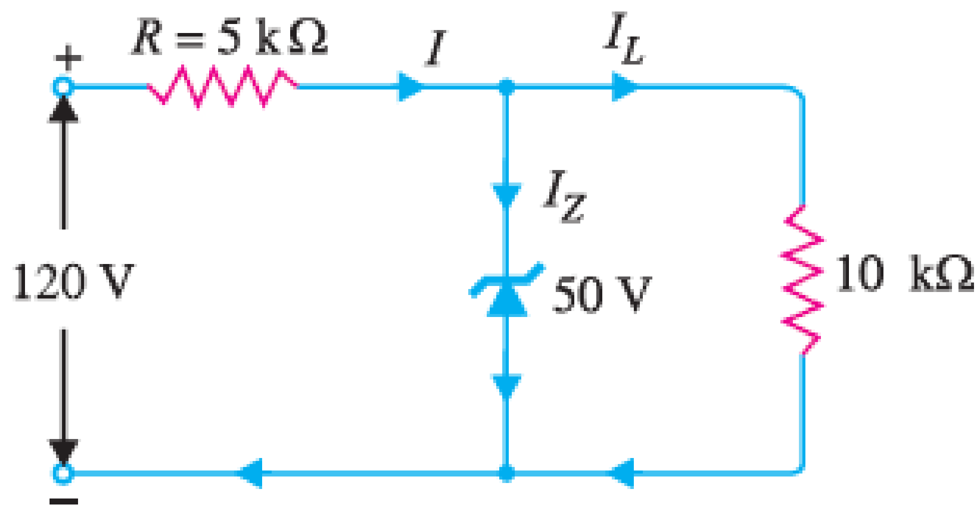
Zener Diode Numerical

Problems and solutions

Q.1: For the circuit , (i) find : (i) the output voltage (ii) the voltage drop across series resistance (iii) the current through zener diode.

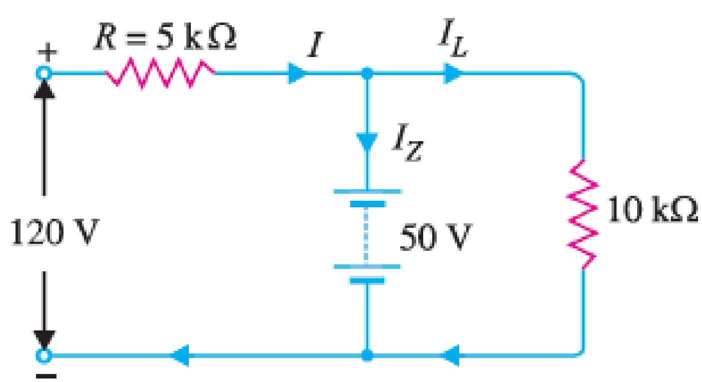


Solution:

If you remove the zener diode in Fig. 1, the voltage V across the open-circuit is given by :

$$V = \frac{R_L\ E_i}{R + R_L} = \frac{10 \times 120}{5 + 10} = 80\ \text{V}$$

Since voltage across zener diode is greater than VZ (= 50 V), the zener is in the "on" state. It can,
therefore, be represented by a battery of 50 V as shown in Fig. 1 (ii).



Output voltage $= V_Z =$ **50 V**

(ii)

Voltage drop across R = Input voltage $- V_Z = 120 - 50 =$ **70 V**

(iii)

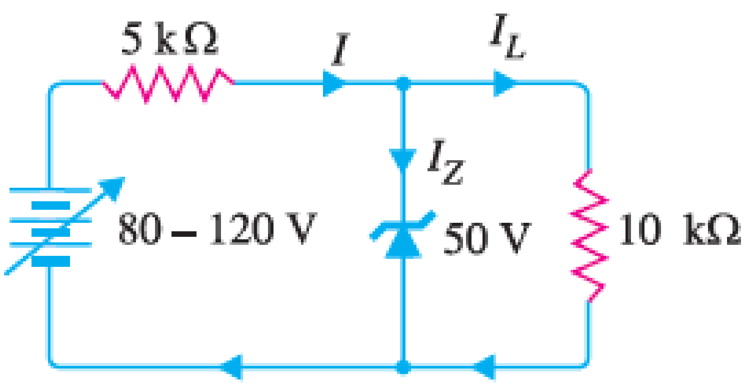
Load current, $I_L = V_Z/R_L = 50 \text{ V}/10 \text{ k}\Omega = 5 \text{ mA}$

$$\text{Current through } R,\ I = \frac{70 \text{ V}}{5 \text{ k}\Omega} = 14 \text{ mA}$$

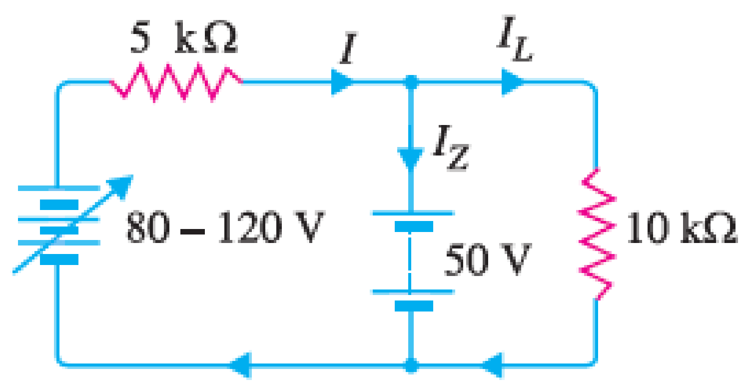
Applying Kirchhoff's first law, $I = I_L + I_Z$

$\therefore$ Zener current, $I_Z = I - I_L = 14 - 5 =$ **9 mA**

Q2. For the circuit (i),find the maximum and minimum values of zener diode current.



(i)



(ii)

Solution:

The first step is to determine the state of the zener diode. It is easy to see that for the given range of voltages (80 – 120 V), the voltage across the zener is greater than VZ (= 50 V). Hence the zener diode will be in the "on" state for this range of applied voltages. Consequently, it can be replaced by a battery of 50 V as shown in Fig. 2(ii).

Maximum zener current: The zener will conduct maximum current when the input voltage is maximum i.e. 120 V. Under such conditions :

$$\text{Voltage across } 5\text{ k}\Omega = 120 - 50 = 70\text{ V}$$

$$\text{Current through } 5\text{ k}\Omega,\ I = \frac{70\text{ V}}{5\text{ k}\Omega} = 14\text{ mA}$$

$$\text{Load current, } I_L = \frac{50\text{ V}}{10\text{ k}\Omega} = 5\text{ mA}$$

$$\text{Applying Kirchhoff's first law, } I = I_L + I_Z$$

$$\therefore \quad \text{Zener current, } I_Z = I - I_L = 14 - 5 = \mathbf{9\text{ mA}}$$

Minimum Zener current: The zener will conduct minimum current when the input voltage is minimum i.e. 80 V. Under such conditions, we have,

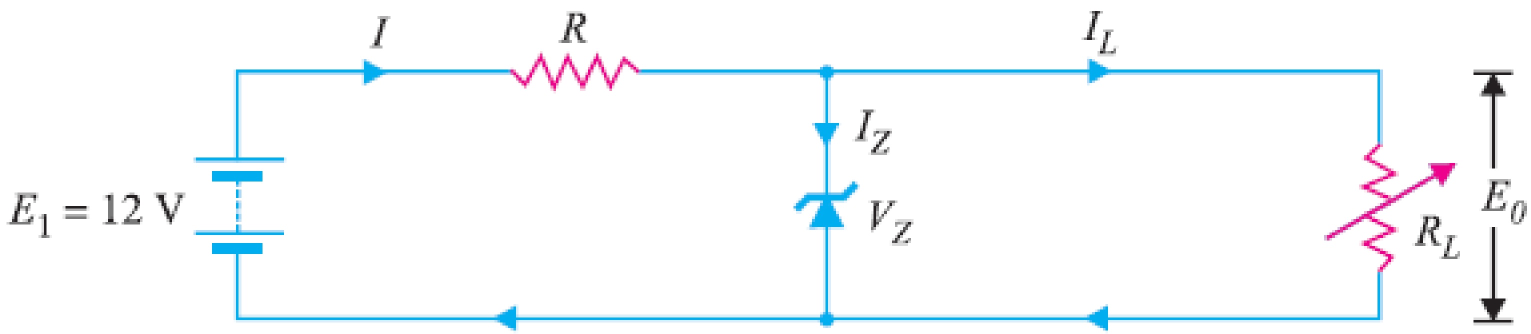
$$\text{Voltage across } 5\text{ k}\Omega = 80 - 50 = 30\text{ V}$$

$$\text{Current through } 5\text{ k}\Omega,\ I = \frac{30\text{ V}}{5\text{ k}\Omega} = 6\text{ mA}$$

$$\text{Load current, } I_L = 5\text{ mA}$$

$$\therefore \quad \text{Zener current, } I_Z = I - I_L = 6 - 5 = \mathbf{1\ mA}$$

Q3. A 7.2 V zener is used in the circuit shown in Fig. 3 and the load current is to vary from 12 to 100 mA. Find the value of series resistance R to maintain a voltage of 7.2 V across the load. The input voltage is constant at 12V and the minimum zener current is 10 mA.



Solution:

$$E_i = 12\text{ V}; \quad V_Z = 7.2\text{ V}$$

$$R = \frac{E_i - E_0}{I_Z + I_L}$$

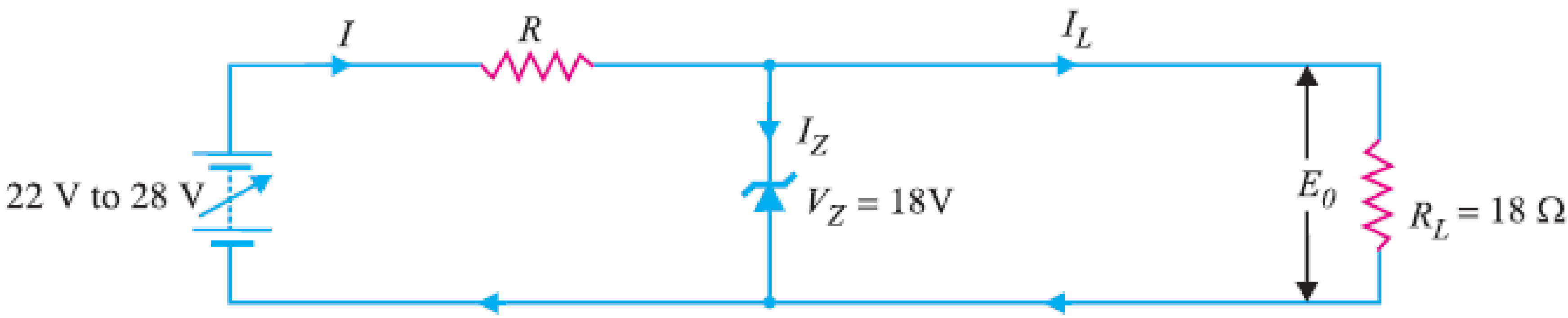
The voltage across R is to remain constant at 12 − 7.2 = 4.8 V as the load current changes from 12 to 100 mA. The minimum zener current will occur when the load current is maximum.

$$\therefore \quad R = \frac{E_i - E_0}{(I_Z)_{min} + (I_L)_{max}} = \frac{12\text{ V} - 7.2\text{ V}}{(10 + 100)\text{ mA}} = \frac{4.8\text{ V}}{110\text{ mA}} = 43.5\ \Omega$$

If R = 43.5 Ω is inserted in the circuit, the output voltage will remain constant over the regulating range. As the load current IL decreases, the zener current IZ will increase to such a value that IZ + IL = 110 mA.

Note that if load resistance is open-circuited, then IL = 0 and zener current becomes 110 mA.

Q4. The zener diode shown in Fig. 4 has VZ = 18 V. The voltage across the load stays at 18 V as long as IZ is maintained between 200 mA and 2 A. Find the value of series resistance R so that E0 remains 18 V while input voltage Ei is free to vary between 22 V to 28V.

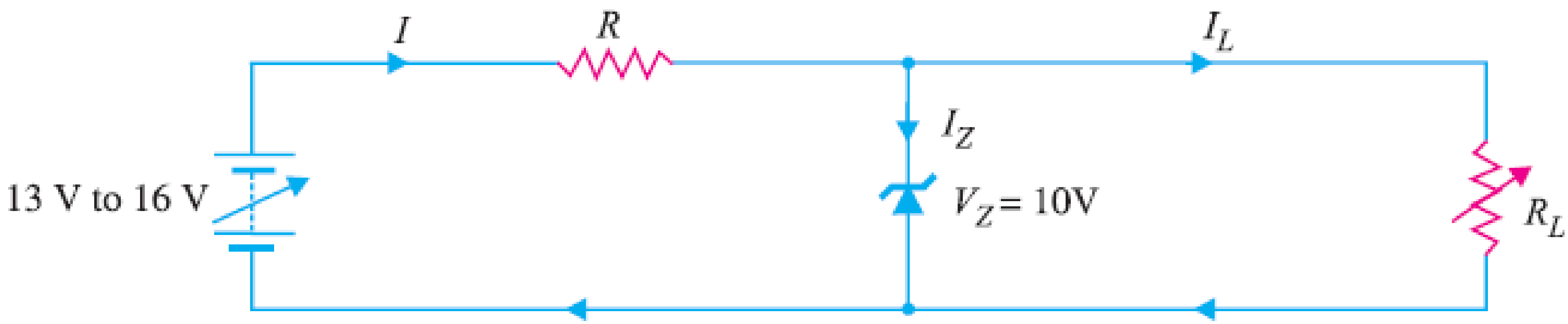


Solution:

The zener current will be minimum (i.e. 200 mA) when the input voltage is minimum (i.e. 22 V). The load current stays at constant value IL = VZ / RL = 18 V/18 Ω = 1 A = 1000 mA.

$$\therefore \quad R = \frac{E_i - E_0}{(I_Z)_{min} + (I_L)_{max}} = \frac{(22 - 18)\text{ V}}{(200 + 1000)\text{ mA}} = \frac{4\text{ V}}{1200\text{ mA}} = \mathbf{3.33\ \Omega}$$

Q5. A 10-V zener diode is used to regulate the voltage across a variable load resistor. The input voltage varies between 13 V and 16 V and the load current varies between 10 mA and 85 mA. The minimum zener current is 15 mA. Calculate the value of series resistance R.

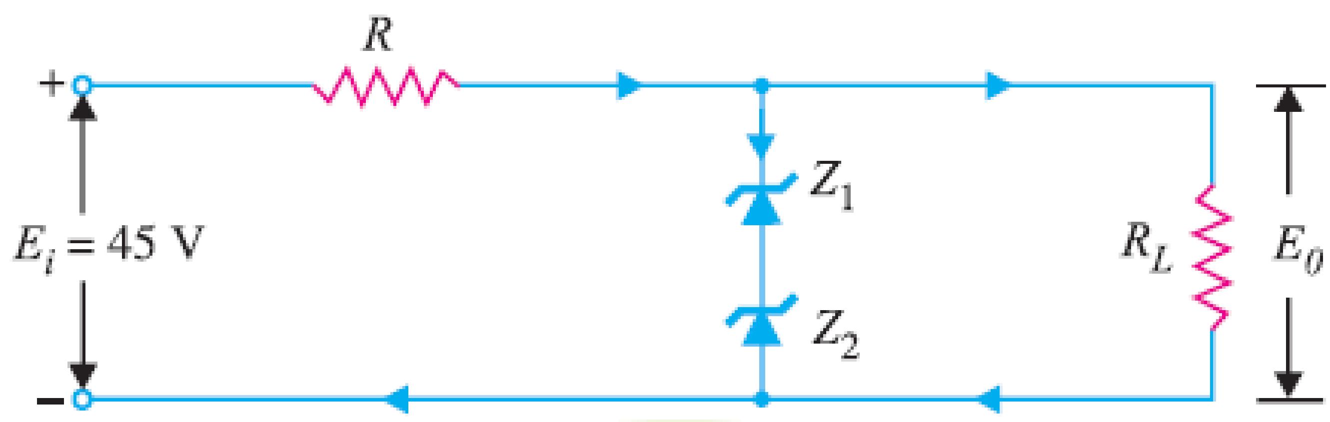


Solution:

The zener will conduct minimum current (i.e. 15 mA) when input voltage is minimum (i.e. 13 V).

$$\therefore \quad R = \frac{E_i - E_0}{(I_Z)_{min} + (I_L)_{max}} = \frac{(13 - 10)\text{ V}}{(15 + 85)\text{ mA}} = \frac{3\text{ V}}{100\text{ mA}} = \mathbf{30\ \Omega}$$

Q6. The circuit uses two zener diodes, each rated at 15 V, 200 mA. If the circuit is connected to a 45-volt unregulated supply, determine :(i) The regulated output voltage (ii) The value of series resistance R.



Solution:

When the desired regulated output voltage is higher than the rated voltage of the zener, two or more zeners are connected in series as shown in Fig. 6. However, in such circuits, care must be taken to select those zeners that have the same current rating.

$$\text{Current rating of each zener, } I_Z = 200 \text{ mA}$$

$$\text{Voltage rating of each zener, } V_Z = 15 \text{ V}$$

$$\text{Input voltage, } E_i = 45 \text{ V}$$

(*i*) $$\text{Regulated output voltage, } E_0 = 15 + 15 = \mathbf{30\ V}$$

(*ii*) $$\text{Series resistance, } R = \frac{E_i - E_0}{I_Z} = \frac{45 - 30}{200 \text{ mA}} = \frac{15 \text{ V}}{200 \text{ mA}} = \mathbf{75\ \Omega}$$

Q7. What value of series resistance is required when three 10-volt, 1000 mA zener diodes are connected in series to obtain a 30-volt regulated output from a 45 volt d.c. power source ?

Solution:

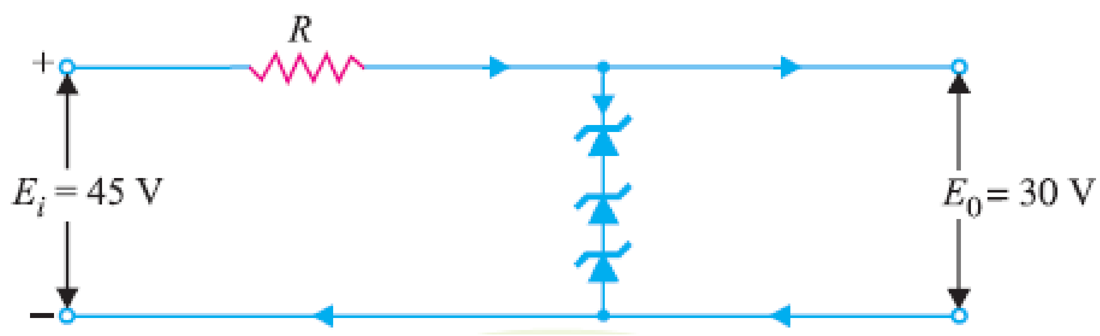


Fig. 7

Voltage rating of each zener, $V_Z = 10\text{V}$

Current rating of each zener, $I_Z = 1000\text{mA}$

Input unregulated voltage, $E_i = 45\text{V}$

Regulated output voltage, $E_0 = 10 + 10 + 10 = 30\text{ V}$

Let R ohms be the required series resistance.

$$\text{Voltage across } R = E_i - E_0 = 45 - 30 = 15\text{ V}$$

$$\therefore \quad R = \frac{E_i - E_0}{I_Z} = \frac{15\text{ V}}{1000\text{ mA}} = 15\ \Omega$$

Half Wave Rectifier

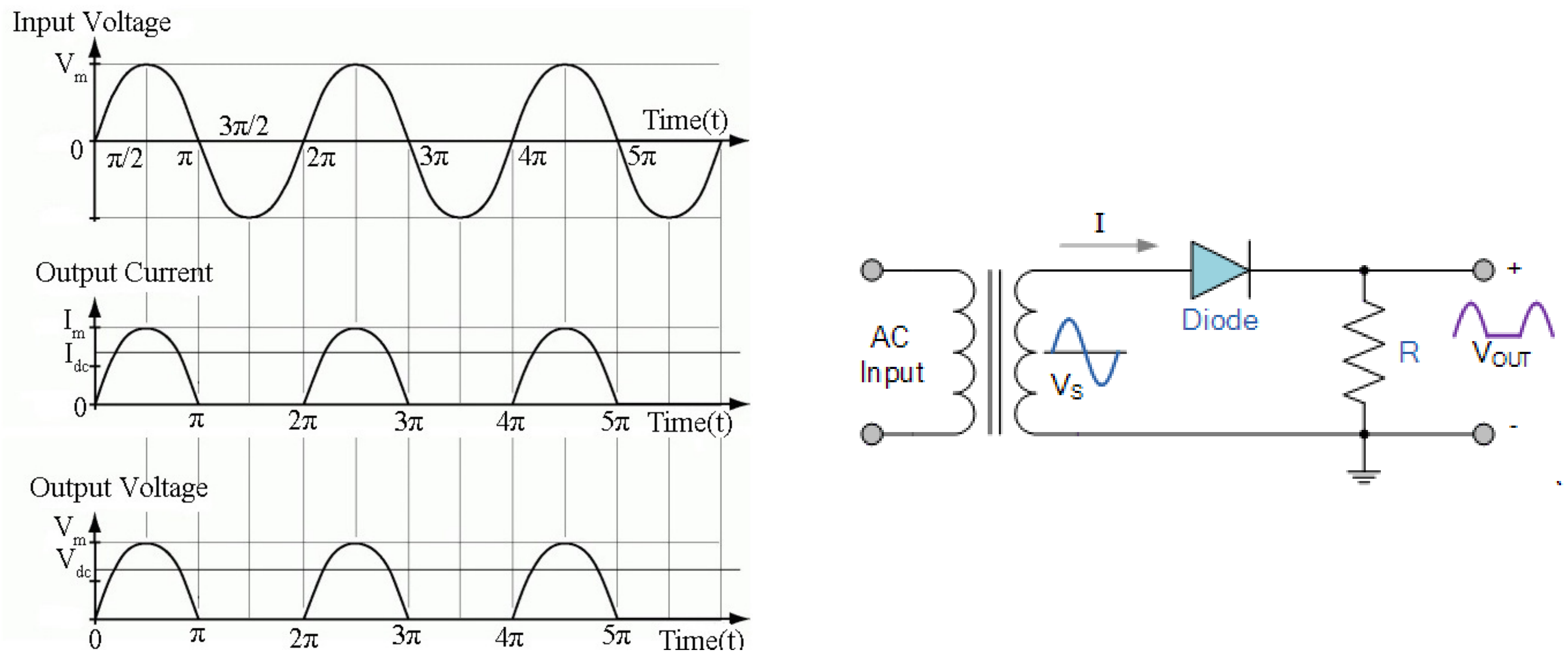


Figure 1

Let the amplitude V_m>> V_v where V_v is the cutin voltage for the pn diode. Hence we may assume that V_v = 0. Further let the diode be idealized with resistance R_f in the ON state and open circuit ($R_r = \infty$) in the OFF state. Then the current i through the diode and the load resistance R_L is given by,

$$v_i = V_m sin\omega t \quad .....(1)$$

$$i = I_m sin\alpha \quad \text{for } 0 \leq \alpha \leq \pi \quad .....(2)$$

$$i = 0 \quad \text{for } \pi \leq \alpha \leq 2\pi \quad .....(3)$$

Where $\alpha = \omega t$

And the peak current I_m is given by

$$I_m = \frac{V_m}{R_f + R_L} \quad ....(4)$$

Figure 1 hows the wave forms of voltage v_i fed to the diode, current I through the diode and the output voltage v_0. Current I flows through the diode and the load resistor R_L. only during the positive half of the applied input voltage v_i. this load current I flowing through the load resistor R_L produces the rectifier output voltage v_o.

Average or DC Current I_{dc} | Half Wave Rectifier

Average or DC output current of half wave rectifier is given by

$$I_{dc} = \frac{1}{2\pi} \int_0^{2\pi} i d\alpha \quad .....(5)$$

Where i is given by equation (2) and (3). Current i = 0 i.e. no current flows during the period $\pi to 2\pi$ radians. Hence,

$$I_d c = \frac{1}{2\pi} \int_0^{\pi} I_m sin\alpha d\alpha \quad .....(6)$$

Or, $I_{dc} = \frac{I_m}{\pi}$

$$= \frac{V_m}{\pi(R_f + R_1)} \quad ......(7)$$

RMS Current | Half Wave Rectifier

The RMS current I is given by,

$$I = [\frac{1}{2\pi} \int_0^{2\pi} i^2 d\alpha]^{\frac{1}{2}} \quad .....(8)$$

Substituting the value of i from equation (2) and (3) into equation (4) we get,

$$I = [\frac{1}{2\pi} \int_0^{\pi} I_m^2 sin^2\alpha d\alpha]^{\frac{1}{2}}$$

$$= \frac{I_m}{2} \quad .....(9)$$

$$= \frac{V_m}{2(R_f + R_L)} \quad .....(10)$$

Average or DC Output Voltage (V_{dc}) | Half Wave Rectifier

Average or DC output voltage of half wave rectifier is given by

$$V_{dc} = I_{dc} R_L = \frac{I_m R_L}{\pi} \quad .....(11)$$

$$= \frac{V_m}{\pi(1 + \frac{R_f}{R_L})} \quad .....(12)$$

RMS Output Voltage (V_O) | Half Wave Rectifier

RMS value of voltage across the load resistor is given by

$$V_O = I R_L = \frac{I_m R_L}{2} = \frac{V_m}{2(1 + \frac{R_f}{R_L})} \quad .....(13)$$

DC Output Power (P_{dc}) | Half Wave Rectifier

The output dc power across the load resistor R_L forms the useful output power and is given by,

$$P_{dc} = I_{dc}^2 R_L = \frac{I_m^2 R_L}{\pi^2} = \frac{V_m^2}{(R_f + R_L)^2} \frac{R_L}{\pi^2} \quad .....(14)$$

Total AC Input Power | Half Wave Rectifier

Out of the total a.c. power P_i from the a.c. voltage source, a part P_d is dissipated at the junction of diode and rest of the power P_r is dissipated in the load resistance R_L. Since the rectifier itself is assumed to be ideal, dissipated P_d takes place in the resistance R_f of the conducting diode. Then we get,

$$P_d = I^2 R_f = \frac{I_m^2}{4} R_f \quad .....(15)$$

$$P_r = I^2 R_L = \frac{I_m^2}{4} R_L \quad .....(16)$$

Total a.c. input power

$$P_i = P_d + P_r = \frac{I_m^2}{4}(R_f + R_L) \quad .....(17)$$

Rectifier Efficiency | Half Wave Rectifier

It is defined as the ratio of the dc output power P_{dc} to the a.c. input Power P_i and is, therefore, given by,

Rectifier Efficiency $\eta = \frac{P_{dc}}{P_i}$

$$= \frac{I_m^2 \frac{R_L}{\pi^2}}{I_m^2 \frac{(R_f + R_L)}{4}}$$

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

Or $\eta = \frac{0.406}{1 + \frac{R_f}{R_L}}$ ......(18)

% rectifier efficiency $= \frac{40.6}{1 + \frac{R_f}{R_L}}$ .....(19)

From equation (18) we conclude that the rectifier efficiency increases as the ratio $\frac{R_f}{R_L}$ reduces. Further fro equation (19) we find that the theoretical maximum value of rectifier efficiency of a half wave rectifier is o 40.6% and this is obtained when $\frac{R_f}{R_L} = 0$.

Assignment:
Find out the efficiency of Full Wave Rectifier