2.1 INTRODUCTION

A rectifier is defined as an electronic circuit that converts an alternating (AC) signal voltage or current into an unidirectional (pulsating D.C) voltage or current. For this purpose, a unidirectional conducting device such as P-N junction diode is used. A PN junction diode is used as a rectifier because it permits easy flow of current in one direction (i.e., during forward bias) but does not permit the current flow in opposite direction (i.e., during reverse bias). *The process of converting AC voltage into unidirectional DC voltage is called rectification.*

2.1.1 Classification of Rectifiers

Based on the conduction of AC input, rectifiers are classified as shown in Fig. 2.1.1,

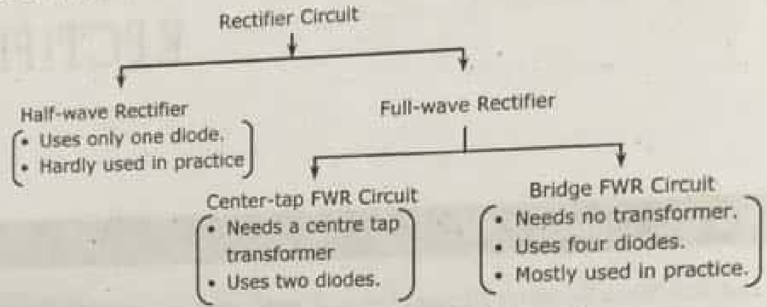


Fig. 2.1.1 Classification of Rectifiers

Before studying various rectifier circuits, let us study the four figures of merit that decide how good a rectifier circuit works. They are,

(1) **Ripple Factor :** The output of a rectifier circuit is unidirectional, but fluctuates greatly with time and has an average value over which a number of unwanted A.C components are superimposed called as ripples. The ripple factor is defined as a measure of the smoothness of the D.C. output and is given as,

$$\boxed{\text{Ripple factor } (\gamma) = \frac{\text{r.m.s value of the A.C components of wave}}{\text{Average or D.C value}}} \quad \text{... (2.1.1)}$$

Obviously, lower the value of ripple factor, the better is the rectifier circuit

(2) **Rectifier Efficiency** : It is defined as the percentage of total input A.C power is converted into useful D.C output power. Thus,

$$\boxed{\eta = \frac{\text{D.C power delivered to the load}}{\text{A.C input power from transformer secondary}} = \frac{P_{D.C}}{P_{A.C}}} \quad \text{... (2.1.2)}$$

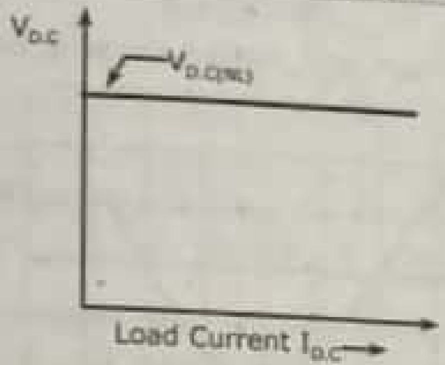
Obviously, greater the value of rectification efficiency, the better is the rectifier circuit.

(3) **Transformer Utilization Factor (TUF) :** The transformer utilization factor is defined as,

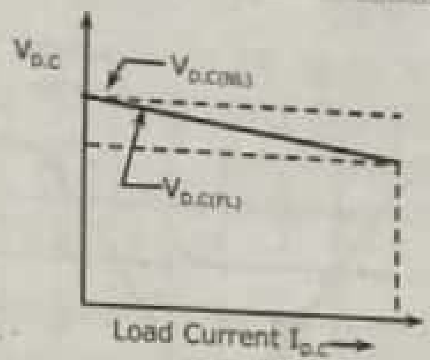
$$\text{TUF} = \frac{\text{D.C power delivered to the load}}{\text{A.C Rating of the transformer secondary}} = \frac{P_{D.C}}{P_{A.C(rating)}} \quad \text{... (2.1.3)}$$

Obviously, greater the value of TUF, the better is the rectifier circuit

(4) **Load Regulation :** A regulator circuit is designed to give a D.C voltage which remains constant even if the load on regulator circuit varies, as shown in Fig. 2.1.2(a). If it does, we say that the load regulation of the regulator circuit is good. Unfortunately, in a practical regulator circuit, the output D.C voltage decreases when the load current increases, as shown in Fig. 2.1.2(b). Because of this, the performance of the electronic equipment connected to the output of the regulator becomes poor.



(a) Good Regulation



(b) Poor Regulation

Fig. 2.1.2 Load Regulation

The regulation is defined as the variation of DC output voltage with the change in DC load current. Thus,

$$\% \text{ Regulation} = \frac{V_{D.C(NL)} - V_{D.C(FL)}}{V_{D.C(FL)}} \times 100\% \quad \text{... (2.1.4)}$$

Where,

$V_{D.C(NL)}$ = Output of D.C voltage under no-load condition (i.e., with $I_{D.C} = 0$, or when $R_L \to \infty$),

$V_{D.C(FL)}$ = Output of D.C voltage under load condition.

2.2 HALFWAVE RECTIFIER WITHOUT FILTERS

Half wave rectifier is an electronic circuit in which only half cycle of A.C signal i.e., either positive or negative sinusoidal wave is converted into an unidirectional (Pulsating D.C) voltage or current.

we get ...

Fig. 2.2.1 shows the half-wave rectifier circuit,

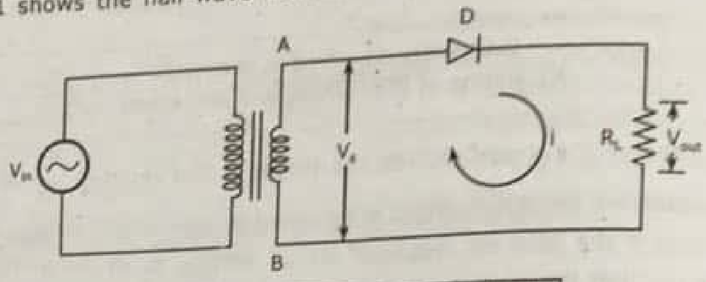


Fig. 2.2.1 Half-wave Rectifier Circuit

The input AC signal voltage (V_{in}) is applied to a single diode connected in series with a load resistor (R_L). A power transformer is used either to step up or to step-down the input signal voltage.

Fig. 2.2.2 shows the input, output voltage and output current waveforms.

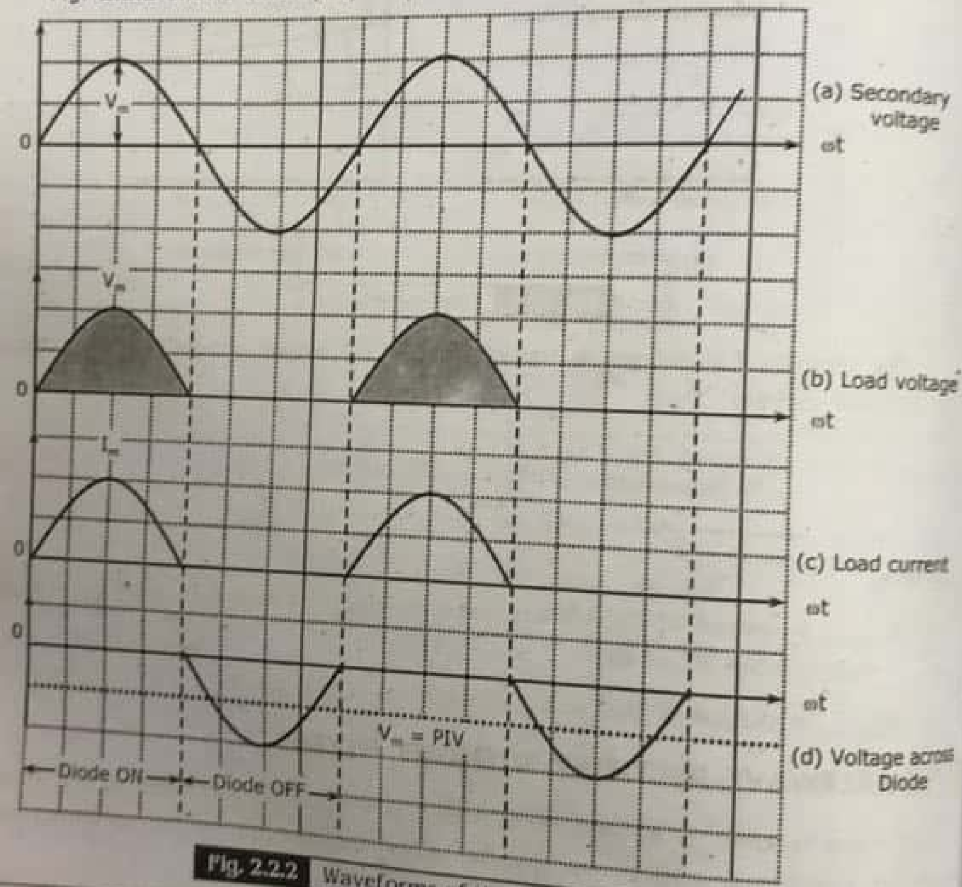


Fig. 2.2.2 Waveforms of the Half Wave Rectifier

Scanned by CamScanner

2.2.1 Working Operation

The working operation of HWR can be understand by using Fig. 2.2.3(a) and 2.2.3(b).

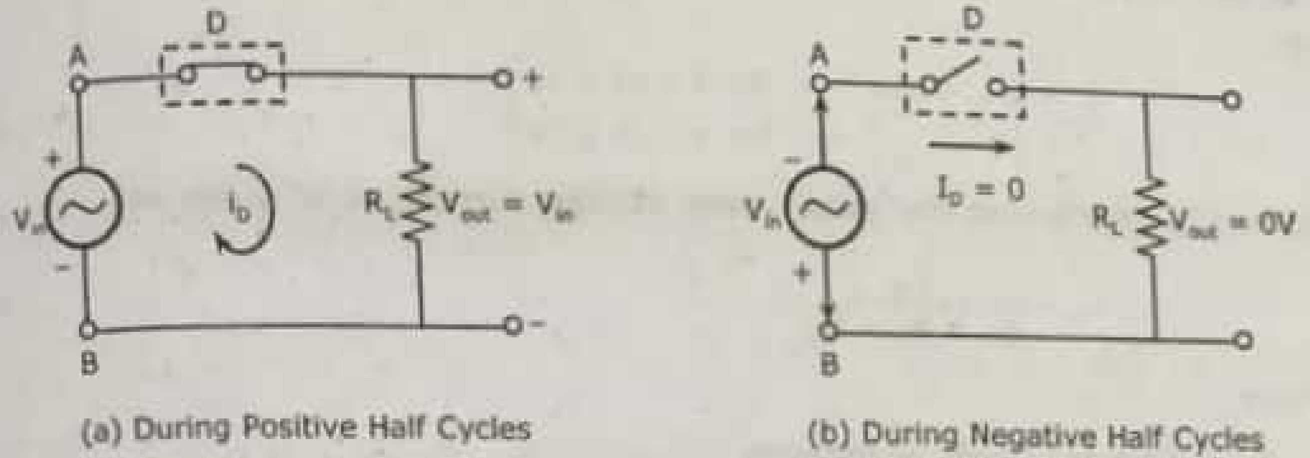


Fig. 2.2.3 Working Operation of HWR

CASE 1 (During Positive Half Cycle) : During the positive half-cycle of the input AC voltage, the diode D is forward biased (ON) and hence it conducts. While conducting, the diode acts as a short-circuit so that in the circuit current flows and hence the positive half cycles of input AC voltage drop is load R_L. Fig. 2.2.2(b) shows the output voltage of the HWR circuit, while Fig. 2.2.2(c) shows the diode or load current.

CASE 2 (During Negative Half Cycle) : During the negative half-cycle of the input AC voltage, the diode D is reverse biased (OFF) and diode acts as a open circuit and hence it does not conduct, i.e., there is no current flow in the circuit ($I_D = 0$). Hence there is no voltage drop across R_L ($V_{out} = 0$). Thus, the negative half cycles are not utilized for delivering power to the load.

COMMENT : ***The input voltage V_{in} alternates in polarity and hence has a zero average value. But the output voltage V_o is unidirectional and hence has a finite average or D.C value $V_{D.C}$***

2.2.2 Performance of Half-Wave Rectifier

As mentioned earlier, to evaluate the performance of rectifier circuits, we need to determine the four figure of merits. To compute them we first need to find the D.C value, the total RMS value and the RMS value of the unwanted A.C components in its output current wave.

Let assume a sinusoidal input voltage (V_{in}) is applied to the input of the rectifier. Thus,

$$V_{in} = V_m \sin \omega t \qquad \dots (2.2.1)$$

Where, V_m represents the peak (maximum) value of the input AC voltage.

Neglecting the voltage drop across the diode D (i.e., V_γ), we have output voltage (i.e., load voltage) as,

$$V_L = \begin{cases} V_m \sin\omega t & \text{for } 0 \le \omega t \le \pi \\ 0 & \text{for } \pi \le \omega t \le 2\pi \end{cases} \quad \dots (2.2.2)$$

The half-wave rectified current flowing through load R_L as shown in Fig. 2.2.2(c) is given by,

$$I_L = \begin{cases} I_m \sin\omega t & \text{for } 0 \le \omega t \le \pi \\ 0 & \text{for } \pi \le \omega t \le 2\pi \end{cases} \quad \dots (2.2.3)$$

Where, I_m represents the peak value of load current, it is given as,

$$\boxed{I_m = \frac{V_m}{R_S + R_f + R_L}} \quad \dots (2.2.4)$$

Where,

R_f = Forward diode resistance.

R_s = Transformer secondary resistance.

R_L = Load resistance.

Comment : *If there is a voltage drop across the diode (i.e., V_γ) then, $I_m = \dfrac{V_m - V_\gamma}{R_S + R_f + R_L}$ Usually V_γ is much smaller than V_m, thus it can be ignored.*

(1) Average D.C Load Current ($I_{D.C}$) : The average D.C value is simply the total area under the curve over one cycle divided by the base. That is,

$$I_{DC} = \frac{\text{Area under one cycle}}{\text{Base of one cycle}}$$

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

$$\Rightarrow \quad I_{DC} = \frac{1}{2\pi}\int_0^{\pi} I_m \sin\omega t \, d(\omega t) + \frac{1}{2\pi}\int_{\pi}^{2\pi} 0 \, d(\omega t)$$

$$\Rightarrow \quad I_{DC} = \frac{I_m}{2\pi}[-\cos\omega t]_0^{\pi} + 0 = \frac{I_m}{2\pi}[-\cos\pi + \cos 0] = \frac{I_m}{2\pi}[1+1]$$

$$\therefore \quad \boxed{I_{DC} = \frac{I_m}{\pi}} \quad \dots (2.2.5)$$

Using the value of I_m from Eq. (2.2.4) in Eq. (2.2.5) we get,

$$\boxed{I_{DC} = \frac{V_m}{\pi(R_S + R_f + R_L)}} \quad \dots (2.2.6)$$

(2) **Average D.C Load Voltage ($V_{D.C}$) :** The D.C output voltage (load voltage) appearing across R_L is given by,

$$V_{D.C} = I_{D.C} R_L = \frac{I_m}{\pi} \cdot R_L \qquad \text{... (2.2.7)}$$

Substituting the value of I_m from Eq. (2.2.4) in Eq. (2.2.7), we have,

$$V_{D.C} = \frac{V_m R_L}{\pi(R_S + R_f + R_L)} = \frac{V_m R_L}{\pi R_L\left(\frac{R_s + R_f}{R_L} + 1\right)}$$

If $R_L >> R_S + R_f$, then the DC output voltage is given by,

$$\therefore \quad \boxed{V_{D.C} = \frac{V_m}{\pi} = 0.318 V_m} \qquad \text{... (2.2.8)}$$

(3) **D.C Output Power ($P_{D.C}$) :** The D.C output power is defined by,

$$P_{D.C} = V_{D.C} \cdot I_{D.C} = I_{D.C}^2 R_L$$

But, $I_{D.C} = \frac{I_m}{\pi}$

$$\therefore \quad \boxed{P_{D.C} = \left(\frac{I_m}{\pi}\right)^2 R_L = \frac{I_m^2}{\pi^2} R_L} \qquad \text{... (2.2.9)}$$

Substituting the value of I_m from Eq. (2.2.4) in Eq. (2.2.9), we have,

$$\therefore \quad \boxed{P_{D.C} = \frac{V_m^2 R_L}{\pi^2 (R_S + R_f + R_L)^2}} \qquad \text{... (2.2.10)}$$

(4) **RMS Output Current and Voltage :** The r.m.s or effective value of the current through the load is given by,

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

$$\Rightarrow \quad I_{rms} = \left[\frac{I_m^2}{2\pi}\int_0^{\pi} \frac{[1-\cos(2\omega t)]}{2} d(\omega t)\right]^{\frac{1}{2}} = \left(\frac{I_m^2}{2\pi \times 2}\left[\omega t - \frac{\sin(2\omega t)}{2}\right]_0^{\pi}\right)^{\frac{1}{2}}$$

$$\Rightarrow \quad I_{rms} = \left(\frac{I_m^2}{4\pi}\left[\pi - \frac{\sin 2\pi}{2} - 0 + \frac{\sin(0)}{2}\right]\right)^{1/2} = \left[\frac{I_m^2}{4\pi}[\pi - 0]\right]^{1/2}$$

$$\therefore \quad \boxed{I_{rms} = \frac{I_m}{2}} \qquad \dots (2.2.11)$$

Using the value of I_m from Eq. (2.2.4) in Eq. (2.2.11), we get,

$$\therefore \quad \boxed{I_{rms} = \frac{V_m}{2(R_f + R_S + R_L)}} \qquad \dots (2.2.12)$$

RMS output voltage is given by,

$$V_{rms} = I_{rms} \times R_L$$

$$\Rightarrow \quad V_{rms} = \frac{V_m R_L}{2(R_f + R_S + R_L)}$$

If $R_L >> R_s + R_f$, then rms output voltage is,

$$V_{rms} = \frac{V_m}{2} \qquad \dots (2.2.13)$$

(5) A.C Input Power ($P_{A.C}$) : The A.C input power is defined by,

$$P_{A.C} = I_{r.m.s}^2 \left[R_S + R_f + R_L\right]$$

From Eq. (2.2.11), $I_{rms} = \frac{I_m}{2}$

$$\therefore \quad \boxed{P_{A.C} = \frac{I_m^2}{4}\left[R_S + R_f + R_L\right]} \qquad \dots (2.2.14)$$

(6) Form Factor : It is defined as the ratio of rms value to the average or DC value of load voltage (or current). That is,

$$F = \frac{\text{rms value}}{\text{Average value}} = \frac{I_m/2}{I_m/\pi} = \frac{0.5\, I_m}{0.318\, I_m} = 1.57$$

(7) Peak Factor : It is defined as the ratio of peak value to r.m.s value of the load voltage (or current)

$$\therefore \quad \text{Peak factor} = \frac{\text{Peak value}}{\text{r.m.s value}} = \frac{V_m}{V_m/2} = 2$$

2.2.2.1 Rectifier Efficiency (η)

The rectifier efficiency is defined as,

$$\eta = \frac{\text{D.C. output power delivered to load}}{\text{A.C. input power from transformer secondary}} = \frac{P_{D.C}}{P_{A.C}} \qquad \dots (2.2.15)$$

Substituting the value of P_{DC} from Eq. (2.2.9) and the value of P_{AC} from Eq. (2.2.14) Eq. (2.2.15), we have,

$$\eta = \frac{\left(\frac{I_m^2}{\pi^2}\right) R_L}{\left(\frac{I_m^2}{4}\right)[R_s + R_f + R_L]}$$

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

If $(R_S + R_f) << R_L$, then we get the maximum theoretical efficiency of half-wave rectifier

is,

$$\boxed{\%\eta_{max} = 0.406 \times 100\% = 40.6\%}$$

COMMENT : ***$\%\eta$ = 40.6% indicates that, under the most ideal conditions, only 40.6% of the A.C input power is converted into D.C output power in the load. The remaining exists as A.C power in the load.***

2.2.2 Ripple Factor

Ripple factor (γ) is defined by,

$$\gamma = \frac{\text{Effective (r.m.s.) value of A.C. components of waves}}{\text{Average or D.C. Component}}$$

$$\gamma = \frac{(V_r)_{rms}}{V_{DC}} = \frac{(I_r)_{rms}}{I_{DC}} \qquad \text{... (2.2.16)}$$

To calculate the ripple factor (γ), one needs to compute the rms value of AC fluctuation (ripples). Let it be represented as $(I_r)_{rms}$. The value of AC fluctuations at any instant of time is as shown in Fig. 2.2.4,

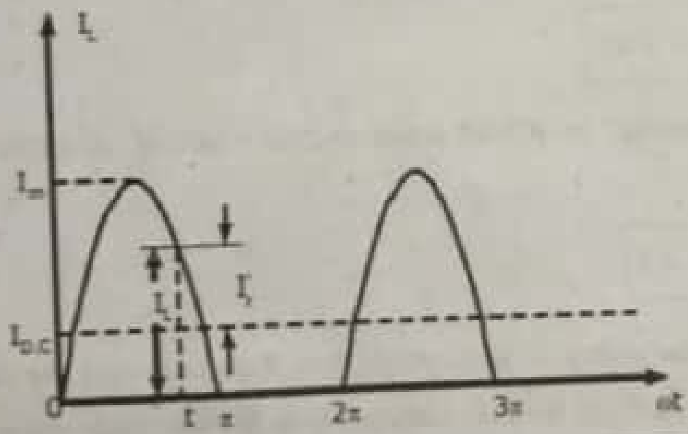


Fig. 2.2.4 Half-wave Rectified Current Wave

$$I_r = I_L - I_{DC}$$

Hence, the RMS value of the AC components is given by,

$$(I_r)_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi}(I_r)^2 d(\omega t)} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi}(I_L - I_{DC})^2 d(\omega t)}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{2\pi}(I_L^2 + I_{DC}^2 - 2I_L I_{DC}) d(\omega t)}$$

$$= \sqrt{\left(\frac{1}{2\pi}\int_0^{2\pi} I_L^2 d(\omega t)\right) + \left(\frac{1}{2\pi}\int_0^{2\pi} I_{DC}^2\, d(\omega t)\right) - \left(\frac{1}{2\pi}\int_0^{2\pi} 2I_L I_{DC} d(\omega t)\right)}$$

$$= \sqrt{I_{rms}^2 + I_{DC}^2 - 2I_{DC}\, I_{DC}}$$

$$\therefore \quad (I_r)_{rms} = \sqrt{I_{rms}^2 - I_{DC}^2} \qquad \text{... (2.2.17)}$$

Using Eq. (2.2.17) in Eq. (2.2.16), we have, Ripple factor as,

$$\gamma = \frac{\sqrt{I_{rms}^2 - I_{DC}^2}}{I_{DC}}$$

$$\therefore \quad \boxed{\gamma = \sqrt{\left(\frac{I_{rms}}{I_{DC}}\right)^2 - 1}} \qquad \text{... (2.2.18)}$$

Using I_{DC} value from Eq. (2.2.5) and I_{rms} value from Eq. (2.2.11) in Eq. (2.2.18), we have,

$$\gamma = \sqrt{\frac{(I_m / 2)^2}{(I_m / \pi)^2} - 1} = \sqrt{\frac{\pi^2}{4} - 1}$$

$$\therefore \quad \boxed{\gamma = 1.21}$$

The "ripple frequency" in a half wave rectifier circuit is same as the AC input signal frequency. That is,

$$\boxed{f_r = f}$$

COMMENT : *Ripple factor shown in percentage form indicates that the amount of A.C fluctuations present in the output is 121% of the D.C. voltage. That is rms ripple voltage exceeds the DC voltage hence poor rectification.*

2.2.2.3 Transformer Utilization Factor (TUF)

Transformer utilization factor (TUF) is defined as,

$$TUF = \frac{P_{O_{DC}}}{\text{VA rating of transformer}} \quad \text{... (2.2.19)}$$

The A.C. power rating or VA rating of transformer can be calculated with the RMS voltage developed across the winding and RMS current flowing through the winding, i.e.,

$$\therefore \quad \text{VA rating of transformer} = V_{r.m.s} \times I_{r.m.s}$$

According to principle of transformer the rated voltage of the secondary coil will be $(V_m/\sqrt{2})$ and the actual r.m.s current flowing through it will be $(I_m/2)$, that is,

$$V_{r.m.s} = \frac{V_m}{\sqrt{2}} \text{ and } I_{r.m.s} = \frac{I_m}{2}$$

Therefore, VA rating of transformer is given by,

$$\text{VA rating} = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{2} = \frac{V_m I_m}{2\sqrt{2}} \quad \text{... (2.2.20)}$$

Substituting the value of V_m from Eq. (2.2.4) in Eq. (2.2.20), we have,

$$\text{VA rating} = \frac{I_m^2 (R_L + R_f + R_S)}{2\sqrt{2}} \quad \text{... (2.2.21)}$$

Hence, using the value of P_{DC} from Eq. (2.2.10) and Eq. (2.2.21) in Eq. (2.2.19) we get the TUF as,

$$TUF = \frac{I_m^2 R_L}{\pi^2} \times \left[\frac{2\sqrt{2}}{I_m^2 (R_L + R_f + R_S)}\right] = \frac{2\sqrt{2}}{\pi^2} \times \left[\frac{1}{1 + \left(\frac{R_f + R_S}{R_L}\right)}\right]$$

$$\Rightarrow \quad TUF = 0.287 \left[\frac{1}{1 + \left(\frac{R_f + R_s}{R_L}\right)}\right]$$

If $(R_f + R_S) << R_L$, we get, TUF = 0.287

$$\therefore \quad \boxed{\%TUF = 28.7\%}$$

COMMENT : *TUF = 28.7% implies that if the transformer rating is 10 kVA (10000 VA) then the HWR can deliver 10,000 × 0.287 = 2870 watts to the load. The value of TUF should be as high as possible*

RELATIONSHIP BETWEEN η AND TUF

We can derive this relationship as follows,

$$TUF = \frac{P_{D.C}}{P_{A.C(rated)}} = \left(\frac{P_{D.C}}{P_{A.C}}\right) \times \left(\frac{P_{A.C}}{P_{A.C(rated)}}\right) = \eta \times \left(\frac{P_{A.C}}{P_{A.C(rated)}}\right) \quad \text{... (2.2.22)}$$

We have,

$$P_{A.C} = I_{rms}^2 (R_L + R_f + R_s) = \left(\frac{I_m}{2}\right)^2 (R_L + R_f + R_s)$$

and, $$P_{A.C(rated)} = \left(\frac{V_m}{\sqrt{2}}\right)\left(\frac{I_m}{2}\right) = \frac{I_m}{\sqrt{2}} (R_L + R_f + R_s)\left(\frac{I_m}{2}\right) = \frac{I_m^2}{2\sqrt{2}} (R_L + R_s + R_f)$$

$$\therefore \quad \frac{P_{A.C}}{P_{A.C(rated)}} = \frac{1}{\sqrt{2}} = 0.707 \quad \text{... (2.2.23)}$$

Using Eq. (2.2.23) in Eq. (2.2.22), we get,

$$\therefore \quad \boxed{TUF = 0.707\eta}$$

2.2.2.4 Voltage Regulation

Percentage load regulation is defined as,

$$\%\text{Regulation} = \frac{(V_{DC})_{NL} - (V_{DC})_{FL}}{(V_{DC})_{FL}} \times 100\% \quad \text{... (2.2.24)}$$

For the half-wave rectifier, the D.C load current is given by,

$$I_{D.C} = \frac{V_m}{\pi(R_S + R_f + R_L)}$$

Therefore, the D.C voltage across the load is given as,

$$\boxed{(V_{D.C})_{FL} = I_{D.C}\, R_L = \frac{V_m R_L}{\pi(R_L + R_S + R_f)}}$$

$$\Rightarrow \quad (V_{DC})_{FL} = \frac{V_m}{\pi}\left[1 - \frac{R_s + R_f}{R_f + R_s + R_L}\right] = \frac{V_m}{\pi} - \frac{V_m(R_s + R_f)}{\pi(R_s + R_f + R_L)} \quad \text{... (2.2.25)}$$

From Eq. (2.2.6), we have $I_{DC} = \dfrac{V_m}{\pi(R_S + R_f + R_L)}$,

Thus, $$(V_{DC}) = \frac{V_m}{\pi} - I_{DC}(R_s + R_f) \quad \text{... (2.2.26)}$$

Eq. (2.2.26) indicates that the half wave rectifier behaves as a constant voltage source (V_m/π) in series with an internal resistance (R_f) and secondary winding resistance (R_s). Thus Eq. (2.2.26) represents the load voltage under full load condition.

Clearly under no load condition, I_{DC} = 0 in Eq. (2.2.26).

Thus, $$(V_{DC})_{NL} = \frac{V_m}{\pi} \quad \text{... (2.2.27)}$$

Using Eq. (2.2.26) and Eq. (2.2.27) in Eq. (2.2.24), we have,

$$\%\text{Regulation} = \frac{\left[\frac{V_m}{\pi} - \frac{V_m}{\pi} + \frac{V_m(R_s + R_f)}{(R_s + R_f + R_L)\pi}\right]}{\left[\frac{V_m}{\pi} - \frac{V_m(R_s + R_f)}{\pi(R_s + R_f + R_L)}\right]}$$

$$= \frac{V_m}{\pi} \times \frac{\left[1 - \frac{R_L}{R_S + R_f + R_L}\right]}{\left[\frac{V_m}{\pi}\left(\frac{R_L}{R_S + R_f + R_L}\right)\right]} \times 100\%$$

$$= \frac{\left(\frac{R_S + R_f + R_L - R_S}{R_S + R_f + R_L}\right)}{\left(\frac{R_L}{R_S + R_f + R_L}\right)} \times 100\%$$

$$\therefore \quad \%\text{Regulation} = \frac{R_f + R_S}{R_L} \times 100\% \quad \text{... (2.2.28)}$$

The voltage regulation is also termed as load regulation. The ideal value of load regulation should be zero.

2.2.3 Peak Inverse Voltage (PIV)

It is the maximum voltage that is expected to appear across the diode when it is reverse biased. It is usually considered safer to select a diode that has reverse breakdown voltage (V_Z) at least 20% greater than the expected PIV.

For the half-wave rectifier circuit the diode D gets reverse-biased during negative half-cycle. Therefore the maximum voltage expected is V_m. Thus, for half-wave rectifier

$$\boxed{PIV = V_m} \quad \text{... (2.2.2}$$

2.2.4 Advantages of a Half-Wave Rectifier

Following are the advantages of half-wave rectifier,

(1) Only one diode is required.

(2) No centre-tap is required on the transformer.

(3) PIV is same as secondary output voltage.

2.2.5 Disadvantages of a Half-Wave Rectifier

Following are the disadvantages of half-wave rectifier,

(1) Low efficiency, only 40.6% (ideal case), less than 40.6% for practical diode.

(2) High ripple factor, 1.21(poor performance).

(3) Low transformer utilization factor LTUF, only 28%.

(4) Low D.C output voltage and current.

(5) Possibility of transformer core saturation due to unidirectional current flow.

EXAMPLE PROBLEM 1

A transformer with turns ratio 1:1 is used for isolation purpose in a half-wave rectifier using a diode with a dynamic (forward) resistance of 200 Ω. The input voltage is 220 V (r.m.s), the resistance of the secondary winding is 20 Ω, and the load resistance is 3 kΩ. Evaluate the following.

(a) I_m, $I_{D.C}$ and $I_{r.m.s}$.

(b) The PIV when the diode is ideal.

(c) The output D.C voltage.

(d) The D.C output power and A.C input power.

(e) The ripple factor.

(f) The rectification Efficiency.

(g) The transformer utilization factor.

(h) The percentage load regulation.

SOLUTION

Given Data : RMS value of supply voltage (V_1) = 220 V

Turns ratio (N_1:N_2) = 1:1

Diode forward resistance (R_f) = 200 Ω

Secondary winding resistance (R_s) = 20 Ω

Load resistance (R_L) = 3 kΩ

Voltage induced at the secondary winding is given by,

$$V_{2rms} = V_{1rms}\left(\frac{N_2}{N_1}\right) = 220\left(\frac{1}{1}\right) = 220 \text{ V}$$

Hence, the maximum value of supply Voltage is given by,

$$V_m = \sqrt{2}\, V_{2rms} \qquad \left(\because V_{rms} = \frac{V_m}{\sqrt{2}}\right)$$

$$= (\sqrt{2})(220) = 311 \text{ V}$$

(a) $$I_m = \frac{V_m}{R_L + R_f + R_S} = \frac{311 \text{ V}}{(3 + 0.2 + 0.02) \text{ k}\Omega} = 96.58 \text{ mA}$$

$$I_{DC} = \frac{I_m}{\pi} = \frac{96.58 \text{ mA}}{3.14} = 30.75 \text{ mA}$$

$$I_{rms} = \frac{I_m}{2} = \frac{96.58 \text{ mA}}{2} = 48.29 \text{ mA}$$

(b) PIV = V_m = *311 V*

(c) $V_{D.C} = I_{D.C} R_L$ = 30.75 mA × 3 kΩ = 92.25 V

(d) The D.C output power is given by,

$$P_{D.C} = I_{D.C}^2 \times R_L = (30.75 \times 10^{-3})^2 \times (3 \times 10^3)\ W = 2.83\ W$$

The input AC power is given by,

$$P_{AC} = \frac{I_m^2}{4}[R_f + R_L + R_S]$$

$$= \frac{(96.58 \times 10^{-3})^2}{4} \times [0.02 \times 10^3 + 0.2 \times 10^3 + 3 \times 10^3]$$

$$= 2.33 \times 10^{-3} \times 3.22 \times 10^3 = 7.50\ watts$$

(e) The ripple factor, γ = **1.21**

(f) The rectification efficiency,

$$\eta = \frac{P_{D.C}}{P_{A.C}} \times 100\% = \frac{2.83}{7.50} \times 100\% = 37.77\%$$

(g) Transformer utilization factor,

$$TUF = 0.287 \times \frac{1}{\left[1 + \left(\frac{R_f + R_s}{R_L}\right)\right]}$$

$$\Rightarrow \quad TUF = 0.287 \times \frac{1}{\left[1 + \left(\frac{0.2 + 0.02}{3}\right)\right]} = 0.287 \times \frac{1}{1.07}$$

$$= 0.2664$$

(h) For a given load, the D.C output voltage is given as,

$$(V_{D.C})_{FL} = \frac{V_m}{\pi} - I_{D.C}(R_S + R_f)$$

Under no-load condition, $I_{D.C}$ = 0. Therefore, the no-load D.C output voltage is given as,

$$V_{D.C(NL)} = \frac{V_m}{\pi} = \frac{311}{3.14} = 99V$$

Under full-load condition, the load resistance R_L = 3 kΩ is connected so tha the D.C. current is 30.75 mA. Thus, the full-load voltage is given as,

$$V_{D.C(FL)} = \frac{V_m}{\pi} - I_{DC}(R_s + R_f) = 99 - [30.75 \times 10^{-3}(0.2 + 0.02) \times 10^3] = 92.23$$

Therefore, the percentage load regulation is given as,

$$\frac{V_{D.C(NL)} - V_{D.C(FL)}}{V_{D.C(FL)}} \times 100\% = \frac{99 - 92.23}{92.23} \times 100 = 7.34\%$$

$p = \frac{z \pm \sqrt{z^2 - 4c_1}}{2c_1}$

2.3 FULL WAVE RECTIFIER

A full wave rectifier is an electronic circuit which remains conducting for both positive and negative cycles of an input AC voltage. There are two classes of full wave rectifier circuits,

(1) Bridge rectifier.

(2) Center tapped rectifier.

2.3.1 Center Tapped FWR

The basic circuit diagram for the FWR with center tapped transformer is shown in Fig. 2.3.1. In this circuit, two diodes D_1 and D_2 are used as the switching elements, one diode conducts for one half cycle and second diode conducts for other half cycle. The transformer used is a center tapped transformer.

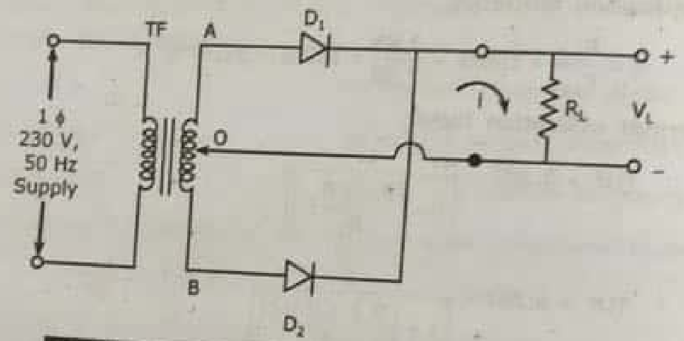


Fig. 2.3.1 FWR with Center Tapped Transformer

2.3.1.1 Working Operation

Case I (During Positive Half cycle of A.C Input ($0 \le \omega t \le \pi$) : In the positive half cycle of the input A.C supply, the polarities of secondary voltage are as shown in Fig. 2.3.2,

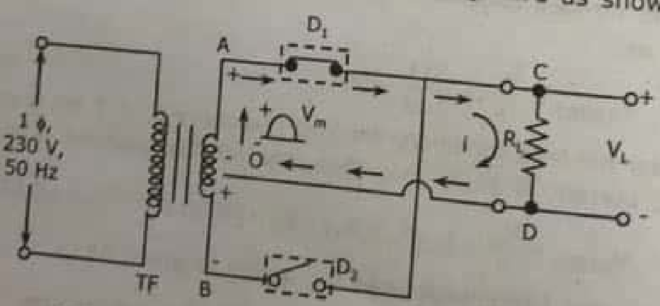


Fig. 2.3.2 FWR During Positive Half Curve

Terminal A of the secondary winding is at a higher potential than the center terminal O and the terminal B is more negative, with respect to terminal O.

This makes forward biasing for the diode D_1 and reverse biasing for the diode D_2. Therefore in this positive half cycle, D_1 conducts and D_2 remains off. Thus load current flows through the diode D_1 and voltage drop across load R_L. The path of current is shown in Fig. 2.3.2. the current in load flows from C to D.

Case II (During Negative Half cycle of A.C Input ($\pi \le \omega t \le 2\pi$) : In the negative half cycle ($\pi \le \omega t \le 2\pi$), terminal B of transformer secondary winding becomes positive to the center terminal O and A becomes negative with respect to the terminal. Therefore diode D_2 conducts for this duration due to forward bias and diode D_1 is OFF as shown in Fig. 2.3.3. Now, the load current flows through diode D_2 and load resistance R_L. Again the current in load flows from C to D.

It is to be noted here that for both half cycles of A.C supply voltage, load current flows in the same direction, therefore producing as unidirectional pulsating D.C voltage.

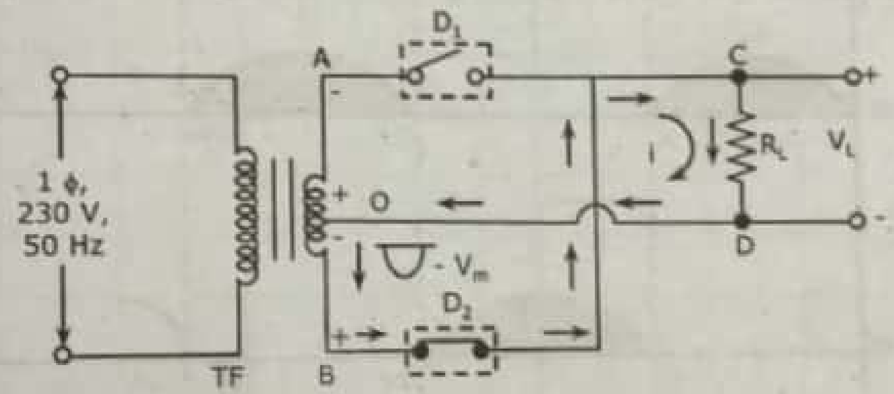


Fig. 2.3.3 FWR During Negative Half Curve

The net-effect of the both parts of the circuit operation can be mingled up now as shown in Fig. 2.3.4,

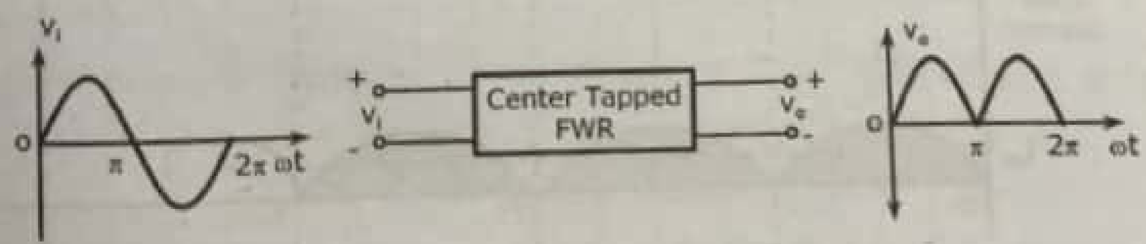


Fig. 2.3.4 FWR with Center Tapped and Input and Output Waveforms

2.3.1.2 Voltage and Current Waveforms of a FWR

Fig. 2.3.5 shows the voltage and current waveforms of a FWR.

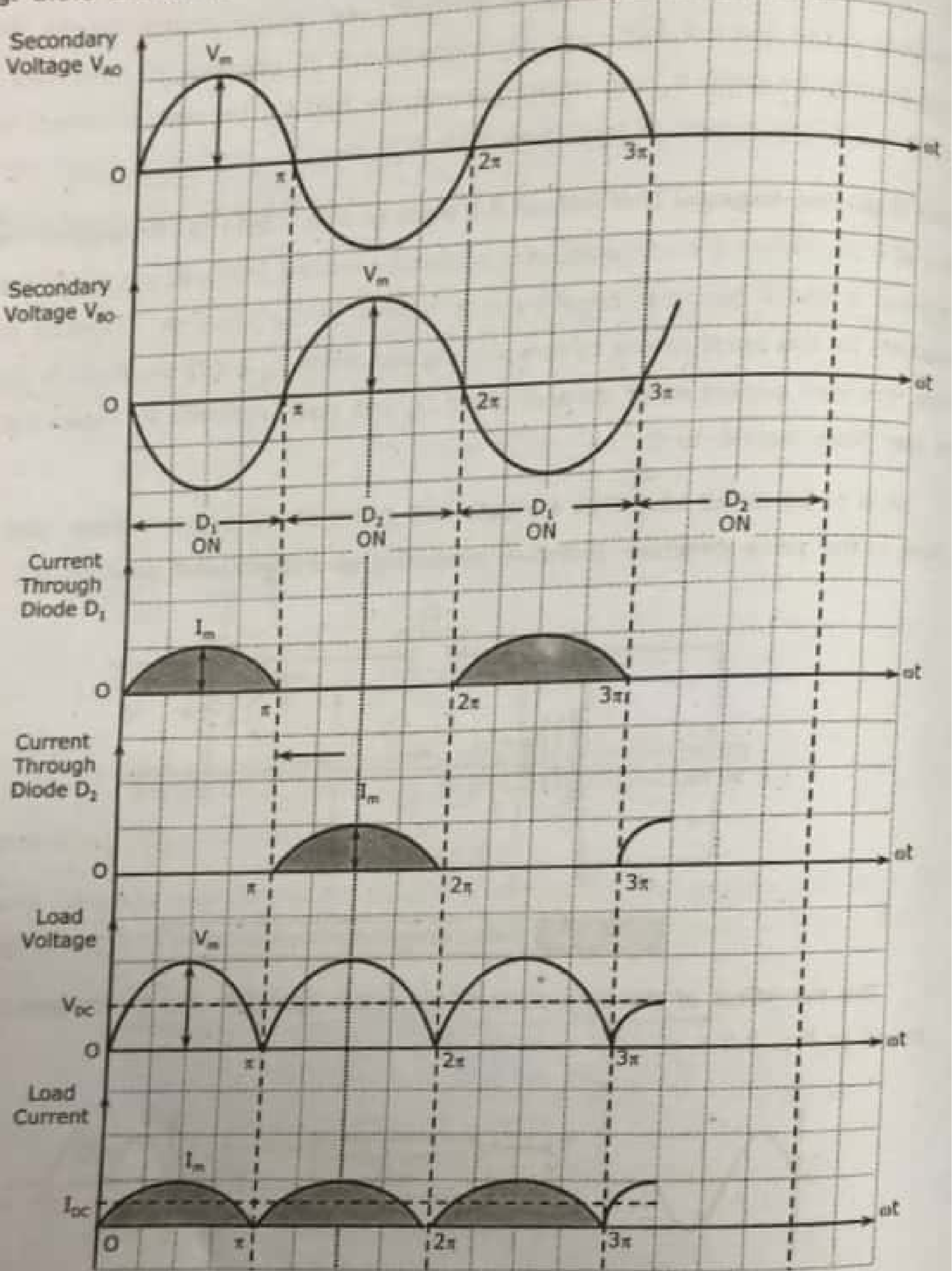


Fig. 2.3.5 Voltage and Current Waveforms for a FWR

2.3.1.3 Performance of a Center Tapped FWR

Let us assume a sinusoidal input voltage is applied to the input of FWR circuit. Thus,

$$V_{in} = V_m \sin(\omega t)$$

Neglecting the voltage drop across a diode, we have output load voltage as,

$$V_L = \begin{cases} V_m \sin\omega t & ; \text{for } 0 \le \omega t \le \pi \\ -V_m \sin\omega t & ; \text{for } \pi \le \omega t \le 2\pi \end{cases}$$

Similarly load current is defined as,

$$I_L = \begin{cases} I_m \sin\omega t & ; \text{for } 0 \le \omega t \le \pi \\ -I_m \sin\omega t & ; \text{for } \pi \le \omega t \le 2\pi \end{cases}$$

Where, I_m indicates the Peak value of the input current and is defined as,

$$I_m = \frac{V_m}{(R_L + R_f + R_S)} \quad \text{... (2.3.1)}$$

(1) **Average D.C Load Current ($I_{D.C}$) :** The average value of D.C load current is given by,

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

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

$$= \frac{I_m}{2\pi}\left[-\cos\pi + \cos 0 + \cos 2\pi + \cos\pi\right] = \frac{I_m}{2\pi}[1+1+1+1]$$

$$I_{D.C} = \frac{2I_m}{\pi} \quad \text{... (2.3.2)}$$

Substituting the value of I_m from Eq. (2.3.1) in Eq. (2.3.2), we have,

$$\therefore \quad \boxed{I_{D.C} = \frac{2}{\pi}\frac{V_m}{(R_L + R_f + R_S)}} \quad \text{... (2.3.3)}$$

(2) **Average D.C Load Voltage ($V_{D.C}$) :** The D.C output voltage (load voltage) across the load R_L is given by,

$$V_{D.C} = I_{D.C} \times R_L$$

$$\Rightarrow \quad V_{D.C} = \frac{2}{\pi}\frac{V_m}{(R_L + R_f + R_S)} \cdot R_L = \frac{2}{\pi}\frac{V_m}{(R_L + R_f + R_S)} \times R_L$$

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$p = \frac{z \pm \sqrt{z^2 - 4c_l}}{2c_l}$

$$\Rightarrow \quad V_{D.C} = \frac{2}{\pi} \frac{V_m}{1 + \left(\frac{R_f + R_S}{R_L}\right)}$$

If $(R_f + R_S) << R_L$, then the D.C output voltage,

$$\therefore \quad \boxed{V_{D.C} = 0.636\ V_m} \quad \dots (2.3.4)$$

(3) D.C Output Power : The D.C output power is given by,

$$P_{DC} = V_{DC} \times I_{DC} = I_{DC}^2 \times R_L$$

But from Eq. (2.3.2), we have $I_{DC} = \frac{2I_m}{\pi}$. Thus,

$$P_{DC} = \left(\frac{2I_m}{\pi}\right)^2 \times R_L$$

$$\therefore \quad \boxed{P_{DC} = \left(\frac{4}{\pi^2}\right) I_m^2 R_L = 0.405\ I_m^2 R_L} \quad \dots (2.3.5)$$

(4) R.M.S Output Current and Voltage

(i) The RMS value of current through the load is given by,

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

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

$$= \frac{I_m}{\sqrt{2\pi}}\left(\left[\frac{1}{2}\omega t\right]_0^{\pi} - \frac{1}{2}\left[\frac{\sin(2\omega t)}{2}\right]_0^{\pi} + \left[\frac{1}{2}\omega t\right]_{\pi}^{2\pi} - \frac{1}{2}\left[\frac{\sin(2\omega t)}{2}\right]_{\pi}^{2\pi}\right)^{1/2}$$

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

$$= \frac{I_m}{\sqrt{2\pi}}\left[\frac{\pi}{2} + \frac{\pi}{2}\right]^{1/2} \quad (\because \sin 2\pi,\ \sin\pi,\ \sin 0 = 0)$$

$$\therefore \quad \boxed{I_{rms} = \frac{I_m}{\sqrt{2}}} \quad \dots (2.3.6)$$

Using the value of I_m from Eq. (2.3.1) in Eq. (2.3.6), we get,

$$\boxed{I_{r.ms} = \frac{1}{\sqrt{2}} \frac{V_m}{(R_L + R_f + R_S)}} \quad ... (2.3.7)$$

(ii) The RMS value of output voltage across the load is given by,

$$V_{r.m.s} = I_{r.m.s} \times R_L \quad ... (2.3.8)$$

Substituting the value of $I_{r.m.s}$, from Eq. (2.3.7) in Eq. (2.3.8), we have,

$$V_{rms} = \frac{1}{\sqrt{2}} \frac{V_m}{(R_L + R_f + R_S)} \times R_L = \frac{1}{\sqrt{2}} \frac{V_m}{1 + \left(\dfrac{R_f + R_S}{R_L}\right)}$$

If, $R_f + R_S << R_L$, then the RMS output voltage,

$$\boxed{V_{r.m.s} = \frac{V_m}{\sqrt{2}}} \quad ... (2.3.9)$$

(5) **A.C Input Power :** The A.C input power is defined as,

$$P_{AC} = I_{rms}^2 [R_s + R_f + R_L]$$

But from Eq. (2.3.6), $I_{rms} = \dfrac{I_m}{\sqrt{2}}$, Thus,

$$\therefore \quad \boxed{P_{AC} = \frac{I_m^2}{2} [R_S + R_f + R_L]} \quad ... (2.3.10)$$

2.3.1.4 Rectifier Efficiency

Rectifier efficiency is defined by,

$$\% \eta = \frac{P_{D.C}}{P_{A.C}} \times 100\% \quad ... (2.3.11)$$

Using P_{DC} from Eq. (2.3.5) and P_{AC} from Eq. (2.3.10) in Eq. (2.3.11), we get,

$$\% \eta = \frac{(4 I_m^2 / \pi^2) R_L}{(I_m^2 / 2)(R_L + R_f + R_S)} \times 100\%$$

$$\Rightarrow \quad \% \eta = \left(\frac{4 I_m^2}{\pi^2}\right) \times \left(\frac{2}{I_m^2}\right) \times \left(\frac{R_L}{R_L + R_f + R_S}\right) \times 100\%$$

$$\Rightarrow \quad \% \eta = \frac{8}{\pi^2} \times \frac{1}{1 + \left(\dfrac{R_f + R_S}{R_L}\right)} \times 100\%$$

$$\%\eta = 81.2 \times \frac{1}{1 + \left(\frac{R_f + R_S}{R_L}\right)} \quad \dots (2.3.12)$$

∴

If we assume $(R_f + R_S) << R_L$ then the Eq. (2.3.12) reduces to,

$$\boxed{\%\eta_{max} \approx 81.2\%}$$

COMMENT : *η = 81.2% indicates that under the ideal conditions, 81.2% of the A.C input power is converted into DC output power in the load.*

2.3.1.5 Ripple Factor

Ripple factor (γ) is defined by,

$$\gamma = \sqrt{\left(\frac{I_{r.m.s}}{I_{D.C}}\right)^2 - 1} \quad \dots (2.3.13)$$

Substituting the values of $I_{D.C}$ AND $I_{r.m.s}$ in Eq. (2.3.13), we get,

$$\gamma = \sqrt{\left(\frac{\frac{I_m}{\sqrt{2}}}{\frac{2\,I_m}{\pi}}\right)^2 - 1} = \sqrt{\frac{\pi^2}{8} - 1} = \underline{0.482}$$

The ripple frequency of the output of the full wave rectifier is twice that is input AC signal frequencies, that is,

$$\boxed{f_r = 2f}$$

COMMENT : *Ripple factor shown in percentage form indicates that amount of AC fluctuations (ripples) present is 48.2% of DC voltage, which is less when compared with HWR, hence better rectification.*

2.3.1.6 Transformer Utilization Factor (TUF)

For the center tapped FWR circuit, the average TUF is given by,

$$\boxed{TUF = \frac{TUF_S + TUF_P}{2}} \quad \dots (2.3.14)$$

Let us first consider the secondary winding and determine TUF_s. The rated r.m.s voltage of half-winding of the secondary is $V_m / \sqrt{2}$. Therefore, for full secondary winding, the rated r.m.s voltage will be $2V_m / \sqrt{2}$. Each half of the secondary winding carries current only for half-cycle. Therefore, the actual r.m.s current flowing through each half of the secondary is $I_m/2$, as in a half-wave rectifier.

Hence,
$$TUF_s = \frac{P_{D.C}}{P_{A.C(rated)}} = \frac{I_{D.C}^2 R_L}{\left(\frac{2V_m}{\sqrt{2}}\right)\left(\frac{I_m}{2}\right)} \quad \text{... (2.3.15)}$$

But from Eq. (2.3.2) and Eq. (2.3.1), we have,

$$I_{D.C} = 2I_m/\pi \text{ and } V_m = I_m(R_L + R_f + R_s).$$

Substituting the above values in Eq. (2.3.15),

We have,
$$TUF_s = \frac{\left(\frac{2I_m}{\pi}\right)^2 R_L}{\left[\frac{2I_m(R_L + R_f + R_s)}{\sqrt{2}}\right]\left[\frac{I_m}{2}\right]}$$

$$\Rightarrow \quad TUF_S = \frac{4I_m^2 R_L}{\pi^2} \times \frac{2\sqrt{2}}{2I_m^2(R_L + R_f + R_s)}$$

$$\therefore \quad TUF_S = = \frac{4\sqrt{2}}{\pi^2} \times \frac{R_L}{R_L + R_F + R_s} = 0.573\frac{R_L}{R_L + R_f + R_s} \quad \text{... (2.3.16)}$$

Next, we find the TUF_p considering the primary winding. Assuming the turns ratio as 1 : 1, the rated r.m.s voltage for the primary winding would be $V_m / \sqrt{2}$.

Since the current flows for full cycle in the primary, the rated r.m.s current is $I_m / \sqrt{2}$.

Hence,

$$TUF_p = \frac{P_{D.C}}{P_{A.C(rated)}} = \frac{I_{D.C}^2 R_L}{\left(\frac{V_m}{\sqrt{2}}\right)\left(\frac{I_m}{\sqrt{2}}\right)} \quad \text{... (2.3.17)}$$

$$TUF_p = \frac{\left(\frac{2I_m}{\pi}\right)^2 R_L}{\left[\frac{I_m(R_f + R_L + R_s)}{\sqrt{2}}\right]\left[\frac{I_m}{\sqrt{2}}\right]} (\because I_{DC} = 2I_m/\pi \text{ and } V_m = I_m(R_f + R_L + R_S)$$

$$\Rightarrow \quad TUF_P = \frac{4I_m^2 R_L}{\pi^2} \times \frac{2}{I_m^2(R_f + R_L + R_s)}$$

$$\Rightarrow \quad TUF_P = \frac{8}{\pi^2} \times \frac{R_L}{R_f + R_L + R_s} = 0.810 \times \frac{R_L}{R_f + R_L + R_s} \quad \text{... (2.3.18)}$$

Substituting Eq. (2.3.16) and Eq. (2.3.18) in Eq. (2.3.14), we have,

$$TUF = \frac{TUF_s + TUF_p}{2} = \frac{0.573 + 0.811}{2} \times \frac{R_L}{R_f + R_L + R_s}$$

$$\Rightarrow \quad TUF = 0.692 \times \frac{R_L}{R_f + R_L + R_s}$$

$$\therefore \quad \boxed{TUF = 0.692 \times \frac{1}{\left[1 + \frac{R_f + R_s}{R_L}\right]}} \quad \ldots (2.3.19)$$

If $R_f + R_S << R_L$, then we get TUF = 0.692

$$\therefore \quad \boxed{\% \, TUF_{max} = 69.2\%}$$

2.3.1.7 Voltage Regulation

Percentage load regulation is defined as,

$$\% \text{ regulation} = \frac{(V_{DC})_{NL} - (V_{DC})_{FL}}{(V_{DC})_{FL}} \times 100\% \quad \ldots (2.3.20)$$

For a full wave rectifier circuit,

$$(V_{DC})_{NL} = \frac{2V_m}{\pi} = \frac{2I_m}{\pi}(R_L + R_f + R_S)$$

$$(V_{DC})_{FL} = I_{DC} R_L = \frac{2I_m}{\pi} R_L$$

$$\therefore \quad \% \text{regulation} = \frac{\frac{2I_m}{\pi}[R_L + R_f + R_S] - \frac{2I_m}{\pi} R_L}{\frac{2I_m}{\pi} R_L} \times 100\%$$

$$= \frac{R_S + R_f + R_L - R_L}{R_L} \times 100\% = \frac{R_S + R_f}{R_L} \times 100\%$$

$$\therefore \quad \boxed{\% \text{Voltage regulation} = \frac{R_S + R_f}{R_L} \times 100\%} \quad \ldots (2.3.21)$$

Neglecting secondary winding resistance R_S, we can express % voltage regulation as,

$$\% \text{Voltage regulation} = \frac{R_f}{R_L} \times 100\%$$

2.3.1.8 Peak Inverse Voltage

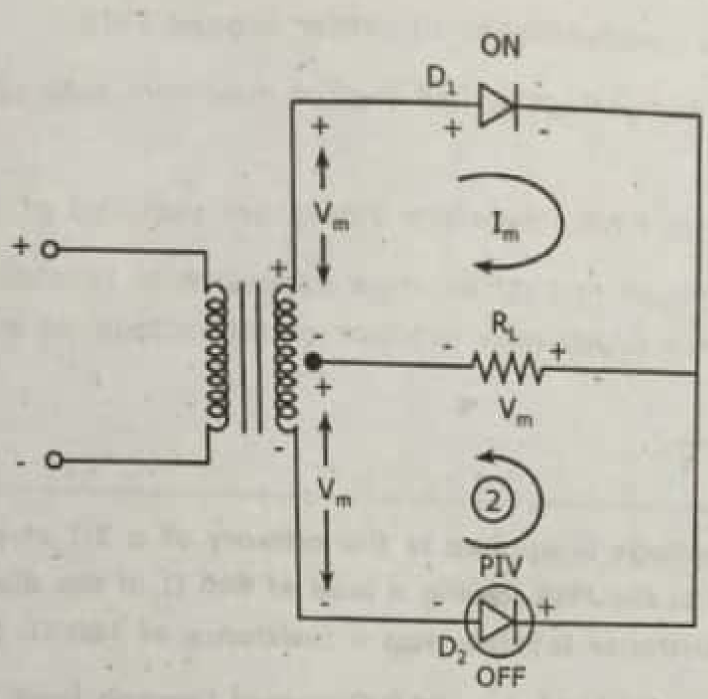


Fig. 2.3.6 Calculation of PIV

PIV for center tapped full wave rectifier circuit can be calculated using the circuit of Fig. 2.3.6. For the positive half cycle of secondary winding voltage diode D_2 gets reverse biased, while diode D_1 conducts. Since diode D_1 conducts, hence current through load R_L drops a voltage V_m across it.

Now applying the KVL in loop (2), we have,

$$V_m + V_m - PIV = 0$$

$$\therefore \quad \boxed{PIV = 2V_m} \qquad \text{... (2.3.22)}$$

2.3.1.9 Advantages of Center Tapped FWR

Following are the advantages of center tapped FWR,

(1) Compared to half-wave rectifier, the output D.C voltage and current are doubled in case of center tapped full wave rectifier.

(2) Ripple factor gets reduced.

(3) No possibility of transformer core saturation.

(4) Better transformer utilization factor.

$\therefore p = \left[\frac{z \pm \sqrt{z^2 - 4c_i^2}}{2c_i} \right]$ — (3)

$p = \frac{z \pm \sqrt{z^2 - 4c_i^2}}{2c_i}$

2.3.1.10 Disadvantages of Center Tapped FWR

Following are the disadvantages of center tapped FWR,

(1) The output maximum voltage is half that of maximum induced voltage at secondary winding.

(2) PIV is twice that of HWR, therefore diodes are required of higher rating.

(3) It is practically difficult and rather more expensive to construct an accurate centre tapped transformer which may produce equal voltage on each of the secondary winding.

EXAMPLE PROBLEM 1

A 230 V, 60 Hz voltage is applied to the primary of a 5:1 step down center tapped transformer used in the FWR having a load of 900 Ω. If the diode resistance and the secondary coil resistance together has a resistance of 100 Ω. Determine.

(a) D.C voltage across load. **(b) D.C current through load.**

(c) TUF. **(d) Ripple factor.**

(e) Rectifier efficiency. **(f) Voltage regulation**

SOLUTION

Given Data : rms value of primary winding ($V_{p,\,rms}$) = 230 V

Turns ratio (N_1:N_2) = 5:1

Load resistance (R_L) = 900 Ω

Winding pulse dynamic resistance ($R_S + R_f$) = 100

Voltage induced on the secondary side of transformer is given by,

$$V_{s(rms)} = V_{p(rms)}\left(\frac{N_2}{N_1}\right) = 230\left(\frac{1}{5}\right) = 46 \text{ V}$$

Voltage across the half of the secondary winding is thus,

$$V_{s1(rms)} = V_{s2(rms)} = \frac{V_{s(rms)}}{2} = \frac{46}{2} = 23 \text{ V}$$

The peak value of secondary winding voltage given to rectifier circuit is,

$$V_m = \sqrt{2}\,V_{s1(rms)} = 1.414 \times 23 = 32.52 \text{ V}$$

The peak value of current is given by,

$$I_m = \frac{V_m}{R_S + R_f + R_L} = \frac{32.52}{100 + 900} = 32.52 \text{ mA}$$

(a) D.C Current

$$I_{D.C} = \frac{2I_m}{\pi} = \frac{2 \times 32.52 \times 10^{-3}}{3.14} = 20.72\ mA$$

(b) D.C Voltage

$$V_{D.C} = I_{D.C} \times R_L = 20.72\ mA \times 900\ \Omega = 18.65\ V$$

(c) Transformer Utilization Factor

$$TUF = 0.692 \times \frac{1}{\left[1 + \frac{R_S + R_f}{R_L}\right]}$$

$$\Rightarrow \quad TUF = 0.692 \times \frac{1}{\left[1 + \frac{100}{900}\right]} = 0.692\left(\frac{900}{1000}\right)$$

$$\Rightarrow \quad TUF = 0.6228$$

$$\therefore \quad \%TUF = 62.28\%$$

(d) Ripple Factor

$$\gamma = 0.482$$

(e) Rectifier Efficiency

$$\%\eta = 81.2 \times \left(\frac{R_L}{R_L + R_S + R_f}\right)$$

$$= 81.2 \times \left(\frac{900}{900 + 100}\right) = 81.2\left(\frac{900}{1000}\right) = 73.08\%$$

(f) Voltage Regulation

$$\%Regulation = \frac{R_S + R_f}{R_L} \times 100\% = \frac{100}{900} \times 100\% = 11.11\%$$

2.3.2 Full Wave Bridge Rectifier

The main disadvantage of the center-tapped full wave rectifier is the need of high PIV rating diode. This problem can be overcome simply by using a bridge of four diodes as shown in Fig. 2.3.7.

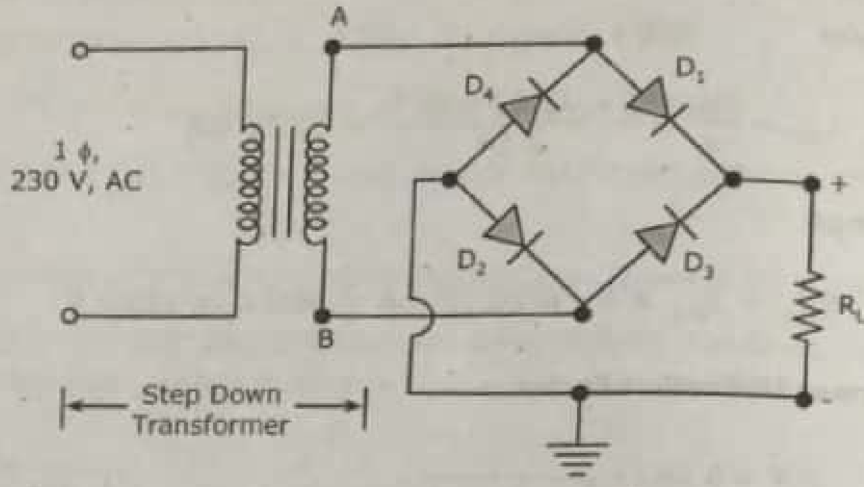
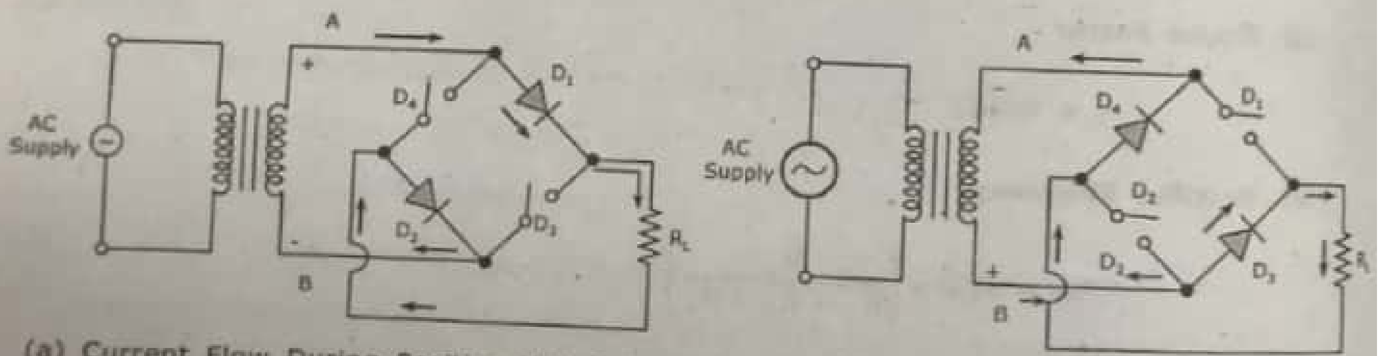


Fig. 2.3.7 A Bridge Rectifier Circuit

Transformer used is a simple step down transformer, here the four diodes D_1, D_2, D_3 and D_4 are connected in such a manner that they form a bridge. Here the two diodes, either D_1 and D_2 or D_3 and D_4 conduct at a time, thus we get the full wave rectification.

2.3.2.1 Working Operation

The working operation of the circuit can be understood with the help of Fig. 2.3.8(a) and Fig. 2.3.8(b).



(a) Current Flow During Positive Half Cycle (b) Current Flow During Negative Half Cycle

Fig. 2.3.8 Fullwave Bridge Rectifier

Case I (During Positive Half Cycle) : During positive half cycle (i.e., $0 \le \omega t \le \pi$) of the supply voltage, the terminal A is at higher potential than terminal B, thus providing the forward biasing to diodes D_1 and D_2, whereas D_3 and D_4 are reverse biased as shown in Fig. 2.3.8(a).

Case II (During Negative Half Cycle) : During negative half cycle (i.e., $\pi \le \omega t \le 2\pi$) of the supply voltage, the terminal B becomes more positive than terminal A, therefore, it forward biases the diode D_3, D_4 and reverse biases D_1 and D_2 as shown in Fig. 2.3.8(b). In both the cases of the current through load (R_L) is in the same direction. Hence, a fluctuating unidirectional voltage is developed across the load (R_L).

2.3.2.2 Voltage and Current Waveforms

Fig. 2.3.9 shows voltage and current waveforms of Bridge FWR.

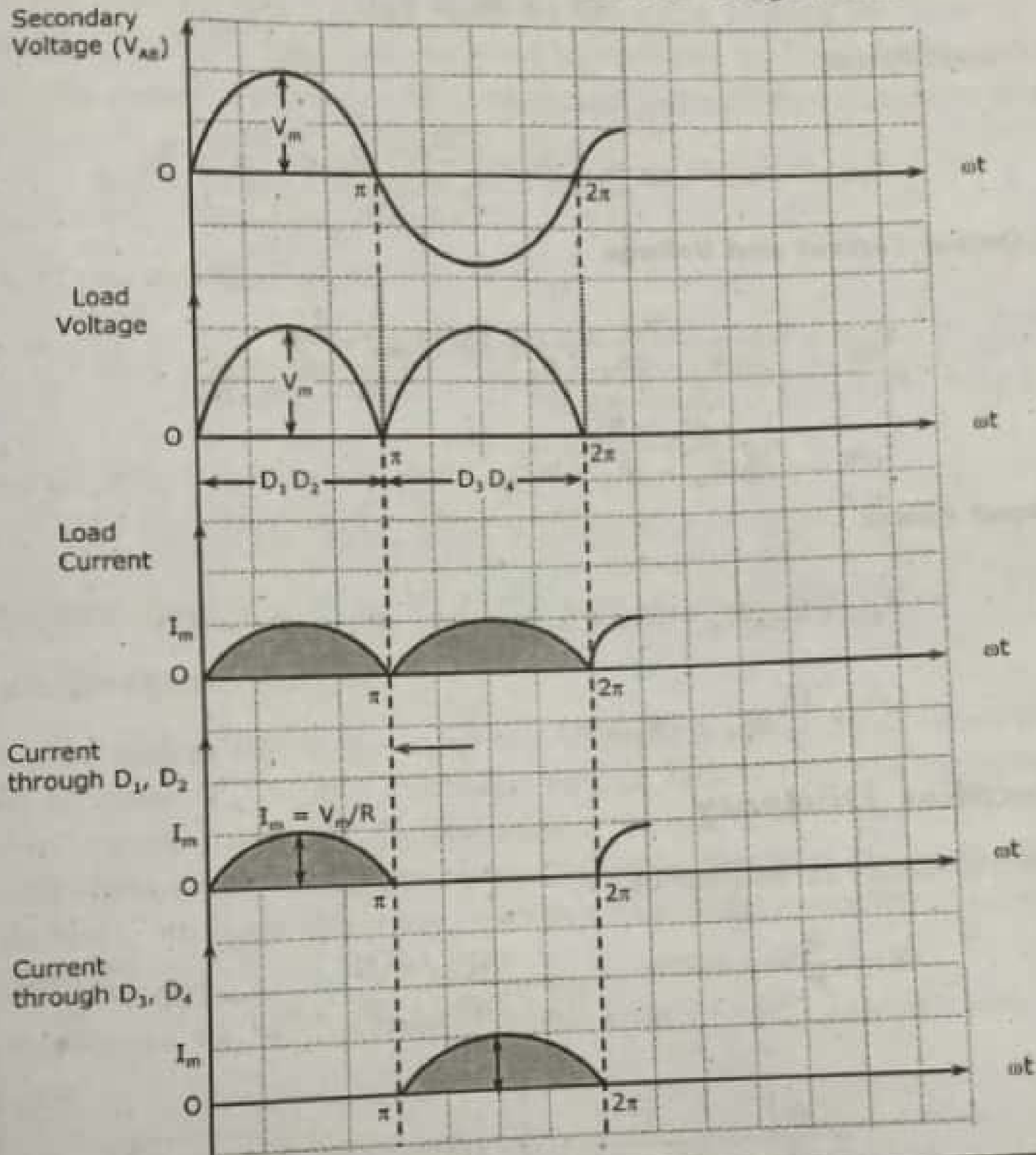


Fig. 2.3.9 Input and Output Waveforms of Bridge Full Wave Rectifier

2.3.2.3 Performance of Full Wave Bridge Rectifier

The analysis for performance parameters of the bridge rectifier is same as the wave rectifier with center tapped transformer discussed. But in case of bridge recti two diodes conduct at a time, thus we take $2R_f$ instead of R_f. Thus the total resista offered is given by,

$$\text{Total resistance} = R_S + 2R_f + R_L$$

(1) Average DC Load Current

$$I_{DC} = \frac{2V_m}{\pi(R_s + 2R_f + R_L)} \text{ (or) } I_{DC} = \frac{2I_m}{\pi}$$

(2) Average D.C Load Voltage

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

(3) D.C Output Power

$$P_{DC} = V_{DC} \times I_{DC} = I_{DC}^2 R_L = \left(\frac{2I_m}{\pi}\right)^2 R_L = \left(\frac{4I_m}{\pi^2}\right)^2 R_L$$

(4) RMS Output Current and Voltage

$$I_{rms} = \frac{V_m}{\sqrt{2}(R_s + 2R_f + R_L)} \text{ (or) } I_{rms} = \frac{I_m}{\sqrt{2}}$$

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

(5) A.C Input Power

$$P_{AC} = I_{rms}^2[R_s + 2R_f + R_L] = \left(\frac{I_m}{\sqrt{2}}\right)^2 (R_s + 2R_f + R_L)$$

$$\therefore \quad P_{AC} = \frac{I_m^2}{2}(R_s + 2R_f + R)$$

2.3.2.4 Rectifier Efficiency

Rectifier efficiency is defined by,

$$\%\eta = \frac{P_{D.C}}{P_{A.C}} \times 100\% = \frac{(4I_m^2/\pi^2)R_L}{(I_m^2/2)(R_S + 2R_f + R_L)} \times 100$$

$$= \frac{8}{\pi^2}\left[\frac{1}{1 + \left(\frac{R_S + 2R_f}{R_L}\right)}\right] \times 100\% = 81.2\left[\frac{1}{1 + \left(\frac{R_S + 2R_f}{R_L}\right)}\right] \times 100\%$$

If $R_s + 2R_f << R_L$, then we have $\%\eta_{max} = 81.2\%$

2.3.2.5 Ripple Factor

Ripple factor is defined by,

$$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{DC}}\right)^2 - 1} = \sqrt{\left(\frac{I_m/\sqrt{2}}{2I_m/\pi}\right)^2 - 1} = \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1}$$

$$\therefore \quad \boxed{\gamma = 0.482}$$

2.3.2.6 Transformer Utilization Factor (TUF)

In bridge FWR circuit, the current flows for full cycle in both the primary and the secondary windings. Thus to find TUF, we need to consider only one winding. The rated rms voltage of the secondary is $V_m/\sqrt{2}$. The actual and rated rms current is $I_m/\sqrt{2}$.

Hence, $$TUF = \frac{P_{DC}}{P_{A.C(rated)}} = \frac{I_{DC}^2 R_L}{(V_m/\sqrt{2})(I_m/\sqrt{2})}$$

But $I_{DC} = 2I_m/\pi$, and $V_m = I_m(R_s + R_L + 2R_f)$.

$$\Rightarrow \quad TUF_p = \frac{(2I_m/\pi)^2 R_L}{[I_m(R_L + 2R_f + R_S)/\sqrt{2}][I_m/\sqrt{2}]} = \frac{8}{\pi^2}\left[\frac{R_L}{R_L + 2R_f + R_S}\right]$$

$$\Rightarrow \quad TUF_p = 0.811 \times \frac{1}{\left(1 + \frac{R_s + 2R_f}{R_L}\right)}$$

Under the best conditions (i.e., no diodes loss, $R_f = 0$), the TUF is 0.811.

2.3.2.7 Peak Inverse Voltage

As mentioned earlier, PIV is the maximum voltage across a diode when it is reverse biased. Let us consider 'V_m' be the maximum voltage attained by the secondary winding of a transformer. Hence diodes D_1, D_2 are conducting and have almost zero voltage drop across them. Whereas diodes D_3, D_4 are non-conducting. Applying KVL in the loop marked by the dashed lines, we have the entire voltage of secondary winding (V_m) is developed across the load (R_L).

The same voltage i.e., V_m developed across each of the non-conducting diodes D_2, D_4.

Thus, $$\boxed{PIV = V_m}$$

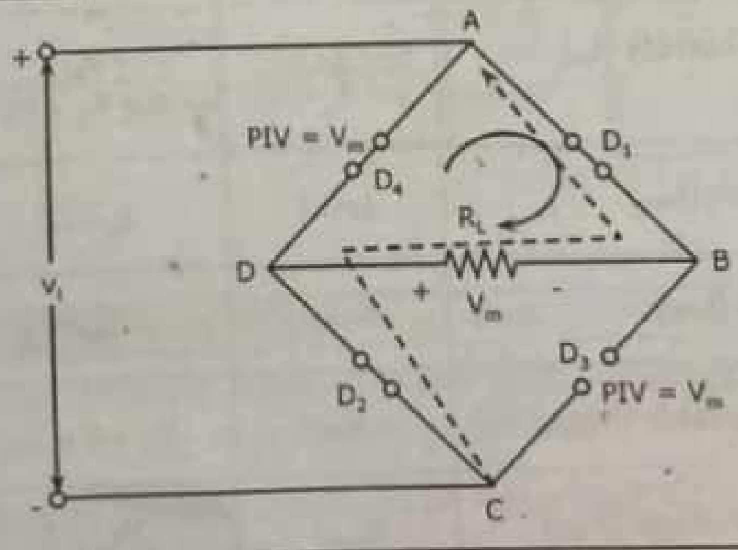


Fig. 2.3.10 PIV Determination of the Diode in Bridged FWR

2.3.2.8 Why Bridge Rectifier is Preferred

The bridge rectifier is the most widely used rectifier circuit as it has many advantages over the centre-tap rectifier circuit. They are,

(1) It does not require a centre-tap transformer. Moreover, stepping down or stepping up of voltage is not needed, then we may not use any transformer.

(2) The PIV of each diode in a bridge rectifier is only V_m, whereas it is $2V_m$ for the diodes in a centre-tap rectifier. This plays a key role when higher D.C voltages are required. The higher the PIV, the costlier the diode.

(3) For the same D.C output voltage, the transformer needed in a bridge rectifier is comparatively less expensive. For a bridge rectifier, the transformer secondary voltage required is only V_m. But for a centre-tap rectifier, transformer secondary voltage is $2V_m$ (for the two sections). Hence, the transformer in the center tap needs to have twice the number of turns in the secondary, compared to the transformer in a bridge rectifier.

Table 2.3.1 lists the comparison between various rectifier circuits.

Table 2.3.1 Comparison of HWR and FWR

S.No.	Parameter	HWR	FWR	
			Centre-tap FWR	Bridge Rectifier
(1)	No. of diodes	1	2	4
(2)	Transformer necessity	No	Yes	No
(3)	PIV	V_m	$2\ V_m$	V_m
(4)	Peak load current (I_m)	$\frac{V_m}{r_f + R_L + R_S}$	$\frac{V_m}{r_f + R_L + R_S}$	$\frac{V_m}{2\ r_f + R_L + R_S}$
(5)	RMS current (I_{rms})	Im/2	$I_m / \sqrt{2}$	$I_m / \sqrt{2}$
(6)	DC current (I_{DC})	I_m / π	$2I_m / \pi$	$2I_m / \pi$
(7)	Secondary peak voltage (V_m)	V_m	$V_m - 0 - V_m$	V_m
(8)	DC output voltage (V_{DC})	V_m / π	$2V_m / \pi$	$2V_m / \pi$

(9)	Maximum efficiency	40.6%	81.2%	81.2%
(10)	Ripple factor	1.21	0.48	0.48
(11)	Form factor	1.57	1.11	1.11
(12)	Peak factor	2	$\sqrt{2}$	$\sqrt{2}$
(13)	TUF	0.286	0.693	0.812
(14)	Ripple frequency	f_{in}	$2f_{in}$	$2f_{in}$
(15)	Voltage regulation	Good	Better	Good

2.4 HALFWAVE AND FULL WAVE RECTIFIERS WITH FILTERS

WHY WE NEED FILTER CIRCUITS?

We have seen that the output of any rectifier circuit is not purely D.C. i.e., pulsating in nature (it has both D.C value and some A.C variations known as ripples). The ripples are unwanted A.C signals which is not removed before applying to the load produces distortions in the form of hum (noise) so in order to get a smooth D.C output for perfectly operating to any electronic circuit we require an extra circuit between rectifier output and load. Thus we can say that *filters are the devices which convert pulsating D.C output of a rectifier to steady D.C level*. Fig 2.4.1 shows the block diagram representation of filter.

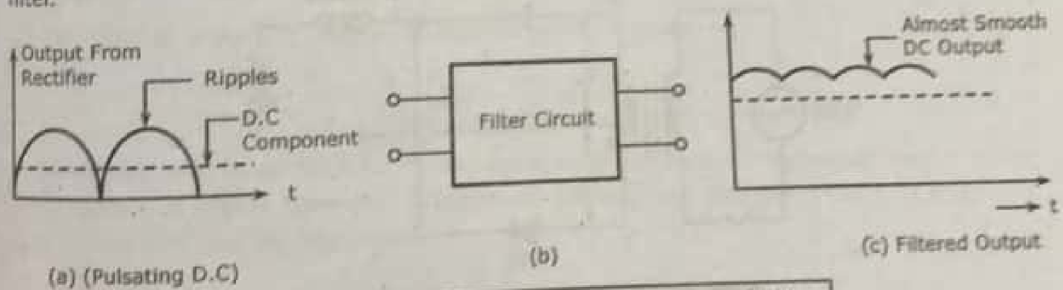


Fig. 2.4.1 Block Diagram Representation of Filter

Before discussing the different types of filters it is very important to know about the main components used in the filter circuit i.e., inductor and capacitor.

Usually all filter circuits employ inductors or capacitors or both as bias frequency selective components.

2.4.1 Rectifiers with Inductor Filter

'L' connected in series with load R_L.

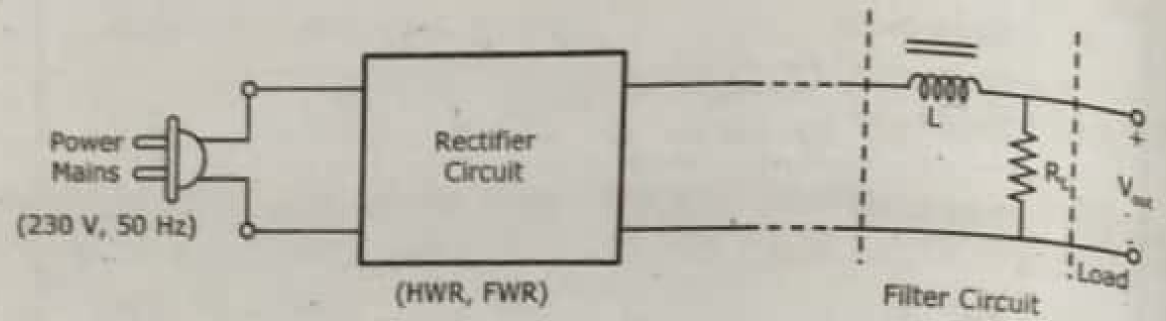


Fig. 2.4.2 Block Diagram of Inductor Filters with Rectifier Circuits

PRINCIPLE OF THE INDUCTOR FILTER

Whenever the current through an inductor tends to change, a back e.m.f is induced. This back e.m.f prevents the current flow from changing. A series inductor filter utilizes this property. The AC reactance of the series inductor (or choke) in Fig. 2.4.2 is given as $X_L = 2\pi f_L$. For DC components ($f = 0$, so $X_L = 2\pi(0)L = 0$), also the choke resistance R is very small and hence very less opposition offered to DC components. While for AC components, the series combination of R_L and X_C offers high opposition (i.e., open circuit). Thus ripples (AC components) gets blocked and only DC components flow through R_L.

2.4.1.1 Construction

Fig. 2.4.3 shows the circuit diagram of center tapped full-wave rectifier with a high value inductor or choke connected in series with a load resistor R_L.

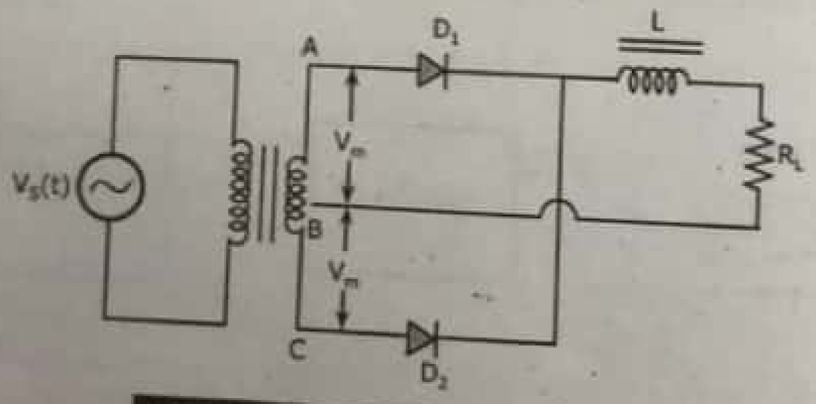


Fig. 2.4.3 FWR with Inductor Filter

2.4.1.2 Working Operation

The filtering action of a series inductor filter depends on its property of opposing any sudden change in the current flowing through it.

The working operation of FWR with inductor filter is explained as follows,

(1) When the output current of the rectifier increases above an average value, then the inductor starts storing the energy in the form of magnetic field.

(2) When the output current of the rectifier decreases below the average value, then the stored magnetic energy prevents the current falling to zero or minimum value.

Thus by using an inductor filter in series with rectifier removes ripples (sudden AC changes) to a large extent.

Fig. 2.4.4 shows the rectified output voltage with and without filter,

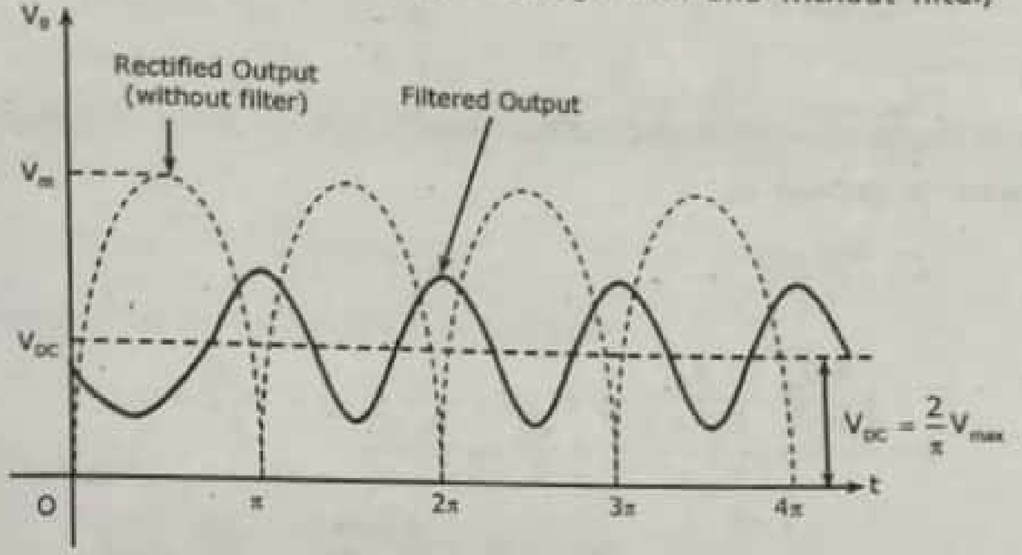


Fig. 2.4.4 Effect of Inductor Filter on Full-wave Rectified Output

2.4.1.3 Expression for a Ripple Factor With Inductor Filter

The series inductor filter is used only with FWRs, as inductor needs continuous current for its operation, which is possible with FWRs.

The rectifier output in terms of Fourier series is given by,

$$V_o = V_m \left[\frac{2}{\pi} - \frac{4}{3\pi}\cos 2\omega t - \frac{4}{15\pi}\cos 4\omega t - \ldots\right] \qquad \ldots (2.4.1)$$

Since, the reactance of inductor increases with increase in frequency hence better filtering action of higher harmonic components takes place. So, the effects of third and higher harmonics can be neglected.

$$\therefore \quad V_o = V_m \left[\frac{2}{\pi} - \frac{4}{3\pi}\cos 2\omega t\right] = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi}\cos 2\omega t \qquad \ldots (2.4.2)$$

Where, $\frac{2V_m}{\pi}$ represents the D.C component,

That is, $$V_{DC} = \frac{2V_m}{\pi} \qquad \ldots (2.4.3)$$

$\therefore p = \left[\frac{z \pm \sqrt{z^2 - 4c_1^2}}{2c_1} \right]$

$p = \frac{z \pm \sqrt{z^2 - 4c_1^2}}{2c_1}$

The AC voltage partly drop across inductor L and partly over load at resistor R_L. As inductor (choke) and R_L are in series, the maximum voltage drop across R_L due to second harmonic $\left(\frac{4V_m}{3\pi}\right)$ is given by,

$$V_{AC,\,max} = \frac{4V_m}{3\pi} \frac{R_L}{\sqrt{R_L^2 + X_L^2}} \quad \text{... (2.4.4)}$$

RMS value of AC component across load R_L is given by,

$$V_{AC,\,RMS} = \frac{V_{AC,\,max}}{\sqrt{2}}$$

$$\therefore \quad V_{AC\,RMS} = \frac{4V_m}{3\pi\sqrt{2}} \frac{R_L}{\sqrt{R_L^2 + X_L^2}} \quad \text{... (2.4.5)}$$

Ripple factor is defined by,

$$\gamma = \frac{V_{AC\,RMS}}{V_{DC}}$$

$$\Rightarrow \quad \gamma = \frac{\left(\frac{4\,V_m}{3\pi\sqrt{2}} \frac{R_L}{\sqrt{R_L^2 + X_L^2}}\right)}{\left(\frac{2\,V_m}{\pi}\right)} = \frac{\sqrt{2}}{3} \frac{R_L}{\sqrt{R_L^2 + X_L^2}}$$

$$\Rightarrow \quad \gamma = \frac{\sqrt{2}}{3} \frac{1}{\sqrt{1 + \frac{X_L^2}{R_L^2}}} \quad \text{... (2.4.6)}$$

If $X_L >> R_L$, we get, $\gamma = \frac{\sqrt{2}}{3} \frac{R_L}{X_L}$ ... (2.4.7)

But, $X_L = 2\pi f_r L = 4\pi f L$ ($\because f_r$ (ripple frequency) = 2f for FWR)

$$\gamma = \frac{\sqrt{2}}{3} \frac{R_L}{4\pi f L}$$

$$\therefore \quad \boxed{\gamma = \frac{R_L}{6\sqrt{2}\,\pi f L} = \frac{R_L}{3\sqrt{2}\,\omega L}} \quad \text{... (2.4.8)}$$

If R_L is very high, i.e., $R_L >> X_L$, then $\frac{X_L^2}{R_L^2}$ can be neglected.

$$\therefore \quad \gamma = \frac{\sqrt{2}}{3} = 0.4714$$

COMMENT : ***Since the filtering action of series inductor filter depends on the current flowing through it. Hence, it will not work with half-wave rectifiers, where no current flows for half of its period.***

EXAMPLE PROBLEM 1

A full wave rectifier with a load resistance of 15 kΩ uses an inductor filter of 15 henry. The peak value of the applied voltage is 250 V and the frequency is 50 cycles/second. Calculate the D.C load current, ripple factor and D.C output voltage.

SOLUTION

Given Data : Peak value of secondary voltage (V_m) = 250 V

Load resistance (R_L) = 15 kΩ

Inductor (L) = 15 henry

Frequency (f) = 50 Hz

The rectified output voltage of FWR rectifier across load resistance R_L upto second harmonic is,

$$V = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi}\cos(2\omega t)$$

D.C component of output voltage is given by,

$$V_{D.C} = \frac{2V_m}{\pi} = \frac{2 \times 250}{3.14} = 159.23 \text{ V}$$

D.C load current,

$$I_{DC} = \frac{V_{DC}}{R_L} = \frac{159.23}{15 \times 10^3} = 10.61 \text{ mA}$$

Ripple factor,

$$\gamma = \frac{\sqrt{2}}{3}\left(\frac{R_L}{\sqrt{R_L^2 + X_L^2}}\right)$$

$$= \frac{\sqrt{2}}{3}\left(\frac{R_L}{\sqrt{R_L^2 + (2\omega L)^2}}\right) = \frac{\sqrt{2}}{3}\left(\frac{15 \times 10^3}{\sqrt{(15 \times 10^3)^2 + (2 \times 3.14 \times 50 \times 15)^2}}\right)$$

$$= \frac{\sqrt{2}}{3}\left(\frac{15 \times 10^3}{15722}\right) = \frac{\sqrt{2}}{3} \times 0.954 = 0.45$$

2.4.1.4 Disadvantages

Following are the disadvantages of Halfwave and Fullwave rectifier with filters,

(1) The output voltage at the load is slightly reduced because of the drop in the resistance of the inductor.

(2) The inductor is more bulky and larger in size, hence occupies more space and increases the weight of the filter circuits.

(3) Since it requires current to flow through it all the times for the operation, it cannot be used in half wave rectifier.

$p = \frac{z \pm \sqrt{z^2 - 4c_1^2}}{2c_1}$

2.4.2 Rectifiers with Capacitor Filter

Fig. 2.4.5 shows the block schematic of capacitor filter.

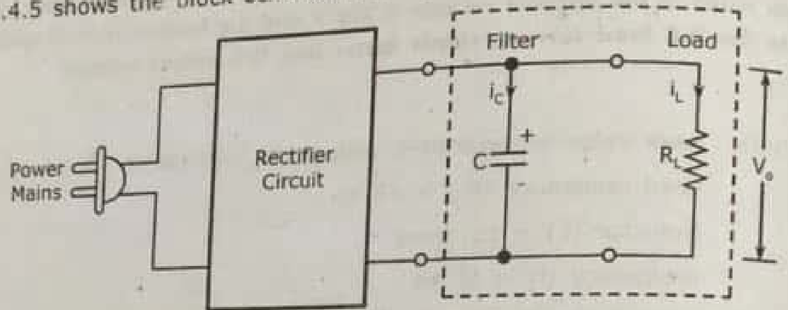


Fig. 2.4.5 FWR with Capacitor Filter

Principle of Capacitor Input Filters : The principle of capacitor filter can be better understood in terms of impedance.

We know that, $X_C = \frac{1}{2\pi fC}$, Hence, for AC components using large value of capacitor 'C' $\left(\text{i.e., } X_C = \frac{1}{2\pi fC} = \text{low}\right)$ offers a low impedance path (short circuit). While for DC components $\left(\text{i.e., } X_C = \frac{1}{2\pi(0)C} = \infty\right)$, it offers high impedance path (i.e., open circuit). Thus ripples (AC components) gets bypassed through capacitor 'C' and only DC components flows through load resistance 'R_L'.

2.4.2.1 Half-Wave Rectifier with Capacitor Filter

CONSTRUCTION

Fig. 2.4.6 shows the capacitor filter with half wave rectifier. It simply consists of a half-wave rectifier, a capacitor (C) connected in parallel with a load resistor (R_L).

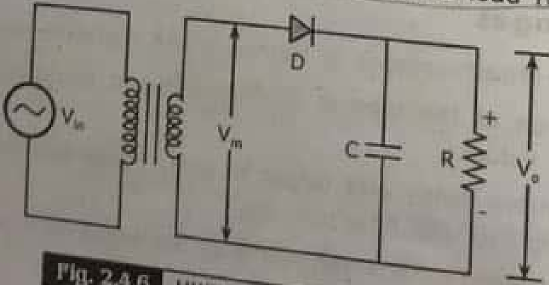


Fig. 2.4.6 HWR with Shunt Capacitor

WORKING OPERATION

The filtering action of a shunt capacitor filter depends on its property of opposing any sudden change in voltage across it.

Let V_{in} be the voltage applied to the rectifier circuit from the secondary winding of the transformer and is given by,

$$V_{in} = V_m \sin \omega t, V_m \gg V_\gamma$$

(1) During the positive half-cycle of the input signal, the anode of the diode becomes more positive than cathode and hence the diode D start conducts. Thus the capacitor C charges to the peak value of the transformer secondary voltage, V_m will try to maintain this value until the input voltage to the rectifier drops to zero.

(2) During the negative half-cycle of the input signal, the anode of the diode becomes negative with respect to cathode and hence the diode D is in OFF state. Thus, the capacitor C discharges through the load resistor R_L.

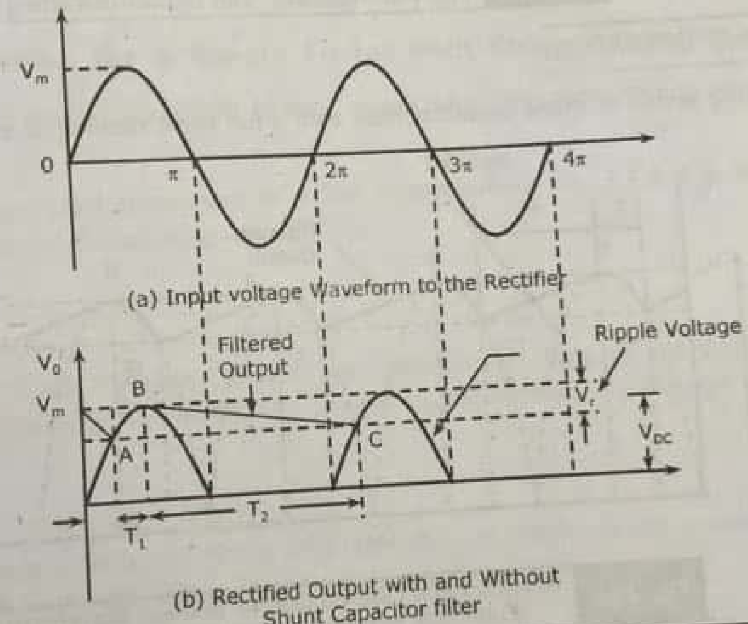


Fig. 2.4.7 Input and Output Waveforms of HWR with capacitor Filter

The rate at which capacitor discharges (during the period BC shown in Fig. 2.4.7), depends on the value of time constant R_LC. The larger is the time constant the lower will be ripples and more steadier the output voltage. This process of charging and discharging of capacitor 'C' will be repeated for each cycle of input voltage. Fig. 2.4.7 shows the output voltage waveforms of rectifier with and without shunt capacitor filter.

$p = \frac{z \pm \sqrt{z^2 - \ldots}}{2c_1}$ ——— (3)

$p = \frac{z \pm \sqrt{z^2 - 4c_1^2}}{2c_1}$

2.4.2.2 Full-Wave Rectifier with Capacitor Filter

CONSTRUCTION

Fig. 2.4.8 shows the capacitor filter with center tapped full-wave rectifier circuit.

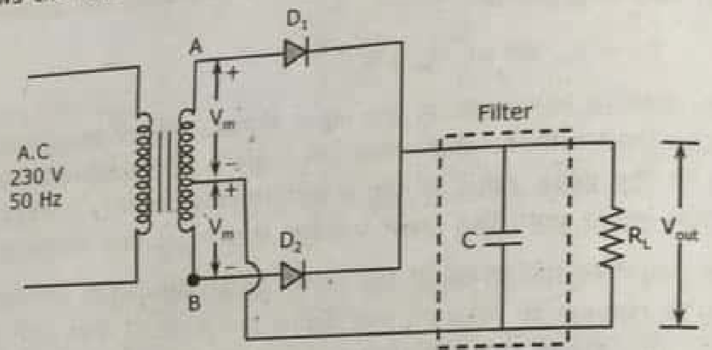


Fig. 2.4.8 Full-wave Rectifier with Capacitor Filter

WORKING OPERATION

The filtering action of shunt capacitor filter with a full wave rectifier is shown in Fig. 2.4.9.

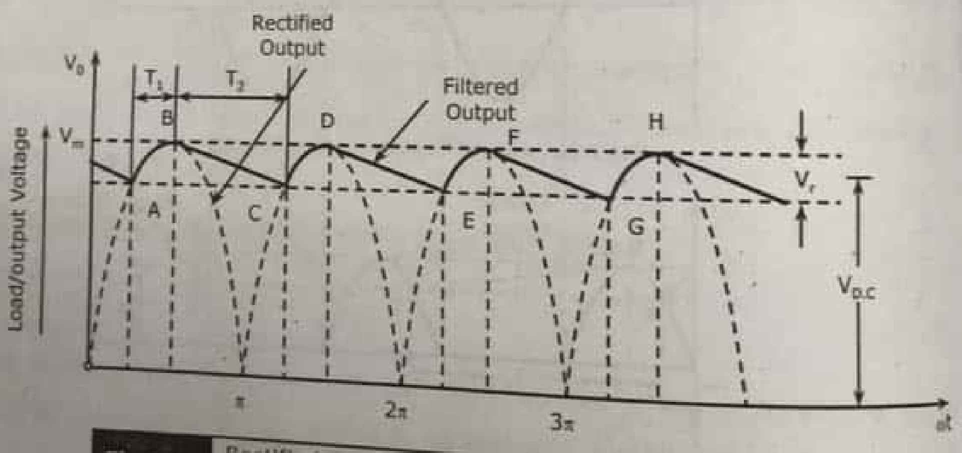


Fig. 2.4.9 Rectified and Filtered Output Voltage Waveform for a Full-wave Rectifier with Shunt Filter Capacitor

The working operation of a shunt capacitor filter with bridge rectifier is explained as follows,

Case I (During $0 < \omega t < \pi/2$) : During the first quarter cycle of the rectifier output, Diode D_1 is forward biased and hence starts conducting. Thereby, capacitor C charges to peak value of secondary voltage V_m i.e., upto point B as shown in Fig. 2.4.9.

CASE II (During $\pi/2 < \omega t > \pi$) : During the second quarter cycle, the diode D_1 stops conducting because its anode voltage decreasing, while its cathode voltage is held at V_m as capacitor C charged to peak value V_m. In this region, capacitor acts as a source and supplies D.C current to load resistor R_L with time constant R_LC.

CASE III (During $\pi < \omega t < 3\pi/2$) : During the third quarter cycle, the terminal B is more potential than that of terminal A (Refer Fig. 2.4.8), hence diode D_2 starts conducting. Thereby, capacitor 'C' charges again to peak value of secondary voltage.

CASE IV (During $3\pi/2 < \omega t < 2\pi$) : During the fourth quarter cycle, as soon as capacitor charges to V_m at point D, the diode D_2 stops conducting and then discharges through load R_L to point E as shown in Fig. 2.4.9.

This process is cumulative and hence repeated for the next cycles of the input signal. As both the diodes conduction, non-conduction periods has reduced, hence the ripple voltage (V_r) has been reduced to half and DC voltage (V_{DC}) has been increased relative to the half-wave rectifier.

2.4.2.3 Expression for a Ripple Factor with Capacitor Filter

Consider the filtered waveform of FWR circuit with capacitor filter as shown in Fig. 2.4.9.

Let V_r be the ripple component of output voltage. From Fig. 2.4.9 it is obvious that DC value of output voltage is given by,

$$V_{DC} = V_m - \frac{V_r}{2} \quad \text{... (2.4.9)}$$

Let T_1 and T_2 be the time taken by the capacitor for charging and discharging. The total charge lost during non-conduction (or discharge) duration T_2 through load is given as,

$$Q_{discharge} = I_{D.C}T_2$$

This charge is replenished during time interval T_1, in which voltage across the capacitor increases by V_r volts. So charge gained by capacitor C is given by,

$$Q_{charge} = CV_r$$

In steady-state,

$$Q_{charge} = Q_{discharge}$$

$$\Rightarrow \quad CV_r = I_{D.C}T_2$$

$$\Rightarrow \quad V_r = \frac{I_{D.C}\ T_2}{C} \quad \text{... (2.4.10)}$$

Assuming $T_1 << T_2$, we have,

$$T_2 = T = \frac{1}{f_r} \quad \dots (2.4.11)$$

Where, f_r represents the ripple frequency,

Using T_2 from Eq. (2.4.11) in Eq. (2.4.10), we have,

$$V_r = \frac{I_{D.C}}{f_r C} \quad \dots (2.4.12)$$

Using V_r, from Eq. (2.4.12) in Eq. (2.4.9), we have,

$$V_{D.C} = V_m - \frac{I_{D.C}}{2f_r C} \quad \dots (2.4.13)$$

From Eq. (2.4.12), it can be seen that ripple voltage varies directly with the load current $I_{D.C}$ and inversely with the capacitance C.

As shown in Fig. 2.4.9, the r.m.s value of the ripple component is of almost triangular wave and is independent of the slope or the length of the almost straight lines BC and CD but depends only on the peak value V_r

The rms value of a triangular wave is given by,

$$V_{A.C,\,r.m.s} = \frac{V_r}{2\sqrt{3}}$$

Hence ripple factor,

$$\gamma = \frac{V_{A.C\,r.m.s}}{V_{D.C}} = \frac{V_r}{2\sqrt{3}\,I_{D.C}\,R_L}$$

$$= \frac{I_{D.C}}{2\sqrt{3}\,I_{D.C}\,R_L f_r C} \qquad \left[\because V_r = \frac{I_{dc}}{f_r C}\right]$$

$$\gamma = \frac{1}{2\sqrt{3}\,CR_L f_r}$$

For HWR, ripple frequency $f_r = f$, thus

$$\therefore \quad \boxed{\gamma = \frac{1}{2\sqrt{3}\,CR_L f}} \quad \dots (2.4.14)$$

For FWR, ripple frequency $f_r = 2f$, thus

$$\therefore \quad \boxed{\gamma = \frac{1}{4\sqrt{3}\,CR_L f}} \quad \dots (2.4.15)$$

2.4.2.4 Advantages and Disadvantages

ADVANTAGES

Following are the advantages of full-wave rectifier with capacitor filter,

(1) Capacitor filter is very popular because of its low cost, small size and light weight.

(2) The magnitude of output D.C is improved because of charging and discharging of capacitor.

(3) It can be applied to both half and full wave rectifier circuit.

DISADVANTAGES

Disadvantage of full-wave rectifier with capacitor filter is, since capacitor itself draws heavy current from the rectifier circuit a small load can be applied with this filter circuit.

EXAMPLE PROBLEM 1

In a laboratory-measurement, it was observed that the waveshape of the output of a rectifier with a load R_L = 400 Ω and a filter of capacitor 625 μF has a peak value of 10 V and the ripples are confined within 0.7 V. The power line frequency was 50 Hz. Determine the observed value of the ripple factor for filter with the calculated value for.

(a) HWR.

(b) FWR.

SOLUTION

Given Data : Peak value of rectified output (V_{in}) = 10 V

Peak value of ripples ($V_{r,p-p}$) = 0.7 V

Load Resistance (R_L) = 400 Ω

Capacitance (C) = 625 μF

Frequency (f) = 50 Hz

The rms value of the ripple voltage, is given by,

$$V_{r,rms} = \frac{V_{r,p-p}}{2\sqrt{3}} = \frac{0.7}{2\sqrt{3}} = 0.202 \text{ V}$$

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

$$V_{DC} = V_{max} - \frac{V_{r,p-p}}{2}$$

$$= 10 - 0.35 = 9.65 \text{ V}$$

$\therefore p = \frac{z \pm \sqrt{z^2 - 4C_1^2}}{2C_1}$ — (3)

Thus, the observed value of the ripple factor is,

$$\gamma = \frac{V_{r,rms}}{V_{dc}} = \frac{0.202}{9.65} = 0.0209 \text{ or } 2.09\%$$

(a) The calculated value of the ripple factor for HWR is

$$\gamma = \frac{1}{2\sqrt{3}\, f R_L C} = \frac{1}{2\sqrt{3} \times 50 \times 400 \times 625 \times 10^{-6}}$$

$$= 0.046 \text{ or } 4.6\%$$

(b) The calculated value of the ripple factor FWR is,

$$\gamma = \frac{0.046}{2}$$

$$= 0.023 \text{ or } 2.3\%$$

2.4.3 Rectifiers with L-Section Filter

We have seen that incase of shunt capacitor filters, ripple factor is inversely proportional to load, hence they will have low ripples at heavy loads. Whereas incase of inductor filters, ripple factor is directly proportional to load, hence they will have low ripples at small loads. Thus it is desirable to use a combination of these filters whose ripple factor is independent of load resistance. This type of filter is referred to as choke input or L-section filter.

2.4.3.1 Construction

Fig. 2.4.10 shows the L-section filter which a center tapped FWR.

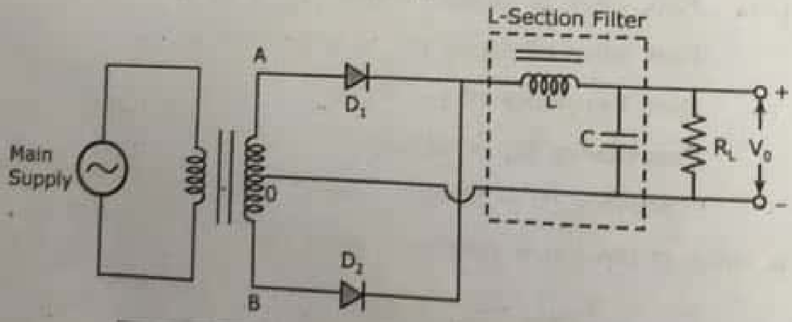


Fig. 2.4.10 Circuit Diagram of L-section Filter

The circuit diagram in Fig. 2.4.12 consists of inductor in series and capacitor in shunt with a load R_L. The name L-section of this filter circuit has been derived from the basic inverted 'L' shaped structure of the circuit.

The input is fed through the inductor so it is also known as the choke-input filter. Here, the inductor plays its role as a current smoothing element and capacitor as the voltage stabilizing element.

COMMENT : *Here, it is notable that several L-section in cascade can be connected in order to get more smooth filter output.*

2.4.3.2 Working Operation

The working operation of choke input filter is similar to a low pass filter. The shunt capacitor bypasses the harmonic currents since it offers very low impedance path to A.C ripple current while it appears as an open circuit to D.C current. On the other hand, the inductor offers a high impedance path (open circuit) to the harmonic components, while it acts as an short circuit to D.C current. In this way, most of the ripple voltage is eliminated from the load voltage.

Fig. 2.4.11 shows the rectifier output with and without a filter.

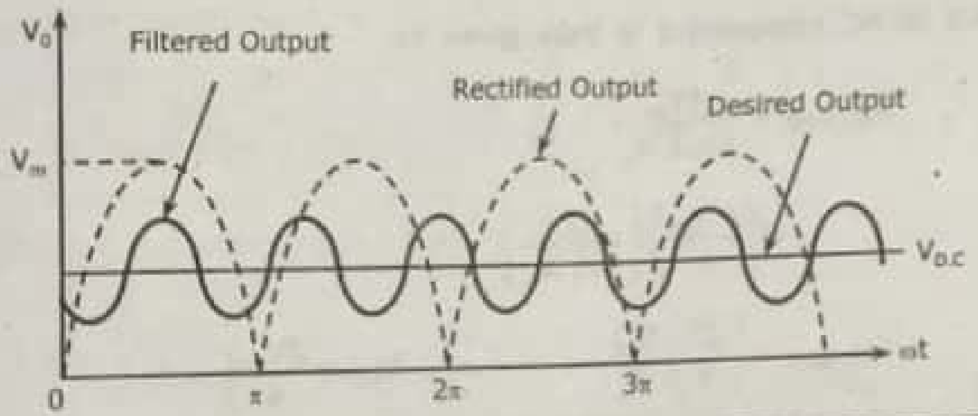


Fig. 2.4.11 Rectified and Filtered Output Voltage Waveform for FWR with L-section Filter

2.4.3.3 Expression for a Ripple factor with L-section Filter

The main objective of the filter is to remove (suppress) harmonic components as far as possible. To do this impedance of inductor must be a larger value as compared with the parallel combination of capacitor and load resistor.

The parallel impedance can be made a small value by choosing the impedance of capacitor much smaller than the load resistor. Now the ripple current which has passed through inductor will not drop much ripple voltage across load (R_L) since the impedance of capacitor (X_C) at the ripple frequency is very small as compared with R_L. Thus for LC filters, we have,

$$\boxed{X_L \geq R_L} \quad \text{and} \quad \boxed{R_L >> X_C}$$

At these conditions, the A.C current through L is determined by 2ωL (i.e., the reactance of the inductor at second harmonic frequency).

The rectifier output in terms of Fourier series is given by,

$$V_{out} = V_m\left[\frac{2}{\pi} - \frac{4}{3\pi}\cos 2\omega t - \frac{4}{15\pi}\cos 4\omega t - ....\right] \quad ... (2.4.16)$$

Neglecting the third and higher harmonics, we have,

$$V_{out} = V_m\left[\frac{2}{\pi} - \frac{4}{3\pi}\cos 2\omega t\right] \quad ... (2.4.17)$$

Where, $\frac{2V_m}{\pi}$ represents the DC component that is,

$$V_{DC} = \frac{2V_m}{\pi} \quad ... (2.4.18)$$

Peak value of AC current through the circuit due to second harmonic component is,

$$I_{AC,\,max} = \frac{4V_m}{3\pi X_L} \quad ... (2.4.19)$$

RMS value of AC component is thus given by,

$$I_{AC,\,RMS} = \frac{4V_m}{3\pi\sqrt{2}\,X_L}$$

$$= \left(\frac{2\,V_m}{\pi}\right)\left(\frac{2}{3\sqrt{2}\,X_L}\right)$$

$$\therefore \quad I_{AC,\,RMS} = \left(\frac{\sqrt{2}}{3}\right)\frac{V_{DC}}{X_L} \qquad \left(\because V_{DC} = \frac{2V_m}{\pi}\right) \quad ... (2.4.20)$$

But, AC voltage across the load is equal to the voltage across the capacitor.

$$V_{AC,RMS} = I_{AC,RMS}\,X_C$$

$$\therefore \quad V_{AC,RMS} = \frac{\sqrt{2}}{3}V_{DC}\left[\frac{X_C}{X_L}\right] \quad ... (2.4.21)$$

Ripple factor,

$$\gamma = \frac{V_{AC,RMS}}{V_{DC}} = \frac{\left(\frac{\sqrt{2}}{3}V_{DC}\frac{X_C}{X_L}\right)}{V_{DC}}$$

$$\therefore \quad \gamma = \frac{\sqrt{2}}{3}\left(\frac{X_C}{X_L}\right) \quad ... (2.4.22)$$

But, $X_L = 2\pi f_r L$, $X_C = \frac{1}{2\pi f_r C}$

where f_r represents the ripple frequency. Using these values in Eq. (2.4.22), we have,

$$\gamma = \frac{\sqrt{2}}{3}\left[\frac{\left(\frac{1}{2\pi f_r C}\right)}{2\pi f_r L}\right]$$

$$= \frac{\sqrt{2}}{3}\left[\frac{1}{4\pi^2 f_r^2 LC}\right] = \frac{\sqrt{2}}{12\pi^2 f_r^2 LC}$$

LC filters can be used with both HWRs and FWRs.

For HWR, ripple frequency, $f_r = f$.

$$\therefore \quad \boxed{\gamma = \frac{\sqrt{2}}{12\pi^2 f^2 LC} = \frac{\sqrt{2}}{3\omega^2 LC}} \qquad \text{... (2.4.23)}$$

For FWR, ripple frequency, $f_r = 2f$

$$\therefore \quad \boxed{\gamma = \frac{\sqrt{2}}{48\pi^2 f^2 LC} = \frac{1}{6\sqrt{2}\,\omega^2 LC}} \qquad \text{... (2.4.24)}$$

For multiple-LC (L-section) filter with 'n' sections, we have,

$$\therefore \quad \gamma = \frac{\sqrt{2}}{3}\left(\frac{X_C}{X_L}\right)^n$$

From Eq. (2.4.24), it can be seen that, ripple factor is independent of load R_L. Hence L-section filters can used for varying loads.

2.4.3.4 Advantages and Disadvantages

Advantage : Advantage of the rectifiers with L-section filter. Ripple current at the output is very low and is independent of load current.

Disadvantages : Following are the disadvantages of rectifiers with L-section filter.

(1) The magnitude of output voltage is less, it can be improved further using π-filter.

(2) It is more bulky and occupies more space.

2.4.4 Rectifiers with π-section Filter

Basically a π-filter is a combination of two capacitors and one inductor. It consists of two stages,

(1) Capacitor shunt filter.

(2) Choke input filter.

2.4.4.1 Construction

A capacitor input π-filter is shown in Fig. 2.4.12. In this case an additional capacitor 'C' is connected in the beginning across the output terminals of the rectifier. Since its shape is like the Greek letter π (Pi) hence it is named as π-filter.

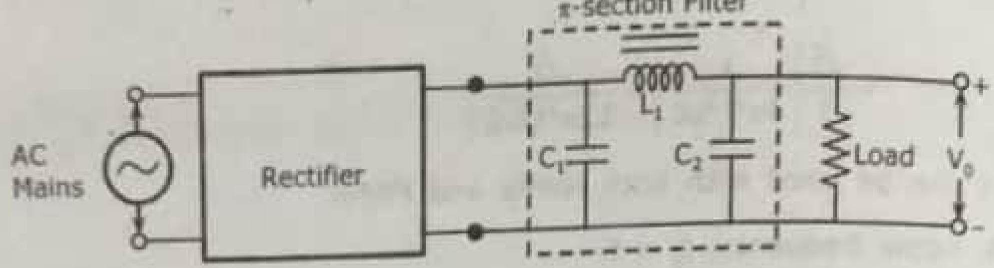


Fig. 2.4.12 Block Diagram of Capacitor Input π - filter

It is also called as capacitor-input filter since the rectifier feeds directly into the capacitor.

The filter action of the three components C_1, L and C_2 is given below,

(1) **Action of C_1 :** It offers low reactance to ripples, while offering it gives infinite reactance to DC component. Therefore, capacitor C_1 bypasses the AC component (ripple) and the DC component continues to flow through the choke L.

(2) **Action of L :** It offers high reactance to the AC component but offers almost zero reactance to the DC component. Therefore, the choke L allows the DC component to flow through it, while the unbypassed ripples are blocked.

(3) **Action of C_2 :** It bypasses the ripples, which the choke L has failed to block. Therefore, only DC component appears across the load.

2.4.4.2 Working Operation

The rectifier output is applied to the filter. The filtering of the output will take place in two stages, first, capacitor C_1 will filters the A.C variation from the rectified output. During the conduction interval, capacitor C_1 charges upto the peak value of input voltage. Then it discharges through choke input filter and load. The remaining pulsating output is filtered by the choke input filter stage or L-section filter stage, which is the second stage of the π-filter. The ripple is opposed by inductor and the remaining is by passed by the capacitor C_2. Hence, π-filter produces D.C output voltage with negligible ripple. The ripple factor of π-filter is product of the ripple factor of capacitor shunt filter stage and the ripple factor of choke input filter stage. If compared with L-section filter, π-filter have a higher output voltage but with poor voltage regulation. Ripple is independent of load resistance in choke input filter while ripple is inversely proportional to load resistance in π-filter.

The rectified and filtered output of a π-section filter is shown in Fig. 2.4.13,

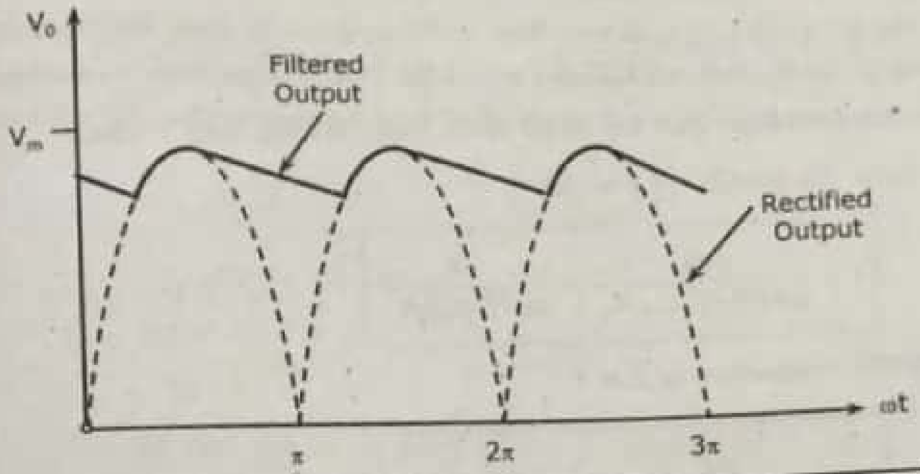


Fig. 2.4.13 Rectified and Filtered Output Voltage Waveforms

2.4.4.3 Expression for a Ripple Factor with π-section Filter

The ripple voltage with shunt capacitor filter is given by,

$$V_r = \frac{I_{DC}}{f_r C} \quad \text{... (2.4.25)}$$

The RMS value of second harmonic voltage is,

$$V_{AC,\,RMS} = \frac{V_r}{\pi\sqrt{2}}$$

$$\Rightarrow \quad V_{AC,\,RMS} = \frac{I_{DC}}{\pi\sqrt{2}\, f_r C}$$

$$\therefore \quad V_{AC\,RMS} = \sqrt{2}\, I_{DC}\, X_{C1} \qquad \left(\because\ X_{C1} = \frac{1}{2\pi f_r C_1}\right) \quad \text{... (2.4.26)}$$

Now, this $V_{AC,\,RMS}$ is applied to L-section. The ripple voltage can be obtained by multiplying X_{c2}/X_L i.e.,

$$V_{AC\,RMS} = V_{AC\,RMS}\, \frac{X_{C2}}{X_L}$$

$$\therefore \quad V_{AC\,RMS} = \sqrt{2}\, I_{DC}\, \frac{X_{C1} X_{C2}}{X_L} \quad \text{... (2.4.27)}$$

Now, Ripple factor,

$$\gamma = \frac{V_{AC\,RMS}}{V_{DC}} = \frac{\left(\sqrt{2}\, I_{DC}\, \dfrac{X_{C1} X_{C2}}{X_L}\right)}{I_{DC} R_L}$$

$$\therefore \quad \gamma = \frac{\sqrt{2}\, X_{C1} X_{C2}}{R_L X_L} \quad \text{... (2.4.2}$$

But $X_L = 2\pi f_r L$, $X_{C1} = \frac{1}{2\pi f_r C_1}$ and $X_{C2} = \frac{1}{2\pi f_r C_2}$

$$\therefore \quad \gamma = \left(\frac{\sqrt{2}}{R_L}\right)\left(\frac{1}{8\,\pi^3 f_r^3 C_1 C_2 L}\right) \quad \dots (2.4.29)$$

CLC or π-section filter can be used with both HWRs and FWRs.

For FWR, ripple frequency $(f_r) = 2f$

$$\therefore \quad \boxed{\gamma = \frac{\sqrt{2}}{64\pi^3 f^3 C_1 C_2 L R_L} = \frac{\sqrt{2}}{8\omega^2 C_1 C_2 L R_L}} \quad \dots (2.4.30)$$

For HWR, ripple frequency $(f_r) = f$

$$\therefore \quad \boxed{\gamma = \frac{\sqrt{2}}{8\pi^3 f^3 C_1 C_2 L R_L} = \frac{\sqrt{2}}{\omega^3 C_1 C_2 L R_L}} \quad \dots (2.4.31)$$

2.4.4.4 Advantages and Disadvantages

Advantages of π-filter : Following are the advantages of rectifiers with π-section filter,

(1) Reduction in the ripples.

(2) Increase in the average load voltage.

(3) It can be used with both half-wave and full wave rectifiers.

Disadvantages of π-filter : Following are the disadvantages of rectifiers with π-section filter,

(1) Ripple factor is dependent on the load.

(2) Regulation is relatively poor.

(3) Diodes-handle large peak current.

2.4.4.5 Comparison of L-section and π-section Filters

(1) In π-filter the D.C output voltage is much larger than that can be had from an L-section filter with the same input voltage.

(2) In π-filter ripples are less in comparison to those in shunt capacitor or L-section filter. So smaller valued choke is required in a π-filter in comparison to that required in L-section filter.

(3) In π-filter, the capacitor is to be charged to the peak value hence the r.m.s current in supply transformer is larger as compared in case of L-section filter.

(4) Voltage regulation in case of π-filter is very poor, as already mentioned. So π-filter are suitable for fixed loads whereas L-section filters can work satisfactorily with varying loads provided a minimum current is maintained.

(5) In case of a π-filter PIV is larger than that in case of an L-section filter.

EXAMPLE PROBLEM 1

A single phase FWR uses π-section filter with two capacitors of 10 μH and a choke of 10 H. Secondary voltage is 280 V RMS with respect to centre-tap. If the load current is 10 μA, find the DC output voltage and % ripple in the output. Assume supply frequency of 50 Hz.

SOLUTION

Given Data : $C_1 = C_2 = C = 10\ \mu F$

$L = 10\ H$

$I_{DC} = 10\ \mu A$

$f = 50\ Hz$

Ripple frequency for FWR is given by,

$$f_r = 2 \times 50 = 100\ Hz$$

Given, $V_{RMS} = 280\ V$

$$\therefore \quad V_m = \sqrt{2}\, V_{RMS}$$

$$= 280\sqrt{2}\ V = 395.98$$

DC output voltage,

$$V_{DC} = V_m - \frac{V_r}{2}$$

$$\Rightarrow \quad V_{DC} = V_m - \frac{I_{DC}}{2f_r C}$$

$$= 395.98 - \frac{10 \times 10^{-6}}{2 \times 100 \times 10 \times 10^{-6}}$$

$$\therefore \quad V_{DC} = 395.9\ V$$

But, $R_L = \frac{V_{DC}}{I_{DC}} = \frac{395.9}{10 \times 10^{-6}} = 39.5\ M\Omega$

Ripple factor,

$$\gamma = \frac{\sqrt{2}}{64\pi^3 f^3 C_1 C_2 L R_L} = \frac{\sqrt{2}}{1981 f_0^3 C_1 C_2 L R_L}$$

$$= \frac{1}{1401 f^3 C^2 L R_L} \quad (\because C_1 = C_2 \text{ given})$$

$$= \frac{1}{1401 \times (50)^3 \times (10 \times 10^{-6})^2 \times 10 \times 39.5 \times 10^{+6}} = \frac{1}{6.93 \times 10^{18-12}}$$

$$\therefore \quad \gamma = 1.44 \times 10^{-7}$$

$q = \frac{-b \pm \sqrt{b}}{2a}$

$= \frac{z \pm \sqrt{z^2 - 4 \times 1 \times C_i^2}}{2 \times C_i^2}$

2.5 ZENER DIODE REGULATOR

Zener Diode : A zener diode is a silicon p-n junction semiconductor device which is operated in its reverse breakdown region. The symbol of zener diode is shown in Fig. 2.5.1.

Fig. 2.5.1 Symbol of Zener Diode

Zener diodes are used in a circuits to maintain fixed voltage across a load. This means that a zener diode will stop a reverse current from flowing through it until the reverse voltage applied across it reaches a fixed value known as the breakdown voltage.

2.5.1 Voltage Regulation using Zener Diode

Fig. 2.5.2 shows the basic circuit arrangement of voltage regulation.

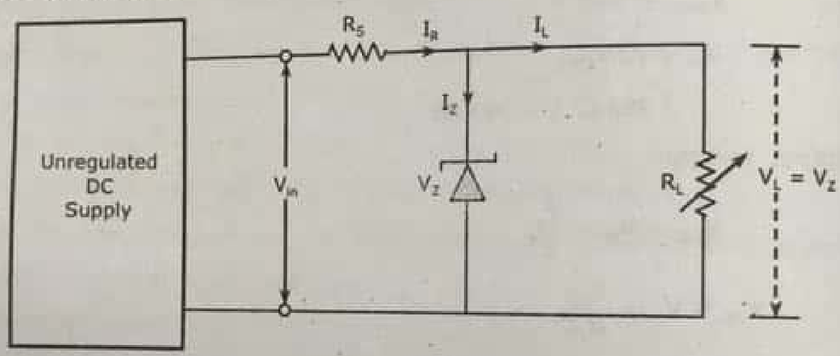


Fig. 2.5.2 Zener Regulator

The principle of the circuit is that zener diode operates in breakdown region, thereby, maintaining a constant voltage across it even for a large change in current through it. Resistance R_S connected in series with input voltage absorbs the output voltage fluctuation so as to maintain constant voltage across the load.

(1) **When $V_{in} < V_Z$:** Let a variable voltage V_{in} be applied across the load R_L. When the value of V_{in} is less than Zener voltage V_Z of the Zener diode, no current flows through it and the same voltage appears across the load.

(2) **When $V_{in} > V_Z$:** When the input voltage V_{in} is more than V_Z, this will cause the Zener diode to conduct a large current I_Z. As a result, more current flows through series resistor R which increases the voltage drop across it. Thus, the input voltage excess of V_Z(i.e., $V_{in} - V_Z$) is absorbed by the series resistor. Hence a constant voltage V_o (= V_Z) is maintained across the load R_L.

COMMENT : *When a Zener diode of Zener voltage V_Z is connected in reverse direction ... load, it maintains a constant voltage across the load equal to V_Z and hence stabilizes the out...*

To understand the operation of this circuit we shall consider its working unde... ...ee different conditions. They are,

(1) Constant V_i and constant R_L.

(2) Constant V_i and variable R_L.

(3) Constant R_L and variable V_i.

The analysis of Zener diode regulator networks in done is two steps,

STEP 1 : Determine the state of Zener diode whether it is "ON" or "OFF". This is done by removing zener diode from the network and calculate the resultant open circuit voltage. Here two cases arises. They are,

(i) If open circuit voltage (V) < V_Z, diode is OFF and replace it with open-circuit.

(ii) If V ≥ V_Z, then the diode is ON and replace it with equivalent circuit.

STEP 2 : Substitute the appropriate equivalent circuit and Calculate the desired parameters.

2.5.1.1 Fixed V_{in} and R_L

The simplest of zener diode circuits appears in Fig. 2.5.3. It has fixed applied D.C voltage V_{in} and fixed load resistance R_L.

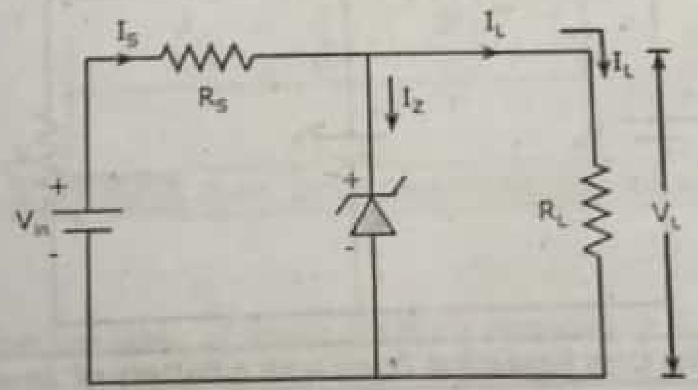


Fig. 2.5.3 Fixed V_{in} and R_L

This circuit analysis is studied using the two steps discussed above.

STEP 1 : Determine the state of the zener diode by removing it from the network and calculate the voltage across the resulting open circuit.

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Step 1 results in the circuit of Fig. 2.5.4. Using voltage divider concept, we get,

$$V_L = V_Z - V_{in} \frac{R_L}{R_L + R_S}$$

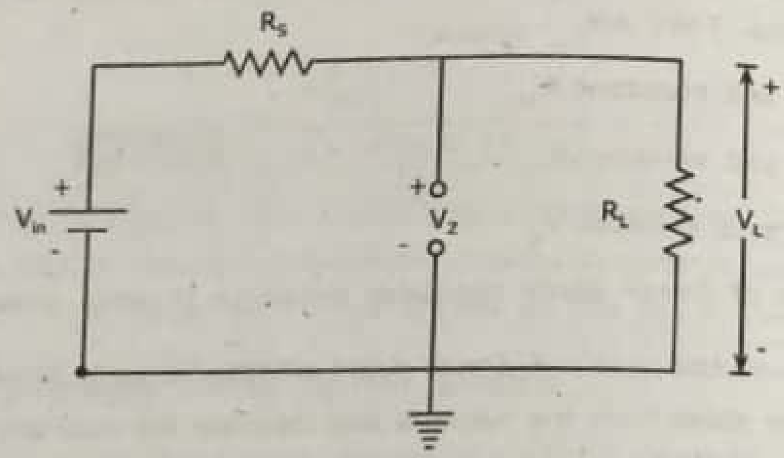


Fig. 2.5.4 If $V < V_Z$ Diode is OFF and Replaced it with Open Circuit

(i) If $V < V_Z$, then zener diode is 'OFF' and hence can be replaced by an open circuit as shown in Fig. 2.5.3.

(ii) But if $V \geq V_Z$, then the zener diode is in ON state.

STEP 2 : Substitute the appropriate equivalent model and solve for desired parameters. Since voltage across parallel elements must be same (i.e.,), $V_L = V_Z$. Hence Fig. 2.5.5 is the equivalent circuit of Fig. 2.5.4,

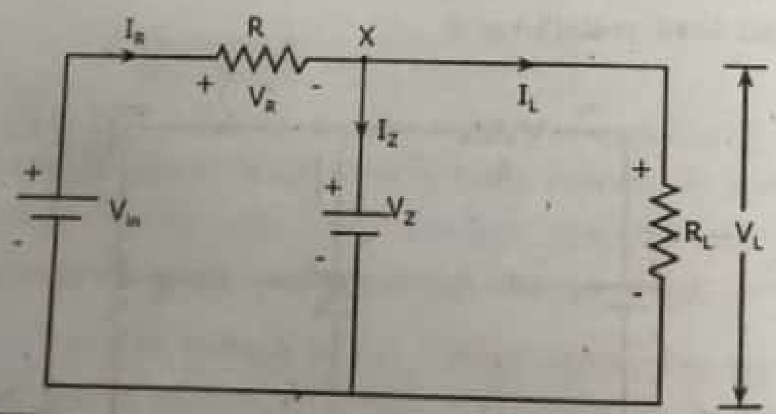


Fig. 2.5.5 If $V \geq V_Z$, then Replacing Zener with a Battery of Zener Potential V_Z

Applying KCL at node X, we have

$$I_R = I_Z + I_L$$

$$\therefore \quad \boxed{I_Z = I_R - I_L} \quad \ldots (2.5.1)$$

Where,

$$I_R = \frac{V_R}{R} = \frac{V_{in} - V_Z}{R}$$

$$I_L = \frac{V_L}{R_L}$$

Also, power dissipated by the zener diode is,

$$\boxed{P_Z = V_Z \times I_Z} \quad \text{... (2.5.2)}$$

COMMENT : *P_Z should be less than P_{ZM}, maximum power rating specified for the device.*

SOLVED PROBLEM 1

For the circuit of Fig. 2.5.6, determine

(a) The output voltage V_o

(b) The current I_L through load resistance R_L.

(c) The voltage drop series resistor R_S.

(d) The current I_Z through zener diode and

(e) The power dissipated in Zener diode.

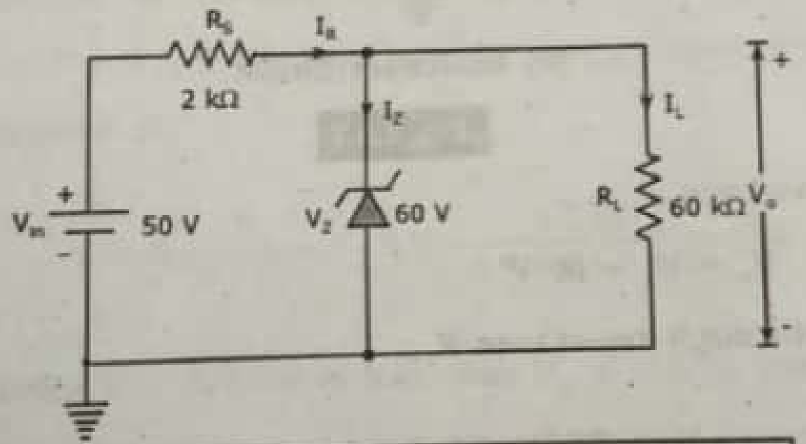


Fig. 2.5.6 Zener Diode as a Shunt Regulator

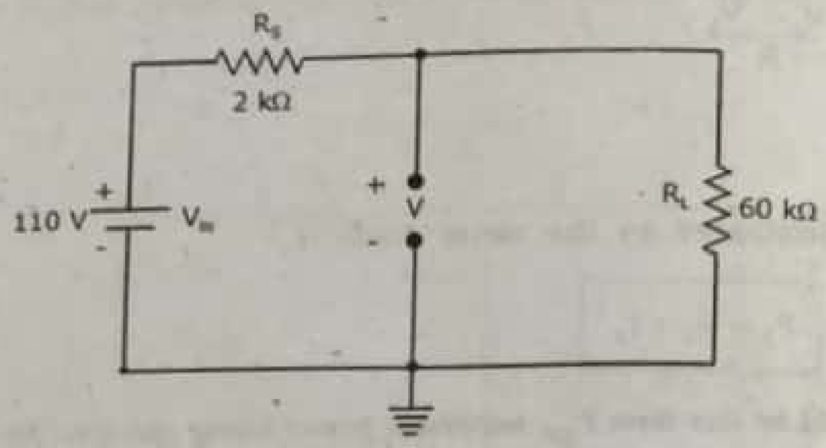
SOLUTION

STEP 1 : Determine the state of zener diode by replacing it with open circuit as shown in Fig. 2.5.7(a). By voltage divider rule, the open-circuit voltage V is given as,

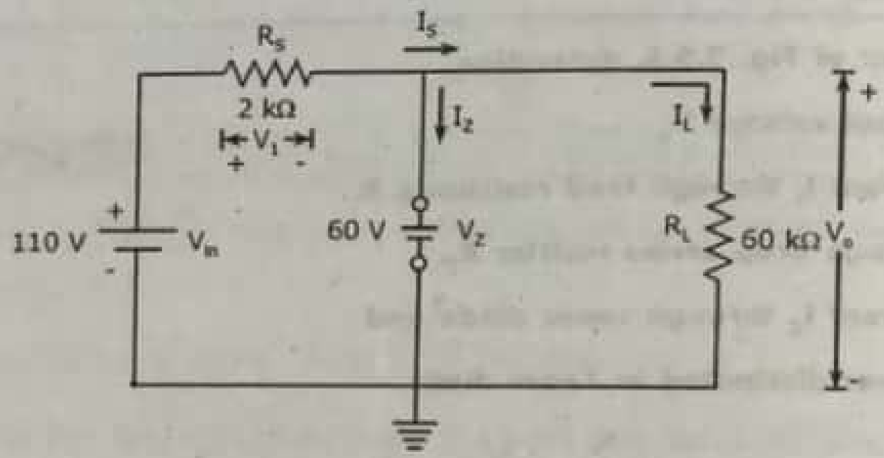
$$V = V_{in} \frac{R_L}{R_S + R_S} = 110\ V \times \frac{6\ k\Omega}{2\ k\Omega + 6\ k\Omega} = 100 \times \frac{6}{8}\ V = 82.5\ V$$

This voltage is more than V_Z(=60 V). Hence, the zener diode is 'ON'. We now replace the zener diode by its equivalent circuit shown in Fig. 2.5.7(b).

STEP 2 : Use equivalent circuit to determine the unknown parameters.



(a) If $V < V_1$ Diode is OFF Replace with Open Circuit



(b) Equivalent Circuit

Fig. 2.5.7

(a) The output voltage,

$$V_o = V_Z = 60\ V$$

(b) The current through resistance R_L,

$$I_L = \frac{V_o}{R_L} = \frac{60\ V}{6\ k\Omega} = 10\ mA$$

(c) The voltage drop across the series resistor R_S,

$$V_1 = V_{in} - V_o$$

$$= 110 - 60 = 50\ V$$

(d) The power dissipated by the Zener diode,

$$P_Z = V_Z I_Z$$

$$= 60\ V \times 15\ mA = 900\ mW$$

SOLVED PROBLEM 2

(a) For the zener diode circuit of Fig. 2.5.8, determine V_o, V_S, I_Z, and P_Z.

(b) Repeat the above with R_L = 4 kΩ.

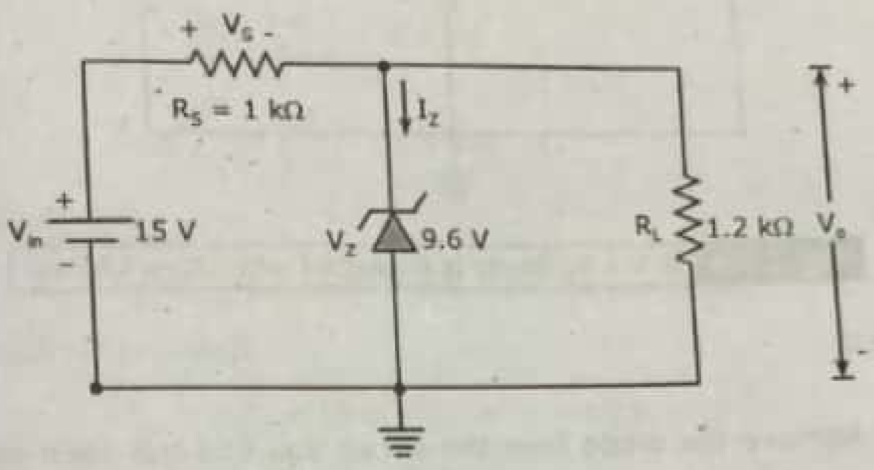


Fig. 2.5.8 Zener Diode as Voltage Regulator

SOLUTION

(a) **STEP 1 :** Determine the state of the zener diode by replacing with open circuit as shown in Fig. 2.5.9. By applying the voltage divider rule, we get the open-circuit voltage V as,

$$V = V_{in}\frac{R_L}{R_S + R_L} = 15\text{ V} \times \frac{1.2\text{ k}\Omega}{1\text{ k}\Omega + 1.2\text{ k}\Omega} = 15 \times 0.545\text{ V} = 8.16\text{ V}$$

STEP 2 : Since V = 8.16 V is less than V_Z = 9.6 V, the diode is in 'OFF' stat replaced by its open-circuit equivalent resulting in the same circuit as in Fig. 2.5.9 From this circuit, we find,

$$V_o = V = 8.16\text{ V}$$

$$V_S = V_{in} - V_o = 15\text{ V} - 8.16\text{ V} = 6.84\text{ V}$$

$$I_Z = 0\text{ A},$$

$$P_Z = V_Z I_Z = V_Z(X,\ 0A) = 0\text{ W}.$$

$-b \pm$
$2a$
$z \pm \sqrt{z^2 - 4 \times 1 \times C_i}$
$2 \times C_i^2$

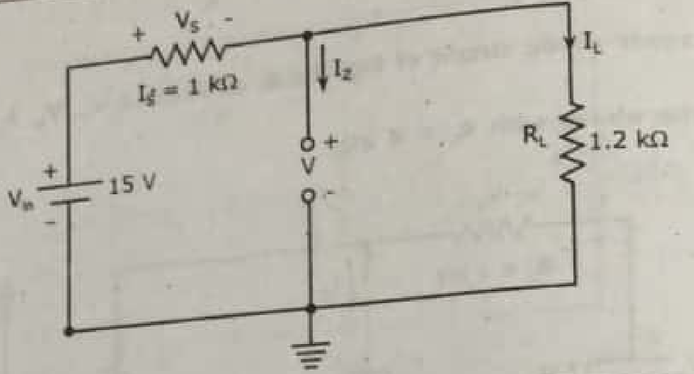


Fig. 2.5.9 If $V < V_Z$ Diode is Replaced with Open Circuit

(b) $R_L = 4$ kΩ

Step 1 : Remove the diode from the circuit and find the open-circuit voltage. By applying the voltage divider rule, as,

$$V = V_{in} \frac{R_L}{R_S + R_L}$$

$$= 15\ \text{V} \times \frac{4\ \text{k}\Omega}{1\ \text{k}\Omega + 4\ \text{k}\Omega} = 15 \times 0.8\ \text{V} = 12\ \text{V}$$

Since $V = 12$ V is greater than $V_Z = 9.6$ V, the diode is in 'ON' state.

Step 2 : The diode is therefore replaced by a battery of 9.6 V, as in Fig. 2.5.10. From this circuit, we get,

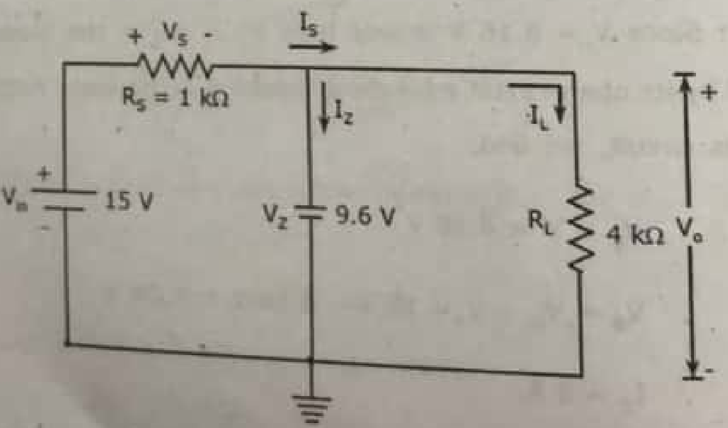


Fig. 2.5.10 If $V \geq V_Z$ Diode is Replaced with Battery of Potential (V_Z)

$$V_o = V_Z = 9.6\text{ V}$$

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

$$= 15\text{ V} - 9.6\text{ V}$$

$$= 5.4\text{ V}$$

$$I_L = \frac{V_o}{R_L} = \frac{9.6\text{ V}}{4\text{ k}\Omega} = 2.4\text{ mA}$$

$$I_S = \frac{V_S}{R_S} = \frac{5.4\text{ V}}{1\text{ k}\Omega} = 5.4\text{ mA}$$

By applying KCL,

$$I_Z = I_S - I_L = 5.4\text{ mA} - 2.4\text{ mA} = 3\text{ mA}$$

The power dissipated,

$$P_Z = V_Z I_Z = (9.6\text{ V})(3\text{ mA}) = 28.8\text{ mW}.$$

2.5.1.2 Fixed V_{in} and Variable R_L

Consider a zener regulator with fixed input voltage and variable load as shown in Fig. 2.5.11(a),

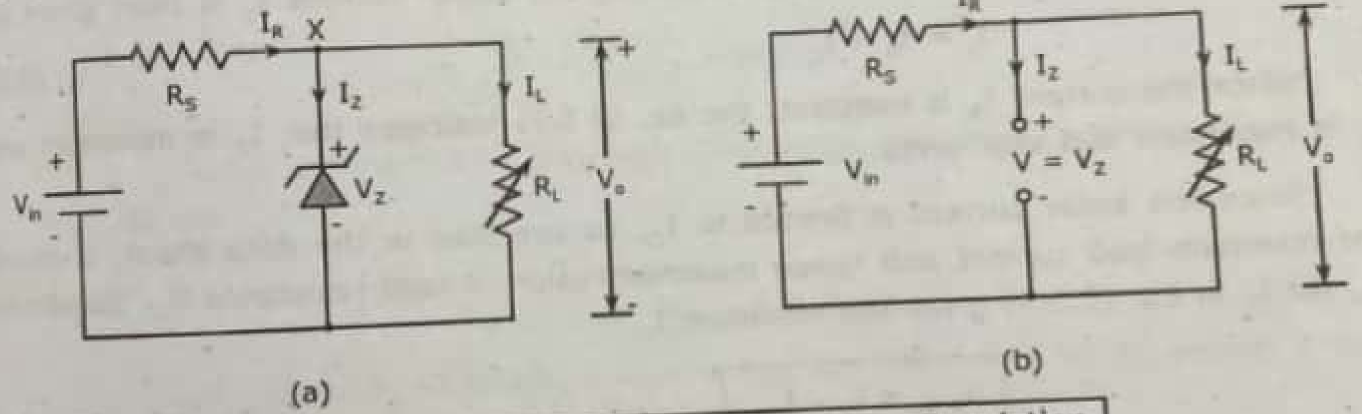


Fig. 2.5.11 Fixed V_{in} and Variable R_L Zener Regulation

The Zener voltage V_Z is equal to the load voltage, V_L can be seen in the circuit of 2.5.10(a). Load voltage is dependent on the load current I_L and load resistance R_L. If R_L becomes too small i.e., $R_L \rightarrow 0$ then $I_L \rightarrow I_R$ and $I_Z \rightarrow 0$. Hence, the Zener diode will not be in ON state as there is no Zener current to keep it in ON state So, there should be a minimum value of R_L which will ensure that the Zener diode is in ON state.

To determine the minimum load resistance of Fig. 2.5.11(a), we simply calculate the value of R_L that will result in an open-circuit voltage V= V_Z as shown in Fig. 2.5.10(b) Using voltage division rule,

$$V_o = V_Z = V_{in}\frac{R_L}{R_S + R_L}$$

Solving for R_L, we get,

$$\boxed{R_{L,min} = \frac{R_s V_Z}{V_{in} - V_Z}} \quad ...(2.5.3)$$

Any load resistance value greater than this $R_{L,min}$ will ensure that the zener is in the 'ON' state, and hence the diode can be replaced by a battery of V_Z voltage.

The condition defined by Eq. (2.5.3) can also specifies the maximum load current as,

$$\boxed{I_{L,max} = \frac{V_o}{R_{L,min}} = \frac{V_Z}{R_{L,min}}} \quad ...(2.5.4)$$

Once the zener diode is in 'ON' state, the voltage across the load is fixed at V_Z and the voltage across R_S remains fixed at,

$$V_S = V_{in} - V_Z \quad ...(2.5.5)$$

The current through resistor R_S is given by,

$$I_s = \frac{V_s}{R_s} \quad ...(2.5.6)$$

Applying KCL at node 'X' in Fig. 2.5.11(a) the Zener current I_Z is then given as,

$$I_z = I_R - I_L \quad ...(2.5.7)$$

Since the current I_R is constant, the Eq. (2.5.7) indicates that I_Z is minimum when I_L is maximum and vice versa.

Since the zener current is limited to I_{ZM} as specified in the data sheet, it decides the minimum load current and hence maximum value of load resistance R_L. Substituting I_{ZM} for I_Z in Eq. (2.5.7) gives the minimum I_L,

$$\boxed{I_{Lmin} = I_R - I_{ZM}} \quad ...(2.5.8)$$

Thus, the maximum permissible value of load resistance is given by,

$$\boxed{R_{L,max} = \frac{V_Z}{I_{L\,min}}} \quad ...(2.5.9)$$

SOLVED PROBLEM 1

(a) Determine the range of R_L and I_L that will result in the output V_o being maintained at 10 V, in the circuit of Fig. 2.5.12.

(b) determine the maximum wattage of the zener diode.

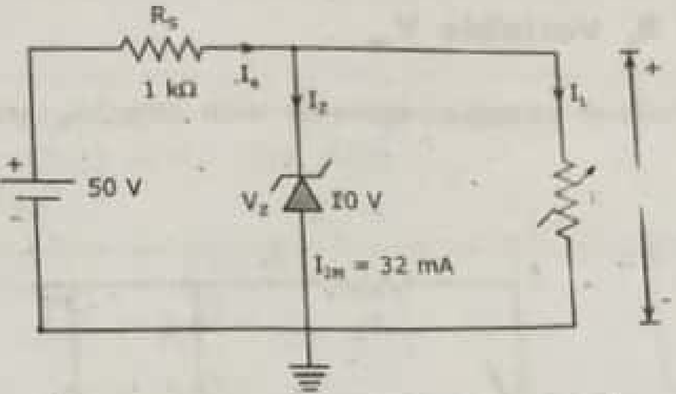


Fig. 2.5.12 Zener Voltage Regulator

SOLUTION

(a) From Fig. 2.5.11, we have current through resistor R_S given by,

$$I_R = \frac{V_{in} - V_Z}{R_S} = \frac{50\text{ V} - 10\text{ V}}{1\text{ k}\Omega} = 40\text{ mA}$$

Load current will be maximum when zener current, $I_Z = 0$. Thus,

$$I_{L,max} = I_R - I_Z = 40\text{ mA} - 0 = 40\text{ mA}.$$

Corresponding load resistance will be minimum and is given by,

$$R_{L,min} = \frac{V_o}{I_{L,max}} = \frac{10\text{ V}}{40\text{ mA}} = 250\ \Omega$$

Load current will be minimum when zener current is maximum. Given I_{ZM} = 32 mA

$$I_{L,min} = I_R - I_{Z,max}$$
$$= 40\text{ mA} - 32\text{ mA} = 8\text{ mA}$$

A plot of V_o versus R_L shown in Fig. 2.5.13(a) and for V_o versus I_L in Fig 2.5.13(b),

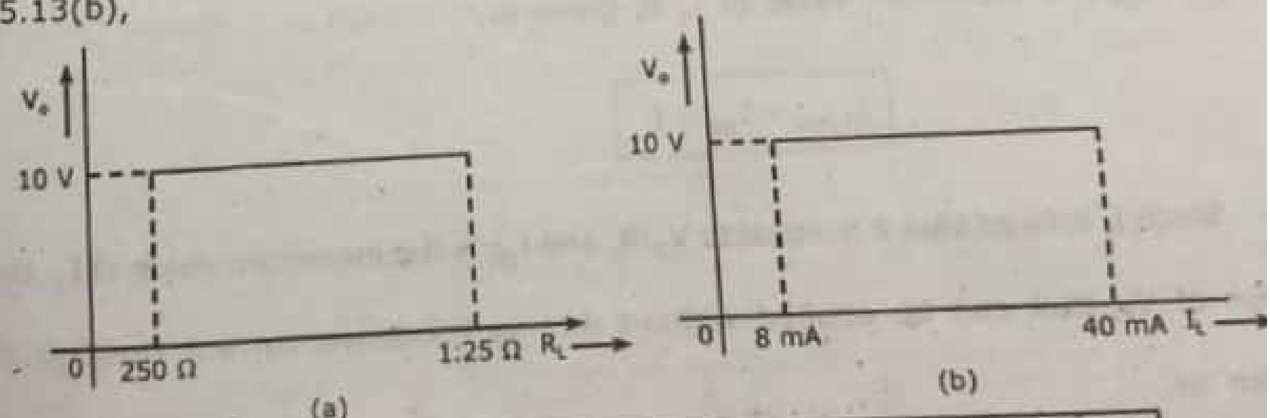


Fig. 2.5.13 V_o Versus R_L and I_L for the Regulator of Fig. 2.5.12

(b) $P_{max} = V_Z I_{ZM}$ = (10 V) (32 mA) = 320 mW

2.5.1.3 Fixed R_L Variable V_{in}

Consider a zener voltage regulator with fixed R_L and variable V_{in} as shown in Fig. 2.5.13,

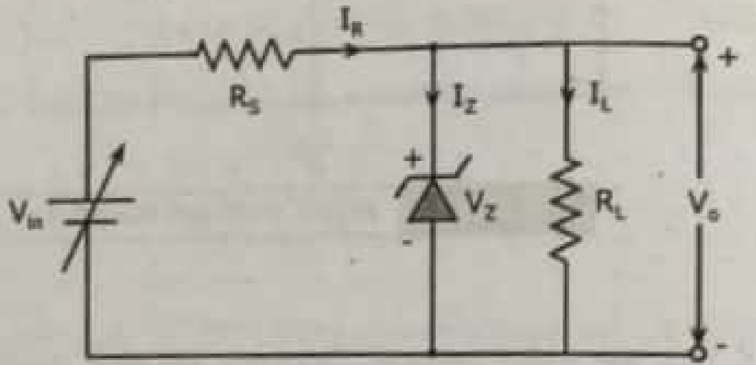


Fig. 2.5.14 Fixed R_L and Variable V_{in} Voltage Regulator

For fixed value of R_L in Fig. 2.5.14, the input D.C voltage V_{in} must be sufficiently large to turn the zener diode 'ON'. The minimum turn-on voltage $V_{in} = V_{in,\,min}$ is determined by,

$$V = V_Z = V_i \frac{R_L}{R_S + R_L}$$

Solving for V_{in},

We get, $$\boxed{V_{in,\,min} = V_Z \frac{R_L + R_S}{R_L}} \quad \text{... (2.5.10)}$$

The maximum voltage of V_{in} is limited by the maximum zener current I_{ZM}. Since $I_R = I_Z + I_L$, the maximum value of I_R is given as,

$$\boxed{I_{R,max} = I_{ZM} + I_L} \quad \text{... (2.5.11)}$$

Since I_L is fixed that it is equal to V_Z/R_L and I_{ZM} is the maximum value of I_Z, the maximum value of V_{in} that can be applied without driving excessive current through the zener is given as,

$$\boxed{V_{in,max} = V_{R,max} + V_Z = I_{R,max} R_S + V_Z} \quad \text{... (2.5.12)}$$

EXAMPLE PROBLEM 1

Determine the range of values of V_i that will maintain the zener diode in the voltage regulator circuit of Fig. 2.5.15 in the 'ON' state.

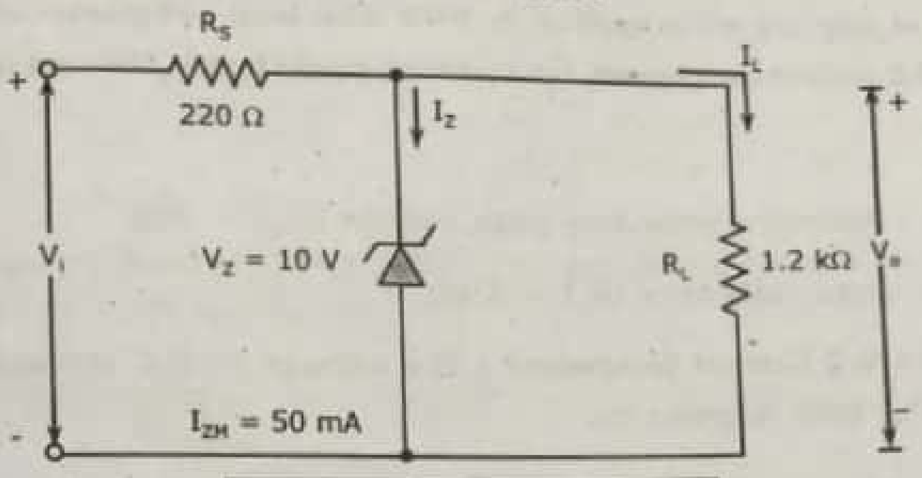


Fig. 2.5.15 Voltage Regulator

SOLUTION

Using Eq. (2.5.10), minimum input voltage is determined as,

$$V_{i(min)} = V_Z \frac{R_L + R_S}{R_L} = (10\text{ V}) \times \frac{1200\ \Omega + 220\ \Omega}{1200\ \Omega} = 11.83\text{ V}$$

The load current is, $I_L = \frac{V_L}{R_L} = \frac{V_z}{R_L} = \frac{10\text{ V}}{1.2\text{ k}\Omega} = 8.33\text{ mA}$

The maximum current through the series resistor is given by Eq. (2.5.11) as,

$$I_{R(max)} = I_{ZM} + I_L = 50\text{ mA} + 8.33\text{ mA} = 58.33\text{ mA}$$

The maximum input voltage is given by Eq. (2.5.12)

$$V_{i(max)} = I_{S(max)} R_S + V_Z = (58.33\text{ mA})(0.22\text{ k}\Omega) + 10\text{ V} = 22.8\text{ V}$$

A plot of V_o versus V_i is shown in Fig. 2.5.16.

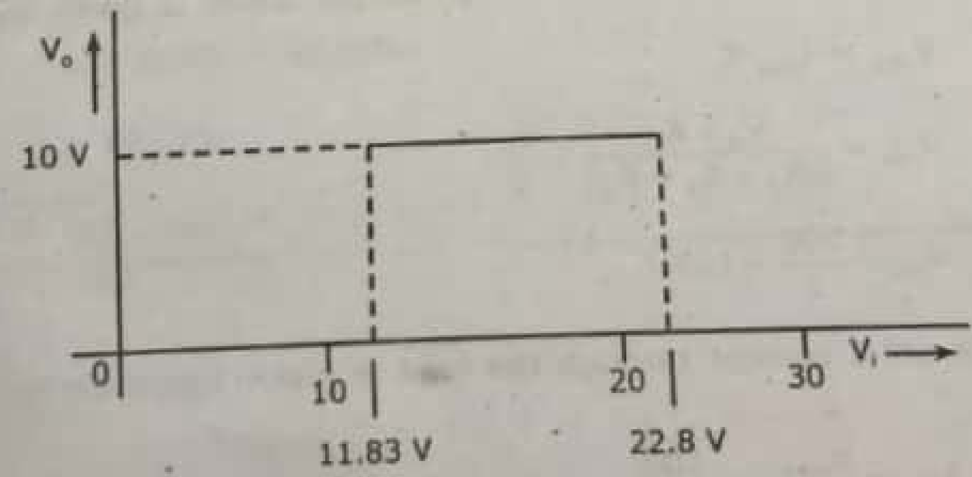


Fig. 2.5.16 Plot of V_o Versus V_i

$1+p$
$1+q^2c_i^2 - q$
$q^2c_i^2 - q2 + 1$ ... eqn in q
quadratic eqn
$q = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ —(2).
$= \frac{2 \pm \sqrt{2^2 - 4 \times 1 \times c_i^2}}{2 \times c_i^2}$

2.6 SOLVED PROBLEMS

SOLVED PROBLEM 1

A voltage of 200 cos ωt is applied to HWR with load resistance of 5 kΩ. Find the maximum D.C current component, r.m.s current, ripple factor, TUF and rectifier efficiency.

[May/June - 08]

SOLUTION

Given Data : Maximum secondary peak voltage (V_m) = 200

Load resistance (R_L) = 5 kΩ

(1) Maximum D.C Current Component : The average or D.C content of the voltage across the load is given by,

$$V_{DC} = \frac{V_m}{\pi(R_L + R_f + R_S)}$$

Assuming diode to be ideal $(R_f = 0)$ and neglecting secondary winding resistance $(R_S = 0)$, we have,

$$I_{DC} = \frac{200}{\pi} = 63.7 \text{ V}$$

Then, the maximum D.C current component of HWR is given by,

$$I_{DC} = \frac{I_m}{\pi} = \frac{V_m}{\pi(R_L + R_f + R_S)}$$

$$= \frac{V_m}{\pi R_L}$$

$$\Rightarrow \quad I_{DC} = \frac{63.7}{5 \times 10^3} = 12.732 \ mA$$

(2) R.M.S Current : For HWR, rms voltage across diode is given by,

$$V_{rms} = I_{rms} R_L$$

$$\Rightarrow \quad V_{rms} = \frac{V_m \times R_L}{2(R_f + R_S + R_L)} = \frac{V_m}{2}$$

$$\therefore \quad V_{rms} = \frac{200}{2} = 100 \text{ V}$$

Then, the r.m.s current through the load is given by,

$$I_{rms} = \frac{V_{rms}}{R_L} = \frac{100}{5 \times 10^3} = 20 \ mA$$

(3) **Ripple Factor :** The expression for ripple factor of HWR is given by,

$$\gamma = \sqrt{\left[\frac{I_{r.m.s}}{I_{D.C}}\right]^2 - 1}$$

$$\Rightarrow \quad \gamma = \sqrt{\left[\frac{20 \times 10^{-3}}{12.732 \times 10^{-3}}\right]^2 - 1}$$

$$\gamma = 1.211$$

(4) **Transformer Utilization Factor (TUF) :** The expression for transformer utilization factor TUF of HWR is given by,

$$TUF = \frac{P_{D.C}}{P_{A.C\ rated}}$$

$$= \frac{I_{D.C}^2 R_L}{\sqrt{2}\, I_{r.m.s}^2 R_L}$$

$$= \frac{(12.732 \times 10^{-3})^2}{\sqrt{2} \times (20 \times 10^{-3})^2}$$

$$= 0.287$$

$$\boxed{TUF = 0.287}$$

(5) **Rectifier Efficiency :** The expression for rectifier efficiency of HWR is given by,

$$\eta = \frac{\text{D.C output power}}{\text{A.C output power}} = \frac{P_{D.C}}{P_{A.C}} = \frac{I_{D.C}^2 R_L}{I_{r.m.s}^2 R_L}$$

$$\Rightarrow \quad \eta = \frac{(12.732 \times 10^{-3})^2}{(20 \times 10^{-3})^2}$$

$$= 0.4053 = 40.53\%$$

$$\therefore \quad \eta = \mathbf{40.53\%}$$

SOLVED PROBLEM 2

Determine

(a) **D.C output voltage**

(b) **PIV**

(c) **Rectification efficiency of the given circuit.**

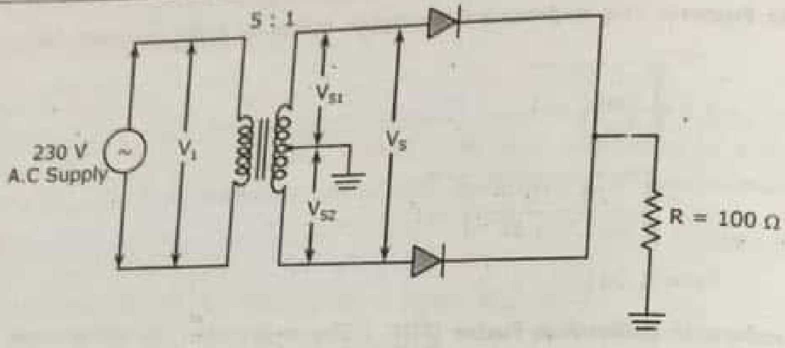


Fig. 2.6.1

SOLUTION [June - 09], [Aug./Sep. - 08], [May/June - 08]

Given Data : RMS value of Supply voltage, (V_1) = 230 V

Turn ratio, $(N_1:N_2)$ = 5 : 1

Load resistance, (R_L) = 100 Ω

The voltage induced at secondary winding is given by,

$$V_{S(rms)} = V\left(\frac{N_1}{N_2}\right) = 230\left(\frac{1}{5}\right) = 46 \text{ V}$$

Voltage across half of secondary winding,

$$V_{S1} = V_{S2} = \frac{V_{S(rms)}}{2} = \frac{46}{2} = 23 \text{ V}$$

Maximum value of secondary voltage,

$$V_m = \sqrt{2}\, V_{S1}$$

$$V_m = \sqrt{2} \times 23 = 32.527 \text{ V}$$

(a) D.C Output Voltage : The D.C output voltage expression is given by,

$$V_{D.C} = \frac{2V_m}{\pi} = \frac{2 \times 32.527}{\pi} = 20.707 \text{ V}$$

(b) PIV (Peak Inverse Voltage) : Peak inverse voltage across each diode is given by,

$$PIV = 2\, V_m = 2 \times 32.527$$

$$\therefore \quad PIV = 65.054 \text{ V}$$

(c) **Rectification Efficiency :** Peak value of secondary current,

$$I_m = \frac{V_m}{R_L} = \frac{32.527}{100} = 325.27\ mA$$

The D.C load current is given by,

$$I_{D.C} = \frac{2\,I_m}{\pi} = \frac{2 \times 325.27 \times 10^{-3}}{\pi} = 207.07\ mA$$

The r.m.s value of the current at the load resistance is given by,

$$I_{r.m.s} = \frac{I_m}{\sqrt{2}} = \frac{325.27 \times 10^{-3}}{\sqrt{2}} = 230\ mA$$

D.C output power,

$$P_{D.C} = I_{D.C}^2 \times R_L$$

$$= (207.07 \times 10^{-3}) \times 100 = 4.288\ Watt$$

A.C output power,

$$P_{A.C} = I_{r.m.s}^2 \times R_L$$

$$= (230 \times 10^{-3})^2 \times 100 = 5.29\ Watt$$

Then, the rectification efficiency of the given full-wave circuit is given by,

$$\eta = \frac{P_{D.C}}{P_{A.C}} = \frac{4.288}{5.29} = 0.811$$

$$= 81.1\%$$

$$\therefore \qquad \eta = 81.1\%$$

SOLVED PROBLEM 3

A diode whose internal resistance is 20 Ω is to supply power to a 100 Ω load from 100 V (r.m.s) source of supply. Calculate

(1) Peak load current

(2) D.C load current

(3) A.C load current

(4) The percentage regulation from no-load to the given load.

$q = \frac{-b \pm \sqrt{b^2 ...}}{2a}$

$= \frac{\pm\sqrt{z^2 - 4 \times 1 \times C_i^2}}{2 \times C_i^2}$

 [Aug./Sep. - 08], [May/June - 09]

SOLUTION

Given Data : Internal resistance of the diode, $(R_f) = 20\ \Omega$

Load resistance, $(R_L) = 100\ \Omega$

R.M.S supply voltage, $(V_{r.m.s}) = 110$ V

Then, the maximum amplitude of the supply voltage is,

$$V_m = \sqrt{2}\, V_{r.m.s} = \sqrt{2} \times 110 = 155.563 \text{ V}$$

(1) Peak Load Current

$$I_m = \frac{V_m}{R_f + R_L} = \frac{155.563}{20+100} = \frac{155.563}{120} \quad \text{(Neglecting } R_S\text{)}$$

$$\therefore \quad I_m = 1.296 \text{ A}$$

(2) D.C Load Current

$$I_{D.C} = \frac{I_m}{\pi} = \frac{1.296}{\pi}$$

$$\therefore \quad I_{D.C} = 0.413 \text{ A}$$

(3) A.C load current

$$I_{A.C} = I_{r.m.s} = \frac{I_m}{2} = \frac{1.296}{2}$$

$$\therefore \quad I_{A.C} = 0.648 \text{ A}$$

(4) The percentage Regulation from No-load to The given Load : No-load output voltage is given by,

$$(V_{DC})_{NL} = \frac{V_m}{\pi} = \frac{155.563}{\pi} = 49.517 \text{ V}$$

Full-load output voltage is given by,

$$(V_{DC})_{FL} = \frac{V_m}{\pi} - I_{DC} R_f = 49.517 - 0.413 \times 20 = 41.257 \text{ V}$$

$$\% \text{ regulation} = \frac{(V_{DC})_{NL} - (V_{DC})_{FL}}{(V_{DC})_{FL}} \times 100\%$$

$$= \frac{49.517 - 41.257}{49.517} \times 100$$

$$\therefore \quad \% \text{ regulation} = 20.02\%$$

SOLVED PROBLEM 4

A FWR circuit is fed from a transformer having a center-tapped secondary winding. The r.m.s voltage from either end of secondary to center tap is 30 V. If the diode forward resistance is 5 Ω and that of the secondary is 10 Ω for a load of 900 Ω. Calculate.

(1) Power delivered to load.

(2) % regulation at full-load.

(3) Efficiency at full-load.

(4) TUF of secondary.

[Aug./Sep. - 07]

SOLUTION

Given Data : $V_m = 30$ V

Diode forward resistance, $(R_f) = 5\ \Omega$

Secondary coil resistance, $(R_S) = 10\ \Omega$

Load resistance, $(R_L) = 900\ \Omega$

The current flowing through the load is given by,

$$I_L = \frac{V_L}{R_S + R_f + R_L} = \frac{19.099}{10 + 5 + 900} = 20.873 \text{ mA}$$

(1) Power Delivered to Load

$$P_{D.C} = I_L^2 R_L$$

$$= (20.873 \times 10^{-3}) \times 900$$

$$= 0.392 \text{ Watt}$$

$$\therefore \quad P_{D.C} = 0.392 \text{ Watts}$$

(2) % Regulation at Full-load

$$\% \text{ regulation at full-load} = \frac{R_s + R_f}{R_L} \times 100$$

$$= \frac{10 + 5}{900} \times 100 = \frac{15}{900} \times 100 = 1.667$$

$$= \frac{15}{900} \times 100 = 1.667$$

$$\therefore \quad \% \text{ regulation} = 1.667$$

(3) **Efficiency at Full-load**

$$\eta = \frac{8}{\pi^2} \times \frac{R_L}{R_s + R_f + R_L}$$

$$= \frac{8}{\pi^2} \times \frac{900}{10 + 5 + 900} = \frac{8}{\pi^2} \times \frac{900}{915} = 0.7973 = 79.73\%$$

$$\therefore \quad \eta = 79.73\%$$

(4) **TUF of Secondary :** R.M.S voltage at the load resistance, R_L is given by,

$$V_{r.m.s} = \frac{V_m}{\sqrt{2}} = \frac{30}{\sqrt{2}} = 21.213 \text{ V}$$

R.M.S current flowing through R_L is given by,

$$I_{r.m.s} = \frac{I_m}{\sqrt{2}} = I_m = \frac{V_m}{R_s + R_f + R_L} = \frac{30}{10 + 5 + 900} = 32.787 \text{ mA}$$

$$\therefore \quad I_{r.m.s} = \frac{32.787 \times 10^{-3}}{\sqrt{2}} = 23.184 \text{ mA}$$

A.C rating of the transformer secondary,

$$P_{A.C} = V_{r.m.s} \times I_{r.m.s}$$

$$= 21.213 \times 23.184 \times 10^{-3}$$

$$\therefore \quad P_{A.C} = 0.492 \text{ Watts}$$

Then, the transformer utilization factor (TUF) is given by,

$$TUF = \frac{P_{DC}}{P_{A.C}} = \frac{0.392}{0.492} = 0.797$$

SOLVED PROBLEM 5

Compute the average and RMS load currents, TUF of an unfiltered centre tapped Full Wave Rectifier specified below?

Input voltage to transformer = 220 V/50 Hz.

Step of transformer secondary winding in each secondary segment and diode forward resistance = 100 Ω?

Load resistance, R_L = 220 Ω?

[Nov. - 2010]

SOLUTION

Given Data : V_{in} = 220 V (RMS voltage)

$R_f = 100\ \Omega$

$R_L = 220\ \Omega$

$N_1 : N_2 = 4:1$

Maximum primary voltage,

$$V_{P,max} = \sqrt{2} \times \text{RMS value of voltage of transformer.}$$

$$= \sqrt{2} \times 220 = 311.12\ V$$

Maximum voltage to bridge rectifier from secondary,

$$V_{S,max} = V_m \times V_{P\,max}\left(\frac{N_2}{N_1}\right)$$

$$= 311.12\left(\frac{1}{4}\right) = 77.78 \text{ volts}$$

$$I_{max} = \frac{V_m}{R_L + R_F}$$

$$= \frac{77.78}{220 + 100} = 0.24\ A$$

Average current,

$$I_{L,DC} = \frac{2I_{max}}{\pi}$$

$$= 0.154\ A$$

RMS current,

$$I_{LRMS} = \frac{I_{max}}{\sqrt{2}}$$

$$= \frac{0.24}{\sqrt{2}}$$

$$= 0.169\ A$$

We have, $$TUF = \frac{8}{\pi^2}\left(\frac{R_L}{R_L + R_F}\right)$$

$$= \frac{8}{(3.14)^2}\left(\frac{220}{320}\right)$$

$$= 0.811\ (0.687) = 0.557$$

SOLVED PROBLEM 6

A HWR circuit has filter capacitor of 1200 μF and is connected to a load of 400 Ω. The rectifier is connected to a 50 Hz, 120 $V_{r.m.s}$ source. It takes 2 msec for the capacitor to recharge during each cycle. Calculate the minimum value of the repetitive surge current for which the diode should be rated.

[Aug./Sep. - 07]

SOLUTION

Given Data : Frequency f = 50 Hz.

Capacitor c = 1200 μf

Load resistance, R_L = 400 Ω

$V_{r.m.s}$ = 120

T = 2 msec.

For a half-wave rectifier with capacitor filter,

Capacitor charging time + Capacitor discharging time = Half the periodic time of the wave from $T_1 + T_2 = \frac{T}{2} = \frac{1}{2f}$ $\qquad \left[\because T = \frac{1}{f}\right]$

$$T_2 = \frac{1}{2f} - T_1 = \frac{1}{2 \times 50} - 2 \times 10^{-3} = 8 \text{ msec}$$

The output voltage of a half-wave rectifier with capacitor filter is given by,

$$V_o(t) = \begin{cases} V_m e^{-\frac{1}{RC}} & 0 \le \omega t \le \beta \\ V_m \cos(\omega t) & \beta \le \omega t \le 2\pi \end{cases}$$

Where, $\beta = \omega T_2 = 2\pi f T_2 = 2\pi \times 50 \times 8 \times 10^{-3} = 2.513$ rad.

The r.m.s value of the output voltage is given by,

$$V_{rms} = \left[\frac{1}{2\pi}\left[\int_0^{\beta}\left[V_m e^{\frac{-\omega t}{\omega RC}}\right]^2 d(\omega t) + \int_{\beta}^{2\pi}(V_m \cos \omega t)^2 d(\omega t)\right]\right]^{\frac{1}{2}}$$

$$\Rightarrow \quad V_{rms} = V_m\left[\frac{1}{2\pi}\left[\int_0^{\beta} e^{\frac{-2\omega t}{\omega RC}} d(\omega t) + \int_{\beta}^{2\pi} \cos^2 \omega t \, d(\omega t)\right]\right]^{\frac{1}{2}}$$

$$\Rightarrow \quad V_{rms} = V_m\left[\frac{1}{2\pi}\left[\frac{\omega RC}{2}\left(1 - e^{\frac{-2\beta}{\omega RC}}\right) + \pi - \frac{\beta}{2} - \frac{\sin 2\beta}{4}\right]\right]^{\frac{1}{2}}$$

$$\Rightarrow \quad V_{rms} = V_m\left[\frac{1}{2\pi}[75.398(1 - 0.967) + \pi - 1.257 + 0.238]\right]^{\frac{1}{2}}$$

$$V_{r.m.s} = V_m[0.857]$$

$$\Rightarrow \quad V_m = \frac{V_{r.m.s}}{0.857}$$

$$= \frac{120}{0.857}$$

$$= 140.023 \text{ V}$$

But, the minimum value of repetitive surge current is equal to the peak current I_m i.e.,

$$I_{surge} = I_m$$

$$= \frac{V_m}{R_L}$$

$$= \frac{140.023}{400}$$

$$= 0.35 \text{ A}$$

$$\therefore \quad I_{surge} = 0.35 \text{ A}$$

VED PROBLEM 7

What is the ripple factor if a power supply of 220 V, 50 Hz is to be full wave rectified and filtered with a 220 μF capacitor before delivering to a resistive load of 120 Ω? Compute the value of the capacitor for the ripple factor to be less than 15%.

[Nov. - 2010]

UTION

Given Data : Frequency f = 50 Hz

Capacitor C = 220 μF

Load resistance, R_L = 120 Ω

(1) Ripple Factor : We have, ripple factor for a full wave rectifier with capacitor filter defined by,

$$\text{Ripple factor} = \frac{1}{4\sqrt{3}\, fCR_L}$$

$$= \frac{1}{4\sqrt{3} \times 50 \times 220 \times 10^{-6} \times 120}$$

$$= \frac{1}{9.14 \times 10^{6} \times 10^{-6}}$$

$$\therefore \quad \gamma = 10.9\%$$

$q^2 C_i^2 - q^2$
quadratic eqn
$q = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ —— ②.
$\pm \sqrt{z^2 - 4 \times 1 \times C_i^2}$

(2) Value of capacitor for ripple factor < 15%

$$\text{Ripple factor} \le \frac{1}{4\sqrt{3}fCR_L}$$

$$15\% \le \frac{1}{4\sqrt{3} \times 50 \times C \times 120}$$

$$e \le \frac{1}{4\sqrt{3} \times 0.15 \times 50 \times 120}$$

$$\le 1.60 \times 10{-}4 \le 160\ \mu F$$

∴ Value of C must be less than 160 μF to get ripple factor less than 15%

SOLVED PROBLEM 8

Compute ripple factor of an L section choke input filter used at the output of a full wave rectifier and capacitor values of the filter are given as 10 H and 8.2 μF respectively?

[Nov. - 2010]

SOLUTION

Given Data : Inductor L = 10 H

Capacitor C = 8.2 μF

$$\text{Ripple factor} = \frac{1}{6\sqrt{2} \times \omega^2 LC}$$

Assume, f = 50 HZ

∴ $\omega = 2\pi f = 2 \times 3.14 \times 50 = 314$ Hz

$$\Rightarrow \text{Ripple factor} = \frac{1}{6\sqrt{2}(314)^2 \times 10 \times 8.2 \times 10^{-6}}$$

$$= 0.014$$

SOLVED PROBLEM 9

A FWR is used to supply power to a 2000 Ω load choke inductors of 20 H inductance and capacitor of 16 μF are available. Compute the ripple factor using,

(i) One Inductor Filter.

(ii) One Capacitor Filter.

[April/May - 09]

SOLUTION

Given Data : Load Resistance $R_L = 200\ \Omega$

Frequency $f = 50$ Hz

Inductor = 20 H

Capacitor = $16\ \mu F = 16 \times 10^{-6}$ f

(i) Inductor Filter

$$\gamma = \frac{R_L}{3\sqrt{2}\,\omega L}$$

$$= \frac{R_L}{3 \times 1.414 \times 2\pi f \times L} \qquad \text{[Using Eq. (3.9.8)]}$$

$$= \frac{2000}{3 \times 1.414 \times 2\pi \times 50 \times 20}$$

$$= \frac{100}{3 \times 1.414 \times 2\pi \times 50}$$

$$\therefore \quad \gamma = 0.074$$

(ii) Capacitor Filter

$$\gamma = \frac{1}{4\sqrt{3}\, fCR_L}$$

$$= \frac{1}{4\sqrt{3} \times 50 \times 16 \times 10^{-6} \times 2000}$$

$$= \frac{1}{4 \times 1.732 \times 50 \times 16 \times 10^{-6} \times 2000}$$

$$\therefore \quad \gamma = 0.009$$

SOLVED PROBLEM 10

A FWR is used has a peak output voltage of 25 volt at 50 Hz and feeds a resistive load of 1 kΩ. The filter is used in shunt capacitor one with C = 20 μF determine,

(i) DC load current.

(ii) DC output voltage.

(iii) Ripple voltage.

(iv) Ripple factor.

SOLUTION

Given Data : Max. value of voltage across the load ($V_{L\ max}$) = $V_{S\ max}$ = 25 V

Load Resistance (R_L) = 1 kΩ = 100 Ω

Shunt capacitance (C) = 20 μF = 2 × 10^{-6} F

Supply frequency (f) = 50 Hz

(i) D.C Load Current

$$V_{dc} = V_{Lmax} - \frac{I_{dc}}{4fC} \text{ (or) } I_{dc} R_L + \frac{I_{dc}}{4fC} = V_{L\ max} \qquad (\because V_{dc} = I_{dc} R_L)$$

$$I_{dc}\left[1000 + \frac{1}{4 \times 50 \times 20 \times 10^{-6}}\right] = V_{L\ max} \text{ (or) } 25$$

$$I_{dc}[1, 250] = 25$$

$$\Rightarrow \qquad I_{dc} = \frac{25}{1250} = 20 \text{ mA}$$

(ii) D.C Output Voltage

$$V_{dc} = I_{dc} R_L = 20 \times 10^{-3} \times 100 = 20 \text{ V}$$

$$\therefore \qquad V_{dc} = 20 \text{ V}$$

(iii) Ripple Voltage

$$V_r = \frac{I_{dc}}{2fC} = \frac{20 \times 10^{-3}}{2 \times 50 \times 20 \times 10^{-6}}$$

$$= 10 \text{ V}$$

$$\therefore \qquad V_r = 10 \text{ V}$$

(iv) Ripple Factor

$$\gamma = \frac{1}{4\sqrt{3}\ fCR_L} \qquad \text{[Using Eq. (3.10.6)]}$$

$$= \frac{1}{4 \times 1.732 \times 50 \times 20 \times 10^{-6} \times 1000}$$

$$= 0.144$$

$$\therefore \qquad \gamma = 0.144$$

SOLVED PROBLEM 11

For the zener voltage regulator circuit shown in Fig. 2.6.2. Determine the range of R_L and I_L that will result in output voltage being maintained at 10 V.

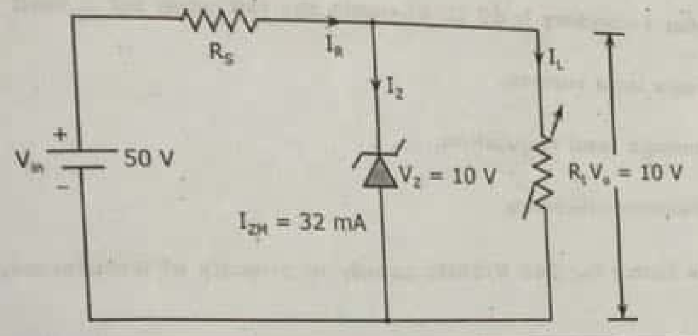


Fig. 2.6.2 Zener Diode Voltage Regulator with Fixed V_{in} and Variable R_L

SOLUTION

[April - 2003], [May/June - 05]

Given Data : Input voltage (V_{in}) = 50 V

Series resistance (R_S) = 1 kΩ

Zener voltage (V_Z) = 10 V

Maximum zener current (I_{ZM}) = 32 mA

From Fig. 2.6.2, we have, current (I_R) as,

$$I_R = \frac{V_{in} - V_o}{R} = \frac{50 - 10}{1,000} = 40 \text{ mA}$$

Load current I_L will be maximum when Zener current I_Z = 0. so,

$$I_{L,max} = I_R - I_{Z\,min} = 40 - 0 = 40 \text{ mA}$$

Corresponding load resistance will be minimum and

$$R_{L\,min} = \frac{V_L}{I_{L\,max}} = \frac{V_Z}{I_{L\,max}} = \frac{10}{40 \times 10^{-3}} = 250\ \Omega$$

Load current I_L will be minimum when I_Z is maximum given $I_{Z,max}$ = 32 mA

$$I_{L\,min} = I_R - I_{Z\,max} = 40 - 32 = 8 \text{ mA}$$

Corresponding load resistance will be maximum and

$$R_{L\,max} = \frac{V_L}{I_{L\,min}} = \frac{10}{8 \times 10^{-3}} = 1.25\ \Omega$$

∴ Range of R_L : 250 Ω to 1.25 kΩ.

Range of I_L : 8 mA to 40 mA

SOLVED PROBLEM 12

The secondary voltages of a centre tapped transformer are given as 60 V 0 V 60 the total resistance of secondary coil and forward diode resistance of each section transformer secondary is 62 Ω. Compute the following for a load resistance of 1 K

(i) Average load current.

(ii) Percentage load regulation.

(iii) Rectification efficiency.

(iv) Ripple factor for 240 V/50Hz supply to primary of transformer.

SOLUTION [Nov. - 2010

Peak value of secondary voltage to the rectifier circuit is,

$$V_m = V_{S1,RMS} \times \sqrt{2}$$

$$= 60\sqrt{2}$$

$$= 84.84 \text{ V}$$

Peak value of current is given by,

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

$$= \frac{84.84}{62 + 1000} \quad (\because \text{ Given } R_S + R_f = 62)$$

$$= \frac{84.84}{1062}$$

$$= 79.88 \text{ mA}$$

(i) Average load current,

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

$$= \frac{2 \times 79.88 \times 10^{-3}}{3.14}$$

$$= 50.87 \text{ mA}$$

(ii) Percentage load regulation

$$\% \text{ Load regulation} = \frac{R_S + R_f}{R_L} \times 100\%$$

$$= \frac{62}{1000} \times 100\% = 6.2\%$$

(iii) Rectification efficiency

$$\eta = \frac{8}{\pi^2} \times \frac{R_L}{R_S + R_f + R_L}$$

$$= 0.810 \times \frac{1000}{1062}$$

$$= 0.7627$$

$$\therefore \quad \% \eta = 76.27\%$$

(iv) Ripple factor 240 V/50 Hz supply to primary of transformer,

$$\gamma = 0.482$$

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