4
CHAPTER

DC POWER SUPPLY

4.1 INTRODUCTION

Today almost every electronic device needs a dc supply for its smooth operation. Regulated DC power supply provides accurate DC voltage, which is derived from AC mains. These DC supplies are cheaper in nature than the DC sources from battery. A regulated DC power supply is used to ensure that the output remains constant even if the input changes.

4.2 REGULATED DC POWER SUPPLY

A regulated DC power supply is also called as a linear power supply. The regulated power supply will accept an ac input and give a constant dc output. Fig. 4.1 below shows the block diagram of a typical regulated dc power supply.

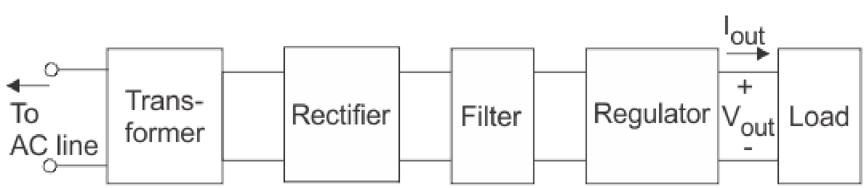

Fig. 4.1 : Block diagram of regulated dc power supply

The basic building blocks of a regulated dc power supply are as follows :

1. A step down transformer
2. A rectifier
3. A DC filter
4. A regulator

Step Down Transformer :

A step down transformer will step down the voltage from the ac mains to the required voltage level. The turn ratio of the transformer is so adjusted such as to obtain the required voltage value. The output of the transformer is given as an input to the rectifier circuit.

Rectifier :

Rectifier is an electronic circuit consisting of diodes which carry out the rectification process. Rectification is the process of converting an alternating voltage or current into corresponding direct (DC) quantity.

Filter :

The rectified voltage from the rectifier is a pulsating DC voltage having very high ripple content. To remove the ripple content the Filter circuit is used. Filter is an electronic circuit which removes the ripple content from the rectified output and provides smooth DC voltage or ripple free output.

Regulator :

Regulator is an electronic circuit which provides constant output voltage to the load against any change in the load current or any change in the input line voltage.

4.3 RECTIFIERS

A rectifier is a circuit which converts the Alternating Current (AC) input power into a Direct Current (DC) output power. There are three types of rectifiers which are as follows

1. Half wave rectifier
2. Center tapped full wave rectifier
3. Bridge type full wave rectifier

4.3.1 Half Wave Rectifier

Fig. 4.2 shows a half wave rectifier circuit. It consists of a single diode in series with a load resistor. The working of a half wave rectifier circuit may be studied by considering separately the positive and negative half cycles of the a.c input voltage.

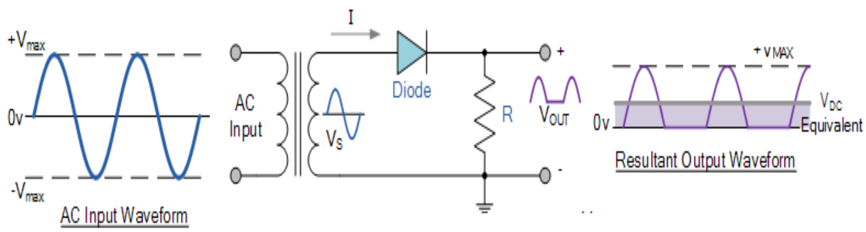

Fig. 4.2 : Half wave rectifier with waveform

Working :

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

Since the load is resistive (resistor R), the current flowing through the load resistor is therefore proportional to the voltage. So the voltage across the load resistor will therefore be the same as the supply voltage, V_s.

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. Therefore, NO current flows through the diode or circuit. Thus in the negative half cycle of the supply, no current flows in the load resistor as no voltage appears across it so therefore, $V_{out} = 0$.

The current on the DC side of the circuit flows in one direction only making the circuit Unidirectional. Then the equivalent DC voltage, V_{DC} across the load resistor is calculated as follows.

1. DC Output voltage [V_{DC}] :

We know that instantaneous value of the sinusoidal a.c. input voltage is given by the relation,

$$V = V_m \sin \omega t \, dt$$

Fig. 4.2 shows the waveform of an output voltage of a half wave rectifier. It indicates that there is an output voltage for a period from 0 to π and nothing for a period from π to 2π. The average or d.c value of the output voltage is given by relation,

$$V_{dc} = \frac{1}{T}\int_0^T v(t)\,dt$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} V_m \sin \omega t\,dt + \int_{\pi}^{2\pi} 0\,dt\right]$$

$$= \frac{V_m}{2\pi}[-\cos \omega t]_0^{\pi} = \frac{V_m}{2\pi}[-\cos(\pi) - (-\cos 0)]$$

$$= \frac{V_m}{2\pi}[-(-1) - (-1)] = \frac{V_m}{\pi} = 0.318\, V_m$$

where V_m is the maximum or peak voltage value of the AC sinusoidal supply.

2. DC Output Current [I_{dc}] :

The average or d.c. value of load current is given by dividing the d.c. value of output voltage by the value of load resistor (R_L).

$$I_{dc} = \frac{V_{DC}}{R_L} = \frac{V_m}{\pi \cdot R_L} = \frac{I_m}{\pi} = 0.318\, I_m$$

In practical condition, it is necessary to include the diode forward resistance (R_f) and secondary winding resistance (R_s) in the relation of average values of output voltage and current. In this case, average value of output voltage,

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And the average value of load current,

$$I_{dc} = \frac{V_m}{\pi (R_f + R_s + R_L)}$$

3. V_{rms} and I_{rms} at the Load Resistance :

$$v(t) = \begin{cases} V_m \sin \omega t & \text{for } t \le \frac{T}{2} \\ 0 & \text{for } \frac{T}{2} < t < T \end{cases}$$

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T v^2 (t)\, dt}$$

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

$$= \left[\frac{V_m^2}{2\pi}\int_0^{T/2} \sin^2 \omega t \; d\,(\omega t)\right]^{1/2}$$

$$\sin^2 \omega t = \frac{1}{2}(1 - \cos 2\omega t),\ \omega T = 2\pi,\ \theta = \omega t$$

$$V_{rms} = \left[\frac{V_m^2}{4\pi}\int_0^{\pi} (1 - \cos 2\theta)\, d\theta\right]^{1/2}$$

$$= \left[\frac{V_m^2}{4\pi}\left(t - \frac{1}{2}\sin 2\theta\right)\Big|_0^{\pi}\right]^{1/2}$$

$$= \left[\frac{V_m^2}{4\pi}\pi - \frac{1}{2}\sin(\pi) - 0 + \frac{1}{2}\sin 2(0)\right]^{1/2}$$

$$= \left[\frac{V_m^2}{4\pi}(\pi - 0 - 0 + 0)\right]^{1/2}$$

$$= \frac{V_m}{2}$$

Also, Irms at the load is given by,

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i_L^2 \cdot d\theta)}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2 \theta \cdot d\theta + \int_{2\pi}^{\pi} (0 \cdot d\theta)}$$

$$\sqrt{\frac{I_m^2}{2\pi}\int_0^{\pi}\left(\frac{1-\cos 2\theta}{2}\right)d\theta} = \sqrt{\frac{I_m^2}{4\pi}\left(\theta - \frac{\sin 2\theta}{2}\right)_0^{\pi}} = \frac{I_m}{2}$$

3. Ripple Factor :

Undesirable AC contents in the DC output of a rectifier are known as ripple. This arises due to fluctuations in the pulsating DC.

The amount of ripple is indicated by a factor known as ripple factor and is defined as "The ratio of rms value of ripple components to DC value of output". It is given as,

$$\text{Ripple} = \frac{V_{r_{rms}}}{V_{dc}}$$

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

$$= \sqrt{\left[\frac{V_{rms}}{V_{dc}}\right]^2 - 1}$$

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

$$= \sqrt{\left[\frac{\pi}{2}\right]^2 - 1}$$

$$= 1.2114$$

Smaller the ripple factor better is the rectifier, however in case of half wave rectifier AC contents are more than DC hence it is inefficient rectifier.

4. Efficiency (Ratio of Rectification) :

It is a figure of merit of rectifier that indicates amount of input AC power that is converted into dc power. It is defined as "The ratio of DC power delivered to the load to the AC input power from transformer secondary".

Efficiency is just 41%. This is because only one half of the input AC voltage is converted in to DC power and also some power is lost across the diode forward resistance (Rf) and transformer secondary resistance (R_S).

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

$$\eta = \frac{V_{dc}^2/R_L}{V^{rms}/R_L} = \frac{(V_m/\pi)^2}{(V_m/2)^2} = \frac{4}{\pi^2} = 0.406$$

or

$$\eta = 40.6\%$$

5. Peak-inverse [Reverse] Voltage (PIV or PRV) :

It is the maximum voltage that appears across the diode when it is reverse biased. In half wave rectifier the maximum voltage appearing across the diode under reverse biased condition is peak-value of secondary voltage i.e. PIV = V_m.

It is an important rating of a diode and to avoid breakdown or damage, PIV should be equal to or little more than Vm.

6. Ripple Frequency :

The pulsating rate of output DC voltage is known as Ripple Frequency. As seen from the Input-Output waveforms one pulse of DC appears over each cycle of input AC voltage. Thus the ripple frequency equals the input AC frequency.

$$f_r = f_i = 50$$

Advantages :

1. Only one diode is required.
2. Circuit is simple & economical.
3. PIV is just equal to Vm.
4. Normal transformer without center tapping is sufficient.

Disadvantages :

1. Poor efficiency (41%) as one of the half cycle of input is wasted.
2. Excessive ripple [121%] i.e. AC contents are more than DC contents in the output.
3. Lower ripple frequency necessitates larger values of L and C in the filter circuits.

4. Relatively poor voltage-regulation.

4.3.2 Center Tapped Full Wave Rectifier

A center tapped full wave rectifier is a type of rectifier which uses a center tapped transformer and two diodes to convert the complete AC signal into DC signal.

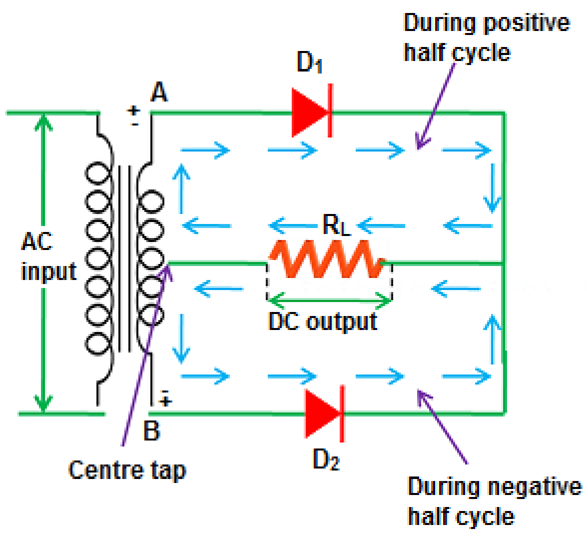


Fig. 4.3 : (a) Center tapped full wave rectifier

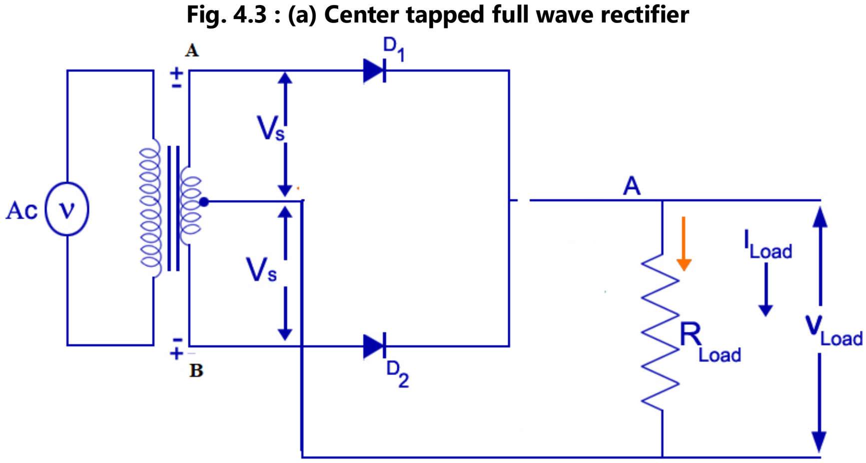


Fig. 4.3 : (b) Working of center tapped full wave rectifier

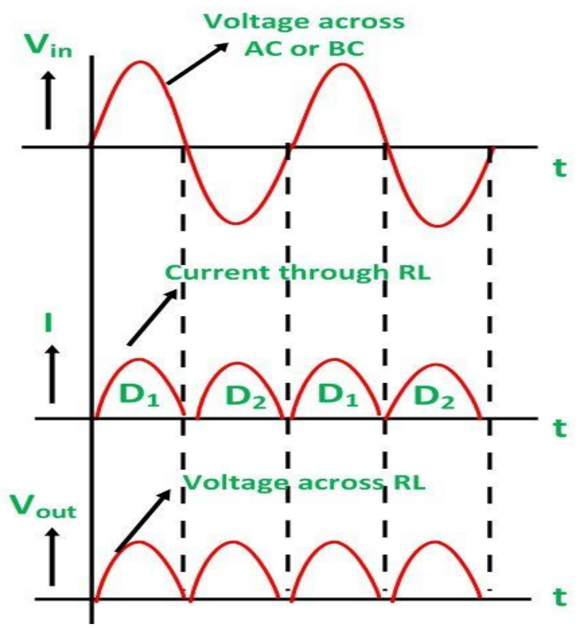


Fig. 4.3 : (c) Waveform of center tapped full wave rectifier

Working : During the positive half cycle of the input AC signal, terminal A become positive, terminal B become negative w. r. t center tap (zero volts). The positive terminal A is connected to the diode D_1 and the negative terminal B is connected to the diode D_2. So the diode D_1 is forward biased during the positive half cycle and D_2 is reverse biased. Electric current flows through D_1, Load R_L and center tap.

During the negative half cycle of the input AC signal, terminal B become positive, terminal A become negative w.r.t center tap (zero volts). The positive terminal B is connected to the diode D_2 and the negative terminal A is connected to the diode D_1. So the diode D_2 is forward biased during the negative half cycle and D_1 is reverse biased. Electric current flows through D_2, Load R_L and center tap. The current through the load resistor is as indicated in the Fig. 4.3 (a).

1. DC Output voltage [V_{dc}] and DC output current (I_{dc}) :

The instantaneous voltage of a sinusoid is given as : $v = V_m \sin\omega t$ and the period of a sinusoid is given as : 2π. The average or d.c. value of the output current is given by,

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

$$= \frac{I_m}{2\pi}(2 + 2)$$

$$= \frac{4I_m}{2\pi}$$

$$I_{dc} = \frac{2I_m}{\pi}$$

$$= \frac{2}{3.14} I_m$$

$$= 0.636 \, I_m$$

And the average or d.c. value of the output voltage,

$$V_{dc} = I_{dc} R_L$$

$$= \frac{2I_m}{\pi} \times R_L$$

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

$$V_{dc} = \frac{2V_m}{\pi (R_s + R_f + R_L)} \times R_L$$

If $$R_L >> R_s + R_f$$

then $$V_{dc} = \frac{2V_m}{\pi}\frac{R_L}{R_L}$$

$$V_{dc} = \frac{2V_m}{\pi}$$

2. V_{rms} and I_{rms} at load resistor :

The R.M.S. value of voltage is given by,

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

and the R.M.S. value of current is given by,

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} i_L^2 \cdot d\theta} = \sqrt{\frac{1}{\pi} I_m^2 \sin^2 \theta \cdot d\theta}$$

$$= \sqrt{\frac{I_m^2}{\pi}\int_0^{\pi}\left(\frac{1 - \cos 2\pi}{2}\right) d\theta}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\left(\theta - \frac{\sin 2\theta}{2}\right)_0^{\pi}}$$

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

2. Ripple Factor (r) : This is the ratio of the root mean square (rms) value of AC component of output voltage to the dc component of the output. It is given by,

We know that the r.m.s. value of the rectified load current

$$I_{rms} = \sqrt{I_{dc}^2 + I_{r\,(rms)}^2}$$

Dividing the above equation on both sides by I_{dc}

$$\frac{I_{rms}}{I_{dc}} = \frac{\sqrt{I_{dc}^2 + I_{r\,(rms)}^2}}{I_{dc}} = \sqrt{1 + \left(\frac{I_{r\,(rms)}}{I_{dc}}\right)^2}$$

Squaring and rearranging the above expression,

$$\frac{I_{r\,(rms)}}{I_{dc}} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

or

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

For full wave $I_{RMS} = \frac{I_m}{\sqrt{2}}$ and $I_{DC} = \frac{2I_m}{\pi}$

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

Ripple factor = γ = 0.48

This indicates that the ripple contents in the output are 48% of the dc component which is much less than that for the half wave rectifier.

3. Efficiency : This is the ratio of DC output power to the AC input power.

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

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

The maximum efficiency of a Full Wave Rectifier is 81.2%.

4. Peak-inverse [Reverse] Voltage (PIV or PRV) :

This is the maximum voltage which occurs across the diodes when they are reverse biased. Here it will be equal to twice the peak of the input voltage, $2V_m$.

5. Ripple Frequency :

The pulsating rate of output DC voltage is known as *Ripple Frequency*. As seen from the Input-Output waveforms two pulses of DC appear over each cycle of input AC voltage. Thus the ripple frequency equals twice the input AC frequency.

$$f_r = 2f_i = 100$$

Advantages :

1. Higher values of average DC current and DC voltage.
2. Ripple factor is comparatively small i.e. DC output contains less amount of AC.
3. Efficiency is higher.
4. Since ripple frequency is twice the input frequency, values of L and C required in filter circuit are small.

Disadvantages :

1. Requires center-tapped transformer and two diodes, which make the circuit little costly.
2. PIV of diode is more ($2V_m$), which also adds to the cost.
3. As DC output is still pulsating, it contains AC components.

4.3.3 Bridge (full Wave) Rectifier

In Full Wave Bridge Rectifier, an ordinary transformer is used in place of a center tapped transformer. The circuit forms a bridge connecting the four diodes D_1, D_2, D_3, and D_4. The circuit diagram of Full Wave rectifier bridge rectifier is shown below Fig. 4.4.

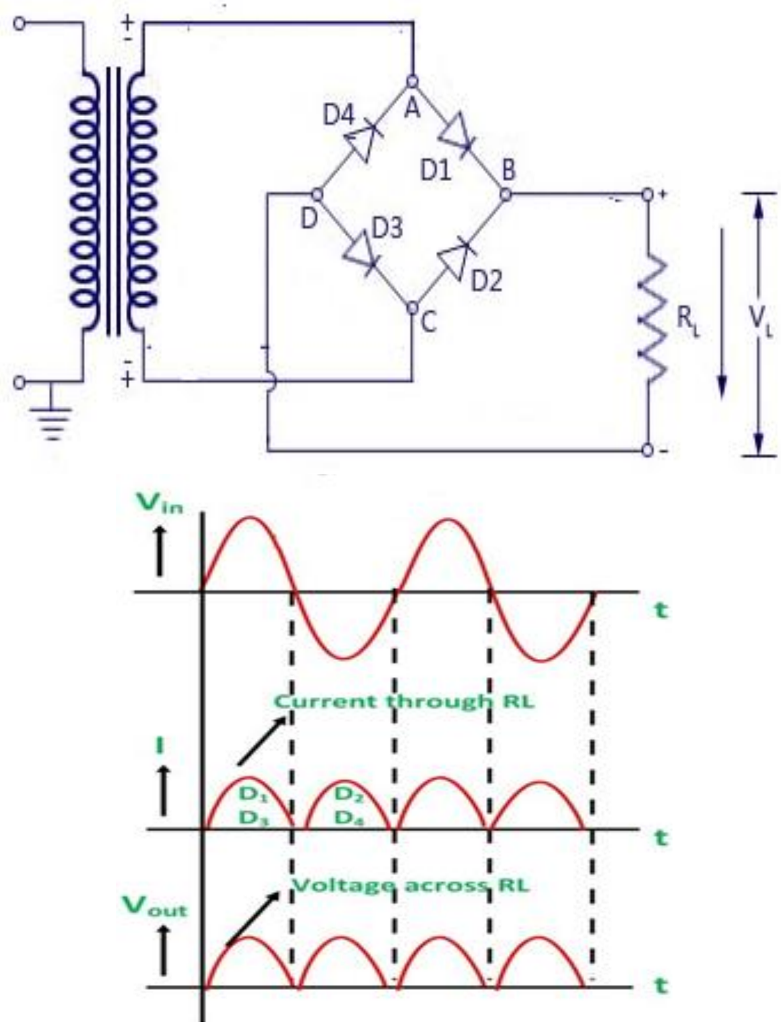


Fig. 4.4 : Circuit diagram and Waveform of Bridge full Wave Rectifier

Working :

During the positive half cycle of the secondary voltage, the end A becomes positive, and end B becomes negative as shown in the figure.

The diodes D_1 and D_3 are forward biased and the diodes D_2 and D_4 are reversed biased. Therefore, diode D_1 and D_3 conduct and diode D_2 and D_4 does not conduct. The current (i) flows through diode D_1, load resistor R_L, diode D_3 and the transformer secondary.

During the negative half cycle, the end A becomes negative and end B positive as shown in the figure. The diode D_2 and D_4 are under forward bias and the diodes D_1 and D_3 are reverse bias. Therefore, diode D_2 and D_4 conduct while diodes D_1 and D_3 does not conduct. Thus, current (i) flows through the diode D_2, load resistor R_L, diode D_4 and the transformer secondary.

The current flows through the load resistor R_L in the same direction during both the half cycles. Hence, a DC output voltage Vout is obtained across the load resistor.

1. DC Output voltage [V_{dc}] and DC output current (I_{dc}) :

From Fig. 4., it is clear that diodes conduct in pairs at any instant, the current flows through two diodes, load resistance and secondary of the transformer. The currents

$$i_1 = \frac{I_m}{\pi}$$

and

$$i_2 = \frac{I_m}{\pi}$$

$$I_{dc} = i_1 + i_2$$

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

And the average or d.c. value of the output voltage,

$$V_{dc} = \frac{2V_m}{\pi}$$

2. Ripple Factor (r) :

This is the ratio of the root mean square (rms) value of AC component to the dc component at the output. It is given by

$$\gamma = \frac{V_{rms}}{V_{dc}} = 0.482 = 48.2\%$$

3. Efficiency :

This is the ratio of DC output power to the AC input power and is equal to 81.2 ≈ 82%.

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

4. Peak-inverse [Reverse] Voltage (PIV or PRV) :

This is the maximum voltage which occurs across the diodes when they are reverse biased. Here it will be equal to the input voltage, Vm .

5. Ripple Frequency :

The pulsating rate of output DC voltage is known as *Ripple Frequency*. As seen from the Input-Output waveforms two pulses of DC appear over each cycle of input AC voltage. Thus the ripple frequency equals twice the input AC frequency.

$$f_r = 2f_i = 100$$

Comparison of rectifiers :

Sr. No.	Parameter	Type of the rectifier		
		Halfwave	**Fullwave**	**Bridge**
1.	Number of diodes	1	2	4
2.	V_{dc}	V_m/π	$2V_m/\pi$	$2V_m/\pi$
3.	Peak inverse voltage	V_m	$2V_m$	V_m
4.	Ripple factor	1.21	0.48	0.48
5.	Rectifier efficiency	40.6%	81.2%	81.2%
6.	Transformer utilisation factor	0.287	0.693	0.812
7.	Form factor	1.57	1.11	1.11
8.	Ripple factor	F_{in}	$2F_{in}$	$2F_{in}$

Advantages of Full Wave Bridge Rectifier :

1. The center tap transformer is not necessary.
2. The output is double to that of the center tapped full wave rectifier for the same secondary voltage.

3. The peak inverse voltage across each diode is one-half of the center tap circuit of the diode.

Disadvantages of Full Wave Bridge Rectifier :

1. It needs four diodes.
2. The circuit is not suitable when a small voltage is required to be rectified. It is because, in this case, the two diodes are connected in series and offer double voltage drop due to their internal resistance.

4.4 FILTERS

The output voltage of rectifier is pulsating in nature. Hence it contains greater amount of ripple. The circuit used to remove the ripple (AC components) and obtain smooth DC output is known as filter. Thus it reduces the ripple and smoothens out the pulsating output of a rectifier to give almost steady DC voltage.

Generally filter is connected between rectifier and the load. It mainly consists of inductor (L) and capacitor (C) or combination of both. Accordingly filter circuits are classified as

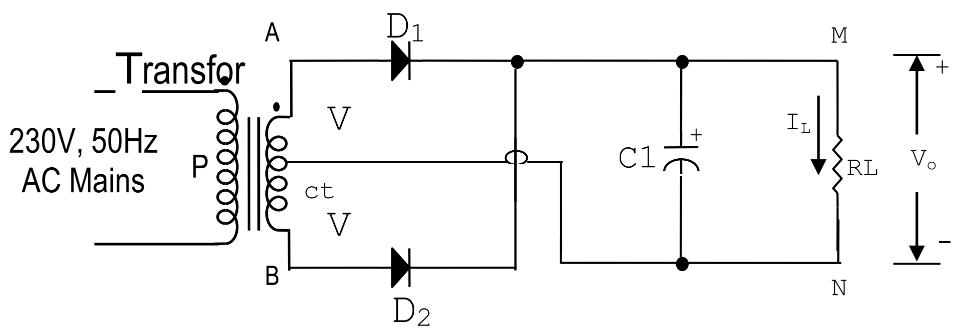


Fig. 4.5 : Circuit diagram of capacitor filter

4.4.1 Shunt Capacitor Filter

Capacitor filter works on the principle of capacitive reactance. A capacitor is reactive device. Its resistance, or impedance, will vary according to the frequency of the signal passing through it. Capacitors are reactive devices which offer higher resistance to lower frequency signals and, conversely, lower resistance to higher frequency signals, according to the formula $X_C = 1/2\pi f_c$.

It is more suitable filter for light loads (large R_L). A capacitor is connected directly across the load, hence it is known as parallel or shunt capacitor filter. The quick charging & slow discharging of capacitor maintains the output voltage almost to peak value minimizing the pulsations in DC output thereby reducing the ripple.

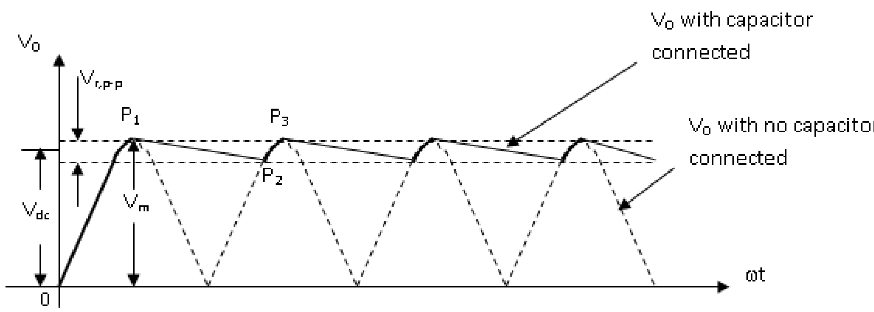


Fig. 4.6 : Waveform of capacitor filter

Working :

Pulsating DC Output of rectifier (indicated by dotted lines) is applied to the capacitor connected in parallel with the load. Capacitor is charged by rectifier current and it discharges through load RL.

Initially, the voltage across capacitor increases from 0 to P_1. Capacitor charges quickly to peak value. As the rectifier voltage begins to fall after first quarter cycle, the voltage at anode of rectifier diode begins to be less than the capacitor voltage at its cathode. Hence, it is reverse biased.

Capacitor, therefore, begins to discharge slowly through R_L from P_1 to P_2. When the output of rectifier begins to be more than capacitor voltage (as at point P_2), capacitor begins to recharge from P_2 to P_3, and the process repeats.

The fast charging and slow discharging of capacitor never allows the output voltage to drop to zero and it is maintained almost around peak value, thereby reducing the ripple. Ripple may be decreased and V_{dc} can be increased either by increasing the load resistance (R_L) or capacitor (C) or both. The ripple factor of a capacitor filter (for 50 Hz supply) is given by the relation,

$$\gamma = \frac{1}{4\sqrt{3}f\,C\,R_L} = \frac{2890}{C\,R_L}$$

where C is in μF.

The product $C*R_L$ is the time constant of the filter circuit.

Advantages :

1. Inexpensive and small in size.
2. Suitable for low current and high voltages.

Disadvantages :

1. Not suitable for large current and small voltages.
2. For high voltage output, capacitor with appropriate voltage rating must be used.

4.5 VOLTAGE REGULATORS

It is found that the output voltage of DC power supply tends to change with current drawn or AC mains voltage varies. Such a supply is known as Unregulated Power Supply. Regulators are used to maintain output voltage constant irrespective of the variations in the input AC voltage or load current drawn. Such a power supply is known as Regulated Power Supply.

Load Regulation :

The ability to maintain output dc voltage constant against variations in the load current is known as Load Regulation. It is defined as "the change in output dc voltage when the load current varies from minimum value to maximum value".

$$\%\,LR = \frac{V_{NL} - V_{FL}}{V_{NL}} \times 100$$

Where, V_{NL}= the no-load output voltage.

V_{FL}= the full-load output voltage.

It should be as small as possible.

Line or source regulation :

When AC mains voltage varies, the output dc voltage also varies accordingly. The ability of power supply to maintain the output dc voltage constant against variations in the input AC voltage is known as line or source or input regulation. It is defined as "the change in the output voltage over a specific range of input line voltage".

$$\% \ SR = \frac{SR}{V_{NOM}} \times 100$$

Where SR = Source regulation

V_{NOM} = Nominal load voltage

% SR should be as small as possible.

4.6 TYPES OF REGULATORS

Different types of regulators are in use. Depending upon the components used and/or operational principles these are classified as,

1. Zener Regulators
2. Transistorized Regulators
3. IC Regulators
4. Switched Mode Power Supply (SMPS)

4.6.1 Zener Regulator (Shunt Regulator)

To use zener for voltage regulation, it should be operated between knee-current and maximum permissible current ($I_{Z,max}$) current rating. The product '$V_Z \times I_{Z,max}$' is known as power rating and is nothing but maximum power that the zener diode can handle without getting damaged.

i.e. $$P_{D,max} = V_z \times I_{z,max}$$

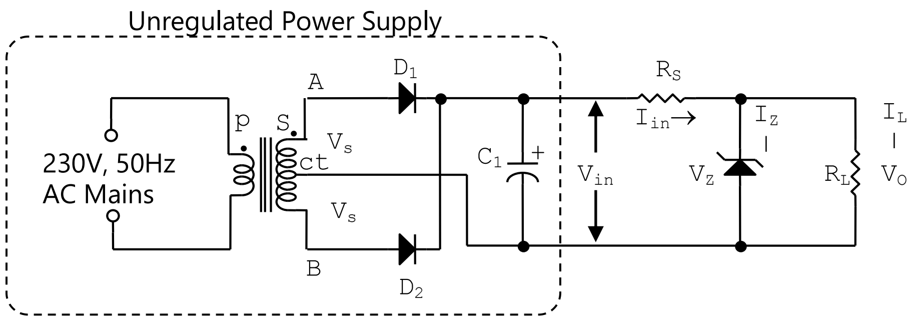


Fig. 4.7 : Circuit diagram of Zener diode as Voltage regulator ()

Zener diode is used to regulate the voltage across the load against variations in the input AC voltage or output load current. Zener regulator shown in Fig. 4.4 consists of a current limiting resistor R_S, connected in series with input voltage (Vin) and zener diode. The zener diode is connected across load R_L and it is operated in reverse biased condition.

From figure,

$$I_{in} = I_Z + I_L$$

The value of current limiting resistor is given by

$$R_S = \frac{V_{in} - V_Z}{I_{in}}$$

Also,

$$V_0 = V_{in} - V_S$$

$$= V_{in} - R_S (I_Z + I_L)$$

where, I_{in} = Input current

I_Z = Zener current

I_L = Load current

Working :

- **Line regulation :**

When there is an increase in the input voltage, the input current increases. Zener diode draws more current keeping the load current constant. The excess voltage is made to drop across R_S. Thus output voltage and load current remain constant as illustrated by chain action given below.

$$V_{in}\uparrow \rightarrow V_O\uparrow \rightarrow I_{in}\uparrow \rightarrow V_S = [R_S (I_Z\uparrow + I_L)] \uparrow\rightarrow V_O = (V_{in} - V_S) \downarrow$$

Similarly, when there is decrease in input voltage, the input current decreases. Now zener draws less current keeping load current constant. Less voltage is made to drop across R_S. Thus the output voltage and load current remain constant as illustrated by chain action given below.

$$V_{in}\downarrow \rightarrow V_O\downarrow \rightarrow I_{in}\downarrow \rightarrow V_S = [R_S (I_Z\downarrow + I_L)] \downarrow \rightarrow V_O = (V_{in} - V_S) \uparrow$$

In this way in spite of change in input voltage, output is maintained constant. This is known as line regulation.

Load regulation :

When the load current increases (R_L decreases) the zener current decreases by the same amount,keeping the input current constant. Therefore, the voltage drop across R_S and hence the output voltage remains constant as illustrated by chain action given below.

$$I_L\uparrow \rightarrow V_O\downarrow \rightarrow I_Z\downarrow \rightarrow \Delta I_{in} = 0 \rightarrow \Delta V_S = 0 \rightarrow \Delta V_O = 0.$$

When the load current decreases (R_L increases) the zener current increases by the same amount keeping the input current constant. Therefore, the voltage drop across R_S and hence the output remain constant as illustrated by chain action given below-

$$I_L\downarrow \rightarrow V_O\uparrow \rightarrow I_Z\uparrow \rightarrow \Delta I_{in} = 0 \rightarrow \Delta V_S = 0 \rightarrow \Delta V_O = 0$$

Thus in spite of change in the load current the output voltage is maintained constant. This is known as load regulation.

Advantages :

1. Simple in design and construction.
2. Economical circuit.
3. Fairly good voltage regulation.

Disadvantages :

1. Input voltage should be greater than zener voltage at least by 2V.
2. Current through zener should be in specific range (I_{ZK} to $I_{Z,max}$).
3. Zener of high wattage is required for high power regulators.
4. Power is wasted in zener diode and series resistance.

4.6.2 Three Terminal Regulators

A functional block diagram of typical Three-Terminal Regulator is shown in the figure 4.8.

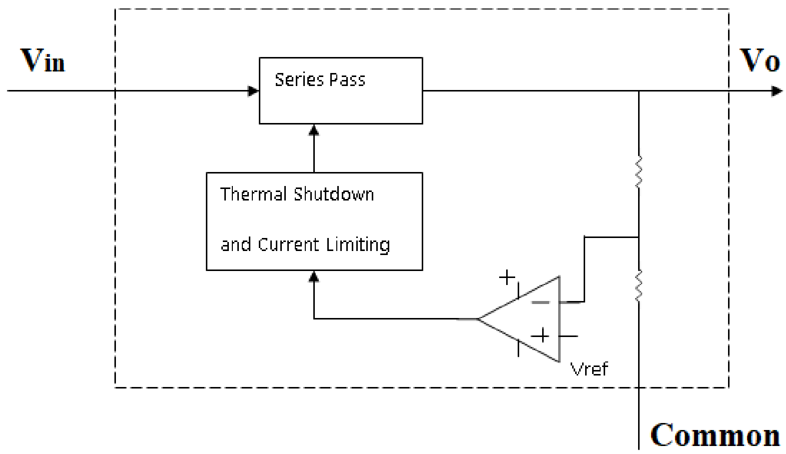


Fig. 4.8 : Block diagram of typical Three-Terminal Regulator

Built in reference voltage (Vref) drives the non-inverting input of error-amplifier. Error amplifier is nothing but an Op-Amp operated as an Inverting Voltage Comparator. The feedback voltage (V_f) is obtained from the internal voltage divider. The chip includes a series pass transistor. The controlled conduction of series pass transistor by output itself regulates the input voltage.

If output voltage V_o tends to increase then $V_f > V_{ref}$, this makes the base voltage of series pass transistor is made less positive by Error Amplifier. It carries therefore less current and drops more voltage thereby not allowing the voltage to increase.

If output voltage V_o tends to decrease then $V_f < V_{ref}$, this makes the base voltage of series pass transistor is made more positive by Error Amplifier. It carries therefore more current and drops less voltage thereby not allowing the voltage to decrease.

The IC also incorporated with thermal shutdown and current limiting circuits. The thermal shutdown automatically turns the pass transistor cut-off when the internal temperature increases beyond certain limits.

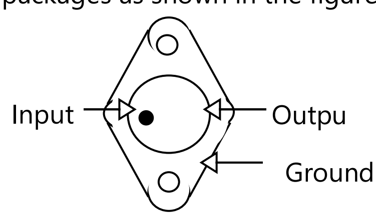
The current limiting circuit protects the Regulator IC in the event the excessive current (over load) or short circuit of output terminals.

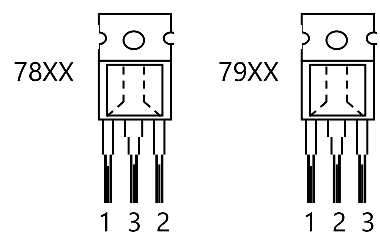
Example of three terminal regulators are-IC 78XX series, IC 79 XX series, IC LM-309, IC CM-320-5, IC LM 340-10, LM-317, etc.

Fixed voltage regulators :

78XX series is a three-terminal positive fixed voltage regulator. This comes with seven-output voltages viz. 5, 6, 8, 12, 15, 18 and 24 V. In 78XX series the last two digits indicate the regulated output voltage. Thus IC 7815 represents a +15 V regulator.

The 79XX series three-terminal fixed output negative voltage regulator. This is complement of 78XX series. The 79XX series has two extra voltages of –2 V and –5.2 V. These regulators are available in two packages as shown in the figures below.





(a) Metal Package (TO-3 type) **(b) Plastic package (TO –220 type)**

Fig. 4.9 : Packages of fixed voltage regulator

Fig. 4.10 below shows the standard connection of IC-78 XX series operating as voltage regulator.

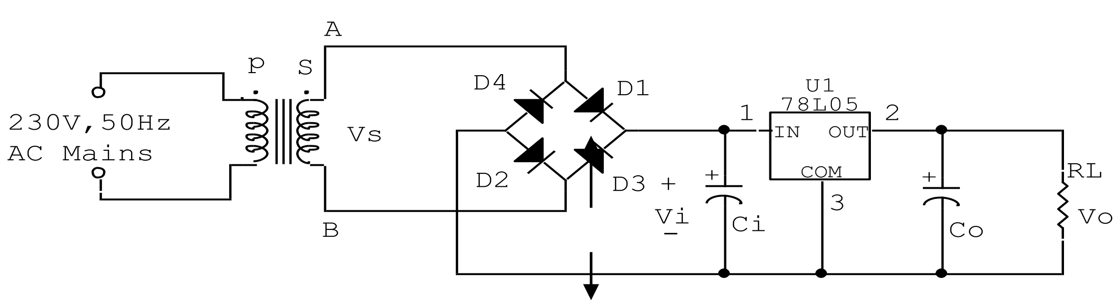


Fig. 4.10 : Voltage Regulator of IC 7805

A capacitor C_i (about 0.33 μf) is usually connected between input terminal and ground to minimize the inductive effects of line distribution leads and avoid the possibility of oscillations. The capacitor C_o (about 1 μf) connected between terminal 2 and 3 improves the transient response of power supply.

Adjustable voltage regulators :

LM 317 Regulator : It is an adjustable three terminal regulator with better line and load regulations as well as better ripple rejection.

1. Adjustable positive output ranging from 1.25 V to 37 V.
2. Maximum load current up to 1.5A.
3. Line regulation of 0.01%.
4. Load regulation of 0.1%.

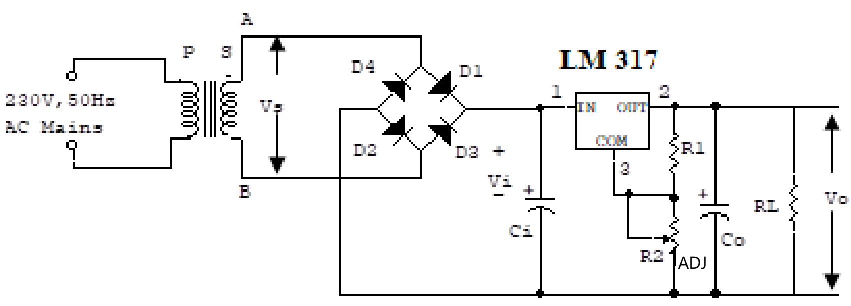


Fig. 4.11 : Adjustable Voltage Regulator of IC LM317

A practical variable voltage regulator using IC LM-317 is shown in Fig. 4.11.

Unregulated DC voltage developed by bridge rectifier is given to pin-1, variable-regulated output is obtained at pin-2. A stable resistor R_1 is connected between 2 and 3 with terminal 3 returned to the ground through variable resistor R_2. By varying the value of R_2, output can be easily varied.

The output voltage is given by following expression,

$$\therefore \qquad V_o = 1.25 \times \left(1 + \frac{R_2}{R_1}\right)$$

For good regulation R_1 = 240 Ω may be used.

4.7 SWITCHING MODE POWER SUPPLY [SMPS]

Main disadvantage of series regulator is that the series pass transistor has to carry full load current. Hence, transistors must possess appropriate power rating and ability to dissipate the power in the form of heat. Sometimes heat sinks become necessary to remove the excess heat. To overcome this drawback switching mode technique is used in specially designed power supply, where large load current can be made to carry by series transistor possessing considerably low power dissipation.

Basic Principle :

In SMPS instead of making series pass transistor to conduct continuously, it is operated as a switch that is rapidly operated to make (close) and break (open), Due to this when the transistor is 'ON' it carries maximum current and gets OFF time to cool down.

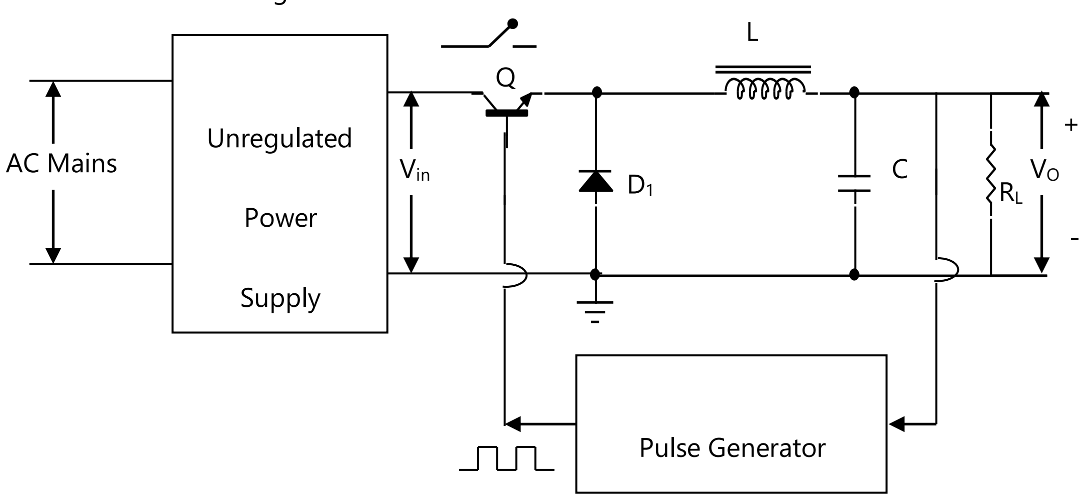


Fig. 4.12 : Basic Working Principle of SMPS

Circuit Diagram :

Unregulated voltage is applied to switching transistor 'Q'. Base of this transistor is driven by the pulses from pulse generator whose duty cycle is inversely proportional to the output voltage. Transistor is operated as switch, which opens and closes at a rapid rate of about 20 kHz.

LC Filter keeps the current through load R_L continuous.

Output is given as,

$$V_o = D \times V_{in}$$

$$D = \frac{T_{ON}}{T_{ON} + T_{OFF}}$$

Working :

SMPS gives regulated output by self adjusting duty cycle of base signal of transistor 'Q' .The output voltage is fed back to the pulse generator to control the duty cycle and hence the ON time of series pass transistor 'Q'.

When the output voltage (V_o) increases either due to increases in the input voltage or decrease in the load current, the duty cycle of base signal is automatically reduced. Therefore, transistor is made to conduct over smaller interval of time in a cycle. This ultimately decreases the output voltage and keeps it at desired level.

On the other hand when the output voltage decreases either due to decreased input voltage or increase in load current, the duty cycle of base signal is automatically increased. Therefore transistor is made to conduct over larger interval of time in a cycle. This ultimately increases the output voltage and keeps it at desired level.

In this way by using negative feedback to control duty cycle, SMPS regulates output voltage. Diode D_1 is connected at emitter of transistor protects the series transistor 'Q' from back e.m.f. (i.e. kick back) of inductor, when the transistor switches off. This also provides the path for inductive current to complete the circuit-loop and hence maintain the load current over a cycle. Diode due to this reason is known as Free Wheeling Diode.

SMPS are available in IC forms, e.g. Fairchild μA 78S40.

Advantages :

1. Small in size and light in weight.

2. The series transistor is made to act as a switch and hence the power is used more efficiently.
3. Since the operating frequency is high, a small transformer, inductor and capacitor need to be used in the LC-filter circuit.
4. Works satisfactorily even with low AC mains voltages.

Disadvantages :

1. Because of switching technique it generates electromagnetic interference, which may disturb the audio section of nearby system.
2. Control part (pulse generator) is complicated and hence expensive and less reliable.
3. Poor transient response with inductive loads.

EXERCISES

(A) Multiple Choice Questions (MCQs) :

1. In half wave rectifier, the load current flows for …….
   (a) complete cycle of input signal
   (b) less than half cycle of input signal
   (c) more than half cycle but less than complete cycle of the input cycle
   (d) **for half cycle of the input signal**
2. The PIV of diode in half wave rectifier is …….
   (a) **V_m** (b) $2 V_m$
   (c) $V_m/2$ (d) $2 V_m/2$
3. Ripple factor of bridge rectifier is …….
   (a) 4.82 (b) 1.21
   (c) 121.1 (d) **0.482**
4. In IC regulators, IC LM317 is …… voltage regulator.
   (a) fixed positive (b) fixed negative
   (c) **variable positive** (d) variable negative
5. Ripple factor of half wave rectifier is …….
   (a) 4.82 (b) **1.21**
   (c) 121.1 (d) 0.482

6. Rectifier is an electronic circuit which converts …….
   (a) **AC to DC** (b) DC to AC
   (c) AC to AC (d) DC to DC
7. Zener diode cab be used as …….
   (a) rectifier (b) oscillator
   (c) **voltage regulator** (d) filter
8. In Capacitor filter, the capacitor is always connected in...... with load.
   (a) series (b) **parallel**
   (c) series and parallel (d) none of these
9. In IC regulators, IC 7805 is …… voltage regulator.
   (a) **fixed positive** (b) fixed negative
   (c) variable positive (d) variable negative

(B) Short Answer Questions :

1. Draw the block diagram of dc power supply and explain each block.
2. Explain half wave rectifier with circuit diagram and its waveform.
3. Write a note on capacitor filter.
4. Draw the block diagram of three terminal IC regulator and explain.
5. Write a note on SMPS.
6. Explain with circuit diagram zener diode as a voltage regulator.

(C) Long Answer Questions :

1. Draw the circuit diagram of Half wave rectifier and explain it with necessary waveforms. Comment on ripple factor and efficiency of the rectifier.
2. Draw the circuit diagram of centre tapped full wave rectifier and explain it with necessary waveforms. Comment on ripple factor and efficiency of the rectifier.
3. Draw the circuit diagram of bridge rectifier and explain it with necessary waveforms. Comment on ripple factor and efficiency of the rectifier.
4. Draw the block diagram of three terminal IC regulator and explain it.

ΘΘΘ