UNIT 3

PN Diode—Equivalent circuit of diode**—**Zener diode**—**Zener diode as voltage regulator**— Rectifiers—**Halfwave**—**Full Wave rectifiers**—**Bridge rectifier**—**and capacitor filter circuit. **Photodiode—LED—Photo coupler**

3.1 INTRODUCTION

- Based on the electrical conductivity, all the materials in nature are classified as insulators, semiconductors, and conductors

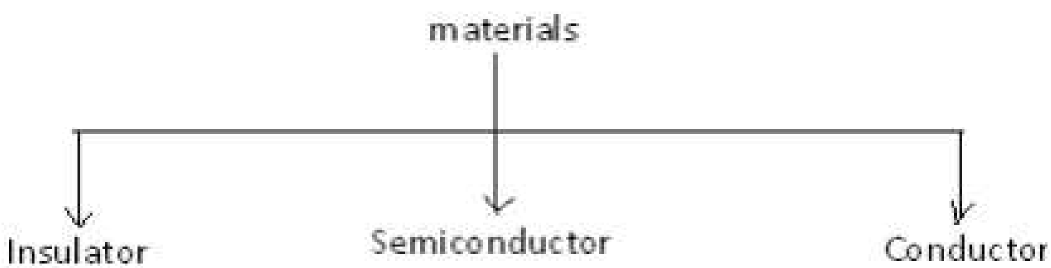


Figure 3.1: materials classification

Insulator: An insulator is a material that offers a very low level (or negligible) of conductivity when voltage is applied.

Eg: Paper, Mica, glass, quartz.

Conductors: A conductor is a material which supports a generous flow of charge when a voltage is applied across its terminals. i.e. it has very high conductivity.

Eg: Copper, Aluminum, Silver, Gold

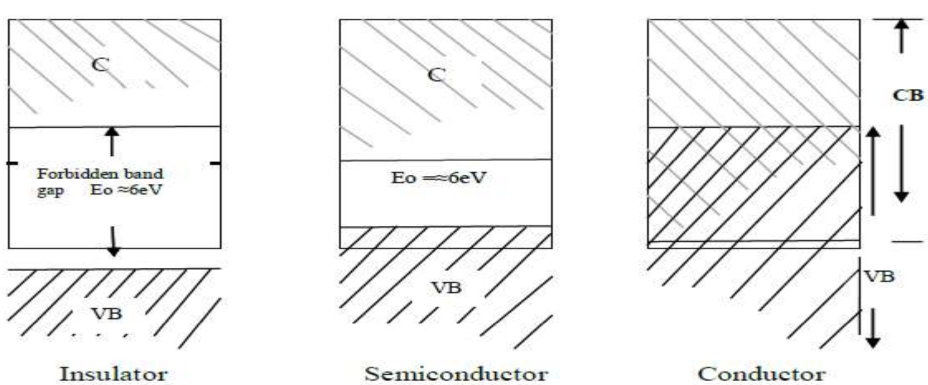


Figure 3.2: Energy band diagram

Semiconductor: A semiconductor is a material that has its conductivity somewhere between the insulator and conductor

Ex: Silicon and germanium.

- Semiconductors are the foundation of modern electronics, including transistors, solar cells, light-emitting diodes (LEDs), quantum dots and digital and analog integrated circuits.

3.2 Semiconductor Types

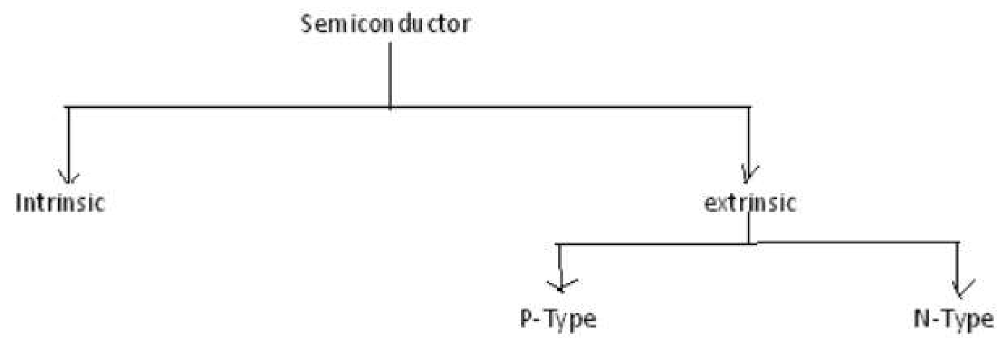


Figure 3.3: Semiconductor classification

- A semiconductor material in its pure form is known as an **intrinsic semiconductor**. Thus, the intrinsic semiconductors are chemically pure, i.e. they are free from impurities
- When a small amount of chemical impurity is added to an intrinsic semiconductor, then the resulting semiconductor material is known as **extrinsic semiconductor**
- Based on the type of doping, the extrinsic semiconductors are classified into two types viz. **N-type semiconductors** and **P-type semiconductors**

N type semiconductor: If the added impurity is a pentavalent atom then the resultant semiconductor is called N-type semiconductor. Examples of pentavalent impurities are Phosphorus, Arsenic, Bismuth, Antimony etc.

P type semiconductor: If the added impurity is a trivalent atom then the resultant semiconductor is called P-type semiconductor. Examples of trivalent impurities are Boron, Gallium , indium etc.

3.3 P-N Junction

- A p–n junction is formed by joining P-type and N-type semiconductors together in very close contact. The term junction refers to the boundary interface where the two regions of the semiconductor meet. Diode is a two-terminal electronic component that conducts electric current in only one direction
- In a n type material has high concentration of free electronics
- p type material has high concentration of free holes
- At junction there is a tendency for electrons to diffuse from n to p,this process is called diffusion.
- As free electrons moves from n to p the donor ions become positively charged,hence positive charge is built on the n side of the junction
- Hence negative charge is built on the p side of the junction
- The net negative charge on the p side prevents the diffusion of electrons from n to p.
- Similarly the positive charge on the n side prevents the holes passing from p to n
- Therefore a barrier is set up near the junction which prevents the movement of charge carriers either electrons or holes
- This is called depletion region,the electro static potential at this junction is called as barrier potential
- the barrier potential for Ge is 0.3V and for Si is 0.6V

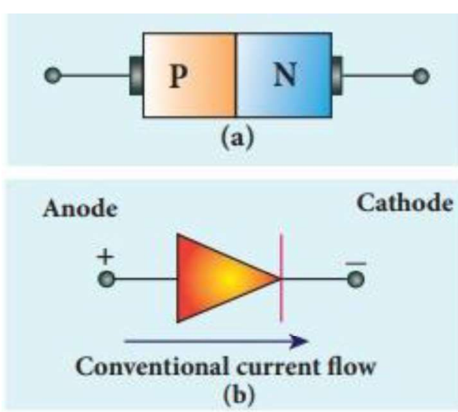


Figure 3.4: pn diode symbol

Figure (a) schematic representation (b) Symbol of PN junction diode

- The term Bias refers to the application of external voltage across the two terminals of the device to extract the response.
- We have two different biasing conditions:
    - Forward Bias
    - Reverse Bias

Zero Bias:

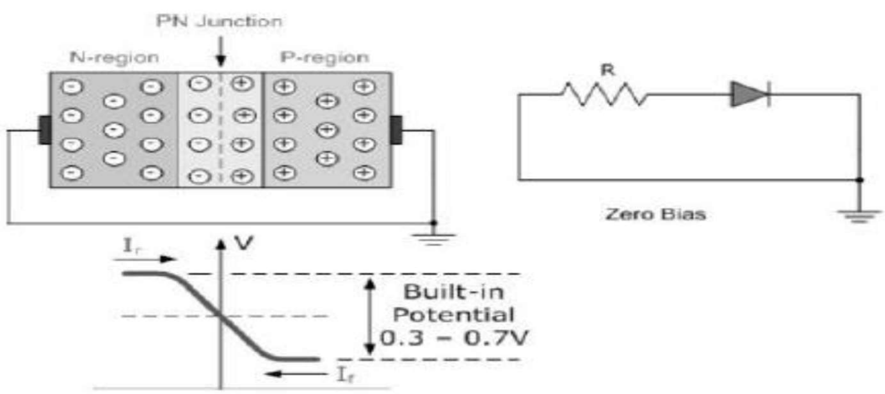


Figure 3.5: pn junction diode under zero bias

When a diode is **Zero Biased** no external energy source is applied and a natural **Potential Barrier** is developed across a depletion layer

<u>Forward Bias condition:</u>

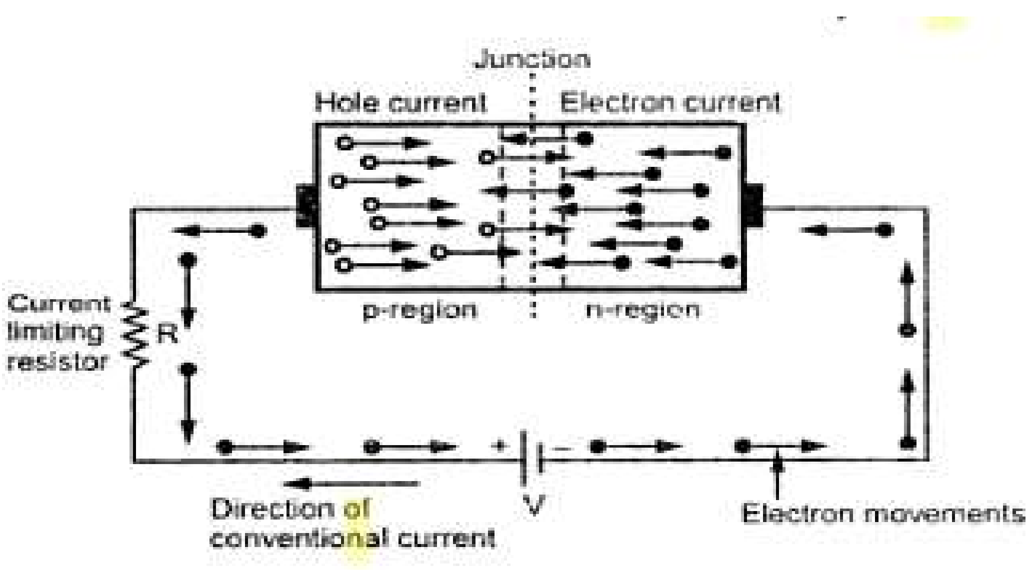


Figure 3.6: Forward biased PN junction: Internal distribution of charge carriers under forward-bias condition

- If the positive terminal of the battery is connected to the p region and negative terminal of the battery is connected to the n region then that biasing is called as forward bias

Operation

- ✓ When p-n junction is in forward bias as long as the applied voltage is less than the barrier potential, then there is no current with in the semiconductor p n Junction diode
- ✓ When applied voltage becomes greater than the barrier potential, the negative terminal of the battery pushes the electrons against the barrier potential from n to p
- ✓ Similarly positive terminal of the battery pushes the holes against the barrier potential from p to n.
- ✓ Thus the applied external voltage overcomes the barrier potential, then it reduces the width of the depletion region
- ✓ Then large number of majority carriers can cross the junction (holes crossing from p to n ,electrons crossing from n to p)
- ✓ These large number of majority carriers constitutes a current known as forward current
- ✓ In p region the current is due to moment of holes which are majority carrier this is called a hole current
- ✓ In n region the current is due to moment of electrons which are majority carrier this is called a electron current
- ✓ The overall forward current is due to both hole current and electron current

Reverse Bias condition:

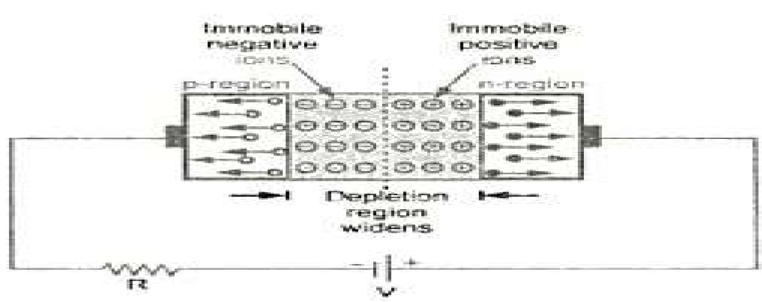


Figure 3.7: Forward biased PN junction: Internal distribution of charge carriers under forward-bias condition

- When the negative terminal of the battery is connected to the p type
- And positive terminal of the battery is connected to the n type the bias is called reverse bias

Operation:

- Under reverse bias the holes which are majority carriers of the p side moves towards the negative terminal of the battery
- Electrons which are majority carriers of n side moves towards the positive terminal of the battery
- Hence width of the depletion region increases and also potential barrier increases which prevents the flow of majority carriers in both directions
- Theoritically no current flows in the circuit
- But practically small current in order of micro ampers or nano ampers Under reverse bias exists

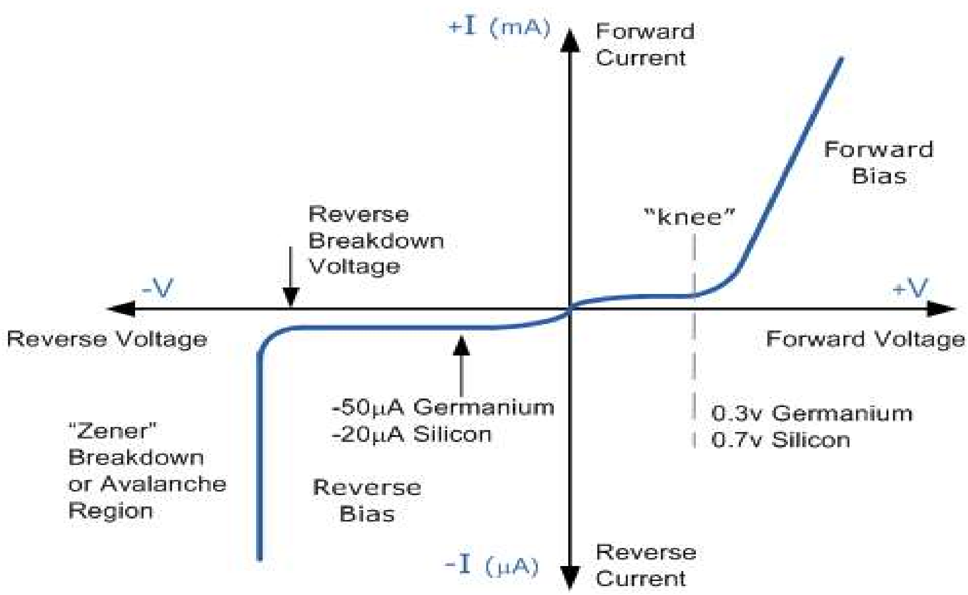


Figure 3.8: V-I characteristics of PN junction Diode

- At certain voltage to the barrier potential the current increases rapidly
- The voltage at which current starts increases is called as cutin voltage
- The cutin voltage for Ge is 0.2 or 0.3V

- For Si is 0.6 or 0.7V

3.4 Diode Current Equation:

- When a diode is subjected to bias there will be a current flow through the diode depending on bias conditions.
- The equation relating pn junction current and voltage levels is called Shockley equation and is represented as

$I_{D=} I_o[e^{V_D/\eta V_T} -1]$

Where

I_o - Reverse Saturation Current

V_D - Applied bias voltage across the diode

η - Constant that depends on material

V_T - Thermal voltage called voltage equivalent of temperature

V_T =KT/q

where

K-Boltzman's constant=$1.38*10^{-23}$ J/K

T- Absolute Temperature=(273+T^{o}c)K

q-change of electron=$1.6*10^{-19}$ C

By substituting the above values V_T can be obtained as

$$V_T = T/11600$$

3.5 Diode Equivalent Circuits:

- For general performance analysis of any device or a system, an equivalent circuit may be used which is an alternate representation of the device or the system.
- An equivalent circuit contains alternate components that best corresponds the actual characteristics of a device or the system under the given operating conditions.

Piecewise Linear Equivalent circuit:

- In order to obtain more precise and an excellent equivalent circuit for a diode approximations for the device characteristics by using straight line segments can be made
- Nonlinear waveforms are often approximated by a number of linear segments in order to simplify the analysis.
- The more the number of linear segments, the more will be the approximations close to the actual waveform such an approximation is called Piecewise Linear approximation.

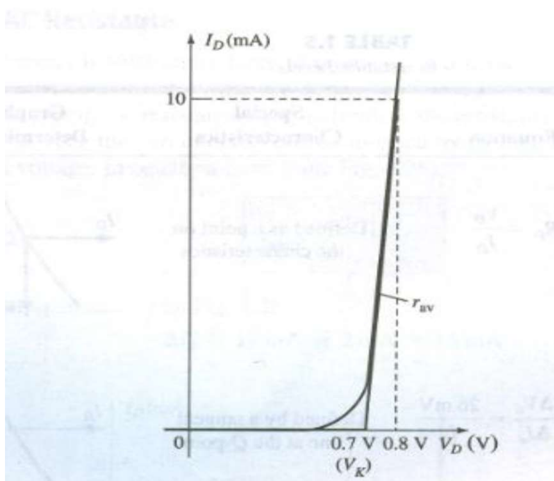


Figure 3.9: Defining the piecewise-linear equivalent circuit using straight-line segments to approximate the characteristic curve.

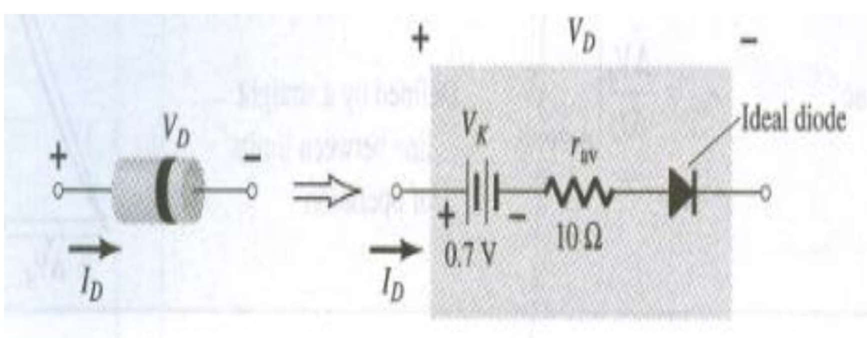


Figure 3.10: Components of piecewise-linear equivalent circuit.

- It should be obvious from the above figure that the straight line segments do not result in exact duplication of the actual characteristics especially in the knee region however, the resulting segments are sufficiently close to the actual curves that establish an equivalent circuit that will provide an excellent first approximation to the actual behaviour of the device.
- The ideal diode is included to establish that there is only one direction of conduction through the device and a reverse bias condition will result in the open circuit state for the device.
- We know that the semiconductor diode does not reach the conduction state until V_D reaches 0.7V with a forward bias, a battery V_K opposing the conduction direction must appear in the equivalent circuit.

3.6 ZENER DIODE

Zener diode is a specially designed ordinary P-N junction diode, which is heavily doped to have a very sharp and almost vertical breakdown.

• They are exclusively operated under reverse bias conditions and designed to operate in breakdown region without damage.

• The device was named after Clarence Zener, who discovered this electrical property.

• The commonly used schematic symbol for Zener diode is shown in Fig

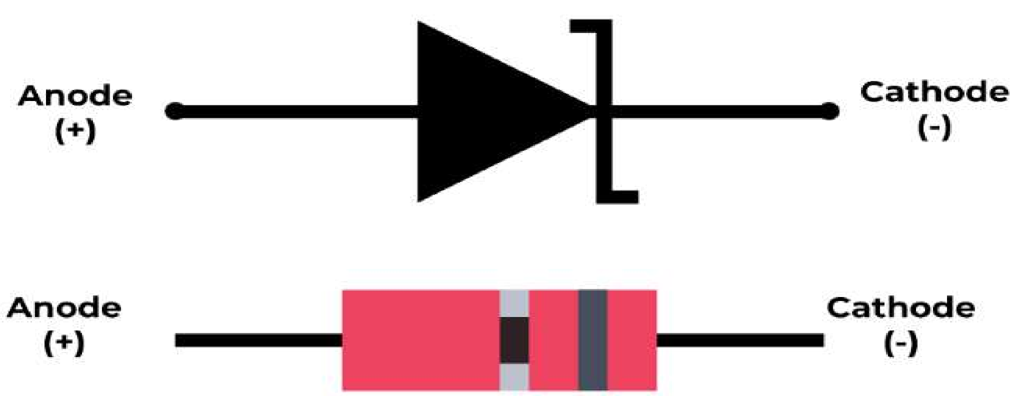


Figure 3.11: symbol of Zener diode

V-I CHARACTERSTICSAND WORKING OF ZENER DIODE

The Forward bias characteristics of Zener diode are same as that of normal PN Junction diode.

- When the applied forward bias voltage ‘VF’ is less than the cut in voltage, the current is negligibly small. When VF becomes greater than cut in voltage, current starts increasing rapidly.
- In reverse bias mode, current is due to minority charge carriers.
- Since the P and N-regions are heavily doped, the depletion layer at the junction will be very narrow.
- The reverse bias voltage sets up a strong electric field across the narrow depletion layer. This field is strong enough to cause rupture of covalent bonds of atoms. Therefore, there is a generation of a large number of electron-hole pairs, leading to a sharp increase in the reverse current.
- When reverse bias is increased, up to a certain voltage called as breakdown voltage.
- A voltage is reached then the diode starts conducting heavily and the reverse current increases sharply. This voltage is called Zener breakdown voltage(Vz).
- A Zener diode maintains a constant voltage across its terminals when the reverse bias exceeds the breakdown voltage. Therefore, it is used as voltage regulator.

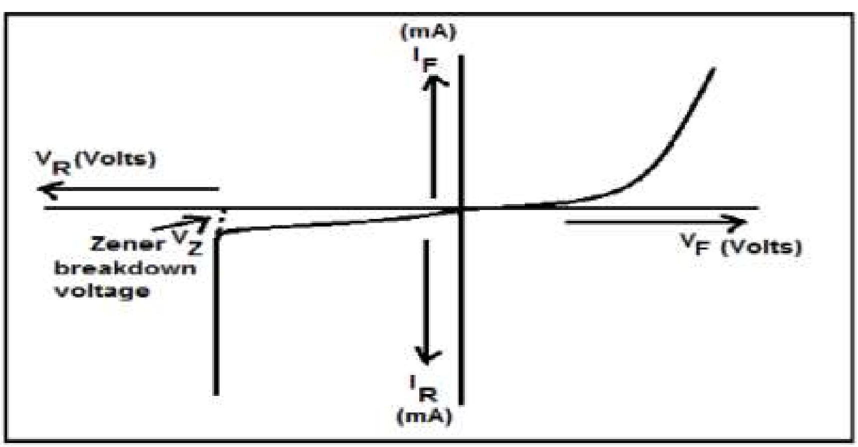


Figure 3.12: V-I CHARACTERSTICS OF ZENER DIODE

In reverse bias condition, two kinds of breakdowns occur for Zener Diode which are

- Avalanche Breakdown
- Zener Breakdown

Avalanche Breakdown

- Avalanche Breakdown occurs due to avalanche multiplication.
- It occurs when the doping concentration is less of order 1 to 10^8..
- Under Reverse bias, the thermally generated carrier crosses the depletion region and acquires Kinetic energy from the applied voltage. This carrier collides with the crystal and disrupts the covalent band. This is known as Impact Ionization.
- The new electron hole pair will be created apart from original carrier. The new carrier in turn collide with another crystal by acquiring enough energy from applied field will create electron hole pair.
- This process continues result in avalanche multiplication. This causes Breakdown known as avalanche Breakdown.

Zener Breakdown

- This breakdown occurs in the heavily doped P and N region.
- When the strong electric field is applied, the direct rupture of covalent bond takes place produce new electron hole pair.
- The new electron hale pair so created will increases the reverse current.
- This reverse current increase at almost 6 volts for heavily doped diode at the field of order 2×107 v/m.
- This kind of breakdown occurs in heavily doped PN region is known as zener breakdown.
- Zener Breakdown occur less than 6 V whereas Avalanche Breakdown occur greater than 6V.

Differences between Zener and Avalanche breakdown:

Table 3.1: difference between avalanche and zener breakdown

Avalanche Breakdown	Zener Breakdown
Avalanche breakdown occurs when the high voltage increase the free electron in the semiconductor and a sudden increase in current is seen.	Zener breakdown happens when electrons from the valance band gain energy and reaches the conduction band which then conducts electricity.
Avalanche breakdown is seen in the diodes having breakdown voltage greater than 8 volts.	Zener breakdown is seen in the diodes having breakdown voltage in the range of 5 to 8 volts.
Avalanche breakdown is observed in diodes that are lightly doped.	Zener breakdown is observed in diodes that are highly doped.
In the Avalanche breakdown, the VI characteristics curve is not as sharp as the VI characteristics curve in the Zener breakdown.	Zener Breakdown has a sharp VI characteristics curve.
For Avalanche breakdown increase in temperature increases the breakdown voltage.	For Zener breakdown increase in temperature decreases the breakdown voltage.

3.7 Zener Diode as Voltage Stabiliser

1. **Regulation with varying input voltage:**

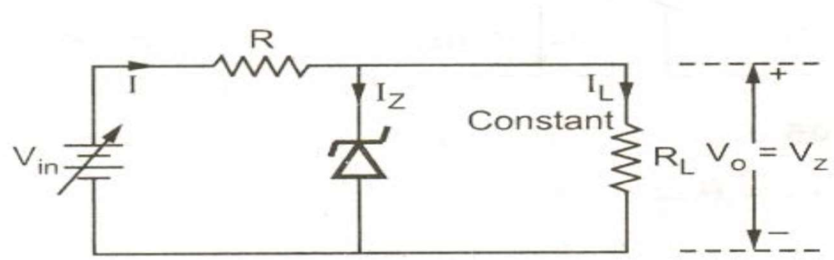


Figure 3.13: Zener Diode as Voltage Stabiliser

- From the above figure $V_0 = V_z$= constant.
- IL = $V_0/R_L=V_Z/R_L$= constant.
- We can write $I=I_L+I_Z$

- If we increase input voltage V_{in} then the current I increases, but WKT current through the load is constant. Hence current through Zener increases to keep IL constant.
- As long as Iz is in between $I_{z(min)}$ and $I_{z(max)}$ the Vz i.e. the ouput voltage V0 is constant i.e. how the change in input voltage is getting compensated and constant output is maintained.
- When V_{in} decreases the current I decrease. But WKT the current through load is constant the current through zener decreases.
- Iz will be in between Iz(max) to Iz(min) to keep the output voltage constant.

2. Regulation with varying load:

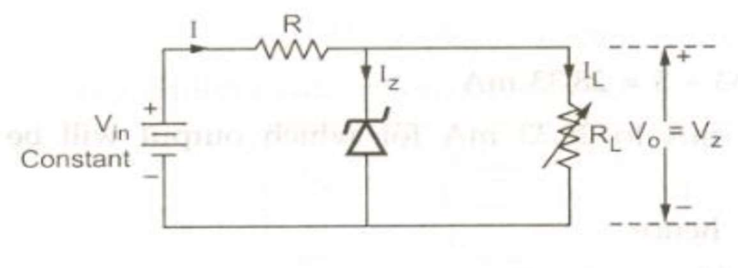
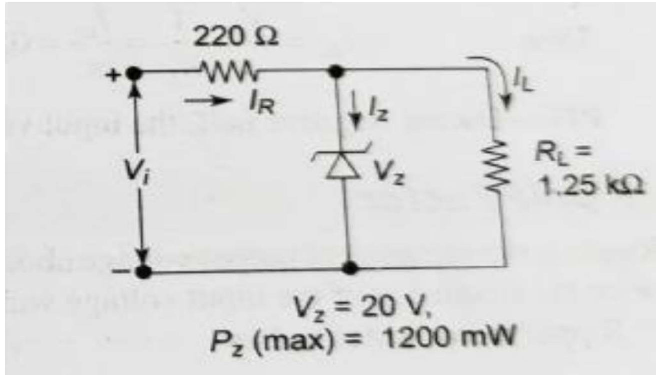


Figure 3.14: Varying load condition

- In the above figure the input voltage V_{in} is kept constant whereas load is varying.
- Her V_{in} is constant and V_0 is also constant
- Current I can be calculated as $I=(V_{in}-Vz)/R$.
- WKT $I_L = V_0/R_L=V_Z/R_L=$ constant.
- If R_L increases then current through load I_L decreases, to keep constant I, I_z increases but as long as I_z is in between $I_{z(min)}$ and $I_{z(max)}$ output voltage will be constant.
- If R_L decreases then current through load I_L increases, to keep constant I, I_z decreases but as long as I_z is in between $I_{z(min)}$ and $I_{z(max)}$ output voltage will be constant.

Problem

(1) Determine the range of V; in which the zener diode of below conducts



Solution

(a) V_z just in conducting state

$$V_z = 20\text{ V}, I_z = 0$$

$$I_R = I_L = \frac{20}{1.25} = 16\text{ mA}$$

$$V_i = 20 + 220 \times 16 \times 10^{-3} = 23.52\text{ V}$$

(b) $$I_z = I_z(\text{max}) = \frac{1200}{20} = 60\text{ mA}$$

$$I_L = 16\text{ mA}$$

$$I_R = 60 + 16 = 76\text{ mA}$$

$$V_i = 20 + 220 \times 76 \times 10^{-3} = 36.72\text{ V}$$

Rectifiers

3.8 Introduction:

A **rectifier** is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. This process is **known as rectification.**

Classification of Rectifiers:

Using one or more diodes in the circuit, following rectifier circuits can be designed.

1) Half - Wave Rectifier

2) Full – Wave Rectifier

3) Bridge Rectifier

3.9 HALF-WAVE RECTIFIER:

A Half – wave rectifier as shown below , which converts a.c. voltage into a pulsating voltage using only one half cycle of the applied a.c. voltage

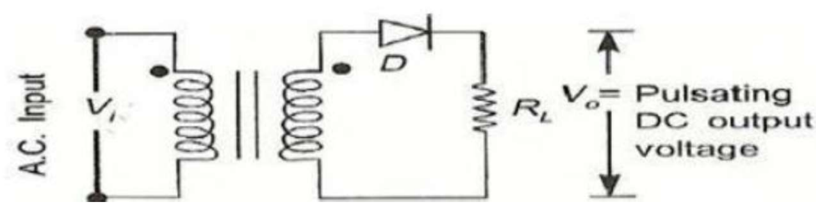


Figure 3.15: Basic structure of half wave rectifier

The a.c. voltage is applied to the rectifier circuit using step-down transformer-rectifying element i.e., p-n junction diode and the source of a.c. voltage, all connected is series. The a.c. voltage is applied to the rectifier circuit using step-down transformer

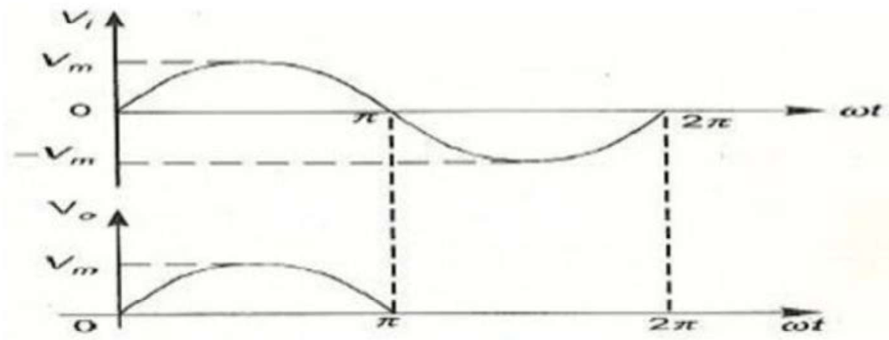


Figure 3.16: input and output waveforms of halfwave rectifier

V=Vm sin (ω t)

The input to the rectifier circuit, Where Vm is the peak value of secondary a.c. voltage.

Operation:

For the positive half-cycle of input a.c. voltage, the diode D is forward biased and hence it conducts. Now a current flows in the circuit and there is a voltage drop across RL. The waveform of the diode current (or) load current is shown in above figure.

For the negative half-cycle of input, the diode D is reverse biased and hence it does not Conduct. Now no current flows in the circuit i.e., i=0 and Vo=0. Thus for the negative half- cycle no power is delivered to the load

Therefore, for an AC voltage given by (1) the output voltage of a half wave rectifier will be (for an ideal diode)

$$V_o(t) = \begin{cases} V_m \sin(\omega t), & 0 \leq t \leq T/2 \\ 0, & T/2 \leq t \leq T \end{cases}$$

…………………………..(1)

Analysis:

Average output voltage of a half wave rectifier

The average value of V (t) over the time period T is defined as

$$\boxed{\overline{V} = \frac{1}{T}\int_0^T V(t)\mathrm{d}t.}$$

…………………………………………….(2)

To calculate the average voltage, Vdc, of the pulsating DC output of a half wave rectifier we use the definition (1). Therefore, for the voltage (2) we have

$$\begin{aligned}
V_{\mathrm{dc}} &= \frac{1}{T}\int_0^T V_{\mathrm{o}}(t)\mathrm{d}t \\
&= \frac{1}{T}\int_0^{T/2} V_m \sin(\omega t)\mathrm{d}t + \frac{1}{T}\int_{T/2}^{T} 0 \ \mathrm{d}t \\
&= \frac{V_m}{T}\int_0^{T/2} \sin(\omega t)\mathrm{d}t \\
&= \frac{V_m}{T}\left[-\frac{\cos(\omega t)}{\omega}\right]_0^{T/2} \\
&= \frac{V_m}{\omega T}\{-\cos(\omega T/2) + \cos(0)\} \\
&= \frac{V_m}{\pi}.
\end{aligned}$$

Here we have used the relation $\omega = 2\pi/T$.

RMS value of the output voltage of a half wave rectifier

To calculate the RMS value of the output voltage, V_{rms}, of the pulsating DC output of a half wave rectifier we use the definition (2). Therefore, for the voltage (1) we have

$$\begin{aligned}
V_{\mathrm{rms}}^2 &= \frac{1}{T}\int_0^T V_{\mathrm{o}}^2(t)\mathrm{d}t \\
&= \frac{V_m^2}{T}\int_0^{T/2} \sin^2(\omega t)\mathrm{d}t + \frac{V_m^2}{T}\int_{T/2}^{T} 0 \ \mathrm{d}t \\
&= \frac{V_m^2}{2T}\int_0^{T/2} 2\sin^2(\omega t)\mathrm{d}t \\
&= \frac{V_m^2}{2T}\int_0^{T/2} \{1-\cos(2\omega t)\}\,\mathrm{d}t \\
&= \frac{V_m^2}{2T}\int_0^{T/2} \mathrm{d}t - \frac{V_m^2}{T}\int_0^{T/2} \cos(2\omega t)\mathrm{d}t \\
&= \frac{V_m^2}{2T}\Big[T\Big]_0^{T/2} - \frac{V_m^2}{2T}\left[\frac{\sin(2\omega t)}{2\omega}\right]_0^{T/2} \\
&= \frac{V_m^2}{4} - \frac{V_m^2}{\omega T}\Big\{\sin(2\omega T) - \sin(0)\Big\} \\
&= \frac{V_m^2}{4}.
\end{aligned}$$

Hence for the half wave rectifier

$$\boxed{V_{\mathrm{rms}} = \frac{V_m}{2}.}$$

Ripple factor of half wave rectifier

Ripple is the unwanted AC component remaining when converting the AC voltage waveform into a DC waveform. Even though we try out best to remove all AC components, there is still some small amount left on the output side which pulsates the DC waveform. This undesirable AC component is called ripple.

To quantify how well the half wave rectifier can convert the AC voltage into DC voltage, we use what is known as the ripple factor (represented by *γ*). The ripple factor is the ratio between the RMS value of the AC voltage and the DC voltage of the rectifier.

$$\boxed{\gamma = \frac{\text{RMS value of the AC component}}{\text{value of DC component}} = \frac{V_{\mathrm{r(rms)}}}{V_{\mathrm{dc}}}.}$$

Note that the RMS value of the AC component of the signal is Vr(rms) and Vrms is the RMS value of the whole voltage signal.

To calculate Vr(rms), the RMS value of the AC component present in the output of the half wave rectifier we write the output voltage as

Vo(t) = Vac + Vdc;

where Vac is the AC component remaining when converting the AC voltage waveform into a DC waveform. The RMS value of the AC component present in the output of the half wave rectifier is given by

$$\boxed{\overline{V} = \frac{1}{T}\int_0^T V(t)\mathrm{d}t.}$$

Therefore,

$$\begin{aligned} |V_{\mathrm{r(rms)}}^2 &= \frac{1}{T}\int_0^T (V_{\mathrm{o}} - V_{\mathrm{dc}})^2\,\mathrm{d}t \\ &= \frac{1}{T}\int_0^T (V_{\mathrm{o}}^2 - 2V_{\mathrm{o}}V_{\mathrm{dc}} + V_{\mathrm{dc}}^2)\,\mathrm{d}t \\ &= \frac{1}{T}\int_0^T V_{\mathrm{o}}^2\,\mathrm{d}t - \frac{2V_{\mathrm{dc}}}{T}\int_0^T V_{\mathrm{o}}\,\mathrm{d}t + V_{\mathrm{dc}}^2 \\ &= V_{\mathrm{rms}}^2 - 2V_{\mathrm{dc}}^2 + V_{\mathrm{dc}}^2 \\ &= V_{\mathrm{rms}}^2 - V_{\mathrm{dc}}^2. \end{aligned}$$

Hence the formula to calculate the ripple factor can be written as

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

Using the values of $V_{rms}=V_m/2$ and $V_{dc}=V_m/\pi$ respectively for the half wave rectifier we find the the ripple factor as

$$\gamma = \sqrt{\left(\frac{V_m}{2} \times \frac{\pi}{V_m}\right)^2 - 1} = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1} \approx 1.21.$$

Note that to construct a good rectifier, one should keep the ripple factor as low as possible. This is why capacitors and inductors as filters are used to reduce the ripples in the circuit.

PEAK FACTOR

$$\textbf{Peak factor} = \frac{peakvalue}{rmsvalue}$$

$$\textbf{Peak Factor} = \frac{V_m}{(V_m/2)}$$

Form Factor

$$\text{Form factor} = \frac{Rmsvalue}{averagevalue}$$

$$\text{Form factor} = \frac{(V_m/2)}{V_m/\Pi}$$

Form Factor =1.57

Efficiency:

$$\eta = \frac{o/ppower}{i/ppower} * 100$$

$$\eta = \frac{p_{ac}}{P_{dc}} * 100$$

$$\eta = 40.8$$

Transformer Utilization Factor (TUF):

The d.c. power to be delivered to the load in a rectifier circuit decides the rating of the transformer used in the circuit. Therefore, transformer utilization factor is defined as

$$TUF = \frac{p_{dc}}{P_{ac(rated)}}$$

$$TUF = 0.286.$$

The value of TUF is low which shows that in half-wave circuit, the transformer is not fully utilized. If the transformer rating is 1 KVA (1000VA) then the half-wave rectifier can deliver 1000 X 0.287 = 287 watts to resistance load

Peak Inverse Voltage (PIV):

It is defined as the maximum reverse voltage that a diode can withstand without destroying the junction. The peak inverse voltage across a diode is the peak of the negative half-cycle. For half-wave rectifier, PIV is Vm

Advantages of half wave rectifier

1.Simple (lower number of components)

2. Cheaper up front cost

Disadvantages Of Half-Wave Rectifier:

1. The ripple factor is high.

2. The efficiency is low.

3. The Transformer Utilization factor is low.

Numericals:

Problem 1

(1) The applied input a.c. power to a half-wave rectifier is 100 watts. The d.c. output power obtained is 40 watts. (i) What is the rectification efficiency? (ii) What happens to remaining 60 watts?

Solution

(i) Rectification efficiency = d.c.output power 40 a.c. input power 100 = = 0.4 = 40%

(ii) 40% efficiency of rectification does not mean that 60% of power is lost in the rectifier circuit. In fact, a crystal diode consumes little power due to its small internal resistance. The 100 W

3.10 Full Wave Rectifier:

A full-wave rectifier converts an ac voltage into a pulsating dc voltage using both half cycles of the applied ac voltage. In order to rectify both the half cycles of ac input, two diodes are used in this circuit

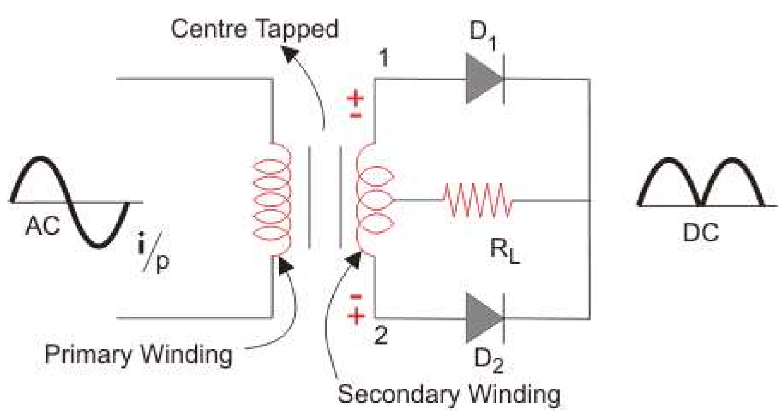


Figure 3.17: Centre tapped full wave rectifier circuit diagram and waveform

During positive half of the input signal, anode of diode D1 becomes positive and at the same time the anode of diode D2 becomes negative. Hence D1 conducts and D2 does not conduct. The load current flows through D1 and the voltage drop across RL will be equal to the input voltage.

During the negative half cycle of the input, the anode of D1 becomes negative and the anode of D2 becomes positive. Hence, D1 does not conduct and D2 conducts. The load current flows through D2 and the voltage drop across RL will be equal to the input voltage. It is noted that the load current flows in the both the half cycles of ac voltage and in the same direction through the load resistance.

For an AC voltage given by (1) the waveform of the output voltage of a full wave rectifier can be written as (for an ideal diode)

$$V_{\mathrm{o}}(t) = \begin{cases} V_m \sin(\omega t), & 0 \leq t \leq T/2 \\ V_m \sin(\omega t - \pi), & T/2 \leq t \leq T \end{cases}$$

Average output voltage of Full wave rectifier:

$$\begin{aligned} V_{\mathrm{dc}} &= \frac{1}{T}\int_0^T V_{\mathrm{o}}(t)\mathrm{d}t \\ &= \frac{1}{T/2}\int_0^{T/2} V_m \sin(\omega t)\mathrm{d}t \\ &= \frac{2V_m}{T}\int_0^{T/2} \sin(\omega t)\mathrm{d}t \\ &= \frac{2V_m}{\pi}. \end{aligned}$$

RMS value

RMS value of the output voltage of a full wave rectifier

$$
\begin{aligned}
V_{\rm rms} &= \left[\frac{1}{T}\int_0^T V_{\rm o}^2(t)\mathrm{d}t\right]^{1/2} \\
&= \left[\frac{V_m^2}{T/2}\int_0^{T/2} \sin^2(\omega t)\mathrm{d}t\right]^{1/2} \\
&= \left[\frac{V_m^2}{T}\int_0^{T/2} 2\sin^2(\omega t)\mathrm{d}t\right]^{1/2} \\
&= \frac{V_m}{\sqrt{2}}.
\end{aligned}
$$

Ripple factor

$$
\begin{aligned}
\gamma &= \sqrt{\left(\frac{V_{\rm rms}}{V_{\rm dc}}\right)^2 - 1} \\
&= \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1} \\
&\approx 0.48
\end{aligned}
$$

Efficiency of Full wave rectifier:

$$
\begin{aligned}
\eta &= \frac{P_{\rm dc}}{P_{\rm dc}} \\
&= \left(\frac{V_{\rm dc}}{V_{\rm rms}}\right)^2 \times \left(1 + \frac{r_f}{R_L}\right) \\
&\approx 0.8106\left(1 + \frac{r_f}{R_L}\right)
\end{aligned}
$$

In reality r_f is much smaller then R_L. If we neglect r_f compare to R_L then the efficiency of the rectifier is maximum. Therefore

$$\boxed{\eta_{\max} \approx 0.8106 = 81.06\%.}$$

PEAK FACTOR:

$$\text{Peak factor} = \frac{peakvalue}{rmsvalue}$$

$$\text{Peak Factor} = \frac{V_m}{(V_m / 2)}$$

$$\text{Peak Factor} = 2$$

FORM FACTOR:

$$\text{Form factor} = \frac{Rms\ value}{averagevalue}$$

$$\text{Form factor} = \frac{(V_m / \sqrt{2})}{2V_m / \Pi}$$

$$\text{Form Factor} = 1.11$$

Transformer Utilization Factor (TUF):

The d.c. power to be delivered to the load in a rectifier circuit decides the rating of the transformer used in the circuit. So, transformer utilization factor is defined as

$$TUF = \frac{p_{dc}}{P_{ac(rated)}}$$

Peak Inverse Voltage (PIV):

It is defined as the maximum reverse voltage that a diode can withstand without destroying the junction. The peak inverse voltage across a diode is the peak of the negative half-cycle. For half- wave rectifier, PIV is 2Vm

Advantages of full wave rectifier

- Full wave rectifiers have higher rectifying efficiency than half-wave rectifiers
- They have low power loss because no voltage signal is wasted in the rectification process.

Disadvantages

- Requires center tapped transformer

3.11 Bridge Rectifier:

- The bridge rectifier circuit is essentially a full wave rectifier circuit, using 4 diodes which are arranged in the form of a bridge and a transformer without centre tapping.
- The figure below shows the bridge rectifier circuit.

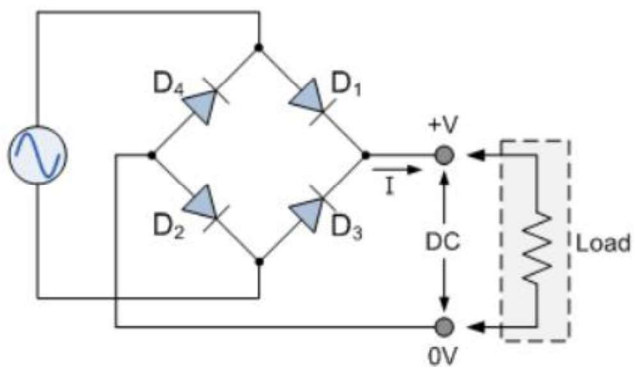


Figure 3.18: Bridge rectifier

The four diodes labeled D1 to D4 are arranged in "series pairs" with only two diodes conducting current during each half cycle. During the positive half cycle of the supply, diodes D1 and D2 conduct in series while diodes D3 and D4 are reverse biased and the current flows through the load

The Positive Half-cycle

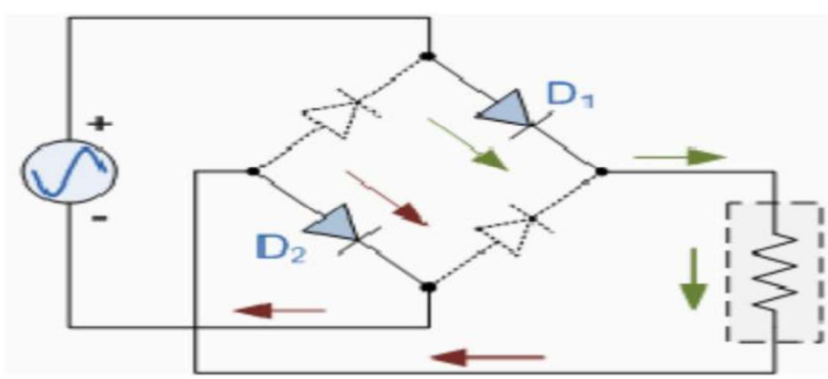


Figure 3.19: Bridge rectifier

The Negative Half-cycle

During the negative half cycle of the supply, diodes D3 and D4 conduct in series (fig 8), but diodes D1 and D2 switch "OFF" as they are now reverse biased. The current flowing through the load is the same direction as before

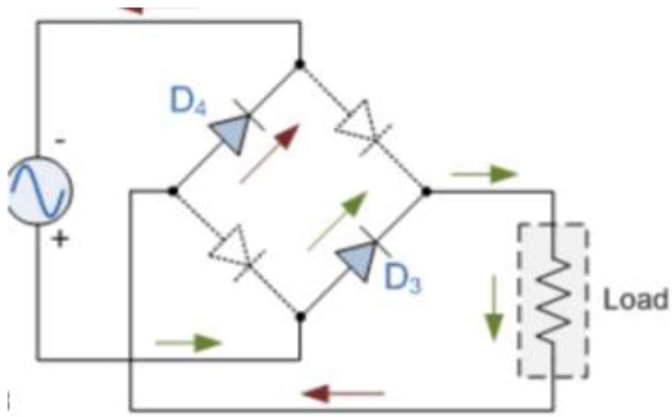


Figure 3.20: Bridge rectifier

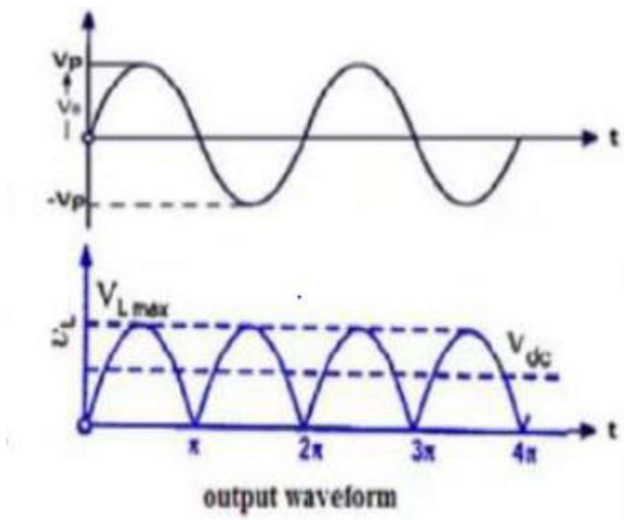


Figure 3.21: Bridge rectifier output waveform

a) Average current = $\frac{2Im}{\pi}$

b) RMS current $= \frac{Im}{\sqrt{2}}$

c) DC output voltage Vdc=$\frac{2Vm}{\pi}$

d) Ripple factor=0.482

e) Rectification Efficiency=0.812

f) DC output full load $V_{DCFL} = \frac{2V_m}{\pi} - I_{dc}(2R_F + R_s)$

Problem 2

(2) A full-wave rectifier uses two diodes, the internal resistance of each diode may be assumed constant at 20 Ω. The transformer r.m.s. secondary voltage from centre tap to each end of secondary is 50 V and load resistance is 980 Ω. Find : (i) the mean load current (ii) the r.m.s. value of load current

Solution.

$$r_f = 20\,\Omega, \quad R_L = 980\,\Omega$$

$$\text{Max. a.c. voltage, } V_m = 50 \times \sqrt{2} = 70.7\text{ V}$$

$$\text{Max. load current, } I_m = \frac{V_m}{r_f + R_L} = \frac{70.7\text{ V}}{(20 + 980)\,\Omega} = 70.7\text{ mA}$$

(i) Mean load current,

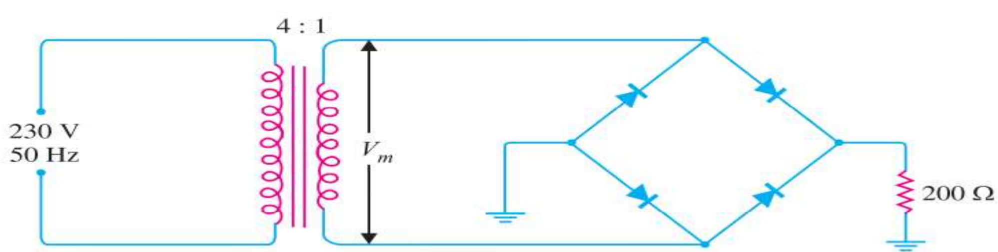
$$I_{dc} = \frac{2I_m}{\pi} = \frac{2 \times 70.7}{\pi} = \mathbf{45\ mA}$$

(ii) R.M.S. value of load current is

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{70.7}{\sqrt{2}}\overrightarrow{AB} = \mathbf{50\ mA}$$

Problem 3

(3) In the bridge type circuit shown in below Fig, the diodes are assumed to be ideal. Find : (i) d.c. output voltage (ii) peak inverse voltage (iii) output frequency. Assume primary to secondary turns to be 4.



Solution.

Primary/secondary turns, $N_1/N_2 = 4$

R.M.S. primary voltage $= 230$ V

$\therefore$ R.M.S. secondary voltage $= 230\,(N_2/N_1) = 230 \times (1/4) = 57.5$ V

Maximum voltage across secondary is

$$V_m = 57.5 \times \sqrt{2} = 81.3 \text{ V}$$

(*i*) Average current, $I_{dc} = \dfrac{2V_m}{\pi R_L} = \dfrac{2 \times 81.3}{\pi \times 200} = 0.26$ A

$\therefore$ d.c. output voltage, $V_{dc} = I_{dc} \times R_L = 0.26 \times 200 =$ **52 V**

(*ii*) The peak inverse voltage is equal to the maximum secondary voltage *i.e.*

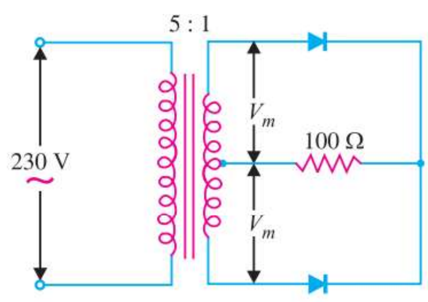
$$PIV = \textbf{81.3 V}$$

(*iii*) In full-wave rectification, there are two output pulses for each complete cycle of the input a.c. voltage. Therefore, the output frequency is twice that of the a.c. supply frequency *i.e.*

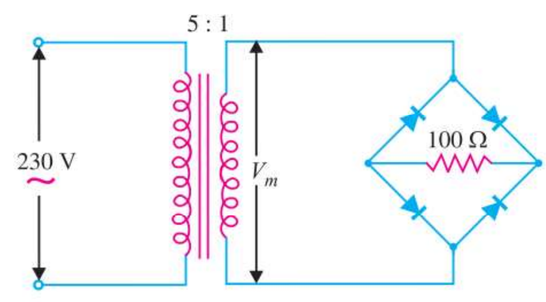
$$f_{out} = 2 \times f_{in} = 2 \times 50 = \textbf{100 Hz}$$

Problem 4

(4) Fig (i) and Fig(ii) show the centre-tap and bridge type circuits having the same load resistance and transformer turn ratio. The primary of each is connected to 230V, 50 Hz supply. (i) Find the d.c. voltage in each case. (ii) PIV for each case for the same d.c. output. Assume the diodes to be ideal



(*i*)



(*ii*)

Solution.

(*i*) D.C. output voltage

Centre-tap circuit

$$\text{R.M.S. secondary voltage} = 230 \times 1/5 = 46 \text{ V}$$

$$\text{Max. voltage across secondary} = 46 \times \sqrt{2} = 65 \text{ V}$$

Max. voltage appearing across half secondary winding is

$$V_m = 65/2 = 32.5 \text{ V}$$

$$\text{Average current, } I_{dc} = \frac{2V_m}{\pi R_L}$$

$$\text{D.C. output voltage, } V_{dc} = I_{dc} \times R_L = \frac{2V_m}{\pi R_L} \times R_L$$

$$= \frac{2V_m}{\pi} = \frac{2 \times 32.5}{\pi} = \mathbf{20.7 \text{ V}}$$

Bridge Circuit

$$\text{Max. voltage across secondary, } V_m = 65 \text{ V}$$

$$\text{D.C. output voltage, } V_{dc} = I_{dc} R_L = \frac{2V_m}{\pi R_L} \times R_L = \frac{2V_m}{\pi} = \frac{2 \times 65}{\pi} = \mathbf{41.4 \text{ V}}$$

This shows that for the same secondary voltage, the d.c. output voltage of bridge circuit is twice that of the centre-tap circuit.

(iii)PIV for same d.c. output voltage

The d.c. output voltage of the two circuits will be the same if Vm (i.e. max. voltage utilised by each circuit for conversion into d.c.) is the same. For this to happen, the turn ratio of the transformers should be as shown in below Fig

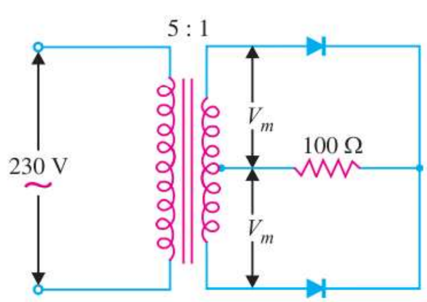
Centre-tap circuit

$$\text{R.M.S. secondary voltage} = 230 \times 1/5 = 46 \text{ V}$$

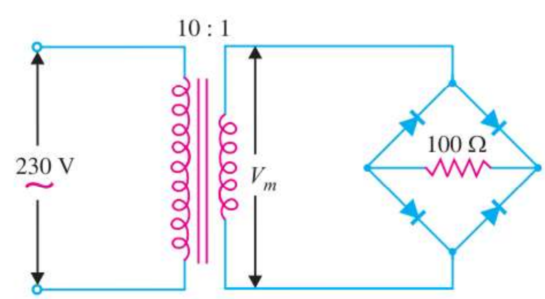
$$\text{Max. voltage across secondary} = 46 \times \sqrt{2} = 65 \text{ V}$$

Max. voltage across half secondary winding is

$$V_m = 65/2 = 32.5 \text{ V}$$



(*i*)



(*ii*)

$\therefore$ $$PIV = 2\,V_m = 2 \times 32.5 = \mathbf{65\ V}$$

Bridge type circuit

R.M.S. secondary voltage $= 230 \times 1/10 = 23$ V

Max. voltage across secondary, $V_m = 23 \times \sqrt{2} = 32.5$ V

$\therefore$ $$PIV = V_m = \mathbf{32.5\ V}$$

This shows that for the same d.c. output voltage, *PIV* of bridge circuit is half that of centre-tap circuit. This is a distinct advantage of bridge circuit.

COMPARISION:

Table 3.2: comparison of rectifiers

Particulars	Half-wave rectifier	Centre-tapped full-wave rectifier	Bridge rectifier
1. No. of diodes	1	2	4
2. I_{dc}	I_m/Π	$2I_m/\Pi$	$2I_m/\Pi$
3. V_{dc}	V_m/Π	$2V_m/\Pi$	$2V_m/\Pi$
4. I_{rms}	$I_m/2$	$I_m/\sqrt{2}$	$I_m/\sqrt{2}$
5. Efficiency	40.6%	81.2%	81.2%
6. PIV	V_m	$2V_m$	V_m
7. Ripple factor	1.21	0.48	0.48

3.12 Half wave rectifier with capacitor filter

Filters are components used to convert (smoothen) pulsating DC waveforms into constant DC waveforms. They achieve this by suppressing the DC ripples in the waveform. Although half-wave rectifiers without filters are theoretically possible, they cannot be used for any practical applications. As DC equipment requires a constant waveform, we need to smooth out this pulsating waveform for it to be any use in the real world. This is why in reality we use half wave rectifiers with a filter. A capacitor or an inductor can be used as a filter {but half wave rectifier with capacitor filter is most commonly used. The circuit diagram below shows how a capacitive filter is can be used to smoothen out a pulsating DC waveform into a constant DC waveform.

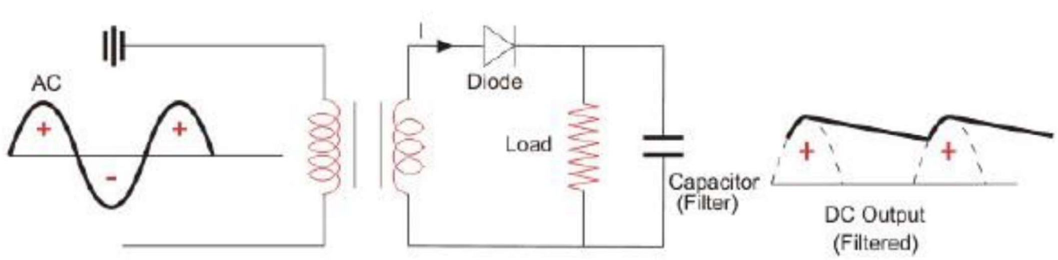


Figure 3.22: Half wave rectifier with capacitor filter and waveform

3.13 PHOTO DIODE

A photodiode is a kind of light detector, which involves the conversion of light into voltage or current, based on the mode of operation of the device.

It is also called as light sensor. The Photodiode works in reverse bias mode.

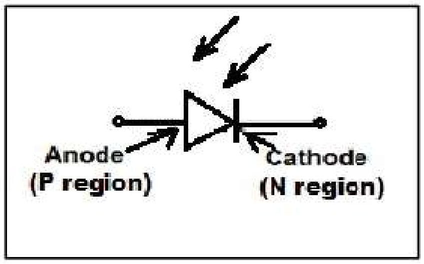


Figure 3.23: symbol of Photodiode

A photodiode is a semi-conductor device, with a p-n junction and an intrinsic layer between p and n layers. It produces photocurrent by generating electron-hole pairs, due to the absorption of light in the intrinsic or depletion region. The photocurrent thus generated is proportional to the absorbed light intensity.

Working Principle of Photodiodes

A photodiode is subjected to photons in the form of light which affects the generation of electron-hole pairs. If the energy of the falling photons (hv) is greater than the energy gap (E_g) of the semiconductor material, electron-hole pairs are created near the depletion region of the diode. The electron-hole pairs created are separated from each other before recombining due to the electric field of the junction. The direction of the electric field in the diode forces the electrons to move towards the n-side and consequently the holes move towards the p-side. As a result of the increase in the number of electrons on the n-side and holes on the p-side, a rise in the electromotive force is observed. Now when an external load is connected to the system, a current flow is observed through it

The more the electromotive force created, the greater the current flow. The magnitude of the electromotive force created depends directly upon the intensity of the incident light. This effect of the proportional change in photocurrent with the change in light intensity can be easily observed by applying a reverse bias.

Since photodiodes generate current flow directly depending upon the light intensity received, they can be used as photodetectors to detect optical signals. Built-in lenses and optical filters may be used to enhance the power and productivity of a photodiode.

Applications:

Photodiodes find application in the following:

- Cameras
- Medical devices
- Safety equipment
- Optical communication devices
- Position sensors
- Bar code scanners
- Automotive devices
- Surveying instruments

3.14 LED (Light Emitting Diode)

A light-emitting diode (LED) is a semiconductor device that emits light when an electric current flows through it. When current passes through an LED, the electrons recombine with holes emitting light in the process. LEDs allow the current to flow in the forward direction and blocks the current in the reverse direction.

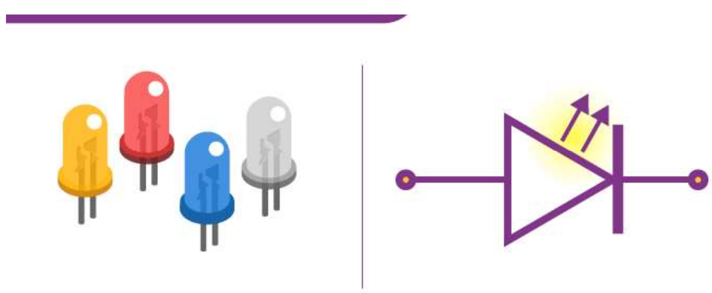


Figure 3.24: LED symbol

Light-emitting diodes are heavily doped p-n junctions. Based on the semiconductor material used and the amount of doping, an LED will emit coloured light at a particular spectral wavelength when forward biased. As shown in the figure, an LED is encapsulated with a transparent cover so that emitted light can come out.

LED Symbol

The LED symbol is the standard symbol for a diode, with the addition of two small arrows denoting the emission of light.

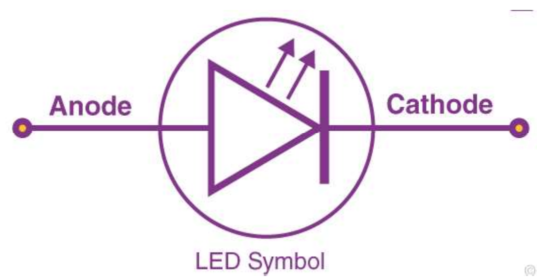


Figure 3.25: LED symbol

Simple LED Circuit

The figure below shows a simple LED circuit

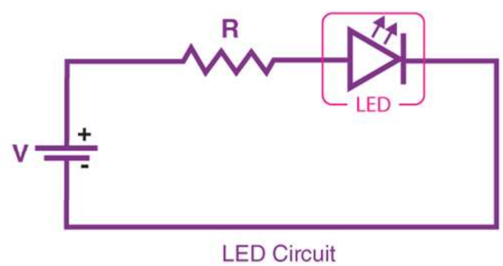


Figure 3.26: LED circuit

The circuit consists of an LED, a voltage supply and a resistor to regulate the current and voltage.

How does an LED work?

When the diode is forward biased, the minority electrons are sent from p → n while the minority holes are sent from n → p. At the junction boundary, the concentration of minority carriers increases. The excess minority carriers at the junction recombine with the majority charges carriers.

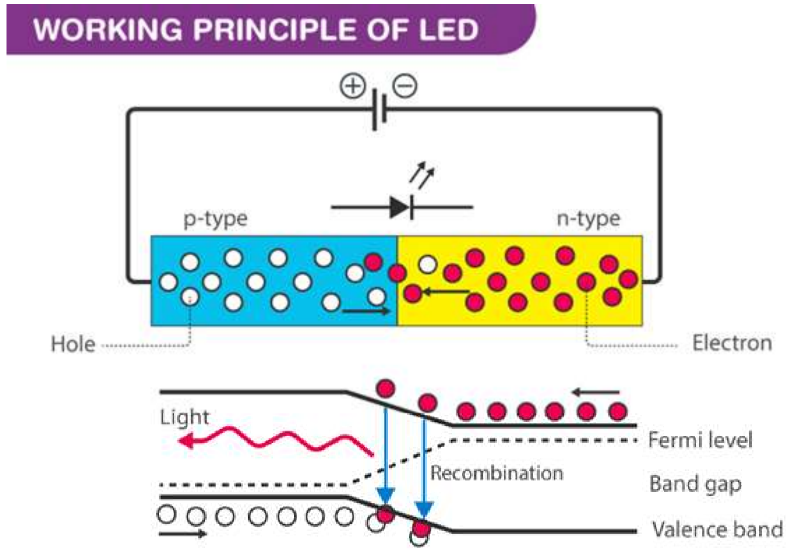


Figure 3.27: LED working principle

The energy is released in the form of photons on recombination. In standard diodes, the energy is released in the form of heat. But in light-emitting diodes, the energy is released in the form of photons. We call this phenomenon electroluminescence. Electroluminescence is an optical phenomenon, and electrical phenomenon where a material emits light in response to an electric current passed through it. As the forward voltage increases, the intensity of the light increases and reaches a maximum.

Applications of LED:

1. Picture phones and digital watches
2. Camera flashes and automotive heat lamps
3. Aviation lighting
4. Digital computers and calculators
5. Traffic signals and Burglar alarms systems
6. Microprocessors and multiplexers
7. Optical Communication
8. Indicator lamps in electric equipment
9. LED television
10. Vehicle head lamps, domestic and decorative illumination, street lighting.

3.15 Photo coupler:

An optoisolator (also called optocoupler) is a device that uses light to couple a signal from its input (a photoemitter e.g., a LED) to its output (a photodetector e.g., a photodiode)

Typically, photo couplers consist of a light emitting device optically coupled with a light detecting device via a transparent galvanic insulator. They are commonly used to transfer an electrical signal between two circuits with different ground potentials by means of light. In the past, electromagnetic relays, isolation transformers, and other devices were used to transfer electrical signals from an integrated circuit or between isolated primary and secondary sides. At present, photo couplers are generally used because they help resolve an impedance mismatch, provide higher isolation between input and output, suppress induced electromotive force, and simplify noise blocking. A photovoltaic-output photo coupler generates electricity on its own in response to light energy from the input light emitting diode (LED). Capable of driving a discrete MOSFET(s) without a power supply, photovoltaic-output photo couplers are expected to replace conventional mechanical relays. This application note provides a description of their electrical characteristics and application circuits for engineers who are unfamiliar with photovoltaic-output photo couplers.

Light emission, light reception, and signal amplification are the three main components of an optical coupler. The input electrical signal causes the light-emitting diode (LED) to emit light of a specific wavelength, which is detected by the photodetector and converted into a photocurrent, which is then output after amplification. This completes the electrical-optical-electrical conversion, acting as input, output, and isolation at the same time. The opto coupler offers good electrical insulation and anti-interference characteristics since its input and output are isolated from each other and the electrical signal transmission is unidirectional.

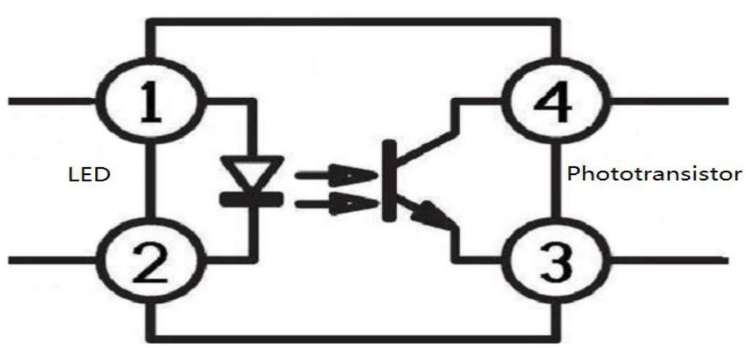


Figure 3.28: Working of photo coupler

The photocoupler's principle is to supply an electrical signal to the photocoupler's input to cause the light-emitting source to emit light. The magnitude of the excitation current determines the light intensity. The photoelectric effect generates a photocurrent once this light is irradiated on the packed light receiver. Is led out of the light receiver's output end, completing the electric-optical-electric conversion. The optocoupler's idea is that an electrical signal drives a light-emitting diode (LED) to emit a specific wavelength of light, which is detected by a photodetector, which generates a photocurrent, which is then amplified and output. This completes the electrical-optical-electrical conversion, acting as input, output, and isolation at the same time.

Where can Photo coupler be used:

(1) Logic circuit application

Optocouplers can be used to create a variety of logic circuits. Because optocouplers have stronger anti-interference and isolation properties than transistors, the logic circuits they generate are more trustworthy.

(2) For use as a solid switch

In the switch circuit, good electrical isolation between the control circuit and the switch is frequently required, which is difficult to achieve with standard electronic switches but relatively simple with a photocoupler.

(3) Use in the trigger circuit

Because the **light-emitting diodes** can be linked in series to the two emitter loops, the photoelectric coupler is employed in the bistable output circuit to effectively handle the problem of output and load isolation.

(4) Pulse amplifier circuit application

In digital circuits, photocouplers are used to amplify pulse signals.

(5) Linear circuit application

Linear photocouplers are employed in linear circuits because of their strong linearity and electrical isolation.

(6) Use in specific circumstances

Photocouplers can also be utilized for high-voltage control, transformer replacement, contact relay replacement, A/D circuits, and other applications.