} E_{sm} = \frac{2}{\pi} \times 30\sqrt{2} = 27\ V$

V_{DC}, full load $= I_{DC}\, R_L = (26.74\ mA)\ (1\ k\Omega)$

$$= 26.74\ V$$

$$\%\ \text{Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100 = \frac{27 - 26.74}{26.74} \times 100$$

$$= 0.97\ \%$$

c) Efficiency of rectification $= \frac{\text{D.C. output}}{\text{A.C. input}}$

$$= \frac{8}{\pi^2} \times \frac{1}{1 + \frac{R_f + R_s}{R_L}} = \frac{8}{\pi^2} \times \frac{1}{1 + \frac{(2+8)}{1000}}$$

$$= 0.802 \quad \text{i.e. } 80.2\ \%$$

d) Transformer secondary rating $= E_{RMS}\ I_{RMS} = [30\ V]\left[\frac{42\ mA}{\sqrt{2}}\right]$

$$= 0.89\ W$$

$\therefore$ $$\text{T.U.F.} = \frac{\text{D.C. power output}}{\text{A.C. rating}}$$

$$= \frac{0.715}{0.89} = 0.802$$

2.4 Bridge Rectifier

- The bridge rectifier circuit is essentially a full wave rectifier circuit, using four diodes, forming the four arms of an electrical bridge and is shown in figure 2.5.
- To one diagonal of the bridge, the a.c voltage is applied through a transformer and the rectified d.c voltage is taken from the other diagonal of the bridge.

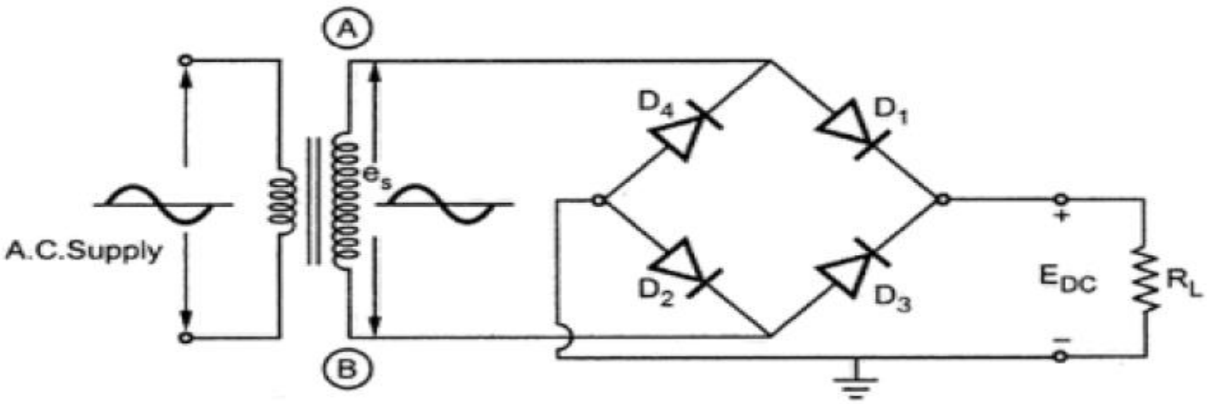


Fig. 2.5 Bridge Rectifier

2.4.1. Operation

- Consider the positive half of ac input voltage.
- The point A of secondary becomes positive. The diodes D_1 and D_2 will be forward biased, while D_3 and D_4 reverse biased.
- The two diodes D_1 and D_2 conduct in series with the load and the current flows as shown in Fig. 2.6.

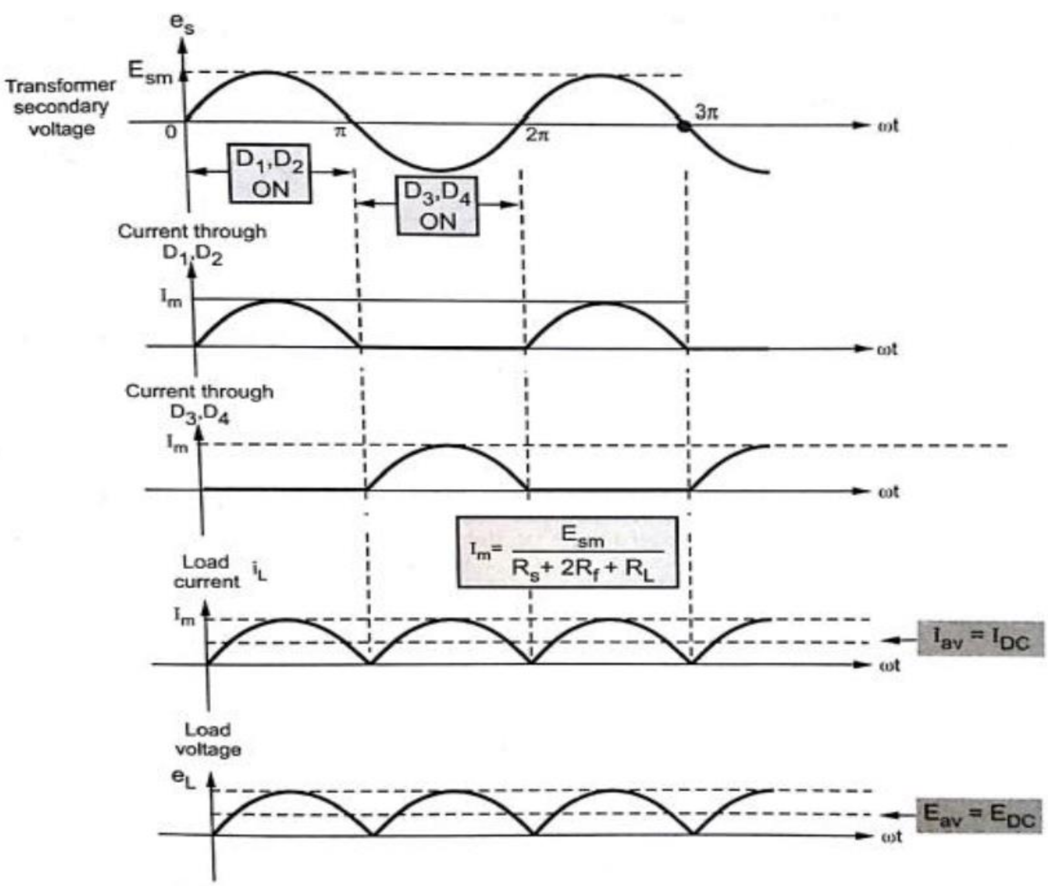


Fig. 2.6 Waveforms of bridge Rectifier

- During negative hall cycle, the polarity of a.c voltage reverses hence point B becomes positive diodes D_3 and D_4 are forward biased, while D_1 and D_2 reverse biased.

- Now the diodes D_3 and D_4 conduct is series with the load and the current flows as shown in Fig. 2.6.
- It is seen that in both cycles of a.c input, the load current is flowing in the same direction.
- The waveforms of load current and voltage remain are shown in figure 2.6.

2.4.2 Expressions for various parameters of Bridge Rectifier

- The bridge rectifier circuit, being basically a full wave rectifier circuit.
- All the derivations discussed previously for a full wave rectifier circuit using two diodes are applicable for a bridge rectifier circuit.
- The relation between I_m the maximum value of load current and I_{DC}, I_{RMS} remains same as derived earlier for the full wave rectifier circuit.

$$I_{DC} = \frac{2I_m}{\pi} \quad \text{and} \quad I_{RMS} = \frac{I_m}{\sqrt{2}}$$

- In each half cycle two diodes conduct simultaneously. Hence maximum value of Load current is,

$$I_m = \frac{E_{sm}}{R_s + 2R_f + R_L}$$

- The remaining expressions are identical to those derived for two diode full wave rectifier and reproduced for the convenience of the reader.

$$E_{DC} = I_{DC} R_L = \frac{2E_{sm}}{\pi}$$

$$P_{DC} = I_{DC}^2 R_L = \frac{4}{\pi^2} I_m^2 R_L$$

$$P_{AC} = I_{RMS}^2 (R_s + 2R_f + R_L) = \frac{I_m^2 (2R_f + R_s + R_L)}{2}$$

$$\eta = \frac{8R_L}{\pi^2 (R_s + 2R_f + R_L)}$$

$$\% \eta_{max} = 81.2 \%$$

$$\gamma = 0.48$$

- The transformer utilization factor is 0.812.
- PIV rating of the diode is E_{sm}

2.4.3 Advantages of Bridge Rectifier

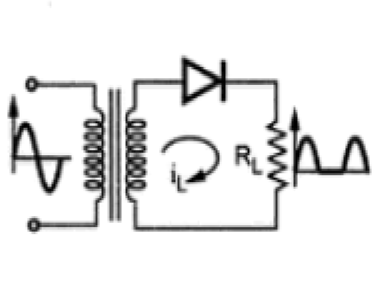
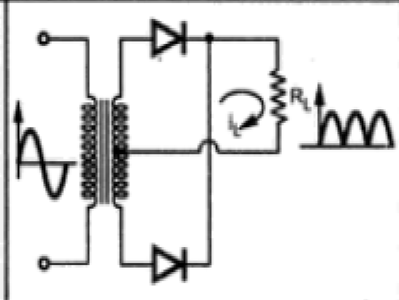
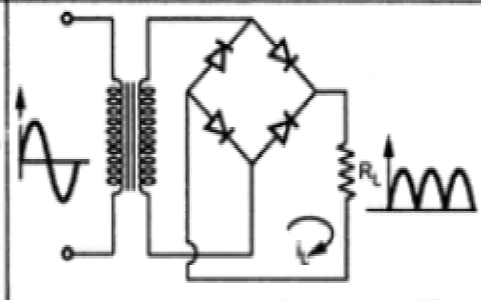
- Power transformer of a small size and less cost may be used.
- No centre tap is required in the transformer secondary.
- The transformer gets utilized effectively
- It is suitable for applications where large powers are required.

- It can be used for high voltage applications.

2.4.4 Disadvantages of Bridge Rectifier

- Use of four diodes
- Due to $2R_f$, this reduces the output voltage

2.5 Comparison of Rectifier Circuits

Circuit diagrams		
Half wave	Full wave	Bridge
		

Sr. No.	Parameter	Half wave	Full wave	Bridge
1.	Number of diodes	1	2	4
2.	Average D.C. current (I_{DC})	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
3.	Average D.C. voltage (E_{DC})	$\frac{E_{sm}}{\pi}$	$\frac{2E_{sm}}{\pi}$	$\frac{2E_{sm}}{\pi}$
4.	R.M.S. current (I_{RMS})	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
5.	D.C. power output (P_{DC})	$\frac{I_m^2 R_L}{\pi^2}$	$\frac{4}{\pi^2} I_m^2 R_L$	$\frac{4}{\pi^2} I_m^2 R_L$
6.	A.C. power input (P_{AC})	$\frac{I_m^2(R_L + R_f + R_s)}{4}$	$\frac{I_m^2(R_f + R_s + R_L)}{2}$	$\frac{I_m^2(2R_f + R_s + R_L)}{2}$
7.	Maximum rectifier efficiency (η)	40.6 %	81.2 %	81.2 %
8.	Ripple factor (γ)	1.21	0.482	0.482
9.	Maximum load current (I_m)	$\frac{E_{sm}}{R_s + R_f + R_L}$	$\frac{E_{sm}}{R_s + R_f + R_L}$	$\frac{E_{sm}}{R_s + 2R_f + R_L}$
10.	PIV rating of diode	E_{sm}	$2\ E_{sm}$	E_{sm}
11.	Ripple frequency	50 Hz	100 Hz	100 Hz
12.	T.U.F.	0.287	0.693	0.812

2.6 Filter Circuits

Definition of filter:

- A **filter circuit** is one which removes the ac component present in the rectified output and allows the dc component to reach the load.

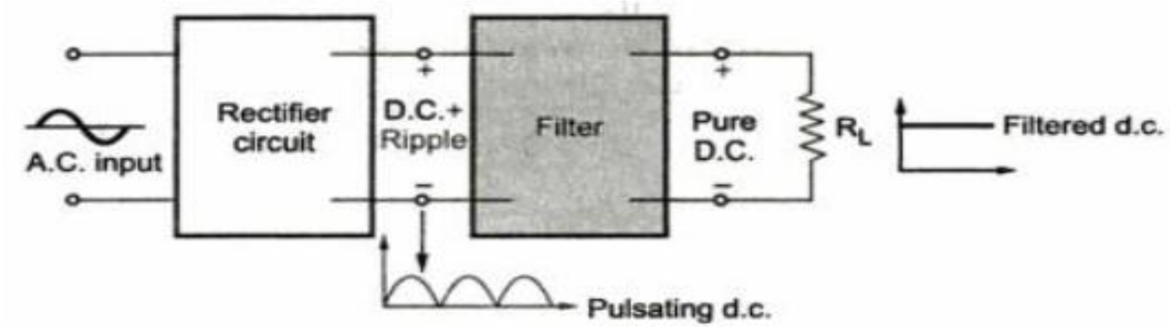


Fig. 2.7 Rectifier and filter

- It is seen that the output of a half wave or full wave rectifier circuit is not pure d.c.
- But it contains fluctuations or ripple, which are undesired.
- To minimize the ripple content in the output of rectifier, filter circuits are used.
- These circuits are connected between the rectifier and load as shown in the Fig. 2.7.
- An a.c input is applied to the rectifier.
- At the output of the rectifier, there will be d.c and ripple voltage present, which is the input to the filter.
- Ideally the output of the filter should be pure d.c.
- Two components which are used in filter circuits are inductance and capacitance.
- An inductor allows dc and blocks ac. A capacitor allows ac and blocks dc.
- In a filter circuit, the inductance is always connected in series with the load.
- In a filter circuit, the capacitance is always connected in parallel with the load.

2.6.1 Types of filter circuits

- Capacitor filter (C Filter)
- Inductor filter (or) Choke filter (L Filter)
- L Section filter (or) LC Filter
- π- Section Filter (CLC Filter)

2.6.2 Capacitor filter (C Filter)

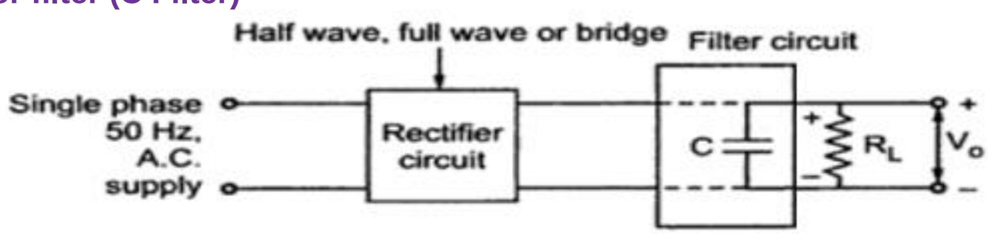


Fig. 2.8 Block Schematic of capacitor filter

- The block schematic of capacitor filter is shown in the Fig. 2.8.
- Looking from the rectifier side the first element in filter is a capacitor.

2.6.2.1 Capacitor filter with Full Wave Rectifier

- The capacitor filter used in full wave rectifier circuit as shown in the Fig. 2.9.

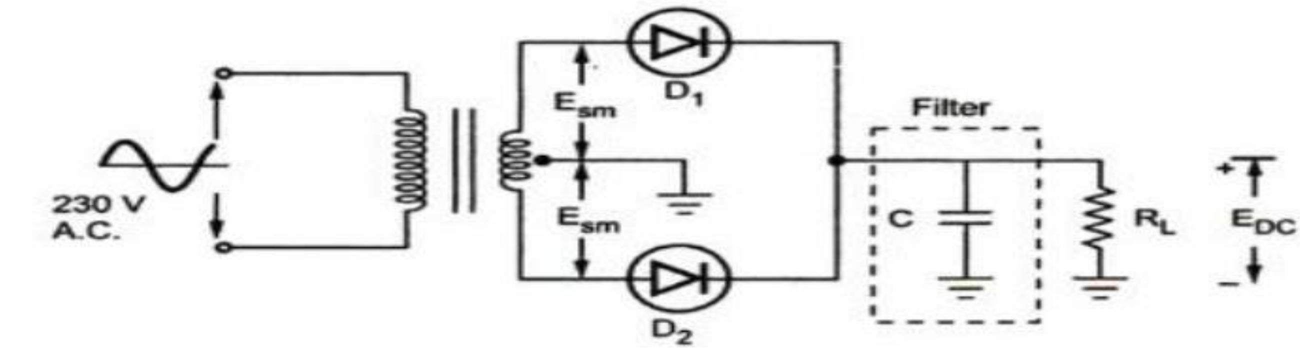


Fig. 2.9 Capacitor input filter with Full wave rectifier

- When power is turned on, the capacitor C gets charged through forward biased diode D_1 to E_{sm}, during first quarter cycle of the rectified output voltage.
- In the next quarter cycle from π/2 to π the capacitor starts discharging through R_L.
- Once capacitor gets charged to E_{sm}, the diode D_1 becomes reverse biased and stops conducting. So during the period from π/2 to π the capacitor C supplies the load current.
- It discharges to point B shown in the Fig. 2.10

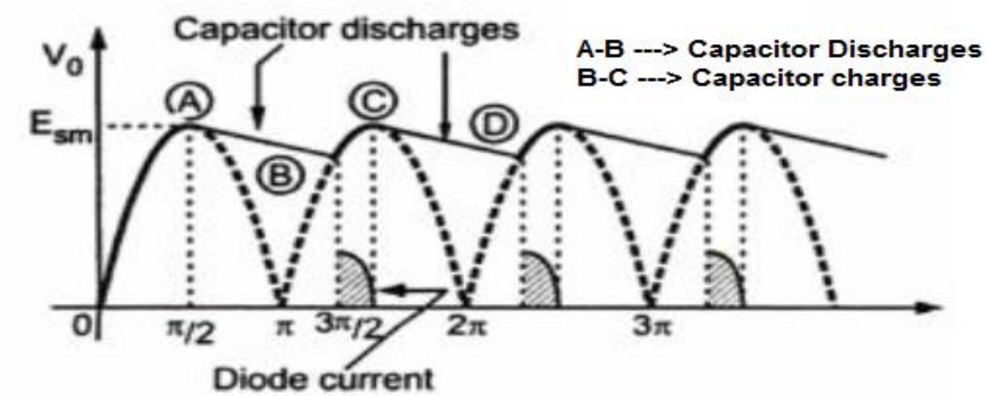


Fig. 2.10 Waveforms of Capacitor input filter with Full wave rectifier

- At point B, lying in the quarter π to 3π/2 of the rectified output voltage, the input voltage exceeds capacitor voltage, making D_2 forward biased. This charges capacitor back to E_{sm} at point C.
- The time required by capacitor C to charge to E_{sm} is quite small and only for this period, diode D_2 is conducting.
- Again at point C, diode D_2 stops conducting and capacitor supplies load and starts discharging upto point D in the next quarter cycle of the rectified output voltage as shown in the Fig. 2.10.
- At this point, the diode D_1 conducts to charge capacitor back to E_{sm}.
- The diode currents are shown shaded in the Fig. 2.11.
- When the capacitor is discharging through the load resistance R_L both the diodes are non-conducting. The capacitor supplies the load current.

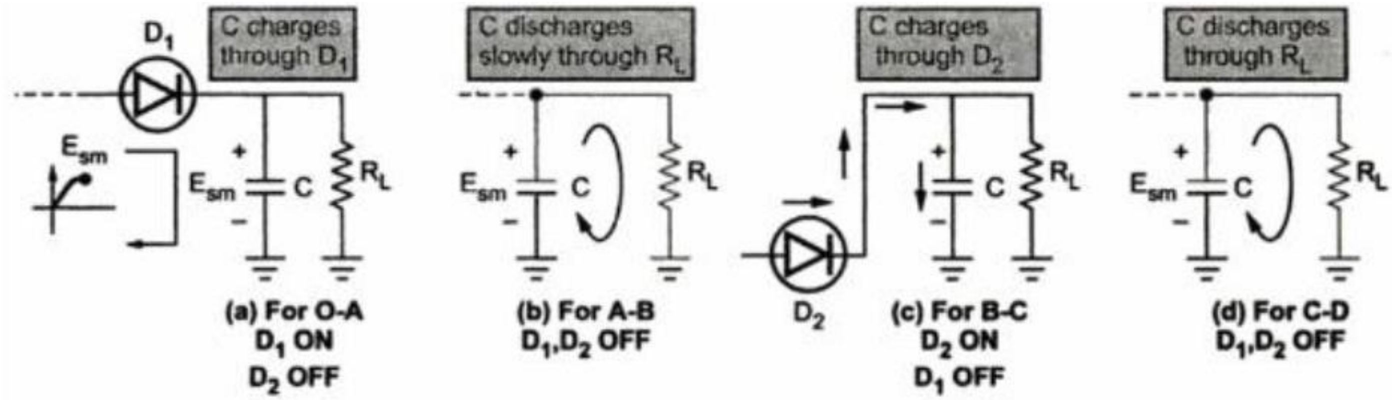


Fig. 2.11 Operation of Capacitor input filter with Full wave rectifier

- Expression for ripple factor of full wave rectifier circuit using a capacitor filter is given below.

$$\text{Ripple factor} = \frac{1}{4\sqrt{3}\, f C R_L} \quad \text{for full wave}$$

- The product CR_L is the time constant of the filter circuit.
- From the expression of the ripple factor, it is dear that increasing the value of capacitor C, the ripple factor gets decreased.
- Thus the output can be made smoother, reducing the ripple content by selecting large value of capacitor.

2.6.2.2 Advantages of C filter

- Less number of components.
- Low ripple factor hence low ripple voltage.
- Suitable for high voltage at small load currents.

2.6.2.3 Disadvantages of C filter

- Ripple factor depends on load resistance.
- Not suitable for variable loads as ripple content increases as R_L decreases.
- Regulation is poor.
- Diodes are subjected to high surge currents hence must be selected accordingly.

Example : *Calculate the value of 'C ' that has to be used for the capacitor filter of a full wave rectifier to get a ripple factor of 0.01 %. The rectifier supplies a load of 2 kΩ while the supply frequency is 50 Hz.*

Solution : The given values are,

$$\gamma = 0.01\,\%,\ R_L = 2\ \text{k}\Omega \text{ and } f = 50\ \text{Hz}$$

For a capacitor filter with full wave rectifier,

$$\%\,\gamma = \frac{1}{4\sqrt{3}\, f C R_L} \times 100$$

$$\therefore \quad 0.01 = \frac{1}{4\sqrt{3} \times 50 \times C \times 2000} \times 100$$

$$\therefore \quad C = \mathbf{14.433\ mF}$$

2.6.3 Inductor filter with Full Wave Rectifier

- In this type of filter, an inductor (choke) is connected in series with the load.
- The inductor opposes change in the current. So, the ripple which is change in the current is opposed by the inductor and it tries to smoothen the output.
- Consider a full wave rectifier with inductor filter which is also called choke filter.
- Fig. 2.12 shows the circuit diagram while Fig. 2.13 shows the current waveform obtained by using choke filter with full wave rectifier.

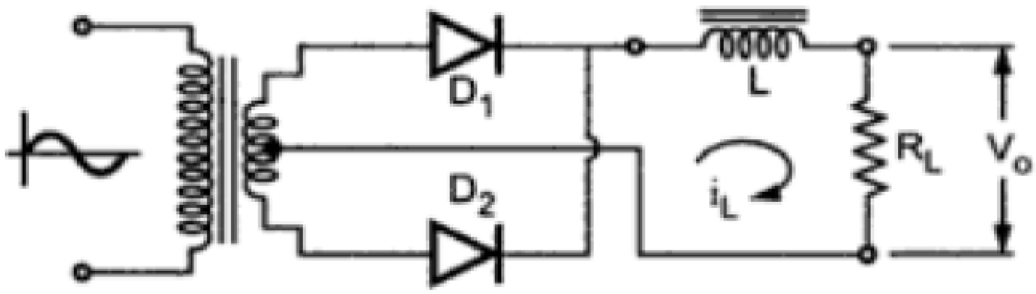


Fig. 2.12 Circuit diagram of Inductor filter

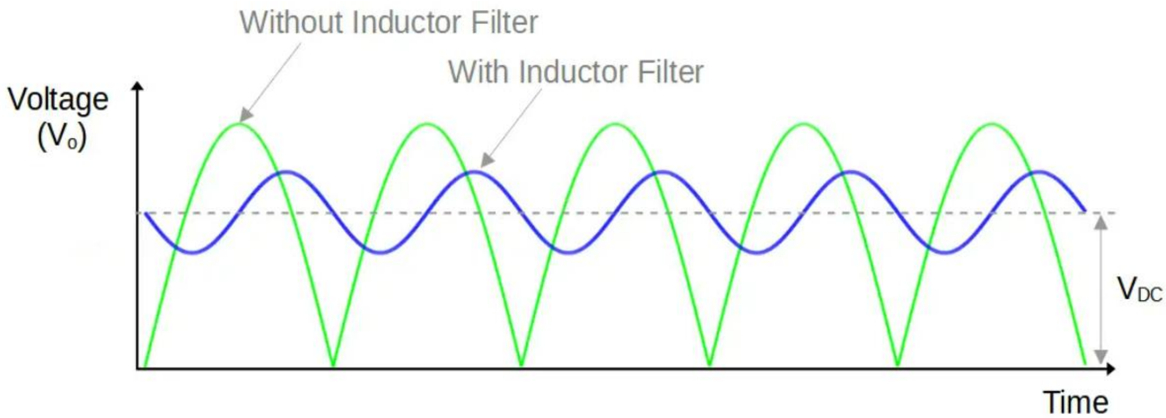


Fig. 2.13 Output Voltage waveform of Inductor filter

- In the positive half cycle of the secondary voltage of the transformer, the diode D_1 is forward biased. Hence the current flows through D_1, L and R_L.
- In the negative half cycle, the diode D_1 is reverse biased while diode D_2 is forward biased. Hence the current flows through D_2, L and R_L.
- Hence, we get unidirectional current through R_L.
- Due to inductor L which opposes change in current, it tries to make the output smooth by opposing the ripple content in the output.
- Expression for ripple factor of full wave rectifier circuit using an Inductor filter is given below.

$$\text{Ripple factor} = \gamma = \frac{R_L}{3\sqrt{2} \cdot \omega L}$$

- So as load changes, ripple charges which is inversely proportional to the value of the inductor.

2.6.3.1 Advantages of series inductor (L) filter

- The series inductor (L) filter reduces the ripple in the DC output of rectifier circuit.
- It has low ripple factor at heavy load currents i.e. low load resistance.

2.6.3.2 Disadvantages of series inductor (L) filter

- It is bulky and more costly.
- It gives low output DC voltage for larger value of inductance.
- It has poor voltage regulation.
- It has high ripple factor for light loads i.e. small load currents.

2.7 Clipper Circuits (or) Limiters (or) Slicers

- The circuits which are used to clip off unwanted portion of the waveform, without distorting the remaining part of the waveform are called clipper circuits or clippers.
- A diode is most important element of any clipper circuit.

2.7.1 Classification of Clippers

- Series clipper
- Parallel Clipper

2.7.1.1 Series clipper

- When the diode is connected in series with the load, it is called Series clipper.
- A series clipper can be used to clip off the entire positive or negative half cycles of input waveforms.
- It also can be used to clip off the portion above the certain reference voltage or below the certain reference voltage.

2.7.1.2 Parallel (or) Shunt Clipper

- When the diode is connected in parallel to the load, it is called Parallel Clipper.

2.7.2 Types of Series clipper

- Series Negative Clipper
- Series Positive Clipper
- Series Clipping Above Reference Voltage V_R
- Series Clipping Below Reference Voltage V_R

2.7.3 Series Negative Clipper Circuit

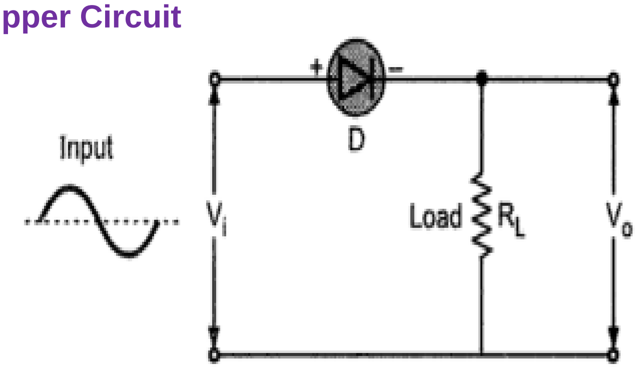


Fig. 2.14 Negative series clipper

2.7.3.1 Operation:

- Consider a circuit shown in the Fig. 2.14 where diode is connected in series with the load.
- For a positive half cycle, the diode D is forward biased and hence the voltage waveform across R_L looks like a positive half cycle of the input voltage.
- While for a negative half cycle, diode D is reverse biased and hence will not conduct at all. Hence there will not be any voltage available across resistance RL.
- Hence the negative half cycle of input voltage gets clipped off.
- The input waveform and the corresponding output voltage waveform is shown in the Fig. 2.15.

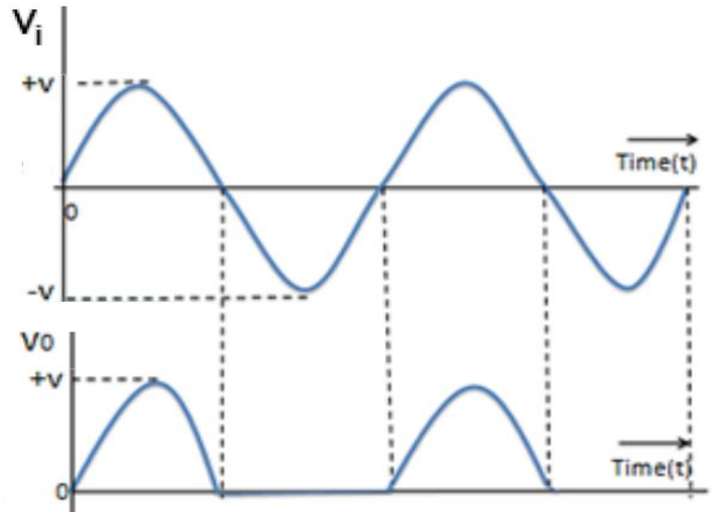


Fig.2.15 Input and Output waveforms

2.7.4 Series Positive Clipper Circuit

- It is similar to series negative clipper, a circuit which clipps off positive part of the input can be obtained.
- The positive series clipper can be obtained by changing the direction of diode in negative clipper circuit.

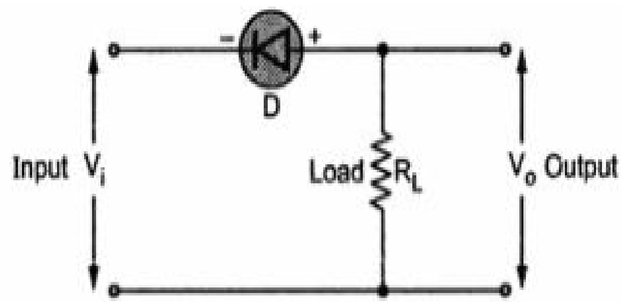


Fig. 2.16 Positive series clipper

- The Fig. 2.16 shows positive series clipper circuit in which diode direction is opposite to that in negative series clipper circuit.

2.7.4.1 Operation:

- For positive half cycle of input, $V_i > 0$ and diode is reverse biased. Hence it acts as open circuit and V_o=0.

- For negative half cycle, when V_i <0, the diode conducts. The output voltage V_o available is same as input voltage.
- Thus, entire negative half cycle of input is available at the output.
- The output waveforms for sinusoidal input waveform is shown in the Fig. 2.17.

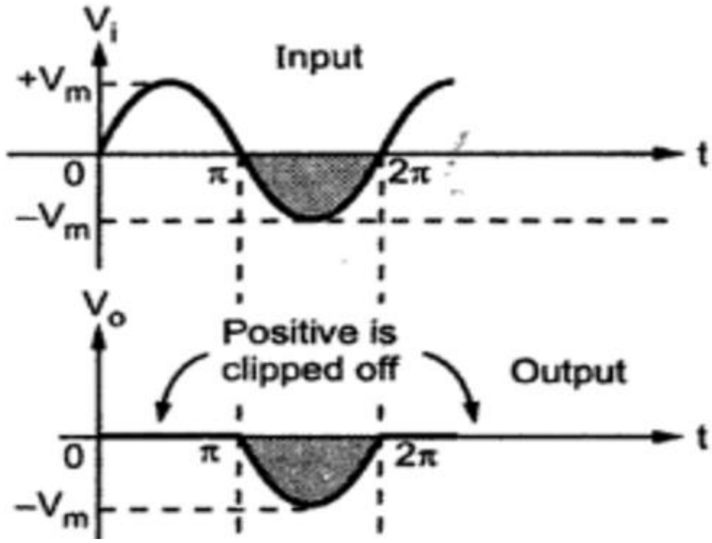


Fig. 2.17 Waveforms of series positive clipper

2.7.5 Parallel (or) Shunt Clippers

- In a parallel clipper circuit, the diode is connected across the load terminals.
- It can be used to clip or limit the positive or negative part of the input signal, as per the requirement.

2.7.5.1 Types of Parallel (or) Shunt clipper

- Shunt Negative Clipper
- Shunt Positive Clipper
- Shunt Clipping Above Reference Voltage V_R
- Shunt Clipping Below Reference Voltage V_R

2.7.6 Parallel Clipper with Positive Clipping

- The Fig. 2.18 shows the basic parallel clipper circuit in which diode D is connected across the load resistance R_L.
- The resistance R1 is current controlling resistance.

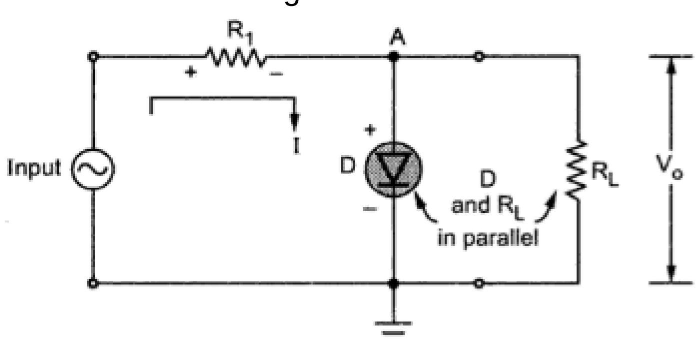


Fig. 2.18 Basic parallel clipper

2.7.6.1 Operation:

- During positive half cycle of the input V_i, the diode D becomes forward biased and remains forward biased for the entire half cycle of the input.
- As R_L is in parallel with diode no current flows through it and output voltage V_o = 0V as shown in the Fig. 2.19.

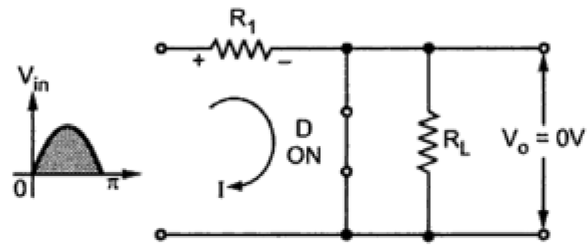


Fig. 2.19 Operation during positive half cycle

- During negative half cycle of input, the diode is reverse biased and acts as open circuit.
- The entire current flows through R_L as shown in the Fig. 2.20.

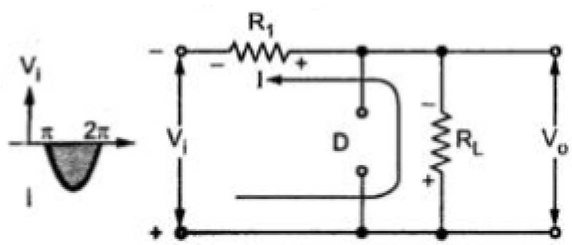


Fig. 2.20 Operation during negative half cycle

- Hence using potential divider rule $V_o = \frac{V_i R_L}{R_L + R_1}$.
- Thus, V_o α V_i and there exists straight line relationship between the input and output voltage.
- The waveforms are shown in the Fig. 2.21.

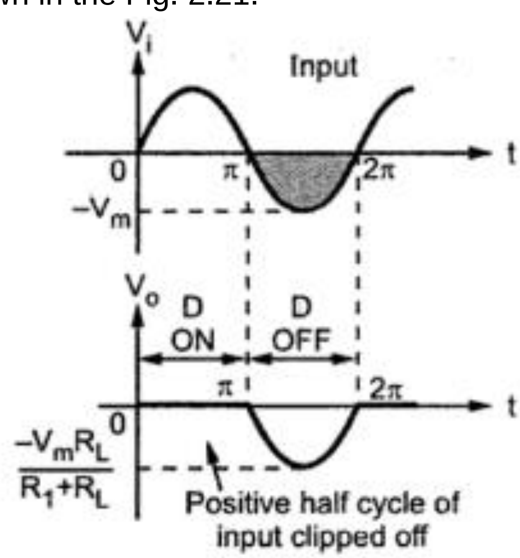


Fig. 2.21 Waveforms for parallel clipper

2.7.7 Clipping at two independent levels

- This type of clipper combines a parallel negative clipper with negative bias (D_2 and V_{R2}) and a parallel positive clipper with positive bias (D_1 and V_{R1}).
- Such a clipper circuit can clip at two independent levels depending upon the bias voltages.
- Fig. 2.22 shows the circuit of a clipping at two independent levels.

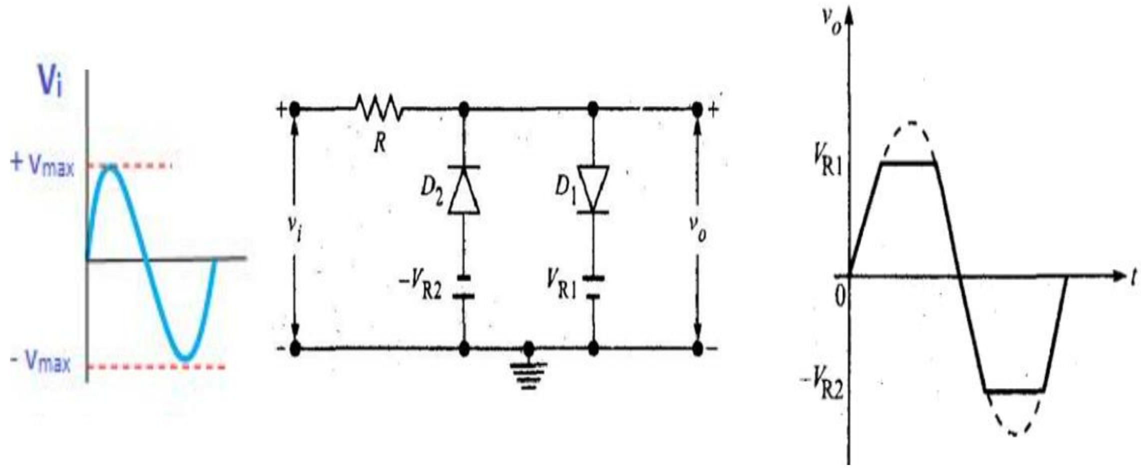


Fig. 2.22 Circuit diagram of a clipping at two independent levels

2.7.7.1 Operation:

- During the positive half cycle of the Input signal, the diode D_1 is forward biased, while diode D_2 is reverse biased.
- Therefore, the diode D_1 will conduct and will acts as a short circuit and the diode D_2 will not conduct and will acts as an open circuit.
- So, the voltage V_{R1} appears across output terminals.
- During the negative half cycle of the Input signal, the diode D_2 acts as a short circuit while the diode D_1 as an open circuit.
- So, the voltage V_{R2} appears across output terminals.
- It may be noted that the clipping levels of the circuit be varied by changing the values of V_{R1} and V_{R2}.
- If the values of V_{R1} and V_{R2} are equal, the circuit will clip both the positive and negative half cycles at the same voltage level.
- In short, the operation of a clipping at two independent levels is given below.

Input v_i	*Output* v_o	*Diode status*
$v_i > V_{R1}$	$v_o = V_{R1}$	D_1 ON, D_2 OFF
$-V_{R2} < v_i < V_{R1}$	$v_o = v_i$	D_1 OFF, D_2 OFF
$v_i < -V_{R2}$	$v_o = -V_{R2}$	D_1 OFF, D_2 ON

2.8 Clamper Circuits

- The circuits which are used to add a d.c. level to the a.c. output signal is called as Clamper circuits.
- The capacitor, diode and resistance are the three basic elements of a clamper circuit.
- The clamper circuits are also called d.c. restorer or d.c. inserter circuits.

2.8.1 Clamping Circuit Theorem

- Clamping Circuit theorem relates the area of the output waveform when diode conducts to the area of the output waveform when diode is OFF.
- It states that, under steady-state conditions, the ratio of area in forward direction A_f to that of reverse direction A_r of output voltage is equal to the ratio of diode forward resistance R_f to resistance R connected across diode.

$$\frac{A_f}{A_r} = \frac{R_f}{R}$$

2.8.2 Types of Clampers

- Depending upon whether the positive d.c. or negative d.c. shift is introduced in the output waveform, the clampers are classified as,

  a) Negative clamper

  b) Positive clamper

2.8.3 Negative Clamper

- A simple negative clamper which adds a negative level to the a.c. output is shown in the Fig. 2.23.
- It consists of a capacitor C, the ideal diode D and the load resistance R_L.

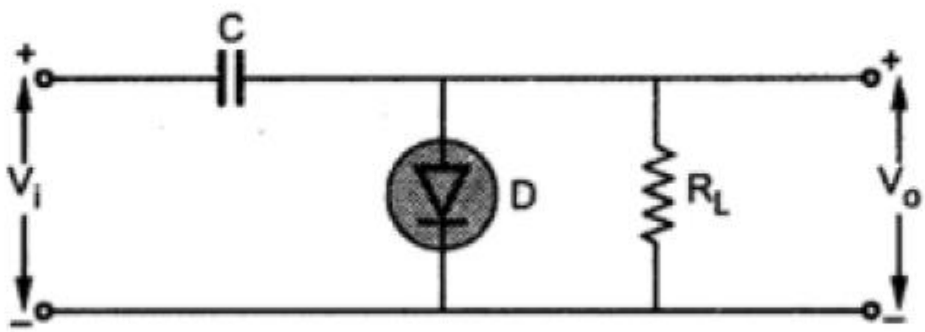


Fig. 2.23 Negative clamper

2.8.3.1 Operation:

- During the first quarter of positive cycle of the input voltage V_i, the capacitor gets charged through forward biased diode D upto the maximum value V_m of the input signal V_i.
- The capacitor charging is almost instantaneous, which is possible by selecting proper values of C and R_L in the circuit.

- The capacitor once charged to V_m, acts as a battery of voltage V_m, as shown in the Fig. 2.24.

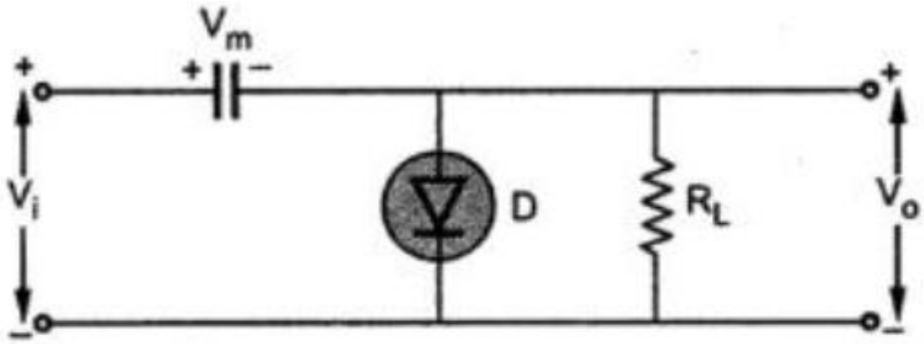


Fig. 2.24 Operation of Negative clamper during first quarter of positive cycle

- Thus, when D is ON, the output voltage V_o is zero.
- As input voltage decreases after attaining its maximum value V_m, the capacitor remains charged to V_m and the diode D becomes reverse biased.
- Due to large RC time constant the capacitor holds its entire charge and capacitor voltage remains as $V_c = V_m$ as shown in the Fig. 2.25.

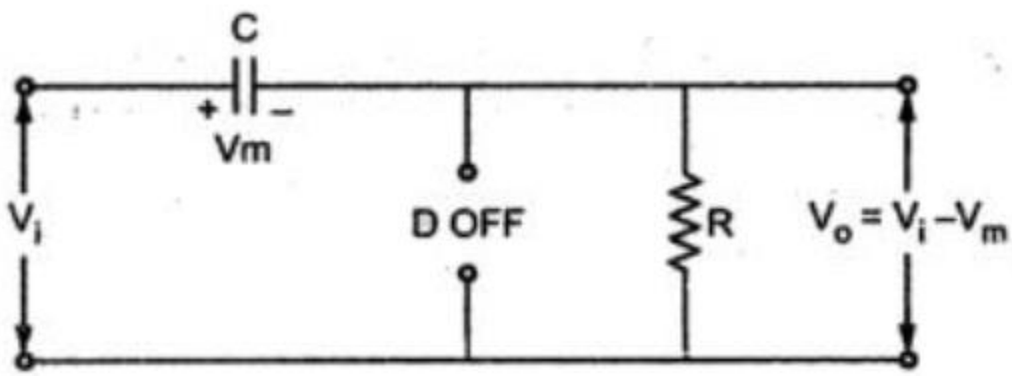


Fig.2.25 Operation of Negative clamper during negative half cycle

- In the negative half cycle of V_i, the diode will remain reverse biased.
- The capacitor starts discharging through the resistance R_L.
- As the time constant R_LC is very large, it can be approximated that the capacitor holds all its charge and remains charged to V_m, during this period also.
- Hence, we can write again that,

$$V_o = V_i - V_c = V_i - V_m \quad \text{for negative half cycle}$$

$$V_o = -V_m, \quad \text{for } V_i = 0$$

$$V_o = 0, \quad \text{for } V_i = V_m$$

$$V_o = -2V_m, \quad \text{for } V_i = -V_m$$

2.8.3.2 Waveforms:

- Assuming ideal diode, the input and output waveforms are shown in the Fig. 2.26.
- The peak to peak amplitude of the input is 2 V_m.
- Similarly, the peak-to-peak amplitude of the output is also 2 V_m.
- Thus, the total swing of the output is always same as the total swing of the input, for a clamper circuit.

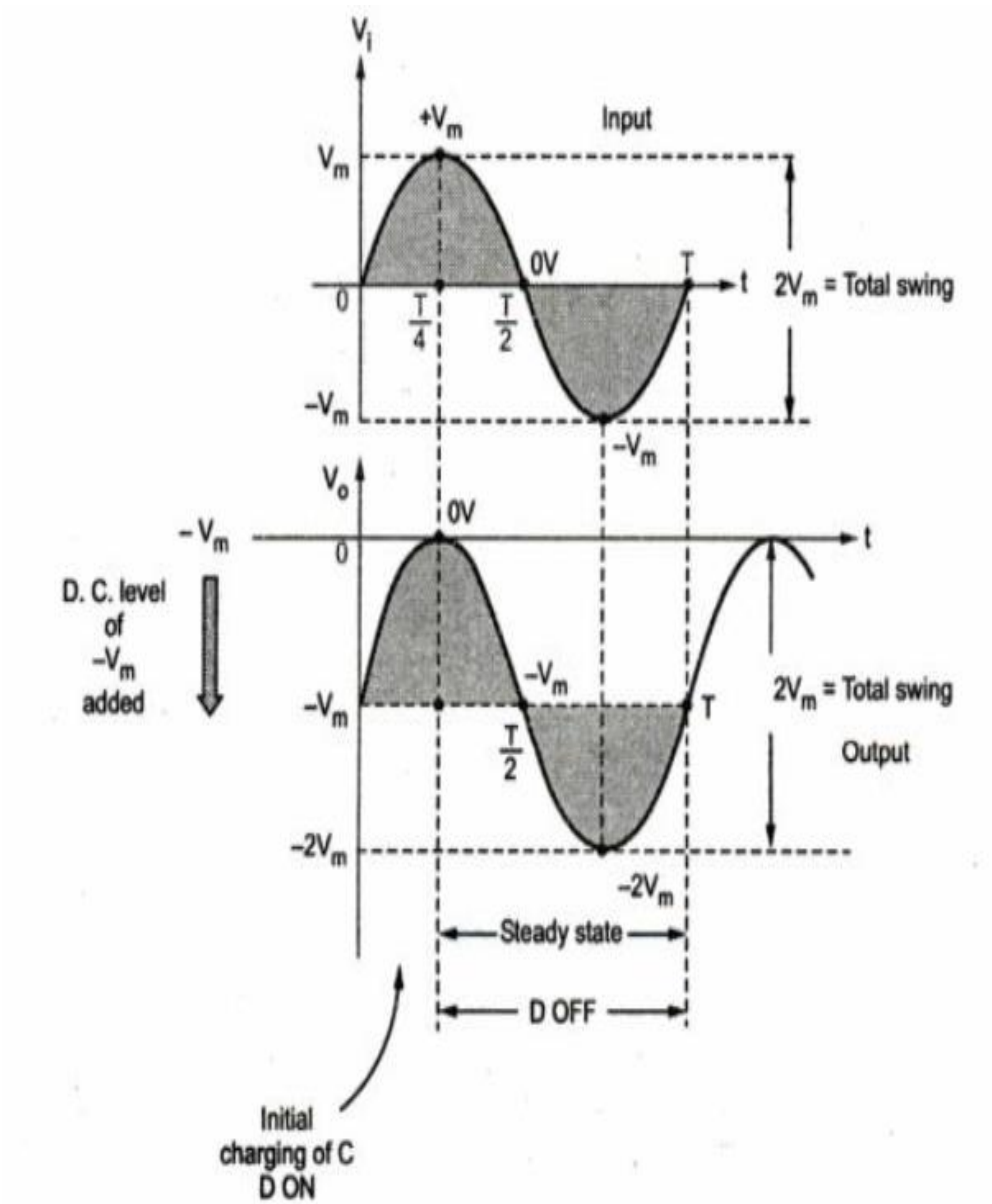


Fig. 2.26 Negative clamper waveforms

2.8.4 Positive Clamper

- By changing the orientation of the diode in the negative clamper, the positive clamper circuit can be achieved.
- The circuit is shown in the Fig. 2.27.

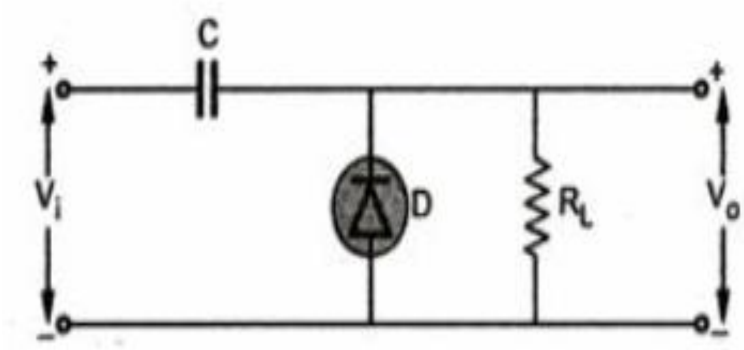


Fig. 2.27 Positive clamper

2.8.4.1 Operation:

- During the first quarter of negative half cycle of the input voltage V_i, diode D gets forward biased and almost instantaneously capacitor gets charged equal to the maximum value V_m of the input signal V_i with the polarities as shown in the Fig. 2.28.

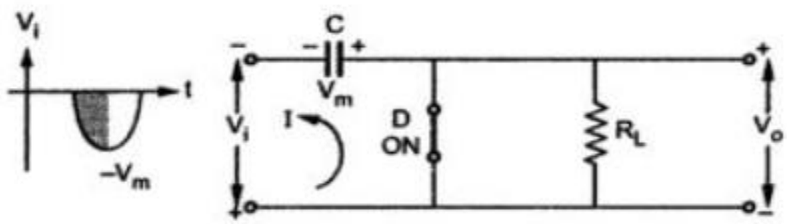


Fig. 2.28 Operation of Positive clamper during first quarter of negative half cycle

- The capacitor once charged to V_m, acts as a battery of voltage V_m with the polarities as shown in the Fig. 2.28.
- This is because RC time constant is very large hence capacitor holds its entire charge all the time.
- Thus when $V_i = V_m$, the output voltage V_o is 2 V_m.
- In the positive half cycle, the diode D is reverse biased.
- The capacitor starts discharging through R_L.
- But due to large time constant, it hardly gets discharged during positive half cycle of V_i. This is shown in the Fig. 2.29.

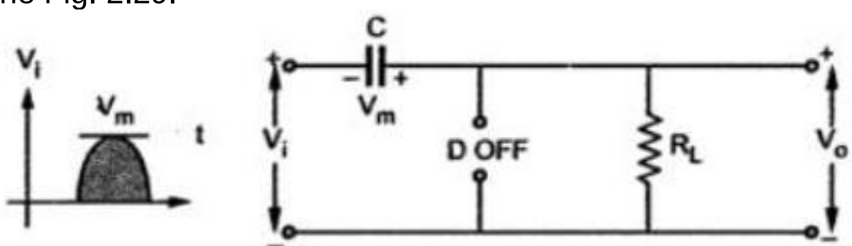


Fig. 2.29 Operation of Positive clamper during Positive half cycle

- Hence, $V_o = V_i + V_m$

$$V_o = V_m, \quad \text{for } V_i = 0$$
$$V_o = 2V_m, \quad \text{for } V_i = V_m$$
$$V_o = 0, \quad \text{for } V_i = -V_m$$

2.8.4.2 Waveforms:

- Assuming ideal diode, the input and output waveforms are shown in the fig. 2.30.

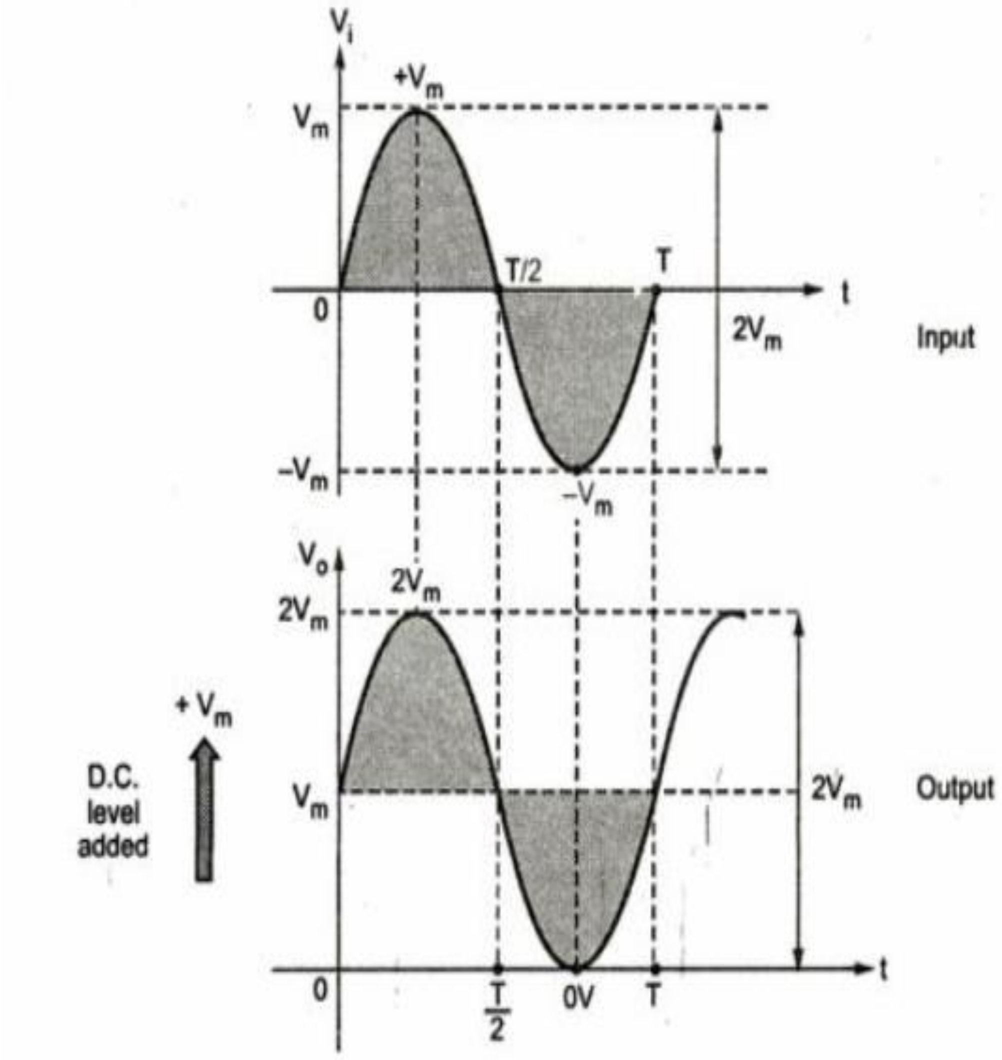


Fig. 2.30 Positive clamper waveforms