SWITCH MODE POWER SUPPLY

Short Note

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1. POWER SUPPLIES

1.1 ELECTRONIC POWER SUPPLY

The function of an Electronic Power Supply unit is to convert the ac or dc line power into the required dc voltages according to the current demands of a particular system or load. The load comprises electronic devices and circuits which require dc power. Hence the name **'Electronic Power Supply'** came. The base of an Electronic Power Supply is its rectifier circuit. In Fig. 1.1 the functional block diagram of an Electronic Power Supply unit are shown that has following functional units:

i. Power transformer
ii. Diode rectifier circuit
iii. Filter circuit and
iv. Regulator

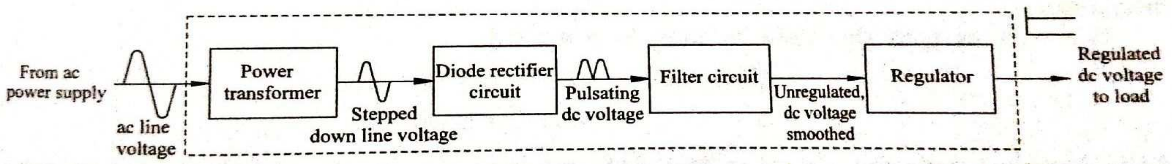

Fig. 1.1 Block diagram showing conversion of ac input to dc output voltage in an electronic power supply.

Functions of Various Functional Units:

i. Power transformer steps down the ac line voltage (230 V, 50 Hz) to about the desired voltage.
ii. The Diode rectifier circuit converts the ac voltage from the transformer secondary into a pulsating dc voltage.
iii. The Filter circuit smoothes out the pulsating dc voltage.
iv. Finally the Regulator maintains a constant output voltage regardless of variations in ac line voltage or the current required by the load or both.

1.2 RECTIFIER

As already said above, a Rectifier circuit converts the ac input voltage to a pulsating dc voltage. Rectifiers are of two types:

i. Half-wave Rectifier
ii. Full-wave Rectifier

1.2.1 Half-wave Rectifier

In Fig. 1.2(a) it is shown that the sinusoidal voltage output of the transformer secondary v_S is applied to a load R_L in series with a diode D.

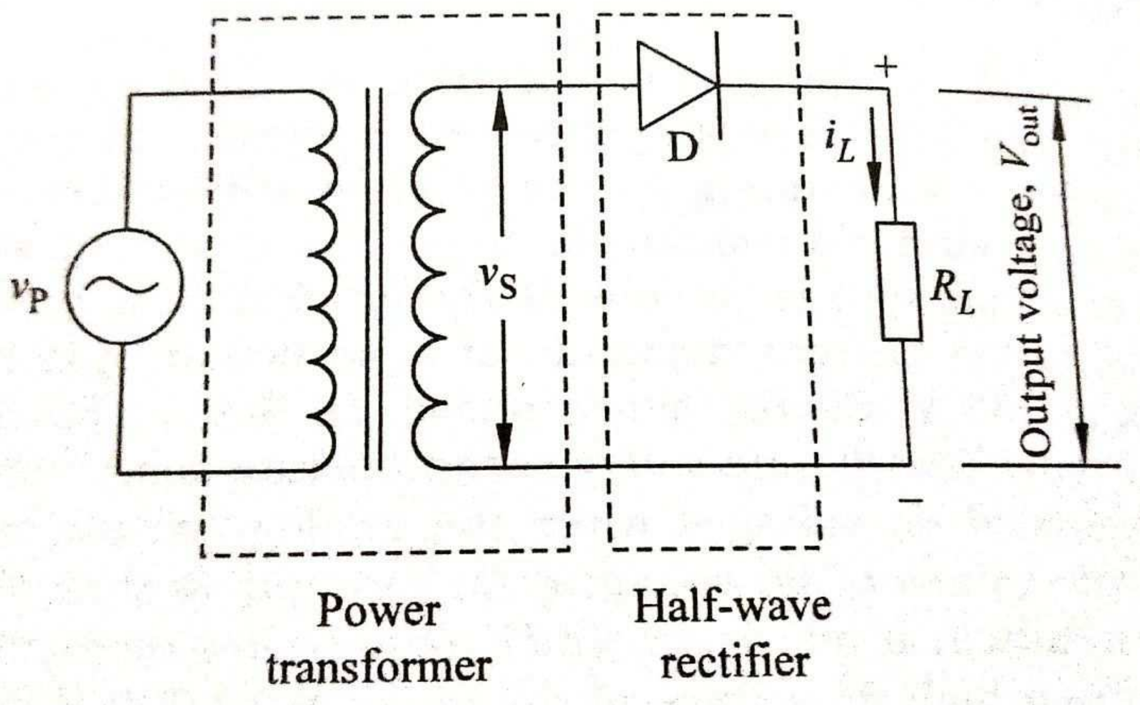

Fig. 1.2(a) Circuit diagram of a half-wave rectifier.

Function of Half-wave rectifier is classified into following two parts:

a) During the positive half-cycle of, the diode D is forward based and thus it conducts, allowing a load current i_L to pass through the load R_L.
b) During the negative half-cycle, the diode D, being reverse biased, does not conduct, and therefore, no current can flow through R_L.

Thus, the current i_L always flows in one directing only through the load R_L. The output voltage V_{out} developed across the load R_L is, therefore, is pulsating dc as shown in Fig. 1.2(b), only for positive half-cycle.

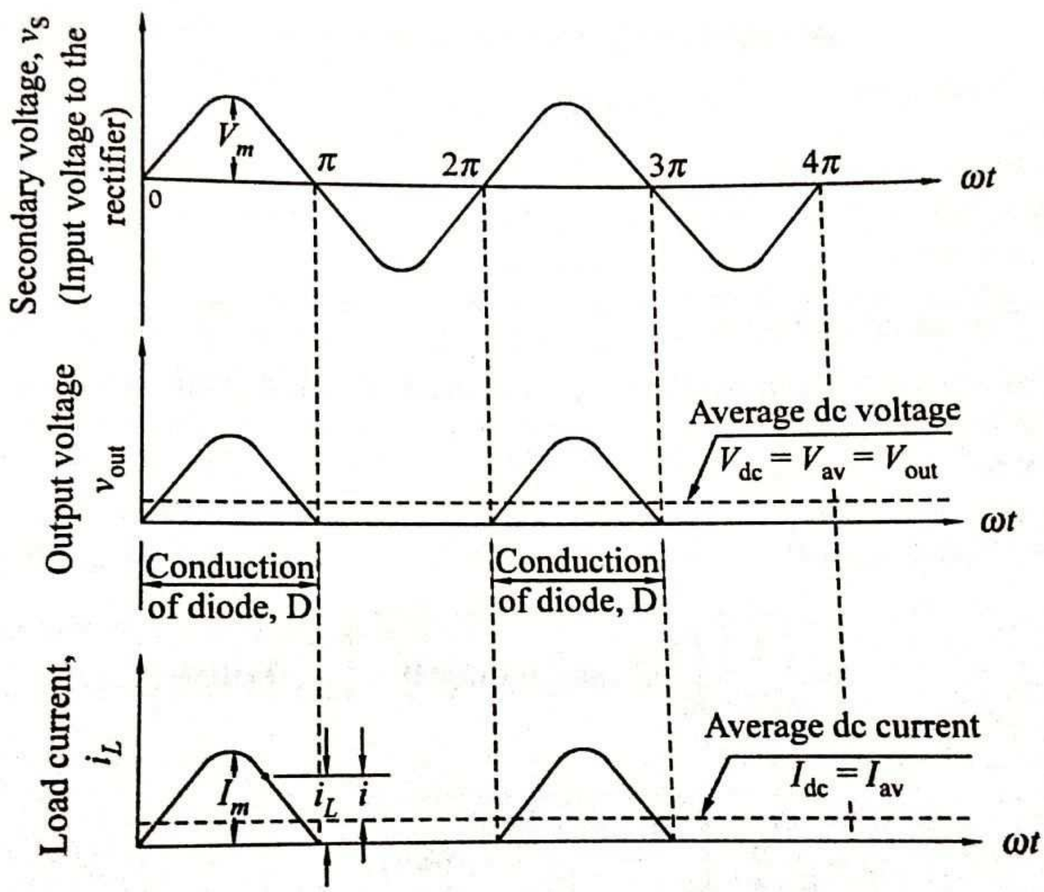

Fig. 1.2(b) Input and output waveforms of a half-wave rectifier.

The current i_L in the diode or load R_L is given by,

$i_L = I_m \sin \omega t$ when $0 \le \omega t \le \pi$

$= 0$ when $\pi \le \omega t \le 2\pi$

Assuming that the open circuit voltage from the transformer secondary is given by,

$v_S = V_m \sin \omega t$

Where V_m = peak value of transformer secondary and

$$I_m = \frac{V_m}{R_f + R_L}$$

Where, $V_m \sin \omega t = V_m \sin 90° = V_m$ [As, peak value occurs when $\omega t = \frac{\pi}{2}$ or 90°]

I_m = peak value of load current and

R_f = dynamic resistance of the diode.

Average or dc value of the load current

The average value I_{av} or the dc value I_{dc} of current through the load R_L is given by,

$$I_{av} = I_{dc} = \frac{area\ under\ the\ i_L\ curve\ over\ a\ cycle}{base}$$

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

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

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

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

$$= \frac{I_m}{2\pi}\,[-cos\ \omega t]_0^{\pi}$$

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

$$= \frac{I_m}{\pi}$$

$$= \frac{V_m}{\pi(\mathrm{R_f} + \mathrm{R_L})} \qquad \textbf{(As, } I_m = \frac{V_m}{\mathrm{R_f} + \mathrm{R_L}}\textbf{)}$$

The average value or dc value of output voltage is given by,

$$V_{av} = V_{dc} = I_{dc}\, R_L$$

$$= \frac{V_m R_L}{\pi(\mathrm{R_f} + \mathrm{R_L})} = \frac{V_m R_L}{\pi \mathrm{R_L}} = \frac{V_m}{\pi} \qquad \textbf{(As, } R_L \gg R_f\textbf{)}$$

RMS value of the load current

The rms value of current flowing through the load R_L in a half-wave rectifier is given by,

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

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

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

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

1.2.2 Full-wave Rectifier Using Centre-tap Transformer

According to the Fig. 1.3(a), a full-wave rectifier contains a centre-tapped transformer secondary and two diodes D_1 and D_2 with two sources of equal and opposite voltages, v_A and v_B.

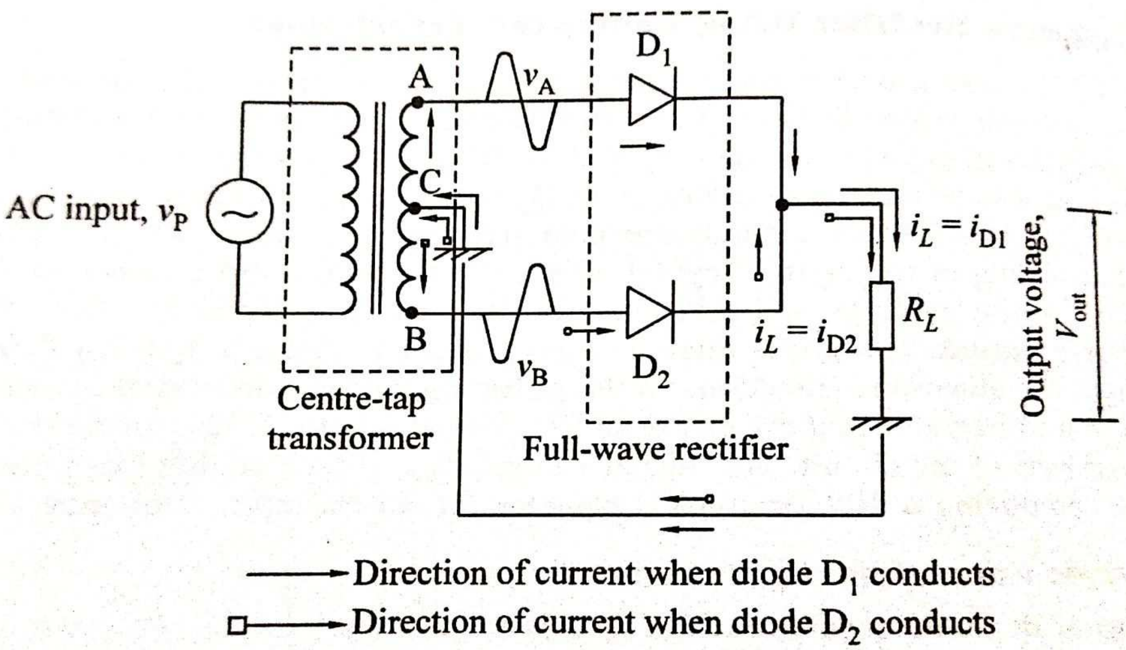

Fig. 1.3(a) Circuit diagram of a full-wave rectifier using centre-tap transformer.

Function of Full-wave rectifier is classified into following two parts:

a) During the positive half-cycle of v_A ($0 \le \omega t \le \pi$), diode D_1 conducts as it is forward biased, but diode D_2 remains cut-off due to reverse voltage v_B. Load current ($i_L = i_{D1}$) flows through the load resister R_L.
b) During the negative half-cycle of v_A ($\pi \le \omega t \le 2\pi$), diode D_1 does not conducts as it is reverse biased, but diode D_2 conducts due to forward voltage v_B. Again load current ($i_L = i_{D2}$) flows through the load resister R_L.

The output voltage V_{out}, thus developed across R_L during both positive and negative half-cycles, is unidirectional [as shown n Fig. 1.3(b)].

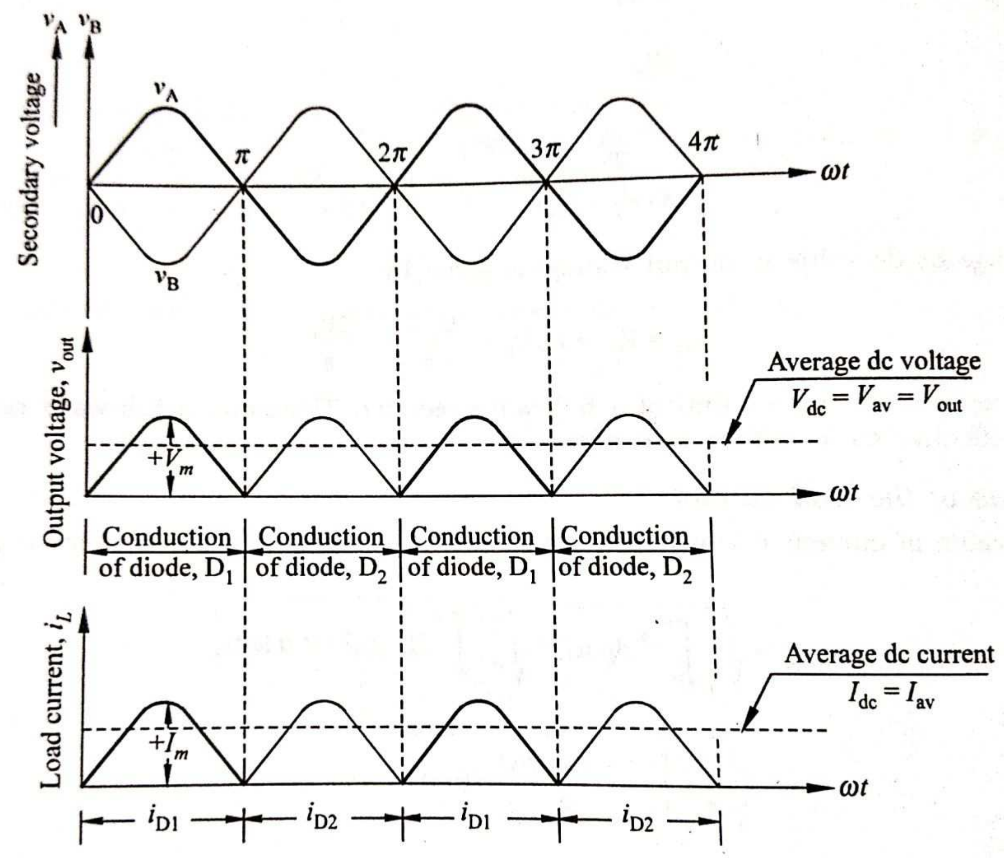

Fig. 1.3(b) Input and output waveforms of a full-wave rectifier using centre-tap transformer.

Average or dc value of the load current

The average value I_{av} or the dc value I_{dc} of load current i_L is given by,

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

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

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

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

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

$$= \frac{2V_m}{\pi(R_f + R_L)} \qquad \text{(As, } I_m = \frac{V_m}{R_f + R_L}\text{)}$$

The average value or dc value of output voltage is given by,

$\mathbf{V_{av} = V_{dc} = I_{dc}\, R_L}$

$$= \frac{2V_m R_L}{\pi(R_f + R_L)} = \frac{2V_m R_L}{\pi R_L} = \frac{2V_m}{\pi} \qquad \textbf{(As, } R_L \gg R_f\textbf{)}$$

RMS value of the load current

The rms value of current i_L flowing through the load R_L in a full-wave rectifier is given by,

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

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

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

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

RMS value of the output voltage

$$V_{rms} = I_{rms}\, R_L = \frac{I_m R_L}{\sqrt{2}} = \frac{V_m}{\sqrt{2}}$$

1.2.3 Full-wave Bridge Rectifier

Bridge rectifier is used for supplying large amounts of dc power. Fig. 1.4(a) shows a bridge rectifier which consists of four diodes D_1, D_2, D_3 and D4 respectively and voltage output of the transformer secondary v_S is applied to a load R_L through the diodes.

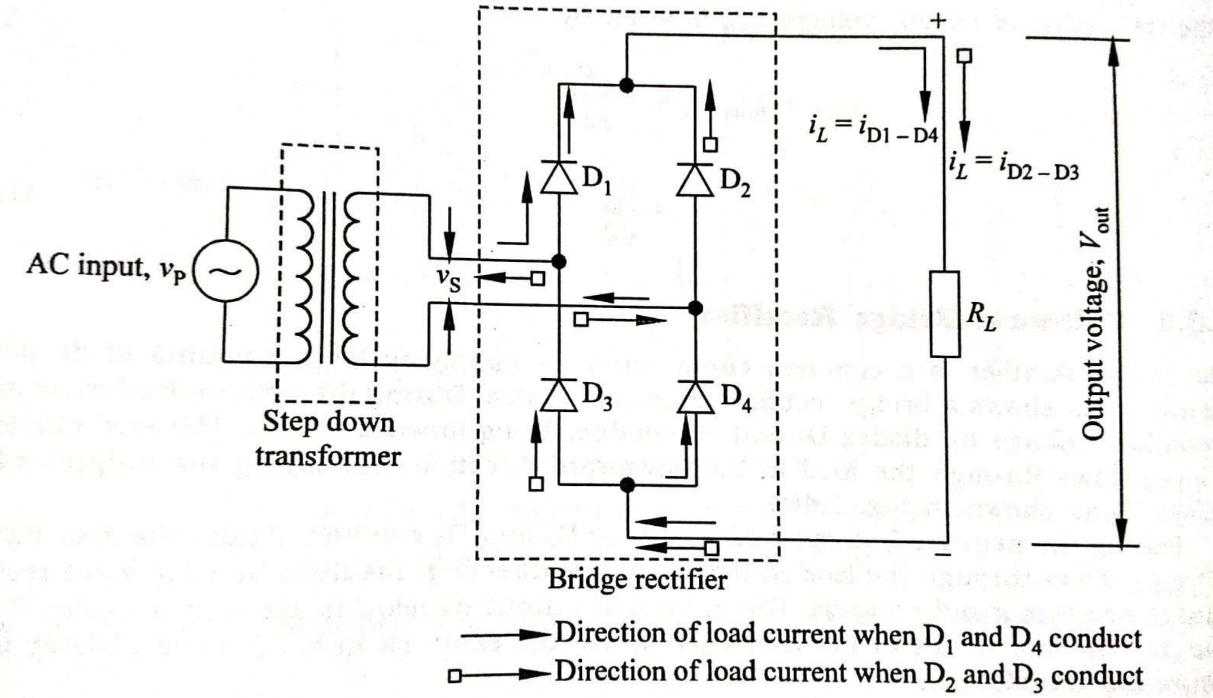

Fig. 1.4(a) Circuit diagram of a full-wave bridge rectifier.

Function of Full-wave Bridge rectifier:

a) During the positive half-cycle of v_S, diodes D_1 and D_4 conduct as they are forward biased. The load current ($i_L = i_{D1-D4}$) flows through R_L, developing the output voltage across R_L.
b) During the negative half-cycle of v_S, diodes D_2 and D_3 conduct as they are forward biased. The load current ($i_L = i_{D2-D3}$) flows through R_L, developing the output voltage across R_L.

Thus, the resulting output voltage is a pulsating dc for both positive and negative half-cycle [as shown n Fig. 1.4(b)].

The dc and rms values of the load current are the same as in a full-wave rectifier using centre-tap transformer.

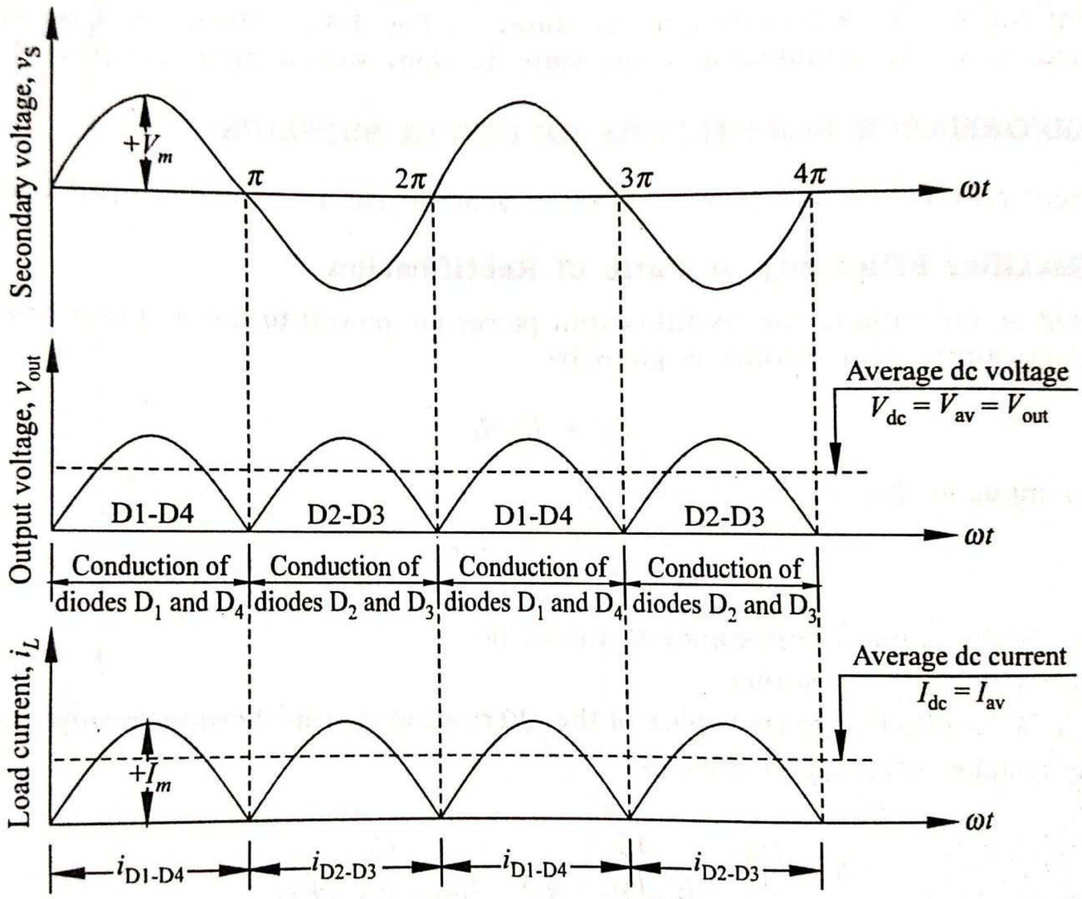

Fig. 1.4(b) Input and output waveforms of a full-wave bridge rectifier.

1.3 PERFORMANCE PARAMETERS OF POWER SUPPLES

1.3.1 Rectifier Efficiency or Raito of Rectification (η_r)

It is termed as the ratio of the useful output power (dc power) to the ac input power.

Now if, **P_{dc} = useful output power = $I_{dc}^2 R_L$**

P_{ac} = ac input power = $I_{rms}^2 (R_f + R_L)$

Where, R_f = dynamic resistance of diode

R_L = load resistance

I_{rms} = rms value of the alternating current flowing through the load

Then the **Rectifier Efficiency** is given by,

η_r = $\frac{P_{dc}}{P_{ac}} = \frac{\mathrm{I}_{dc}^2\,\mathrm{R_L}}{\mathrm{I}_{rms}^2\,(\mathrm{R_f}+\mathrm{R_L})} = \frac{\mathrm{I}_{dc}^2}{\mathrm{I}_{rms}^2\,(1+\mathrm{R_f}/\mathrm{R_L})}$

a) For half-wave rectifier, $\mathbf{I_{dc}} = \frac{I_m}{\pi}$ and $\mathbf{I_{rms}} = \frac{I_m}{2}$

Therefore, **Rectifier Efficiency (η_r)** = $\frac{(I_m/\pi)^2}{(I_m/2)^2\;(1+\mathrm{R_f}/\mathrm{R_L})}$ **x 100 %**

$= \frac{0.406}{(1+\mathrm{R_f}/\mathrm{R_L})}$ **x 100 %**

Practically, $R_L \gg R_f$, hence **Rectifier Efficiency** of a half-wave rectifier is **40.6%.** That is, if there is no diode loss, 40.6% of the ac input is converted into dc power in the load.

b) For full-wave rectifier, $\mathbf{I_{dc}} = \frac{2I_m}{\pi}$ and $\mathbf{I_{rms}} = \frac{I_m}{\sqrt{2}}$

Therefore, **Rectifier Efficiency (η_r)** = $\frac{(2I_m/\pi)^2}{(I_m/\sqrt{2})^2\;(1+\mathrm{R_f}/\mathrm{R_L})}$ **x 100 %**

$= \frac{0.812}{(1+\mathrm{R_f}/\mathrm{R_L})}$ **x 100 %**

Practically, $R_L \gg R_f$, hence **Rectifier Efficiency** of a full-wave rectifier is **81.2%** which is twice that of a half-wave rectifier.

1.3.2 Utilization Factor of a Transformer

This is defined as the ratio of dc load power to the ac rating of the transformer secondary.

Now if, **P_{dc} = dc load power = $I_{dc}^2\,R_L$**

$P_{ac,\,rated}$ = ac rating of transformer secondary = $V_{rms}\,.\,I_{rms}$

Where, I_{rms} = rms value of the alternating current flowing through the load

And, V_{rms} = rms value of the alternating voltage across transformer secondary = $\frac{V_m}{\sqrt{2}}$

Then the **Utilization Factor** is given by,

UF = $\frac{P_{dc}}{P_{ac,rated}} = \frac{\mathrm{I}_{dc}^2\,\mathrm{R_L}}{\mathrm{V_{rms}\,I_{rms}}} = \frac{\mathrm{I}_{dc}^2\,\mathrm{R_L}}{(\mathrm{V_m}/\sqrt{2})\,\mathrm{I_{rms}}}$

a) For half-wave rectifier, $\mathbf{I_{dc}} = \frac{I_m}{\pi}$ and $\mathbf{I_{rms}} = \frac{I_m}{2}$

Therefore, **Utilization Factor (UF)** = $\frac{(I_m/\pi)^2 R_L}{(V_m/\sqrt{2})(I_m/2)}$

$$= \frac{(I_m/\pi)^2 R_L}{\{I_m(R_f + R_L)/\sqrt{2}\}(I_m/2)}$$

$$= \frac{2\sqrt{2}}{\pi^2} * \frac{R_L}{(R_f + R_L)}$$

$$= 0.287 * \frac{R_L}{(R_f + R_L)}$$

Practically, R_L » R_f, hence **Utilization Factor** of a half-wave rectifier is **0.287**.

b) For full-wave rectifier, $\mathbf{I_{dc}} = \frac{2I_m}{\pi}$ and $\mathbf{I_{rms}} = \frac{I_m}{\sqrt{2}}$

Therefore, **Utilization Factor (UF)** = $\frac{(2I_m/\pi)^2 R_L}{(V_m/\sqrt{2})(I_m/2)}$

$$= \frac{(2I_m/\pi)^2 R_L}{\{I_m(R_f + R_L)/\sqrt{2}\}(I_m/2)}$$

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

$$= 0.81 * \frac{R_L}{(R_f + R_L)}$$

Practically, R_L » R_f, hence **Utilization Factor** of a full-wave rectifier is **0.81**.

1.3.3 Peak Inverse Voltage (P.I.V.)

The maximum instantaneous voltage that occurs during the negative half-cycle and that the diode can safely withstand without breakdown is termed as **Peak Inverse Voltage** or **Peak Reverse Voltage.**

a) In a half-wave rectifier or a full-wave bridge rectifier, the P.I.V. for a diode is equal to the peak voltage of the transformer secondary, i.e. $\mathbf{V_m}$.

b) In a full-wave rectifier with a centre-tap transformer, the P.I.V. for a diode is twice the peak voltage of the transformer secondary, i.e. $\mathbf{2V_m}$.

The value of P.I.V. is an important factor considered when selecting a diode as a rectifier for a power supply. If reverse voltage across a diode exceeds its P.I.V., reverse current increases sharply and breaks down the P-N junction because of excessive heat generated.

1.3.4 Voltage Regulation

Voltage Regulation is defined as the change in dc output voltage caused by the change in load current.

Now if, V_{NL} = no load dc output voltage, i.e. with zero load current

V_{FL} = full load dc output voltage, i.e. with full load current

Then, **Percentage Voltage Regulation (VR) =** $\frac{V_{NL} - V_{FL}}{V_{FL}}$ **x 100%**

In an ideal power supply, the output voltage is independent of load current, i.e. $V_{FL} = V_{NL}$; hence, the **Percentage Regulation** is **zero.** Therefore, lower regulation means a better power supply.

Poor voltage regulation means that the load voltage changes appreciably with the change in load current.

1.3.5 Line Regulation or Source Regulation

Line Regulation is defined as the change in output voltage for a change in the input voltage at a constant chip temperature.

Now if, ΔV_{out} = change in output voltage

ΔV_{in} = change in input voltage

Then, **Line Regulation (LR) =** $\frac{\Delta V_{out}}{\Delta V_{in}}$ **x 100%**

1.3.6 Load Regulation

Load Regulation is defined as the change in output voltage for a change in the load current at a constant chip temperature.

Now if, ΔV_{out} = change in output voltage

ΔV_{L} = change in load current

Then, **Load Regulation (LR) =** $\frac{\Delta V_{out}}{\Delta V_{L}}$ **x 100%**

1.3.7 Thermal Regulation

Thermal Regulation is defined as the percentage change in the output voltage for a given change in power dissipation over a specified time period.

1.3.8 Temperature Stability

Temperature Stability is defined as the percentage change in input for a thermal variation from room temperature to either temperature extreme.

1.3.9 Maximum Power Dissipation

It is the maximum total power dissipation in the device for which the regulator will operate within its specification.

1.3.10 Ripple Rejection

The rectifier circuit produces pulsating dc voltage (i.e. combination of dc components as well as ac components) as an output. These ac components in the output are known as **ripple.**

Now if, $V_{out,\ ripple}$ = output ripple voltage

$V_{in,\ ripple}$ = input ripple voltage

Then, **Percentage Ripple Rejection (RR) =** $\frac{V_{out,ripple}}{V_{in,ripple}}$ **x 100%**

The unit of **Ripple Rejection** is **dB.** A ripple rejection of 80 dB means that the output ripple is 80 dB less than the input ripple.

1.3.11 Stabilization Factor

The degree of stabilization against output voltage variation offered by a constant voltage regulated power supply at a constant value of load current is given by the Stabilization factor, S.

Now if, δV_{out} = change in output voltage

δV_{in} = change in input voltage

Then, **Stabilization factor (S) =** $\frac{\delta V_{out}}{\delta V_{in}}$

1.3.12 Ripple Factor

Ripple Factor is defined as,

Ripple Factor = $\frac{rms\ value\ of\ the\ ac\ components\ in\ pulsating\ dc}{dc\ value\ of\ the\ pulsating\ dc}$

$$= \frac{V_{ripple,rms}}{V_{dc}}$$

Let, V_{rms} = rms value of the transformer secondary voltage.

Now, from the definition of ripple, we can say that,

$$V_{rms}^{2} = V_{dc}^{2} + V_{ripple,\,rms}^{2}$$

Or, $V_{ripple,\,rms} = \sqrt{V_{rms}^2 - V_{dc}^2}$

Therefore, **Ripple Factor** = $\dfrac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}} = \sqrt{\left(\dfrac{V_{rms}}{V_{dc}}\right)^2 - 1}$

Similarly, **Ripple Factor** = $\dfrac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{dc}} = \sqrt{\left(\dfrac{I_{rms}}{I_{dc}}\right)^2 - 1}$

a) For half-wave rectifier, $V_{dc} = \dfrac{V_m}{\pi}$ and $V_{rms} = \dfrac{V_m}{2}$

Therefore, **Ripple Factor** = $\sqrt{\left(\dfrac{V_{rms}}{V_{dc}}\right)^2 - 1}$

$$= \sqrt{\left(\frac{V_m/2}{V_m/\pi}\right)^2 - 1}$$

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

b) For full-wave rectifier, $V_{dc} = \dfrac{2V_m}{\pi}$ and $V_{rms} = \dfrac{V_m}{\sqrt{2}}$

Therefore, **Ripple Factor** = $\sqrt{\left(\dfrac{V_{rms}}{V_{dc}}\right)^2 - 1}$

$$= \sqrt{\left(\frac{V_m/\sqrt{2}}{2V_m/\pi}\right)^2 - 1}$$

$$= \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1} = 0.482$$

Importance of ripple factor

The rectifier output contains dc components along with ac components (ripple). These unwanted ripple components create pulsations in the rectifier output. Therefore, the smaller the ripple component, the greater will be the rectifier effectiveness.

1.4 COMPARISON OF RECTIFIER CIRCUITS (WITH RESISTIVE LOAD)

Parameter	***Half-wave Rectifier***	***Full-wave Rectifier using centre-tap transformer***	***Full-wave Bridge Rectifier***
Secondary voltage	v_s	$2v_s$	v_s
Number of diodes	1	2	4
P.I.V.	V_m	$2V_m$	V_m
Ripple Factor	1.21	0.482	0.482
Ripple frequency	f	$2f$	$2f$
No load dc output	$\frac{V_m}{\pi}$	$\frac{2V_m}{\pi}$	$\frac{2V_m}{\pi}$
Percentage efficiency	40.6	81.2	81.2
Utilization Factor	0.287	0.693	0.812