Zener Diode

A properly doped crystal diode which has a sharp breakdown voltage is called a Zener diode. Zener diode is a special type of semiconductor diode which works in a breakdown region. A Zener diode uses reverse (VR/IR) characteristics for its operation. Therefore, it is always reverse connected in the circuit i.e. it is always reverse biased.

Explanation

Zener diode acts as a simple diode when operated in forward-bias mode but when operated in reverse breakdown, Zener diode are found to have, extremely stable breakdown voltage over wide range of current levels. Hence Zener diode acts as the backbone of the voltage regulators.

- A Zener diode is like an ordinary diode except that it is properly doped so as to have a sharp breakdown voltage.
- A Zener diode is always reverse connected i.e. it is always reverse biased.
- A Zener diode has sharp breakdown voltage ,called Zener voltage VZ.
- when forward biased ,its characteristics are just those of ordinary diode.
- The Zener diode is not immediately burnt because it has entered the breakdown region. As long as the external circuit connected to the diode limits the diode current to less than burnt out value, the diode will not burn out. By reducing reverse voltage below Zener voltage(VZ),the Zener can be brought out of its breakdown level and restored to the pre breakdown state.

Symbol of Zener Diode

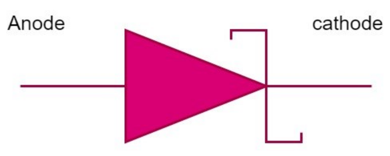


Fig: Symbol of Zener Diode

The symbol of Zener diode is same as an ordinary diode except that the bar is turned into Z-shape.

Zener Diode

Characteristics of Zener Diode

Voltage Vz: Reverse breakdown voltage 2.4 V to about 200 V; maximum up to 1 kV
Current Iz (max.): Maximum current at the rated Zener voltage Vz—200 uA to 200 A.
Current Iz (min.): Minimum current required for the diode to break down—5 mA and 10 mA.
Power rating: The maximum power the Zener diode can dissipate is the product of voltage across the diode and the current flowing through.
Typical values are 400 mW, 500 mW, 1 W, and 5 W; for surface mounted, 200 mW, 350 mW, 500 mW, and 1 W are typical.
Voltage tolerance: Typically ±5%.
Temperature stability: Diodes around 5 V is stable.
Zener resistance (Rz): The diode exhibits some resistance as evident from the IV characteristics.

Breakdown of Zener Diode

when Zener diode is operated in reverse biased mode there will always be same thermally produced electrons and holes. As the reverse voltage is increases ,the free electrons move with higher speed. Higher the reverse bias voltage greater is the speed of electrons, thus electrons collide with the atom of semiconductor ejecting valence electrons and this phenomenon continues until high current flows in the diode and the process is called breakdown.

Normally there are three breakdowns in Zener diode:

1. **Thermal Breakdown**
2. **Zener Breakdown**
3. **Avalanche Breakdown**

1.Thermal Breakdown:

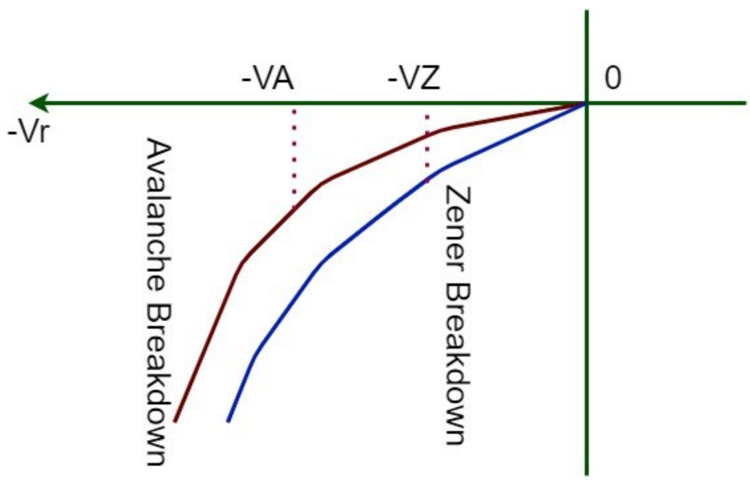
In ordinary diode, when reverse biasing voltage is increased to a breakdown value, a heavy current flow through device. This will cause overheating of device that permanently destroys it and the process is irreversible process.

2.Zener Breakdown:

In a heavily doped PN junction diode, Zener effect occurs due to spontaneous generation of hole-electrons pairs within the junction region by the effect of intense electric filed across it. The ionization is occurred due to the higher electric filed, causing the bonds to break and flow of high current. This effect is negative temperature coefficient(NTC) i.e. increase in temperature causes reduction in flow of current due to more ionization and less mobility of ions which occurs at low voltage. It is reversible process.

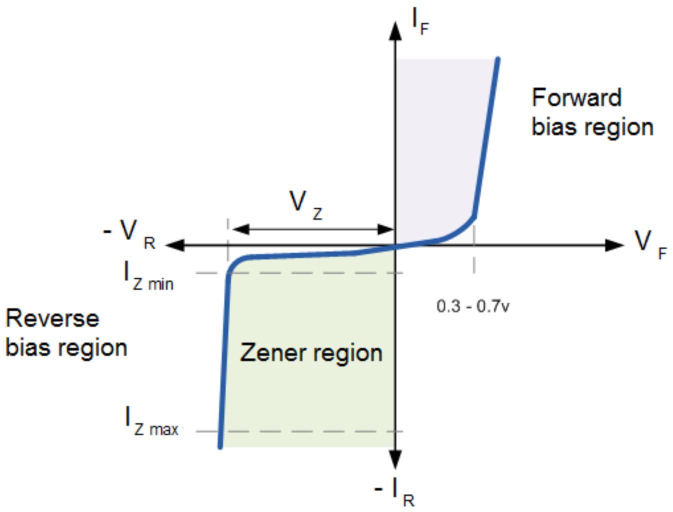
3.Avalanche Breakdown:

In a lightly doped PN junction diode, the high speed electrons due to large reverse bias voltage collide with valence electrons of the atoms fixed in the crystal lattice of depletion region. As a result some electrons are liberated out of the covalent bond, creating further hole electron pairs. The ionization occurs due to collisions of high speed electrons with valence electrons of depletion region, it is positive temperature coefficient(PTC) i.e. increase in temperature causes increases in flow of current occurs at high voltage. It is also reversible process.



Characteristics curve of Zener Diode

A Zener diode uses reverse(VR/IR) characteristics for its operation. Therefore it is always reverse connected in the circuit i.e. it is always reverse biased. As we increase reverse voltage from 0V,there is a very small reverse current IR (a few μA) which essentially remains constant until breakdown voltage is reached. Once the breakdown voltage (=VZ, Zener voltage) is reached ,the Zener diode conducts current heavily.



Zener Diode as Voltage stabilizer / Regulator

A Zener diode can be used as a voltage regulator to provide a constant voltage from a source whose voltage may vary over sufficient range. The Zener diode of Zener voltage Vz is reverse connected across the load RL across which constant output is desired. The series resistance R absorbs the output voltage fluctuations so as to maintain constant voltage across the load. Zener diode will maintain a constant voltage Vz(=E0) across the load so long as the input voltage does not fall below Vz.

When the circuit is properly designed, the load voltage E0 remains essentially constant (equal to vz) even though the input voltage Ei and load resistance RL may vary over a wide range.

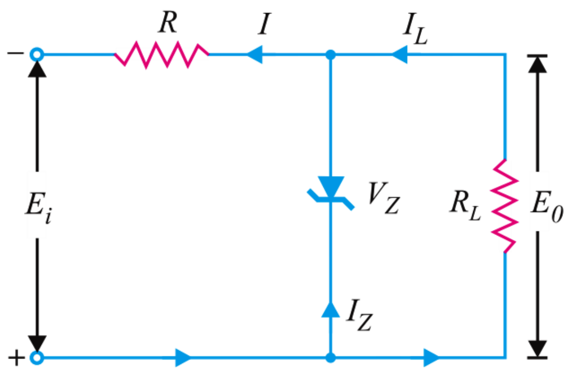
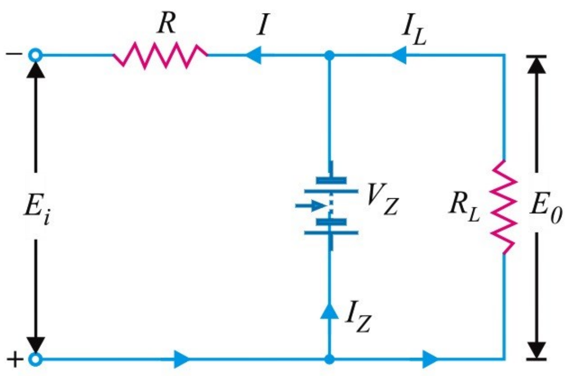


Fig (i)



Fig(ii)

- Suppose the input voltage increases. Since the Zener diode is in the breakdown region, the Zener diode is equivalent to a battery Vz as shown in figure (ii). It is clear that output voltage remains constant at Vz(=E0).The excess voltage is dropped across the series resistance R. This will cause an increase in the value of the total current I. The Zener will conduct the increase of current in I while the load current remains constant. Hence the output voltage E0 remains constant irrespective of the changes in the input voltage (Ei).
- Now suppose that input voltage is constant but the load resistance RL decreases. This will cause an increase in load current. The extra current cannot come form the source because drop in R will not change as the Zener diode is within its regulating range. The additional load current will come from a decrease in Zener current Iz. The output voltage stays at constant value(=E0=Vz).

Numerical:

Q1. For the circuit shown in Fig.1 (i), find : (i) the output voltage (ii) the voltage drop across series resistance (iii) the current through zener diode.

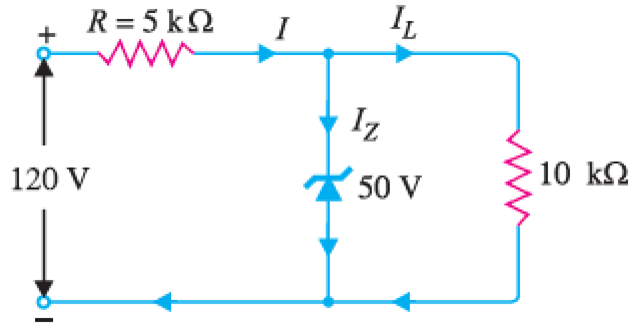


Fig.1 (i)

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).

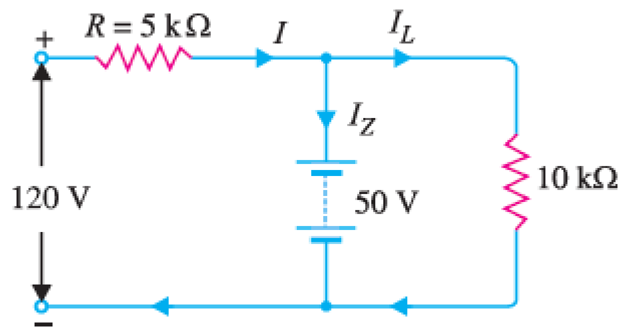


Fig. 1(ii)

(i) Referring to Fig. 1 (ii),

$$\text{Output voltage } = V_Z = \mathbf{50 \ V}$$

(ii) $\text{Voltage drop across } R = \text{Input voltage} - V_Z = 120 - 50 = \mathbf{70 \ V}$

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

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

(iii)

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

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

Q2. For the circuit shown in Fig. 2 (i),find the maximum and minimum values of zener diode current.

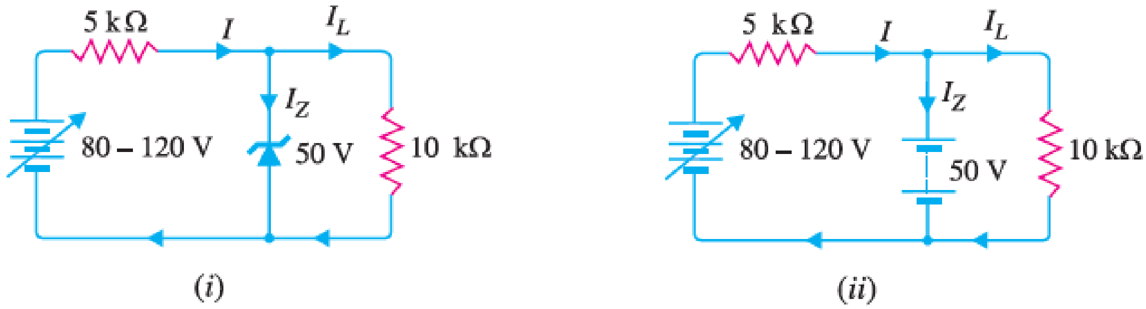


Fig.2

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 :

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

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

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

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

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

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

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

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

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

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

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.

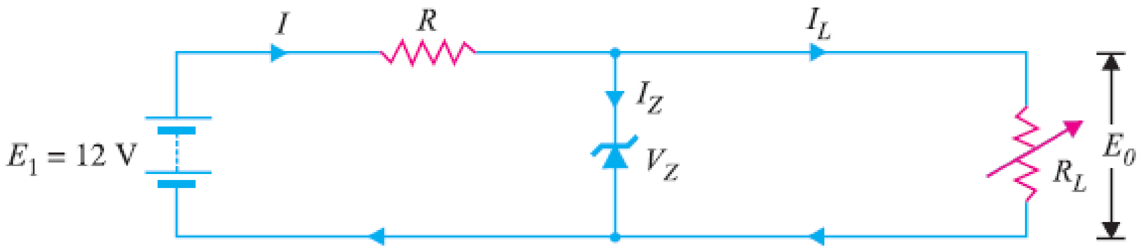


Fig. 3

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.

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

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.

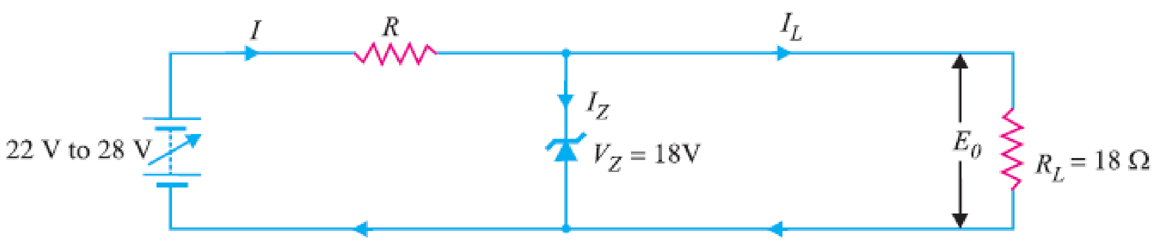


Fig. 4

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.

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