Module 3

Syllabus

Single Phase Transformers: Necessity of transformer, Principle of operation, Types and construction of transformers. emf equation. losses, variation of losses with respect to load, efficiency, Condition for maximum efficiency.

Domestic Wiring: Service mains, meter board and distribution board. Brief discussion on concealed conduit wiring. Two-way and three-way control Elementary discussion on circuit protective devices:Fuse and Miniature Circuit Breaker (MCB's),electric shock, precautions against shock. Earthing:Pipe and Plate earthing. **(RBT Levels :Ll, L2 & L3)**

Module 3 a: Single Phase Transformers

3.1 INTRODUCTION

The main advantage of alternating currents over direct currents is that, the alternating currents can be easily transferable from low voltage to high or high voltage to low. Alternating voltages can be raised or lowered as per requirements in the different stages of electrical network as generation, transmission, distribution and utilization. This is possible with a static device called transformer. The transformer works on the principle of mutual induction. It transfers an electric energy from one circuit to other when there is no electrical connection between the two circuits. Thus we can define transformer as below.

The transformer is a static piece of apparatus by means of which an electrical power is transformed from one alternating current circuit to another with the desired change in voltage and current, without any change in the frequency.

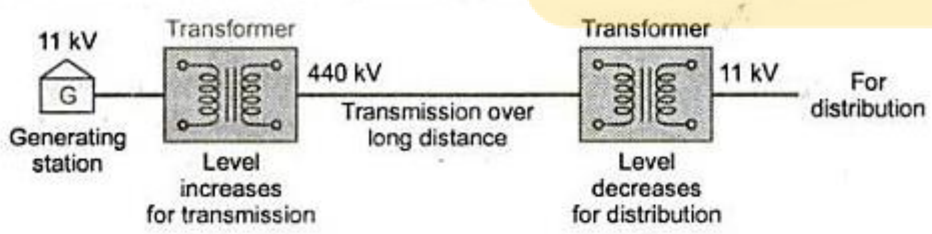


Fig 3.1:Use of transformers in transmission system

3.2 Principle of operation

A transformer works on the principle of electromagnetic induction and mutual inductance between the two coils. The general arrangement of the transformer is shown in fig 3.2.1

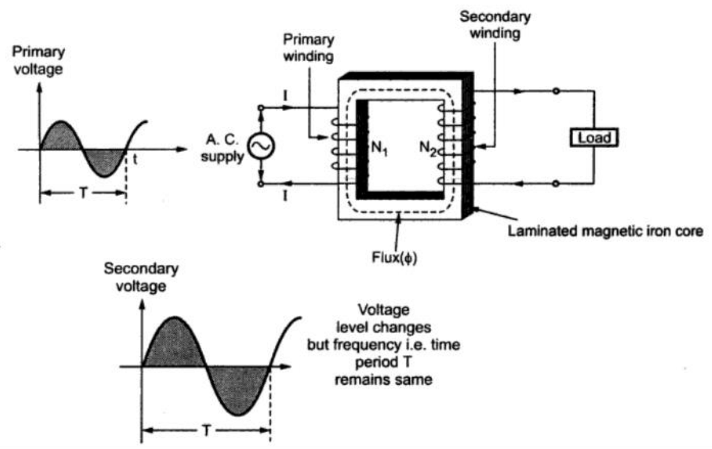


Fig 3.2.1 Basic Transformer

A steel core consists of laminated sheets about 0.4-0.7mm thick insulated from each other. The core is laminated to reduce eddy current loss. The vertical parts of the core are known as limbs, while the top and bottom parts are called yokes.

There are two separate electrical windings, which are linked through a common magnetic part. These windings are isolated from each other electrically.

The coil into which electrical energy is fed is called primary winding (P), while the other coil from which electrical energy is drawn is called the secondary winding (S). The primary winding has N_1 number of turns while the secondary winding has N_2 number of turns.

When the primary winding is connected to an alternating voltage V_1 , an alternating current flows through the primary winding P and this current produces an alternating flux φ in the steel core, the mean path of this flux being indicated by the dotted lines. If the entire flux produced by P passes through S, the EMF induced in each turn is the same for P and S.

The above mentioned alternating flux φ produces self induced EMF E_1 in the primary winding P, while due to mutual induction i.e., due to flux produced by primary linking the secondary, it produces mutually induced EMF E_2 in the secondary winding S.

Then EMFs are $E_1 = -N_1 \frac{d\varphi}{dt}$ and $E_2 = -N_2 \frac{d\varphi}{dt}$

Therefore $\frac{E_1}{E_2} = \frac{N_1}{N_2} = K$

K is known as the ***voltage transformation ratio.***

The frequency of the two EMFs is the same. The voltage transformation ratio may be alternatively obtained as follows.

The EMF per turn is the same for P and S. hence,

$$\frac{\text{total EMF induced in S}}{\text{total EMF induced in P}} = \frac{N_2 * \text{EMF per turn}}{N_1 * \text{EMF per turn}} = \frac{N_2}{N_1} = K$$

When the secondary is on open circuit, its terminal voltage is the same as the induced EMF. The primary current is then small, so that the applied voltage V_1 is practically equal and opposite to the EMF induced in P. Hence

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} = K \text{--------------------(1)}$$

As the full load efficiency of a transformer is almost 100%

$V_1 I_1$* Primary power factor = $V_2 I_2$* secondary power factor

As both the primary and secondary power factor are almost equal on full load

$$\frac{I_1}{I_2} = \frac{V_2}{V_1} = K \text{ ----------------------(2)}$$

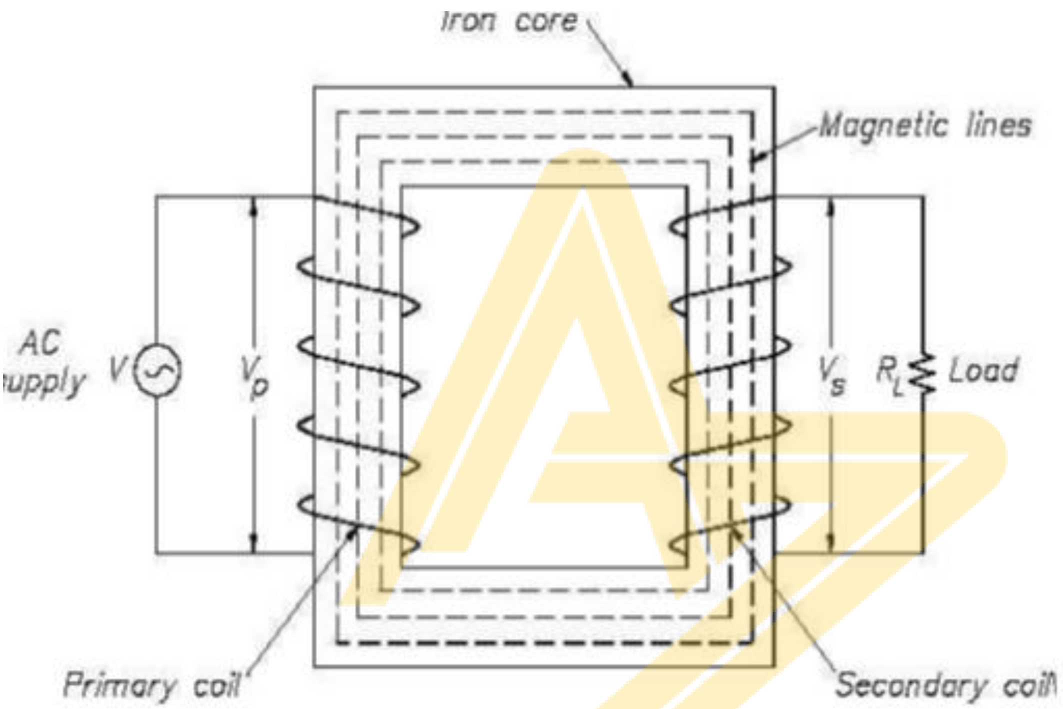
From eqns (1) and (2)

$$\boldsymbol{\frac{V_2}{V_1} = \frac{I_1}{I_2} = K}$$

3.3 Construction of transformers

- There are two basic parts of a transformer:
  1) Magnetic core 2) winding
- The core of the transformer is either rectangular or square in size.
- The core is divided into i) Yoke ii)Limb
- Core is made up of silicon steel which has high permeability and low hysteresis co-efficient.
- The vertical portion on which the winding is wound is called Limb.
- The top and bottom horizontal portion is called Yoke.
- The core forms the magnetic circuit
- There are 2 windings i) Primary winding ii) Secondary winding which forms the Electric circuit. made up of conducting material like copper.
- The winding which is connected to the supply is called primary winding and having 'N1' number of turns.

- The winding which is connected to a load is secondary winding and having 'N2' number of turns.
- Lamination of the core minimises eddy current loss.
- These laminations are insulated from each other by a thin coating of suitable varnish.
- The thickness of the lamination ranges from 0.35mm for a frequency of 25Hz to 0.5mm for a frequency of 50Hz.
- The lamination strips are assembled, where the joints are staggered to avoid narrow gaps all through the cross section of the core



3.4 Types of Transformer

The two main types of transformers are

1. core type
2. shell type

3.4.1 Core type transformer

- It has a single magnetic circuit.
- The core is rectangular having two limbs.
- The winding encircles the core.
- The coils used are of cylindrical type.
- The coils are wound in helical layer with different layers insulated from each other by paper or mica.

- Both the coils are placed on both the limbs.
- The low voltage coil is placed inside, near the core while the high voltage coil surrounds the low voltage coil.
- Core is made up of large number of thin laminations.
- As the windings are uniformly distributed over the two limbs the natural cooling is more effective.
- The coils can be easily removed by removing the lamination of the top yoke , for maintenance.
- Fig 3.4.1(a) shows the schematic representation of the core type transformer while 3.4.2(b) shows the view of actual construction of the core type transformer.

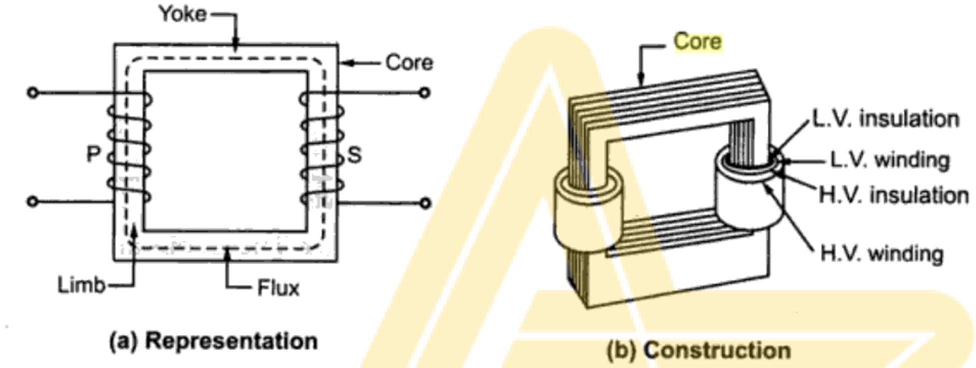


Fig 3.4.1 :Core Type of Transformer

3.4.2 Shell type transformer

- It has a double magnetic circuit.
- The core has three limbs.
- Both the windings are placed on the central limb.
- The core encircles most part of the windings.
- The coils used a re generally multilayer disc type or sandwich coils.
- Each high voltage coil is in between low voltage coils and low voltage coils are nearest to top and bottom of the yokes.
- The core is laminated.
- While arranging the lamination of the core, the care is taken that all the joints at alternate layers are staggered.
- This is done to avoid narrow air gap at the joints, right through the cross section of the core. Such joints are called overlapped or imbricated joints.
- Generally for very high voltage transformers, the shell type construction is preferred.
- As the winding is surrounded by the core, the natural cooling does not exist.

- Fig 3.4.2(a) shows the schematic representation of the shell type transformer while 3.4.2(b) shows the view of actual construction of the shell type transformer

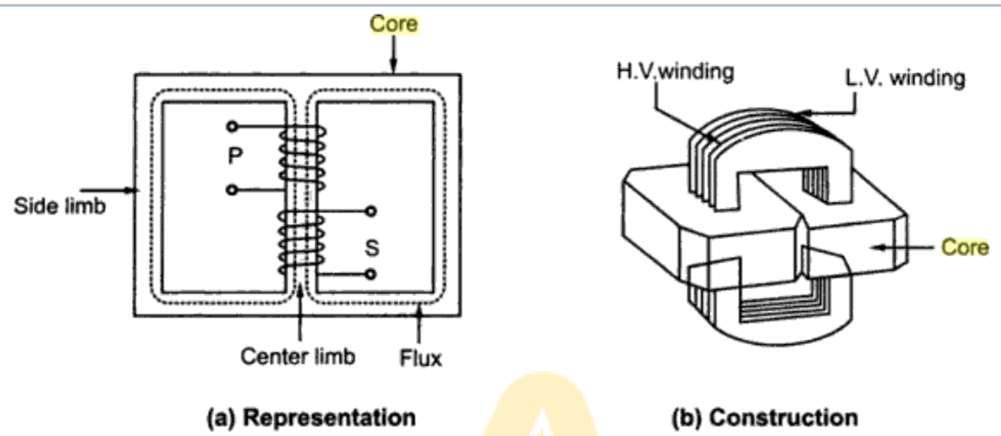


Fig 3.4.2 Shell Type Transformer

3.5 EMF Equation

Let us consider a transformer having:

N_1 = primary turns

N_2 = secondary turns

φ_m = maximum value of the flux in the core linking both the windings

= B_mA

Where B_m= maximum flux density in the core (Wb/ m^2)

A = area of cross section of the core (m^2)

f = frequency of AC input in hertz (Hz)

The flux in the core will wary sinusoidally as shown in fig 3.5, so that it increases from zero to maximum value φ_m in one quarter of the cycle i.e in $\frac{1}{4f}$ seconds

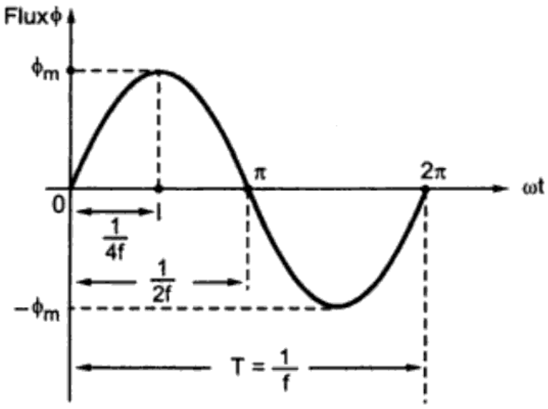


Fig 3.5 Sinusoidal Flux

Therefore, average rate of change of flux = $\frac{\varphi_m}{\frac{1}{4f}}$ = 4 f φ_m

We know that rate of change of flux per turn means induced EMF in volts

Therefore average EMF/ turn = 4 f φ_m

Since the flux is varying sinusoidally, the RMS value of the induced EMF is obtained by multiplying the average value by the form factor.

Therefore RMS value of the EMF induced/ turn = 1.11 * 4 f φ_m

= 4.44 f φ_m volts

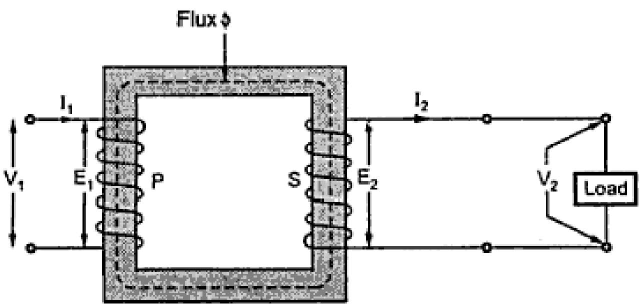
Therefore RMS value of induced EMF in the entire primary winding = (induced EMF/turn) * no. of primary turns

E_1 = 4.44 f $\varphi_m N_1$ = 4.44 f B_m A N_1------------------(1)

In the similar manner, the RMS value of induced EMF in the entire secondary winding is

E_2 = 4.44 f $\varphi_m N_2$ = 4.44 f B_m A N_2-----------------(2)

Ratios of a Transformer



Current Ratio

For an ideal transformer there are no losses. Hence the product of primary voltage V_1 and primary current I_1 is same as the product of secondary voltage V_2 and the secondary current I_2 .

$V_1 I_1$ = input KVA and $V_2 I_2$ = output KVA

For an ideal transformer

$$V_1 I_1 = V_2 I_2$$

$$\frac{V_2}{V_1} = \frac{I_1}{I_2} = K$$

Volt ampere rating

When electrical power is transferred from primary winding to secondary, there are few power losses in between. These power losses appear in the form of heat which increases the temperature of the device. Now this temperature must be maintained below certain limiting value as it is always harmful from insulation point of view. As current is the main cause in producing heat, the output maximum rating is generally specified as the product of output voltage and output current i.e. $V_2 I_2$. This always indicates that when transformer is operated under this specified rating, its temperature rise will not be excessive. The copper losses depend on current and iron losses depend on voltage. These losses are independent of the load power factor $\cos\varphi_2$. Hence though the output power depends on $\cos\varphi_2$, the transformer losses are functions of V and I and the rating of the transformer is specified as the product of voltage and current called VA rating. This rating is generally expressed in kVA (kilovolt amperes rating).

Now , $$\frac{V_2}{V_1} = \frac{I_1}{I_2} = K$$

$$V_1 I_1 = V_2 I_2$$

$$\text{KVA rating of transformer} = \frac{V_1 I_1}{1000} = \frac{V_2 I_2}{1000}$$

If V_1 and V_2 are the terminal voltages of primary and secondary then from specified kVA rating we can decide full load currents of primary and secondary, I_1 and I_2. This is the safe maximum current limit which may carry, keeping temperature rise below its limiting value.

$$I_1 \text{ full load} = \frac{\text{kVA rating} \times 1000}{V_1} \quad \text{... (1000 to convert kVA to VA)}$$

$$I_2 \text{ full load} = \frac{\text{kVA rating} \times 1000}{V_2}$$

3.7 Losses in Transformer

There are two types of power losses occur in a transformer

1) Iron loss 2) Copper loss

1) **Iron Loss (Pi)**: This is the power loss that occurs in the iron part. This loss is due to the alternating frequency of the emf. Iron loss in further classified into two other losses.
a) Eddy current loss b) Hysteresis loss

The Iron losses are called as the constant losses.

a) Eddy current loss (We) :
This power loss is due to the alternating flux linking the core, which will induced an emf , due to which a current called the eddy current is being circulated in the core.
As there is some resistance in the core with this eddy current circulation converts into heat called the eddy current power loss.

$$\boxed{\text{Eddy current loss} = K_e B_m^2 f^2 t^2 \text{ watts/unit volume}}$$

where K_e = eddy current constant

t = thickness of the core

 Eddy current loss is proportional to the square of the supply frequency.
 Eddy current loss can be minimized by using the core made of thin sheets of silicon steel material, and each lamination is coated with varnish insulation to suppress the path of the eddy currents.

b) Hysteresis loss (W_h): This is the loss in the iron core, due to the magnetic reversal of the flux in the core, which results in the form of heat in the core. This loss is directly proportional to the supply frequency.

$$\boxed{\text{Hysteresis loss} = K_h B_m^{1.67} f v \text{ watts}}$$

K_h = hysteresis constant depends on material

B_m = maximum flux density

f = frequency.

v = volume of the core

Hysteresis loss can be minimized by using the core material having high permeability.

Total Iron loss Pi = We + Wh

The flux in the core is almost constant as supply voltage V_1 at rated frequency f is always constant. Hence the flux density B_m in the core and hence both hysteresis and eddy current losses are constants at all the loads. Hence the core or iron losses are also called constant losses. The iron losses are denoted as W_i.

The iron losses are minimised by using high grade core material like silicon steel having very low hysteresis loop and by manufacturing the core in the form of laminations.

2) **Copper loss or I^2R losses (Pcu) :**
The copper losses are due to the power wasted in the form of I^2R loss due to the resistances of the primary and secondary windings. The copper loss depends on the magnitude of the currents flowing through the windings.

$$\text{Total Cu loss} = I_1^2 R_1 + I_2^2 R_2$$
$$= I_1^2 (R_1 + R_2') = I_2^2 (R_2 + R_1')$$
$$= I_1^2 R_{1e} = I_2^2 R_{2e}$$

The copper losses are denoted by W_{cu}. If the current through the winding is full load current, we get copper losses at full load. If the load on the transformer is half then we get copper losses at half loads which are less than full load copper losses. Thus copper losses are called variable losses. For transformer VA rating is $V_1 I_1$ or $V_2 I_2$. As V_1 is constant we can say that copper losses are proportional to the square of the KVA rating and square of the current.
So, $W_{cu}\, \alpha\, I^2\, \alpha\, (KVA)^2$
Thus for a transformer
Total loss = iron losses + copper losses = $W_i + W_{cu}$
Thus if current is full load then copper losses are full load losses denoted by $W_{cu}\,(F.L)$. If current is fraction of full load where n is the fraction then new copper losses are $n^2 W_{cu}\,(F.L)$.

3.8 Efficiency of Transformer

Due to the losses in a transformer, the output power of a transformer is less than the input power supplied

Therefore Power output = Power input – total losses

Therefore Power input = Power output + total losses

= Power output + $W_i + W_{cu}$

The efficiency of any device is defined as the ratio of power output to power input. So for a transformer the efficiency can be expressed as

$$\eta = \frac{\text{Power output}}{\text{Power input}}$$

$$\eta = \frac{\text{Power output}}{\text{Power output} + W_i + W_{cu}}$$

Now power output = $V_2 I_2 cos\varphi$

Where $cos\varphi$ = load power factor

The transformer supplies full load of current I_2 and with terminal voltage V_2

W_{cu} = copper loss on full load = $I_2^2 R_{2e}$

Therefore, $\eta = \frac{V_2 I_2 \cos\varphi}{V_2 I_2 \cos\varphi + W_i + I_2^2 R_{2e}}$

but $V_2 I_2$ = VA rating of a transformer

Therefore $\eta = \frac{(\text{VA rating})\cos\varphi}{(\text{VA rating})\cos\varphi + W_i + I_2^2 R_{2e}}$

$$\boldsymbol{\eta = \frac{(\text{VA rating})\cos\varphi}{(\text{VA rating})\cos\varphi + W_i + I_2^2 R_{2e}} * 100} \text{ .... Full load efficiency}$$

$$\boldsymbol{\eta = \frac{(\text{VA rating})\cos\varphi}{(\text{VA rating})\cos\varphi + W_i + W_{cu}(\text{F.L})} * 100} \text{..................full load efficiency}$$

But if the transformer is subjected to fractional load then using the appropriate values of the quantities, the efficiency can be obtained.

When load changes, the load current changes by same proportion

Therefore new $I_2 = n\, I_2$ (F.L)

Similarly as copper losses are proportional to the square of the current then,

$$\text{New } (W_{cu}) = n^2 W_{cu}(\text{F.L})$$

In general for fractional load the efficiency is given by

$$\boldsymbol{\eta = \frac{(\text{VA rating})\cos\varphi}{(\text{VA rating})\cos\varphi + W_i + n^2 W_{cu}(\text{F.L})} * 100}$$

3.9 Condition for Maximum Efficiency

When a transformer works on a constant Input voltage and frequency then efficiency varies with the load. As load increases, the efficiency increases. At a certain load current, it achieves a maximum value. If the transformer is loaded further the efficiency starts decreasing.

Let us determine,

1. Condition for maximum efficiency.

2. Load current at which η_{max} occurs.

The efficiency is functions of loads i.e. load current I_2 assuming $\cos\varphi_2$ constant. The secondary terminal voltage V_2 is also assumed constant So for maximum efficiency,

$$\frac{d\eta}{dI_2} = 0$$

Now $$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + W_i + I_2^2 R_{2e}}$$

$$\therefore \quad \frac{d\eta}{dI_2} = \frac{d}{dI_2}\left[\frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + W_i + I_2^2 R_{2e}}\right] = 0$$

$$\therefore (V_2 I_2 \cos\phi_2 + W_i + I_2^2 R_{2e}) \frac{d}{dI_2}(V_2 I_2 \cos\phi_2)$$

$$-(V_2 I_2 \cos\phi_2) \cdot \frac{d}{dI_2}(V_2 I_2 \cos\phi_2 + W_i + I_2^2 R_{2e}) = 0$$

$$(V_2 I_2 \cos\varphi_2 + W_i + I_2^2 R_{2e})(V_2 \cos\varphi_2) - (V_2 I_2 \cos\varphi_2)(V_2 \cos\varphi_2 + 2I_2 R_{2e}) = 0$$

Cancelling $V_2\cos\varphi_2$ from both the terms we get

$$V_2 I_2 \cos\varphi_2 + W_i + I_2^2 R_{2e} - V_2 I_2 \cos\varphi_2 - 2I_2^2 R_{2e} = 0$$

$$W_i - I_2^2 R_{2e} = 0$$

$$\mathbf{W_i = I_2^2 R_{2e} = W_{cu}}$$

So condition to achieve maximum efficiency is that

Copper loss = Iron Loss i.e. $\mathbf{W_i = W_{cu}}$

Load corresponding to maximum efficiency

If X is the load under maximum condition, W_i becomes cu loss for X kVA. We know that Cu loss is directly proportional to $(\mathrm{kVA})^2$, so

$W_{cu}\ \alpha\ (\text{full load kVA})^2$

Or $W_i\ \alpha\ (\mathrm{X})^2$

Therefore , $\left(\frac{X}{full\ load\ kVA}\right)^2 = \frac{W_i}{W_{cu}}$

$$\mathrm{X} = \text{Full load kVA} * \sqrt{\frac{W_i}{W_{cu}}}$$

$$X = \text{Full load kVA} * \sqrt{\frac{Iron\ loss}{full\ load\ copper\ loss}}$$

MODULE 3B: DOMESTIC WIRING

3.1 Introduction

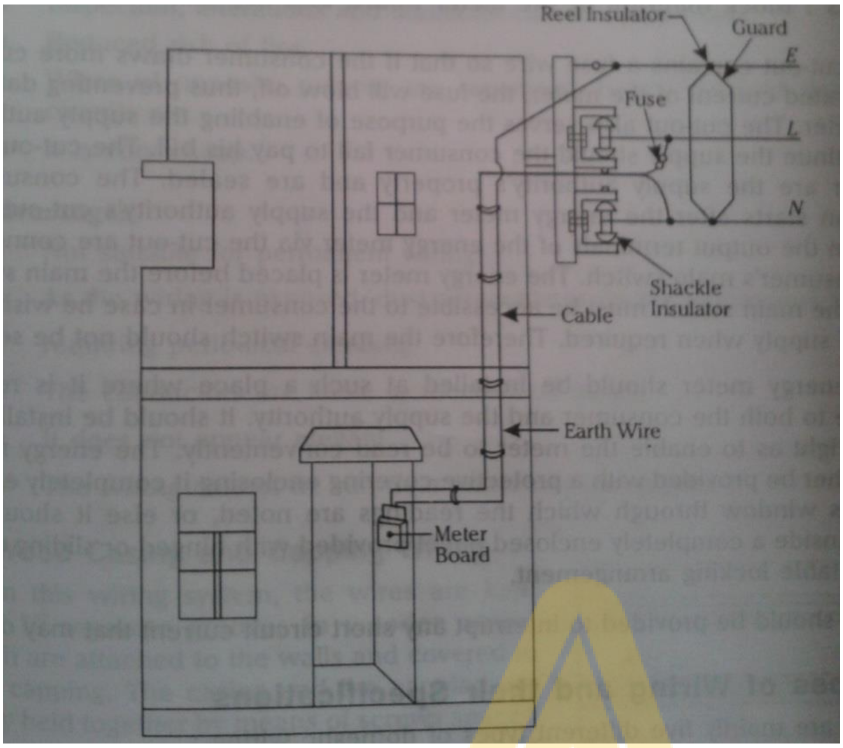
Wiring done in domestic premises for providing power for lighting, fans and domestic appliances is called domestic wiring.

The primary objective of wiring system is to distribute electrical energy to the various points at which it is required, duly considering the following

1. **Electrical safety**: This is the most important aspects – there must be no danger of leakage or of electric shock to persons using the supply.
2. **Mechanical immunity**: A wiring system which is suitable for one type of building may not be suitable for another. The wiring selected for a particular type of building should be able to withstand weather changes for a long period and should be protected from physical damage during its usage.
3. **Permanence**: There should not be any undue deterioration in wiring due to action of dampness, fumes, weather etc.
4. **Appearance**: In certain cases appearance or invisibility is important. However in case of factory wiring, appearance apart from neatness is usually not important.
5. **Cost**: the cost of wiring installation is an important consideration. The system chosen should depend upon the type of building and the purpose for which it is used, keeping economy in view.

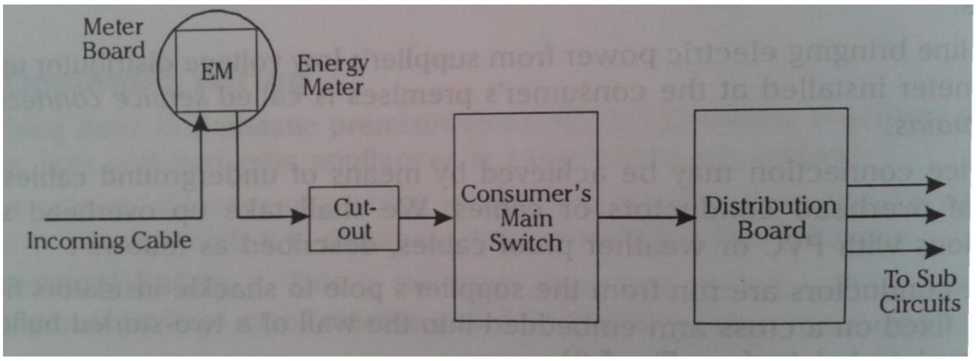
3.2 Service Mains

- The supplier`s distribution system brings power to the consumers through overhead lines or by means of underground cables to a spot outside the consumer`s premises.
- The line bringing electrical power from supplier`s low voltage distributor upto the energy meter installed at the consumer`s premises is called service connection or service mains.
- Service connection may be achieved by means of underground cables or by means of overhead conductors or cables.
- Bare conductors are run from the supplier`s pole to shackle insulators fitted to brackets fixed on a cross arm embedded into the wall of a two storied building at an appropriate height.
- Thereafter service connections are taken from the bare conductors by means of PVC or weather proof cables run on wooden battens or through GI pipe.



3.3 Meter board and Distribution board

- The supplier service line which is brought to the consumers premises, is now connected to the consumer`s internal wiring.
- The supply authority has to charge the consumer for the electrical energy consumed.
- For this purpose the supplier's service will be connected to the input terminal of the energy meter, which has to be provided by the supply authority.
- After the energy meter the service line is connected to the cut-out.
- The cut-out contains the fuse wire so that if the consumer draws more current than the rated current of the meter, the fuse will blow off, thus preventing damage to the meter.
- The cut-out also serves the purpose of enabling the supply authority to discontinue the supply should the customer failed to pay his bill.
- The cut-out and the meter are the supply authorities' property and are sealed.
- The consumer`s distribution starts after the energy meter and the supply authority`s cut out.

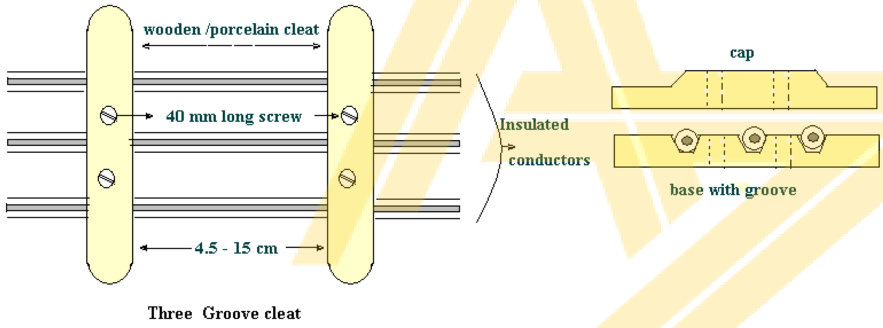


- The leads from the output terminals of the energy meter via the cut out are connected to the consumer's main switch.
- The energy meter is placed before the main switch because the main switch must be accessible to the consumer in case he wishes to switch off the supply when required. Therefore the main switch should not be sealed.
- The energy meter should be installed in such a place where it is readily accessible to both the consumer and the supply authority.

3.4 Types of wiring and their specification

3.4.1. Cleat wiring:

In this type of wiring, insulated conductors (usually VIR, Vulcanized Indian Rubber) are supported on porcelain or wooden cleats. The cleats have two halves one base and the other cap. The cables are placed in the grooves provided in the base and then the cap is placed. Both are fixed securely on the walls by 40mm long screws. The cleats are easy to erect and are fixed 4.5 – 15 cms apart. This wiring is suitable for temporary installations where cost is the main criteria but not the appearance.



Advantages:

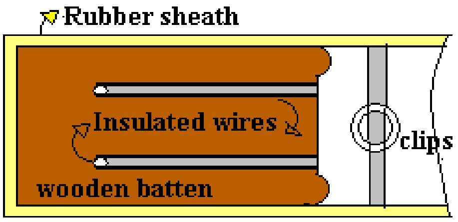
1. Easy installation
2. Materials can be retrieved for reuse
3. Flexibility provided for inspection, modifications and expansion.
4. Relatively economical
5. Skilled manpower not required.

Disadvantages:

1. Appearance is not good
2. Open system of wiring requiring regular cleaning.
3. Higher risk of mechanical injury

3.4.2. CTS (Cable Tyre Sheathed) / TRS (Tough Rubber Sheathed) / Batten wiring:

In this wiring system, wires sheathed in tough rubber are used which are quite flexible. They are clipped on wooden battens with brass clips (link or joint) and fixed on to the walls or ceilings by flat head screws. These cables are moisture and chemical proof. They are suitable for damp climate but not suitable for outdoor use in sunlight. TRS wiring is suitable for lighting in low voltage installations.



CTS/TRS WIRING

Advantages:

1. Easy installation and is durable
2. Lower risk of short circuit.
3. Cheaper than casing and capping system of wiring
4. Gives a good appearance if properly erected.

Disadvantages:

1. Danger of mechanical injury.
2. Danger of fire hazard.
3. Should not be exposed to direct sunlight.
4. Skilled workmen are required

3.4.3. Metal Sheathed or Lead Sheathed wiring :

The wiring is similar to that of CTS but the conductors (two or three) are individually insulated and covered with a common outer lead-aluminum alloy sheath. The sheath protects the cable against dampness, atmospheric extremities and mechanical damages. The sheath is earthed at every junction to provide a path to ground for the leakage current. They are fixed by means of metal clips on wooden battens. The wiring system is very expensive. It is suitable for low voltage installations.

Precautions to be taken during installation

1. The clips used to fix the cables on battens should not react with the sheath.
2. Lead sheath should be properly earthed to prevent shocks due to leakage currents.
3. Cables should not be run in damp places and in areas where chemicals (may react with the lead) are used.

Advantages:

1. Easy installation and is aesthetic in appearance.
2. Highly durable
3. Suitable in adverse climatic conditions provided the joints are not exposed

Disadvantages:

1. Requires skilled labor
2. Very expensive
3. Unsuitable for chemical industries

3.4.4. Casing and Capping:

It consists of insulated conductors laid inside rectangular, teakwood or PVC boxes having grooves inside it. A rectangular strip of wood called capping having same width as that of casing is fixed over it. Both the casing and the capping are screwed together at every 15 cms. Casing is attached to the wall. Two or more wires of same polarity are drawn through different grooves. The system is suitable for indoor and domestic installations.

Advantages:

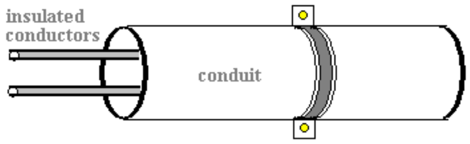
1. Cheaper than lead sheathed and conduit wiring.
2. Provides good isolation as the conductors are placed apart reducing the risk of short circuit.
3. Easily accessible for inspection and repairs.
4. Since the wires are not exposed to atmosphere, insulation is less affected by dust, dirt and climatic variations.

Disadvantages:

1. Highly inflammable.
2. Usage of unseasoned wood gets damaged by termites.
3. Skilled workmanship required.

3.4.5. Conduit wiring:

In this system PVC (polyvinyl chloride) or VIR cables are run through metallic or PVC pipes providing good protection against mechanical injury and fire due to short circuit. They are either embedded inside the walls or supported over the walls, and are known as concealed wiring or surface conduit wiring (open conduit) respectively. The conduits are buried inside the walls on wooden gutties and the wires are drawn through them with fish (steel) wires. The system is best suited for public buildings, industries and workshops.



CONDUIT WIRING

Advantages:

1. No risk of fire and good protection against mechanical injury.
2. The lead and return wires can be carried in the same tube.
3. Earthing and continuity is assured.
4. Water-proof and trouble shooting is easy.
5. Shock- proof with proper earthing and bonding
6. Durable and maintenance free
7. Aesthetic in appearance

Disadvantages:

1. Very expensive system of wiring.
2. Requires good skilled workmanship.
3. Erection is quiet complicated and is time consuming.
4. Risk of short circuit under wet conditions (due to condensation of water in tubes).

3.5 Specification of Wires:

The conductor material, insulation, size and the number of cores, specifies the electrical wires. These are important parameters as they determine the current and voltage handling capability of the wires. The conductors are usually of either copper or aluminium. Various insulating materials like PVC, TRS, and VIR are used. The wires may be of single strand or multi strand. Wires with combination of different diameters and the number of cores or strands are available.

For example: The VIR conductors are specified as 1/20, 3/22,….7/20 ………

The numerator indicates the number of strands while the denominator corresponds to the diameter of the wire in SWG (Standard Wire Gauge). SWG 20 corresponds to a wire of diameter 0.914mm, while SWG 22 corresponds to a wire of diameter 0.737 mm.

A 7/0 wire means, it is a 7-cored wire of diameter 12.7mm (0.5 inch). The selection of the wire is made depending on the requirement considering factors like current and voltage ratings, cost and application.

Example: Application: domestic wiring

1. Lighting - 3/20 copper wire
2. Heating - 7/20 copper wire

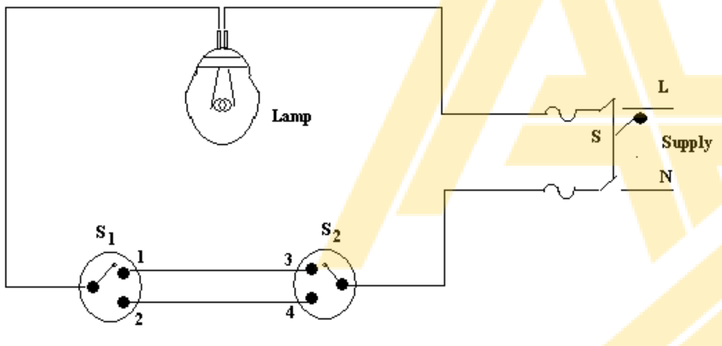
The enamel coating (on the individual strands) mutually insulates the strands and the wire on the whole is provided with PVC insulation. The current carrying capacity depends on the total area of the wire. If cost is the criteria then aluminium conductors are preferred. In that case, for the same current rating a much larger diameter of wire is to be used.

3.6 Two- way and Three- way Control of Lamps:

The domestic lighting circuits are quite simple and they are usually controlled from one point. But in certain cases it might be necessary to control a single lamp from more than one point (Two or Three different points). For example: Staircases, long corridors, large halls etc.

3.6.1 **Two-way Control of lamp**:

Two-way control is usually used for staircase lighting. The lamp can be controlled from two different points: one at the top and the other at the bottom - using two- way switches which are interconnected by strap wires. They are also used in bedrooms, big halls and large corridors. The circuit is shown in the following figure.



Two -way control of lamp

Switches **S_1** and **S_2** are two-way switches with a pair of terminals 1&2, and 3&4 respectively. When the switch **S_1** is in position**1** and switch **S_2** is in position **4**, the circuit does not form a closed loop and there is no path for the current to flow and hence the lamp will be **OFF.** When **S_1** is changed to position **2** the circuit gets completed and hence the lamp glows or is **ON**. Now if **S_2** is changed to position **3** with **S_1** at position **2** the circuit continuity is broken and the lamp is off. Thus the lamp can be controlled from two different points.

Position of S1	Position of S2	Condition of lamp
1	3	ON
1	4	OFF
2	3	OFF
2	4	ON

3.6.2 Three- way Control of lamp:

In case of very long corridors it may be necessary to control the lamp from 3 different points. In such cases, the circuit connection requires two; two-way switches **S_1**and **S_2** and an intermediate switch **S_3**. An intermediate switch is a combination of two, two way switches coupled together. It has 4 terminals ABCD. It can be connected in two ways

a) Straight connection

b) Cross connection

In case of straight connection, the terminals or points AB and CD are connected as shown in figure 1(a) while in case of cross connection, the terminals AB and

C D is connected as shown in figure 1(b). As explained in two –way control the lamp is ON if the circuit is complete and is OFF if the circuit does not form a closed loop.

Three -way control of lamp

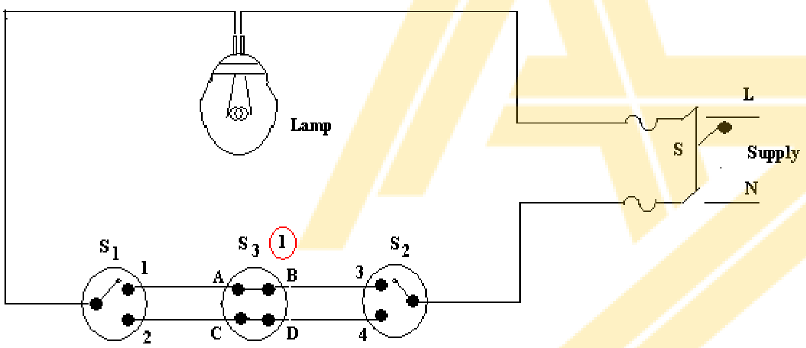


Figure 1 (a) Straight connection

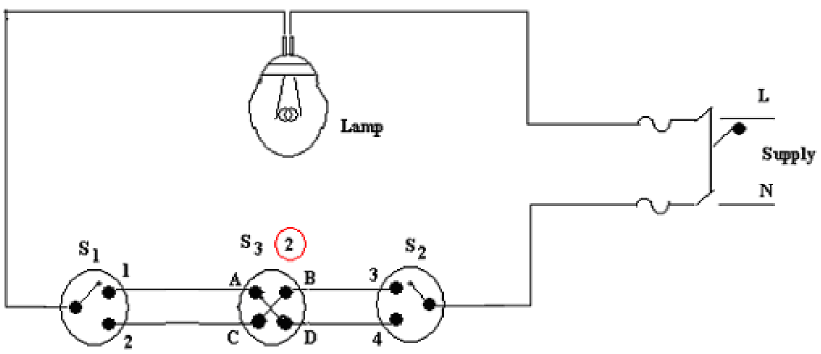


Figure 1 (b) Cross connection

The condition of the lamp is given in the table depending on the positions of the switches **S_1**, **S_2** and **S_3**.

Position of S3	Position of S1	Position of S2	Condition of the lamp
1 straight connection	1	3	ON
	1	4	OFF
	2	3	OFF
	2	4	ON
2 cross connection	1	3	OFF
	1	4	ON
	2	3	ON
	2	4	OFF

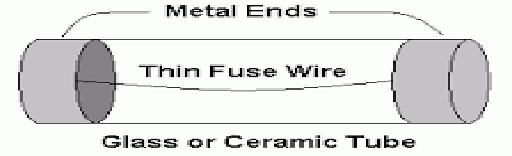
3.7 PROTECTIVE DEVICES

Protection for electrical installation must be provided in the event of faults such as short circuit, overload and earth faults. The protective circuit or device must be fast acting and isolate the faulty part of the circuit immediately. It also helps in isolating only required part of the circuit without affecting the remaining circuit during maintenance. The following devices are usually used to provide the necessary protection:

- Fuses
- Miniature circuit breakers(MCB)
- Earth leakage circuit breakers(ELCB)
- Residual Current Circuit Breaker (RCCB)

3.7.1 Fuse

A fuse is a safety device, a weak link connected in series with the circuit, which melts whenever the current in the circuit exceeds the value of the fuse provided, either due to overload or short circuit, thus opening the circuit and protecting other material in the circuit.



- A fuse consists of a metal strip or wire fuse element, of small cross-section compared to the circuit conductors, mounted between a pair of electrical terminals, and (usually) enclosed by a non-combustible housing.
- The fuse is arranged in series to carry all the current passing through the protected circuit.
- The resistance of the element generates heat due to the current flow.

- The size and construction of the element is (empirically) determined so that the heat produced for a normal current does not cause the element to attain a high temperature.
- If too high a current flows, the element rises to a higher temperature and either directly melts, or else melts a soldered joint within the fuse, opening the circuit.

Definitions

1. **Fuse element**

The part of the fuse which melts when excessive current flows through it is called fuse element or fuse wire.

2. **Fusing current**

The minimum value of the current at which the fuse element melts to interrupt the circuit current is called fusing current. Its value is always more than the current rating of the fuse.

3. **Fusing Factor**

The ratio of the minimum fusing current and the current rating of the fuse is called the fusing factor. As minimum fusing current is more than the current rating, the fusing factor is always greater than one.

$$\text{Fusing Factor} = \frac{\text{minimum fusing current}}{\text{current rating of the fuse}}$$

4. **Rated current of fuse**

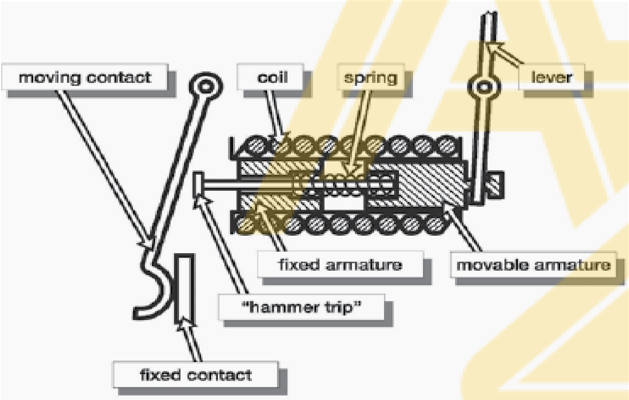
It is that maximum current which fusing element can normally carry without any overheating or melting. It depends on,

1. Temperature rise of fuse contact of fuse holder
2. Fusing element material
3. Deterioration of fuse to oxidation

3.7.2 Miniature Circuit Breaker (MCB)

- **MCB**s or **Miniature Circuit Breakers** are electromechanical devices which protect an electrical circuit from an over current.
- The over current, in an electrical circuit, may result from short circuit, overload or faulty design.
- An MCB is a better alternative to a Fuse since it does not require replacement once an overload is detected.
- Unlike fuse, an MCB can be easily reset and thus offers improved operational safety and greater convenience without incurring large operating cost.

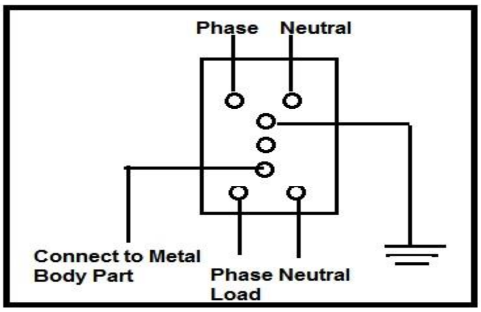
- An MCB functions by interrupting the continuity of electrical flow through the circuit once a fault is detected.
- In simple terms MCB is a switch which automatically turns off when the current flowing through it passes the maximum allowable limit.
- Generally MCB are designed to protect against over current and over temperature faults (over heating).
- There are two contacts one is fixed and the other moveable.
- When the current exceeds the predefined limit a solenoid forces the moveable contact to open (i.e., disconnect from the fixed contact) and the MCB turns off thereby stopping the current to flow in the circuit.
- In order to restart the flow of current the MCB is manually turned on.
- This mechanism is used to protect from the faults arising due to over current or over load.



- To protect against fault arising due to over heating or increase in temperature a bi-metallic strip is used.
- MCBs are generally designed to trip within 2.5 millisecond when an over current fault arises.
- In case of temperature rise or over heating it may take 2 seconds to 2 minutes for the MCB to trip.

3.7.3 Earth Leakage Circuit Breaker (ELCB)

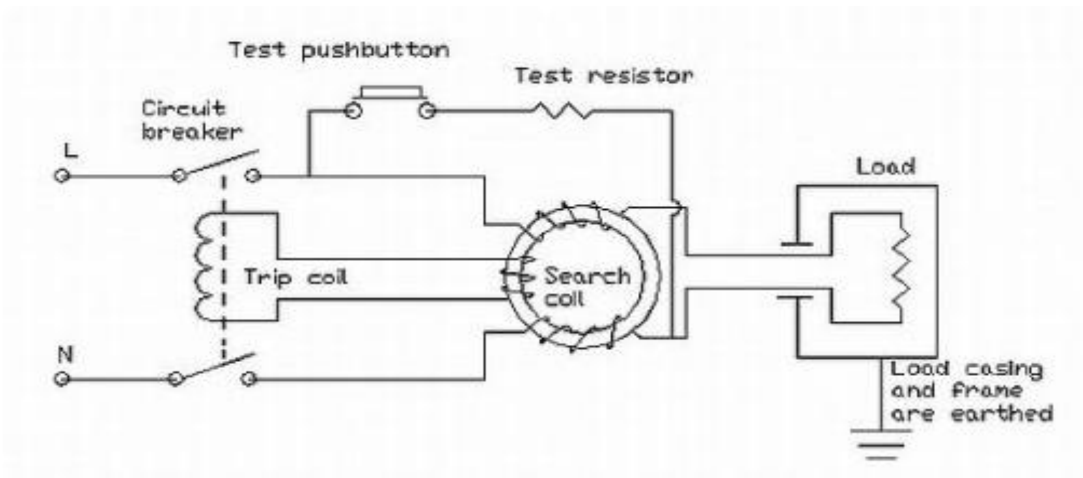
- There are certain situations where leakage current flows through the metal bodies of appliances. Thus person touching such appliances may get a shock.
- There is a risk of fire due to such leakage current flowing to the earth.
- The MCB and fuse cannot provide protection against earth leakage current.
- Hence there is a need of a device which can directly detect the earth leakage currents and cut the supply if such currents exceed a preset value. Such a device is called Earth Leakage Circuit Breaker (ELCB).



- Voltage Operate ELCB contains a relay coil or ELCB coil.
- One end of the ELCB coil is given connection to the load and the other end to the earth wire.
- When the voltage of the load rises, there will be a difference in voltage between the load and the earth wire resulting in electric shock.
- This potential or voltage difference causes a current to flow from the load to the ground through the relay coil loop.
- When the voltage difference becomes greater than 50 volt, current through the loop moves the relay and hence disconnect the supply. In other words, the trip mechanism operates.
- Voltage Operate ELCB detects only the electric faults from the phase to the earth wire within the load it protects.
- It cannot detect the fault currents that flow between the phase and any other earth (person, ground water pipes etc.).
- In such a case, the ELCB cannot protect against electric shock.

3.7.4 Residual Current Circuit Breaker (RCCB)

- Current operated ELCBs are generally known as Residual current devices (RCD).
- These also protect against earth leakage.
- Both circuit conductors (supply and return) are run through a sensing coil; any imbalance of the currents means the magnetic field does not perfectly cancel.
- The device detects the imbalance and trips the contact



- The supply coil, the neutral coil and the search coil all wound on a common transformer core.

- On a healthy circuit the same current passes through the phase coil, the load and return back through the neutral coil.
- Both the phase and the neutral coils are wound in such a way that they will produce an opposing magnetic flux.
- With the same current passing through both coils, their magnetic effect will cancel out under a healthy circuit condition.
- In a situation when there is fault or a leakage to earth in the load circuit, or anywhere between the load circuit and the output connection of the RCB circuit, the current returning through the neutral coil has been reduced. Then the magnetic flux inside the transformer core is not balanced anymore.
- The total sum of the opposing magnetic flux is no longer zero. This net remaining flux is what we call a residual flux.
- The periodically changing residual flux inside the transformer core crosses path with the winding of the search coil.
- This action produces an electromotive force (e.m.f.) across the search coil.
- An electromotive force is actually an alternating voltage.
- The induced voltage across the search coil produces a current inside the wiring of the trip circuit.
- It is this current that operates the trip coil of the circuit breaker.
- Since the trip current is driven by the residual magnetic flux (the resulting flux, the net effect between both fluxes) between the phase and the neutral coils, it is called the residual current device
- With a circuit breaker incorporated as part of the circuit, the assembled system is called residual current circuit breaker (RCCB) or residual current devise (RCD).
- The incoming current has to pass through the circuit breaker first before going to the phase coil.
- The return neutral path passes through the second circuit breaker pole.
- During tripping when a fault is detected, both the phase and neutral connection is isolated.

3.9 Electric Shock

- A sudden agitation of the nervous system of a body, due to the passage of an electric current is called an electric shock.
- The factors affecting the severity of the shock are
  - Magnitude of current through the body
  - Path of the current through the body
  - Time for which the current is passed through the body
  - Frequency of the current
  - Physical and psychological condition of the person

3.9.1 Elementary first aid against shock

The first aid can save the life and reduce severity of the accidents. Hence elementary first aid is important. The first aid against the electric shock involves following steps,

1. Do not panic
2. Carry the affected person and lay him in a comfortable position and call the doctor immediately.
3. Look for stoppage of breathing
4. Start giving him artificial respiration if breathing is stopped.
5. Never give anything to the person to drink when the person is unconscious.
6. The artificial respiration should be continued for longer time.
7. The burns caused due to electric flashes should be covered with sterile dressing and then bandaged.
8. Do not crowd and let the person get fresh air.

3.9.2 Safety precaution against electric shock

1. Insulation of the conductor used must be proper and in good condition. If it is not so the current carried by the conductor may leak out. The person coming in contact with such faulty insulated conductors may receive a shock.
2. Megger test should be conducted and insulation must be checked. With the help of megger all the test must be performed, on the new wiring before starting use of it.
3. Earth connection should be always maintained in proper condition.
4. Switch off the main supply and remove the fuses before starting to work with any installation.
5. Fuses must have correct rating.
6. Use rubber soled shoes while working. Use some wooden supper under the feet, this removes the contact with earth.
7. Use rubber gloves while touching any terminal or removing insulation layer from the conductor.
8. Use a line tester to check whether a live terminal carries any current.
9. Always use insulated screw driver, pliers etc
10. Never touch two different terminals at the same time.
11. Never remove the plug by pulling the wires connected to it.
12. The sockets should be fixed at a height beyond the reach of the children.

3.9 Earthing

The potential of the earth is considered to be at zero for all practical purposes as the generator (supply) neutral is always earthed. The body of any electrical equipment is connected to the earth by means of a wire of negligible resistance to safely discharge electric energy, which may be due to failure of the insulation, line coming in contact with the casing etc. Earthing brings the potential of the body of the equipment to ZERO i.e. to the earth's potential, thus protecting the operating personnel against electrical shock. The body of the electrical equipment is not connected to the supply neutral because due to long transmission lines and intermediate substations, the same neutral wire of the generator will not be available at the load end. Even if the same neutral wire is running it will have a self resistance which is higher than the human body resistance. Hence, the body of the electrical equipment is connected to earth only.

Thus earthing is to connect any electrical equipment to earth with a very low resistance wire, making it to attain earth's potential. The wire is usually connected to a copper plate placed at a depth of 2.5 to 3meters from the ground level.

3.9.1 Necessity of Earthing:

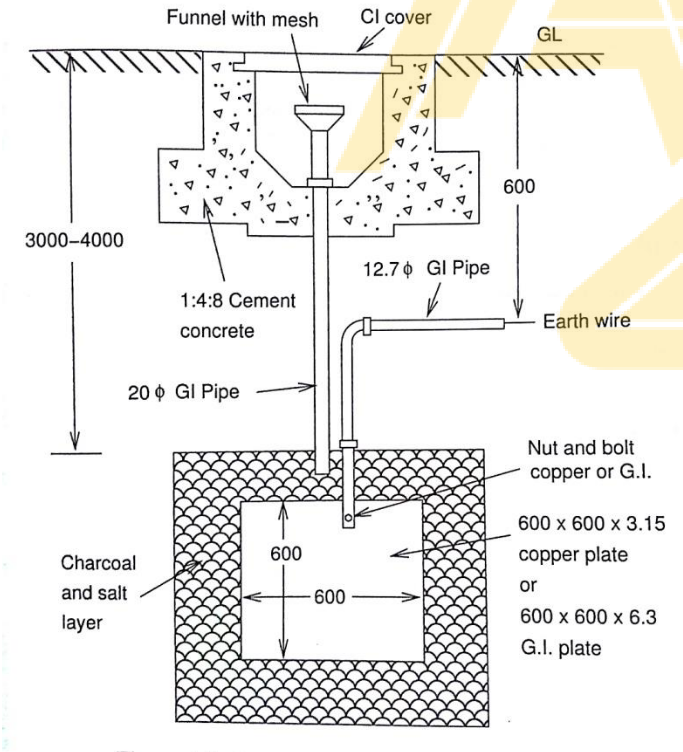
1. To protect the operating personnel from danger of shock in case they come in contact with the charged frame due to defective insulation.
2. To maintain the line voltage constant under unbalanced load condition.
3. Protection of the equipments
4. Protection of large buildings and all machines fed from overhead lines against lightning.

3.9.2 Methods of Earthing:

The important methods of earthing are the plate earthing and the pipe earthing. The earth resistance for copper wire is 1 ohm and that of G I wire less than 3 ohms. The earth resistance should be kept as low as possible so that the neutral of any electrical system which is earthed is maintained almost at the earth potential. The typical value of the earth resistance at power house is 0. 5 ohm and that at substation is 1 ohm

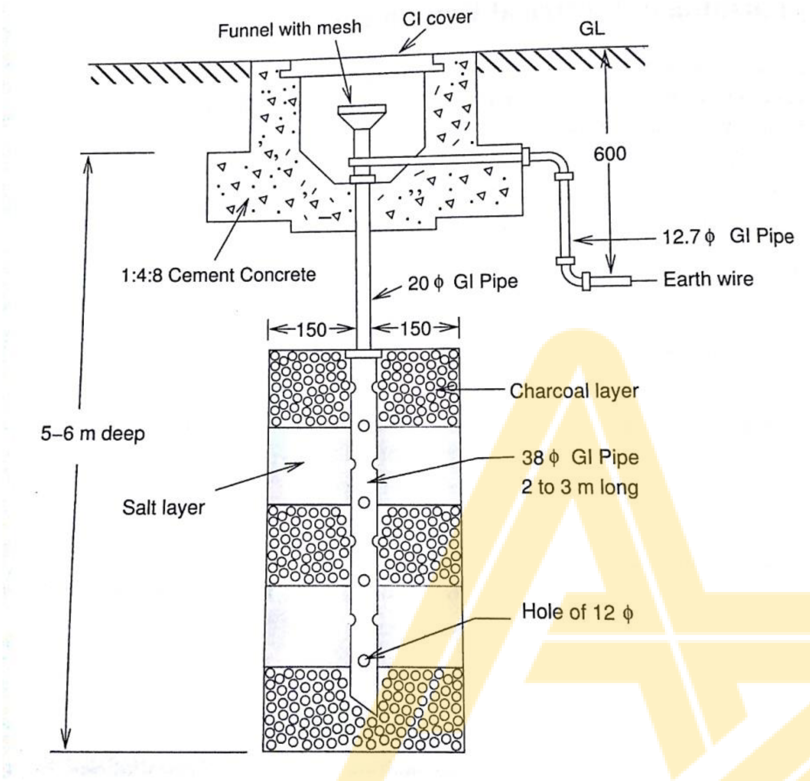
3.9.2.1 Plate Earthing

In this method a copper plate of 60cm x 60cm x 3.15cm or a GI plate of the size 60cm x 60cm x 6.35cm is used for earthing. The plate is placed vertically down inside the ground at a depth of 3m and is embedded in alternate layers of coal and salt for a thickness of 15 cm. In addition, water is poured for keeping the earth electrode resistance value well below a maximum of 5 ohms. The earth wire is securely bolted to the earth plate. A cement masonry chamber is built with a cast iron cover for easy regular maintenance.



3.9.2.2 Pipe Earthing

Earth electrode made of a GI pipe of 38mm diameter and 2m length (depending on the current) with 12mm holes on the surface is placed upright at a depth of 4.75m in a permanently wet ground. To keep the value of the earth resistance at the desired level, the area(15 cms) surrounding the GI pipe is filled with a mixture of salt and coal.. The efficiency of the earthing system is improved by pouring water through the funnel periodically. The GI earth wires of sufficient cross- sectional area are run through a 12.7mm diameter pipe (at 60cms below) from the 19mm diameter pipe and secured tightly at the top as shown in the following figure.



When compared to the plate earth system the pipe earth system can carry larger leakage currents as a much larger surface area is in contact with the soil for a given electrode size. The system also enables easy maintenance as the earth wire connection is housed at the ground level.