3.1 Rectification: The process of converting the alternating voltages and currents to direct currents.

3.2 Rectifiers Classification:

There are two types of rectifiers Uncontrolled and Controlled, single phase and three phase.

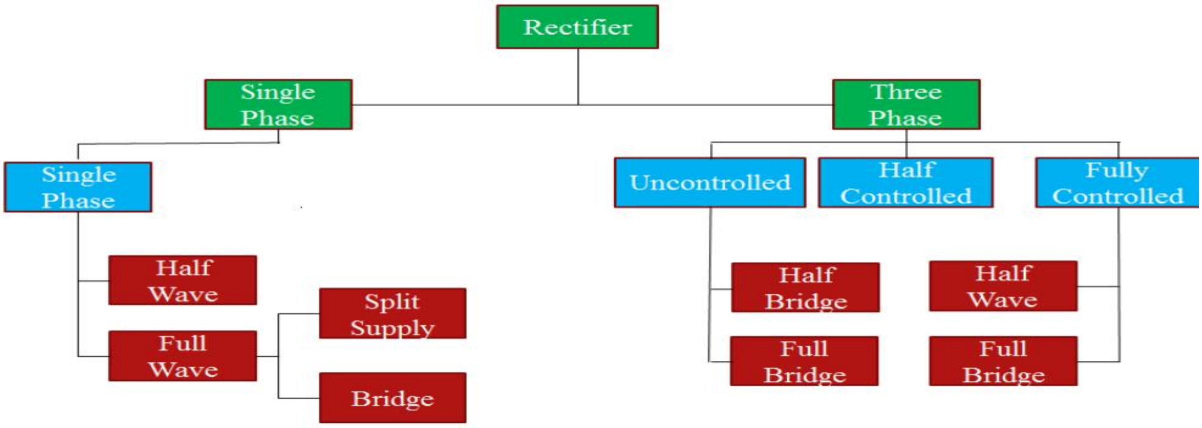

Fig3.1 Rectifiers Classification

3.3 Performance Parameters

- rectification effeciency

$$\eta = P_{dc} / P_{ac} \tag{3.1}$$

- The **form factor** (a measure for the shape of output voltage)

$$FF = V_{rms} / V_{dc} \tag{3.2}$$

- The ***effective (rms) value*** of the ac component of output voltage

$$V_{ac} = \sqrt{V_{rms}^2 - V_{dc}^2} \tag{3.3}$$

- The **ripple factor** (a measure for the ripple content)

$$RF = \frac{V_{ac}}{V_{dc}} = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}} = \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1} = \sqrt{FF^2 - 1} \tag{3.4}$$

- The **harmonic factor** or **total harmonic distortion** (a measure for distortion of a waveform] of the input current

$$THD_i = \sqrt{\frac{I_S^2 - I_{S1}^2}{I_{S1}^2}} = \sqrt{\frac{I_S^2}{I_{S1}^2} - 1} \tag{3.5}$$

Where I_{s1} is the rms value of the fundamental component of the input current. And I_s is the rms value of the input current.

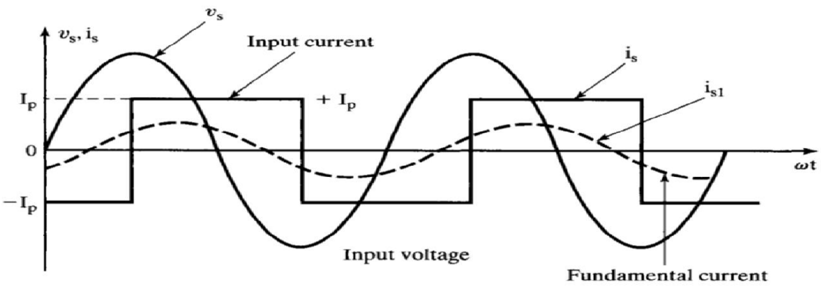

Fig 3.2: Input and fondamental components

If Φ_1 is the angle between the fundamental component of the input current and the voltage, the displacement factor

$$DF = \cos \phi_1 \tag{3.6}$$

The input Power factor

$$PF = \frac{P}{V_S\ I_S} = \frac{V_S\ I_{S1}\cos\phi_1}{V_S\ I_S} = \frac{I_{S1}}{I_S}\cos\phi_1 \tag{3.7}$$

$$= Distortion\ Factor * Displacement\ Faactor$$

- **Transformer Utilization Factor**

$$TUF = \frac{P_{dc}}{V_S\ I_S} = \frac{V_{dc}\ I_{dc}}{V_S\ I_S} \tag{3.8}$$

The main disadvantages of half wave rectifier are:

- High ripple factor,
- Low rectification efficiency,
- Low transformer utilization factor, and,
- DC saturation of transformer secondary winding.

3.4. Single phase half wave rectifier with R load

During each "positive" half cycle of the AC sine wave, the diode is forward biased as the anode is positive with respect to the cathode resulting in current flowing through the diode.

Since the DC load is resistive (resistor, R), the current flowing in the load resistor is therefore proportional to the voltage (Ohm´s Law), and the voltage across the load resistor will therefore be the same as the supply voltage, V_s , that is the "DC" voltage across the load is sinusoidal for the first half cycle only so $V_{out} = Vs$. During each "negative" half cycle of the AC sinusoidal input waveform, the diode is reverse biased as the anode is negative with respect to the cathode.

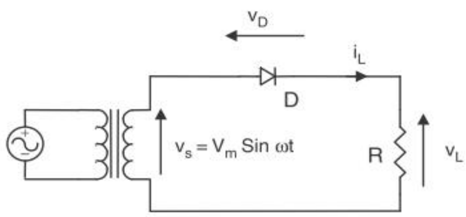

Fig3.3 A single-phase half-wave rectifier with R load.

The average output voltage is

$$V_{dc} = \frac{1}{2\pi}\int_0^{\pi} V_m \sin\omega t \; d\omega t = \frac{V_m}{\pi} \qquad (3.9)$$

and the average load current

$$I_{dc} = \frac{V_{dc}}{R} = \frac{V_m}{\pi R} \qquad (3.10)$$

The rms output voltage and current are

$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} V_m^2 \sin^2\omega t \; d\omega t} = \frac{V_m}{2} \qquad (3.11)$$

$$I_{rms} = \frac{V_{rms}}{R} = \frac{V_m}{2R} \qquad (3.12)$$

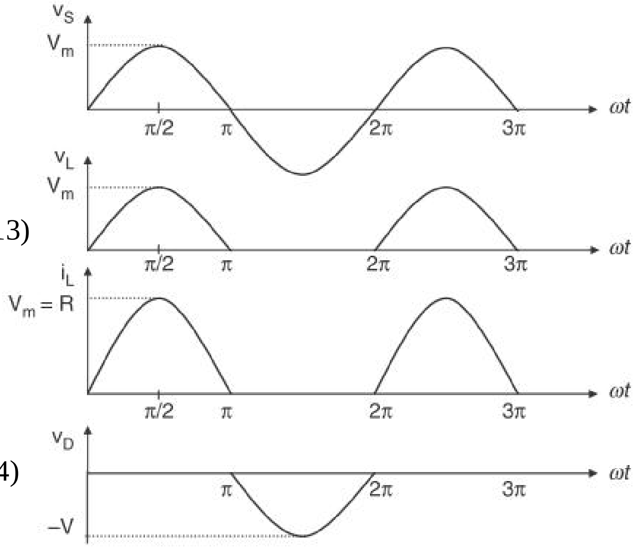

Fig.3.4 Voltage and current waveforms of the half-wave rectifier with resistive load.

The efficiency is given by

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{V_{dc} * I_{dc}}{V_{rms} * I_{rms}} = \frac{\frac{V_m}{\pi} * \frac{V_m}{\pi R}}{\frac{V_m}{2} * \frac{V_m}{2R}} = 40.53\% \qquad (3.13)$$

where, the form factor is

$$FF = \frac{V_{rms}}{V_{dc}} = \frac{\frac{V_m}{2}}{\frac{V_m}{\pi}} = \frac{\pi}{2} = 1.57 \qquad (3.14)$$

and the ripple factor is given by

$$RF = \frac{V_{ac}}{V_{dc}} = \sqrt{FF^2 - 1} = \sqrt{1.57^2 - 1} = 1.211 \qquad (3.15)$$

Transformer Utilization Factor

$$\mathrm{TUF} = \frac{P_{dc}}{V_s I_s} = \frac{V_{dc} I_{dc}}{V_s I_s} \qquad (3.16)$$

The load and diode currents

$$I_S = I_D = \frac{V_m}{2R} \qquad (3.17)$$

Therefore, $\mathrm{TUF} = \frac{0.318^2}{0.707 \times 0.5} = 0.286$

The poor TUF of a half-wave rectifier signifies that the transformer employed must have a 3.496 (1/0.286) VA rating in order to deliver 1 W dc output power to the load. In addition, the transformer secondary winding has to carry a dc current that may cause magnetic core saturation. As a result, half-wave rectifiers are used only when the current requirement is small.

PIV: From Fig3.2 the PIV is V_m

3.5 Single-phase Full-wave Rectifiers

3.5.1 Full-wave rectifier with center-tapped transformer

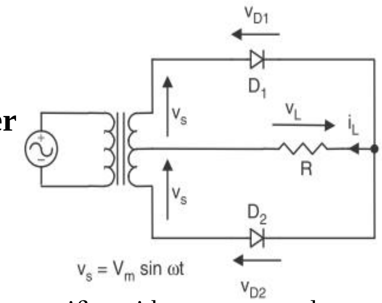

Fig3.5 Full-wave rectifier with center-tapped transformer

$$v_0(wt) = \begin{bmatrix} Vm \sin wt, 0 \le wt \le \pi \\ -Vm \sin wt, \pi \le wt \le 2\pi \end{bmatrix}$$

The Average output voltage and current are;

$$V_{dc} = \frac{1}{\pi}\int_0^{\pi} V_m \sin \omega t \; d\omega t = \frac{2V_m}{\pi}$$

$$I_{dc} = \frac{2V_m}{\pi \; R}$$

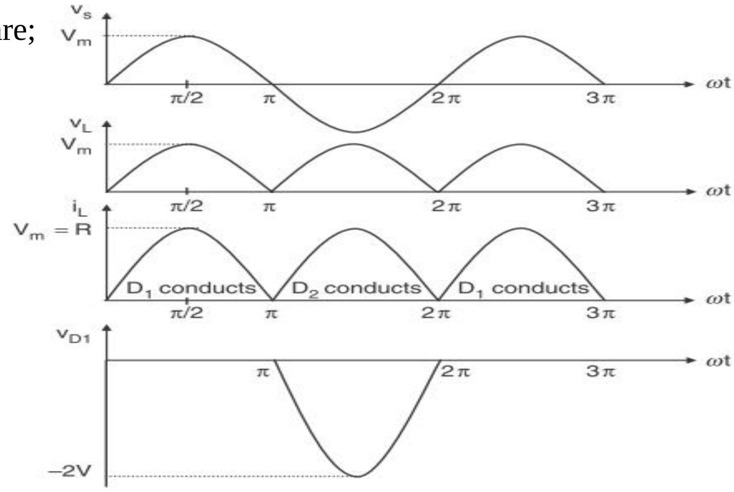

Fig. 3.6 Voltage and current waveforms of the full-wave rectifier with center-tapped transformer.

The RMS output voltage and current are

$$V_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} (V_m \sin \omega t)^2 \; d\omega t} = \frac{V_m}{\sqrt{2}}$$

$$I_{rms} = \frac{V_m}{\sqrt{2} \; R}$$

The RMS input current $I_S = I_D = \dfrac{V_m}{2 \; R}$

PIV of each diode is $2V_m$

One disadvantage of this full-wave rectifier design is necessity of transformer with center-tapped secondary winding.

- In high power circuit, size and expense of suitable transformer is significant. Consequently, center-tap rectifier design is only seen in low-power applications

Example 1. The rectifier in Fig.3.5 has a purely resistive load of *R* Determine (a) The efficiency, (b) Form factor (c) Ripple factor (d) TUF (e) Peak inverse voltage (PIV) of diode D1 and(f) Crest factor of transformer secondary current.

Solution:

a) The efficiency:

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{V_{dc} * I_{dc}}{V_{rms} * I_{rms}} = \frac{\frac{2\,V_m}{\pi} * \frac{2\,V_m}{\pi\,R}}{\frac{V_m}{\sqrt{2}} * \frac{V_m}{\sqrt{2}\,R}} = 81.05\%$$

b)Form factor

$$FF = \frac{V_{rms}}{V_{dc}} = \frac{\frac{V_m}{\sqrt{2}}}{\frac{2\,V_m}{\pi}} = \frac{\pi}{2\,\sqrt{2}} = 1.11$$

c) Ripple factor

$$RF = \frac{V_{ac}}{V_{dc}} = \sqrt{FF^2 - 1} = \sqrt{1.11^2 - 1} = 0.483$$

d) TUF:

the secondary rms voltage is $V_s = \frac{V_m}{\sqrt{2}} = 0.707 V_m$

the secondary rms current is

Therefore, $I_s = \frac{0.707 V_m}{R}$

$$\text{TUF} = \frac{4 \times 0.318^2}{2 \times 0.707 \times 0.5} = 0.572$$

In the case of a full-wave rectifier with center-tapped transformer, the circuit can be treated as two half-wave rectifiers operating together. Therefore, the transformer secondary VA rating, Vs Is , is double that of a half-wave rectifier.

e) The PIV is $2V_m$

f) The crest factor $CF = \frac{I_{Speak}}{I_S}$

and

$$I_S = I_D = \frac{V_m}{2\ R}$$

Therefore: CF=2.

3.5.2 Single-Phase Full Bridge Diode Rectifier With Resistive Load

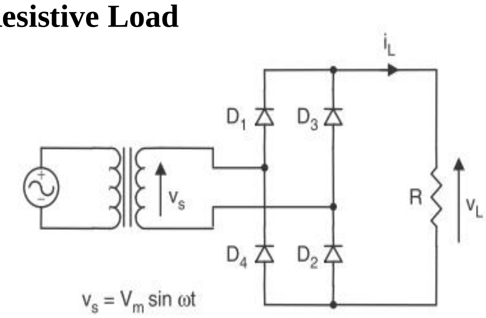

Fig.3.7 Single-Phase Full Bridge Diode Rectifier With Resistive Load

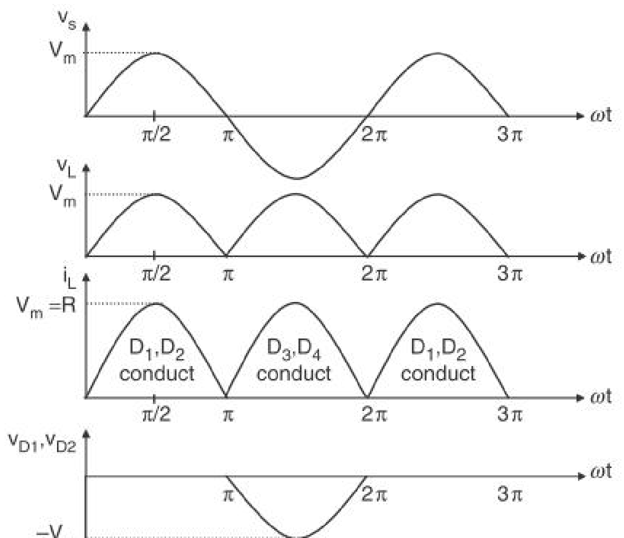

Fig3.8 Voltage and current waveforms of the bridge rectifier

Example 2: single-phase diode bridge rectfier has a purely resistive load of *R*=15 ohms and, *VS*=300 sin 314 *t* and unity transformer ratio. Determine (a) The efficiency, (b) Form factor, (c) Ripple factor, (d) The peak inverse voltage, (PIV) of each diode, , and, (e) Input power factor.

Solution:

a) The efficiency

$$V_{dc} = \frac{1}{\pi}\int_0^{\pi} V_m \sin \omega t\ d\omega t = \frac{2V_m}{\pi} = 190.956\ V \qquad I_{dc} = \frac{2V_m}{\pi\ R} = 12.7324\ \ A$$

$$V_{rms} = \left[\frac{1}{\pi} \int_0^{\pi} (V_m \sin \omega t)^2 \, d\omega t \right]^{1/2} = \frac{V_m}{\sqrt{2}} = 212.132 \ \ V$$

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{V_{dc} \, I_{dc}}{V_{rms} \, I_{rms}} = 81.06 \ \ \%$$

b) Form factor

$$FF = \frac{V_{rms}}{V_{dc}} = 1.11$$

c) Ripple factor

$$RF = \frac{V_{ac}}{V_{dc}} = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}} = \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1} = \sqrt{FF^2 - 1} = 0.482$$

d) The peak inverse voltage, (PIV) of each diode

The PIV=*300V*

e) Input power factor.

Input power factor = $\frac{\text{Re}\,al \ \ Power}{Apperant \ \ Power} = \frac{V_S \ I_S \cos\phi}{V_S \ I_S} = 1$