9.19 Zener Diode

It has already been discussed that when the reverse bias on a crystal diode is increased, a critical voltage, called *breakdown voltage* is reached where the reverse current increases sharply to a high value. The breakdown region is the knee of the reverse characteristic as shown in Fig. 9.39. The satisfactory explanation of this breakdown of the junction was first given by the American scientist C. Zener. Therefore, the breakdown voltage is sometimes called, *Zener voltage* and the sudden increase in current is known as Zener current.

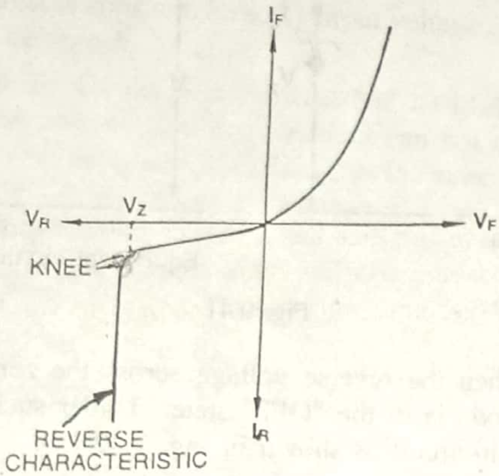

Fig. 9.39

The breakdown or Zener voltage depends upon the amount of doping. If the diode is heavily doped, depletion layer will be thin and consequently the breakdown of the junction will occur at a lower reverse voltage. On the other hand, a lightly doped diode has a higher breakdown voltage. When an ordinary crystal diode is properly doped so that it has a sharp breakdown voltage, it is called a zener diode.

A properly doped crystal diode which has a sharp breakdown voltage is known as a **Zener diode.**

Fig. 9.40 shows the symbol of a zener diode. It may be seen that it is just like an ordinary diode except that the bar is turned into Z-shape. The following points may be noted about the zener diode :

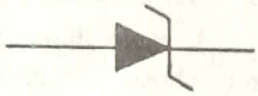

Fig. 9.40

(i) A zener diode is like an ordinary diode except that it is properly doped so as to have a sharp breakdown voltage.

(ii) A zener diode is always reverse connected *i.e.* it is always reverse biased.

(iii) A zener diode has sharp breakdown voltage, called zener voltage V_Z.

(iv) When forward biased, its characteristics are just those of ordinary diode.

(v) The zener diode is not immediately burnt just because it has entered the *breakdown region. As long as the external circuit connected to the diode limits the diode current to less than *burn out* value, the diode will not burn out.

9.20 Equivalent Circuit of Zener Diode

The analysis of circuits using zener diodes can be made quite easily by replacing the zener diode by its equivalent circuit.

* The current is limited only by both external resistance and the power dissipation of zener diode.

(*i*) **"On" state.** When reverse voltage across a zener diode is equal to or more than breakdown voltage V_Z, the current increases very sharply. In this region, the curve is almost vertical. It means that voltage across zener diode is constant at V_Z even though the current through it changes. Therefore in the breakdown region, an *ideal zener diode can be represented by a battery of voltage V_Z as shown in Fig. 9.41 (*ii*). Under such conditions, the zener diode is said to be in the "on" state.

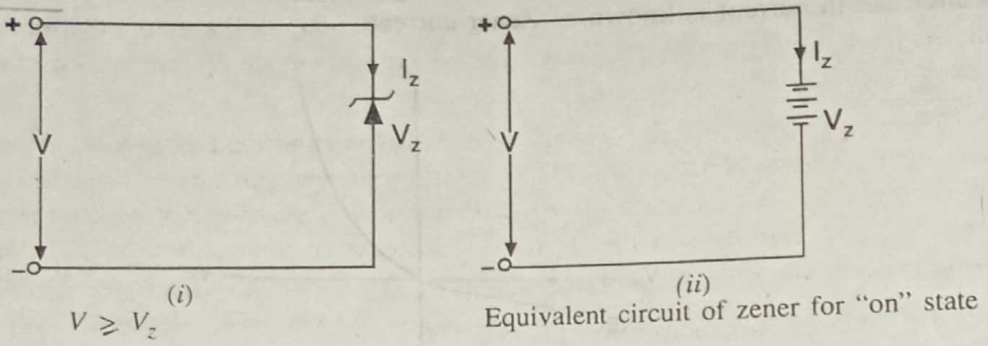

Fig. 9.41

(*ii*) **"OFF" state.** When the reverse voltage across the zener diode is less than V_Z but greater than 0V, the zener diode is in the "OFF" state. Under such conditions, the zener diode can be represented by an open-circuit as shown in Fig. 9.42 (*ii*).

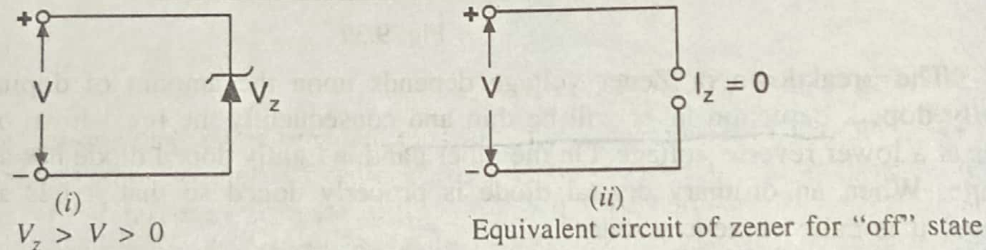

Fig. 9.42

9.21 Zener Diode as Voltage Stabiliser

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 circuit arrangement is shown in Fig. 9.43 (*i*). The zener diode of zener voltage V_Z is reverse connected across the load R_L across which constant output is desired. The series resistance R absorbs the output voltage fluctuations so as to maintain constant voltage across the load. It may be noted that the zener will maintain a constant voltage $V_Z (= E_0)$ across the load so long as the input voltage does not fall below V_Z.

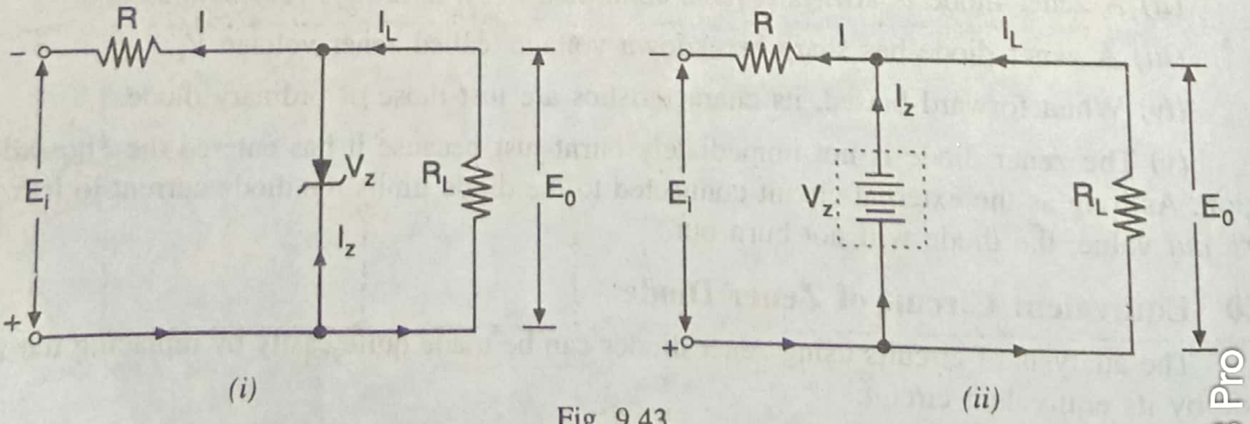

Fig. 9.43

* This assumption is fairly reasonable as the impedance of zener diode is quite small in the breakdown region.

When the circuit is properly designed, the load voltage E_o remains essentially constant (equal to V_Z) even though the input voltage E_i and load resistance R_L may vary over a wide range.

(*i*) Suppose the input voltage increases. Since the zener is in the breakdown region, the zener diode is equivalent to a battery V_Z as shown in Fig. 9.43 (*ii*). It is clear that output voltage remains constant at V_Z (= E_o). The excess voltage is dropped across the series resistance *R*. This will cause an increase in the value of total current *I*. The zener will conduct the increase of current in *I* while the load current remains constant. Hence, output voltage E_o remains constant irrespective of the changes in the input voltage E_i.

(*ii*) Now suppose that input voltage is constant but the load resistance R_L decreases. This will cause an increase in load current. The extra current can not come from the source because drop in *R* (and hence source current *I*) will not change as the zener is within its regulating range. The additional load current will come from a decrease in zener current I_Z. Consequently, the output voltage stays at constant value.

Voltage drop across $R = E_i - E_o$

Current through *R*, $I = I_Z + I_L$

Applying ohm's law, we have,

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

9.22 Solving Zener Diode Circuits

The analysis of zener diode circuits is quite similar to that applied to the analysis of semiconductor diodes. The first step is to determine the state of zener diode *i.e.*, whether the zener is in the "on" state or "off" state. Next, the zener is replaced by its appropriate model. Finally, the unknown quantities are determined from the resulting circuit.

1. E_i and R_L fixed. This is the simplest case and is shown in Fig. 9.44 (*i*). Here the applied voltage (E_i) as well as load R_L is fixed. The first step is to find the state of zener diode. This can be determined by removing the zener from the circuit and calculating the voltage V across the resulting open-circuit as shown in Fig. 9.44 (*ii*).

$$V = E_0 = \frac{R_L E_i}{R + R_L}$$

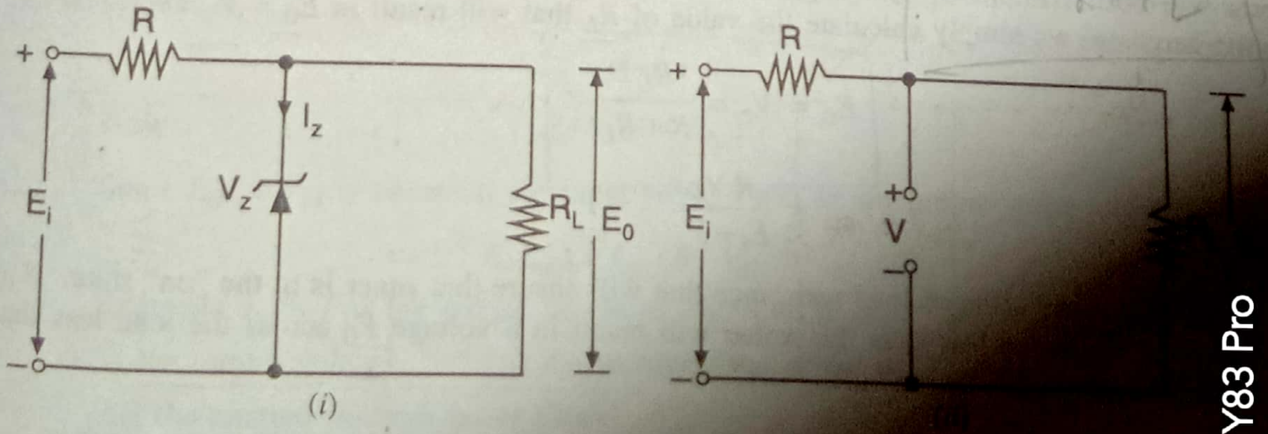

Fig. 9.44

If $V \geq V_Z$, the zener diode is in the "on" state and its equivalent model can be substituted as shown in Fig. 9.45 (*i*). If $V < V_Z$, the diode is in the "off" state as shown in Fig. 9.45 (*ii*).

Zener Diode as Voltage Regulator

The Zener diode is like a general-purpose signal diode. When biased in the forward direction it behaves just like a normal signal diode, but when a reverse voltage is applied to it, the voltage remains constant for a wide range of currents.

Avalanche Breakdown: There is a limit for the reverse voltage. Reverse voltage can increase until the diode breakdown voltage reaches. This point is called *Avalanche Breakdown* region. At this stage maximum current will flow through the zener diode. This breakdown point is referred as "Zener voltage".

The Zener Diode is used in its "reverse bias". From the I-V Characteristics curve we can study that the zener diode has a region in its reverse bias characteristics of almost a constant negative voltage regardless of the value of the current flowing through the diode and remains nearly constant even with large changes in current as long as the zener diodes current remains between the breakdown current $I_{Z(min)}$ and the maximum current rating $I_{Z(max)}$.

This ability to control itself can be used to great effect to regulate or stabilise a voltage source against supply or load variations. The fact that the voltage across the diode in the breakdown region is almost constant turns out to be an important application of the zener diode as a voltage regulator.

Fig 1: Zener diode

Characteristics

Figure 2 shows the current versus voltage curve for a Zener diode. Observe the nearly constant voltage in the breakdown region.

Fig 2: Zener diode characteristic curve

The forward bias region of a Zener diode is identical to that of a regular diode. The typical forward voltage at room temperature with a current of around 1 mA is around 0.6 volts. In the reverse bias condition the Zener diode is an open circuit and only a small leakage current is flowing as shown on the exaggerated plot. As the breakdown voltage is approached the current will begin to avalanche. The initial transition from leakage to breakdown is soft but then the current rapidly increases as shown on the plot. The voltage across the Zener diode in the breakdown region is very nearly constant with only a small increase in voltage with increasing current. At some high current level the power dissipation of the diode becomes excessive and the part is destroyed. There is a minimum Zener current, $I_{Z(min)}$, that places the operating point in the desired breakdown. There is a maximum Zener current, $I_{Z(max)}$, at which the power dissipation drives the junction temperature to the maximum allowed. Beyond that current the diode can be damaged.

Zener diodes are available from about 2.4 to 200 volts typically using the same sequence of values as used for the 5% resistor series −2.4, 2.7, 3.0 3.3, 3.6, 3.9, 4.3, 4.7, 5.1, 5.6, 6.2, 6.8, 7.5, 8.2, 9.1, 10, 11, 12, 13, 15, 16, 18, 20, 22, 24, etc. All Zener diodes have a power rating, Pz. From Watt's law the maximum current is $I_{Z(MAX)} = P_Z / V_Z$. Zener diodes are typically available with power ratings of 0.25, 0.4, 0.5, 1, 2, 3, and 5 watts although other values are available.

Zener Diode as Voltage Regulators

The function of a regulator is to provide a constant output voltage to a load connected in parallel with it in spite of the ripples in the supply voltage or the variation in the load current and the zener diode will continue to regulate the voltage until the diodes current falls below the minimum $I_{Z(min)}$ value in the reverse breakdown region. It permits current to flow in the forward direction as normal, but will also allow it to flow in the reverse direction when the voltage is above a certain value - the breakdown voltage known as the Zener voltage. The Zener diode specially made to have a reverse voltage breakdown at a specific voltage. Its characteristics are otherwise very similar to common diodes. In breakdown the voltage across the Zener diode is close to constant over a wide range of currents thus making it useful as a shunt voltage regulator.

The purpose of a voltage regulator is to maintain a constant voltage across a load regardless of variations in the applied input voltage and variations in the load current. A typical Zener diode shunt regulator is shown in Figure 3. The resistor is selected so that when the input voltage is at $V_{IN(min)}$ and the load current is at $I_{L(max)}$ that the current through the Zener diode is at least $I_{Z(min)}$. Then for all other combinations of input voltage and load current the Zener diode conducts the excess current thus maintaining a constant voltage across the load. The Zener conducts the least current when the load current is the highest and it conducts the most current when the load current is the lowest.

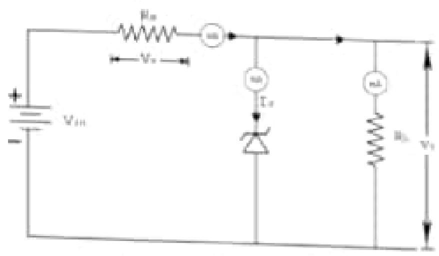

Fig 3: Zener diode shunt regulator

If there is no load resistance, shunt regulators can be used to dissipate total power through the series resistance and the Zener diode. Shunt regulators have an inherent current limiting advantage under load fault conditions because the series resistor limits excess current.

A zener diode of break down voltage V_Z is reverse connected to an input voltage source V_i across a load resistance R_L and a series resistor R_S. The voltage across the zener will remain steady at its break down voltage V_Z for all the values of zener current I_Z as long as the current remains in the break down region. Hence a regulated DC output voltage $V_0 = V_Z$ is obtained across RL, whenever the input voltage remains within a minimum and maximum voltage.

Basically there are two type of regulations such as:

a) Line Regulation

In this type of regulation, series resistance and load resistance are fixed, only input voltage is changing. Output voltage remains the same as long as the input voltage is maintained above a minimum value.

Percentage of line regulation can be calculated by = $\frac{\Delta V_0}{\Delta V_{IN}} * 100$

where V_0 is the output voltage and V_{IN} is the input voltage and ΔV_0 is the change in output voltage for a particular change in input voltage ΔV_{IN}

b) Load Regulation

In this type of regulation, input voltage is fixed and the load resistance is varying. Output volt remains same, as long as the load resistance is maintained above a minimum value.

Percentage of load regulation = $\left[\frac{V_{NL} - V_{FL}}{V_{NL}}\right] * 100$

where V_{NL} is the null load resistor voltage (ie. remove the load resistance and measure the voltage across the Zener Diode) and V_{FL} is the full load resistor voltage

Design a Voltage Regulator

When selecting the zener diode, be sure that its maximum power rating is not exceeded.

I_{max} Maximum current for Zener diode

$$I_{max} = \frac{Power}{Zener\ voltage}$$

- V_Z Zener Diode standard voltage
- V_{in} Input voltage(it is known)
- V_s Voltage across series resistance
- V_L Voltage across the load resistance
- I_s Current passing through the series resistance
- I_z Current passing through the Zener diode
- I_L Current passing through the load resistance

Calculating voltage and current

The total current drawn from the source is the same as that through the series resistor

$$I_S = \frac{V_S}{R_S}$$

The current through the load resistor is

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

and the zener diode current is

$$I_Z = I_S - I_L$$

If the voltage source is greater than Vz

$$V_s = V_{in} - V_L \quad \text{and} \quad V_L = V_Z$$

If the voltage source is less than Vz

$$V_s = \frac{R_S * V_{in}}{(R_S + R_L)} \quad \text{and} \quad V_L = \frac{R_L * V_{in}}{(R_S + R_L)}$$