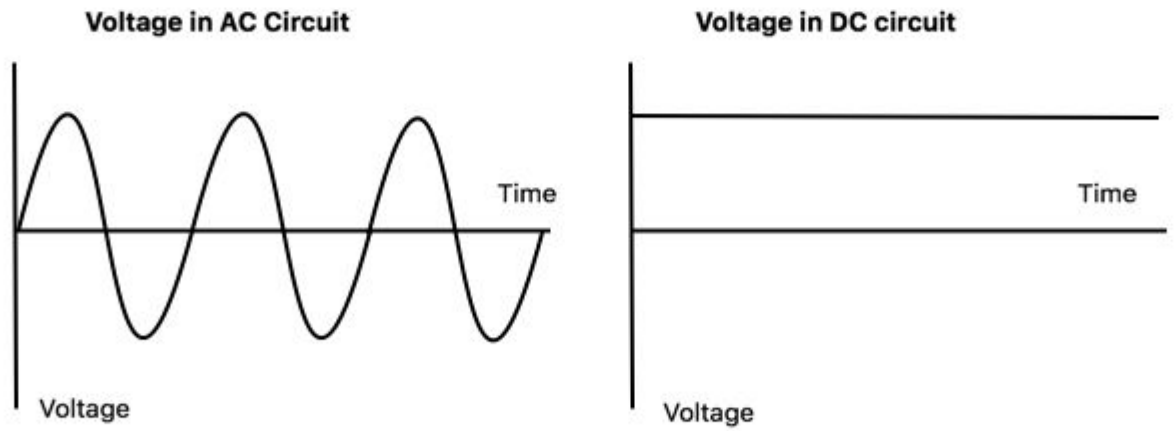
# UNIT II

# DIODE CIRCUITS

- Rectifiers
  - Half Wave Rectifier (HWR)
  - Full Wave Rectifier (FWR)
  - Bride Full wave rectifier
- Filters
  - Inductive (L) filters
  - Capacitive (C) filters
  - LC filters
  - CLC filters
- Clippers
- Clampers
- Voltage Multipliers

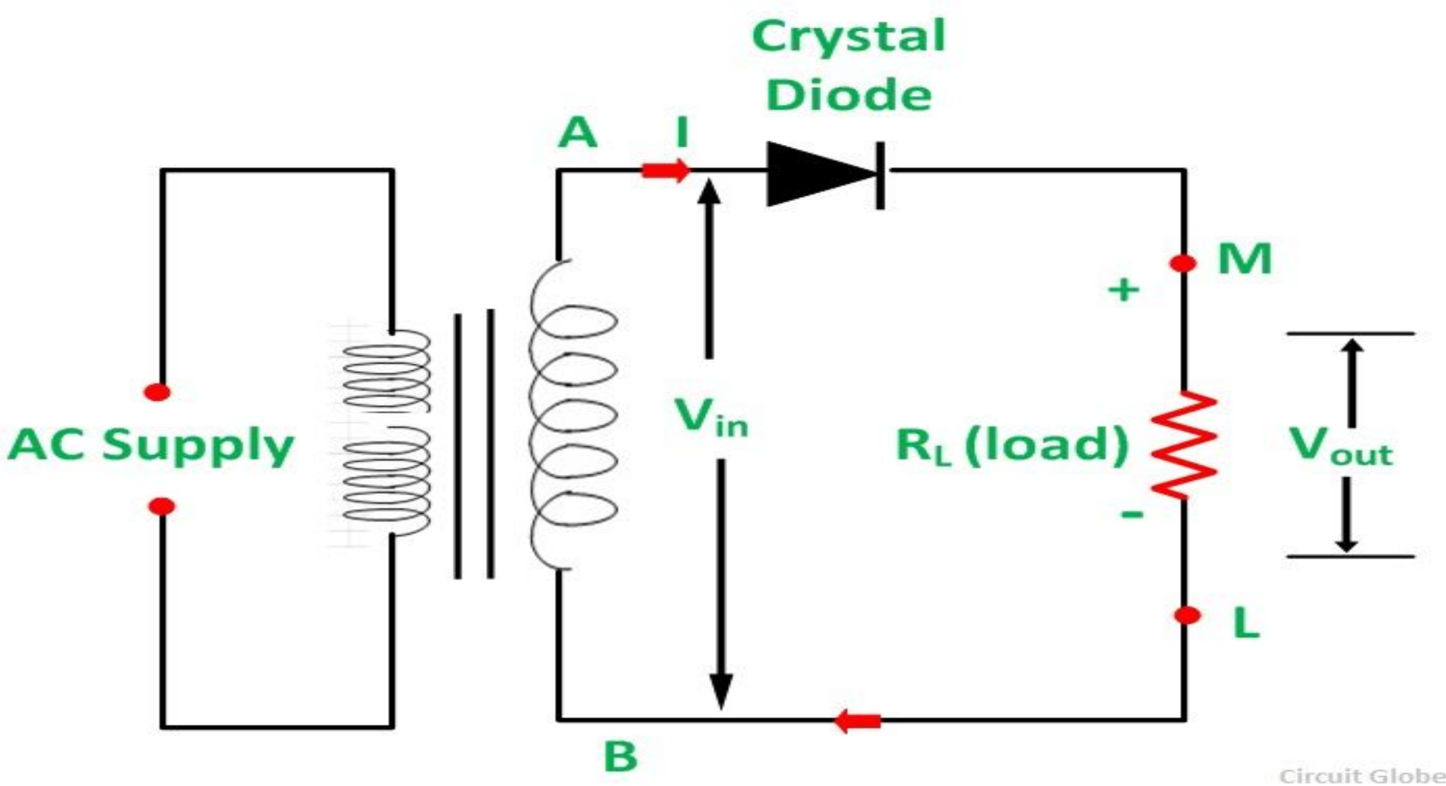
# Rectifiers

- Type of circuit used to convert AC voltage to DC voltage

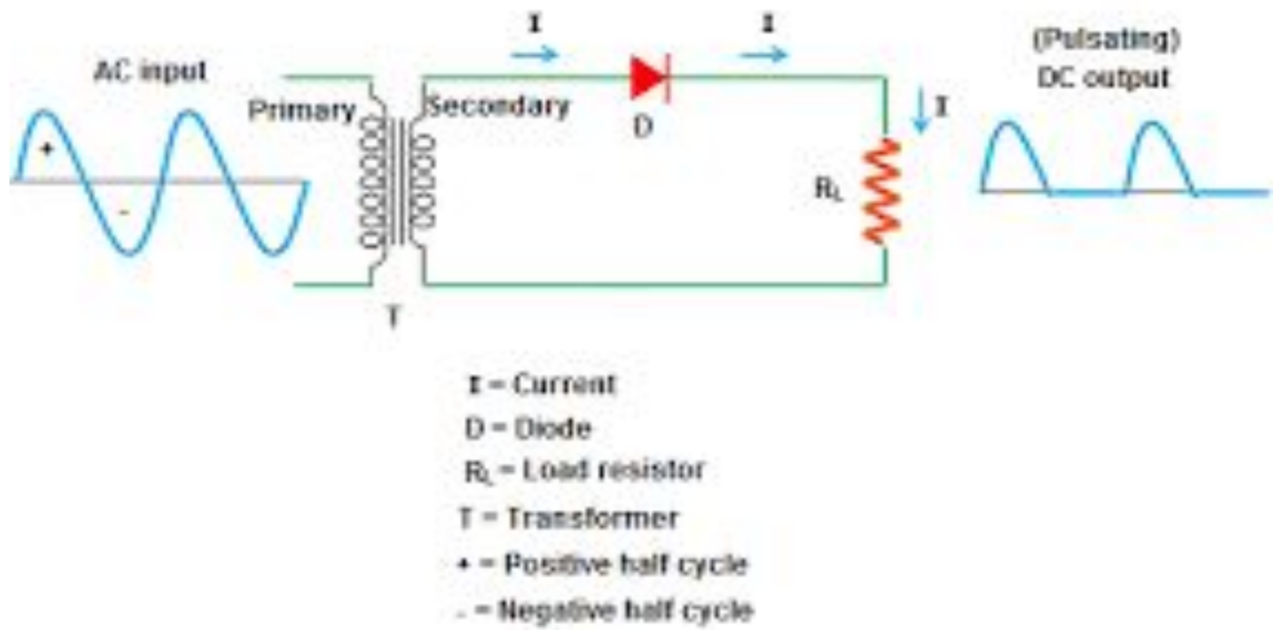



  - Half Wave Rectifier (HWR)
  - Full Wave Rectifier (FWR)
  - Bride Full wave rectifier

# Half Wave Rectifier (HWR)

- Rectifier that only allows one half-cycle of an AC voltage waveform to pass, blocking the other half-cycle.
- 

- During the positive half cycle of the AC voltage
  – the diode will be forward biased and the current flows through the diode.
- During the negative half cycle of the AC voltage
  – the diode will be reverse biased and the flow of current will be blocked.




Half wave rectifier

- **Ripple Factor (Γ ) of Half Wave Rectifier**
  - ‘Ripple’ is the unwanted AC component remaining when converting the AC voltage waveform into a DC waveform.
  - Even though we try out best to remove all AC components, there is still some small amount left on the output side which pulsates the DC waveform.
  - This undesirable AC component is called ‘ripple’.
  - Note that for us to construct a good rectifier, we want to keep the ripple factor as low as possible.
  - This is why we use capacitors and inductors as filters to reduce the ripples in the circuit.

- The ripple factor is the ratio between the RMS value of the AC component (on the input side) and the DC component (on the output side) of the rectifier

$$Ripple\ Factor = \frac{r.m.s.\ value\ of\ a.c.component}{value\ of\ d.c.component} = \frac{I_{ac}}{I_{dc}}$$

  - the effective or r.m.s value of total load current is

$$I_{rms} = \sqrt{I_{dc}^2 + I_{ac}^2}$$

or

$$I_{ac} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

  - Dividing by $I_{dc}$ ,

$$\frac{I_{ac}}{I_{dc}} = \frac{1}{I_{dc}}\sqrt{I_{rms}^2 - I_{dc}^2}$$

But $I_{ac}/I_{dc}$ is the ripple factor.

$$\therefore \quad \text{Ripple factor} = \frac{1}{I_{dc}}\sqrt{I_{rms}^2 - I_{dc}^2} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

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

$$= \frac{1}{2\pi} \left[ \int_0^{\pi} i_d \, d(\omega t) + \int_{\pi}^{2\pi} i_d \, d(\omega t) \right]$$

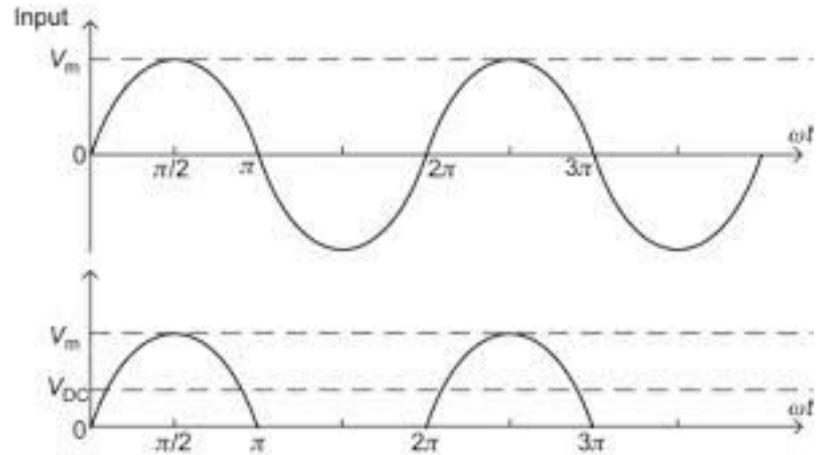
id=0 in the range $\pi$ to $2\pi$

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

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

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

$$\boxed{\therefore I_{dc} = \frac{I_m}{\pi}}$$




$$I_{rms} = \sqrt{ \frac{1}{2\pi} \int_0^{2\pi} i_L^2 \; d(\omega t) }$$

$$= \sqrt{ \frac{1}{2\pi} \left[ \int_0^{\pi} I_m^2 \sin^2 \omega t \, d(\omega t) + \int_{\pi}^{2\pi} 0 \, d(\omega t) \right] }$$

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

$$\boxed{\therefore I_{rms} = \frac{I_m}{2}}$$

$$Ripple\ factor = \sqrt{ \left( \frac{I_{rms}}{I_{dc}} \right)^2 - 1 } = \sqrt{ \left( \frac{I_m/2}{I_m/\pi} \right)^2 - 1 } \quad \boxed{= 1.21}$$

- **Efficiency (η) of Half Wave Rectifier**
  - Rectifier efficiency is the ratio between the output DC power and the input AC power.
  - The formula for the efficiency is

$$\eta = \frac{\text{Output DC power}}{\text{Input AC power}} \text{ x } 100\%$$

$$\therefore \eta = \frac{P_{dc}}{P_{ac}}$$

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

$$P_{ac} = I_{rms}^2 \; R_L + R_f \; = \frac{I_m^2}{4} \; R_L + R_f$$

$$\therefore \eta = \frac{P_{dc}}{P_{ac}} = \frac{I_m^2 R_L}{\pi^2} \times \frac{4}{I_m^2 \; R_L + R_f} = \frac{4}{\pi^2}\left(\frac{R_L}{R_L + R_f}\right)$$

$$\Rightarrow \eta = \frac{4}{\pi^2} \cdot \frac{1}{\left(1 + \frac{R_f}{R_L}\right)} = \frac{0.406}{1 + \frac{R_f}{R_L}}$$

$$\Rightarrow \% \eta = \frac{40.6}{1 + \frac{R_f}{R_L}}$$

Theoretically the maximum value of rectifier efficiency of a half-wave rectifier is 40.6% when $\frac{R_f}{R_L} = 0$.

**% of η = 40.6**

- **Transformer Utilization Factor (TUF)**
  - In design of power supply the rating of the transformer should be determined

$$TUF = \frac{\text{D.C Power output delivered to the load}}{\text{A.C Rating of transformer secondary}}$$

  - the average or DC output current is for half wave rectifier is equal to $(I_m/\pi)$ , where $I_m$ is peak value of output current.
  - Similarly, the average or dc voltage output is equal to $(V_m/\pi)$.
  - DC Power Output, $P_{dc}$ = Average Current x Average Voltage

$$= (I_m/\pi)\,(V_m/\pi)$$

$$= (I_m\,V_m)/\pi^2$$

- Next we need to find the effective AC rating of Transformer.
- Since the voltage of source is sinusoidal, therefore its rms value will be equal to $(V_m/\sqrt{2})$.
- But the source current is not sinusoidal for half wave rectifier rather it is governed by the waveform of the load current. This is just because of transformer action.
- This means, the rms value of the source current will be equal to the rms value of the load current.
- As the rms value of load current for half wave rectifier is equal to $(I_m/2)$, therefore the rms value of source current will also be equal to $(I_m/2)$.
- AC rating of Transformer $= (V_m/\sqrt{2})(I_m/2)$

$$(V_m I_m)/(2\times\sqrt{2})$$

- $TUF = [(I_m V_m)/\pi^2] / [(V_m I_m)/(2x\sqrt{2})]$

  $= [(2x\sqrt{2})/\pi^2]$

  **TUF = 0.2865**

- It means that the AC rating of transformer required for half wave rectifier is approximately 3.5 times (1/0.2865 = 3.5) of the DC power output.
- For example, the VA rating of required transformer for 100 watt load will be around 350 VA (0.35×100 = 350). This is quite poor utilization of transformer.

- **Form Factor (F.F)**
  - Form factor is the ratio between RMS value and average value, as shown in the formula below

$$F.F = \frac{RMS\ value}{Average\ value} = \frac{I_m/2}{I_m/\pi} = 1.57$$

$$\boxed{\textbf{F.F = 1.57}}$$

- **Peak Inverse Voltage (PIV)**
  - The maximum voltage that the diode can withstand during reverse bias condition.
  - If a voltage is applied more than the PIV, the diode will be destroyed.

$$\boxed{\textbf{PIV} = \textbf{V}_\textbf{m}}$$

- **Peak factor**
  - the ratio of the maximum value to the RMS value of an alternating quantity.
  - Peak factor $= \dfrac{\text{Peak value}}{\text{RMS value}} = \dfrac{V_m}{V_{RMS}}$
  - RMS voltage of a half wawave rectifier, $V_{RMS} = V_m/2$,

    where $V_m$ is the Maximum or peak voltage.

    $V_m / V_{RMS} = V_m / ( V_m / 2 )$

    $= 2 V_m / V_m = 2$

**Peak factor**

**= 2**

- Problems

1. **A half-wave rectifier, having a resistive load of 1000 Ω, rectifies an alternating voltage of 325 V peak the diode has a forward resistance of 100 Ω. Calculate (a) peak, average and rms value of current (b) ( output (c) a.c. input power, and (d) efficiency of the rectifier.**

(a) Peak value of current, $I_m = \dfrac{V_m}{r_f + R_L} = \dfrac{325}{100 + 100} = 295.45 \text{ mA}$

Average current, $I_{d.c.} = \dfrac{I_m}{\pi} = \dfrac{295.45}{\pi} \text{ mA} = 94.046 \text{ mA}$

RMS value of current, $I_{rms} = \dfrac{I_m}{2} = \dfrac{295.45}{2} = 147.725 \text{ mA}$

(b) The d.c. power output, $P_{d.c.} = I^2_{d.c.} \times R_L$

$$= (94.046 \times 10^{-3})^2 \times 1000 = 8.845 \text{ W}$$

(c) The a.c. input power, $P_{a.c.} = (I_{rms})^2 \times (r_f + R_L)$

$$= (147.725 \times 10^{-3})^2 (1100) = 24 \text{ W}$$

(d) Efficiency of rectification, $\eta = \dfrac{P_{d.c.}}{P_{a.c.}} = \dfrac{8.845}{24} = 36.85\%.$

2. **A half-wave rectifier is used to supply 24 V d.c. to a resistive load of 500 Ω and the diode has a forward resistance of 50 Ω. Calculate the maximum value of the a.c. voltage required at the input.**

*Solution* Average value of load current,

$$I_{\text{d.c.}} = \frac{V_{\text{d.c.}}}{R_L} = \frac{24}{500} = 48 \text{ mA}$$

Maximum value of load current, $I_m = \pi \times I_{\text{d.c.}} = \pi \times 48 \text{ mA} = 150.8 \text{ mA}$

Therefore, maximum a.c. voltage required at the input,

$$V_m = I_m \times (r_f + R_L)$$

3. **A half-wave rectifier is used to supply 24 V d.c. to a resistive load of 500 Ω and the diode has a forward resistance of 50 Ω. Calculate the maximum value of the a.c. voltage required at the input.**

*Solution* Average value of load current,

$$I_{\text{d.c.}} = \frac{V_{\text{d.c.}}}{R_L} = \frac{24}{500} = 48 \text{ mA}$$

Maximum value of load current, $I_m = \pi \times I_{\text{d.c.}} = \pi \times 48 \text{ mA} = 150.8 \text{ mA}$

Therefore, maximum a.c. voltage required at the input,

$$V_m = I_m \times (r_f + R_L)$$
$$= 150.8 \times 10^{-3} \times 550 = 82.94 \text{ V}$$

4. **A diode has an internal resistance of 20 Ω and 1000 Ω load from a 110 V rms source of supply. Calcula, (i) the efficiency of rectification and (ii) the percentage regulation from no load to full load.**

*Solution* Given $r_f = 20\ \Omega$, $R_L = 1000\ \Omega$ and $V_{rms}$ (secondary) = 110 V

The half-wave rectifier uses a single diode.

Therefore, $V_m = \sqrt{2}\, V_{rms}$ (secondary) $= \sqrt{2} \times 110 = 155.56$ V

$$I_m = \frac{V_m}{r_f + R_L} = \frac{155.56}{20 + 1000} = 0.1525 \text{ A}$$

$$I_{d.c.} = \frac{I_m}{\pi} = \frac{0.1525}{\pi} = 0.04854 \text{ A}$$

$$V_{d.c.} = I_{d.c.} R_L = 0.04854 \times 1000 = 48.54 \text{ V}$$

$$P_{d.c.} = V_{d.c.} I_{d.c.} = 48.54 \times 0.04854 = 2.36 \text{ W}$$

$$P_{a.c.} = I_{rms}^2 (r_f + R_L) = \left(\frac{I_m}{2}\right)^2 (r_f + R_L) \quad \left(\text{since } I_{rms} = \frac{I_m}{2} \text{ for half-wave}\right)$$

$$= \left(\frac{0.1525}{2}\right)^2 (20 + 1000) = 5.93 \text{ W}$$

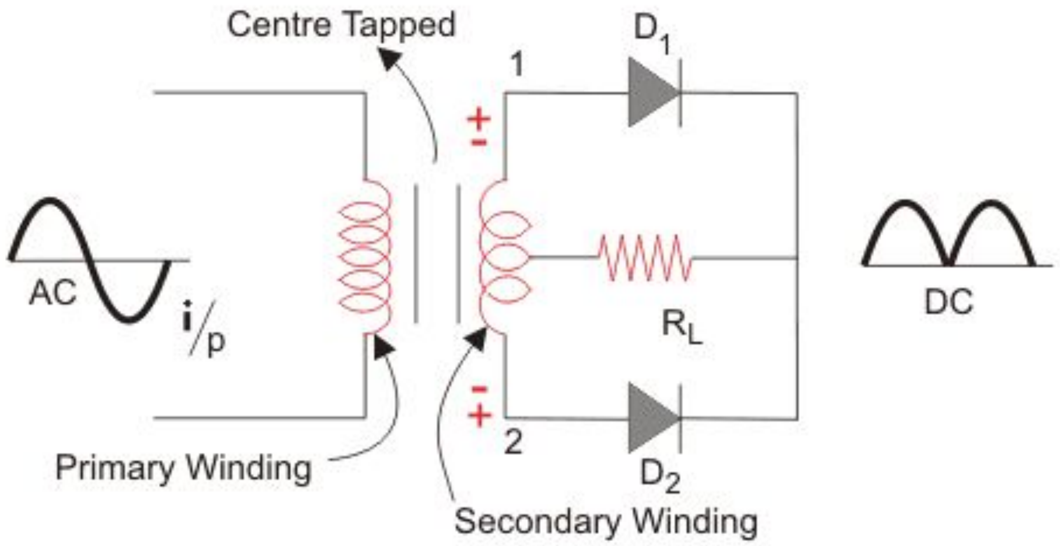
Efficiency, $$\eta = \frac{P_{d.c.}}{P_{a.c.}} \times 100 = \frac{2.36}{5.93} \times 100 = 39.7346\%$$

Percentage of line regulation $$= \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100 = \frac{\frac{V_m}{\pi} - V_{d.c.}}{V_{d.c.}} \times 100$$

$$= \frac{\frac{155.56}{\pi} - 48.54}{48.54} \times 100 = 2\%$$

# FULL WAVE RECTIFIER

- A full wave rectifier converts both halves of each cycle of an alternating wave (AC signal) into pulsating DC signal.
- Uses a centre tapped transformer




Centre Tapped Full Wave Rectifier
Figure - 1

- **Centre-tapped Transformer**
  - transformer with an additional wire connected to the exact centre of the secondary winding.
  - This type of construction divides the AC voltage into two equal and opposite voltages namely +Ve voltage ($V_a$) and -Ve voltage ($V_b$).
  - The total output voltag $V = V_a + V_b$

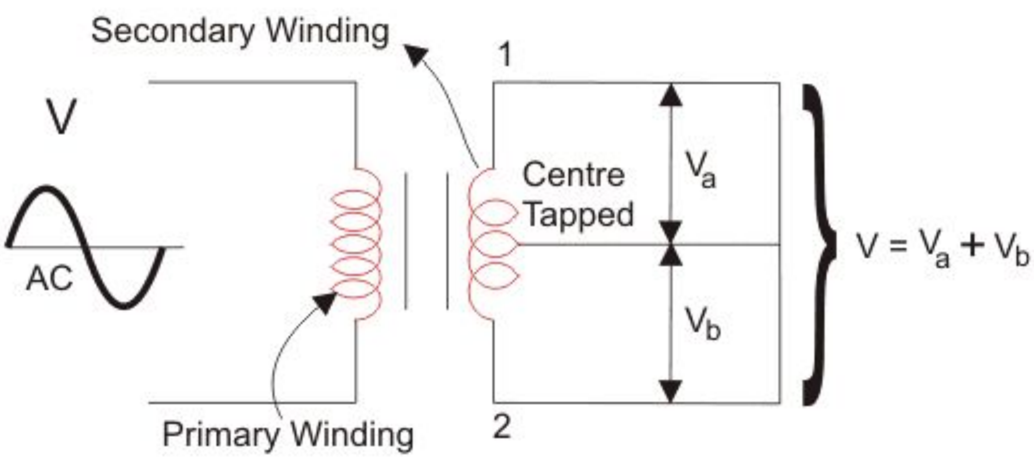



Figure - 3

- During the positive half-cycle of the AC voltage, terminal 1 will be positive, centre-tap will be at zero potential and terminal 2 will be negative potential.
- This will lead to forward bias in diode $D_1$ and cause current to flow through it. During this time diode D is in reverse bias and will block ough it.

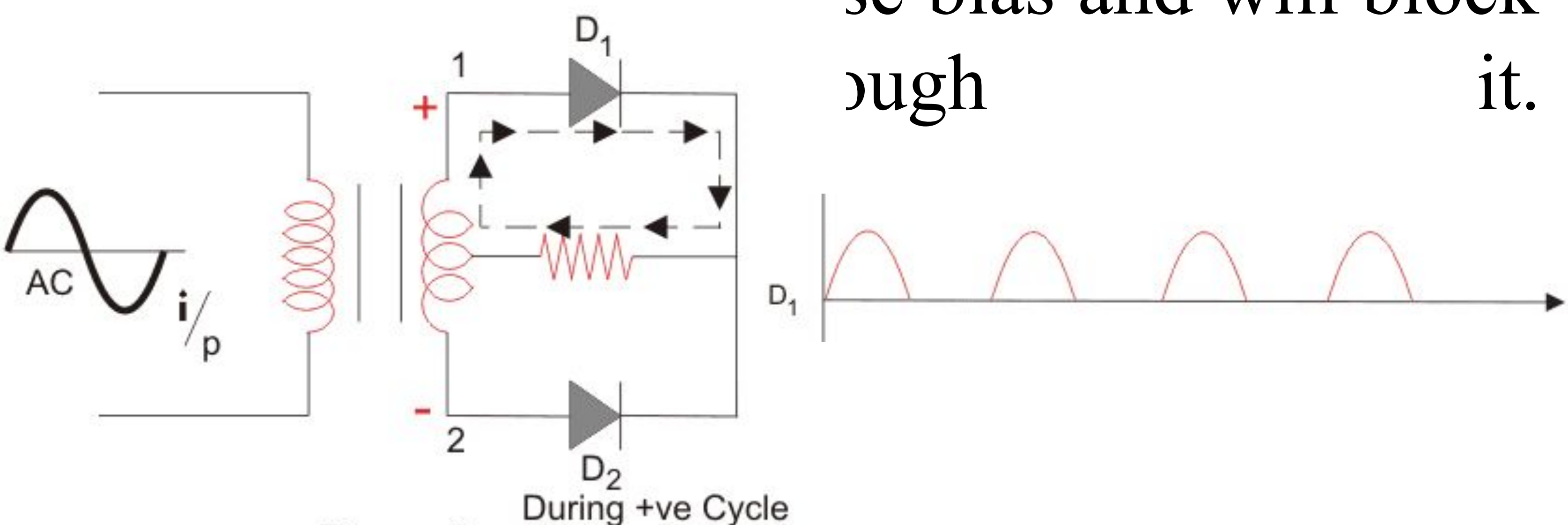
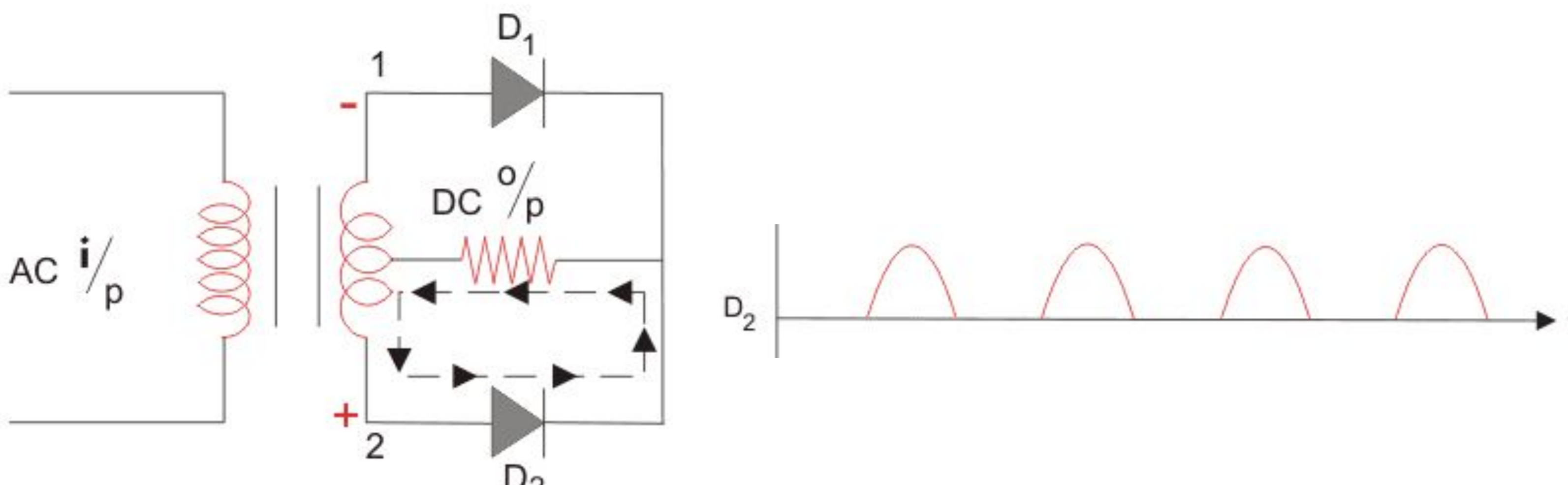



Figure - 6

- During the negative half-cycle of the input AC voltage, terminal 2 will become positive with relative to terminal 2 and centre-tap.
- This will lead to forward bias in diode $D_2$ and cause current to flow through it. During this time, diode $D_1$ is in reverse bias and will block

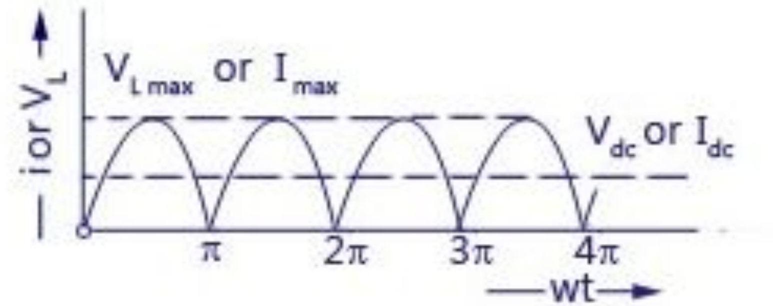


During -ve half Cycle

Figure - 7

- **Ripple Factor(Γ)**

$$I_{dc} = 1/\ \pi \int_0^{\pi} i1\ d(wt)$$




$= 2I_m / \pi$

$$I^2_{rms} = \ 1/\pi \int_0^{\pi} i12\ d(wt)$$

$= Im/\surd\ 2$

$\Gamma = \surd\ (I_{rms} / I_{dc})^2 -1$

$= \surd\ (Im/\surd\ 2/\ 2Im\ /\ \pi)2\ -1$

$\boxed{\Gamma\ =}$

**0.48**

## *Efficiency*

$$\eta = \frac{dc\ output\ power}{ac\ input\ power} = \frac{P_{dc}}{P_{ac}}$$

$$\frac{V_{dc}^{2}/R_L}{V_{rms}^{2}/R_L} = \frac{\left[2V_m/\pi\right]^2}{\left[V_m/\sqrt{2}\right]^2} = 8/\pi^2 = 0.812 = \underline{\underline{81.2\%}}$$

## Transformer Utilization Factor

TUF can be used to determine the rating of a transformer secondary. It is determined by considering the primary and the secondary winding separately and it gives a value of 0.693.

$$Form\ factor = \frac{rms\ value\ of\ output\ voltage}{average\ value\ of\ the\ output\ voltage}$$

$$= \frac{\left(\frac{V_m}{\sqrt{2}}\right)}{\left(\frac{2V_m}{\pi}\right)} = \frac{\pi}{2\sqrt{2}} = \underline{\underline{1.11}}$$

$$Peak\ factor = \frac{peak\ value\ of\ the\ output\ voltage}{rms\ value\ of\ the\ output\ voltage} = \frac{V_m}{\left(\frac{V_m}{\sqrt{2}}\right)} = \underline{\underline{\sqrt{2}}}$$

**Peak inverse voltage**

For Full Wave Rectifier is $2V_m$ because the entire secondary voltage appears across the non-conducting diode.

A 230 V, 60 Hz voltage is applied to the primary of a 5:1 step-down, center-tap transformer use in a full wave rectifier having a load of 900 Ω. If the diode resistance and secondary coil resistance together has a resistance of 100 Ω, determine (a) d.c. voltage across the load, (b) d.c. current flowing through the load, (c) d.c. power delivered to the load, (d) PIV across each diode, (e) ripple voltage and its frequency and (f) rectification efficiency.

A full-wave rectifier delivers 50 W to a load of 200 Ω. If the ripple factor is 1%, calculate the a.c. ripple voltage across the load.

A full-wave rectifier circuit uses two silicon diodes with a forward resistance of 20 Ω each. A d.c. voltmeter connected across the load of 1 kΩ reads 55.4 Volts. Calculate

(a) $I_{rms}$

(b) average voltage across each diode

(c) ripple factor and

(d) transformer secondary voltage rating.

# Bridge Rectifier

- Bridge rectifier composed of four diodes $D_1$, $D_2$, $D_3$ and $D_4$ in which the input is supplied across two terminals A and B in the figure while the output is collected across the load resi

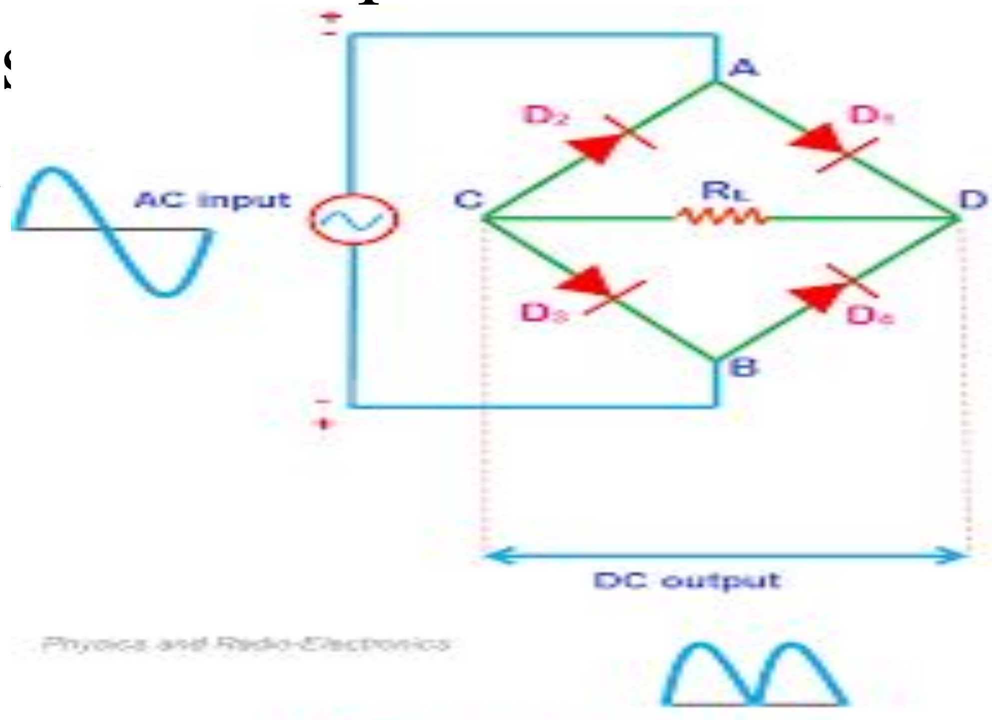



Fig: Bridge Rectifier

he terminals C and

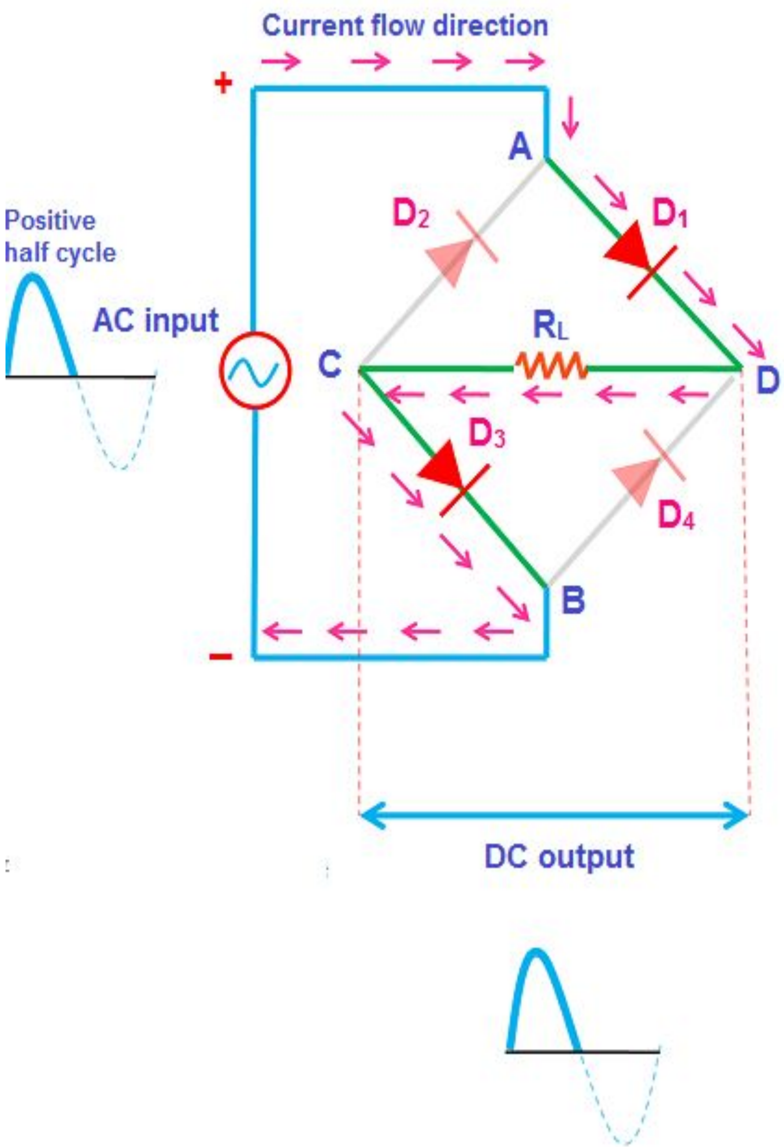



Fig A: Bridge rectifier during positive half cycle

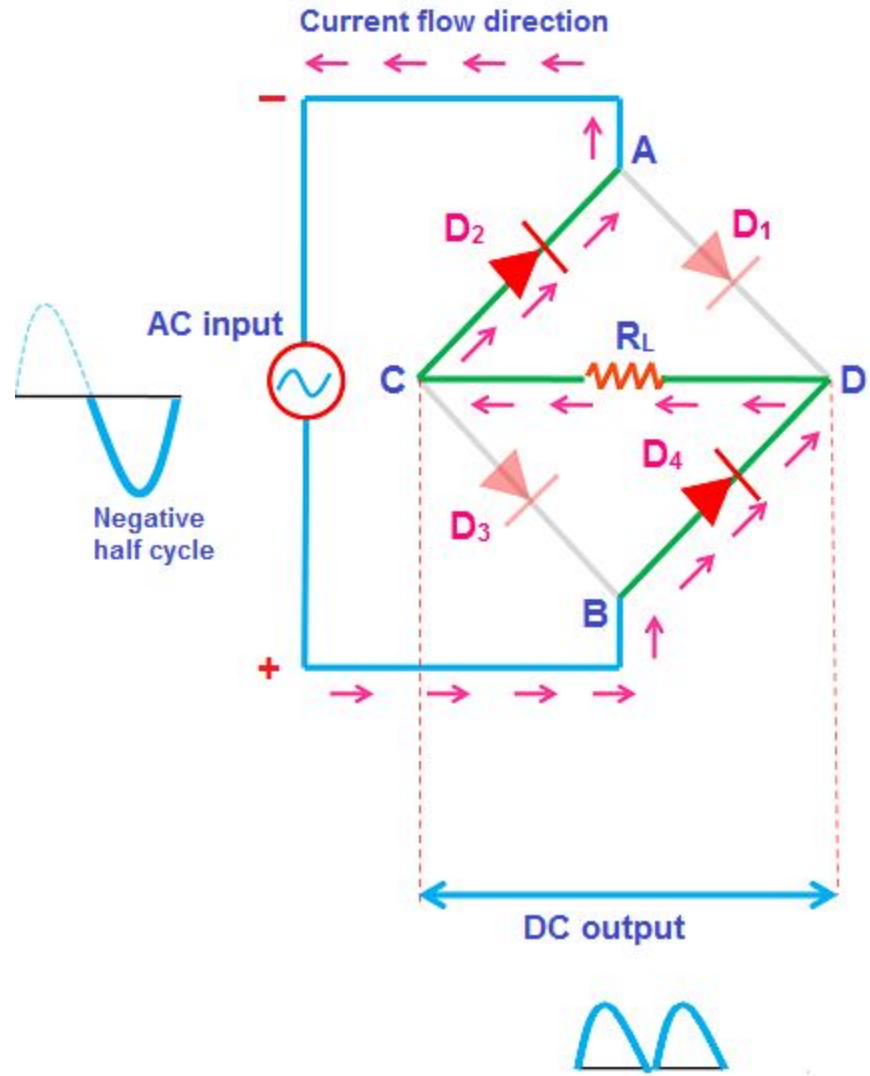



Fig B: Bridge rectifier during negative half cycle

| Parameters | Bridge rectifier |
|---|---|
| Number of diodes | 4 |
| Maximum efficiency | 81.2% |
| Peak inverse voltage | $V_m$ |
| Vdc(no load) | $2V_m/\pi$ |
| Transformer utilization factor | 0.812 |
| Ripple factor | 0.48 |
| Form factor | 1.11 |
| Peak factor | **√2** |
| Average current | $I_{dc}/2$ |
| Output frequency | 2f |