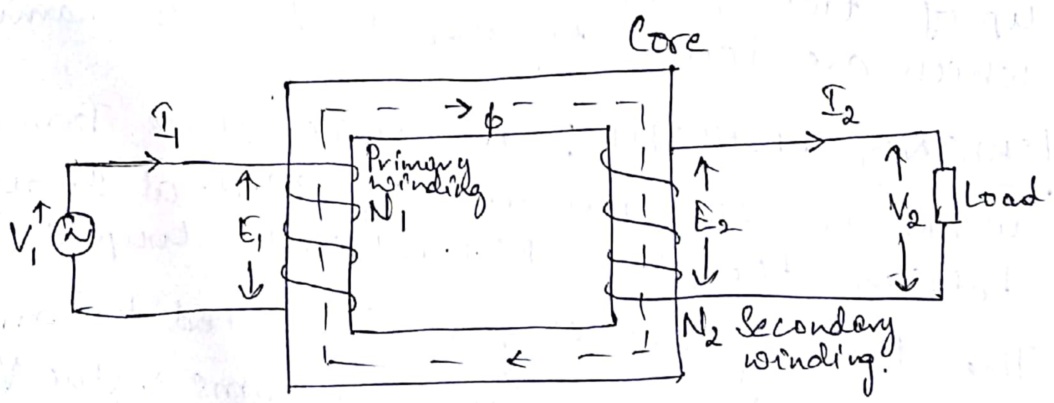
TRANSFORMERS :

① Introduction : A Transformer is a Static Electrical device, which transfers Electrical power from One Electrical Circuit to the other, which are Magnetically Coupled together with or without change of voltage & current and without any change of Power & frequency.

↳ The Transformer is a Static apparatus & has no moving apparatus, hence there are no Mechanical losses. Hence the efficiency of a Transformer is very high of the order of 95 to 98%

CONSTRUCTION :



A Single phase Transformer consists of 2-parts
(i) Windings.
(ii) Core.

↳ The windings are made of copper because they possess very small resistance. The winding which is connected to the supply is called primary winding & the one which is connected to the load is called secondary winding.
The primary winding has N_1 number of turns & secondary has N_2 number of turns.

↳ The core is madeup of silicon steel which has high relative permeability & low hysteresis co-efficient. The core is laminated to reduce eddy current losses.
For small transformers each lamination is a single piece. For large transformers each section is made up of two or more sections of E, T or L shaped, which are joined together to form the lamination.

WORKING PRINCIPLE: A single phase transformer works on the principle of mutual induction between the two magnetically coupled coils.

↳ The primary winding is connected to an alternating voltage source of rms value V_1 volts, hence an alternating current I_1 flows through the primary winding & sets up an alternating flux 'ϕ' in the transformer core which links both primary & secondary winding. Therefore an EMF 'E_1' is induced in the primary winding & an EMF 'E_2' is induced in the secondary winding.

w.k.t $e_1 = -N_1 \frac{d\phi}{dt}$ & $e_2 = -N_2 \frac{d\phi}{dt}$

$$\therefore \frac{e_2}{e_1} = \frac{N_2}{N_1} = \frac{E_2}{E_1}$$

$$\therefore \frac{E_2}{E_1} = \frac{N_2}{N_1} = 'K' \text{ Transformation Ratio.}$$

Power i/p to the Primary winding } = { Power o/p from the Secondary winding.

$$E_1 I_1 = E_2 I_2$$

$$\therefore \frac{E_2}{E_1} = \frac{I_1}{I_2} = K$$

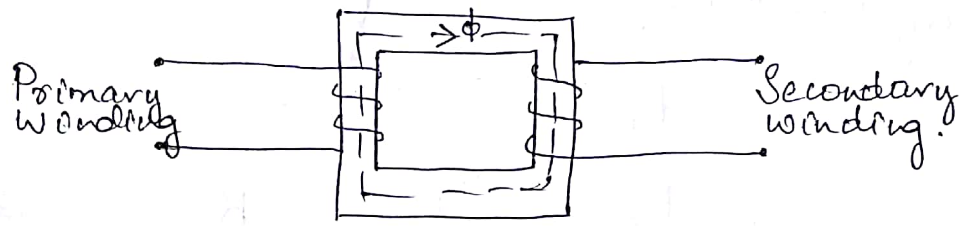
$$\therefore \boxed{\frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = K}$$

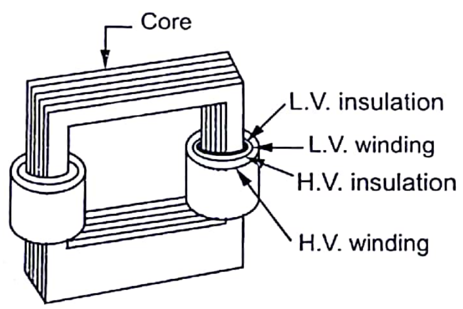
or

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

TYPES OF TRANSFORMERS : Depending on the way in which Primary & Secondary windings are wound on the Core, The Transformers are classified into two types (i) CORE TYPE
(ii) SHELL TYPE

(i) CORE TYPE TRANSFORMERS : The Primary & Secondary windings are connected on Seperate limbs to reduce the Leakage flux.





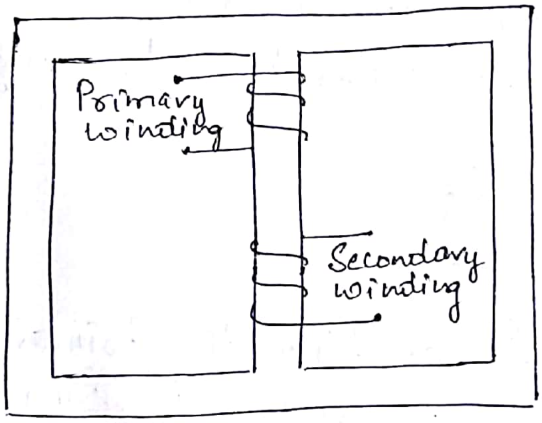
(b) Construction

↳ The coils may be Circular or Rectangular oval, In practice, One Half of the Primary winding & One half of the Secondary winding are placed Concentrically On One limb, the low voltage one nearer to the core.

↳ The Core is always laminated to reduce the eddy Current loss. For Small sized Transformers the Core is Rectangular in Shape but for Large Size Transformers Cruciform Core is used.

↳ The core type Transformers are used to handle low & Medium voltages.

SHELL TYPE TRANSFORMERS :↳ The Primary and Secondary windings are located on central limb.



↳ The coils are wound as Multilayer disc type in the form of Pancake.

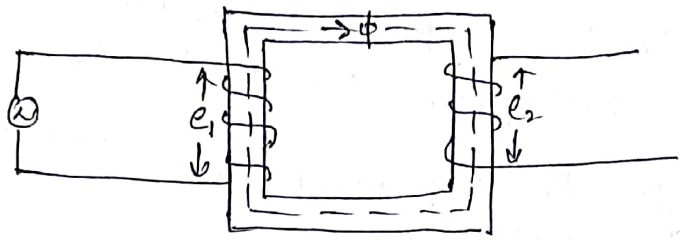
↳ Such Multilayer discs are insulated from each other by Paper.

↳ The core is rectangular in Shape & is laminated to reduce eddy current losses.

↳ The choice of core for shell type Transformer depends on Voltage rating, KVA rating, weight, Insulation Stress, Heat distribution etc.

↳ Shell type Transformers are used for handling very high voltages.

EMF Equation of a Transformer :



↳ When an Alternating voltage $V = V_m \sin\omega t$ of rms Value $V_1 = \frac{V_m}{\sqrt{2}}$ is applied to the Primary winding of the Transformer, the Alternating current produces an alternating flux 'ϕ', which links both Primary and Secondary winding.

w.k.t $$e_1 = -N_1 \frac{d\phi}{dt}$$

$\phi = \phi_m \sin\omega t$. Since the Primary applied voltage is Sinusoidal.

$$\therefore \; e_1 = -N \frac{d[\phi_m \sin\omega t]}{dt}$$

$$= -\omega N_1 \phi_m \cos\omega t$$

$$e_1 = 2\pi f N_1 \phi_m \sin(\omega t - 90^\circ)$$ $\left\{ -\cos\omega t = \sin(\omega t - 90^\circ) \right.$

∴ The Magnitude of the Maximum value of Induced EMF in Primary winding is

$$E_{m1} = 2\pi f N_1 \phi_m$$

∴ The rms value of Induced EMF in the Primary winding is $\Big\}$ $E_1 = \frac{E_{m1}}{\sqrt{2}}$

$$E_1 = \frac{2\pi f N_1 \phi_m}{\sqrt{2}}$$

$$\therefore \boxed{E_1 = 4.44 f \phi_m N_1}$$

Similarly rms value of EMF induced in the Secondary winding is

$$\boxed{E_2 = 4.44 f \phi_m N_2}$$

$$\therefore \frac{E_2}{E_1} = \frac{N_2}{N_1} = \text{'K' Transformation Ratio.}$$

or

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} \rightarrow$$ EMF induced per turn in both Primary & Secondary winding.

LOSSES IN A TRANSFORMER :- The losses that Occur in a Transformer are

(i) Iron loss
(ii) Copper loss

(i) **IRON LOSS (W_i)** : It is called as core loss as it occurs in the core portion of the Transformer.

Iron loss is of 2-types,
(a) Eddy Current loss (W_e)
(b) Hysteresis loss (W_h)

(a) ↳ The Eddy Current loss (W_e) Occurs due to flow of eddy Currents in the laminations of the Core.

↳ The Eddy Currents are induced in the laminations because of the alternating flux produced by Primary winding links them.

↳ These eddy Currents cause power loss in the core of the Transformer by heating up the core.

↳ The Eddy Current loss is given by the 'Empirical formula'

$$\boxed{W_e = \beta B_m^2 f^2 t^2 V \text{ watts}}$$

where, W_e = Eddy Current loss in watts

B_m = Maximum value of Flux density in the core (Wb/m^2)

f = Supply frequency (Hz)

t = Thickness of the laminations (m)

V = Volume of the core (m^3)

β = A constant, which depends on the Magnetic material in the core.

NOTE : To keep the Eddy Current loss as small as possible, the core is made of thin laminations of High Permeability magnetic material, such as Silicon Steel & they are insulated from one another by coating them with Varnish or an Oxide layer.

(b) Hysteresis loss : Since the flux in a Transformer core is alternating, therefore, power is required for the continuous reversal of the molecular magnets, which compose the core. This power is dissipated in the form of heat & is known as Hysteresis loss.

It is given by empirical formula,

$$\boxed{W_h = \eta B_m^{1.6} f V \text{ watts}}$$

where, W_h = Hysteresis loss in watts

B_m = Maximum value of flux density (wb/m²)

f = Supply frequency (Hz)

V = Volume of the core (m³)

η = A constant, which depends on the magnetic material in the core.

IRON LOSS = EDDY CURRENT LOSS + HYSTERESIS LOSS

$$W_i = W_e + W_h$$

$$W_i = \left(\beta B_m^2 f^2 t^2 V + \eta B_m^{1.6} f V\right) \text{ watts.}$$

(ii) COPPER LOSS :- (W_{cu}) This loss is due to the Resistances R_1 & R_2 of the Primary & Secondary windings respectively.

$\therefore$ Total Copper loss = Copper loss in Primary. + Copper loss in Secondary.

$$W_{cu} = I_1^2 R_1 + I_2^2 R_2 \text{ watts}$$

$$= I_1^2 R_1 + I_1^2 R_2'$$

$$\boxed{W_{cu} = I_1^2 (R_1 + R_2') = I_1^2 R_{01}}$$

or

$$\boxed{W_{cu} = I_2^2 (R_2 + R_1') = I_2^2 R_{02}}$$

The copper loss depends on the currents I_1 & I_2, which vary with load. Hence the copper loss in the Transformer is a variable loss.

EFFICINCY OF A TRANSFORMER : The efficiency of a Transformer at any load & Power factor is defined as the Ratio of the Power Output at the Secondary to the Power i/p at the Primary winding.

$$\text{Efficiency } \eta = \frac{\text{Power o/p in watts}}{\text{Power i/p in watts}}$$

Power i/p $= V_1 I_1 \cos\phi$

where, V_1 = Primary applied voltage
I_1 = Primary current.
$\cos\phi_1$ = Power factor of the Primary

$$\eta = \frac{\text{Input} - \text{losses}}{\text{Input}} = \frac{\text{Input} - \text{Copper loss} - \text{Iron loss}}{\text{Input}}$$

$$\eta = \frac{V_1 I_1 \cos\phi - I_1^2 R_{01} - W_i}{V_1 I_1 \cos\phi}$$

$$\eta = 1 - \frac{I_1 R_{01}}{V_1 \cos\phi_1} - \frac{W_i}{V_1 I_1 \cos\phi}$$

Efficiency is Maximum, when $\frac{d\eta}{dI_1} = 0$

$$\frac{d\eta}{dI_1} = 0 - \frac{R_{01}}{V_1 \cos\phi_1} + \frac{W_i}{V_1 I_1^2 \cos\phi_1} = 0$$

$$\frac{R_{01}}{\cancel{V_1 \cos\phi_1}} = \frac{W_i}{\cancel{V_1} I_1^2 \cancel{\cos\phi_1}}$$

$$W_i = I_1^2 R_{01} = I_2^2 R_{02}$$

$$\therefore W_i = W_{cu}$$

i.e $\boxed{\text{Iron Loss} = \text{Copper Loss}}$ is the Condition for Maximum efficiency of a Transformer

Consider, $W_i = I_2^2 R_{02}$

$$\boxed{I_2 = \sqrt{\frac{W_i}{R_{02}}}}$$ is the load current for which efficiency is maximum.

The KVA of the TRANSFORMER at which 'MAXIMUM EFFICIENCY' occurs is derived as follows:

Let, W_i = Iron loss of the Transformer.
W_{cu} = Full load copper loss.

w.k.t $W_{cu} \propto (\text{Full load KVA})^2$ ....(a)

Let, x = KVA o/p at which efficiency is maximum.

At x KVA, $W_i = W_{cu}$

$\therefore W_i \propto x^2$ ......(b)

Comparing equns (a) & (b)

$$\left(\frac{x}{\text{Full load KVA}}\right)^2 = \frac{W_i}{W_{cu}}$$

$$\therefore \boxed{x = \text{Full load KVA}\sqrt{\frac{W_i}{W_{cu}}} = \text{Full load KVA}\sqrt{\frac{\text{Iron loss}}{\text{Full load Cu-loss}}}}$$

NOTE : The efficiency at any load & P.f is given by,

$$\boxed{\eta_x = \frac{x \times KVA \times 1{,}000 \times P.f}{(x \times KVA \times 1{,}000 \times P.f) + (W_i) + (x^2 W_{cu})}}$$

where, x = Load, expressed as a fraction of full load.

$x = 1$, for full load

&

$x = 1/2$, for Half full load.

DOMESTIC WIRING :-

SERVICE MAINS :-

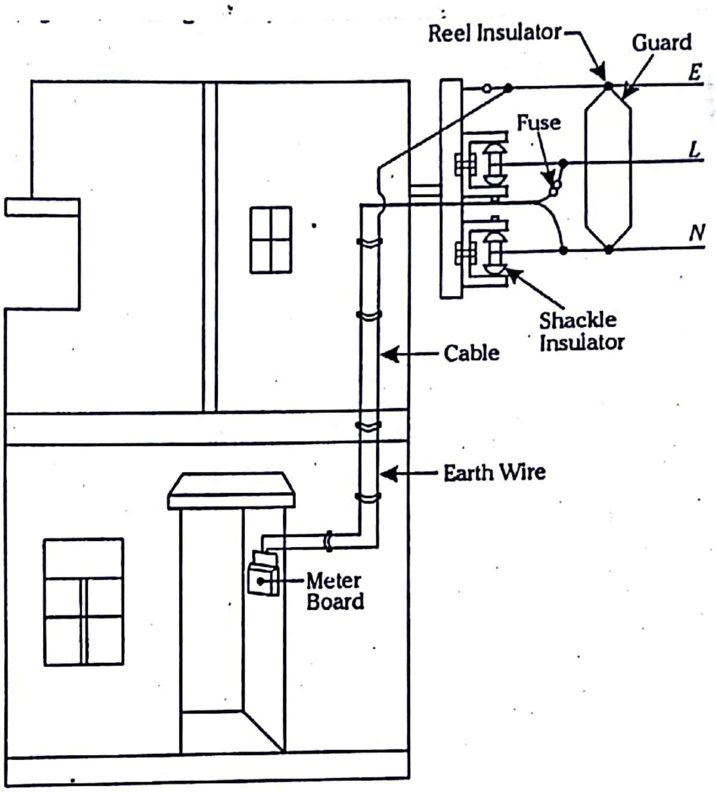


Fig. 3.81 : Service connections with PVC or weather proof cables

↳ Line bringing power from Suppliers distribution System to Consumer premises [energy meter] is called Service connection (or) Service main.

↳ Can be achieved by means of Underground Cables or by means of Overhead Conductors.

↳ Overhead with PVC Cables or Weatherproof cables.

Construction : Bare conductors are run from the suppliers pole to shackle insulators fitted to brackets fixed on a cross arm, embedded into the wall of a two storeyed building at an appropriate height.

METER BOARD & DISTRIBUTION BOARD :-

- Meter board is connected to consumer internal wiring
- Supply authority has to charge the consumer for the ~~___~~ electrical energy consumed. Hence it is connected to energy meter.

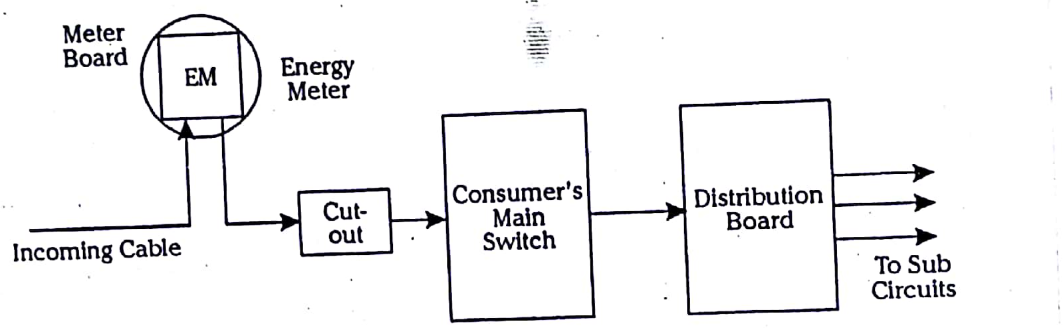


Fig. 3.82 : Block diagram of the meter board and the distribution board

- The cut-out contains a 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 & meters are the supply authority's property.
- The energy meter should be installed at such a place where it is readily accessible to both the consumer & the supply authority.

- The energymeter should be provided with a protective covering enclosing it completely & a glass ~~wa~~ window through which readings can be taken.
- Fuses should be provided to interrupt any short circuit current that may occur.

The type of Wiring to be adopted for taking electrical connections from the Supply agency depends on Various factors.

Important factors to be considered are,

(a) Durability
(b) Saftey
(c) Appearence
(d) Cost
(e) Accessebility
(f) Maintainance Cost.

(a) DURABILITY :- The type of wiring selected should be of Proper Specification so that, it is durable & does not give rise to problems quite often.

(b) SAFTEY :- Saftey is a very important factor in Selecting a wiring System & the wiring System must be fool proof from any electrical Shock.

(c) APPEARENCE :- The wiring System should enhance the appearence or atleast should be concealed.

(d) COST : Type of wiring System Selected should not eat much into the budget of the owner, Look for convinience rather than luxury in Selecting a Wiring System.

(e) ACCESSEBILITY : Various Switches & plugpoints must be easily accessible i.e near to the place where appliances are usually kept.

There must be provision for the extension of wiring System & Renewal if necessary.

(f) MAINTAINENCE COST :- Maintainance cost of the wiring system should be as minimum as possible.

SYSTEMS OF WIRING :- The Following are the Various Systems of Wirings.

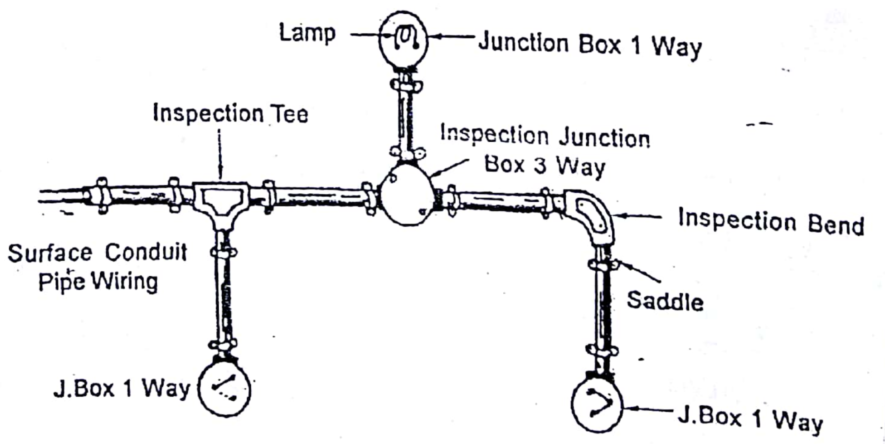
(i) Cleat wiring.

(ii) Wooden casing & Capping wiring.

(iii) Conduit wiring
- Surface Conduit wiring.
- Concealed Conduit wiring

(iv) Lead Sheathed or Metal Sheathed wiring.

SURFACE CONDUIT WIRING : In this System of wiring, Conduits are fixed on the Surface of walls or Ceilings by means of Saddles, Secured to Wooden gutties with Screws at an interval of 1m.



: Surface conduit wiring

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↳ The VIR or PVC cables/wires are drawn by means of 18SWG GI wire. The Earth wire is fixed by means of earth clips

CONCEALED CONDUIT WIRING :- Here the conduits is buried under the wall or ceiling.

↳ PVC conduits are most popular because of their lower cost & require less time to install.

↳ The channels are provided in the wall before plastering & then conduit is fixed in the channels by means of clamps & hooks.

↳ The 18 SWG GI wire are drawn & covered by cement plastering to make it moisture proof.

	SURFACE CONDUIT WIRING	CONCEALED CONDUIT WIRING
(i)	The conduit/pipe is fixed on the wall.	The conduit/pipe is completely sunk into the RCC wall.
(ii)	It has Bad Appearence.	It is concealed & does not affect the appearence.
(iii)	It is cheaper	Comparitively it is costlier.
(iv)	It is ~~cheaper~~ not fully protected from Mechanical injury	It is fully protected from Mechanical injury.
(v)	It is fixed by means of Saddles	It is fixed by means of J-hooks.
(vi)	It uses Tees & Elbows	Only Bends are used.

TWO-WAY CONTROL OF LAMPS :

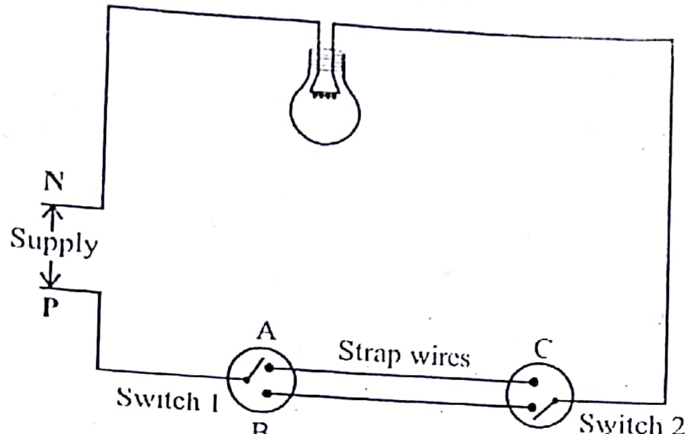

Fig.7.9

SWITCHING TABLE :

S.No.	Position of Switch 1	Position of Switch 2	Lamp ON or OFF
1	A	D	OFF
2	A	C	ON
3	B	C	OFF
4	B	D	ON

- The wires used b/w switches are called strap wires.
- When the switch-1 is in position-A & switch-2 is in position-D, the lamp circuit is not closed & hence the lamp is OFF.
- When the switch-1 is changed to position-B, the lamp circuit is closed & hence lamp is ON.
- If the switch-2 is changed to position-C, again the lamp circuit is broken and the lamp is switched OFF.

THREE WAY CONTROL OF LAMPS: Sometimes in very big corridors, Godowns or workshops, it may be necessary to control the lamps from three points.

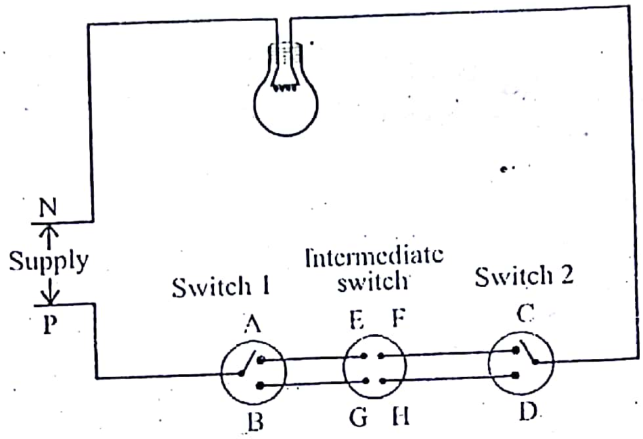

Fig.7.10

Sl No	Position of Switch-1	Position of Intermediate Switch	Position of Switch-2	Lamp ON or OFF
1	A	EF, GH	C	ON
2	A	EF, GH	D	OFF
3	B	EF, GH	C	OFF
4	B	EF, GH	D	ON
5	A	EH, GF	C	OFF
6	A	EH, GF	D	ON
7	B	EH, GF	C	ON
8	B	EH, GF	D	OFF

↳ When the Switches-1 & 2 are in position-A & B respectively, and the Intermediate Switch is in position of Straight connection i.e when EF & GH are connected, the lamp circuit is closed & hence the lamp glows (ON)

↳ Now if the Intermediate Switch is changed to position of cross connection i.e when EH & GF are connected, the lamp circuit is open & hence the lamp is switched OFF.

↳ Now if the position of Switch-2 is changed from 'C' to 'D', the lamp circuit is closed & the lamp is Switched ON.

Thus the lamp can be controlled from 3-points.

EARTHING :- Earthing or Grounding is to connect the body of an Electrical equipment to the general mass of the earth by a wire of negligable resistance.

↳ Earthing brings the body of the equipment to zero potential & thus avoids shocks to the personnel, incase the body of the equipment comes in contact with live wire.

↳ The Neutral of the Supply System is solidly earthed to ensure that its potential is also zero.

NECESSITY OF EARTHING :- Earthing is necessary for the following reasons.

(a) To protect the Human being from dis-ability or death incase the human body comes in contact with the frame of any Electrical machinery, appliance or component which is electrically charged due to leakage current or fault.

(b) To maintain a constant line voltage.

(c) To protect tall buildings & structures from atmospheric lightening strikes.

(d) To protect all machines, fed from overhead lines, from atmospheric lightening.

(e) To serve as the return conductor for Telephone, Telegraph & Traction work.

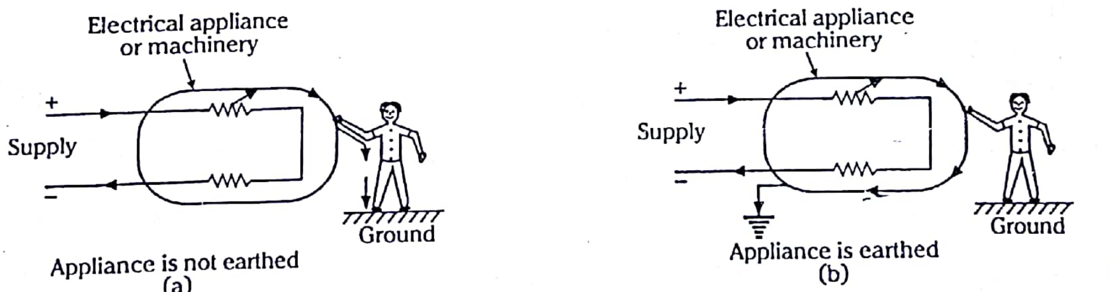

Fig. 3.87

TYPES OF EARTHING :- There are 2-types of earthing.

(i) Pipe earthing.

(ii) Plate earthing.

PIPE EARTHING :

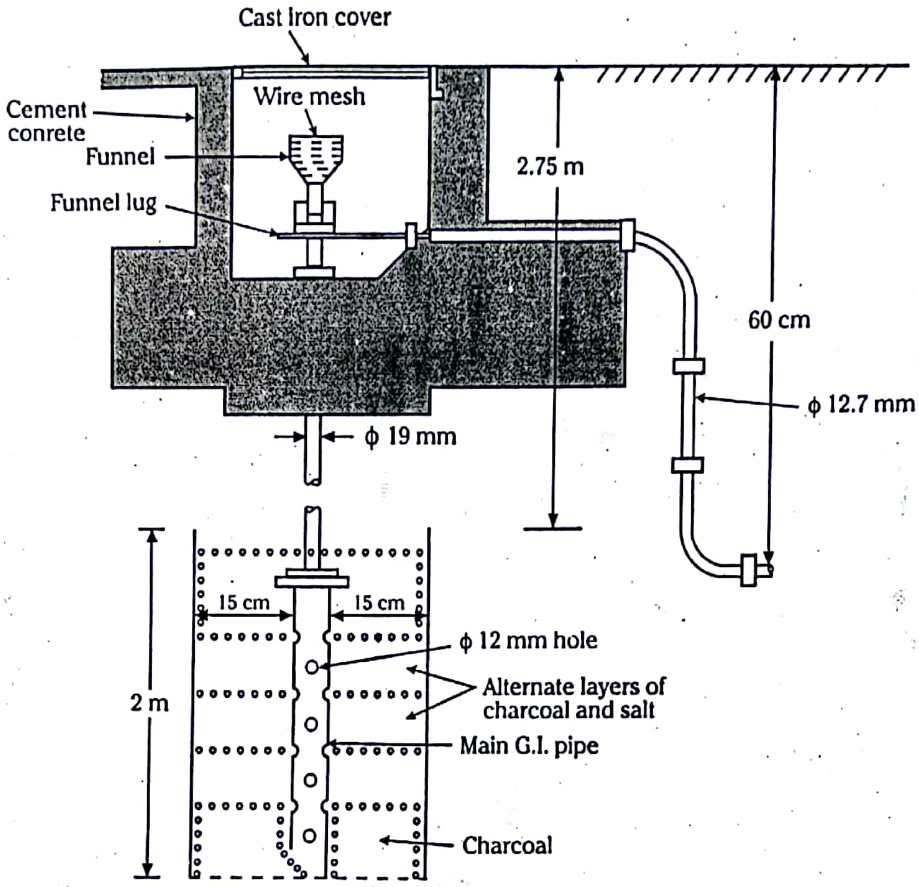

Fig. 3.89 Pipe Earthing

- A G.I pipe of 38mm diameter & 2m length is vertically embedded into the ground to serve as earth eletrode, the depth depending on the soil condition
- According to Indian Standard, the pipe should go down to a depth of 4.75m
- The pipe must be placed upright in wet ground. The pit area around the G.I pipe is filled with salt & charcol mixture for a distance of 15cm around pipe. This mixture improves the soil condition & efficiency of Earthing System.

↳ In Summer, the soil becomes dry in which case Salt water is poured through the funnel connected to the main G.I pipe through 19mm diameter pipe, to keep the soil wet.

↳ The Earthwire from the 19mm diameter G.I pipe should be carried in a conduit of G.I pipe of diameter 12.7mm at a depth of 60cm below the ground.

PLATE EARTHING :-

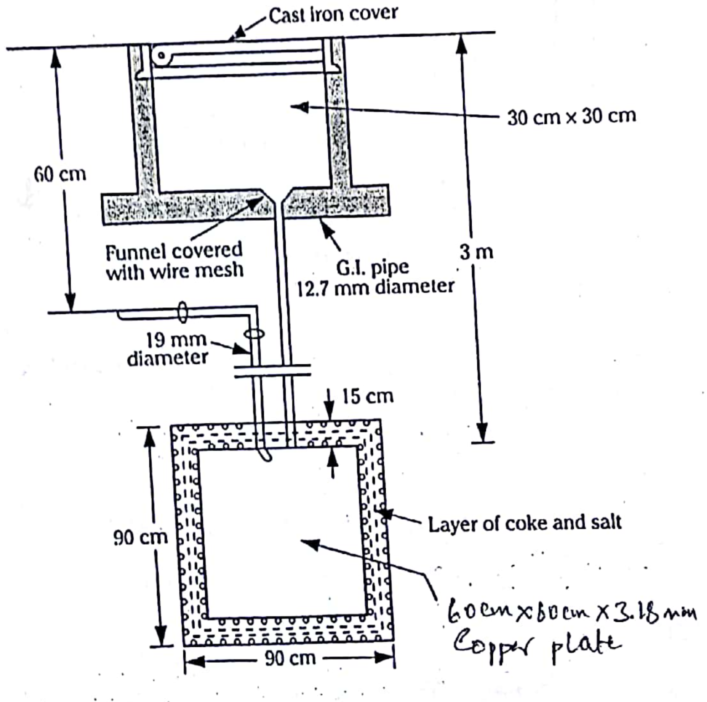

Plate Earthing

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↳ A Copper plate of size 60cm × 60cm × 3.18mm is used for the purpose of earthing. The plate is kept with its face vertical at a depth of 3m & it is so arranged that it is embedded in alternate layers of salt & charcoal, for a thickness of about 15cm.

↳ The nut & bolts must be made of copper for copper plate and of Galvanised Iron for G.I plate.

↳ The Earthwire is drawn through a G.I pipe of 19mm diameter, at about 60cm below the ground.

↳ The G.I pipe is fitted with a funnel on the top. To achieve effective earthing, salt water is poured periodically through the funnel.

PROTECTIVE DEVICES :

(1) **FUSE** : A fuse is a saftey 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 & protecting other materials in the circuit.

Need for FUSE : If there is an overload or fault occurs, the conductor will carry a large current than normal current, this will cause overheating of conductor & damage to appliances & devices.

↳ Hence the need is felt for a built-in mechanism by which the entire installation is saved from possible damage, in the event of a short circuit or fault.

RATINGS :-

FUSING FACTOR : Fusing factor of a fuse is defined as the ratio of the 'Minimum fusing current' to the 'Current rating' of the fuse element.

$$\text{Fusing Factor} = \frac{\text{Minimum fusing current}}{\text{current rating of the fusing element.}}$$

↳ The value of fusing factor is always more than 1.

MINIMUM FUSING CURRENT: This is the minimum value of current at which a fuse shall melt.

↳ The various factors on which the fusing current depends, are as follows. (i) Material of the fuse element.
(ii) Length.
(iii) Diameter.

↳ In practice an alloy of Tin & Lead is used as an ordinary fuse wire.

RATED CURRENT: It is the maximum current which a fuse can carry without any undue heating or melting.

MINIATURE CIRCUIT BREAKER (MCB):

[What is MCB? Explain its need & features?]

↳ A Miniature Circuit Breaker is an Electromechanical device, which makes the circuit in normal operation & disconnects the circuit under the abnormal condition when the current exceeds the preset value.

↳ MCB is a high fault capacity current limiting, trip free automatic switching device with thermal & magnetic operation to provide protection against overload & short circuit.

MCB has the following features :-

(i) Its operation is very fast & opens in less than one millisecond.

(ii) No tripping circuit is necessary & the operation is automatic.

(iii) Provides protection against overload & short circuit without noise, smoke & flame.

(iv) It can be ~~reset~~ reset very quickly after connecting the fault, just by switching a button. No re-wiring is required.

(v) It cannot be reclosed if fault persists.

(vi) The Mechanical life is upto or more than One Lakh operating cycle.

Hence now a days MCB's are used rather than re-wirable fuse.

ELECTRIC SHOCK :- when a person comes in contact with live wire supplying electricity, he recieves a shock. The severity of the shock received depends on the voltage of the wire & the body resistance of the person.

↳ The voltages used domestically are 230V for lighting & heating and 440V for running Induction motors. These voltages can give severe shocks & may cause death to the person.

↳ The Maximum current the human body can withstand is 30mA for not more than 25ms duration.

↳ The current flowing through the body of a person during shock depends on the Body Resistance (R_b)

(a) For a ~~[illegible]~~ Dry body, $R_b = 1,00,000\,\Omega$

(b) For a Wet body, $R_b = 1,000\,\Omega$

PREVETION OF SHOCKS :- The following precautions may be taken by persons from getting Electric Shocks in home.

(i) Care must be taken to see that ground points are properly provided to all the sockets to which electrical appliances are connected.

(ii) Proper earthing has to be provided & periodically the Earthing resistance has to be checked to see that it does not exceed 3 to 5Ω

(iii) Cover all Electrical sockets with plastic saftey caps.

(iv) Replace all worn chords & wiring.

(v) Never use an Electrical appliance like Radio or Iron ~~[illegible]~~ near water.

(vi) Do not touch Electrical appliances & switches with wet hands.