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Asst. Lec. Morteza Abbas Imran		DATE : 2024/2025

AC-DC CONVERSION (RECTIFICATIONS)

The purpose of a rectifier may be to produce an output that is purely dc, but in practice it has a dc component with a certain ripple as shown in fig. 1

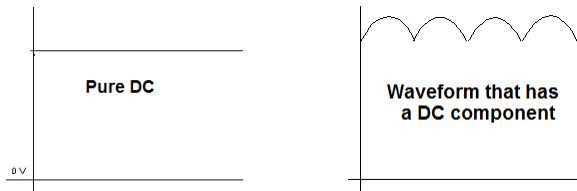


fig.1

Several types of rectifier circuits are available:

single-phase and three-phase half-wave and full-wave, controlled and uncontrolled, etc. For a given application, the type used is determined by the requirements of that application. In general the types of rectifiers are:

1-Uncontrolled Rectifier : Provide a fixed d.c. output voltage for a given a.c. supply where diodes are used only.

2-Controlled Rectifier : Provide an adjustable d.c. output voltage by controlling the phase at which the devices are turned on, where thyristors and diodes are used.

A- Half-controlled: allows electrical power flow from a.c. to d.c. (i.e. rectification only)

B- *Fully – controlled*: allow power flow in both directions (i.e. rectification and inversion)

There are many applications for rectifiers. Some of them are:

- 1- Variable speed dc drives,
- 2- Battery chargers,
- 3- DC power supplies for electric railways
- 4- Power supply for a specific application like electroplating

Power rating of a single-phase rectifier tends to be lower than **10 kW**.

Three-phase bridge rectifiers are used for delivering higher power output, up to **500 kW at 500 V** dc or even more.

In the following study we neglect **forward voltage drop, and reverse and forward leakage currents in diodes and thyristors**, we shall also neglect **transient switching effects related to the dynamic characteristics of the solid-state components**. We always assume that **the pulse is of sufficient amplitude to switch on the appropriate thyristor**.

Performans parameters of rectifiers

1-The average value of output (load) voltage given as V_{dc}

2-The average value of output (load) current given by I_{dc}

3-The output dc power given by $P_{dc} = V_{dc} I_{dc}$

4-The rms value of output voltage given as V_{rms}

5-The rms value of output current given as I_{rms}

6-The output ac power given by $P_{ac} = V_{rms} I_{rms}$

7-The efficiency or rectification ratio of a rectifier is given by $\eta = \frac{P_{dc}}{P_{ac}}$

8-The output voltage consists of two components, such as ac component and dc component. The effective value of the ac component of output voltage is given by

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

9-The form factor which is a measure of the shape of the output voltage is given

$$\text{by } FF = \frac{V_{rms}}{V_{dc}}$$

10-The ripple factor which is a measure of the ripple content is given by

$$RF = \frac{V_{ac}}{V_{dc}}$$

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

11-The *transformer utilization factor* is defined as $TUF = \frac{P_{dc}}{V_s I_s}$

where V_s and I_s are the rms voltage and rms current of the transformer secondary respectively

12- V_s is the sinusoidal input voltage

13- I_s is the instantaneous input current

14 – I_{s1} is the fundamental component of i_s

15- The displacement angle ϕ is the angle between fundamental components of input current and voltage.

16- The displacement factor (DF) or Displacement Power Factor (DPF) is defined as $DF = \cos \phi$

17- The harmonic factor (HF) also known as total harmonic distortion (THD) is a measure of the distortion of a waveform. The harmonic factor of the input current is given as

$$HF = \sqrt{\frac{I_s^2 - I_{s1}^2}{I_{s1}^2}} = \sqrt{\frac{I_s^2}{I_{s1}^2} - 1}$$

18- The *crest factor* is a comparison of the peak input current to its rms

$$CF = \frac{I_{s1 \text{ peak}}}{I_s}$$

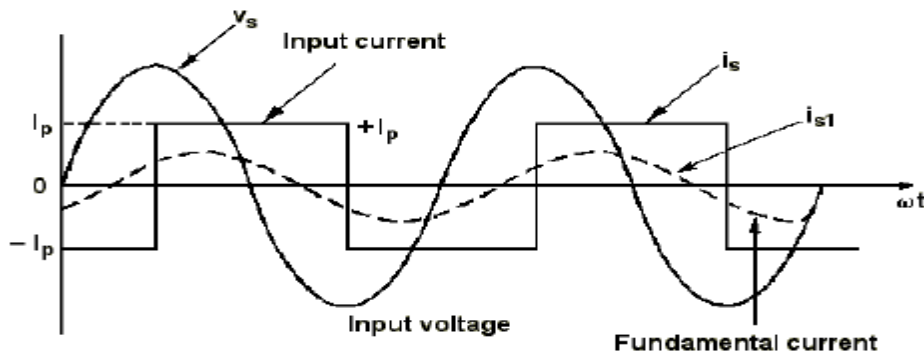


Fig. 2

19- Power factor of a rectifier (PF): the definition of the power factor of a rectifier is

$$PF = \frac{\text{Actual power input to the rectifier}}{\text{Apparent power input to the rectifier}}$$

Ideal rectifier should have:

$$\eta = 100\%, V_{ac} = 0, RF = 0, TUF = 1 \text{ \& } HF = THD = 0 \text{ PF} = DPF = 1$$

1-Uncontrolled Rectifications

In this type, the generated DC power is fixed with the converter used and the input AC power. They usually use diodes as their power switches. The following subsections deal with the basic operation of some examples of uncontrolled rectifiers single-phase half-wave rectifier loaded with resistive and resistive inductive loads.

1-1Single-phase Half-Wave Uncontrolled Rectifier with resistive load

In practice, the half-wave rectifier is used most often in low-power applications **because the average current in the supply will not be zero**, and nonzero average current may cause saturation problems in transformer performance. Fig.3 shows the basic circuit for a single-phase, half-wave uncontrolled rectifier supplying a resistive load.

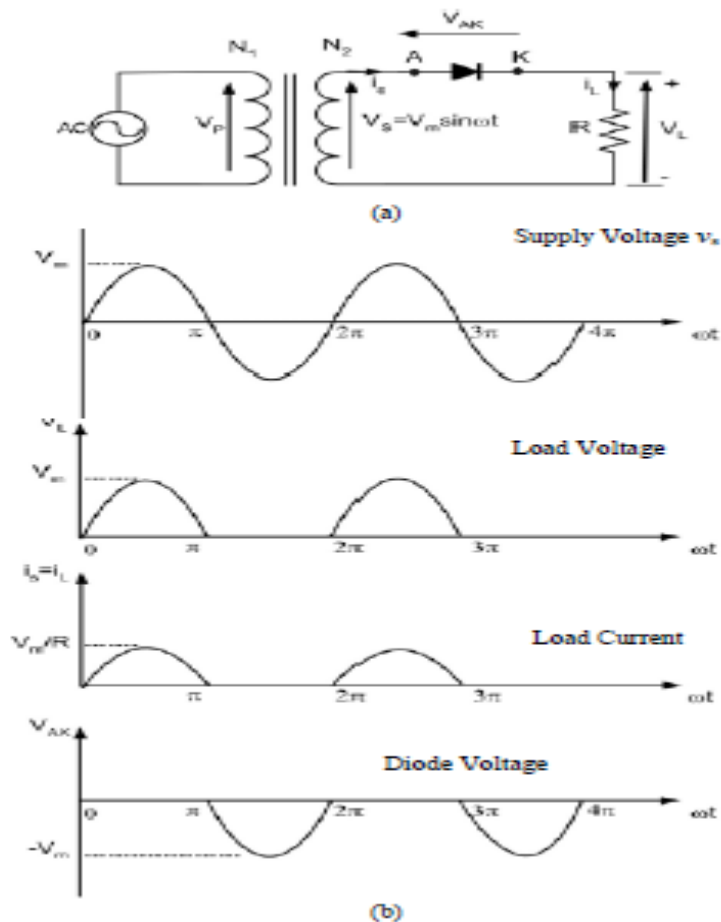


Fig.3 Single-phase half-wave rectifier: (a) circuit and (b) waveforms

The circuit is supplied by a single phase transformer whose secondary represents the rectifier's circuit AC source (v_s) that is represented by a sinusoidal wave given by

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

where v_s is the supply voltage, V_{max} is the peak value of the supply voltage, ω is the angular frequency, and t is the time.

For this configuration, the diode will conduct (becomes forward biased) whenever the supply voltage (v_s) is positive.

It is the simplest type of rectifiers.

- ❖ During the positive half cycle D1 conducts and the input voltage appears across the load.
- ❖ During the negative half cycle Diode D1 is in blocking condition, and output voltage is zero.
- ❖ Note that there is a small forward voltage drop across the D1.

Disadvantages of half wave rectifier

- 1- DC output voltage is discontinuous and contains harmonics.
- 2- Input current is not sinusoidal
- 3- Transformer output current has dc component (saturation problem)

Average output voltage

$$\begin{aligned} V_{dc} &= \frac{1}{T} \int_0^T v_L(t) dt = \frac{1}{T} \int_0^{T/2} V_m \sin \omega t dt \\ &= \frac{-V_m}{\omega T} \left(\cos \frac{\omega T}{2} - 1 \right) \xrightarrow{\omega = \frac{2\pi}{T}} \boxed{V_{dc} = \frac{V_m}{\pi}} \end{aligned}$$

Effective output voltage

$$V_{rms} = \sqrt{\frac{1}{T} \int_0^T v_L^2(t) dt} = \sqrt{\frac{1}{T} \int_0^{T/2} (V_m \sin \omega t)^2 dt} \Rightarrow \boxed{V_{rms} = \frac{V_m}{2}}$$

Example: For half-wave rectifier with R Load, determine; a) efficiency, b) form factor, c) ripple factor, d) TUF, e) PIV of D1, f) CF of input current.

1-2 Single-phase Half-Wave Uncontrolled Rectifier with Inductive load

If the load consists of a series resistor and inductor, the current will flow through the negative cycle as well; Fig.4 shows the circuit diagram

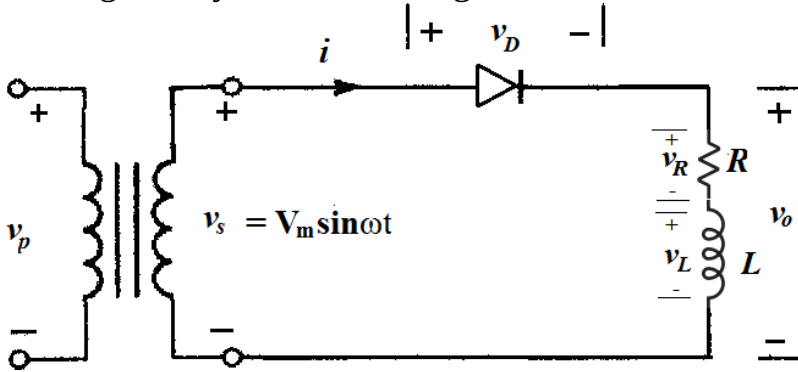


Fig.4 Single – phase half – wave rectifier with $R-L$ load.

and Fig.5 shows the load voltage and current waveform for this case.

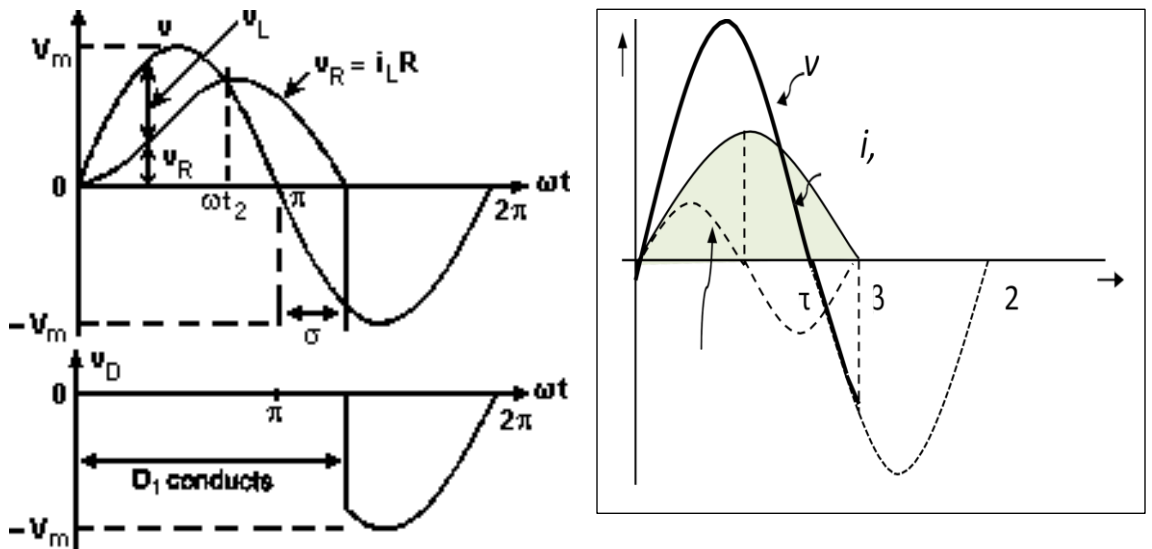


Fig.5 the load voltage and current waveform

During conduction period ,we have by KVL;

$$V_m \sin \omega t = i R + L \frac{di}{dt}$$

Each supply period (cycle) in Fig. 5 can be divided into 4-distinct regions:-

Region 1.

From 0- ωt_1 : the current rises from zero to peak, which lags the voltage peak due to circuit inductance; v_L is positive and

the inductance store energy.

Region 2.

From $\omega t_1 - \pi$: the current decays, and hence v_L is negative.

Both source and inductance supply energy to R .

Region 3.

From $\pi - \beta$: the current continues to decay until it reaches zero, v_L remains negative, and hence energy is supplied by inductance to both source and resistor.

Region 4.

From $\beta - 2\pi$: at β current reaches zero and the diode cut- out. Current remains zero until the beginning of the next positive half cycle.

The average output voltage is

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

$$V_{dc} = \frac{V_m}{2\pi} [-\cos \omega t]_0^{\beta} = \frac{V_m}{2\pi} [-\cos \beta + \cos 0] = \frac{V_m}{2\pi} [1 - \cos \beta]$$

Note :the average output voltage decreases with inductive load.

The average output current is

$$I_{dc} = \frac{V_{dc}}{R}, \quad I_{dc} = \frac{V_m}{2\pi R} [1 - \cos \beta]$$

The rms(effective) output voltage is

$$V_{\text{RMS}} = \sqrt{\frac{1}{2\pi} \int_0^{\beta} 2V_i^2 \sin^2 \omega t d\omega t} = \sqrt{\frac{V_i^2}{2\pi} \left(\beta - \frac{1}{2} \sin 2\beta \right)} = \frac{V_i}{\sqrt{2}} \sqrt{\frac{2\beta - \sin 2\beta}{2\pi}}$$

The form factor of the waveform is

$$V_{\text{OFF}} = \frac{V_{\text{RMS}}}{V_{\text{OAV}}} = \pi \sqrt{\frac{2\beta - \sin 2\beta}{2\pi(1 - \cos \beta)^2}}$$

The ripple factor of the waveform is

$$V_{ORF} = \sqrt{V_{OFF}^2 - 1} = \sqrt{\frac{\pi(2\beta - \sin 2\beta)}{2(1 - \cos \beta)^2} - 1}$$

Equation of the current:

The equation for the current through R-L load can be found from the solution of the differential equation for $0 \leq \omega t \leq \beta$

$$v_i = \sqrt{2}V_i \sin \omega t = L \frac{di_o}{dt} + Ri_o$$

$$i_o(\omega t = 0) = i_o(\omega t = \beta) = 0$$

This is a first order differential equation. The solution of this equation has two parts :

- 1- Steady state solution
 - 2- Transient solution
- is given by

$$i_{ss}(\omega t) = \frac{V_m}{Z} \sin(\omega t - \theta)$$

$$: i_{tr}(\omega t) = A e^{-\frac{t}{\tau}}$$

$$i_o = I_0 e^{\frac{\omega t}{\tan \phi}} + \frac{\sqrt{2}V_i}{Z} \sin(\omega t - \phi)$$

Where $\tan \phi = \frac{\omega L}{R}$

$$Z = \sqrt{R^2 + \omega^2 L^2}$$

Putting the initial conditions

$$i_o = \frac{\sqrt{2}V_i}{Z} \left[\sin \phi e^{\frac{\omega t}{\tan \phi}} + \sin(\omega t - \phi) \right]$$

$$i_o(\omega t = \beta) = \frac{\sqrt{2}V_i}{Z} \left[\sin \phi e^{\frac{\beta}{\tan \phi}} + \sin(\beta - \phi) \right] = 0$$

$$\text{or } \sin \phi e^{\frac{\beta}{\tan \phi}} = \sin(\phi - \beta)$$

Fig.6 illustrates the equation of load current.

β as a function of ϕ can be obtained by solving the above equation

It can be shown that β increases with ϕ . V_{OAV} decreases with increasing β while

V_{ORMS} increases with β . Therefore, with increasing ϕ (and hence increasing L)

the form factor and the ripple factor of v_o worsens. However, the ripple factor of

i_0 decreases with increasing L . Therefore, in certain applications, where a smooth dc current is of prime importance (e.g. the field supply of a dc motor) this configuration of the rectifier is preferred.

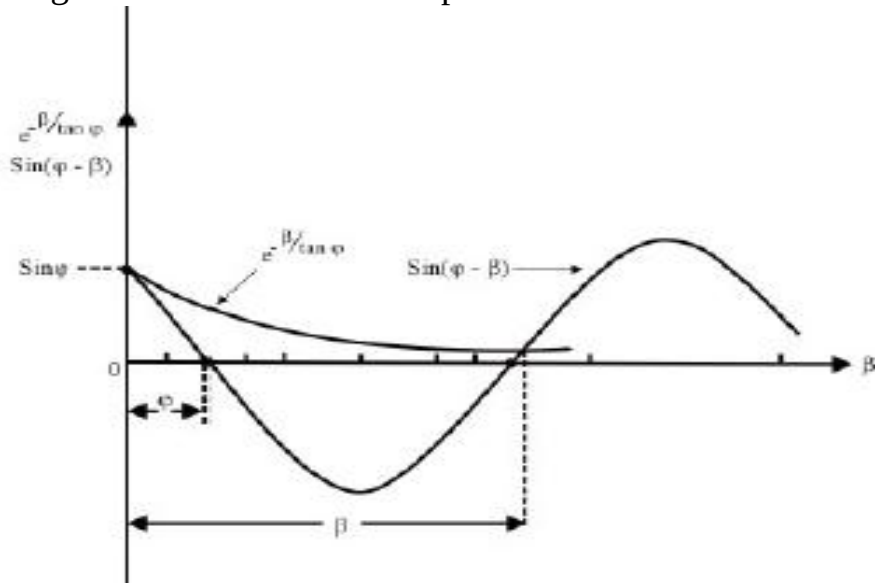


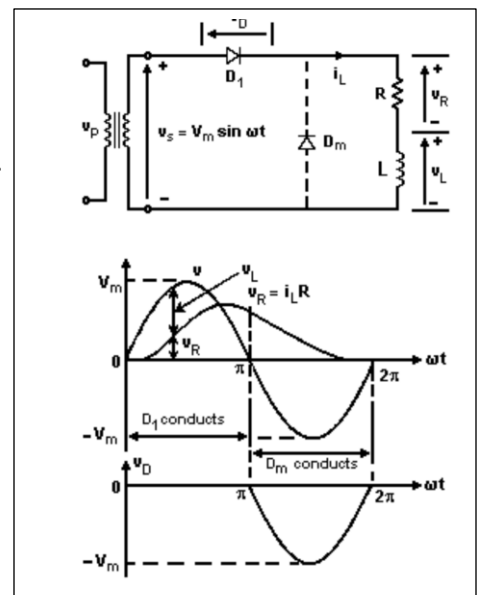
Fig.6 load current for characteristics

1-3 phase Half-Wave Uncontrolled Rectifier with freewheeling diode.

as shown in fig. 7 Freewheeling diode prevents negative voltage appearing across the load. The magnetic energy stored in inductor increased. The current transferred from D_1 to D_m this Process is called as commutation. The load time constant is

$$\tau = \frac{\omega L}{R}$$

If the load time constant is large enough the load current can be continues. Note that, the average output voltage is equal to the case of the resistive load



F ig.7 Single phase rectifier with FWD