7

Internal Wiring Systems and Lamp Circuits

1. **Introduction.** During these days alternating current is usually supplied by the Electric Companies. The electric energy (A.C.) received by the consumer has to pass through various systems after its generation in the power house. These systems are as follows:

(*i*) **Transmission.** It consists of :

(*a*) Step up substations

(*b*) H.T. overhead lines and underground cables

(*ii*) *Distribution.* It consists of :

(*a*) Step-down Substations

(*b*) L.T. Overhead lines and underground cables.

(*iii*) *Service Connections.* From the distributor the consumer's main switches are connected through service connections and electric energy meters. One end of the service connection is connected to the distributor and the other end to the meter which is connected to the main switch. No electric company in India permits the installation of the energy meter after the main switch to prevent theft of electric energy.

After the main switch, there are wires which convey the electric current to each lamp and appliance. In this chapter the various systems by which the wiring to feed electricity to the lamps and appliances is done, have been explained. *The transmitting distribution and service connections have been dealt with in chapter 8.*

In accordance with the Indian Electricity Rules ; the supply companies and undertakings are supposed to maintain (*a*) the voltage at the consumer premises ± 5% of the declared L.T. voltage and ± 12.5% of the declared H.T. voltage (*b*) the supply frequency at 50 cycles and variation allowed is ± 1%.

The lamps and other appliances are connected in parallel as otherwise these will not receive the full voltage. Therefore the leads or wires must be capable of carrying the current equal to the sum of current required by all lamps or appliances after making due allowance for demand factor*

2. Wiring System. The fundamentals of wiring systems are :

(*a*) The switchgears and switches should be placed on the live wire or the phase. The second terminal of the switch should be connected to the lamp or appliance. The neutral should be directly connected to the lamp. This is to be strictly observed as otherwise even if the switch is in off-position the current will flow to the lamps through the wires even if there is fault (assuming the fuse does not melt) and thus causing damages. The advantage of placing the switch in phase or live wire is that the workman can safely rectify the defects by switching off the supply.

(*b*) The fuses should be placed on the live wire or the phase otherwise the whole purpose of safety will be defeated. The lamp will get the electric current even after the fuse has blown.

(*c*) All the lamps and appliances should be connected in parallel to enable all of them to get nearly equal voltage and to avoid excessive voltage drops.

Keeping into consideration the above fundamentals the wiring can be done by any of the following systems :

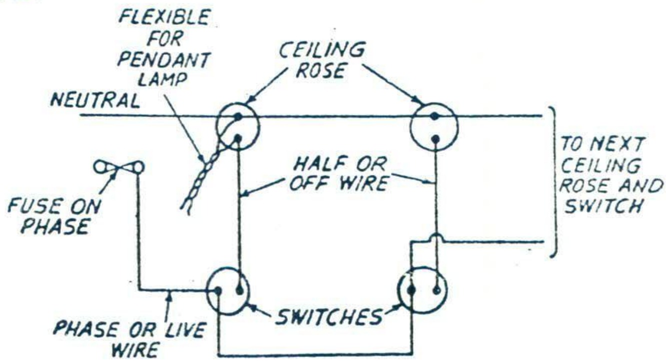
(*i*) *Looping-in system.*
(*ii*) *Tree system*
(*iii*) *Ring system*

These systems have been dealt with in details in subsequent paras.

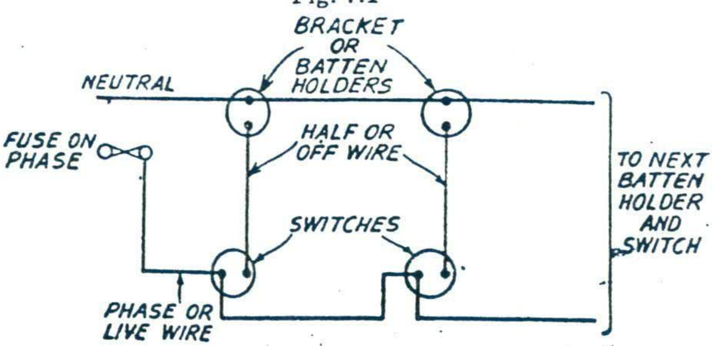
*A consumer may have number of lamps, plugs, fans etc. and all of them may not be working at a time, so his demand may not the sum of current required by all lamps, plugs and fans, but only a fraction of it. So the demand factor is defined as the ratio of the actual maximum demand (in amperes) divided by the connected load (in amperes).

3. **Looping in System.** The looping at the wires can be done in either of the following ways :

(*a*) **Looping out from switch and ceiling Rose.** Fig. 7.1 shows a simple looping in method which is commonly employed. It will be seen that one terminal of the ceiling roses and switches is connected to the wires coming from the main switch and other terminals of both are connected to each other. The system is similar even if the light point is to be provided with a batten or bracket holder intead of pendant holder. In that case one terminal of the holders is commonly connected to the neutral and other terminal of each is connected to the live wire or phase through a switch as shown in Fig. 7.2.

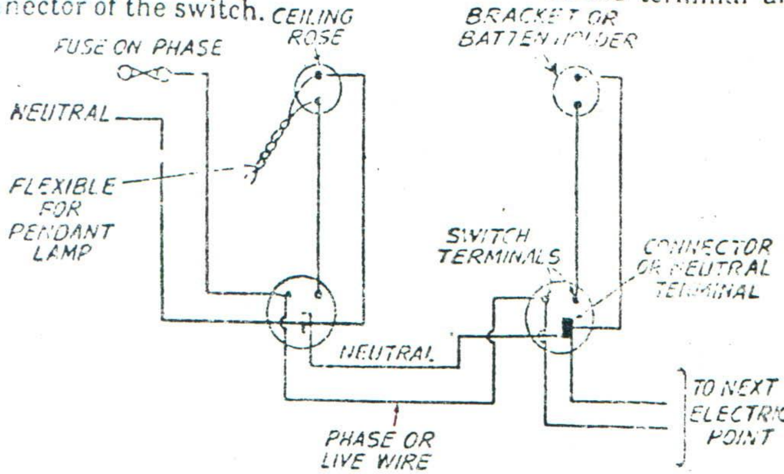


Looping in system with switches and ceiling roses
Fig. 7.1



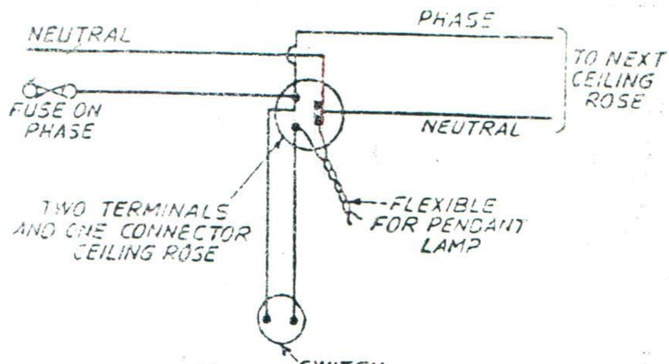
Looping in system with switch and holder
Fig. 7.2

(*b*) **Looping out from Switch.** In this system special two terminals and one connector switches are used as shown in Fig. 7.3. As seen from the diagram both phase or live wire and natural wire are taken to the switch. The live wire is connected to one of the actual terminal and neutral to extra terminal or connector. The lamp or the appliance is connected to the second terminal and connector of the switch.



Wiring with two terminals and one connector switch
Fig. 7.3

(*c*) **Looping out from Ceiling Rose.** In this system special three terminals and connector ceiling roses as shown in Fig. 7.4 are used. As can be seen wiring is similar to (*b*) above.



Wiring with two terminals and one connector ceiling rose
Fig. 7.4

(*d*) **Looping out with Junction box.** In this system pair of conductor from the switches and ceiling roses will terminate in a box known as junction box. The junction box is kept in the centre of all light points for the economy in wire length. This system is only economical in small houses having few lighting points because the looping is only done in the joint box as shown in Fig. 7.5.

4. Wiring of a Building. Fig. 7.6 shows the wiring of a house with single phase A.C. or two wire D.C. supply. From the main

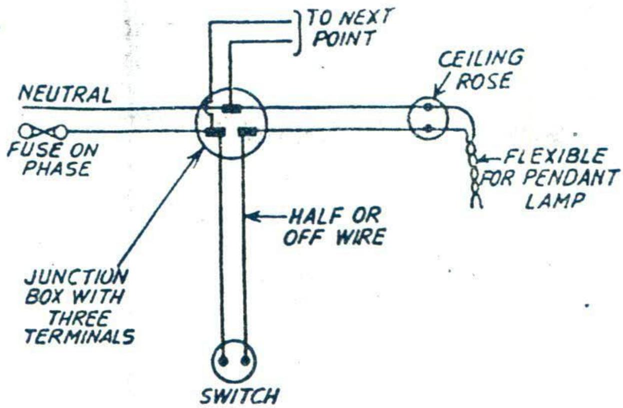
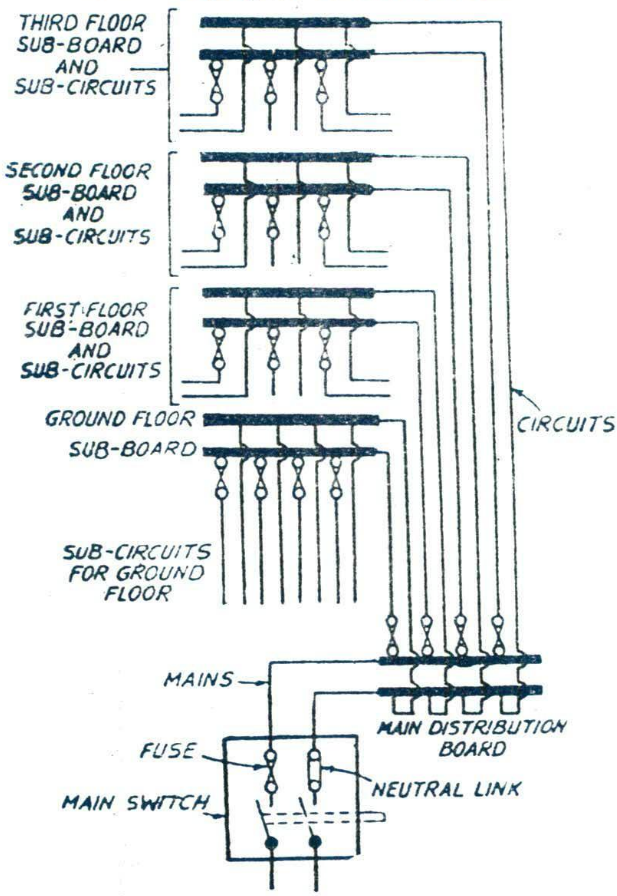


Fig. 7.5 Looping out with Junction Box

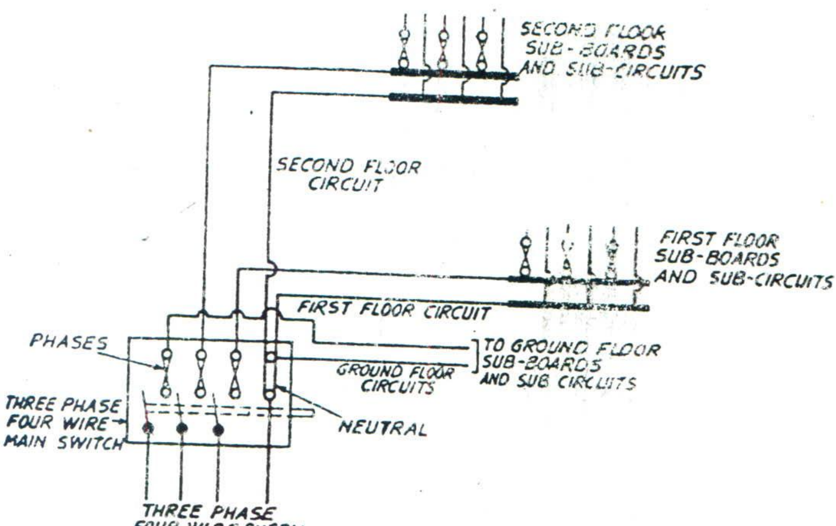


single phase supply

Fig. 7.6

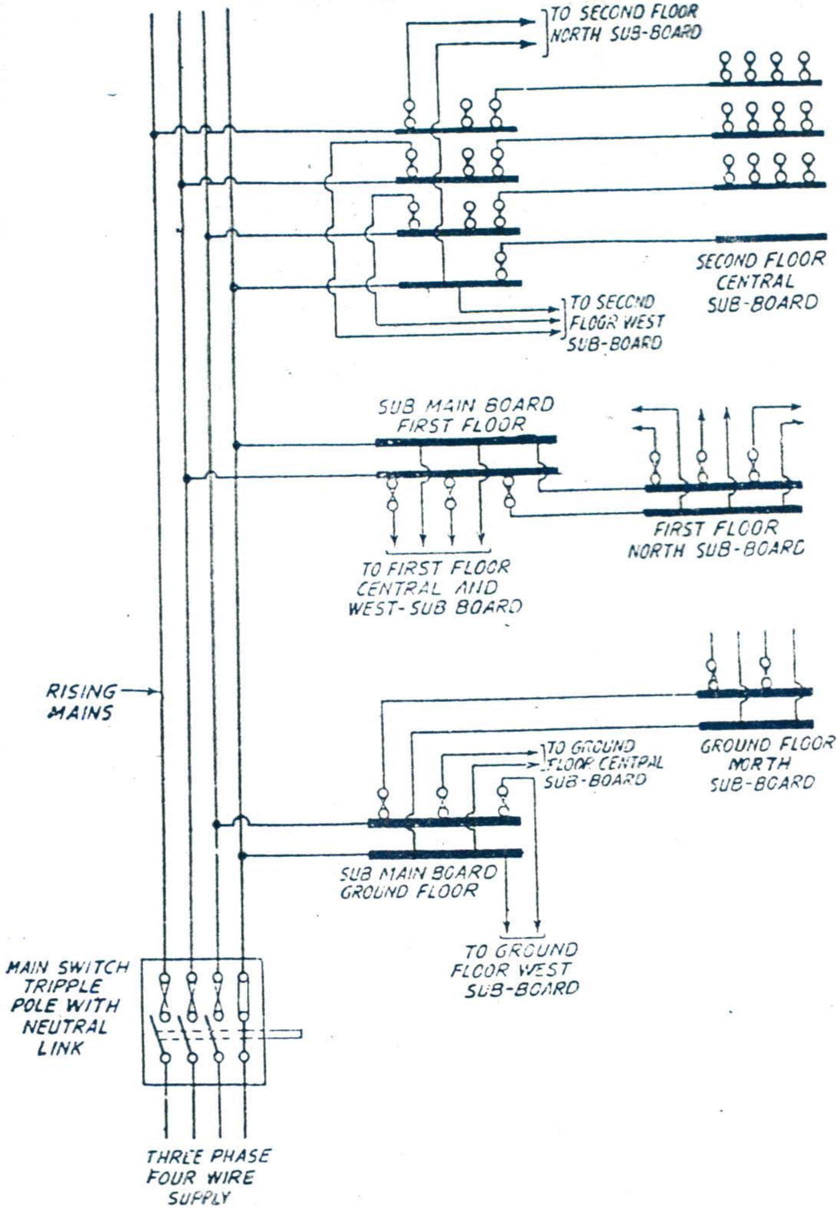
switch the leads known as *mains* are taken to *main distribution board*. From the main distribution board wires are taken to various distribution boards which are known as *sub-boards*. The connections between the main distribution board and sub-boards are known as *circuits*. *Various sub-circuits* as shown are drawn from the sub-boards for connection to various electric load points. *The wiring of the points is done by any of the methods explained in article 3*. For the purpose of reliability and safety, the fusing current capacity of the fuse wire inserted at the main switch should be 1.5 times the numerical sum of the all loads. Similar principle is to be adopted while inserting fuse in circuits and sub-circuits. The wire size of the mains circuits and sub-circuits should be in accordance with the electric loads on them. For economy, the bigger size of the wire is used for sub-circuits in the beginning and later on small size of wire matching the load is used.

Fig. 7.7 shows the wiring of a building with three-phase four-wire A.C. source without any main board.



Wiring of a building with three-phase four-wire supply.
Fig. 7.7

5. Tree System. In this system from the main switch *rising mains* are run to every floor. Rising mains are of copper or aluminium strips which go up from the main switch to all floors.



Wiring of building by Tree system
Fig. 7.8

The rising mains are usually provided in the centre of the load for the purpose of economy. At each floor rising mains are connected to sub-main boards as shown in Fig. 7.8. Various circuits are taken from the sub-main board to sub-board. Sub-circuits are taken from the sub-boards. The sub circuits are used for wiring the portion of the load in accordance with the method explained in articles 3 and 4.

6. **Ring System.** In this systems a pair of conductors are run through all the rooms. The ceiling roses, plugs and appliances are fitted after decision on the layout of furniture is taken. The ring circuits is brought back to the main board. With this system, wiring is required to be done with suitable fuse in each plug and ceiling roses if the both ends of the conductors are ending on the same main sub-board. There may be saving of Copper because the current can be fed from both sides, but the method is not used because of higher cost of the special plugs and ceiling roses.

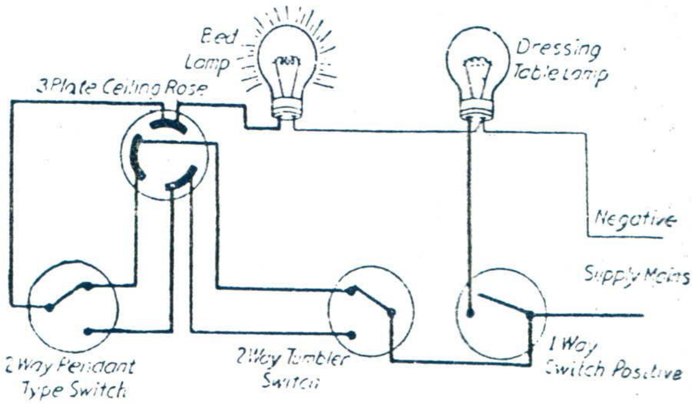
Sometimes the main boards are connected to two different switches of suitable capacity. The both ends of the ring circuits terminate ina separate switch. One of the switches is always kept in off-position. This reduces the cost of the special type of plugs and ceiling roses and also increases the reliability.

7. **Lamp Circuits.** The lamp circuits used for house wiring are quite simple and they are generally controlled from one point, such as room lighting, bathroom lighting, lavatory lighting etc. ; but in staircase wiring it is necessary to control the lamp circuit from two points, *i.e.* at the top and bottom of the staircase. Similarly in halls or corridors or bedrooms, it may be necessary to control the lamp from more than two points. But still there are other circuits which are not frequently used for particular house wiring, but still they have utility in other spheres of life. In general the lamp circuits can be divided into the following heads :

(1) *Simple Circuits.*
(2) *Series-Parallel Circuits.*
(3) *Master Switch Circuits.*
(4) *Pilot Circuits.*
(5) *Miscellaneous Circuits.*

8. **Simple Circuits.** In addition to the lamp circuits explained in article 3, the following are commonly used :

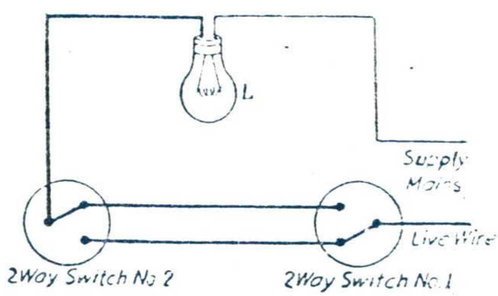
(*a*) *Bed-room Lighting.* In bed-rooms a light is required at the dressing table which may be a single switch circuit, and another light provided near the bed must be controlled by two 2-way switches. One of the two-way switches used should be a tumbler switch and the other should be a pendant type, suspended from a 3-plate ceiling rose. The circuit for such type of lighting is as shown in Fig. 7.9.



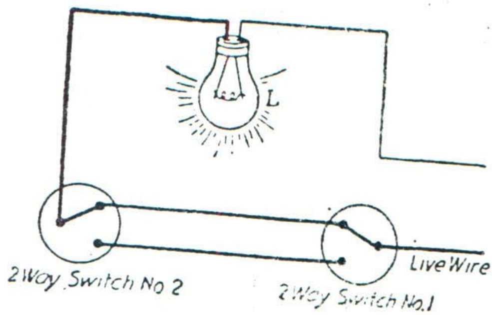
Circuit for bed-room lighting
Fig. 7.9

(b) *Staircase wiring or lamp circuit controlled by two switches.* For the lamps to be controlled by two switches, it is necessary to use two-way switches. Fig. 7.10 (*a*) shows that the lamp is dark. The wires used between the switches are called as strap wires.

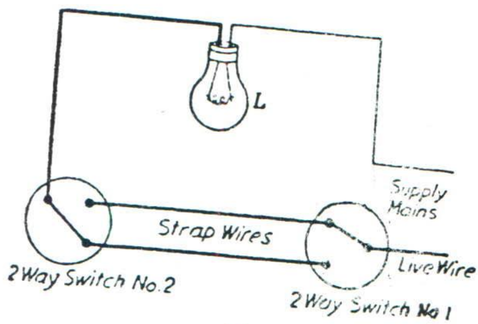
In Fig. 7.10 (*b*) the lamp is switched on with the switch No. 1, while Fig. 7.10 (*c*) represents that the lighted lamp is switched off with switch No. 2 and in Fig. 7.10 (*d*) the lamp is again lighted with switch No. 1. Thus when the lamp is lighted either of the strap wires carries current.



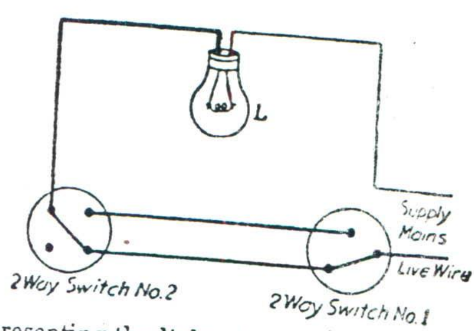
(*a*)
Lamp made off with switch No. 2
Fig. 7.10.



(*b*)
Lamp made on with switch No. 1

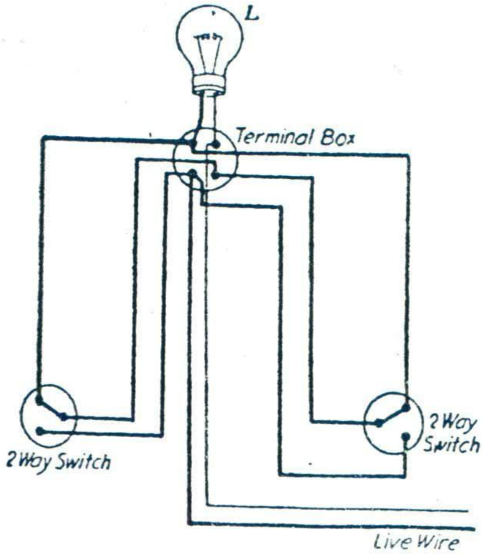


(*c*)
Showing lamp dark



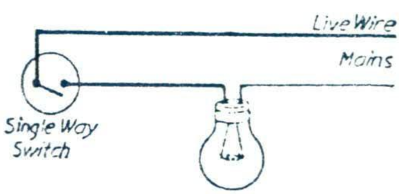
Representing the lighted lamp with Switch No. 1.
Fig. 7.10 (*d*)

(*c*) *Staircase Wiring with T.R.S.* For having a staircase wiring with T.R.S. wire, a four-way terminal box is required. The circuit is shown in Fig. 7.11. For completing the type of wiring between terminal box and mains, also for terminal box and lamp 2-core cable is used; but for wiring between terminal box and either of the 2-way switches 3-core cable is used.



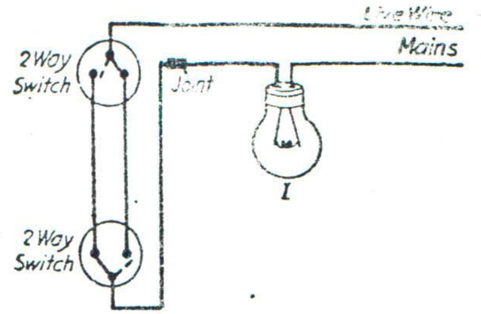
Staircase wiring with the help of a T.R.S. Wire
Fig. 7.11

(*d*) *Conversion of Single-way Switch Circuit to two 2-way Switch Circuit.* Sometimes it is necessary to convert single-way switch circuit to two 2-way switch circuit. Fig. 7.12 (*a*) shows a lamp



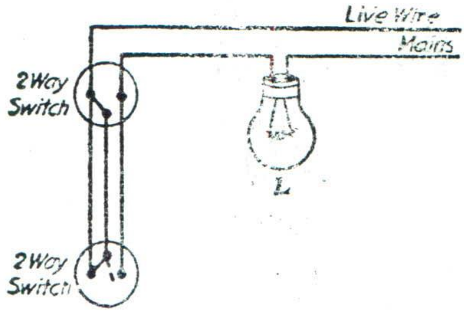
L mp circuit controlled by single-way switch
(*a*)
Fig. 7.12.

circuit being controlled by a single-way switch. For conversion the single-way switch is removed and is replaced by a two-way switch. Now if the connections to the two 2-way switches are made in a similar manner as in the previous cases, then it is necessary to have a joint at the point shown in Fig. 7.12 (*b*). A revised method of connecting two switches is as shown in which case no jointing of wires is required.



Conversion to 2-way switch circuit with the help of a joint provided at the point shown.

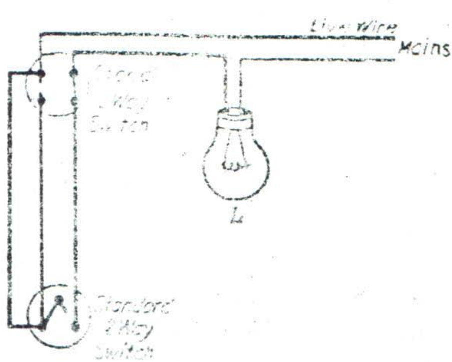
(b)



Correct method of conversion

Fig. 7.12 (c)

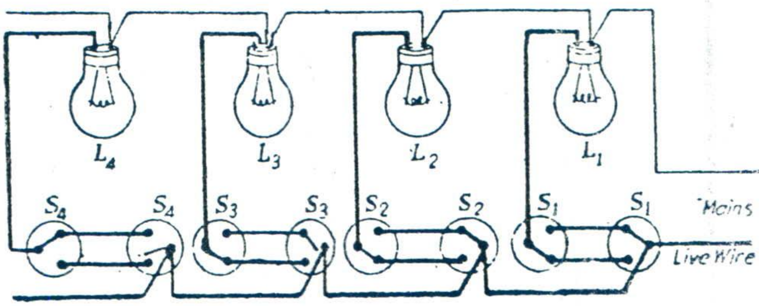
There is an alternative method of conversion in which case one of the two-way switch is of special type having 4 terminals, two of which are shorted together as shown in Fig. 7.13.



Alternative method of conversion of a single-way switch circuit to two-way switch circuit.

Fig. 7.13

(*e*) *Corridor Lighting Circuits.* Let the corridor have a number of lamps and let each lamp be controlled by two switches. For such a scheme the circuit is as shown in Fig. 7.14. In this case L_1, L_2 L_3 and L_4 are different lamps having controls at S_1 S_1, S_2 S_2, S_3 S_3 and S_4 S_4 respectively.

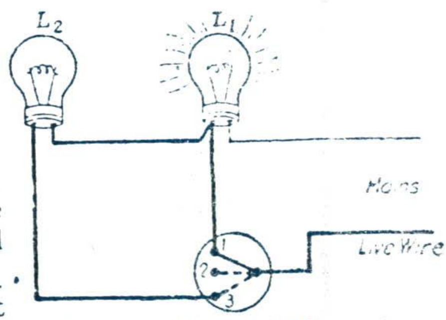


Corridor lighting
Fig. 7.14

9. Series Parallel Circuits. Series parallel circuits are used to either provide dim lights or full bright lights. Such lights are required in hospitals, bedrooms, hotels, railway carriages etc. The dim lights are usually obtained by connecting the parallel lamps of the circuit in series. The following are the methods of obtaining such lights

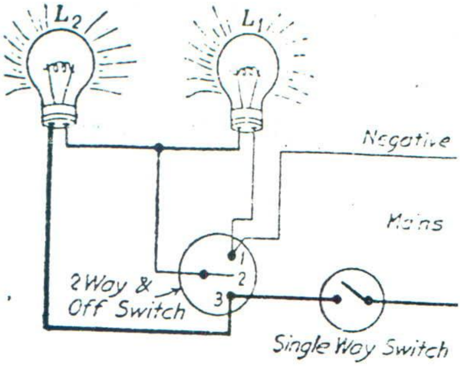
(*i*) *With "Two-way ON and OFF" Switch.*

In the circuit shown the lamp No. L_1 is lighted to full brightness when the switch position is on the terminal No. 1. When the switch position is on terminal No. 2, the whole of the circuit is off. When the switch is on position No. 3 the lamps No. L_1 and L_2 are connected in series so as to give dim light. Thus with such an arrangement either lamp No. L_1 can be lighted to full brightness or lamp No. L_1 and L_2 are connected in series for dim lighting.



Two-way ON and OFF circuit
Fig. 7.15

(*ii*). *Circuit for either lamp full bright or two lamps is series*



Circuit for one of the lamp bright or two in series
Fig. 7.16

First assume that the single-way switch of circuit shown in Fig. 7.16 is in the 'ON' position. When the two-way switch is on terminal 1, the lamp No. L_1 is short-circuited and lamp No. L_2 is full bright. Alternatively when the two-way switch is on terminal 3 the lamp No. L_2 is short circuited while the lamp No. L_1 is full bright. When the two-way switch is on the 'OFF' position both the lamp are made in series for dim lighting. The purpose of single-way switch is to control both the lamps.

(*iii*) *Circuit for only one particular lamp bright or two lamps in series.* For such circuit one single-way switch and one ordinary 2-way switch is used. Assume the single-way switch to be in the on-position and the 2-way switch is on the position No. 1, then the lamp No. L_1 is fully bright and lamp No. L_2 is out of circuit. When the 2-way switch is on position No. 2 ; at that instant both the lamps are made in series to give dim light.

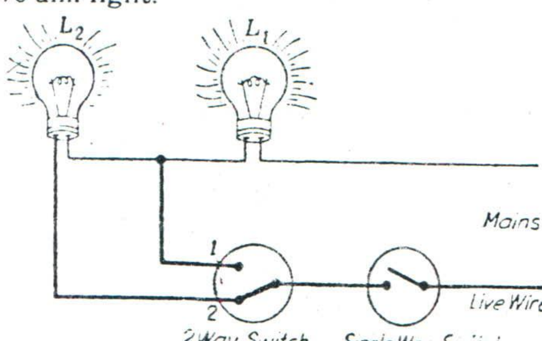
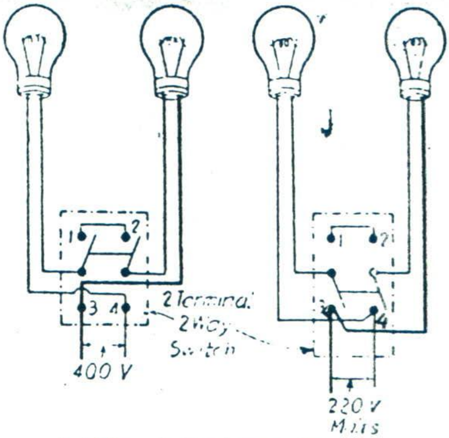


Fig. 7.17 Circuit for one particular lamp bright or two lamps in series

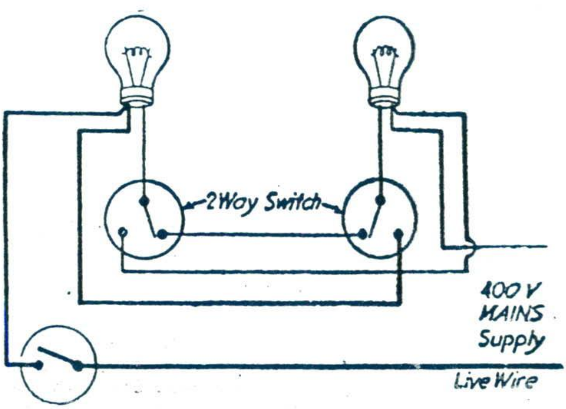
(*iv*) *Circuit for operation either both lamps in series or both in parallel across mains.* Such a circuit is most useful practically for having a lamp load to be connected across 230 V supply mains as well as for 400 V mains. Since each lamp is for 230 V mains, so when they are to be operated at 400 V, they are connected in series, and for operation at 230 V they must be in parallel . Such a circuit can be obtained with the help of a 2-terminal two-way switch. When the switch is at top making contact with terminals 1 and 2, the lamps are connected in series as shown in Fig. 7.18. When the switch is moved down making contact with terminals 3 and 4 the lamps are connected in parallel across 220 V mains.



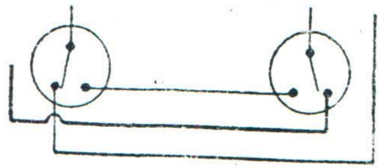
(*a*) Circuit for lamps in series
(*b*) Circuit for lamps in parallel
Fig. 7.18

Such a circuit can also be obtained with the help of either two ordinary 2-way switches and a single-way switch or by a single 2-way switches and single-way switch or by a single 2-way ON and OFF switch and a single-way switch.

Fig. 7.19 (*a*) represents the circuit in which the position of 2-way switches is so shown that the lamps become in series while Fig. 7.19 (*b*) represents the position of 2-way switches for the lamps to be connected in parallel across the main.



Circuit for lamps in series.
Fig. 7.19 (*a*)



Alternative position of 2-way switches for operation of lamps in parallel.
Fig. 7.19 (*b*)

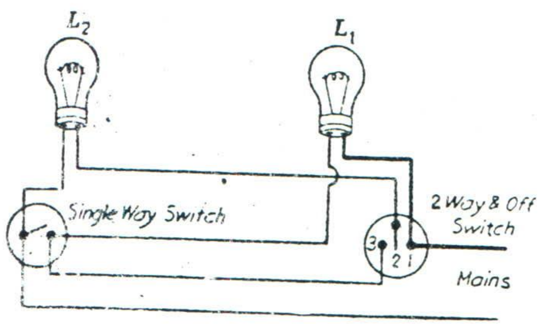


Fig. 7.20

The alternative circuit for achievement of above-mentioned aims is as shown in Fig. 7.20 in which one of the switches is single-way and the other is 2-way with off-position. When the 2-way switch is connected to terminal 3 and the single-way switch is off, the two lamps are connected in series across the mains. When the 2-way switch is connected to terminal 1 and the single-way switch is switched on, then both the lamps are connected in parallel across the mains.

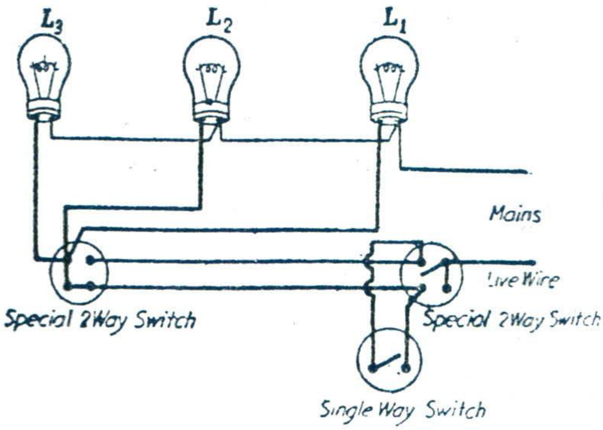
10. Master Switch Circuit. The master switch is just an ordinary standard switch either single-way or two-way, but it has attained its name due to its function. Following are the main objects of the master switch :

(1) to put off the lamps irrespective of the position of the individual switches and to prevent anybody switching on the lamps, such a control is also called as "*Master off*" ;

(2) to switch on the lamps and to prevent anybody switching them off with individual switches ; such a control is also called as "*Master on*" ;

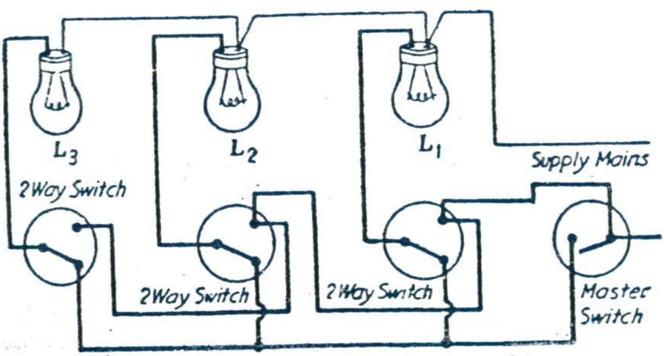
(3) to control either switching on or off of the circuit, *i.e.* its function is as in (1) or in (2), so it is called as variable master control.

(a) *"Master on" Switch Circuits.* (1) Fig. 7.21 represents the two-way control of the 3 lamps in the corridor, but when a single-way switch is connected across terminals 1 and 2 of the two-way and is switched on, then the independent control of the 3 lamps by the two-way switches goes away. Whatever be the positions of the two-way switches, the lamps will remain lighted.



Master on circuit with two 2-way switches and one single-way switch
Fig. 7.21

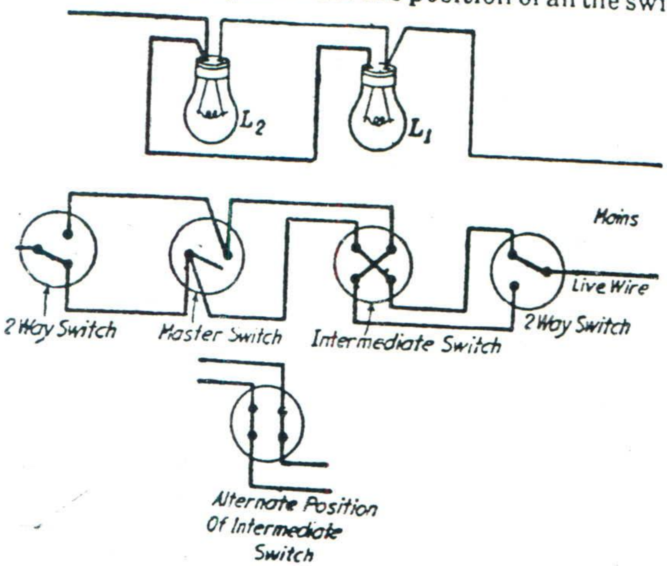
Fig. 7.22 represents a circuit for 3 lamps being independently controlled by the two switches. The three two-way switches used are worked as single-way switches. In addition to these independent



Master control on circuit with three two-way switches and one single-way switch
Fig. 7.22

controls is connected a single-way switch in series with the live wire which acts as a master control and it is so connected that when the switch is made on, the lamps remain lighted independent of the position of 2-way switches.

Fig. 7.23 represents a circuit for two corridor lamps being controlled by 3 switches (2 two-way switches, and one intermediate switch), in addition to these switches a master switch is connected in the circuit as shown. When the master switch is switched on, the lamps remain lighted independent of the position of all the switches.



Master control on circuit with two way switches and one intermediate switch.
Fig. 7.23

(b)"*Master off' Circuit.* Fig. 7.24 shows three lamps being controlled by three single-way switches independently. Across the main supply is connected a double-pole switch and when this switch

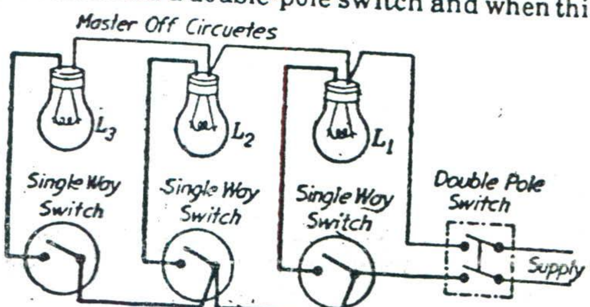
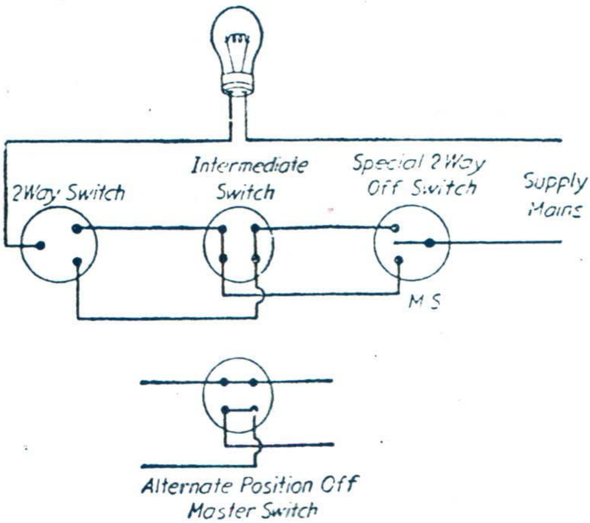


Fig. 7.24 Master off circuit

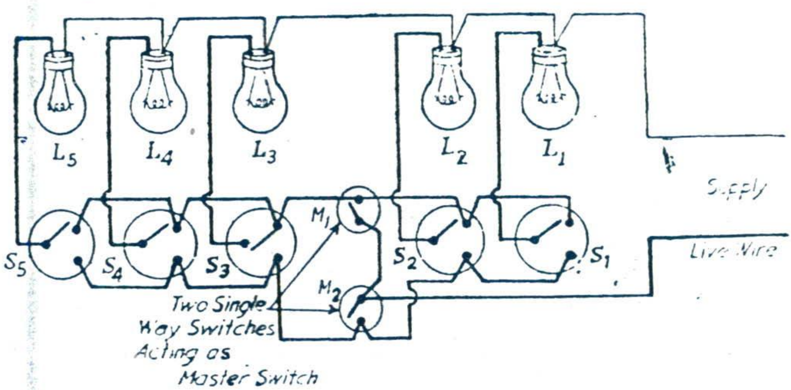
is made off, then the complete circuit is isolated from the mains and the lamps cannot be lighted until and unless the main switch is made on.

In Fig. 7.25 the lamp is being controlled by 3 switches, if the first 2-way switch used is of the special type, *i.e.* two-way on and off switch. The special two-way switch acts as a master off switch, *i.e.* when it is put on the off-position the lamps cannot be lighted.



Master off circuit
Fig. 7.25

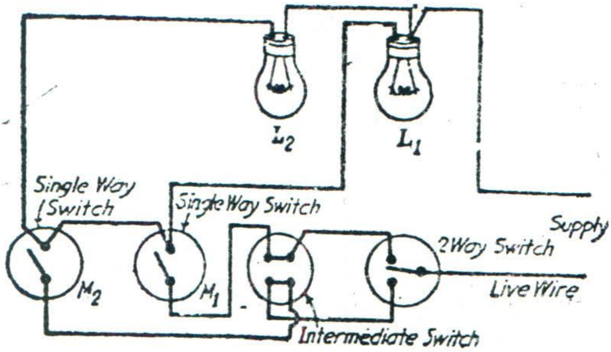
(c) *Variable Master Control.* The variable master controls are those master switches which act both as "Master on" and "Master off". In Fig. 7.26 the five lamps are being controlled independently



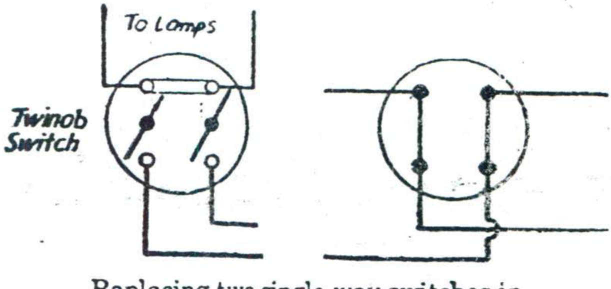
Variable master control
Fig. 7.26

by their switches while the two single-way switches, M_1 and M_2 act as variable master controls. When both switches M_1 and M_2 are in the off-position, no lamp will light thus acting as Master off Control. If either of the switches M_1 or M_2 switched on, then all lamps can be individually controlled, *i.e.* can be lighted or extinguished at will, but when both the switches M_1 and M_2 are switched on, then lamps will remain always lighted independent of the position of their individual switches, thus acting as Master On Control.

Fig. 7.27 (*a*) represents the corridor lights being controlled by two-way and the intermediate switch. The single-way switches M_1 and M_2 connected in the circuit act as variable master control. When both the switches are off, lamps will not light, and when one of single-way switches is switched on, then the lamps can be controlled by the two switches, but when both the switches M_1 and M_2 are switched on the lamps will remain lighted. The two single-way switches M_1 and M_2 can be replaced by a twin knob single switch as shown in Fig. 7.27 (*b*).

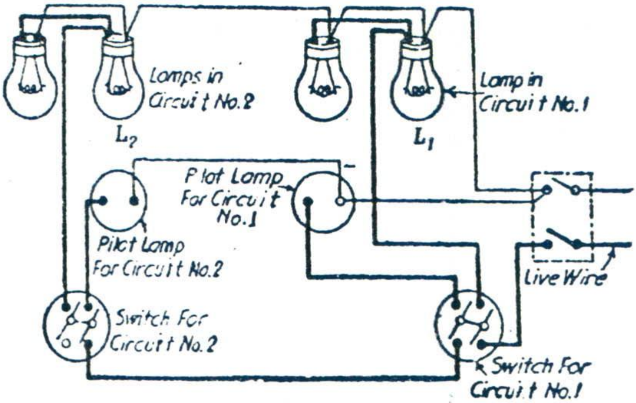


Variable master control circuit for corridor lights
(*a*)



Replacing two single-way switches in Fig. 7.27 (*a*) with twin knob switches
Fig. 7.27 (*b*)

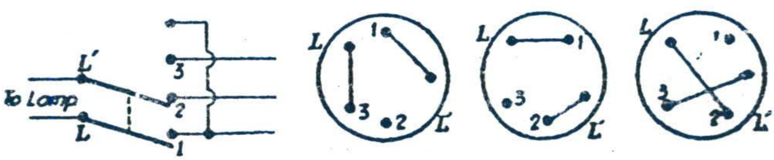
11. Pilot Circuits. The pilot circuits are used only to indicate whether at the remote point, the load is on or off. The simplest pilot indicator is a lamp which is automatically switched on when the remote load is switched on. Fig. 7.28 represents circuits for 2 lamp-loads at different remote places. Fig. 7.28 also shows the two pilot lamps in the circuit.



Pilot circuit
Fig. 7.28

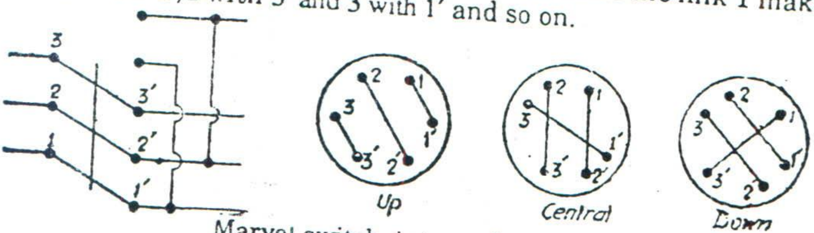
12. Circuits Using Special Types of Switches. The following are the different types of switches :

(1) *Marvel Switch, Ordinary Type.* Such a switch has six terminals and three positions of the operating lever. The terminals L and L' are for lamp connections. When the level is up, the lamp terminals L L' make contact with the terminals 1 and 3 respectively. For one central position of the level, the lamp terminal L makes contact with terminal 1 while L' makes contact with terminal 2. Again, if the level is in the down position L and L' make contact with terminals 2 and 3 respectively. Fig. 7.29 represents an equivalent circuit of the marvel switch, which represents the two movable links L and L' making contact with terminals 1 and 2 and the switch is so arranged that both of these movable contacts move together. Thus when L makes contact with 2, L' will make contact with 3.



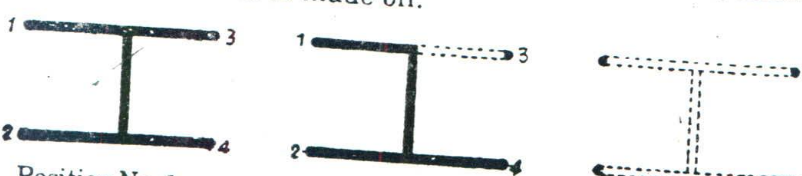
Ordinary Marvel Switch
Fig. 7.29.

(2) *Marvel Switch, Intermediate Type.* Such a switch has 6 terminals and 3 movable links having permanent connection with terminals 1, 2 and 3 while these links make contact with the other three terminals 1′, 2′ and 3′ in a cyclic order. Fig. 7.30 represents the three positions of the intermediate switch. The Fig. represents an equivalent circuit of the switch. The three links make contact with the terminals 1′, 2′, 3′ and these three movable contacts move in unison. When the switch is in the central position the link 1 makes contact with 2′, 2 with 3′ and 3 with 1′ and so on.



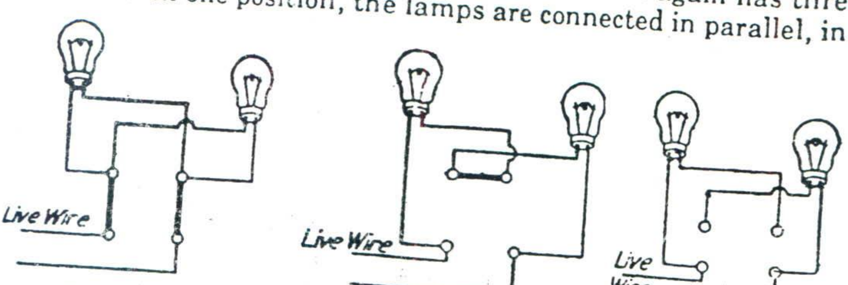
Marvel switch, intermediate type
Fig. 7.30

(3) *Whole or Part Circuit Switch.* This type of switch has four terminals, for such a switch the live wire comes to terminal 1, while terminals 3 and 4 are connected to the lamps. In one position, the whole of the circuit comes into the circuit, in the second position, only the part circuit remains in the circuit, and in the third position the whole of the circuit is made off.



Position No. 1 Position No. 2 Position No. 3
Fig. 7.31

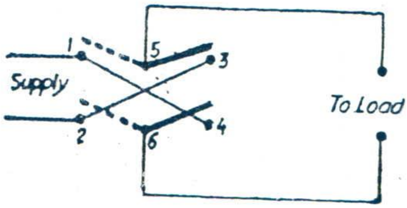
(4) *Parallel or Series Switch.* Such a switch again has three positions. In one position, the lamps are connected in parallel, in



Ist Position 2nd Position 3rd Position
Parallel or Series Switch
Fig. 7.32

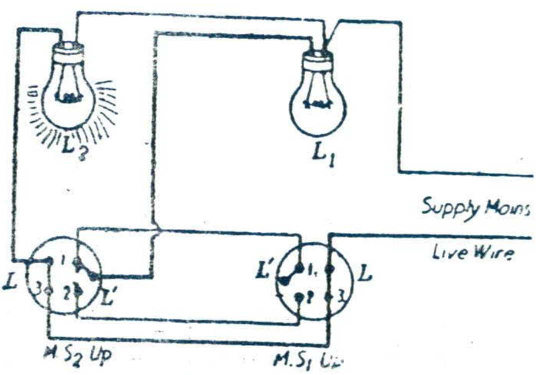
the second position, the lamps are connected in series while in the third position, all the lamps are switched off.

(5) *Reversing Switch.* The reversing switch is generally used to reverse the direction of current in the load. It is a six-terminal switch. The terminal 1 and 4 also 2 and 3 are short circuited. The terminals 5 and 6 are connected to two links which move in unison and can either be connected to terminals 3, 4 or to terminals 1 and 2 as shown in Fig. 7.33.



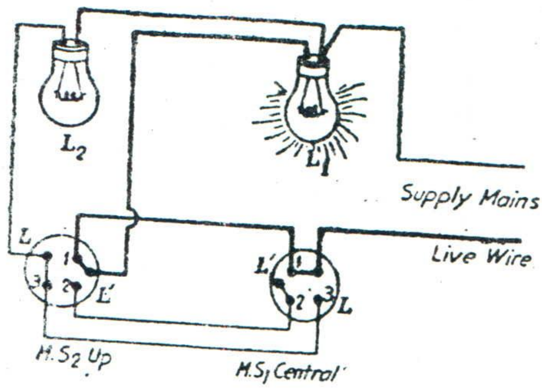
Reversing Switch
Fig. 7.33

6. Use of Marvel Switch. Fig. 7.34 (*a*) represents a 2-lamp circuit controlled by two Marvel switches. There are nine different positions of the switch with which a lamp can be lighted. In Fig. 7.34 (*a*) it will be observed that either of the lamp can be lighted in turn or whole of the circuit is switched off, *i.e.* it is a restrictive circuit in which the number of lamp lighted at a time is restricted. The use of restrictive circuit is that it reduces the maximum demand by reducing the number of lamps lighted at a time without sacrificing the conveniences gained from multi-control lighting system. Such circuits are useful in hotels where the usual demand of the load is very high. Fig. 7.34 (*a*) to Fig. 7.34 (*i*) represent 9 alternative circuits.



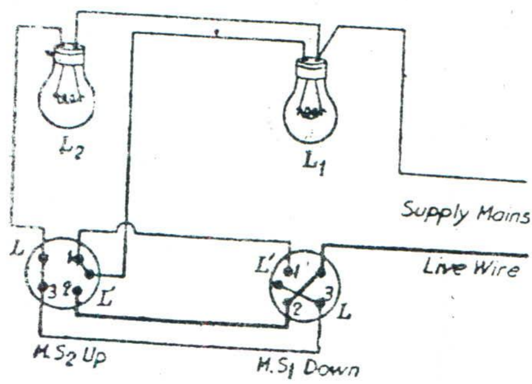
Position No. 1
Fig. 7.34 (*a*)

In Fig. 7.34 (a) the moveable contacts of both the switches are up. In each of the switches the terminals L and 3 are connected and terminals 1 and L' are shorted. In this case the lamp L_2 lights while the lamp L_2 is off.



Position No. 2
Fig. 7.34 (b)

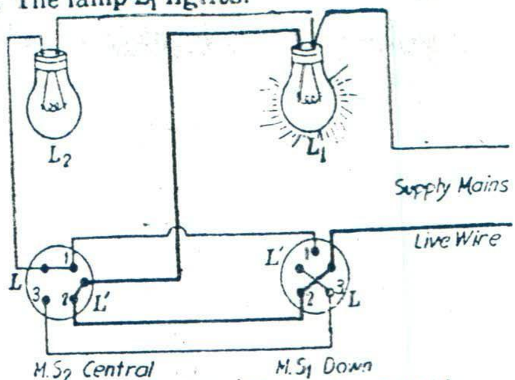
In Fig. 7.34 (b) the Marvel switch S_1 is in the central position thus terminal L and L′ and 2 are shorted, while the switch M.S_2 is up and the moveable links make contacts with terminals 1 and 3. Thus the circuit of L_1 is completed and Lamp L_2 is off.



Position No. 3
Fig. 7.34 (c)

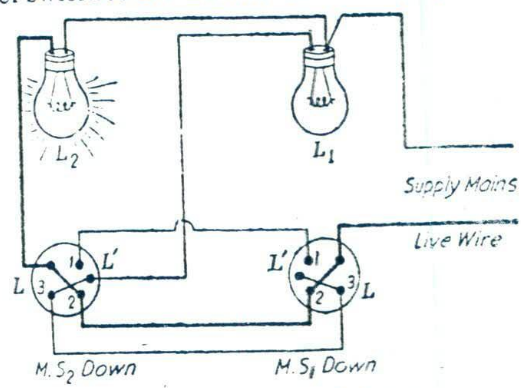
In Fig. 7.34 (c) switch M.S_1 is in the down position and so the moveable links make contact with terminals 2 and 3, while switch S_2 is up. It is clear from Fig. 7.34 (c) that the circuit of either lamp is not completed, thus both of them remain off.

In this circuit [Fig. 7.34 (*d*)] M. S_1 is down, while M. S_2 is in central position. The lamp L_1 lights.



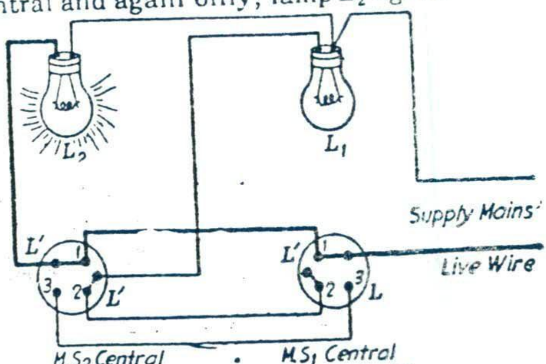
Position No. 4 Fig. 7.34 (*d*)

For the circuit shown in Fig. 7.34 (*e*) the moveable contacts of the two Marvel switches are down. Thus lamp L_2 lights.

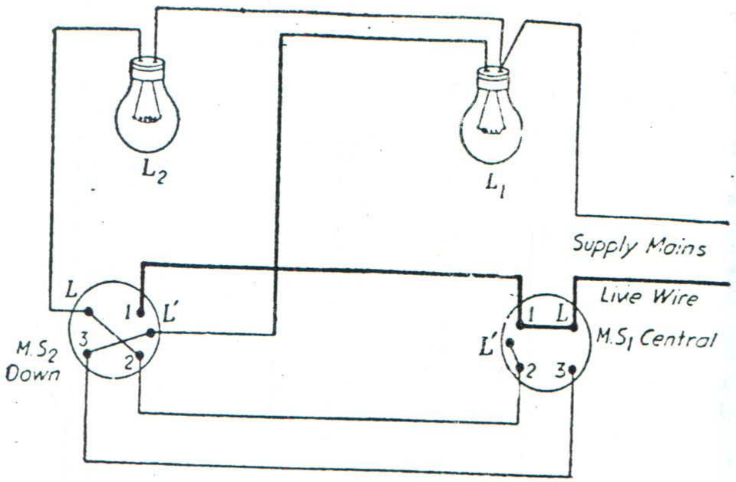


Position No. 5—Fig. 7.34 (*e*)

For the circuit shown in Fig. 7.34 (*f*) the position of both the switches is central and again only, lamp L_2 lights.



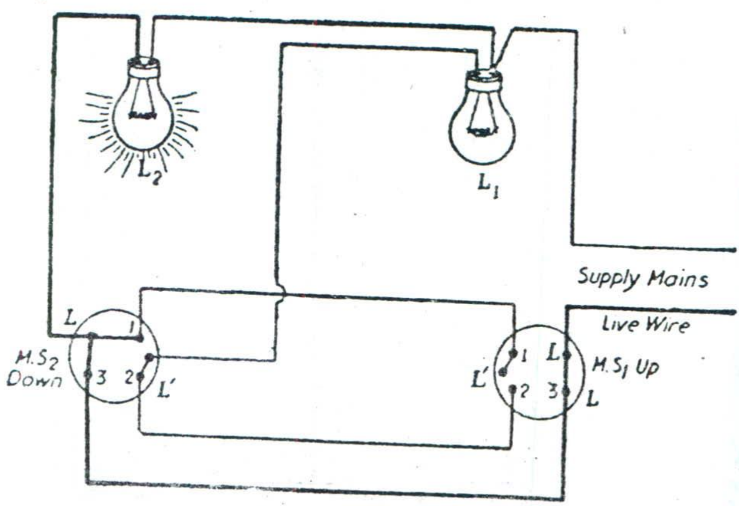
Position No. 6—Fig. 7.34 (*f*)



Position No. 7
M.S_1......Central
M.S_2......Down
No. Lamp lights
Fig. 7.34 (*g*)

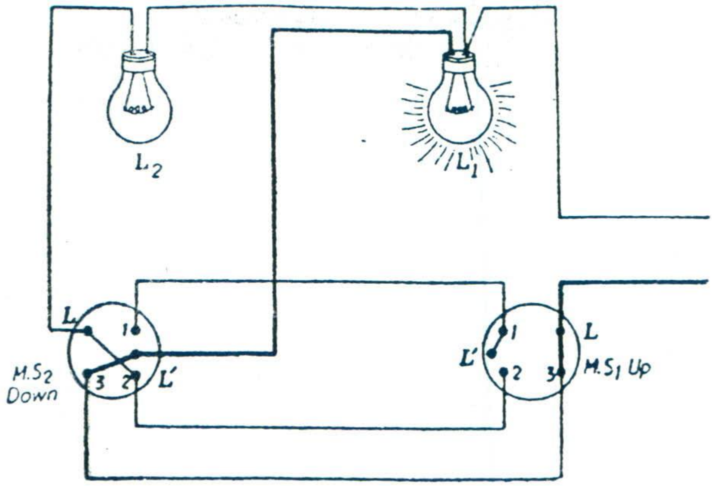
In this circuit [Fig. 7.34 (*g*)] M.S_1 is in the central position while M.S_2 is in the down position and the circuit of neither lamp is completed, thus the lamps remain in the off-position.

In Fig. 7.34 (*h*) M.S_2 is in down position and M.S_1 is in up position



Position No. 8
Fig. 7.34 (*h*)

and again lamp L_2 is lighted whereas when the switches are on the position as shown in Fig. 7.34 (*i*), lamp L_1 is lighted.



Position No. 9
Lamp L_1 lights ; M.S_1——Up ; M.S_2——Down
Fig. 7.34 (*i*)

Circuits of either one lamp or both of them light in parallel. With the revised connections in between the two Marvel switches, a circuit for either lamp L_1 or lamps L_1 and L_2 in parallel can be lighted. When the switch positions of M.S_1 and M.S_2 are in the Down and "Up" directions respectively, no lamp will light as shown in Fig. 7.35 (*b*). The position of the two Marvel switches are similarly to the other positions as shown in Fig. 7.34.

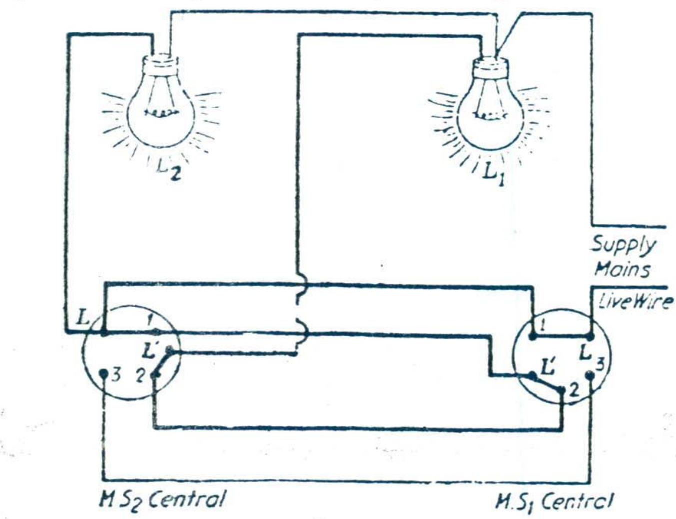
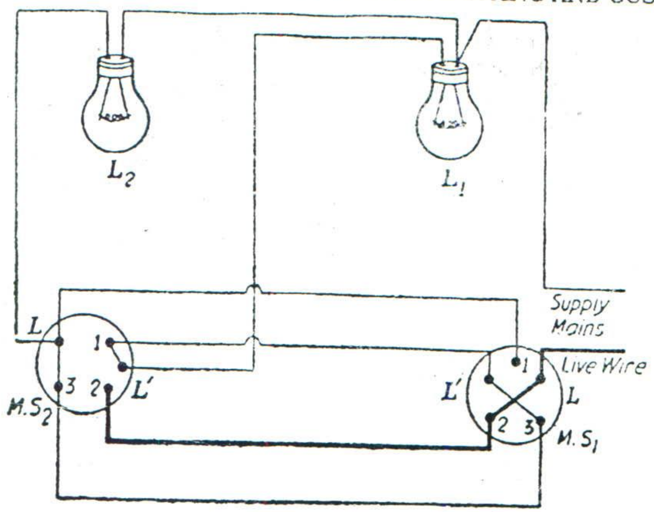
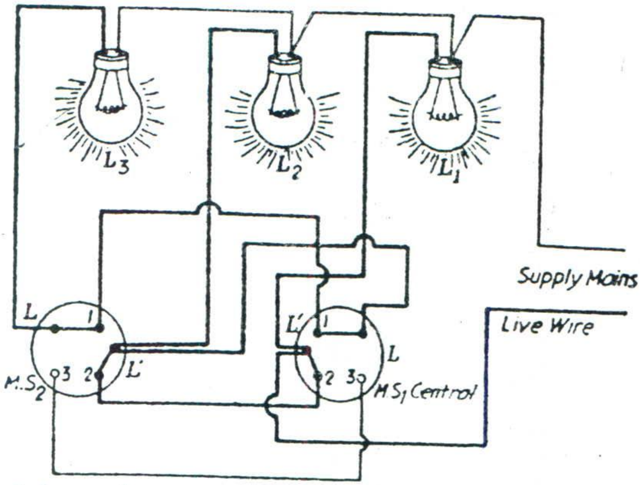


Fig. 7.35 (*a*) Two lamps in parallel



$M.S_2$ UP   Fig. 7.35 (b) $M.S_1$ DOWN

Circuit for one lamp or two lamps or three lamps. Fig. 7.36 represents the circuit for the three lamps being lighted at a time when both of the Marvel switches $M.S_1$ and $M.S_2$ are in the central positions.

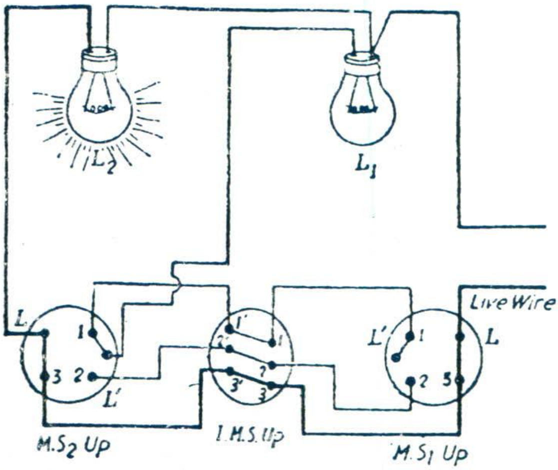


Circuit for one lamp or two lamp or three lamps without off position
Fig. 7.36

For other positions of these switches, it will be observed that either lamp L_1 alone lights, or L_1 and L_2 light in parallel and *there is no off position.*

Lamp controls at 3 places with the help of Marvel Switches. Fig. 7.37 represents a two-lamp circuit similar to that of shown in Fig. 7.34 in which case the two Marvel switches $M.S_1$ and

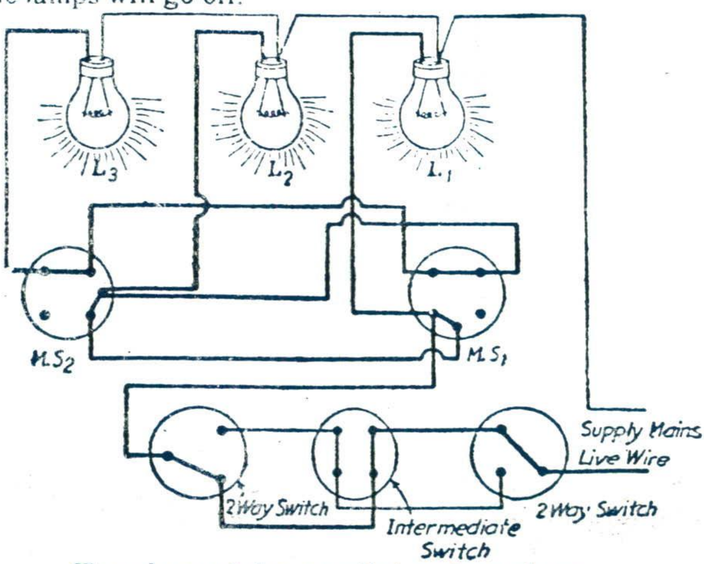
$M.S_2$ are in the up-position ; but in between these two switches is connected the Intermediate Marvel switch which is again in the up-position. The different positions of the Intermediate switches are shown in Fig. 7.38.



Circuit for controlling the lamps at three places

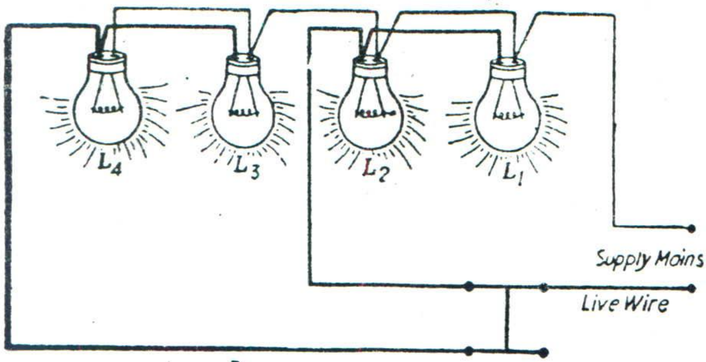
Fig. 7.37

The alternative method of controlling the lamps is as shown in Fig. 7.38 in which case the connections between $M.S_1$ and $M.S_2$ are so made as to as "Master On" Circuit, *i.e.* at no position of $M.S_1$ or $M.S_2$,the lamps will go off.



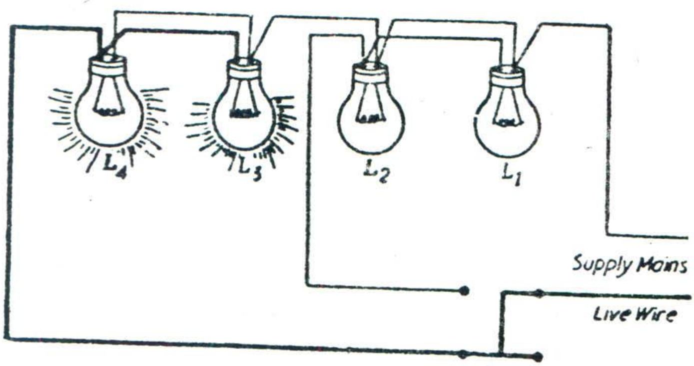
Three lamps being controlled at three places

Fig. 7.38



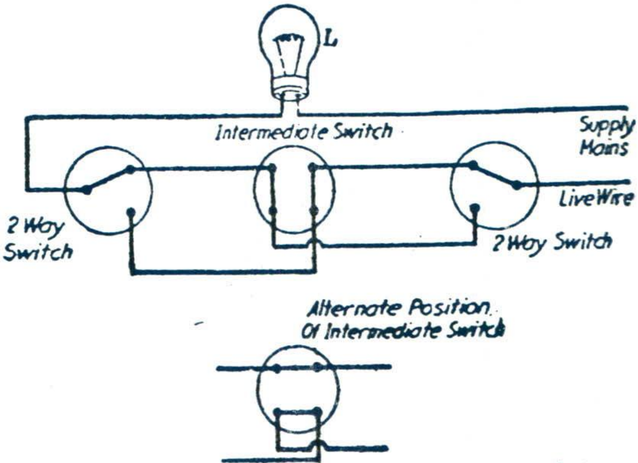
Whole circuit is lighted
Fig. 7.39

Use of whole or part circuit switch. The switch is connected in series with the live wire as shown in Fig. 7.39. In this position, all the four lamps are lighted, but in the other position of the switch, only two lamps are lighted as shown in Fig. 7.40. In the third position of the switch, no lamp lights. If this switch, instead of being put in series with the live wire is put in series with the negative wire and this circuit is used in series with two 2-way switches and one Intermediate switch, the whole or part circuit switch will act as Master Off switch.

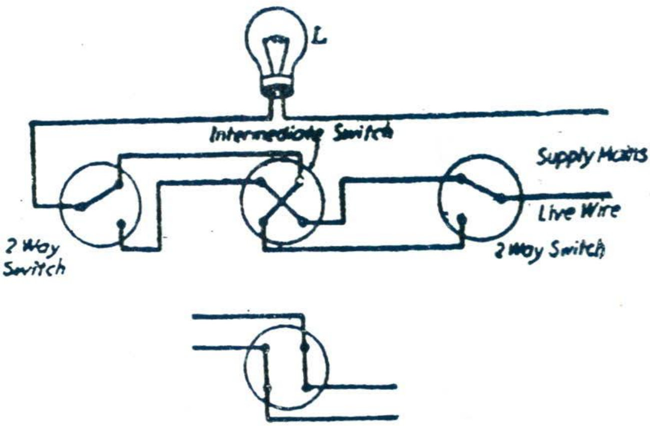


Part of the circuit is lighted
Fig. 7.40

14. Lamp Control circuit from more than two points or alternative method of corridor lighting. The other system of corridor lighting is to connect all the lamps in parallel and all such lamps may be controlled either from three or four points. The circuits for such controls are usually achieved with the help of Intermediate switches and the ordinary 2-way switches. Fundamentally, the Intermediate switch is a combination of two 2-way switches coupled together. Fig. 7.41 represents the circuit of the lamp being controlled at three points. The Intermediate switch used has four terminals, the two positions of this switch are shown in Fig. 7.41. The alternative type of Intermediate switch which can be used for the lamp to be operated from three positions is as shown in Fig. 7.42.

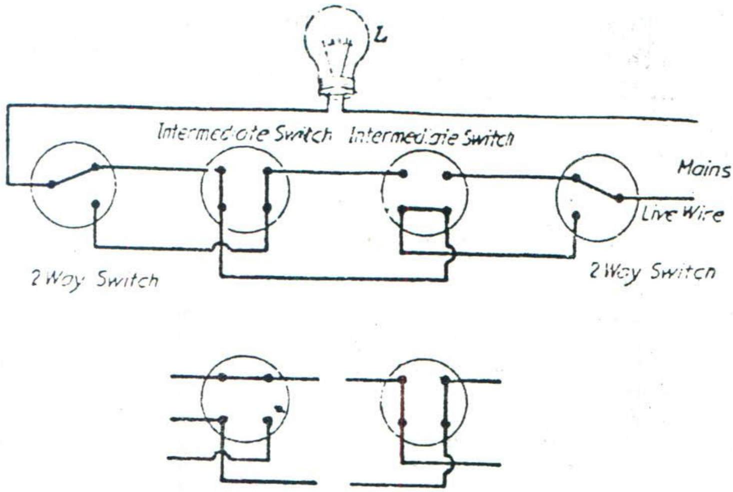


Controlling a lamp from more than one point
Fig. 7.41

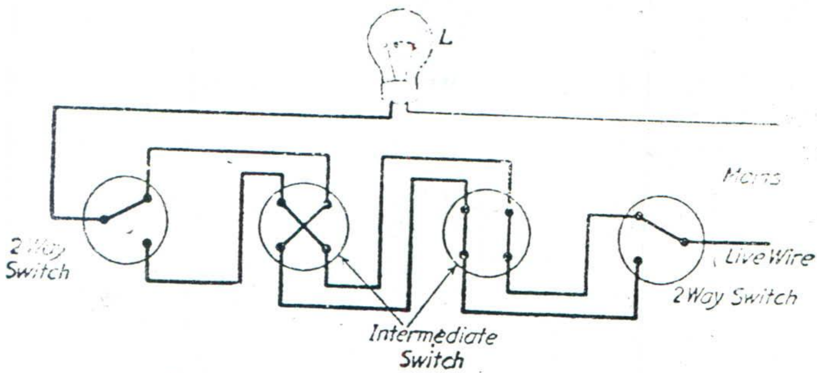


Controlling of a lamp from more than two points
Fig. 7.42

For the lamps to be controlled at four different points, two intermediate switches are used in addition to two ordinary two-way switches. Figs. 7.43 and 7.44 represent the two circuits for the lamps to be controlled from 4 alternate positions ; in each diagram the different types of Intermediate switches are used.

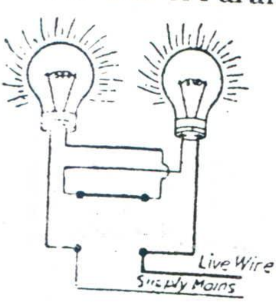


Controlling of a lamp from four points
Fig. 7.43

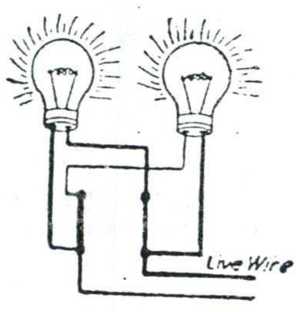


Controlling of a lamp from four points
Fig. 7.44

15. Use of Parallel or Series Switch.

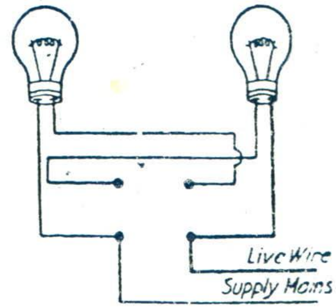


Series connections of switch.
Fig. 7.45 (*a*)



Parallel connection of switch
Fig. 7.45 (*b*)

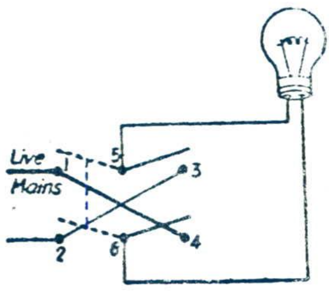
As explained earlier, the parallel or series switch has three positions and has four terminals. In one position the two lamps operate in parallel as shown in Fig. 7.45 (*b*) so that they give full light. In the other position shown in Fig. 7.45 (*a*) the two lamps are connected in series so that they give dim light. In the third position the lamp circuit remains off as represents in Fig. 7.45 (*c*).



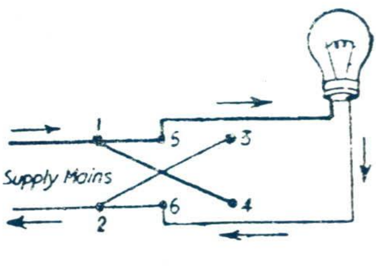
The circuit remains 'OFF'
(c)
Fig. 7.45

16. Use of Reversing Switch.

To terminals 5 and 6 is connected the lamp. In Fig. 7.46 (*a*) the circuit is off while in Fig. 7.46 (*b*) the two links are connected to terminals 1 and 2 , thus the direction of current in the lamp load is



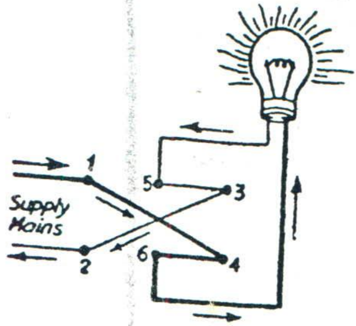
Off position of the circuit with reversing switch
(*a*)



Position of the reversing switch when the current is in clockwise direction
(*b*)

Fig. 7.46

clockwise while in Fig. 7.46 (*c*) the links are connected to terminals 3 and 4 which changes the circuit in the lamp to the anti-clockwise direction.

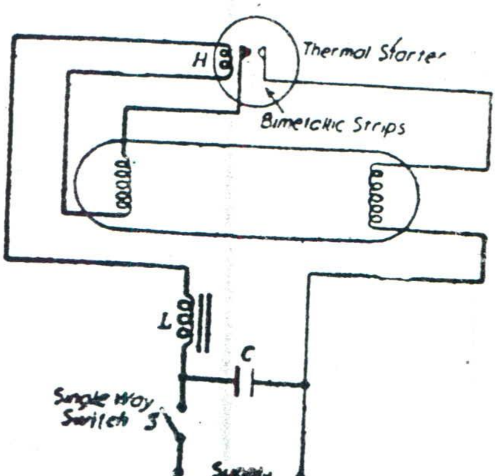


Position of the reversing switch when the current is in anti-clockwise direction

(c)

Fig. 7.46

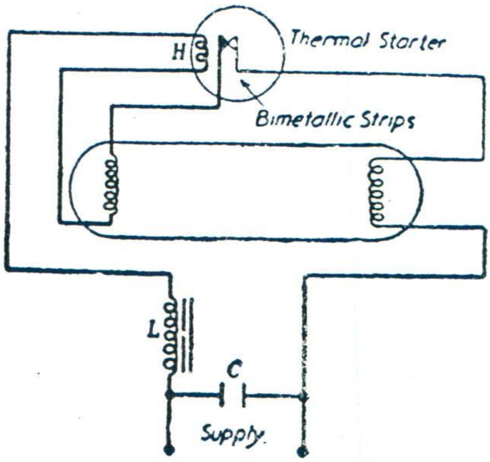
17. Fluorescent Tube Lighting. The fluorescent tubes are usually available in lengths of 0.61 metre and 1.22 metres. The tubes are generally coated from inside with fluorescent materials and the colour of light given out by these tubes depend upon the fluorescent material used. The powder used as a fluorescent material is activated by the ultraviolet rays generated in the tube. The popularity of this tubes in the daily life is due to the reason that total illumination given out by them is much higher than filament lamps they operate at low temperatures and the glare is eliminated. The illumination of 80 W. Tube (4 ft. length) is same as that of 200 W filament lamp. The following are the wiring diagrams for starting the tube circuit.



Circuit of a fluorescent tube with thermal starter

Fig. 7.47

18. Circuit with a Thermal Starter. Fig. 7.47 represents the tube circuit which consists of a choke *L*, condenser *C* and a thermal starter. The thermal starter consists of two bimetallic strips and a heater coil *H*. When no current passes through the heater the bimetallic strips make contact with each other. When the tube is switched on to the mains, the current passes through the choke *L*, heater *H*, left electrode of the tube and back to the mains through the right electrode as shown in Fig. 7.48.

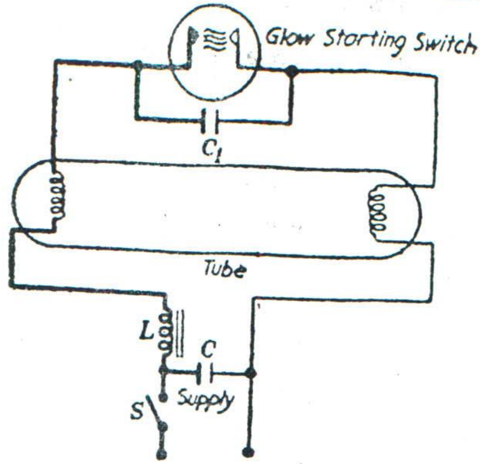


Circuit with a thermal starter immediately after switching on

Fig. 7.48

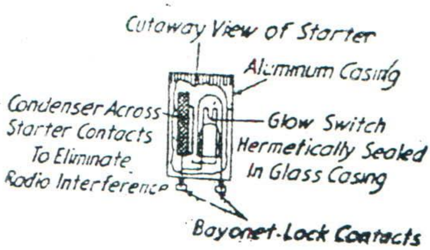
As the current passes through the electrode of the tube, they are heated and produce electrons into the tube path, at the same time the heater *H* heats the bimetallic strips and this heating causes them to spring apart, thus the current into the circuit is interrupted. The sudden interruption of the current in an inductive circuit causes a high voltage surge across the electrodes of the tube, which is sufficient to start the tube in operation. Note that the function of the choke is to produce a blast (high voltage at starting) for starting the tube. As the choke is in series with the circuit, it makes the tube to work at a very low power factor, approximately 0.5 lagging. So in order to improve the power factor, a condenser *C* is connected across the main supply. The value of the capacitor should be 7.5 μF for an 80-watt tube, and 3.25 μF for a 40 watt-tube.

19. Tube Circuit with Glow Starting Switch. In Fig. 7.49 when the switch *S* is closed, the full voltage is applied across the starter bimetallic strips and the normal supply voltage is sufficient to start a glow across the starter terminals, *i.e.*, for that period for which the glow persists, the tube cathodes are short circuited and are heated up. At the same time, the glow across the bimetallic strips heat them up and so they are bent and the glow disappears,

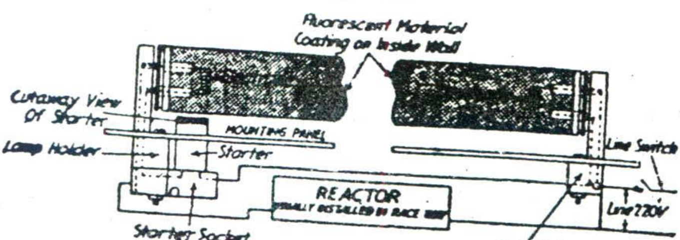


Tube circuit with a glow starter
Fig. 7.49

i.e. the circuit breaks. This sudden interruption of the current in the inductive circuits causes high voltage to appear across the tube electrodes which is sufficient to start the discharge in the fluorescent tube. A small condenser C_1 across the two bimetallic strips suppress the radio interference generated by the lamp. The condenser C across the supply mains is for improving the power factor. Fig. 7.50 represents the internal view of the starter, while Fig. 7.51 represents a circuit with the tube in position.



Internal view of starter
Fig. 7.50



Internal view of starter with tube in position
Fig. 7.51

20. The Instant Start Circuit of Fluorescent Tube. The use of instant start for the tube is felt where the tubes are fixed to inaccessible position and where maintenance for the starter and the tube is difficult. For such a circuit an auto-transformer is required, the primary of which is in parallel with the main supply and the secondary is connected to the electrodes of the tube. When the tube is switched on, the auto transformer supplies heating current to the electrodes and when the electrodes are sufficiently heated, the high voltage of the transformer strikes the tube at that instant. Just after starting the voltage across the electrodes is brought to normal by the choke. The starting is helped by the capacitance between the lamp and earthed conductor as shown in Fig. 7.52.

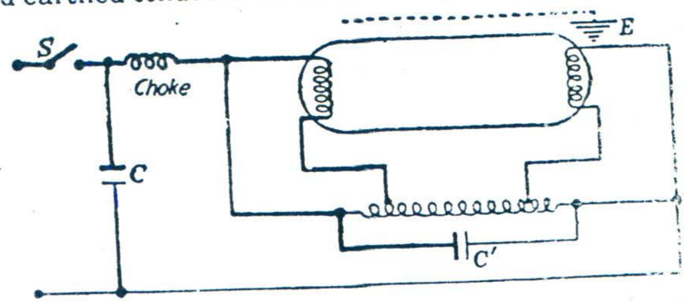
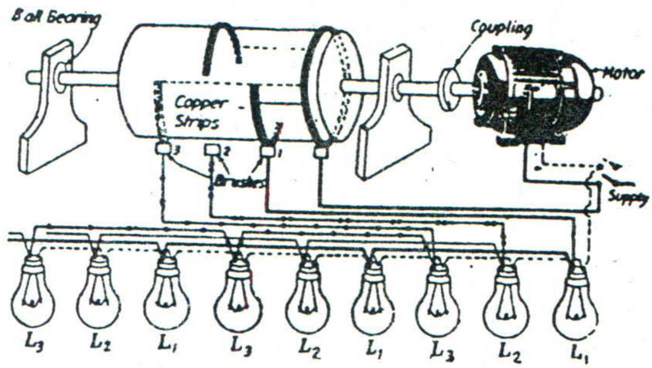


Fig. 7.52 Instant start circuit of a fluorescent tube

21. Flasher for Moving Lights. For decoration purposes in marriages etc., moving lights are used. The moving effect is usually obtained by means of a flasher, which consists of a wooden cylinder which rotates into the two ball bearings at the two ends. The wooden cylinder is connected to the motor through a belt or a coupling. The speed of the motor and the selection of pulley should be so made that the wooden cylinder rotates at about 100 r.p.m. On the wooden cylinder is provided, a copper ring (to which the live wire is connected through a brush) and 3 copper segments 120° apart from each other and each end of these segments is permanently connected to the copper ring : As this cylinder rotates, these three segments make contact alternately with the brushes 1, 2 and 3 in turn. The brush No. 1 is connected to lamps L_1, the brushes No. 2 and 3 are connected to lamps L_2 and L_3 respectively. Fig. 7.53 shows the instant when the copper segment No. 1 makes contact with the brush No. 1, it lights all the lamps L_1. As the cylinder rotates through 1/3rd of the revolution the circuit No. 1 goes off and just at the same instant circuit No. 2 becomes alive and lights all the lamp L_2, and after a further 1/3rd of the revolution the circuit No. 3 becomes alive and lights all the lamps L_3 and in such a system of lighting, the lamps circuit is repeated and it so appears that the lights move from right to left.

Such moving effects of lights can be used to show Waving Flag, Flickering light or Lighting etc.

22. Suggested Position of Electrical Fittings. For the purpose of obtaining proper illumination, air circulation, ease of operation, normal comforts, safety etc., it is necessary the various



Circuit for moving lights with a flasher
Fig. 7.53

electrical fittings shall be placed in a room at appropriate places Fig. 7.54 represents section view for showing heights of different electrical fittings. The suggestion given is this sketch will also facilitate the students and readers to plan and design for internal using scheme.

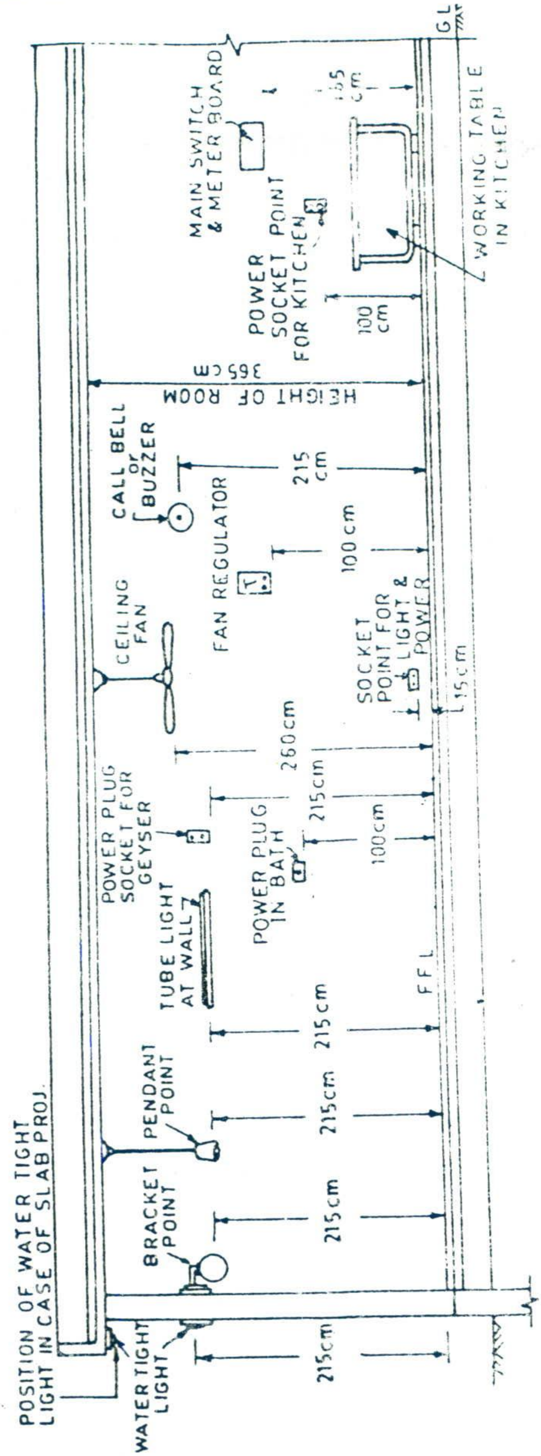

GL
MAIN SWITCH
& METER BOARD
165 cm
WORKING TABLE
IN KITCHEN
POWER
SOCKET POINT
FOR KITCHEN
100 cm
365 CM
HEIGHT OF ROOM
CALL BELL
or
BUZZER
215 cm
FAN REGULATOR
100 cm
CEILING
FAN
SOCKET
POINT FOR
LIGHT &
POWER
15 cm
260 cm
215 cm
POWER PLUG
SOCKET FOR
GEYSER
POWER PLUG
IN BATH
100 cm
TUBE LIGHT
AT WALL
FFL
215 cm
PENDANT
POINT
215 cm
BRACKET
POINT
215 cm
POSITION OF WATER TIGHT
LIGHT IN CASE OF SLAB PROJ.
WATER TIGHT
LIGHT
215 cm

Fig. 7.54

TYPICAL QUESTIONS

1. Explain the looping in system of wiring.
2. Explain the looping in system of wiring with junction box.
3. What are the different types of house wiring ?
4. State the precautions to be observed in various types of wiring.
5. What are the various types of lamp circuits ?
6. Explain with diagram the application of series parallel circuit.
7. Explain with diagram the working principle of a fluorescent tube
8. What do you understand by Master switch circuits ? Explain with diagram the Master-on circuit.
9. How many types of marvel switches are there ? Write short note on any two of them.

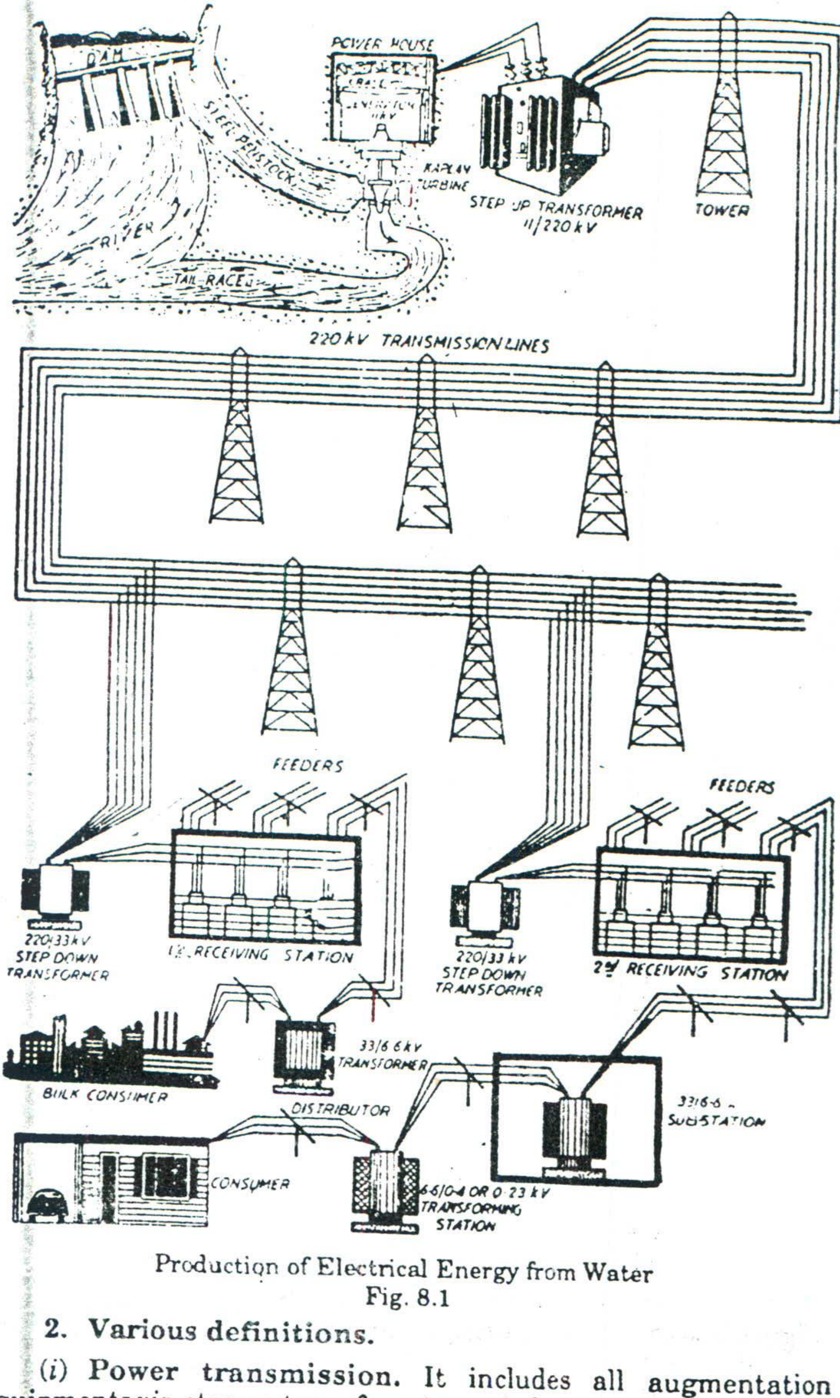
8

Transmission and Distribution of Electrical Energy and House Service Connections

1. Introduction. It is well known that the electrical energy is generated in power houses or generating station. For this purpose big dams have been constructed throughout the country. Until and unless this energy is conveyed to the users, no useful purpose is going to be served by merely generating the same. The electrical energy is converted to the users through transmission and distribution networks.

Typical power scheme by which the electrical energy is obtained from water has been shown in Fig. 8.1. The generator coupled to the turbine generators 11 KV A.C. supply which is stepped up to 220 KV at the sending end and is transmitted to the receiving station. At the receiving station the voltage is reduced to 33 KV with the help of stepdown transformers. From these sub-stations again will radiate out a number of feeder to various distribution substations where the energy is further stepped down to 11 KV or 6.6 KV. Various distributors for feeding the bulk consumers or the transforming stations will radiate from these substations. The voltage at the transforming station is further reduced to 400 volts.

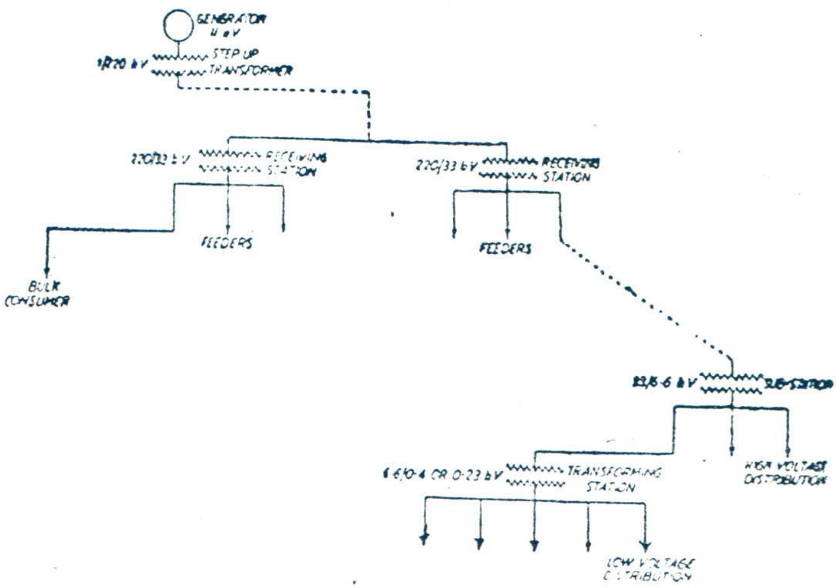
Fig. 8.2 represents the line diagram of the power scheme.



Production of Electrical Energy from Water
Fig. 8.1

2. Various definitions.

(*i*) **Power transmission.** It includes all augmentation equipments *viz*. step up transformers, switchgears etc. at the power house, overhead lines, underground cables and switchgears between power house and bulk consumers, a distribution sub-station.



Line diagram of the Power Scheme from Water
Fig. 8.2

(*ii*) **Transmission lines.** These are the overhead lines which convey the electrical energy from the generating station at high or extra high voltage to the distribution sub-stations. These are also known as **feeders**. The current loading of these feeders usually remains the same as these are not usually tapped for feeding the consumers. However at certain places, the bulk consumers are fed by tapping the feeders, but such tappings are very few and therefore, current loading of feeders will vary from the tapping point to bulk consumers and will remain same upto distribution sub-station.

(*iii*) **Distribution System.** All the equipment in the distribution sub-station, overhead lines U/G cable radiating from the distribution sub-station combine together is known as distribution system.

(*iv*) **Distributors.** As clear from the name, these are the overhead lines from which number of consumers are fed by electrical energy at low voltage.

(*v*) **Service Connections.** The aluminium conductors or the weather proof connecting the distributors with the consumers mains is known as service connections.

3. **D.C. & A.C. Systems of Supply.** It is not possible to increase the voltage in d.c. system, with the results, the electrical energy in case of d.c. system is to be transmitted and distributed at the generated voltage. It is not possible to generate the d.c. energy beyond 440V potential. Whereas from article 1, it will be seen that in case of A.C., voltage can be increased to 120 KV. Thus, for the same amount of power the currents is tremendously reduced. The copper losses which are directly proportional to the square of the current are therefore negligible in A.C. system. Due to this reason the a.c. system is preferred to d.c. system. Comparison between a.c. and d.c. transmission and distribution is given below.

(A) **Comparison between A.C. & D.C. transmission system.** The advantages and disadvantages of a.c. transmission and d.c. transmission are given below.

(*i*) **Disadvantage of a.c. system.**

(*a*) For the same working voltage, the potential stress across the insulators terminals for the same working voltage is in case of a.c. system $\sqrt{2}$ times than the d.c. system. To avoid this, more spacing is required between the insulators to avoid corona loss and to provide insulation. This will increase the cost of the cross arm.

(*b*) In a.c. system, one has to take into consideration the effect of inductance and capacitance while designing the a.c. transmission line, whereas there is no such problem in d.c. system. Due to capacitance, there is continuous loss due to charging current and even if there is no load on the line, the loss will take place continuously.

(*c*) Due to the skin effect, the resistance of the same line is more in a.c. system than d.c. system. This will cause more copper losses in a.c. system for the same amount of power transmitted at constant voltage.

(*d*) If the load and sending end voltages are same, the voltage regulation for d.c. transmission line is better.

(*e*) If underground cables are used, dielectric losses due to potential stress will be more in a.c. transmission system.

(*f*) A.C. transmission is very much complicated in comparison to d.c. system. More staff is therefore required to erect and maintain the a.c. transmission system.

(*ii*) **Advantage of a.c. transmission system.** The main advantage is that the transmission voltage in case of a.c. system is very high with the results, the transmission of electrical energy at a wide distance after generation is possible with much less copper losses. This phenomena in a.c. supply is such an important that almost all the countries have adopted the alternating current system of supply.

4. Distribution of Electrical Energy. As the transmission is usually done with a.c. supply, the a.c. energy is distributed after stepping down the voltage due to the following reasons :

(*a*) The cost of conversion plant is high in comparison to stepdown transformer.

(*b*) By running three phase four wire distributor it is possible to obtain 400V for motors and other industrial machine and 230V for residential lighting and domestic appliances.

(*c*) Maintenance cost of a.c. distributor is low.

However the main **disadvantage** of a.c. distributor is that the initial cost of distributor is more in comparison to d.c. distributors where only three conductors are seen. The copper efficiencies of various terms for transmission and distribution have been tabulated in Table 8.1.

5. Overhead Lines. An overhead line mainly comprises of the following :

(*i*) Conductor

(*ii*) Supports or poles and cross-arm brackets

(*iii*) Insulators

(*iv*) Pole fittings

(*v*) Stays or Guy wire

(*vi*) Miscellaneous items such as lightning arrestors, guard wire, danger plate, anticlimbing devices, jumpers, earthing etc.

While erecting an overhead line, the following points are to be taken into consideration.

(*i*) The voltage at the tail end of the lines should be within the prescribed limits which are (*a*) ± 5% of the declared L.T voltage and (*b*) ± 12.5% of the declared H.T voltage.

(*ii*) It should be in a position to conduct the desired load efficiently.

(*iii*) The lines should be strong enough to stand during adverse climatic conditions. Wherever required the guy wire should be provided at a proper angle.

(*iv*) Continuous earth wire of proper size which is solidly earthed at sub-station is to run all along the route of overhead line. For reason of safety after every fifth span, the pole is to be provided with the earth from the ground. This earth wire is to be connected solidly with the continuous earth.

(*v*) All metallic portion *viz* supports and bolts are to be connected with the earth.

Table 8.1

Systems	*Copper efficiencies*	
	Maximum voltage between one conductor and earth	*Maximum voltage between two outgoing conductors*
(*a*) D. C. System		
(*i*) two-wire system	1	1
(*ii*) two-wire system with mid-point earthed	0.25	1
(*iii*) three-wire system	0.3125	1.25
(*b*) Single phase A.C. System		
(*i*) two-wire system	$\frac{2}{\cos^2\theta}$	$\frac{2}{\cos^2\theta}$
(*ii*) two-wire with mid-point earthed	$\frac{0.5}{\cos^2\theta}$	$\frac{2}{\cos^2\theta}$
(*iii*) three-wire system	$\frac{0.625}{\cos^2\theta}$	$\frac{2\cdot5}{\cos^2\theta}$
(*c*) Three-phase System		
(*i*) three-phase three wire system	$\frac{0.5}{\cos^2\theta}$	$\frac{1\cdot5}{\cos^2\theta}$
(*ii*) three-phase four wire system	$\frac{0.583}{\cos^2\theta}$	$\frac{1\cdot75}{\cos^2\theta}$

Table 8.2

S. No.	Type of overhead line	Minimum clearance of Conductor above ground			Vertical clearance above building if the line is passing over it	Horizontal clearance from building
		While crossing the road or a public thorough fare	Along a road or a public place	At other places		
1.	Low tension	5.8 metres	5.5 metres	4.6 metres	2.5 metres	1.25 metres
2.	upto 11kV	6.1 metres	5.8 metres	5.2 metres	3.66 metres	1.25 metres
3.	upto 33KV	6.1 metres	5.8 metres	5.2 metres	3.66 metres	1.83 metres
4.	Above 33KV	—	—	5.2 metres + 0.305 metre for every additional 33 KV or part thereof.	3.66 metres +0.305 metre for every additional 33KV or part thereof	1.83 metres + 0.305 metre for every additional 33 KV or part thereof.

(*vi*) The clearance of Conductors from the ground and adjoining buildings should be in accordance with I.E. rule 77 and 79. This has been tabulated in table 8.2.

(*vii*) In normal soil about one sixth of the pole length is to be buried in the ground.

(*viii*) Spacing as given in Table 8.3 should be provided between the conductors.

Table 8.3

S. No.	*Working voltage*	*Spacing between conductors for*		*Spacing between conductors and supporting structure*
		Vertical formation	*Horizontal formation*	
1.	Low Tension	38 cm.	46 cm.	15 cm.
2.	6.6 KV or 11 KV	76 cm.	1.14 metres	30.5
3.	33KV	1.22 metres	1.53 metres	61 cm.
4.	66 KV	1.98 metres	3.23 metres	76 cm.
5.	110 KV	3.13 metres	4.96 metres	1.07 metres
6.	132 KV	3.66 metres	4.87 metres	1.30 metres

(*ix*) Anticlimbing devices and danger boards should be provided on each pole for overhead lines 6.6 KV and above.

(*x*) The guards as indicated below should be provided :

(*a*) In a span, the guards near each supporting pole should be provided if the line is passing along the roads or in open land.

(*b*) If the overhead line crosses some building or road, numbers of guards should be provided.

(*c*) Number of guards should be provided if two different lines cross each other.

(*xi*) The jointing of conductors should be done with sleeves of proper size.

(*xii*) At each support, the conductors should be bound properly with help of binding wires.

(*xiii*) Shackle of points should be provided after about 10 spans or as required for the purpose of isolating the faulty area.

(*xiv*) Jumpers of proper size should be used.

(*xv*) *In snow bound area, wooden poles are roofed before installation to avoid snow or ice standing on the top of pole. This is done by providing 45° metallic slanting cap on the top of the pole to prevent decay from snow.*

(*xvi*) Pole steps are provided for the line man to climb the pole.

(*xvii*) The cost of the overhead lines should be low. For this purpose the span of the line should be optimum. This will reduce the number of poles and other fixture thereby. While deciding upon the length of the span, public safety and Govt. regulations must be kept in mind. The maximum length of the span should be as under.

(*a*) With wooden poles : 40—50 metres
(*b*) With tubular poles: 50—80 metres
(*c*) With R.C.C. Poles: 80—100 metres
(*d*) With steel towers: 100—300 metres

It should be remembered that the insulation cost at high voltage can be kept low by increasing the length of the span.

6. Types of Conductors. The metals which are used as conductors are of copper and aluminium. The advantages of each metal has been explained below.

(*A*) **Copper.** The most common conductor used for transmission and distribution is hard drawn copper, as it is twice as strong as soft drawn copper. The merits of copper as a conductor are given below.

(*i*) It has a best conductivity as compared to other metals. However the conductivity also depends upon the impurities present in it and the method by which it is drawn.

(*ii*) It has a larger current density and so far a given current rating, the cross-sectional area of the copper conductor is less in comparison to other metals.

(*iii*) Copper is quite homogeneous.

(*iv*) It has a low specific resistance.

(*v*) It is durable and has a high scrap value

Its properties are given in Table 8.1

(*B*) **Aluminium.** Next to copper aluminium is the conductor used in order of preference for conducting the electrical energy.

(*i*) It is cheaper than copper

(*ii*) It is lighter in weight

(*iii*) It is second in conductivity. Commonly hard drawn aluminium wire at standard temperature has approximately 60.6 per cent conductivity in comparison to standard annealed copper Conductor.

(*iv*) For same ohmic resistance, its diameter is about 1.27 times that of copper.

(*v*) At higher voltages, there is less corona loss in aluminium conductor.

(*vi*) Since the diameter of the conductor is more, it is liable to be subjected to more wind pressure and ice load due to which the greater is the sag.

(*vii*) As the melting point of aluminium is low, therefore, there is more damage to the aluminium conductor when short circuited.

(*viii*) Jointing of aluminium is much more difficult than copper.

Table 8.4
Properties of Annealed and Hard-dran Copper

S. No.	*Gauge No. SWG*	*Nominal dia. mm.*	*Area sq. mm.*	*Weight kg/km.*	*Nominal breaking load kg.*	*Standard resistance at 20°C hard drawn wire ohms/km.*	*Standard resistance at 20°C annealed wire ohms/km.*
1	7/0	12.7	126.7	1,126	4,170	0.1388	0.1361
2	6/0	11.8	109.1	969.8	3,711	0.1613	0.15804
3	5/0	11.0	94.56	840.7	3,313	0.1863	0.18232
4	4/0	10.2	81.07	720.7	2,917	0.2175	0.2127
5	3/0	9.45	70.12	623.4	2,584	0.2516	0.2459
6	2/0	8.84	61.36	545.5	2,310	0.2877	0.2810
7	1/0	8.23	53.19	472.9	2,040	0.3320	0.3241
8	1	7.62	45.60	405.4	1,781	0.3875	0.3781
9	2	7.01	38.60	343.2	1,535	0.4579	0.4467
10	3	6.40	32.18	286.1	1,119	0.5495	0.5353
11	4	5.89	27.27	242.4	945	0.6489	0.6322
12	5	5.38	22.77	202.4	787	0.7770	0.7571
13	6	4.88	18.68	166.06	671	0.9478	0.9230
14	7	4.47	15.70	139.53	562	1.129	1.0985
15	8	4.06	12.97	115.32	461	1.366	1.3291
16	9	3.66	10.51	93.43	370	1.686	1.6409
17	10	3.25	8.302	73.19	307	2.136	1.077
18	11	2.95	6.818	60.63	249	3.601	2.529
19	12	2.64	5.480	48.72	196	3.237	3.146

Table 8.5

Properties of Solid Aluminium Conductor Used for Making A.C.S.R.

(The particulars are based on data from I.S. 398)

S.No.	Dia. mm.	Standard sectional area mm^2	Standard weight per km/kg.	Standard resistance at 20°C ohms/km.	U.T. stress km/mm^2	Minimum breaking load kg.
1	2.11	3.497	9.45	8.136	18.14	64
2	2.36	4.374	11.82	6.504	17.65	77
3	2.54	5.067	13.70	5.615	17.37	88
4	2.59	5.269	14.24	5.400	17.30	91
5	2.79	6.114	16.53	4.654	17.11	105
6	3.00	7.069	19.11	4.025	16.80	119
7	3.10	7.548	20.40	3.769	16.66	126
8	3.18	7.942	21.47	3.582	16.59	132
9	3.35	8.814	23.82	3.228	16.52	146
10	3.40	9.079	24.54	3.154	16.45	149
11	3.53	9.786	26.45	2.907	16.38	160
12	3.66	10.521	28.44	2.704	16.31	172
13	3.71	10.810	29.22	2.632	16.31	176
14	3.78	11.222	30.33	2.535	16.24	182
15	3.86	11.702	31.63	2.431	16.24	189
16	3.91	12.007	33.46	2.369	16.24	194
17	3.99	12.504	33.80	2.275	16.17	202
18	4.09	13.138	35.51	2.165	16.17	212
19	4.17	13.657	36.92	2.083	16.17	221
20	4.22	13.987	37.81	2.034	16.17	226
21	4.27	14.320	38.71	1.987	16.17	231
22	4.39	15.136	40.91	1.880	16.17	245
23	4.50	15.904	42.99	1.789	16.17	257
24	4.65	15.982	45.90	1.675	16.17	275
25	4.72	17.497	47.30	1.625	16.17	283
26	5.00	19.635	53.07	1.449	16.17	317
27	5.28	21.896	59.18	1.229	16.17	354
28	5.36	22.564	60.99	1.261	16.17	365

Because of shortage of copper ores in India, the use of aluminium conductor in transmission and distribution has been adopted.

Thé mechanical properties of aluminium are given in Table 8.5.

(*C*) **Steel.** No doubt it has not got the greatest tensile strength, but it is least used for transmission of electrical energy as it has got high resistance. Bare steel conductors are not used since, it deteriorates rapidly owing to rusting. Generally galvanized steel wires are used for telecommunication lines. It has the following properties.

(1) It is lowest in conductivity.

(2) It has high internal reactance.

(3) It is much subjected to eddy current and hysterisis loss.

(4) In a damp atmosphere it is rusted.

Hence its use is limited.

(*D*) **Aluminium Conductor with Steel Reinforced (A. C. S. R.).** An aluminium conductor having a central core of galvanized steel wire , is used for high voltage transmission purposes. This is done to increase the tensile strength of aluminium conductor. The galvanized steel core is covered by one or more strands of aluminium wires. The steel conductors used are galvanized in order to prevent rusting and electrolytic corrosion (since zinc is near to aluminium and there is no electro-chemical action between the two metals). The cross-sections of the two metals are in the ratio 1 : 6, but in case of high strength conductors their ratio is 1 : 4. Thus the steel reinforced aluminium conductor has less sag and longer span then copper conductor line since it has high tensile strength.

The aluminium steel conductor has a larger diameter than any other type of conductor of same resistance.

For all calculation purposes, it is assumed that the current is passing only in the aluminium section.

Table 8.6 represents various properties of this type of conductor. Tables 8.7 and 8.8 represent the mechanical properties of various types of conductors and comparison of aluminium and copper conductors respectively.

8. Line Supports. The line supports are poles and the chief requirements for such supports are :

(1) They must be mechanically strong with factor of safety of 2.5 to 3.

(2) They must be light in weight without the loss of strength.

(3) They must have least number of parts.

(4) They must be cheap.

(5) Their maintenance cost should be minimum.

Table 8.6

Particulars of Aluminium Conductor Steel Reinforced (ACSR) Conforming to I.S. 398. 1961

Standard Nominal Copper area mm^2	Standard No. and wire dia.in mm. Aluminium No.	Aluminium Dia.	Steel No.	Steel Dia	Dia. of complete conductor mm	Calculated equivalent area of Aluminium mm^2	Approx. ultimate tensile strength of conductor kg/mm^2	Calculated resistance at 20°C ohms/km	Approx. wt. in kg. per km. Aluminium	Approx. wt. in kg. per km. Steel	Approx. wt. in kg. per km. Complete cable	Standard length of conductor in metres	Approx. wt. of standard length kg.
13	6	2.11	1	2.11	6.33	20.71	771	1.374	57.5	27.2	84.7	2,500	212
16	6	2.36	1	2.36	7.08	25.91	952	1.098	71.9	34.1	106.0	2,000	212
20	6	2.59	1	2.59	7.77	31.21	1,136	0.9116	86.6	41.1	127.7	1,650	211
25	6	3.00	1	3.00	9.00	41.87	1,503	0.6795	116.2	55.1	171.3	1,220	209
30	6	3.35	1	3.35	10.05	52.21	1,860	0.5449	144.8	68.8	213.6	1,960	419
40	6	3.66	1	3.66	10.98	62.32	2,207	0.4565	172.9	82.1	255.0	1,600	408
45	6	3.99	1	3.99	11.97	74.07	2,613	0.3841	205.5	97.5	303.0	1,350	409
48	6	4.09	1	4.09	12.27	77.85	2,746	0.3656	215.9	102.5	318.4	1,280	408
50	26	2.54	7	1.90	12.66	82.83	2,923	0.3434	229.9	109.1	339.5	1,200	407
55	30	2.36	7	2.36	13.55	94.21	3,324	0.3020	261.4	124.0	385.4	1,060	409
65	30	2.59	7	2.59	14.15	103.60	3,299	0.2745	287.6	106.4	394.0	1,110	438
80	30	2.79	7	2.79	15.84	129.70	4,137	0.2193	359.8	133.8	493.6	885	437
80	30	2.54	7	1.90	15.86	128.51	4,638	0.2214	365.1	155.8	520.9	2,020	1,053
80	30	2.36	7	2.36	16.52	128.10	5,758	0.2221	363.4	240.4	603.8	1,960	1,184
85	30	2.59	7	2.59	18.13	154.30	6,880	0.1844	437.8	289.6	727.4	1,640	1,193
110	30	2.79	7	2.79	19.53	179.00	7,950	0.1589	508.1	336.1	844.2	1,410	1,191
130	30	3.00	7	3.00	21.00	207.00	9,127	0.1375	587.4	388.6	976.0	1,225	1,196
140	30	3.18	7	3.18	22.26	232.50	10,210	0.1223	660.0	436.6	1096.6	1,090	1,196
160	30	3.35	7	3.35	23.45	258.10	11,310	0.1102	732.2	484.5	1216.7	1,975	1,187
185	30	3.71	7	3.71	25.97	316.50	13,780	0.08889	898.2	594.2	1492.4	1,555	2.314
225	30	3.99	7	3.99	27.93	366.10	15,910	0.07771	1,093	687.3	1725.3	1,335	2,305
260	30	4.27	7	4.27	29.89	419.30	18,230	0.06786	1,190	787.2	1977.2	1,165	2,304
300	30	4.50	7	4.50	31.50	465.70	20,240	0.06110	1321.5	874.2	2195.7	1,050	2,306
325	54	3.53	7	3.53	31.77	515.70	16,250	0.05517	1,463.6	537.9	2001.5	880	1,762

Table 8.7

Showing Properties of the Conductors

Mechanical properties	*Copper*	*Aluminium*	*Steel**	*Aluminium 1 : 3*	*Steel 1 : 4*
Specific weight kg/cm.^{3}	8.9×10^{-3}	2.7×10^{-3}	7.86×10^{-3}	3.45×10^{-3}	3.7×10^{-3}
Young's Modulus kg/mm^2	13,000	5,600	20,700	7,5000	8,300
Ultimate Tensile Strength kg/mm.^{2}	40	18	40 to 320	120	120
Specific resistance ρ at 20°C in $\Omega \frac{m}{mm^2}$	0·01786	0·0287	0·178	—	—
Conductivity 1 at 20°C $= \frac{1}{\rho}$	56	34·8	5·6	—	—
Resistance temperature coefficient per°C	0·0038	0·004	0·00496	—	—

Table 8.8

Comparison of Aluminium and Copper Conductors

Particulars	*Aluminium*	*Copper*
A. For equal resistance		
(*i*) Area ratio	1·61	1
(*ii*) Diameter ratio round conductor	1·27	1
(*iii*) Weight ratio	0·48	1
B. For equal current and temp. rise		
(*i*) Area ratio	1·39	1
(*ii*) Diameter ratio for round conductor	1·18	1
(*iii*) Weight ratio	0·42	1
C. For Equal Diameter		
(*i*) Resistance ratio	1·61	1
(*ii*) Current carrying capacity	0·78	1

(6) They must be easily accessible for paint and erection of line conductors.

(7) They must have longer life.

(8) They must be of pleasing shape.

The poles are grouted in the earth with cement concrete in the ratio of 1 : 2 : 4 and one-sixth of the pole is embedded in the earth.

*The values vary to a large extent depending upon degree hardness.

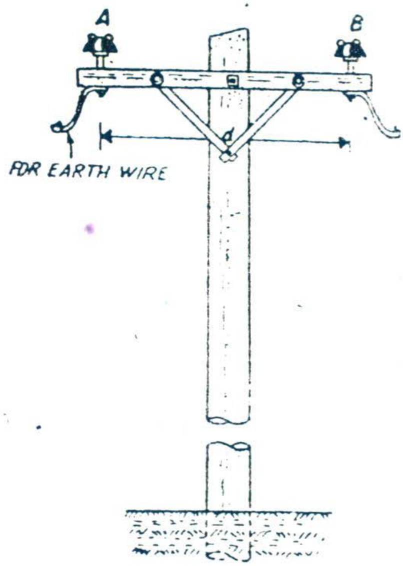
The different types of poles which can be used as line supports are :

(*i*) **Wooden Poles.** The use of such poles as line supports is limited to low voltages and are generally used for distribution purposes. Initially these poles are cheap and provide an insulating property. The poles preferably must be straight, strong with gradual taper and free from knots. The wooden pole should have 70 to 76 cm. grith of butt and 38 cm. to 50 cm. grith of butt. Its length should be between 9 m to 11 m.

The main disadvantages of such poles are that they are elastic and tend to rot, hence their life is short.

The portion of the pole which is buried in the ground must be treated with a creosote oil or with any other representative.

(*ii*) **Steel Tubular Poles.** The wooden poles may be substituted by steel tubular poles. Since these poles are stronger than wood, so with the help of these poles longer spans are possible. To increase the life of poles, they must be galvanized or painted regularly. For safety purposes, they must be earthed to increase the longitudinal strength of the pole, by steel rope guys.



Single-phase single-circuit.
Fig. 8.3

(*iii*) **Reinforced Concrete Poles.** In the modern days, the reinforced concrete poles have almost replaced the wooden and steel tubular poles, since they are attractive to look at. Such poles are quite heavy, so transportation cost increases ; but their maintenance cost is quite low and are mechanically very strong and hence have longer life.

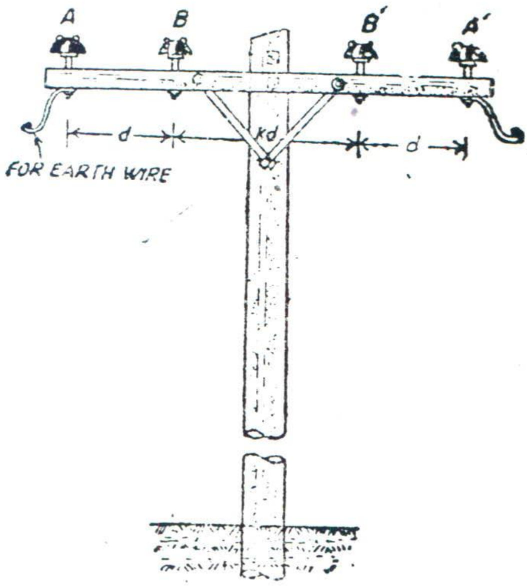
These poles having sectional bottom varying from 23 cm. × 23 cm. to 30 cm. × 30 cm. are usually used.

(*iv*) **Steel Towers.** The poles are used for distribution purposes, but the towers are useful for long transmission lines. It is not a hard and fast rule ; even wooden poles may also sometimes be used for transmission purposes depending upon the need and circumstances. Generally broad base lattice-steel towers are used, which are mechanically very strong and have longer life. It is said that if its design is given a proper care, the steel tower is good indefinitely. Due to robust construction, long spans can be used and much useful for crossing fields, valleys, railway lines, rivers etc. Fig. 8.7 to 8.10 represent the steel towers.

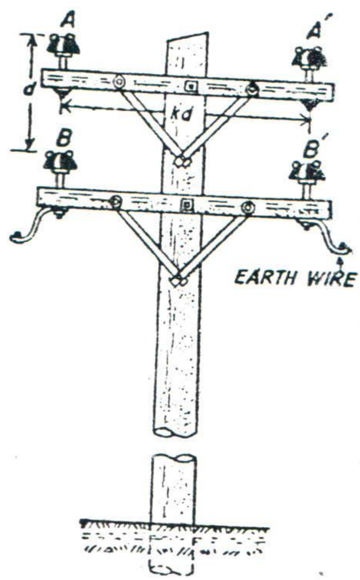
8. Arrangements of Conductors

A Transmission Lines. The following are the methods of arrangement of conductors over the line supports :

(*i*) *Single-phase circuits.* The single-phase transmission lines can either be single-circuit or double-circuit. Fig. 8.3 represents the most common method of single-phase single-circuit transmission. Fig. 8.4 represents a double-circuit single-circuit transmission line with conductors arranged in a horizontal disposition, while Fig. 8.5 represents double-circuit with vertical disposition of conductors.



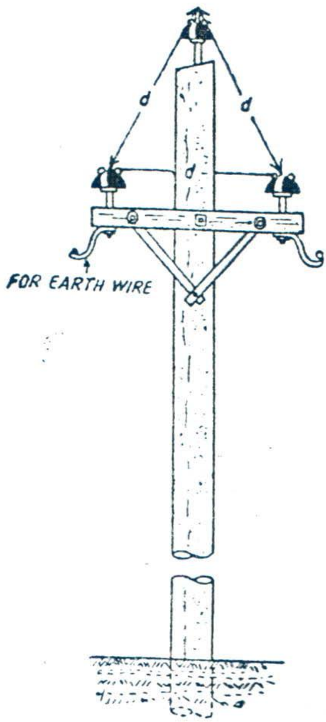
Single-phase double-circuit horizontal disposition.
Fig. 8.4



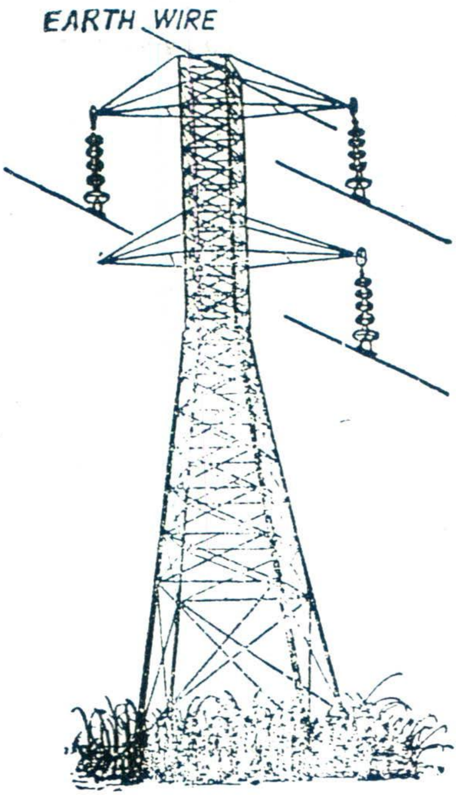
Single-phase double-circuit vertical disposition.
Fig. 8.5

(*ii*) *Three-phase circuits.* Figs. 8.6, 8.7, 8.8, 8.9 and 8.10 represent a method of three-phase transmission. In Fig. 8.6 conductors have been arranged at the corners of an equilateral triangle

In Fig. 8.7 the conductors are arranged at the corners of right-angled triangle, so that the distance between them is unequal.



Three-phase single-circuit over wooden or steel tubular poles.
Fig. 8.6



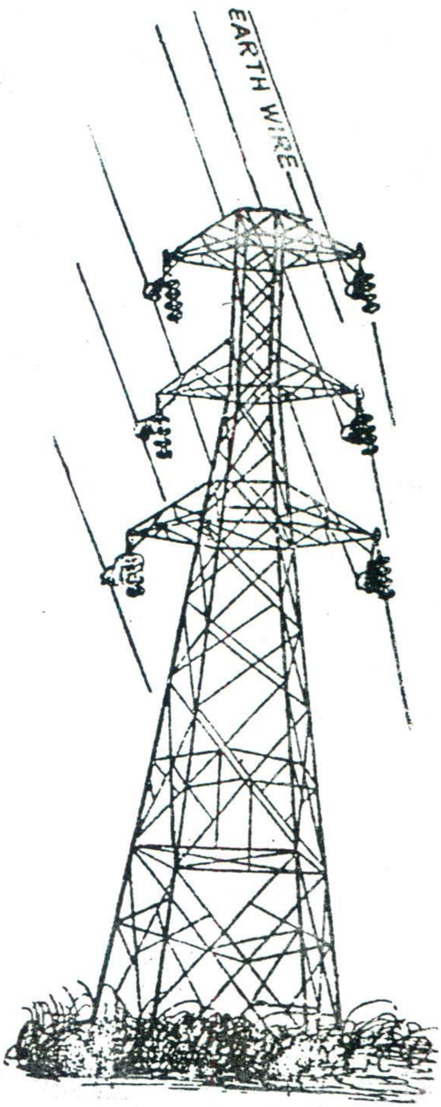
Three-phase single-circuit with unequal distance between the conductors.
Fig. 8.7

Fig. 8.8 represents the methods of transmission of electrical power by two-circuits. It represents a small tower used for medium voltage transmissions.

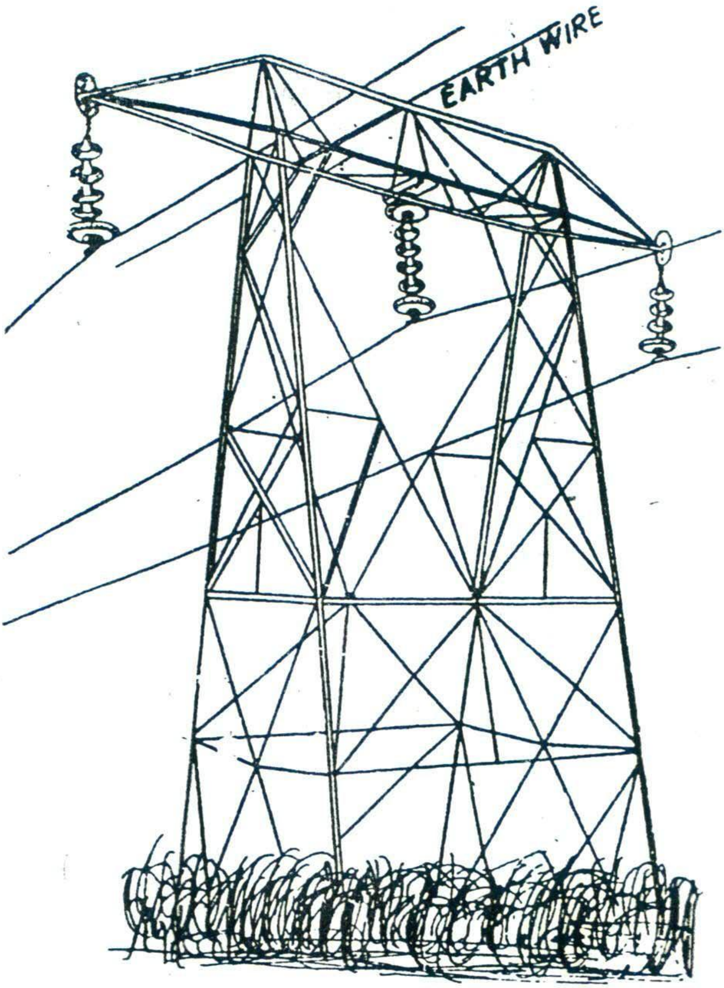
In Fig. 8.9 the conductors are arranged in a horizontal plane, and it will also result into an unequal distance between conductors.

Fig. 8.10 represents two-circuit transmission lines used for very high voltages of 132 KV or 220 KV.

Due to unequal spacing, the three conductors of the transmission line will be having unequal inductance and capacitance and thus phase will be unbalanced. This effect is overcome by transposition. Transposition of line means the position of all three conductors are mutually changed in such a way that each conductor is placed in one position for 1/3rd length of the transmission line. The transposition also avoids disturbance on the parallel running telephone lines.



Three-phase double-circuit, over steel towers for medium voltage.
Fig. 8.8

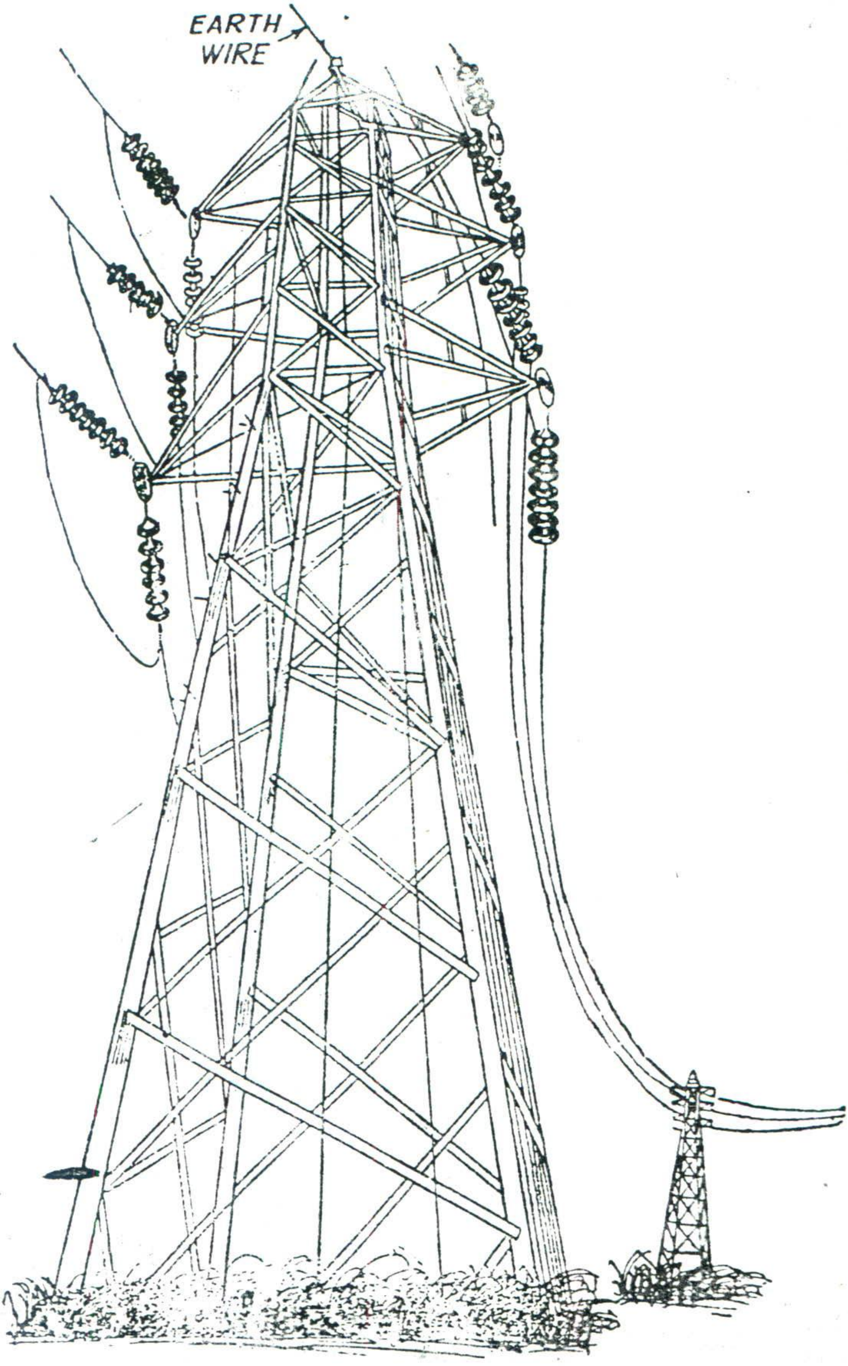


Three-phase single-circuit horizontal disposition of conductor and steel towers.
Fig. 8.9

B. Distribution lines. The following are the methods of arrangement of conductors over line supports.

(*i*) *Vertical formation.* In this formation the conductors are placed over the poles one below the other. Natural conductors is kept at the bottom. Shackle type insulators are used for this purpose.

(*ii*) *Horizontal formation.* In this formation the conductors are placed over the poles as shown in Fig. 8.6.



Three-phase double-circuit over steel towers for high voltage.
Fig. 8.10

(*iii*) In certain congested area, where it is not possible to have the minimum clearance from the building as prescribed, projected brackets of required lengths are used. Horizontal or vertical formation of conductors are made depending upon the requirement. Necessary support to projected bracket is provided with braces.

A.C. supply can be distributed by single phase distributor or three-phase four-wire distributors. The single-phase distributor has 230 volts between the phase and neutral and in three-phase four-wire distributor the voltage between two-phases will be 400V and 230V between a phase and neutral. D.C. supply can be distributed by two wire or three-wire distributors. The voltage of the line in two-wire distributor is 220V, and in three wire distributor, it is 440V.

9. Insulators. In order to prevent the flow of current to the earth from supports, the transmission lines or distribution lines are all secured to the supporting towers or poles with the help of insulators. Thus the insulators play an important part in the successful operation of the lines. The chief requirements for the insulators are :

(*i*) They must be mechanically very strong.

(*ii*) Their dielectric strength must be very high.

(*iii*) They must provide high insulation resistance to the leakage currents.

(*iv*) They must be free from internal impurities or flaws.

(*v*) They should not be porous.

(*vi*) They must be impervious to the entrance of gases or liquids into the materials.

(*vii*) They must have high ratio of puncture strength to flash over voltage.

The main cause of failure of insulators is due to flash over or puncture. The flash over may occur between the line conductor and the earth *i.e.* the pin of the insulator, and due to production of extreme heat produced by arc, the insulator may puncture.

10. Material of Insulators. Porcelain is the most common material used for insulators, but in addition to this moulded toughened glass and steatite are also used.

(*a*) **Porcelain Insulators.** The porcelain is manufactured from china clay which occurs in nature in the form of aluminium silicate. It is mixed with plastic kaolin, felspar and quartz and the mixture is heated in a kiln at a controlled temperature. The insulator so obtained must be hard, smooth, glazed and free from porosity, due to the glaze of the material its surface will be free from traces of water. The porosity of the insulator material will decrease its dielectric strength, also any impurity or air bubble left within the material will result in a lower dielectric strength.

If the insulating material is manufactured at lower temperature, its mechanical properties improve, but the material remains porous and when it is put in service it may deteriorate. If the material is manufactured at higher temperature, the porosity of it decreases but the material becomes brittle. So, a compromise is always made between the mechanical strength and the porosity of the material and a suitable temperature of the kiln is designed. A mechanically sound porcelain insulator has a dielectric strength of about 60,000 V per cm. of its thickness, and its compressive and tensile strengths are 70,000 kg./cm.^{2} and 500 kg./cm.^{2}.

(*b*) *Glass Insulators.* Many times glass is used as an insulating material. The glass is made tough by annealing and these insulators have the following *advantages* :

(*i*) They have very high dielectric strength of the order of about 140 KV per cm. of thickness of the material.

(*ii*) When properly annealed they have high resistivity.

(*iii*) They have low coefficient of thermal expansion.

(*iv*) Due to higher dielectric strength, the glass insulators have simpler design and even one-piece designs can be used.

(*v*) They have higher compressive strength than porcelain insulators.

(*vi*) They are transported, so any flaw, impurities air bubbles, cracks, impurities etc. can be easily detected.

(*vii*) They are quite homogeneous.

(*viii*) They are cheaper than porcelain.

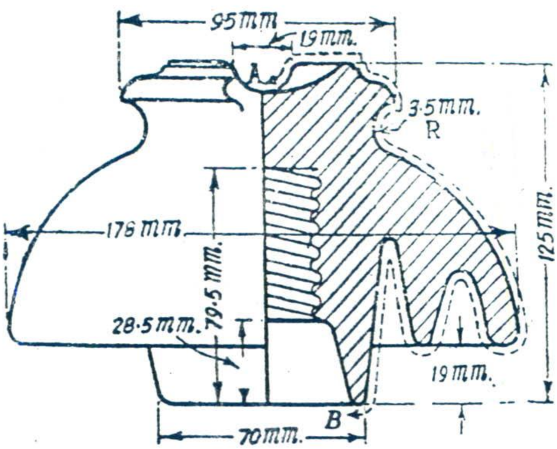
The main *disadvantages* of such type of insulators are :

(*i*) The moisture easily condenses over the surface, due to which dirt will deposit on its surface and it will help to the leakage of currents.

(*ii*) For higher voltages, the glass cannot be casted in irregular shapes, since due to irregular cooling, internal strains are caused.

(*c*) *Steatite Insulators.* The steatite is a magnesium silicate, found in various proportions of magnesium oxide and silica in many parts of the world. It has a very high tensile strength as compared to porcelain insulator, and can advantageously be used in situations where the insulator is in pure tension *i.e.* when transmission lines takes sharp turns.

11. Pin Type Insulator. It is one of the earliest designs used for supporting line conductors, since then, many changes have been made in its design, but its appearance has not changed. For lower voltages, generally one piece type of insulator is used. Fig. 8.11 represents the two one-piece insulators, and the leakage paths are shown by the dotted line *AB*. In order to increase this distance one, two, three rain sheds or petticoats are made. These rain sheds are so designed that when these insulators are wet (its outer surface is almost conducting), even then, a sufficient dry space is provided by the inner sheds.



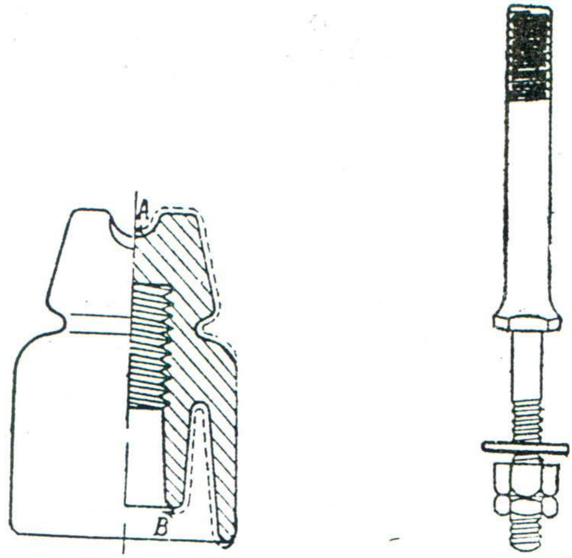
(*a*) One-piece Pin insulator for 25,000 V
Fig. 8.11

The pin insulators are screwed on and firmly attached to galvanized steel bolts shown in Fig. 8.11 (c). There are various methods of securing insulator to the bolt. They are :

(*a*) The insulator has coarse threads, and the steel bolt also has coarse threads but is provided with a soft washer at the top.

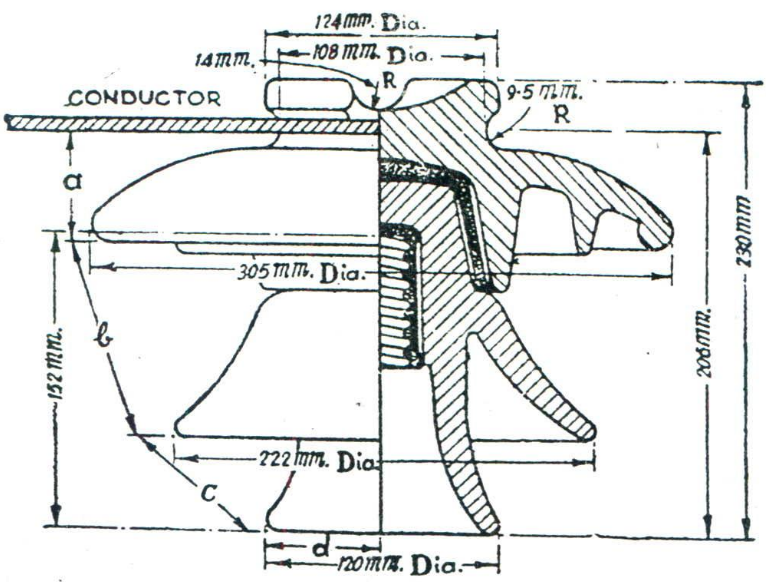
(*b*) The porcelain insulator has coarse threads but they are lined with a soft material into which the coarse steel pin is screwed. This method is generally adopted.

(*c*) Into the coarse threaded pocelain insulator is screwed, the steel bolt with a lead head.



(b) One-piece Pin insulator. (c) Galvanized Steel pin.

Fig. 8.11

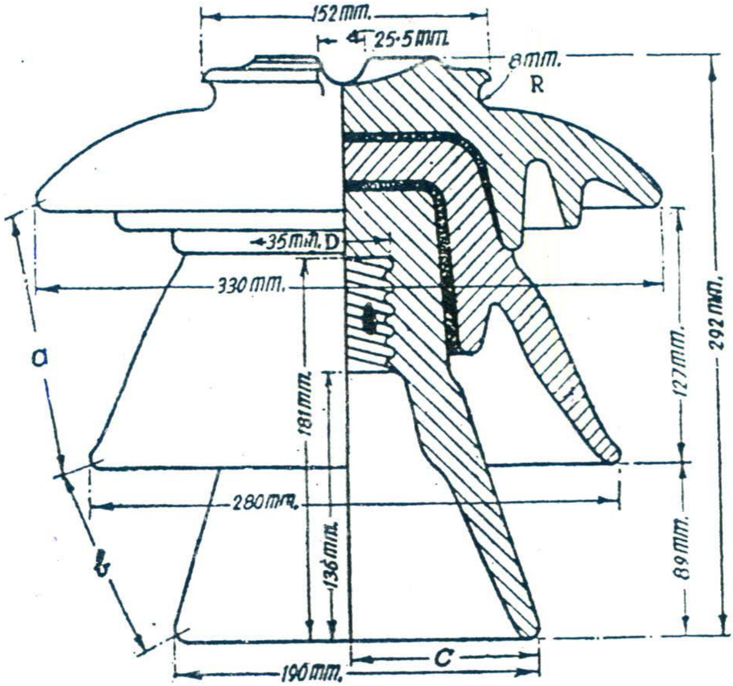


Two-part 33 KV pin insulator for 33,000 V

Fig. 8.12

Such type of insulators are used only for straight run of the lines.

For higher voltages, the thickness of the material required for insulator purposes is more, but from practical point of view a quite thick single piece insulator cannot be manufactured. Hence for higher voltages, multipart pin-type insulator can be used, which consists of a number of shells fixed together by Portland cement. Figs. 8.12 and 8.13 represent two multi-part insulators which can be used for 33 KV and 66 KV volts, the flash over distances are also represented when the insulators are dry and wet in Figs. 8.12 and 8.13 respectively.



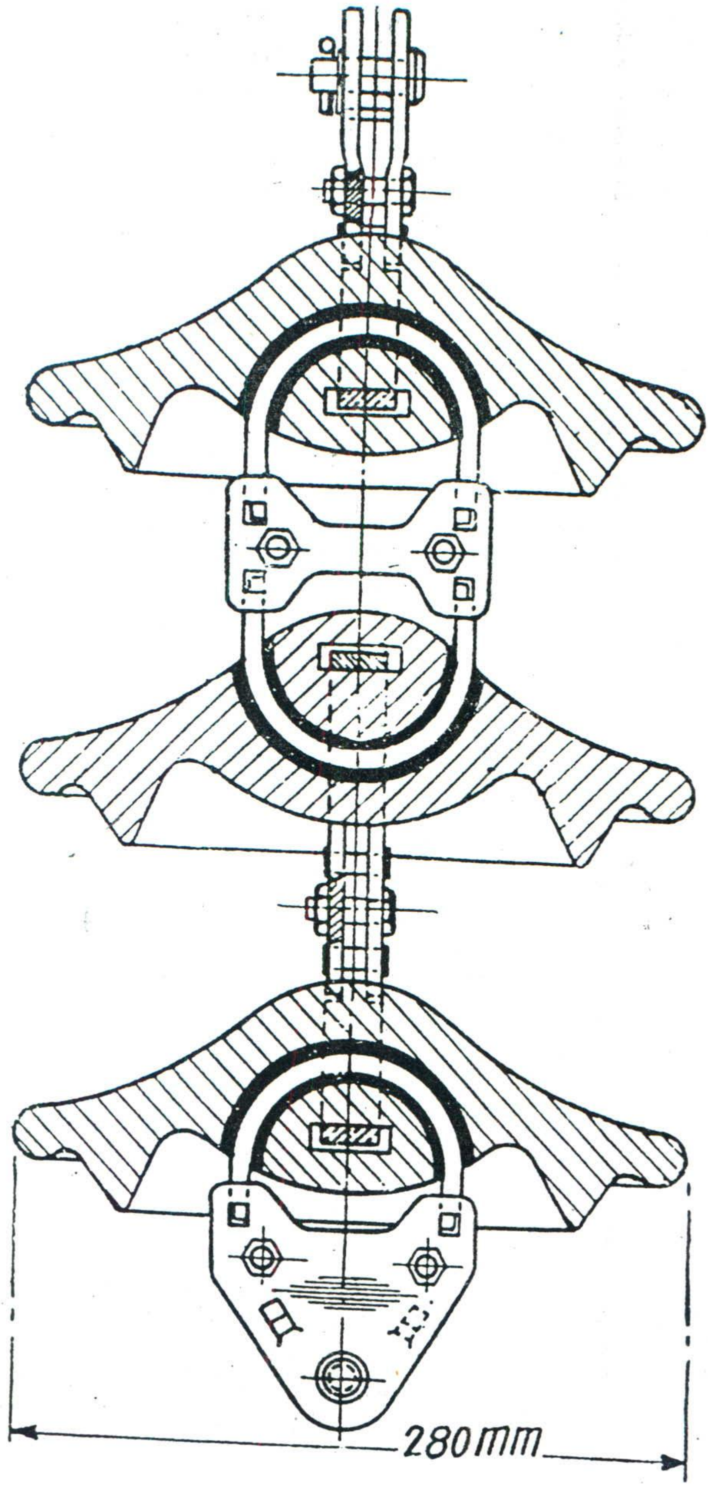
Three-part 66 V. pin in insulator for 66,000V

Fig. 8.13

12. Suspension Type Insulators. As the line voltage increases, the pin insulator to be used becomes heavy and complicated in construction, also its cost increases. Further the replacement of the damaged insulator will cost more. So, pin insulators are not an economical for higher voltages.

For higher voltages suspension insulators are used, a number of them are connected in series by metallic links to form a chain and the line conductor is carried by the bottom-most insulator. The *advantages* of such a system are :

(*i*) Each suspension insulator is designed for 11 KV, so by connecting a number of such insulators a string of insulators can be designed for any required voltage.



Hewiett Suspension Insulators

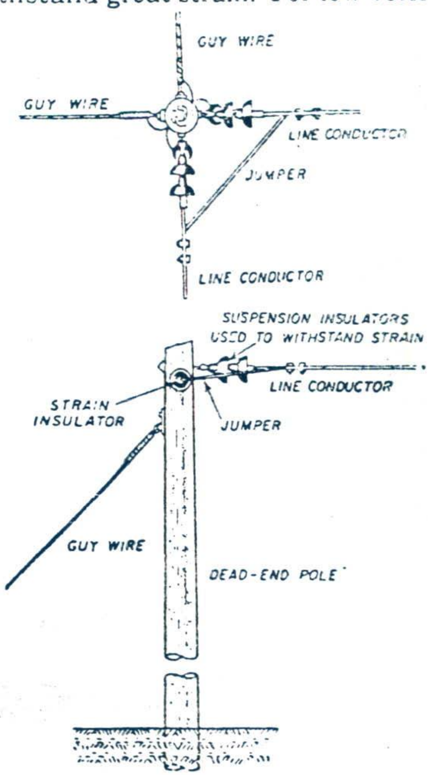
(*ii*) If any one of the insulator in the string fails, it can be replaced easily and at a lesser cost.

(*iii*) The mechanical stresses on the string decrease since the line suspended is flexible and it can oscillate a bit and it will attain that position where the stress is pure tensile.

(*iv*) When the string of the insulator is used in conjunction with the steel towers, line conductors are less effected by lightening, since the line conductors are lower than the cross arm which is earthed and acts as a lightning arrestor.

(*v*) If the load of be supplied, by the transmission lines increases, it can either be accomplished by running another parallel line which will no doubt cost more, or the potential of the existing line can be further increased by simply increasing the number of insulators in the string. Fig. 8.14 represents such type of insulator.

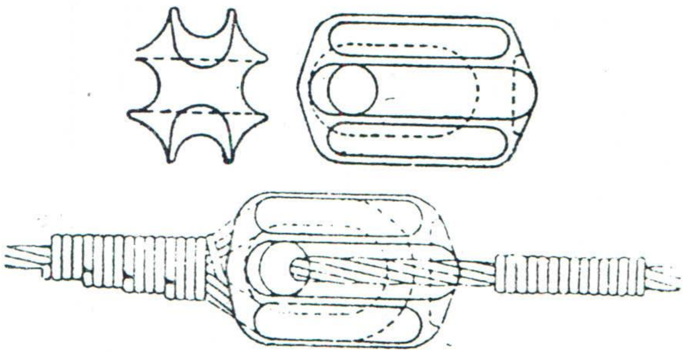
13. Strain Insulators. When there is a dead end of the line or there is a corner or a sharp curve or the lines crosses river etc., the line is to withstand great strain. For low voltage lines shackle



Suspension Insulators used as strain insulators.
Fig. 8.15

insulators can be used, but for high voltage transmission lines, strain insulator consists of an assembly of suspension insulators as shown in **Fig. 8.15.** If the pull on the string of the suspension insulators is high such as in case of long spans across the river, under these circumstances two, three of four strings of insulators are used in series. The top portion of Fig. 8.15 is the plan of the line.

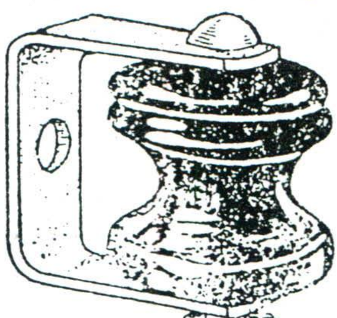
14. Stay insulators. For low voltage line, the stays are to be insulated from ground at a height not less than 3 metres from the ground. The insulator used in the stay wire is called as the stay insulator and is usually of porcelain and are so designed that in case of breakage of the insulator, the guywire will not fall to the ground. Fig. 8.16 represents the stay insulator and the method of inserting the stay into the insulator.



Stay Insulator
Fig. 8.16

15. Shackle Insulators or Spool Insulators. The shackle insulator or the spool insulator is mostly used for low voltage

Shackle insulator
(a)

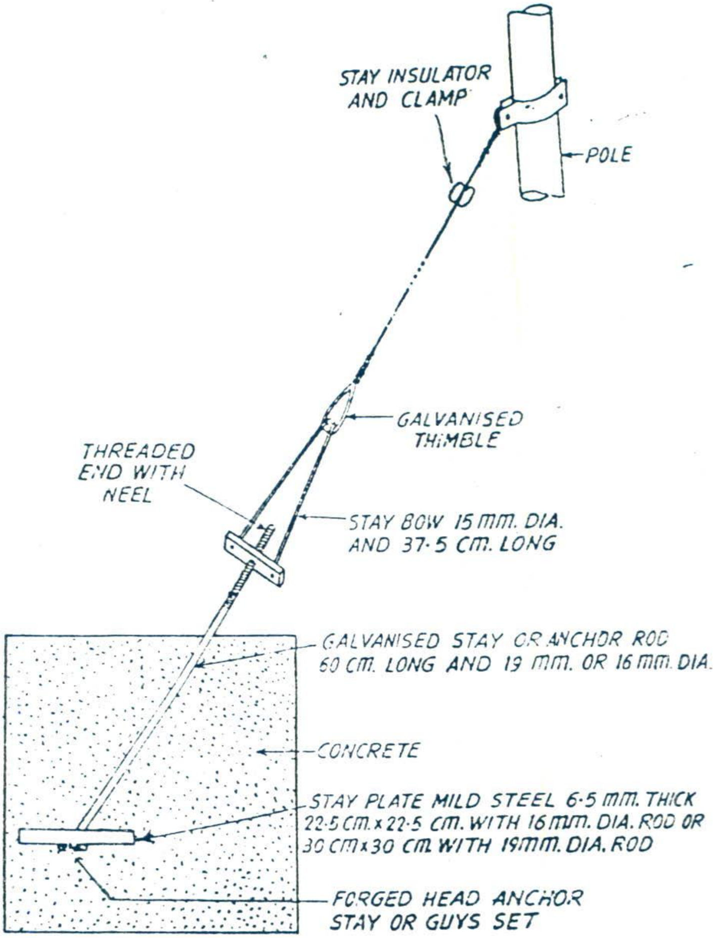


Shackle insulator mounted in a D clamp
(b)

Fig. 8.17

distribution lines. Such insulators can either be used in a horizontal position or in a vertical position. Fig. 8.17 (*a*) represents a shackle insulator, while Fig. 8.17 (*b*) represents when it is mounted in a clamp. The conductors in the groove are fixed with the help of soft binding wires.

16. Stay Set and Stay Wire or Guy wire. Fig. 8.18 represents the complete stay assembly. It consists of :



Anchor stay or guys set
Fig. 8.18

(*i*) Mild steel stay plate 6.5 mm. thick, 22.5 cm × 22.5 cm having 16 mm dia. or 30 cm × 30 cm having mm dia. pole in its centre.

(*ii*) Galvanised stay rod 60 cm. long and 16 mm or 19 mm dia.

(*iii*) Stay bow galvanised having 15 mm dia. and about 37.5 cm. length

(*iv*) Galvanised thimble.

The stay plate is embeded in the ground with concrete as shown. One end of stay rod or anchor rod is projected enough above the ground level.

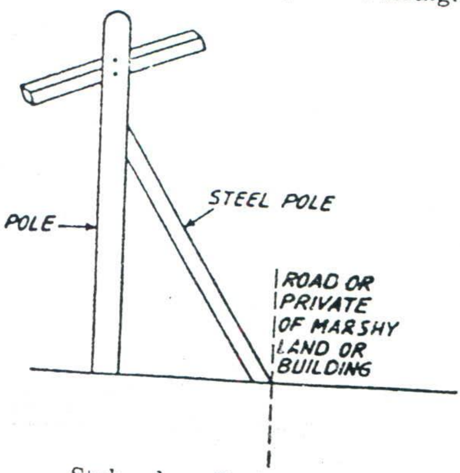
Galvanised iron stay wire having 7 or 10 strands of SWG 8 wire is connected with the stay assembly. The other end of stay wire is connected with the stay insulator and further connected to stay clamp fixed on the pole. The stay wire is twisted rigidly to provide a permanent joints at both ends.

The tension on the pole can be increased or decreased tightening or loosening the nut on the stay or anchor rod.

The stay assembly is erected in such a manner that it cancels the tension on the pole due to conductors which will be found at the terminal pole, at the angle, or where the conductor size on spans or both sides of the pole differ. *The more is the tension on the pole, the more is the angle subtended by the guy wire with the pole.* The guys or the stays represented in Fig. 8.18 are known as anchor guys or stays.

In certain places, there may not be sufficient space for the anchor stay to be inserted.. In such cases, following types of stays are provided :

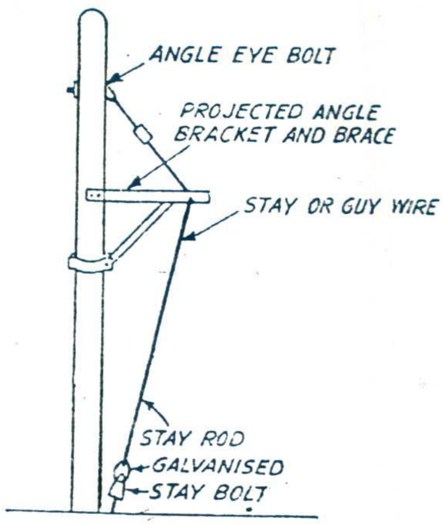
(*i*) *Sub pole or Push brace.* A pole of smaller length known as stub pole or push brace is butted with the pole as shown in Fig. 8.19. The stub or the push brace keeps the pole in straight position.



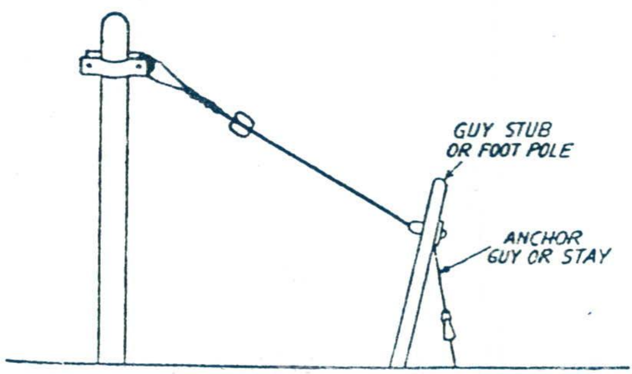
Stub pole or Push Brace
Fig. 8.19

(*ii*) *Foot or Braced angled Stay or Guy.* In this case, projected angle iron and brace is fixed with pole as shown in Fig. 8.20. By this method, the angle subtended by the guy wire at the pole is increased. This method is employed only when the tension on the pole due to conductor is small.

(*iii*) *Flying or Stub Stay or Guy.* In this case another pole across the road is erected either straight or at an angle. The minimum height of this pole above the ground should be 5.791 metres. The guy wire is fixed as shown in Fig. 8.21. It will be seen that the anchoring is done in similar way as shown in Fig. 8.18.



Foot or braced angled stays or guy
Fig. 8.20



Flying stay or stub guy
Fig. 8.21

17. Pole Fittings. It comprises of brackets, clamps, bolts etc. Each of them has been discussed separately :

(*i*) **Brackets.** *Cross-arm brackets and projected brackets are in use.*

The conductors are supported on the corss-arm brackets as shown in Figs. 8.4, 8.5 and 8.6. For wooden poles teak or sheesam wood cross-arm brackets are used. For steel and R.C.C. poles mild steel angle iron cross-arm brackets are used. The spacing of the conductors is done as given in Table 8.1. The cross-arms are supported with braces as shown in Figs. 8.4, 8.5 and 8.6.

Projected brackets and braces are shown in Fig. 8.20. These are used to (*i*) install foot or braced angle stay or guy and (*ii*) to carry overhead conductors on the pole at a prescribed distance from the building to avoid accessibility.

(*ii*) **Clamps**

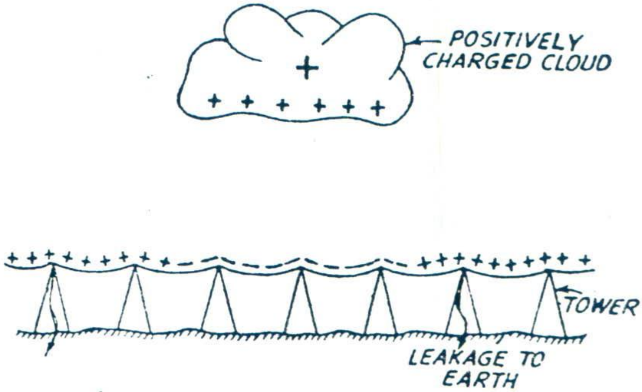
(*a*) *D clamps* are used to fix shackie insulators on the pole. These are made of mild steel flat 50 mm × 6.5 mm and are shown in Fig. 8.17 (*b*). The central hole on the clamp is to accommodate bolt for fixing it on the pole.

(*b*) *Stay clamps.* These are also made of mild steel flat 50 mm × 6.5 mm and used for fixing the stay or guy wire with the pole. Stay clamp is shown in Fig. 8.18.

(*c*) *Eye clamps.* These are used to accommodate L.T pin insulator specially on the service pole. There is also made of flat iron. Such a clamp is shown in Fig. 8.25.

(*d*) *Service bracket clamps.* These clamps are also of M.S. flat or 50 mm × 6.5 mm and are used to fix the service bracket or pipe with the wall. Such type of clamp is shown in Fig. 8.24.

18. Lightning Arrestors. Lighting arrestor is a device which protect overhead lines and other electrical apparatus *viz.*, transformer from overhead voltages and lightning. In Fig. 8.22 it will be seen that positively charged cloud will produce negative potential by electrostatic induction on the overhead line. This negative charge will however be present right under the cloud and portion of the line away from this point will be charged positively. This charge on the line will not flow, because it is a bound charge. The positive charge on the far end will however flow to earth slowly through insulators and metallic parts etc., thus leaving the negative charge on the line directly under the cloud. Now assume that due to direct discharge occurring between this cloud and passing by negative charge cloud the charge in the cloud in question is neutralised, then the charge on the line is no more bound charge and is free to travel on both directions in the form of waves. These travelling waves will be of light magnitude (10 to 15 KV) and have steep wave front which can damage the unprotected equipment connected to the line. These waves are passed to the earth quickly through lightning arrestors. The lines are protected from direct strokes of lightning by providing ground wire of sufficient mechanical strength placed in a manner shown in Figs. 8.7 and 8.8.



Static charging of the line due to a cloud.
Fig. 8.22

19. Different Types of Lighting Arrestors. Following types of lightning arrestors are used to protect the overhead lines from travelling waves of steep wave front :

1. Rod gap arrestor.
2. Sphere gap lightning arrestor.
3. Horn gap lightning arrestor.
4. Expulsion type arrestor
5. Impulse protective gap with electrolyte lightning arrestor.
6. Electrolytic type.
7. Lead oxide type.
8. Pellet type of lead peroxide type.
9. Thyrite type.
10. Valve type.

20. Miscellaneous Fittings. Following miscellaneous fittings are installed on the pole.

(*i*) *Danger plate.* On all lines above 6.6 KV, a danger plate written in the language known to the local public and indicating the voltage with danger sign is provided at 2.5 metres high above the ground on each pole.

(*ii*) *Anticlimbing Device.* On overhead lines above 6.6 KV, anticlimbing device made of barbed wire is provided on each pole. This is done to avoid climbing of unauthorised persons on the pole.

(*iii*) *Bird Guards.* On metallic poles, the isulators are fitted on the cross-arm brackets with wooden pieces of suitable size. These wooden pieces are provided to avoid short-circuiting of two phases or one phase and earth due to sitting of the birds on the pole.

21. Earthing of Overhead Lines. It has already been said that the continues earth wire from the substation is run along the line. This wire is solidly connected to the earth provided at the substation and later on every sixth pole is earthed.

All metallic parts other than conductors shall be efficiently earthed. Galvanised iron wire of 8 SWG or bigger size is used as earthing conductor. The maximum continuity resistance of the earth should not be more than 5 ohms.

Methods of earthing has been completely explained in chapter 10.

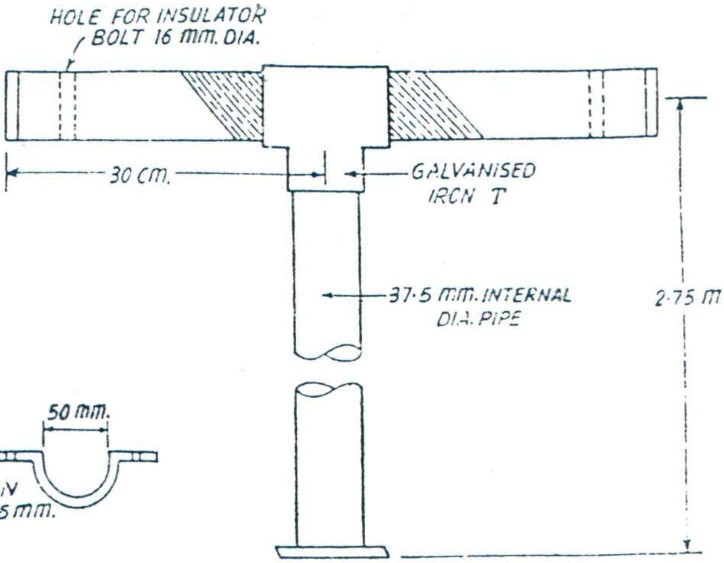
22. Service Lines. As already said that the service lines are tapped from the distributors with water proof cable of suitable size and the other rends of the water proof cable terminate in meter. The service line laid in such a way is known as Overhead Service Line.

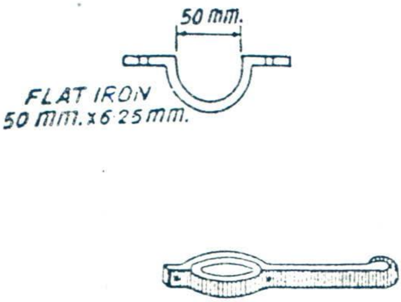
House service brackets as shown in Fig. 8.23 are used. The house service bracket are fixed with two clamps as shown in Fig. 8.24. Eye clamp is fixed on the pole on which pin-type insulators are fixed. From the conductors and neutral are brought on these insulators. Weather proof wire is tapped from these insulators and taken upto the service pole. Bobins are used to keep the weather proof span in tight position. From the insulators at the service pole VIR or lead covered cable is taken upto meter.

Sometimes in building having height more than the distributor, the service connection is given with angle iron projected bracket fixed on the wall. B-type clamps are fixed on the bracket for installing pin insulators on the bracket.

Underground cable of suitable size is also used to provide service connection, if the consumer is willing to pay the cost.

Meters of suitable size are placed at about 165 cm. above the floor level. The low tension meter can be single phase three-phase three wire, three-phase four-wire of varying capacity depending upon the requirement. In case of very high loads at high voltage, L.T. meters of smaller rating with C.T. (current transformer) and P.T. (Potential transformer) of desired ratings are used.





Clamps for fixing House Service Bracket
Fig. 8.24

House Service line Bracket
Fig. 8.23

23. Comparison between overhead system and underground system. *Following are the advantages and disadvantages of overhead system over underground system.*

Advantages :

(*i*) **Repair.** It is easy to repair the overhead line as compared to underground cable.

(*ii*) **Fault location.** The fault in overhead lines can be detected easily and quickly as compared to underground cable.

(*iii*) **Initial cost.** Overhead system has a lower cost than the underground system.

(*iv*) **Charging Current.** Due to more spacing of the conductors, the charging current is less in overhead system than the underground cable.

(*v*) **Jointing.** Jointing in underground cable is difficult and precise as compared to overhead conductors.

Disadvantages.

(*i*) **Maintenance Cost.** The maintenance cost of overhead system is more than the underground system *as there are more faults in overhead lines.*

(*ii*) **Safety.** Underground cables are buried in the ground and therefore more safer to the public.

(*iii*) **Appearance.** Overhead system produces a shabby appearance, whereas underground cables are not visible.

(*iv*) **Effect of lightning and thunderstorm.** Lightning and thunderstorm produces effect on overhead system whereas these do not produce any effect or underground cables.

(*v*) **Effect of Surge.** The surges are absorbed by the metallic sheath of underground cable and as such produce no demaging effect.

(*vi*) **Accidents.** There can be accidents by overhead lines, whereas chances are remote in underground system.

(*vii*) **Voltage drop.** The inductance in an overhead line is more because of larger spacing of conductors, therefore more voltage drop is there in an overhead line.

(*viii*) **Interference to telephone lines.** The overhead lines will interfere with the nearby telecommunication lines, where underground cables do not have any effect on them.

24. Tariffs. Consumers can be classified as "Good" and "poor". consumers are those who take regular supplies during 24 Hours or when the general demand is low. Poor consumers are those who require supplies only at times of general maximum demand (M.D.) Hence consumers must be charged according to their type of load, as well as to the number of units they consume. The following tariffs are available.

1. **Maximum-demand tariffs.** (2 part or 3 part M.D. tariffs)

(*a*) a FIXED charge based on the maximum power required.

(*b*) a MAXIMUM-DEMAND charge based on the M.D. made in each month or year.

(*c*) A Unit charge based on the number of units used.

2. **Block Tariffs :**

(*a*) First block depending on the consumers' requirements.

(*b*) Second block depending on the demand and (*c*) Third block or the lowest price encouraging long period usage, giving incentive to improve Load Factor.

3. **Special OFF PEAK tariffs :**

This encourages the usage of electricity from 7 p.m. to 7 a.m.

4. **Flat - rate tariffs :**

This is applied to domestic services. Here the charges are made per unit of consumption at a rate determined from time to time.

5. **TWO PART or ALL tariffs.**

This is also applied to domestic services. Here the charges are made flat rate per KWH plus a fixed charge per year related to requirements.

6. **Night and Day tariffs.**

This is also applicable to domestic services. This encourages large unit consumption during OFF - PEAK Hours.

A knowledge of the above is essential before the distribution system is designed since the type of supply and the tariff to be applied will affect the metering arrangements, system of distribution equipment and circuiting.

25 Protection for Domestic Installations

IER states that every consumer's instalation should be properly controlled by a switch gear in an easily accessible position. The switch gear should incorporate.

(*a*) a Means of separating the supply in the event of excess current.

(*b*) a Means of separating the supply in the event of dangerous earth leakage.

(*c*) a Means of isolation.

The following is the Table given by IEE Regulations in the 13th edition with regard to consumer's supply controls.

CONSUMER'S SUPPLY CONTROLS

System of Supply	No of poles of to be broken by circuit breaker of any type, or switch.	Position of operating coil of over load circuit breaker, or fuse.
2W, permanently and effectively earthed on one pole	2	In non-earthed conductor.
2W, not permanently and effectively earthed on either pole	2	In each Conductor.

(*Contd.*

CONSUMER'S SUPPLY CONTROLS

2W, neither pole earthed but system earthed at mid-point	2	In each Conductor.
3W, d.c. or single phase a.c.	3 or 2 provided one pole broken in each outer conductor	In each outer conductor
3W, 3 phase a.c.	3	In non earthed conductor of at least two phases for ckt. breaker or each phase for fuses.
4W, 3 phase a.c.	4 or 3 provided one pole is broken in each phase conductor.	In each phase conductor.

TYPICAL QUESTIONS

1. What are the advantages of aluminium as a conductor ?

2. How many types of Insulators are there ? Of what material these are made ?

3. Explain where the following are used :

(*i*) Pin-type insulator

(*ii*) Suspension type insulator

(*iii*) Stay insulator

4. What are the advantages of pin-type insulators and why shackle insulators are not used for high voltage ?

5. How the size of conductor is expressed ?

6. Explain why lightning arrestor is used on overhead lines.

7. How many types of lightning arrestor are there ?

8. Why stay or guy is used ?

9. Explain the various parts of stay guy set ?

10. What are the most common types of stays ?

11. What should be the vertical clearance of the conductor above the building and horizontal clearance from the building ?

12. Why flying, foot stays and stubs are used ?

13. How service connections to the consumers are given from the distributor ?

14. Why poles of overhead lines are earthed ?

15. What are the advantages and disadvantages of overhead system over underground system ?

16. In how many different ways service connection is given ?
17. How the conductors are arranged in an overhead line ?
18. Compare D.C. and A.C. system of supply.
19. Explain why it is necessary to transmit the electrical power ?
20. What are the essential components of an overhead line ?
21. Explain about different types of tariffs.

9

Underground Cables and Installation

1. Introduction. 2. Cable insulation. 3. Material used for different class of Insulating Material. 4. Characteristics of some Insulating materials in Cables. 5. Different types of cables and Their Application. 6. Underground Cables. 7. General Information about Cables. 8. Types of 3-phase Cables. 9. Cable laying. 10. Grading of Cables. 11. Measurement of Insulation resistance of Cables. 12. Cable jointing. 13. Filling compound in the sleeve. 14. Jointing a multicore cable.

1. **Introduction.** Underground cables are being mostly utilised for transmission and distribution of electrical energy. In certain posh colonies, the consumers desire service connection by underground cables because of the reason that such a connection does not spoil the beauty of their construction. In addition, for certain loads *viz.* air-field, thickly populated areas etc. it is necessary to use underground cable for distribution, transmission and service connections. Aluminium conductor underground cables are being used in India. Thus the underground cable can be specified by number of cores, voltage they can withstand or type of insulation.

2. **Cable Insulation.** The cables are usually classified according to the type of insulation used. The type of insulation to be used must have the following properties :

(1) It should have high specific resistance.

(2) It should be tough and flexible.

(3) It should not be hygroscopic.

(4) It should be capable of standing high temperatures without much deterioration.

(5) It should be non–inflammable.

(6) It should not be attacked by acids or alkalies.

(7) It should not be capable of withstanding high rupturing voltages.

(8) It should have low viscosity at working temperature (solid cable only)

(9) It should have low water absorption.

(10) It should have low permittivity.

(11) It should have high viscosity at impregnation temperature.

(12) It should have high mechanical strength.

(13) The insulation provided should be of such thickness that it may give high degree of safety and reliability at the working voltage for which is designed.

Although it is not possible to have all the above-mentioned qualities in one particular type of insulation, the selection of a particular type of insulation to be used is dependent upon the purpose for which the cable is required and qualities of the insulation to be aimed at. The following are the chief types of insulation groups which can be used :

(*i*) Rubber.

(*ii*) Fibrous material, such as paper or jute etc.

(*iii*) Vulcanized bitumen.

(*iv*) Gutta percha.

(*v*) Silk, cotton, enamel.

(*i*) *Rubber.* Rubber is the most commonly used insulation in cables. Rubber has a dielectric constant between 2 and 3, dielectric stress is 350 KV/cm. approximately, and specific resistance of $10^{17}\Omega$/cm cube. It absorbs moisture slightly and the maximum safe temperature is approximately 100°F. So the pure rubber cannot be used as an insulation since it cannot withstand high temperatures and cannot be up to rough usage, being too soft. Thus mostly the rubber used as an insulation on wires consists of 20 to 40 per cent of India rubber, the remainder being mineral matter such as zinc oxide, red lead etc. ; also a little bit of sulphur is added. The method of applying insulation is as given below.

First the rubber is washed and is then mixed with mineral matters by means of working through heated rollers, until it is plastic. Then the compound so formed is rolled out into thin sheets and cut into strips. On small wires, the rubber compound is applied by passing it through a die at the centre of which there is a copper or aluminium conductor. For large wires the insulation is usually applied parallel to the wire and is pressed hard into the ground rollers. After the insulation is applied, it is vulcanized at a temperature of 100°F. It is usually done by enclosing it in steel drums and introducing steam into it at a pressure of 25 lb. per square inch. The process makes the sulphur to combine chemically with the rubber, which changes the rubber from plastic state to firmness. If the rubber used in cables is of good quality and is kept dry and cool, longer life can be expected ; but when it is exposed to air it becomes brittle.

If vulcanized rubber is used as an insulation it becomes much stronger, more durable, can withstand high temperatures and remains more elastic than pure rubber. But the drawback in using vulcanized rubber insulation is that it attacks copper. So before using vulcanized rubber as an insulation, the copper conductor must be tinned well. If the conductor is not tinned well, it will become black or the vulcanized rubber insulation will change its colour ; such cables should be rejected. Sometimes the tinned copper conductor is given coating of pure rubber first as it retards the blackening of tinned copper conductor or discoloration of rubber insulation but does not fully prevent it. Sometimes vulcanized insulation is covered with one or two braids of cotton which are thoroughly filled with weather proof compound.

(*ii*) *Paper.* The paper insulation in power cable has almost superseded the rubber insulation. The foremost reason of this is that it is quite cheap and has a low capacitance and high dielectric strength. It is hygroscopic and its specific resistance is of the order of 10^9 Ω/cm, cube but it much depends upon its dryness, a small amount of moisture lowers its insulation resistance. So before using paper as an insulation, it is impregnated in an insulating oil. The maximum safe temperatures of paper-insulated cable is 200°F approx. The paper-insulated cables should never be left unsealed, or its ends should temporarily be covered with wax or tar.

The compound usually used for the impregnation purposes is a high grade mineral oil mixed with resin, the actual proportions of oil and resin depending upon the particular manufacturer.

Paper insulated cables are used for conveying large blocks of power in transmission and distribution and particularly for distribution at low voltage in congested areas where the joints are to be provided only at the terminal apparatus or where the joints are rare, owing to cheapness and durability over V.I.R. cables.

(*iii*) *Vulcanized Bitumen.* It is much cheaper than rubber. It resists corrosion due to gases, fumes and water. Its specific resistance is 1×10^{14} per cm. cube. It is not affected by moisture. The main drawback of it is that it cannot withstand temperatures more than 120°F. And after this temperature it becomes soft and the cable conductors sink down and thus there will be every danger of short circuit. Only vulcanized bitumen has got such properties. If natural bitumen is used, it is quickly softened by alkaline water and coal gas.

Another important point which is worth mentioning is that it is not attacked by rats.

(iv) Varnished Cambric (or Empire tape). When a cotton cloth is impregnated and coated with varnish, it is known as Empira tape. It has very smooth surface. The cambric is lapped in the form of tape on to the conductor and its surfaces are coated with petroleum jolly compound to give easy sliding of the surfaces. Such cables require protective covering like lead sheath because this insulating material is hygroscopic. Its dielectric constant is 2.5 to 3.8. Such cables do not require scaling.

(v) Polyvinyl chloride (P.V.C.) : This is one of the synthetic compounds. For obtaining this material as a cable dielectric or sheathing, it is processed with certain materials known as plasticizer and its type will depend upon the use of finished product as P.V.C. It is inert to oxygen, oils and to many alkalies and acids and therefore its use preferred over V.I.R. in extreme environments, such as in cement or chemical factory. The mechanical properties (*i.e.* elasticity) of P.V.C. are not so good as those of rubber. P.V.C. insulated cables are mostly used for low and medium voltage domestic and industrial lights and power installations in these days.

(vi) Gutta percha. It is much similar to rubber, but it becomes soft at about 150°F. Its resistance/cm. cube is 6 to 25×10^6 ohm. It becomes brittle in air. It does not absorb moisture. It cannot withstand even medium voltages. It is mostly used for submarine cables for telegraphic or telephone purposes. The jointing of gutta-percha cables is a special art.

(vii) Silk and Cotton. This insulation is used on conductors required for low voltage. The conductor may have a single layer or double layer covering according to the type of work for which the wires are required. Mostly cotton or silk covered wires are used for instrument and motor winding.

(viii) Enamel insulation. Again the enamelled wires are used for similar purpose as silk and cotton, but enamel is cheaper than cotton or silk although it is more liable to crack.

(ix) Asbestos insulation. It is fire-proof and has a specific resistance of 1.6×10^5 Ω/cm. cube but it absorbs moisture. Moreover it will act as a wick for oil in case of switchboard fires.

3. Material used for Different Class of Insulating Materials.

Type	Temp. allowable	Materials
class O or class Y	90°	Organic material, such as cotton, silk or paper etc. (non–impregnated)
Class A	105°	Organic material such as cotton, silk or paper etc. (impregnated, with varnish or enamel)
Class E	120°	Synthetic - resin enamels, cotton and paper laminates with formal dehyde bonding.
Class B	130°	Inorgaic material such as mica, fibre glass, asbestos held together by an organic binder.
Class F	155°	Inorganic materials like mica, fibre glass etc., with more thermally resistant binding materials.
Class H	200°	Inorganic materials such as mica, fibre glass, asbestos held together with a silicone substance as a binder.
Class C	Above 200°	Only inorganic materials such as mica, glass or porcelain.

4. Characteristics of Some Insulating Materials in Cables

Sl. No.	Name of Insulation	BDV KV/mm	Dielectric Constant	Maxm. Temp.	Remarks
1.	Paper Impregnated	20 to 30	3.6	50° to 80°C	The compounds used are paraffine or Naphthenic mineral oil or resin
2.	Vulcanised India Rubber (VIR)	10 to 20	2.5	48°C	By adding with talc, zinc oxide and sulphur, the dielectric constant improves to 6%
3.	a) Varnished cambric	4	2.5 to 3.8	80°C	Not Water proof
	b) Varnished Terylene	4	2.5 to 3.8	120°C	Not Water proof
4.	Plastic	2.0 to 3.0	0.8 to 1.2	Ambi-temp.	Elasticity and Recovery from stretching good. Advantages : Inert to Oxygen, oils and many alkalis. To be used for temporary lighting, P.A. system.
5.	Poly Vinyal Chloride (PVC)	14	6 to 8	160°C	Long life, elegant look, can be wired on wooden reapers or run in conduits.

Sl. No.	Name of Insulation	BDV KV/mm	Dielectirc Constant	Maxm. Temp.	Remarks
6.	Silicone Rubber or Ethelene Proplene (EP) or Butyl	1.2 to 3.0	3.6 to 9.0	175°C	Chains of alternate Silicone and Oxygen atoms Flexibility of Operation, –90° to + 250°C, **Adv:** Good Resistance to oils, ozone and water. **Disadv:** Poor resistance to acids, alkalis.
7.	Tough Rubber Sheathed (pvc) or Cab Tyre sheathed (CTS), Armoured PVC insulated	10 to 30	2.7 to 4.0	70°C	Long Life > 15 years. Can be wired and clipped directly in wooden reapers or run in conduits. Normally used for lighting schemes only. To be used continuously for less than at 2/3, maxm. temp. cotninuously.
8.	Weather Proof (W.P)	10 to 30	2.7 to 4.0	70° C	Over the Tough rubber, cotton is braided in one or two layers to withstand all weather conditions. Used in O.H. service lines, for extention of temporay lines etc.
9.	Cross Linked Polyethylene	22	2.55	90° (Cont.) 250° C (Inter)	Higher current rating, higher overload capacity, higher short circuit current rating, higher in weight, smaller bending radius, easier jointing and termination. **Application :** 1. Corrosive environments such as fertiliser, chemical industries, industries near sea shore. 2. Heavy Industries steel rolling mills, Aluminium preparing industries, driving piles for foundation. 3. Power stations, sub stations and city power distribution.

5. Different types of Cables and Their Applications.

Sl. No.	Name of cable	I S I std.	Voltage Rating	Application
1.	Rubber insulated solid and flexible	434—1964	upto 600 V	Power and Lighting
2.	PVC insulated cables and Flexible cords. (sheathed and unsheathed)	694—1964 part - II	250/440 V 650/1100 V	-do-
3.	Polythene insulated cables, sheathed with PVC, Polythen insuleted, taped, Braided	1596 & 3035—1964	-do-	-do-
4.	Wire Armoured paper Insulated	3961—1967	upto 11 KV	Mines.
5	Cables and Flexible cords insulated with varnished cambric and heat resisting, fibre glass	693—1965	upto 6 KV	Chemical, Ferti-liser plants, cement factories, textile machines, heating cham-bers Hot plates
6.	Trailing cables	1. 4817—1968 2. 2593—1964 3. 691—1966	upto 11 V	Mines
7.	Silicone Rubber (SR) or Ethylene Pro-plene (EP) insulated cables and flexible cords	434—1964 3961—1697	upto 1000 V	Large power
8.	Mineral insulated cables	—	upto 600 V	Power and Lighting
9.	Armoured PVC insulated cables	3961—1967	upto 1100 V	Small power transmission
10.	Aluminium sheathed cables	3961—1967	upto 22 KV	Medium Power transmisson

(Contd.)

Sl. No.	Name of cable	I S I std.	Voltage Rating	Application
11.	Lead or Lead alloy sheathed cable	3961—1967	upto 33 KV	-do-
12.	Vulcanised India Rubber (VIR)	3961—1964	upto 600 V	Small powr and Lighting.
13.	Tough Rubber Sheathed (TRS)	434—1964 part I & II	upto 600 V	upto 2 HP & Lighting upto a few KW
14.	Flame proof compound, High speed oil soaked (HSOS) cable. Asbestos Covered Heat resistance, Flame proof cable.	3035—1964	upto 6.6 KV	Mines, chemical plants, Refractory Kilns, Ovens, carbon arc lamps, Heating chambers, etc.

6. Underground cables. The power from the generating stations can be transmitted either by overhead lines or by cables placed underground. Although underground system is costlier and maintenance is difficult, still the system of transmitting the power with cables is preferred in thickly populated areas and in cities. The cables are usually classified according to the voltage for which they are manufactured. According to the voltage they can be classified .

(1) L.T. (Low Tension Cables) up to 1000 volts.

(2) H.T. (High Tension Cables) up to 22 kv.

(3) S.T. (Super Tension Cables) from 22,000 volts to 33,000 volts.

(4) E.H.T. cables from 33,000 to 66,000 volts

(5) Oil-filled and Pressure and Gas Pressure Cables for 66,000 volts to 132,000 volts.

The general construction of the cables is given below :

(*a*) *Core.* All cables have one centre core or a number of cores, of stranded copper conductors having highest conductivity. Generally there are one, two, three, three and half or four cores.

(*b*) *Insulation.* The different insulations used to insulate the conductors are paper, varnished cambric and vulcanized bitumen for low voltages. But mostly impregnated paper is used which is an excellent insulating material. When varnished cambric is used as a

(c) *Metallic Sheath.* A metallic sheath is provided over the insulation so as to prevent the entry of the moisture into the insulating material. The metallic sheath is usually of lead or lead alloy.

(d) *Bedding.* Over the metallic sheath comes a layer of bedding, which consists of paper tape compounded with a fibrous material. Also sometimes, jute strands or hessian tape (Strong coarse cloth of hemp or jute) is also used for bedding. The purpose of providing the bedding is to protect the metallic sheath from mechanical injury from the armouring.

(e) *Armouring.* Armouring is provided to avoid mechanical injury to the cable and it consists of providing one or two layers of galvanised steel wires or two layers of steel tape.

(f) *Serving.* Over and above armouring fibrous material is again provided which is similar to that of bedding but is called as serving.

7. General Information about Cables

(a) **Core Identification :**

Cores are identified by colour of PVC insulation :

(1) 1 core — Red, Black, Yellow, Blue.

(2) 2 core — Red and Black.

(3) 3 core — Red, Yellow, Blue.

(4) $3\frac{1}{2}$ core — Reduced neutral core is black.

(5) 4 core — Red, Yellow, Blue and Black.

(6) 5 core — Red, Yellow, Blue, Black & Grey.

(7) 6 core & above — Two adjacent cores (counting direction), in each layer. Blue & Yellow - remaining cores Grey.

(b) **Cables Code :**

The following code letters are used for designation of cables :

A → Aluminium conductor (if the type does NOT contain the letter 'A' in the beginning, then the cable is copper conductor.

Y → At first or second place in type designation, it stands for PVC insulation.

W → Steel round wire armour.

WW → Steel double round wire armour.

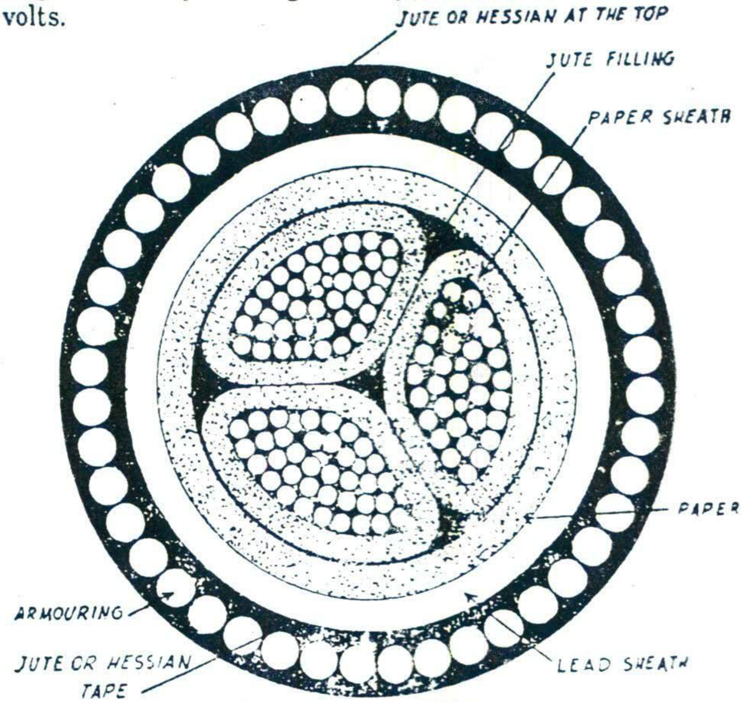
FF → Steel Double Flat strip armour.

Y → When last, in type designation, it stands for PVC outer sheath.

Mfl → Flat cables, sheathed.

8. Types of 3-phase cables. The following are the types of 3-phase cables.

(1) *Belted Cables.* Fig. 9.1 represents the 3-core belted cables in which case each of the conductor is insulated from the other with impregnated paper. Surrounding the three conductors is again provided a belt of paper and the intersticks between them is filled with fibrous insulating material. In such cables each core may have conductors of different diameters so arranged as to form a sector shape in order to avoid the undue wastes space in cable. Over-belt is provided over a metallic sheath than a layer of braiding, armouring and finally serving. Such type of cables are used upto 11000 volts.



Belted type cable.

Fig. 9.1

(2) *Super Tension Cables.* The belted type constructed cable is not suitable for the voltages above 22 KV because of development of both the radial and tangential stresses. The tangential stresses act along the insulation. The dielectric strength of the impregnated paper is much higher across the layers than along the layers. The leakage current on account of tangential stresses along the impregnated paper insulation causes power loss at the centre filling and local heating resulting in breakdown at any moment. Further owing to non-homogenity of dielectric in belted construction, when

cables are loaded and unloaded some portions of the dielectric are stressed less whereas some portions are over stressed resulting in formation of vacuous spaces and voids. These vacuous spaces are ionised when voltage is applied and ultimately deteriorate the cable insulation. The above drawbacks have been overcome in the screened cables where leakage currents are conducted to earth through metallic sheaths.

(*a*) *H-Type Cable* (Fig. 9.2). The H-Type of cable has of belt insulation, each of the conductor is insulated with paper to the desired thickness and over this is provided a layer of metallized paper, perforated to facilitate the process of impregnation. The fibrous material in the centre and along the filler spaces gives the round shape to the cable. Over this comes the copper woven tape so that the lead sheath, the binder of the metallized foil, are all at earth potential. Then layers of braiding, armouring and serving are provided as in the previous case. These cables an used upto 66000 volts.

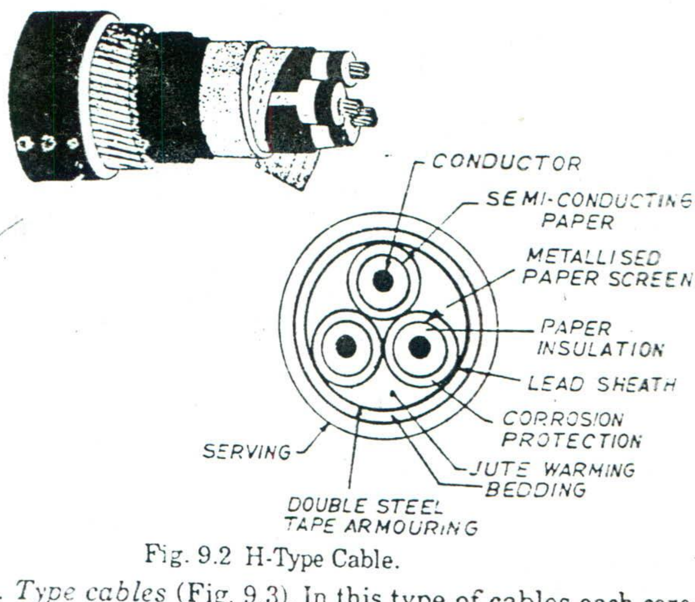


Fig. 9.2 H-Type Cable.

(*b*) *S.L. Type cables* (Fig. 9.3). In this type of cables each core is first insulated with an impregnated paper and then each of them, is separately lead sheathed. Now the three cores are just equivalent to three separate cables, each having its own lead sheath. The three cables are laid up with fillers, armoured and served overall with impregnated hessian tape as usual. The surrounding of all the three cores are provided with lead sheaths.

The advantages of S.L. type cables over H-type cables are :

(*i*) Owing to no overall lead sheath, bending of cable becomes possible.

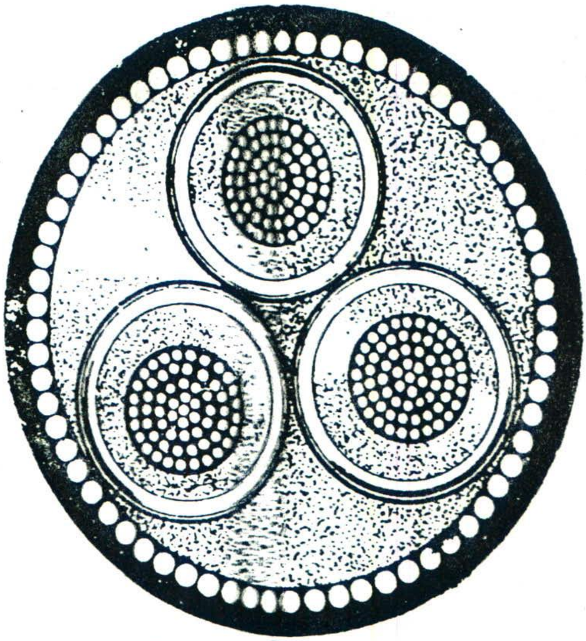
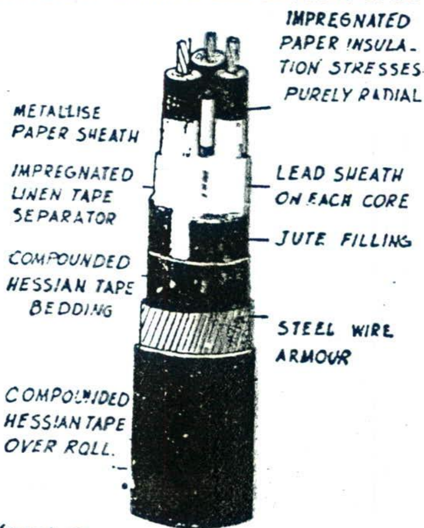


Fig. 9.3 S.L. type cable.

(*ii*) Owing to elimination of filler spaces containing compound, there is less tendency for oil drainage on hilly routes.

The drawback of S.L. type cable is that the manufacturing is difficult on account of thinner lead sheaths to be used in this cable.



'HSL' Type Cable for Supertension power transmission.

Fig. 9.4.

S.L. type cables can be used upto 66 K V

(c) *H.S.L. Cable* (Fig. 9.4). Such a cables is a combination of H-type and S.L. type cables in which each conductor is insulated, sheathed with metallized paper and is then lead sheathed. The three cores are than laid up and provided with filler, braided, armoured and finally served.

In addition to the above types of cables there are oil-filled cables.

Advantages of screened types of cables over Belted type cables

(*i*) Possibility of core to core faults is reduced to some extent in the metal sheathed core cable on account of having a greater core to core thickness for a given overall diameter than a plain cable.

(*ii*) Electric stresses are uniformly radial in all sections of the dielectric to be used in the metal sheathed core cable.

(*iii*) Possibility of formation of voids within the electric field is not there as there is no warming or packing in the electric field and dielectric subjected to electric stress is only paper which is quite homogenous.

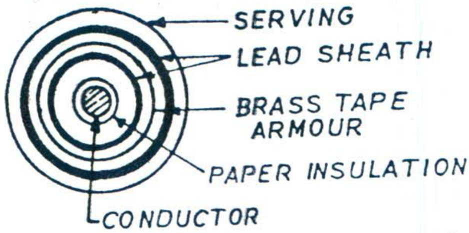
(*iv*) The current carrying capacity of the cables in increased because the metal sheaths help in dissipation of heat.

Extra High Tension Cables.

To overcome the drawbacks of belted cables and super tension cables, the manufacturing of extra High Tension Cables in done. Such cables meet the demand for 132 KV and above. In these cables, voids have been eliminated by increasing the pressure of the compound and that is why these cables are also known as **Pressure Cables.** These are of two types :

(*a*) Oil Filled cables (*b*) gas pressure or compression cables.

(*a*) **Oil Filled Cables.** A single core oil filled cable is shown in the Fig. In this cable, a channel is formed at the centre of the core by stranding the conductor wire around a hollow cylindrical steel spiral. The channel is filled with thin oil by means of oil reservoirs and feeding tanks, placed about every 600 metres along its length and maintained at a pressure, not below atmospheric one at any point along the cable. The oil used is the light mineral oil of low viscosity as used for initial impregnation. The system is designed in such a way that when the oil gets expanded due to increase in temperature of cable, the extra oil is collected in the external reservoir, the same is sent back during contraction when the temperature falls down during light load conditions. Such cables are known as single core conductor channel cables.



Single core conductor channel oil filled cable.
Fig. 9.5

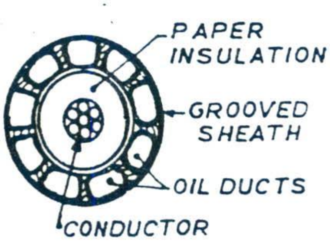
Disadvantages

It has complicated system of jointing as to the fact that the channel is at middle of the cable and is at full voltage with respect to earth.

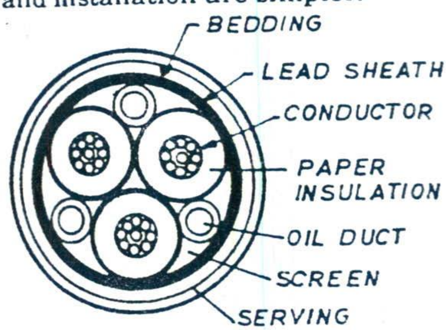
Advantage

It is advantageous from the point of view of potential gradient due to larger diameter of conductor and its hallow construction.

The other type of single core oil filled cable is sheath channel cable. In this type of cables, the oil channel are produced either by grooving the sheath or by arranging spaces between the dielectric and lead sheath. In this cable, since the channels are at earth potential, so system of joints and installation are simpler.



Single core sheath channel oil filled cable
Fig. 9.6



Three core Filler space channel oil Filled cable
Fig. 9.7

In 3 core oil filled cables, the oil ducts are accommodated in the hollow filler spaces. The fillers are made of perforated metal ribbon tubing and are at earth potential. At the time of jointing the cable, great care is to be taken.

Single core oil filled cables can be used upto 1,32000 volts and three core oil filled cables can be used upto 66000 volts.

Advantages of oil filled cables

(*i*) Due to reduction in the thickness of dielectric to be used, the cable can be manufactured smaller in size and in reduced weight.

(*ii*) There is no oxidation, formation of voids and no ionisation.

(*iii*) There is possibility of increased temperature range in service.

(*iv*) It has perfect impregnation than others

(*v*) Due to reduction in thickness of dielectric to be used, the cable has smaller thermal resistance.

(*vi*) There is possibility of impregnation even after sheathing.

(*vii*) The cable can bear more stresses.

(*viii*) Fault can be located easily due to leakage of oil, if anywhere.

Disadvantages of oil Filled Cables

(*i*) The cable is more costly than that of others.

(*ii*) Maintenance of the cables is difficult.

(*iii*) Laying of cable is complicated.

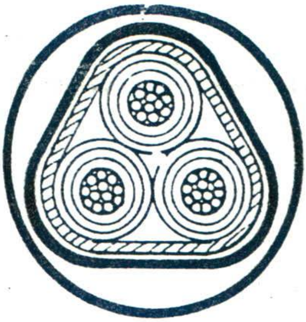
(*b*) **Gas Pressure Cables**

These are of two types :

(*i*) External Pressure cable (*ii*) Gas Filled cables

(*i*) *External Pressure Cables.* When the oil filled type cables are developed for the highest voltages, they are known as external pressure cables. In such a cable the pressure is applied externally and raised to such an extent that no ionisation can take place. Due to increased pressure in the cable, the radial compression tend to close any voids. The power factor of such a cable is also improved.

The external pressure cables are similar in construction to that of ordinary solid type except it is triangular instead of 75% circular in section. The triangular section reduces the weight and gives low thermal resistance. The lead sheath acts as a pressure membrane. The cable is armoured with a thin metal tape so that the formation of any abnormal ties over its surface is avoided. The cable is laid in a steel pipe of some larger section. The pipe is filled with nitrogen at a atmospheric pressure from 12 to 15 which continually compressed the cable radially from outside and any voids etc. if any, are closed. To avoid corrosion effect on the pipes, they are coated with a special paint and it is further protected with an impregnated felt.



External Pressure Cables
Fig. 9.8

Such cables can carry 1.5 times the load current, double the operating voltage than that of a normal cable and thus transmit 3 times power. The steel pipes provide mechanical protection to the cables. The nitrogen in steel pipes help in quenching any flame. The maximum potential gradient is 10 KV/mm. and the dielectric power factor at 15°C is 0.6%·The disadvantage of these cables is that they are costly one.

(*ii*) *Internal Pressure Cables.* These are of 3 types.

(*a*) High pressure gas filled cables

(*b*) Gas cushion cables

(*c*) Impregnated pressure cables.

In high pressure cables, spaces are provided in the dielectric itself for the gas like nitrogen at a atmospheric pressure of about 12 for super voltage cables and about 6 atmospheric pressure for extra high tension cables. Pressure is retained by means of a lead sheath in a single core cables, having a diametral clearance of about 0.63 mm.

In case of multi-core cables, this clearance is not essential, the filler spaces and strands providing a sufficiently low resistance path for the flow of gas.

In gas cushion cable, screened space is provided all along the length of cable, in between the lead sheath and the dielectric. The inert gas is stored at various points along the run of a cable. This facilitates the jointing of cable without loosing gas from the entire cable. No arrangement is required for the transmission of pressure to the cables from outside. So the cable is a complete unit with its own armouring, and no external pipe protection is required.

Impregnated pressure cable is similar to solid cable except tha such a cable consists of a mass-impregnated paper dielectric an this is maintained under a atmospheric pressure of 14 by means o Nitrogen. Special reinforcement is provided in the form of metalli tapes to cater for the large hoop and longitudinal stresses set up.

The advantages of the internal pressure cables are :

(1) The cable can be used for vertical run without any fear of damage with suitable design.

(2) Due to increase pressure, there is an improvement in the power factor of the cable dielectric.

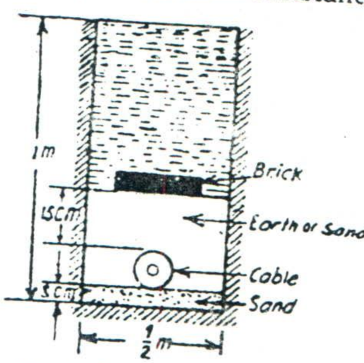
(3) There is no need of wiring any external accessories.

9. Cable Laying. Before laying cable under the ground its route should be surveyed and the position of water mains or drains etc. should be ascertained.

The cable to be buried underground must have the following properties :

(1) The moisture of the soil should not enter the core of the cable.

(2) It must have high insulation resistance.



Method for laying the cable
Fig. 9.9

(3) It should be able to withstand the heat produced due to flow of current

(4) It should not be capable of being damaged while handling or laying in the ground ; so due to this reason armoured cables are usually used.

(5) It should be sufficiently flexible.

(6) It should not be bulky.

(7) It should not be costly.

The following are the different methods of laying the cable underground :

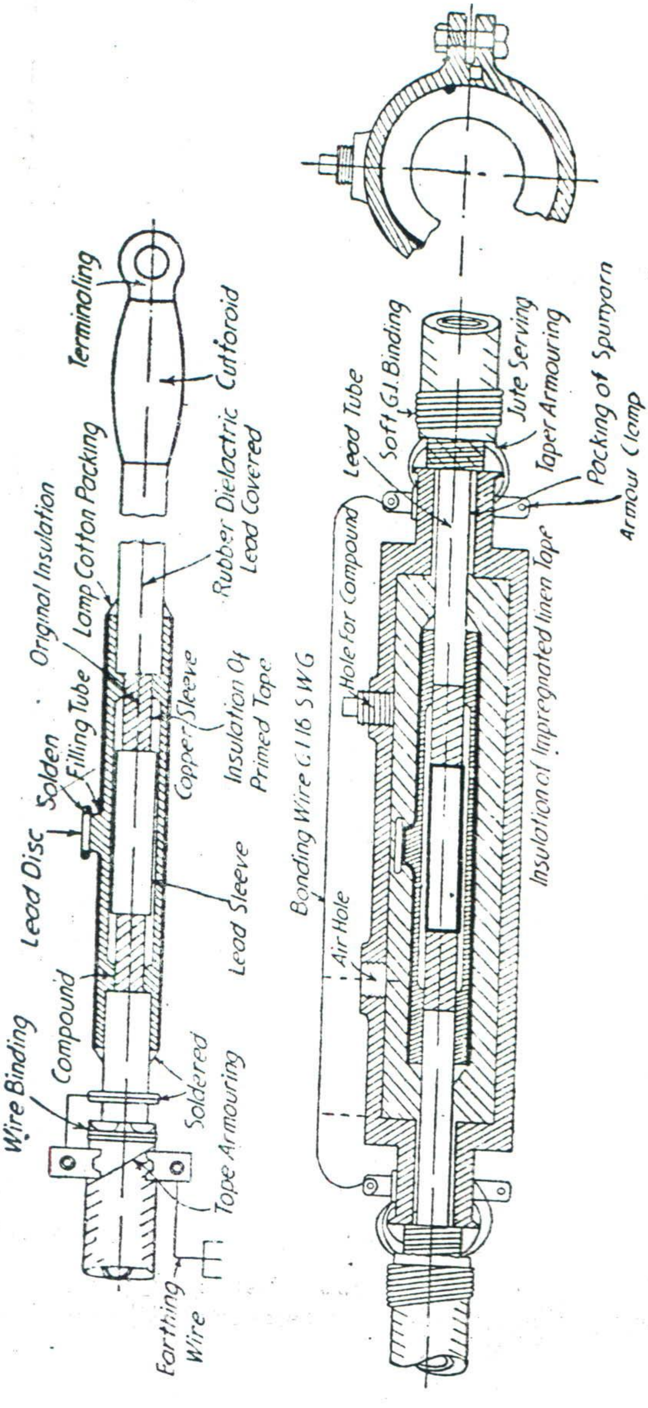
(1) *Cables buried directly underground.* For cable laying a trench of 1/2 m. wide and 1 m. deep is made throughout the route of the cable ; the trench must be of uniform depth and the cable must rest on the even and solid ground. A bed of sand about 5 cm. thick is made under the cable to avoid the clay underneath attacking and soft beddings. Then the cable is covered with more sand to a height of about 15 cm., care being taken that no sharp stone should come to protect the cable from mechanical injury when somebody digs near about the cable route. Whenever the pick-axe of the digger strikes against the brick, he gets a warning of being careful so as not to damage anything below.

If two or three cables are to follow the same route, they may be put in the same trench but they must be separated as far apart as possible to minimize the mutual heating effect. They should not be allowed to cross each other and their protection must be preserved.

Great care must be taken in stretching the cable to avoid any injury to it. The cable drum is put on two wheels of axle. The wheel diameters are usually half metre more than that of drum and the axle is passed through the drum. The cable is stretched by Wheeling the drum near the trench. Another way of stretching the cable is by means of bodily lifting it on men's shoulders loop by loop, and the drum is so turned that the cable should come out for the top of the drum.

(*ii*) *Solid system of laying the cable.* In this system the trench all along the route is made as in the direct laying system. Then the troughs of china clay are placed in a row and the cable is laid out in these troughs. The troughs are then filled with bitumen compound and are covered with slabs when the bitumen is still hot and in a liquid state. When the compound solidifies, it seals the cable throughout its length.

10. Grading of cables. It has been noted that in a single core cable, the electrostatic stress is maximum at the surface of the conductor and decreases towards the sheath. The maximum voltage which can be safely applied to a cable having homogeneous insulation is limited by the electrostatic stress of the surface of the conductor. If a dielectric of high strength is used in the cable, there is no doubt that it will be useful just over the conductor where the stress is maximum but as we go away from the surface of the conductor, the value of dielectric stress decreases. In this way, the excessive dielectric will be used and it will be expensive one. If by



Jointing of cables
Fig. 9.10

some means, the stress may be distributed that its value in the outer layers of the dielectric is increased without increasing the stress near the conductor, insulation of less thickness will be required for any given working voltage and an import economy is effected.

Thus the process of achieving uniformity in dielectric stress is known as grading of cables.

There are two methods of grading :

(*i*) Capacitance grading.

(*ii*) Intersheath grading.

(*iii*) *Capacitance grading.* By applying this method to the cable grading, the uniformity in dielectric stress is achieved by using various layers of different dielectrics in such a way that the permittivity, K, of any layer is inversely proportional to its radius or distance from the centre *i.e.*

$$K \propto \frac{1}{x}$$

or $$Kx = \text{constant}$$

Thus we observe that if such a condition is achieved, the value of dielectric stress of any point is constant and is independent of distance from the centre, and the grading will be ideal one. But it is not possible to use infinite number of dielectrics for a single cable and in practice two or three dielectrics are used in such a way that the permittivity of the dielectric near the core has got highest value and then it decreases and finally it has got minimum value in the outer most layer.

The advantage of this type of grading is that if the overall diameter is same for a non-graded and graded cable, then the permissible safe potential of the cable is increased *i.e.* for the same permissible safe potential, the size of the graded cable will be smaller than that of the non-graded cable.

(*ii*) *Intersheath grading.* A homogeneous dielectric is used in this method of cable grading. The dielectric is divided into various layers, placing suitably the metallic intersheaths. These metallic intersheaths are held at certain potential, which are in between the core potential and the earth potential. There is thus a definite potential difference between the inner and outer layer of earth sheath, so that each sheath can be treated like a homogeneous single core cable.

The modern trend is to avoid grading as far possible and employ oil filled or gas pressure cables because with the capacitance grading, there are only few high grade insulating materials of reasonable cost and with inter sheath grading, there is possibility of damaging to the intersheath the time of transportation and installation. The heat looses are also there due to charging currents.

11. Measurement of Insulation Resistance of Cables.

1. Galvanometer method. To apply this method to measure the insulation resistance of the cables, a very sensitive galvanometer of high resistance *i.e.* of 1000 ohm or more is connected in series with the resistance to be measured and to a battery supply. The deflection on the galvanometer dial reads the insulation resistance of the cable under measurement. This method of measuring the insulation resistance of the cable is not precise. This method is only sufficient to indicate whether the insulation is faulty or otherwise.

2. By Insulation Testing megger. The adequate and accurate method of testing the insulation resistance of the cables is with the help of megger. It carries two terminals marked *E* and *L*. The terminal *L* is connected to the core of the cable and terminal '*E*' is connected to earth terminal. Now the handle of the megger is rotated at uniform speed, then there will be deflection of the pointer on the calibrated dial of the megger. This is the direct reading of insulation resistance of the cable between core and earth.

12. Cable Jointing. The cable jointing is the work of a highly skilled man, since the successful working of the cable depends upon the quality of the joint made. All joints in the cables must be mechanically and electrically perfect as imperfect joints are the source of weakness and danger. The cable jointing can be divided into following heads :

(*a*) *Preparation of the ends of the cable.* When all the materials required for cable jointing and their equipment is ready, the seal of the cable should be broken. Remove the lead sheath only two-thirds of its thickness for a length of about 15 cm. (about 4 cm. greater than the half length of the sleeve of the joint) by means of a back knife and hammer. Care should be taken to make a slanting cut in the lead sheath so that the core insulation may not be damaged.

After this operation, bare the conductor for a length of about 0.625 cm. more than the half length of the sleeve and the bare stranded conductor should be cleaned with naptha. The remaining length of the cable from which 2/3rd thickness of lead is removed is protected (*i.e.* 3 cm approx.) with the help of a tape. Then the stranded end of the conductor is secured with the help of two turns of binding wire, also near the end of the of cut the cable is secured with a few turns of tinned copper binding wire. Now remove the first binding wire made solder it either with the help of a soldering iron or by pouring molten solder from one ladle to another. For such soldering, powdered resin may be used as flux.

(b) *Making sleeve for the joint.* For making the sleeve for the joint, the conductors are made to butt each other in the sleeve and are soldered. The sleeve usually is made from a sheet of copper, which is cleaned thoroughly and is bent to form a split tube. Two holes of about 1.25 cm. diameter are drilled from each end of the tube. Then a layer of pure tallow is applied on the inside and outside of the tube. Now a layer of solder is applied on the inside and outside of the sleeve, first by rolling in it powdered resin and then dipping it in molten solder. The excess of the solder on the sleeve is usually removed by means of pulling a piece of rag through the sleeve when hot.

(c) *Jointing.* Before the actual process of jointing starts, a lead pipe about 20 cm. long is taken to cover the jointing copper sleeve and a hole of 0.5 cm. dia. is made which is called the filling hole. Then beat up the lead so that a lip is formed at the top of the hole. Drill two holes more, one at each end so as to act as air vents. Clean the ends of the lead pipe and scrap outer edges slightly. If it is not done, the joint will not take solder. Now thoroughly clean the lead sheath on each end of the cable and pass this lead pipe on one end of the cable.

Now insert the prepared ends of the copper or aluminium conductors of the cable into the copper sleeve. It is necessary that this sleeve should be a close fit over the conductors, and conductors should be placed so as to butt each other. Pour molten solder over the split copper sleeve from a small ladle and keep another ladle below the joint to catch the drops of the solder. The excess of the molten solder should be wiped off. Care must be taken that the joint is in a horizontal position. *It should be remembered that the jointing should not take more than half a minute otherwise the insulation of the cable will be spoiled.*

(d) *Insulating the joint.* The method of insulating rubber insulated cables and paper insulated cables is different. For insulated rubber cable, India rubber tape is used with the help of rubber solution which is available either in collapsible tubes or in tins. Before the rubber tape is provided over the joint, it is necessary to check up the rubber insulation on the cable ; if it is damaged during the soldering operation, it must be cut away. Also bare the insulation for about 3 cm. on each side of the joint. Clean the insulation by scraping so that no dust or threads etc. are left out. The rubber insulation on the cable now should be tapered by means of curved scissors for about 1.5 cm. on each side.

Now just beyond the point of taper, start providing tape on the bare conductors and copper sleeve. *Care should be taken not to use rubber solution for the first layer, i.e. rubber solution should not come in contact with copper conductor.* After first layer the second layer is provided, so that this layer overlaps the previous one for half of its width ; over the first layer, apply a small quantity of rubber solution and the serving of this tape now should be continued (only after the conductor is covered with rubber tape) upto the tapered portion of the rubber insulation. The serving of the tape should be continued until the insulation provided is of so much thickness that it comes up to the level of the rubber insulation with continued use of rubber solution on both sides of the tape. The last two layers should be continued beyond the start of tapered rubber insulation for about 1.25 cm. For insulating the joint, care should be taken that the work must be clean and the rubber solution should be sparingly used. The cable insulation should be kept tapered only for the minimum period and in no case dirt or dust should come in contact with it.

For insulation of paper-insulated cable joints, impregnated cotton tape, usually available in tins, is used. Before such tapes are used, they are kept in a hot solution of sleeve compound at a temperature of about 230°F, but in no case the tape should come in contact with the container vessel. The impregnated tape should be removed from the compound only when it has sufficiently cooled. The applied tape should be drawn as tightly over the joint as possible in order to exclude air, and moreover each lap should overlap the preceding one by half its width. In case of high voltage cables, (not in case of low voltage ad medium voltage cables) after the insulation is provided over the conductor, the core insulation is removed in a tapered fashion for a length of 4 cm. to 7 5 cm. depending upon the voltage. This is obtained thus : Give a turn on the cable with the help of a copper wire and remove the paper insulation, and now give the turn at a distance of about 0.6 cm. from the previous joint (moving towards the end of the cable) and again remove the paper insulation up to this point and so on. Now the joint should be covered with an impregnated cotton tape ; the thickness of the cotton tape provided should vary from $1\frac{1}{2}$ to 2 times that of the paper insulation. The tape should be tapered to tape 1.25 cm. beyond the lead sleeve.

(*e*) *Jointing of lead sleeve.* After the conductors have been soldered and an insulation is provided over them, it is necessary to protect this insulation against mechanical injury and from the effect of atmosphere. Such protection is usually provided by slipping a lead sleeve over the joint and filling it with a compound. This sleeve is the same one which has been mentioned earlier and slipped over the cable before the conductors are soldered. Assuming that the lead sleeve and the lead over the cable have been well cleaned or scraped, the following are two methods of jointing the sleeve with the lead sheath on the cable :

(*i*) *Soldered joint.*
(*ii*) *Amalgaline plumbing.*

(*i*) *Soldered joint.* Slip the lead sleeve over the insulated joint and dress down its ends over the cable sheath. Insert cotton waste into the joints near the ends. Light up a blow lamp and adjust its flame about 5 cm. long. Warm up the lead on the sleeve and on the cable, taking care that only the tip of the flame should touch the lead and to heat the cable only at one point. Now bring the solder near the cable joint and apply flame on the solder only, so that it is laid first roughly over the joint in the form of lumps. Now heat the joint by moving the flame round the cable. Care should be taken to solder the edges properly. In order to check whether any pin-holes are left or not while the joint is warm apply tallow or a solution of glycerine and soft soap solution. Thus any pin-hole left is soldered properly.

Similarly the other end of the sleeve is soldered.

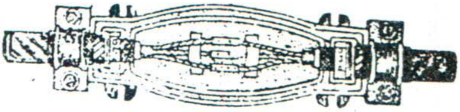
(*ii*) *Amalgaline plumbing.* In this method the lead on the sleeve and the cable are properly cleaned and the ribbon of amalgaline wrapped round the lead sheath of the cable. Then the lead in the sleeve is dressed down so that it tightly fits over the ribbon. Now apply heat by means of a blow lamp until the ribbon melts and at the same time the lead sheath of the cable and sleeve melts and run together to form a solid joint. Such a method is quicker and neater.

13. Filling Compound in the Sleeve. The compound to be filled in is heated in a pan or a ladle, taking care not to overheat. If it is overheated the insulating properties of the compound will deteriorate. So the compound should be heated up to a particular temperatures which varies according to the composition of the compound and a thermometer should be used for noting the temperature. In general the compound should not be heated beyond 300°F.

When the compound is melted, the lead sleeve is warmed up taking care not to overheat it, otherwise the solder at the ends will be melted and the joint will be weakened. The warming of it is necessary, otherwise the poured compound will solidify and thus prevent the complete compounding of the joint.

Pour the molten compound into the lip hole of the sleeve until it comes out of the vent holes of the sleeve. Allow the sleeve to cool down and then pour more compound to allow for shrinkage. Seal the filling by means of soldering a lead cover over it, while the air vents should be soldered with drops of solder.

14. Jointing a Multicore Cable. For multi-core cables also the tapered lead sleeve joints are the best, since approximates to the actual construction of the cable. But such a method is quite expensive and takes more time, so such joint are not justified for low voltage and medium voltage cables. For such cables, the conductor joints so made (without lead sleeve) can well be insulated and protected in a cast iron box which is filled with an insulating compound. The method of making a straight joint for 3,500 V. 3-core paper cable is as explained below :



Jointing of a multi-core cable
Fig. 9.11

(1) Mark the cutting points, giving an allowance of 2.5 cm. for overlap.

(2) Bind the armouring of the cable with a 16 S.W.G. binding wire giving about 6 or 7 turns as a distance of about 20 cm. from either end of the cable and remove the armouring of the cable up to this point with a triangular file.

(3) Remove the lead sheath up to a length of 18 cm.

(4) Remove paper insulation and bare the conductor for a length of about 2.5 cm.

(5) Protect the exposed paper insulation from moisture and solder etc. with the help of an impregnated cotton tape.

(6) Twist the conductor ends and insert the two conductors in a tinned brass connector so that both the conductors meet each other.

(7) Solder perforated tinned copper bonding strips before soldering brighten the lead sheath under the bonding strip.

(8) Over the lead sheath at the point shown, bind the compounded canvas tape until the overall diameter is slightly more than

the internal diameter of the inner gland. For proper adhesion each turn is warmed up with blow lamp.

(9) At the points where both the cables are to be gripped, clean the armouring of each cable and bind with lead strip 1.5 mm. thick until the overall diameter is slightly more than the internal diameter of the armour clamp.

(10) The three cores joined together should be separated with the help of porcelain spreader which must be quite dry. For this purpose before use, it is immersed in a hot compound.

(11) Place the bottom half of the box under the joint so made and provide the armour clamp as shown and bolt it to the cable. The inside of the clamp must be well cleaned in order to ensure better electrical contact.

(12) With the stud, connect the lead bonding strip to the box.

(13) Warm the bottom half of the box with filling compound and while the compound is hot, place the upper half of the box over it and provide a bolt.

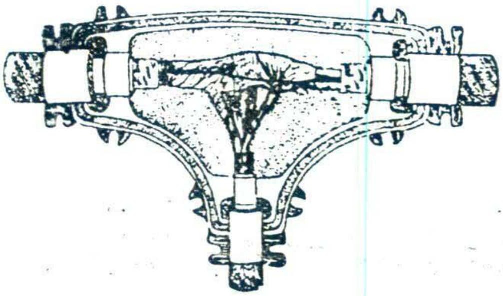
(14) Remove the manhole and heat up the box from outside and fill it up with the compound.

(15) Remove the filling plugs of the glands and provide sealing compound over the glands.

(16) Allow the joint to cool down, and after the contraction of the insulating compound, provide more quantity of it.

(17) After the contraction is complete, fill the groove shown with the sealing compound and replace the manhole. Before replacing the manhole, sealing compound should be provided there.

(18) All the openings should be sealed with the sealing compound.



The Fig. represents a two core T joint
Fig. 9.12

(19) When the job is completed it should be painted black with bitumen paint, in addition several metres of cable on both ends of the joint are coated with bitumen paint.

Typical Questions

1. What is the use of under ground cables ? Explain about the properties which the insulation of under ground cable possess ?

2. What type of insulating material are mostly used for under ground cables ? Explain about them.

3. Explain about the general construction of underground cable. How are the cables classified according to voltage ?

4. What are the types of 3 phases cables ?

Explain about them with their diagrams.

5. What points are taken into consideration at the time of laying under ground cables ?

6. What methods are adopted for laying of cables under ground ? Explain about them.

7. What are the advantages of screened types of cables over belted type cables ?

8. What are the advantages and disadvantages of oil filled cables ?

9. What do you understand by grading of cables ? Explain about the different methods of grading ?

10. What methods are adopted to measure the insulation resistance of under ground cables ?

11. Describe about the cables jointing.

12. Explain about the straight joint for 3500 V, 3-core paper cable.

10

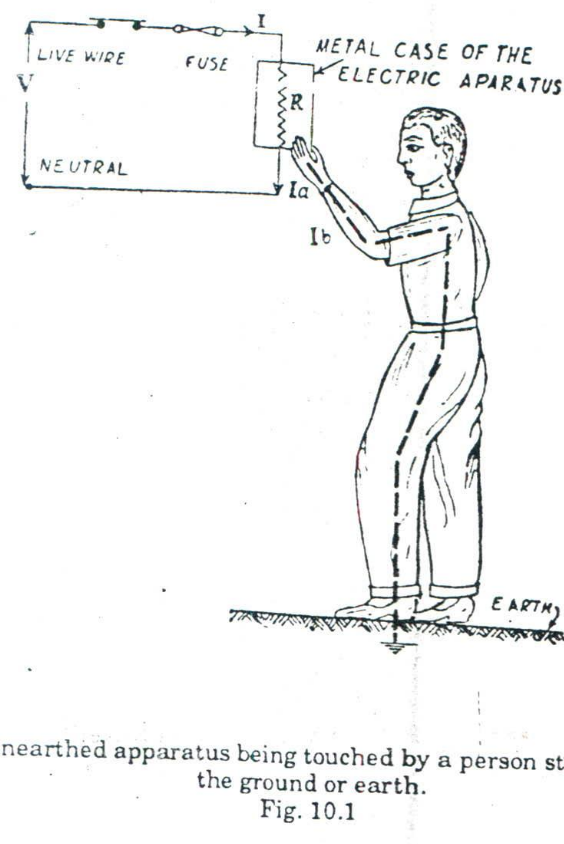
Electric Earthing and Shock

1. Introduction. 2. Neutral Wire. 3. Why grounding is required. 4. Comparison between Neutral and Earth Wire. 5. Fire hazards from electricity. 6. Why fuse is not used in the neutral. 7. Connection with earth. 8. Value of earth resistance and factors on which it is dependent. 9. Methods of earthing. 10. Definitions. 11. Points to remember while earthing. 12. Earth Leakage circuit Breaker System. 13. Electric shock 14. Cure of shocks. 15. Artificial respiration. 16. Precautions against shock.

1. Introduction. The meaning of the term earthing or grounding is to connect the electrical equipment to the general mass of earth by wire of negligible resistance. This brings the body of the electrical equipment to zero potential and thus will avoid the shock to the operator. The neutral of the supply system is also solidly earthed to ensure its potential equal to zero. According to Indian Electricity Rules, "*the earthed or connected with earth means connected with the general mass of the earth in such manner as to ensure at all times an immediate discharge of energy without danger.*

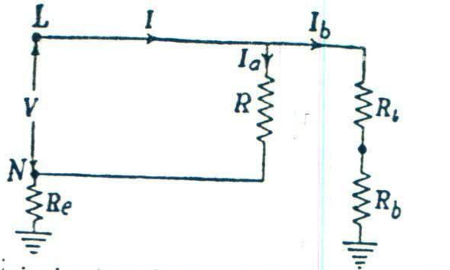
2. Neutral Wire. In India the general distribution is by means of A.C. 3-phase 4-wire distributors. The potential between any two phases is 440 V and the potential between any of the three-phases and the fourth-wire known as **neutral** is 230 V, and this neutral is connected to the junction of the three-phases at the generating end. The neutral wire is always grounded at the generating station. The residential electrical appliances such as lamp, radio, heater, iron etc., all operate at 230 V, so for the residential wiring, one of the outer phases and neutral are brought into the house. If the consumer's load is quite high, then all the three-phases and neutral are brought in, but the appliances are connected between a phase and a neutral and whole of the load is equally distributed on all the phases.

3. Why grounding is required. Let an electrical apparatus of resistance R be connected across the supply mains and let it be not earthed as shown in Fig. 10.1. Let us assume that the potential between the live wire and neutral is V. If the insulation resistance between the electrical element of the apparatus and its metal case be R_i and resistance of the body of a person, who happens to touch the apparatus be R_b. If the person who touches the apparatus standing on the earth, then the current from the supply main will have an alternative path through the insulation resistance R_i of the electrical apparatus resistance R_b of the body to earth, and finally through the earth resistance R_e to the neutral of the supply. The electrical circuit for the above is shown in Fig. 10.2. The current I_b in the second shunt path depends upon the insulation resistance R_i, R_b, R_e and the applied voltage V. However, mostly it is dependent upon R_i since it varies from infinity when the insulation is quite sound and zero ohms when there is a dead short circuit between the element and the metal case respectively. No current will pass through alternative circuit, if the insulator resistance is infinity.



An unearthed apparatus being touched by a person standing on the ground or earth.

Fig. 10.1



Electric circuit at the time of getting a shock
Fig. 10.2

When the apparatus is sound

$$R_i = \infty. \qquad \text{...(10.1)}$$

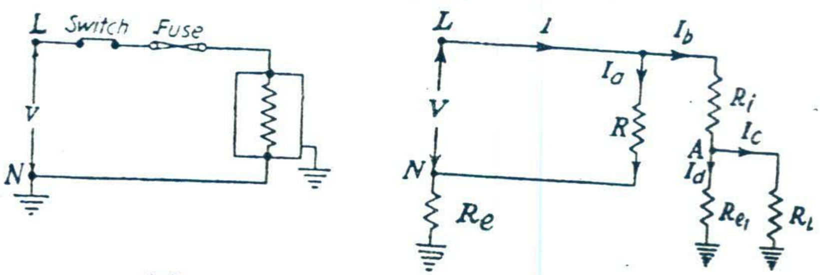
$$I_b = \frac{V}{\infty + R_b + R_e} = 0 \qquad \text{...(10.2)}$$

Hence no current passes through the body and no shock is experienced by the person.

When the insulation of the element becomes defective, the insulation resistance of the apparatus will approach zero, and then the value of I_b will be much dependent upon the resistance R_b of the body and it may be quite sufficient to give a fatal shock to the person.

In this case,

$$I_b = \frac{V}{R_b + R_e} \qquad \text{(10.3)}$$



(a)
Illustrating an earthed apparatus.

(b)
Electric circuit when the apparatus is earthed.

Fig. 10.3

Now let the metal case be earthed as shown in Fig. 10.3 (a). Fig. 10.3 (b) represents the electrical circuit when any person standing on the earth touches the apparatus.

Again the leakage current will largely be determined by the resistance R_i ; when the insulation of the element is sound, the value of R_i will be very high and the leakage current I_b will be almost negligible. When the insulation deteriorates, the value of R_i approaches zero ; the value of the leakage current no doubt will be quite sufficient to give a fatal shock, but at junction A before it passes through the body, it divides into two paths open for it, one through the body offering resistance R_b and the other through the earth resistances R_{e1} which is negligible. The resistance R_{e1} comprises of the resistance of the earth electrode and resistance of the general mass of earth which is denoted as R_e. As R_b and R_{e1} re párallel, the effective resistance will be approximately equal to R_b.

Thus the equivalent resistance of the alternative path will be :

$$R = R_i + \frac{1}{1/R_{e1} + 1/R_b}$$

$$= R_i + \frac{R_{e1} \times R_b}{R_{e1} + R_b} \qquad \ldots(10.4)$$

In view of Eqn. (10.4),

$$I_b = \frac{V}{R_i + \frac{R_{e1} \times R_b}{R_{e1} + R_b}} \qquad \ldots(10.5)$$

The current for which value has been arrived at in Eqn. (10.5) will be divided in two parts at junction A. If the value of the current through the body and earth be I_e and I_d which adjust themselves in the inverse ratio of their resistance, then.

$$I_c = \frac{I_b}{R_{e1} + R_b} \times R_{e1} \qquad \ldots(10.6)$$

and

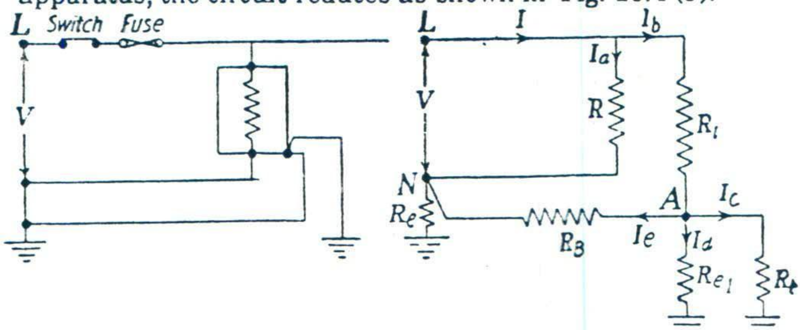
$$I_d = \frac{I_b}{R_{e1} + R_b} \times R_b. \qquad \ldots(10.7)$$

Since the maximum value R_{e1} is of the order of 5 ohms, (according to I.S.I. specifications) R_b under worst condition will be 1,000 ohms, thus current I_d will be much more than that of I_e and this current will not be sufficient to cause any shock.

The value of the leakage current I_b will be sufficiently high to cause the fuse in the circuit to melt and thus will help to isolate the electrical appliance from the supply mains.

It will be observed from the above that the effective isolation of the plant from the supply mains depend upon the earth resistance comprising the resistance of earth electrodes and the resistance of general mass of the earth in between these two points. *If due to some reasons, the earth resistances rise above the safe limits, it will cause the current through the body to increase to thus the possibility of the shock further increases. Hence the arrangement is not fool-proof.*

In order to make the arrangement absolutely safe from shock point of view, an alternative arrangement is to run an earth wire between the electrical apparatus to be protected and the neutral of the source of supply called a bonding connection, as shown in Fig. 10.4 (*b*). When any person touches the metal case of the electrical apparatus, the circuit reduces as shown in Fig. 10.4 (*b*).



Illustrating an earthed apparatus and bonding connection
(*a*)

Equivalent electrical circuit of Fig. 10.3 (*b*)
(*b*)

Fig. 10.4

Thus it will provide an alternative low resistance path to the neutral. *The salient features of the bonding must be :*

(*i*) the earth wire acting as a bonding connection must be of sufficient cross-section to carry the fault current under worst conditions ;

(*ii*) the bonding must be continuous from the appliance to be protected to the neutral of the source ;

(*iii*) the resistance of the bonding must be very low ;

(*iv*) the bonding wire must be strong enough so that it cannot be broken easily at any point ;

(*v*) the connection of the bonding wire must be perfect at both ends ;

(*vi*) all bonding connection should be protected against corrosion.

4. Comparison Between Netural and Earth Wire :

S. No.	*Neutral Wire*	*Earth Wire*
1.	It is directly connected to the neutral point of the supply system.	It may be directly connected to the neutral point to supply system.
2.	It serves as a return conductor.	It may carry current only in case of a fault.
3.	Its potential at some point may be substantially far from zero. It is therefore insulated from the pole on which it is supported. In this case, the insulator is smaller in size than the one supporting the phase conductors.	It is supposed to be at zero potential. It is not mounted on any insulator and is in direct metalic contact with the support metals work.
4.	It may not be connected to earth at an intermediate point in the line.	It must be connected to earth at least at 3 places in a Km or at 4 places an a mile.

5. Fire Hazards from Electricity. Whenever there is a breakdown of insulation over the wires it is always accompanied by generation of heat and increase of temperature near about the fault. If there is a faulty earth and there is no isolation of circuit due to fault current, then the fault persists which further increases the temperature of the surrounding and if the temperature reaches ignition point, the insulation starts burning, and fire breaks out.

Hence to avoid the fire hazard earthing or bonding is a necessity.

6. Why the fuse is not used in the neutral. According to Indian Electricity Rule 32 clause 2, no cut-out, link or switch other than a linked switch arranged to operate simultaneously on the earthed or earthed neutral conductor and live conductors shall be inserted or remain inserted in any earthed or earthed neutral conductor of a two-wire system or in any earthed or earthed neutral conductor of a multi-wire system or in any conductor connected thereto with the following exceptions :

(*a*) A link for testing purpose, or

(*b*) A switch for use in controlling a generator or transformer.

In order to prove it, let a fuse be inserted in the neutral of the supply as shown in Fig. 10.5 and let the metallic body of the electric appliance be earthed to avoid electric shock. Let the insulation of the appliance deteriorate and there is a leakage current and this makes the fuse in the neutral to melt first. But as soon as the some-one touches the electric appliance in order to know what has happened, he will complete the circuit through his body to earth and source and thus will get a severe shock since it is still not disconnected from the live mains.

Hence for safety reasons, a fuse should never be used in the neutral.

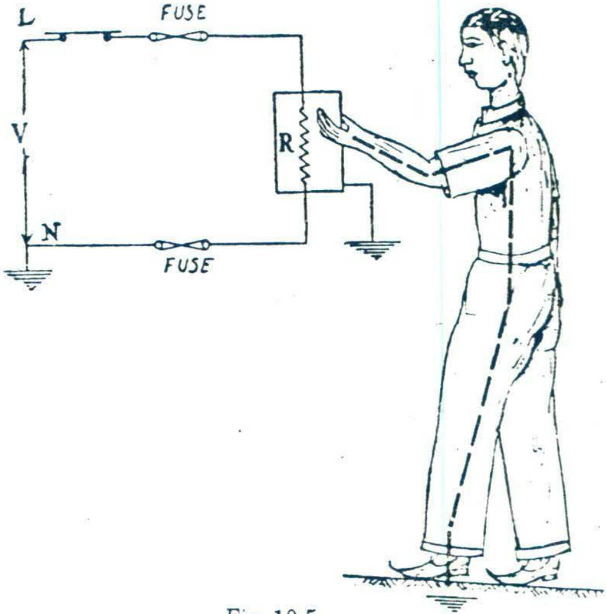


Fig. 10.5

7. Connection with Earth. (*i*) According to Indian Electricity Rule 61, the following provisions shall apply to the connection with earth of a system at low voltage in cases where the voltage normally exceeds 125 volts and of the systems at medium voltage : (*a*) *The neutral conductor of a 3-phase four-wire system and the middle conductor of a two phase 3-wire system shall be earthed by not less than two separate and distinct connections with earth both at the generating station and at a the substations. It may also be earthed at one or more points along the distribution system or service line in addition to any connection with earth which may be at the consumer's premises.*

(*b*) *The frame of every generator, stationary motor and so far as is practicable, portable motor, and the metallic parts (not intended as conductors) of all transformers and any other apparatus used for regulating or controlling energy and all medium voltage energy consuming apparatus shall be earthed by the owner by two separate and distinct connection with earth.*

(c) All metallic coverings containing electric supply wires, metallic apparatus *viz.,* iron clad switches, distribution fuse boards down rod of fan, water-tight switches etc. should be earthed. In addition to running earth conductor, the main switch board at consumers premises should be earthed with an earth electrode.

(*d*) All apparatus *viz.* refrigerator, energy meters, cooking range, oven, electric heaters, press etc. should be earthed.

(*e*) In an underground cable, metallic sheath should be earthed by two separate and distinct connection with the earth.

(*f*) Iron clamps, brackets, steel poles, steel tower stay wires of a distribution and transmission system should be earthed.

(*g*) No earth connection is made to that gas pipe.

(*h*) In case of d.c. supply, the middle conductor should be earthed at the generating stations.

8. Values of earth electrode resistance and factors on which it is dependent :

The earth resistance is dependent upon many factors as detailed below and as such its value can vary :

(*a*) Material of electrodes and earth wire.

(*b*) Size of electrode and earth wire.

(*c*) Temperature of the soil.

(*d*) Moisture of the soil.

(*e*) Depth to which it is embedded.

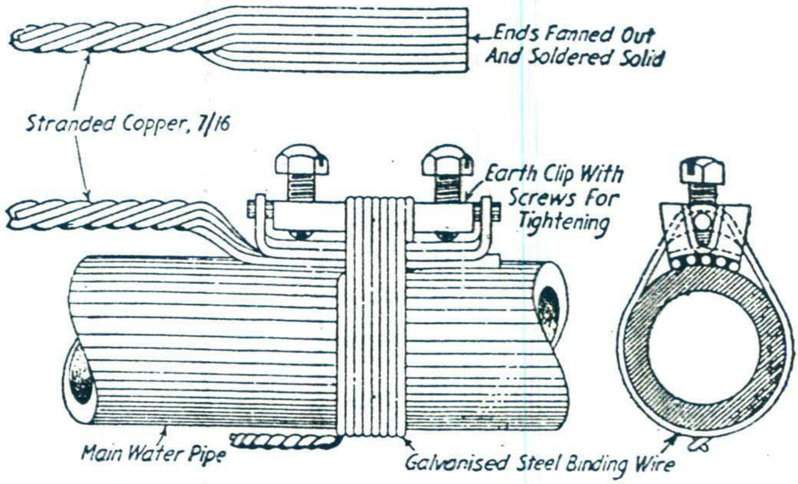
(*f*) quantity of coal and charcoal in the earth electrode pit.

Maximum value beyond which the earth electrode resistance should not be increased is 5 ohms. However for better performance at power house and substation, its value should be 0.5 ohm and 1.00 ohm respectively. Water is poured in the earth pit containing electrode to improve the resistance.

9. Methods of Earthing. There are three methods of earthing.

1. Earthing through a water main. Before making an earthing connection to the water main, it must be ascertained that throughout G. I. pipes have been used, otherwise if the cement concrete pipes have been used, the earthing will not be effective. When making an earthing connection, care must be taken to limit the contact resistance to the minimum. For that purpose properly designed earthing clamp should be used. The stranded copper lead is fanned out and is soldered to make it solid. Then the lead strip is bent round the pipe so that it may be seated properly over the pipe. The surface of the pipe is cleaned properly, and all traces or grease

... placed the clamp. In between the clamp and pipe is inserted the lead and is tightened with the screws shown in Fig. 10.6.



Representing earth connection with water main.
Fig. 10.6

This method is however not popular as water means are of concrete or cement.

(2) *Pipe Earthing.* If the water-pipe cannot be used as an earth, a galvanised iron pipe of approved length and diameter can be used. The size of the pipe depends upon (*a*) the current to be carried, (*b*) the type of soil. According to I.S.I. Standard No. 732—1963 the galvanizd iron pipe shall not be less than 38.1 mm. diameter and 2 m. long for ordinary soil but if the soil is dry and rocky, the length of the pipe should be increased to 2.75 m.

The pipe is placed upright as shown in Fig. 10.7, and must be placed in a permanently wet ground. The depth at which the pipe should be buried depend on the condition of the ground moisture. According to Indian Standard, the pipe should be placed at a depth of 4.75 m. ; it can be less if the soil provides sufficient moisture earlier. The pipe at the bottom should be surrounded by broken pieces of coke or charcoal for a distance of about 15 cm. around the pipe. The coke increases the effective areas of the earth practically to the outside of the coke bed.

Impregnating the coke with salt decreases the earth resistance. Generally alternate layers of salt and coke are used for best results as represented in Fig. 10.7. In India in summer season the moisture in the soil will decrease to a large extent which will increase the

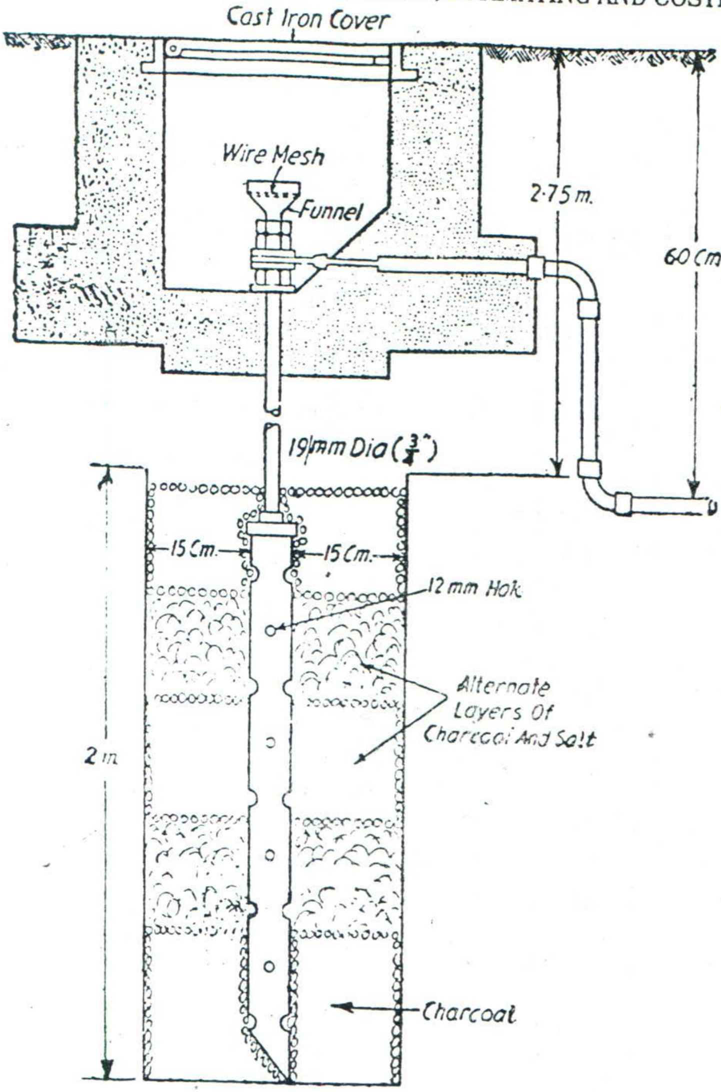


Fig. 10.7 Pipe earthing

earth resistance. So in order to have an effective earth, whenever needed, 3 to 4 buckets of water should be put into the funnel connected to the main G. I. pipe through 19 mm. dia. pipe.

The earth lead used must be G. I. wire or G. I. strip (*not of copper*) of sufficient cross-sectional area to carry fault current safely. (It should not be less than electrical equivalent of copper conductor of 12.97 sq. mm (8 SWG) cross-sectional area. The earth wire from the G.I.pipe of 19 mm dia. should be carried in a G.I. pipe of dia. 12.7 mm. at a depth of about 60 cm. below the ground. Further when the earth wire is carried over from one machine to the other, it should be well protected from mechanical injury, by carrying the earth wire in a recessed portion.

Plate Earthing. The earth connection can again be provided with the help of a copper plate or a G.I. plate. When G.I. plate is used it should not be of less than 60 cm. × 60 cm. × 6.35 mm while for copper plate these dimensions may be 60 cm. × 60 cm. × 3.18 mm. However, the use of the copper plate in these days, is limited.

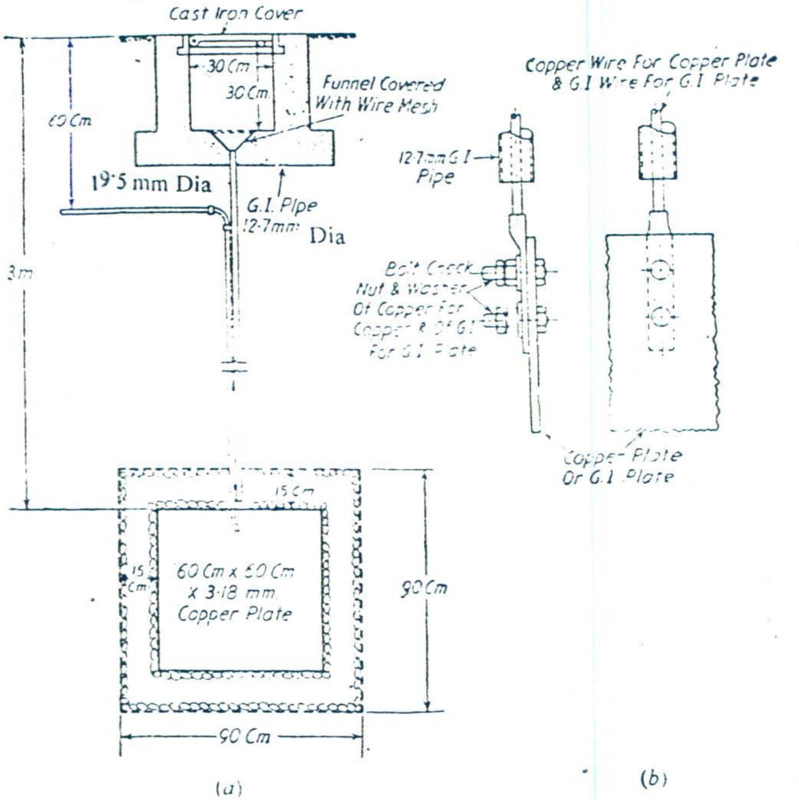


Fig. 10.8 Plate earthing

The plate is kept with its face vertical at a depth of 3 m. (10 ft.) and is so arranged that it is embedded in an alternate layer of coke and salt for a minimum thickness of about 15 cm. in case earthing is done by copper plate and in coke layers of 15 cm. if it is done with G. I. plate. The earth wire is securely bolted to the earth plate with the help of bolt nut and washer, the details of which are shown in Fig. 10.8 (*b*). *It should be remembered that the nuts and bolts must be of copper for copper plate and should be of galvanized iron for galvanized plate.* The other details of plate earthing are same as that of G.I. pipe earthing.

10. Definitions.

(*i*) **Earth Electrode.** The conductor embedded in the grou for the purpose of making connection with the general mass of ear is known as earth electrode and the wire which connects overhe earth wire (or any other equipment to be earthed) with ear electrode is known as earthing lead.

Where available underground water pipes or lead sheathed a steel armoured cables should not be used as earth electrodes. The are prohibited by ISI, vide IS 732—1963 (Revised)

"Sprinkler pipes or conveying gas, water or flammable liqui conduit, metallic enclosures of cables, conductors and lightni protection system, shall not be used as a means of earthing installation, or even as a link in earthing system."

The reason is, the water pipes are not usually in direct conta with earth, particularly if no-conducting joining have been us between section of water main. The same is the case with lead shea or steel armouring of cables.

There are 3 types of artificial electrodes, following t specifications of ISS.

(*i*) Driven Electrodes *i.e.* pipe or rode electrodes.
(*ii*) Strip electrodes.
(*iii*) Plate electrodes.

(*ii*) **Driven Electrodes.** The electrode is made of metal rod pipe having a clean surface line, not covered by any poor conducting material such as paint or enamel. Rod electrodes of ste or iron shall have a minimum dia. of 16 mm and those of copper at least 12.5mm dia. Pipe electrodes shall not be less than 38m internal dia-meter if made of iron or steel, (galvanised.) The lengt of this electrodes shall be not less than 2.5m. The electrodes sha normally be driven to a depth of at least 1.25 metres. But if rock encountered, they may be burried in a horizontal trench and sha be not less than 2.5m. in length.

(*iii*) **Strip Electrodes.** These consist of copper strips, n smaller than 25mm × 1.6mm in cross section of bare coppe conductor not less than 3mm^2 in section. They are burried i horizontal trenches, not less than 2.5m deep. The length shall b such as to give required earth resistance.

(*iv*) **Plate Electrodes.** A plate of copper or galvanised iron c (0.6 × 0.6 × 0.006 m for iron OR 0.6 × 0.6 × 0.003 m. copper) is burrie with its face vertical in an alternate layer of coke and salt for minimum thickness of about 15cm. The earthing lead is enclosed i a G.I. pipe of 12.7 mm dia and is bolted to the earth plate with th help of bolt, nut and washer.

Earch conductivity is electrolytic in nature and is affected by moisture content of the soil and its chemical composition. Therefore electrodes shall use as far as possible, practicable, be embedded below permanent moisture level. Even then the earth resistance may increase appreciably during summer when the moisture in the soil decreases considerably. Arrangement, must therefore be made to keep the electrode wet, even during such periods by pouring 3 to 4 buckets of water into the sump once for every few days. Further to reduce the soil resistivity, some common salt is dissolved in the moisture by packing it all around the electrode.

The electrode material does not affect earth resistance and so a material which can resist corrosion is to be chosen. For a.c. circuits, zinc coated iron electrodes should normally be used, as the price of copper is very high. But in d.c. system, the electrolytic electrodes are generally used.

For a low protective fault current, pipe electrodes are used. For a large protective fault current, plate electrodes are used.

(*v*) **Earthing lead or the main earthing conductor.** The wire connecting the earth electrode with the main switch board or with the continuous earth wire run along the distribution, transmission or the service line is known as earthing lead or the main earthing conductor.

(*vi*) **Sub-main earthing conductor.** The earth wire which runs between the main switch board to the distribution board or in other words along the sub-mains is known as sub-main earthing conductor.

(*vii*) **Earthing continuity conductor.** The wire running between the distribution board and various plugs and appliances is known as earth continuity conductor.

11. Earth Leakage Circuit Breaker System

In this system, the parts of an electrical installation to be protected even from leakage of very low current, are connected to an earth electrode through the coil of an earth leakage circuit breaker, which controls the supply to that part of the installation, in addition to the already earthed equipment. As shown in the fig. it provides the means of disconnecting the faulty circuit at a current level of about 30 milli-amps. which is only a fraction of the normal full load current, and is the most effective method of protection. This method is especially recommended for installations of high earth resistance. The trip circuit breaker may be provided with time lag feature to allow the operation of the protective devices protecting individual circuit.

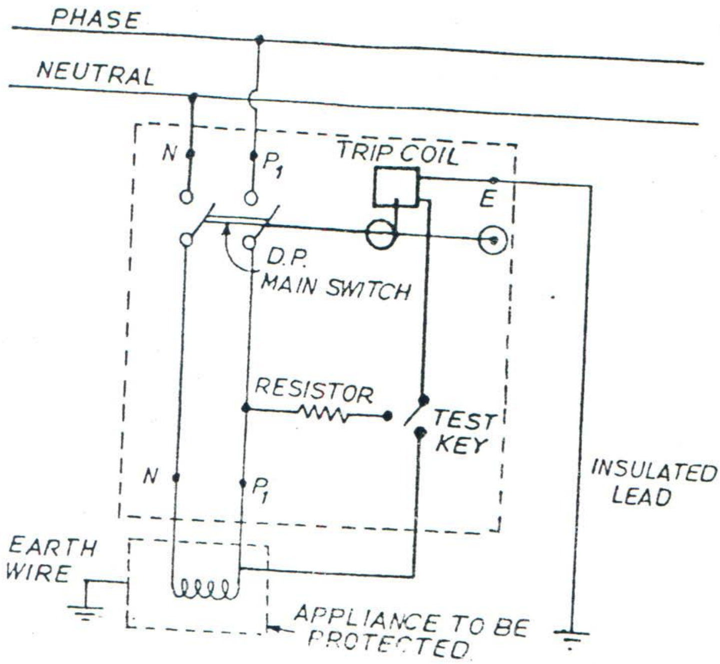


Fig. 10.9 Shows the Earth Leakage Circuit Breaker System

12. Points to remember while providing earthing.

Following points should be remembered while providing earthing to an installation and premises. Various details given as per I.S. specification are :

(*i*) **Distance.** The distance of the electrode from the installation at the premises should be more than 1.5 metre.

(*ii*) **Cross-section of the earthing lead.** It should never be less than half the cross-section of the mains wire or conductor. The selection should be made in such a way that even in worst condition it shall not fuse out. The minimum size of the earthing lead should not be less than electrical equivalent of copper conductor of 8 SWG (12.97 sq. mm cross-section). The sizes of earthing lead for various loads and installations are given in Table 10.1

(*iii*) **Cross-section of the earth continuity conductor.** The size of the earth continuity conductor should not be less than 14 SWG (2.894 sq. mm)

(*iv*) **Electrode.** As already discussed, the earthing can be done either with plate or pipe electrode. *It should be remembered that the* *material for earth electrode and earth lead should be same and the electrode should always be placed in vertical position. The size of the plate earth electrode for various loads and insulation should be in accordance with the details given in Table 10.1.*

(*v*) **Earth resistance.** The earth resistance of any earthing should not be more than 5 ohms. As already said that for better performance at power house and sub-stations or for high horse power motor beyond 100 H.P. the earth resistance should be upto 0.5 ohm and 1 ohm respectively.

Table 10.1

Type of loads and installation	*Size of the earth lead*				*Size of the earth electrode*	
	Copper		*G.I. Wire*			
	SWG	*Area in sq. mm*	*SWG*	*Area in sq. mm*	*Copper*	*G.I.*
Consumers residential premises	8	12.97	8	12.97	60cm.× 60cm. × 3.18 mm	60cm.× 60cm. × 6.35 mm
Pole earthing of transmission or distribution lines	-do-	-do-	8	12.97	-do-	-do-
Industrial loads upto 10 HP	-do-	-do-	8	12.97	-do-	-do-
Industrial loads between 10 HP to 15 HP	-do-	-do-	6	18.68	-do-	-do-
Industrial loads between 15 HP to 30 HP	6	18.68	2	38.60	-do-	90cm.× 90cm. × 6.35 mm
Industrial loads between 30 HP to 50 HP	4	27.27	not	used	90cm.× 90cm. × 6.35 mm	Not used
Industrial loads between 50 HP to 100 HP	(*i*) 2 (*ii*) copper strip	38.60 12.7mm 2.54mm	not	used	-do-	Not used
Industrial loads above 100 HP	copper strip	25.4mm 2.54mm	not	used	-do-	Not used
Power Houses and sub-stations	copper strip	25.4mm 2.54mm	not	used	-do-	Not used

The resistance of earth is dependent upon area of electrode in contact with the general mass of earth, the quantity of earth, coal and salt.

The resistance of an existing earth can be increased by pouring water for G.I. plate earthing, salted water for copper plate earthing or by replacing the coke and salt.

The low earthing resistance can be obtained by increasing the cross-sectional area of electrodes and this can be achieved by connecting a number of electrodes in parallel.

13. Electric Shock. The effect of electric shock may be death—

(1) due to fibrillation of heart. *i.e.*, damaging the heart to small pieces causing the stopping of breathing :

(2) due to stopping of breathing action caused by blockade in the nervous system causing respiration ;

(3) due to local overheating or burning of the body.

The fibrillation of the heart is the most serious cause of death and there is no cure, although there is possibility of rescuing a man who has suffered by the latter two causes. The seriousness of the electric shock is dependent upon the following factors.

(*i*) *The Current Strength.* It has been experienced that in alternating currents of low frequency the current between 1 mA and 8 mA are just bearable, but currents between 8 mA and 15 mA give a painful shock which sometimes contract muscles too. If the leakage current is between 20 mA ad 50 mA and it passes through chest it may stop breathing and currents between 100 mA and 200 mA may cause fibrillation of heart. Current beyond 200 mA will cause burn and if it passes through heart even, it will not cause fibrillation but may stop breathing temporarily.

Thus it is seen that it is the current which gives shock although it depends upon the voltage. The leakage current is given

$$I = \frac{E}{R} \qquad \ldots(10.1)$$

where E is the supply voltage and R is the body resistance.

The body resistance is different under different conditions. When the body is dry, its resistance varies between 70,000 Ω and 100,000 Ω per sq. cm. (the skin resistance is high while the internal resistance is low), but when the body is wet, its resistance reduces to between 700 Ω and 1,000 Ω per sq. cm. The average effective resistance of the body may be taken as 50,000 Ω when dry and 1,000 Ω when wet. The high voltage causing currents beyond 200 mA punctures the outer skin causing burns. Table 10.2 gives the results of shock under different conditions and under different voltages.

Hence it is concluded that when body is wet 100 V supply is as dangerous as 10,000 V when the body is dry.

(ii) *The frequency of currents. The lower the frequency, the more dangerous is the shock, and the direct current shock is the most severe.*

(iii) *The path taken by the current through the body.* If the path of the leakage current is without involving the chest or heart, survival is possible but there are severe burns on the parts of the body involved in the shock depending upon the value of the current.

Table 10.2

Condition of body	*Electric resistance of the body ohms*	*100 V*		*500 V*		*10,000 V*	
		Current A	*Effect*	*Current A*	*Effect*	*Current A*	*Effect*
Totally wet	1,000	0.1	Certain death and slight burns	0.5 A	Burns. probable death	10	Severe burns; may survive
Neither wet not dry	5,000	0.02	No burns or injury; painful shock	0.1	Certain death; slight burns	2	Severe burns; may survive
Dry	100,000	0.001	Very light shock; no burns	0.005	Light shock, no burns	0.1	Sure death; slight burns

14. Cure of Shocks. In most of the cases the electric shock due to accidents is momentary and the contact with the live wire is imperfect, in such cases breath stops momentarily. But if due to the shock the victim becomes unconscious, stops breathing and his heart still beats, the most urgent and immediate cure for this victim is that should be given immediate artificial respiration in the manner detailed on next pages below, and it should be continued until the victim starts breathing normally. It should be borne in mind that if the artificial respiration is stopped just after the victim recovers, he is liable to become unconscious again. In some cases the artificial respiration is to be continued for 6 to 8 hours.

If due to shock the heart stops beating it means that fibrillation of the heart has occured and death is certain.

15. Artificial Respiration. At the time of accident due to electric shock, proceed as follows :

(i) When anyone gets a shock, the first and foremost duty of the observer is to break the contact of the live mains and body either by switching off the main supply, or the body should be rolled away with a dry wooden stick. If a stick etc. is not at hand, a dry piece of cloth should be used to detach the body from the live mains, or if that is also not available the loose cloth such as coat or shirt of the victim should be pulled with care without touching his body.

(*ii*) See, if the operator's clothes are smouldering ; if so, extinguish the sparks etc.

(*iii*) Check up if the patient is breathing or not : if he is not breathing, immediately start artificial respiration as detailed below until medical aid arrives—

Lay the patient so that no pressure on the burns of the patient is applied. There are two methods of laying the patient for artificial respiration:

Method 1. Lay the patient as represented in Fig. 10.10. Kneel over the patient's back, and place both the hands on the patient's thin portion of the back near the lowest rib in such a manner that the fingers remain spread on the sides and the two thumbs almost touch each other and are parallel to spine. Now press gradually, and slowly for about 3 seconds by leaning forward your hands as shown in 10.10 Fig. The patient should be kept warm.

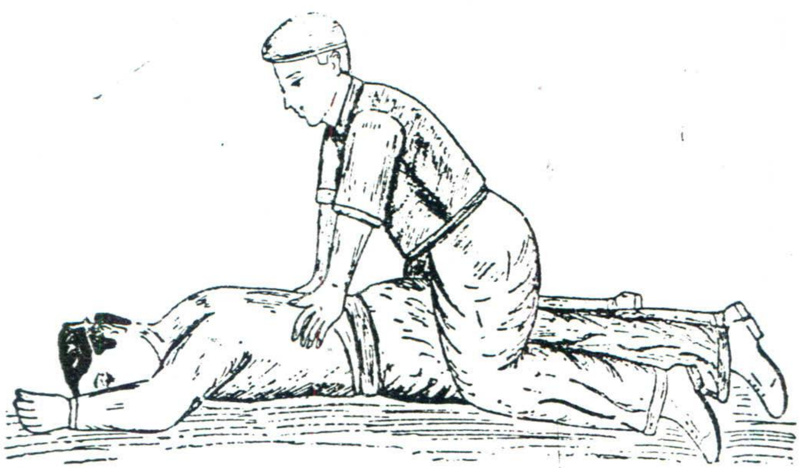
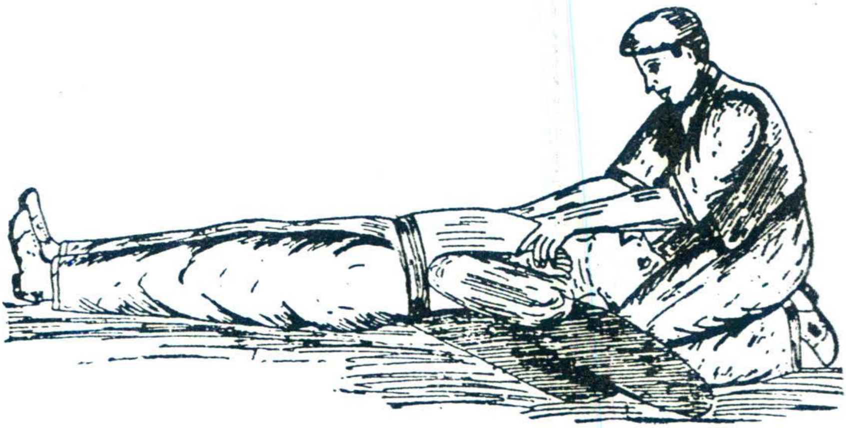


Fig. 10.10. Artificial respiration

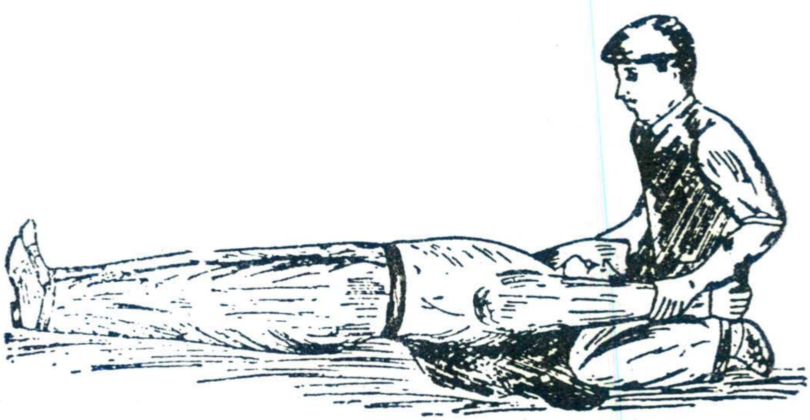
Now relax the pressure slowly and come to the original kneeling position for about two seconds as represented in Fig. 10.9. Repeat the process for about 12 to 15 times in a minute. It expands and contracts the patient's lungs so as to initiate breathing. The process should be continued with great patience and in so case violence should be used.

Method 2. When the patient has got burns etc. on his chest or anywhere on front side, then the patient must definitely not be laid as in Fig. 10.11, instead lay him as shown in Fig. 10.12 with a pillow or rolled coat under his shoulders. The clothes of the patient must be loosened before starting the process of artificial respiration.



Artificial respiration
Fig. 10.11

(*a*) Hold the patient just below the elbows and draw his hands over his head until they are horizontal, keep them in that position for about two seconds. Now bring the patient's hands on to his sides kneeling over the patient's hands so as to compress them down as represented in Fig. 10.12. After 2 seconds repeat the process again.



Artificial respiration
Fig. 10.12

(*b*) If the operator has got burns only, the burns should be dressed properly ; oil should never be used on the burns. After the patient's burns have been dressed properly, he may look cheerful and quite all right. It is important to note that one who has received electric shock is liable to get an attack of hyperstatic pneumonia. So it is necessary to keep him warm for at least one day.

16. Precautions against Shock. It is always necessary to observe the following precautions against shock, since prevention is better than cure :

(1) Try to avoid work on live mains which should be switched off before working.

(2) If it is not possible to switch off the mains, be sure before working that your hands or feet are not wet and insulated with rubber shoes.

(3) In order to rescue a person who has got an electric shock if there is no other insulator available for rescuing, use your feet rather than hands, wearing the rebber shoes or P.V.C. shoes.

(4) When working on high voltages, be sure that the floor is not conductor. Concrete floors are dangerously conductive.

(5) When working on high voltage, try to keep your left hand in the pocket *i.e.* avoid your left hand to get in contact with any live conductor or metallic causing of an apparatus or metal pole or cross arms.

(6) Do not work in such a place where your head is liable to touch the live mains before making the circuit dead.

TYPICAL QUESTIONS

1. Why earthing is done ?
2. Why fuse is not used in the neutral ?
3. What are the various points which are to be earthed in accordance with Indian Electricity Rule ?
4. Write short notes on the following :
   (*i*) Earth lead (*ii*) Electrode
   (*iii*) Earth continuity conductor (*iv*) Sub-main earthing conductor
5. What are the various points to be remembered while earthing ?
6. What are the values of earth resistance ?
7. What are factors on which earth resistance depend ?
8. What are the various methods of earthing ? Explain one of the method with sketch.
9. Recommend type of earthing for residential accommodation.
10. What should be the size of conductor and plate electrode recommended for earthing at various places ?
11. What do you understand by the phenomena of "Electric Shock" ?
12. How a person who has suffered an electric shock is to be cured.
13. Suggest various precautions required to be taken to avoid electric shock to a worker.
14. Write down the specifications for :
    (*a*) Plate electrode (*b*) Pipe electrode
    (*c*) Earth lead (*d*) Earth conductor

11

Power Stations and Substations

Power Station. Electric power stations are classified according to the kind of energy used by the prime-movers and named as :

1. **Thermal Power Stations.** In thermal power stations, the heat of combustion of coal is utilized by the boilers to produce steam at a high pressure and temperature. This steam is used in driving the steam turbines or sometimes the steam engines coupled to generators which produce the electric power. The fuel used in the boilers is mainly bituminous coal but in case of emergency some heavy oil can be used for the fuel.

The thermal plant is preferred where the generation of large electric power is required and where the financial, climatic and geographical conditions do not permit the installation of hydro-electric power stations.

Its operating cost in about Rs. 100 per kW of installed capacity and Rs. 0.04 per unit generated.

The advantages and disadvantages of thermal plants are given below :

Advantages (*i*) Fuel used is cheaper (*ii*) Less space is required in comparison with that of hydro electric plants (*iii*) cheaper in initial cost than other power stations. (*iv*) Its cost varies from Rs. 800 to Rs. 1,000 per kW of installed capacity (*v*) Cheaper in production cost than that of diesel power stations. (*vi*) Such plants can be installed at any place whereas hydro-electric plants can be developed only at the source of water power. (*vii*) Such plants can be located near the load centres, whereas the hydro-electric plants to be installed at source of power which is usually isolated from urban areas.

Disadvantages. (*i*) Costlier in running cost than that of hydro-electric power plants. (*ii*) Atmosphere is polluted by fumes and residues.

Schematic arrangement of a modern coal fed power-plant. The entire arrangement, may be divided into 4 main circuits namely (*i*) fuel and ash circuit (*ii*) air and flue gases circuit (*iii*) feed water and steam circuit and (*iv*) cooling water circuit.

(*i*) *Fuel and Ash Circuit.* Coal is delivered from the supply points to the storage site by road, rail or water. By road, coal is transported in trucks and for small stations such inland transport may be enough. Where power plants are situated close to a water

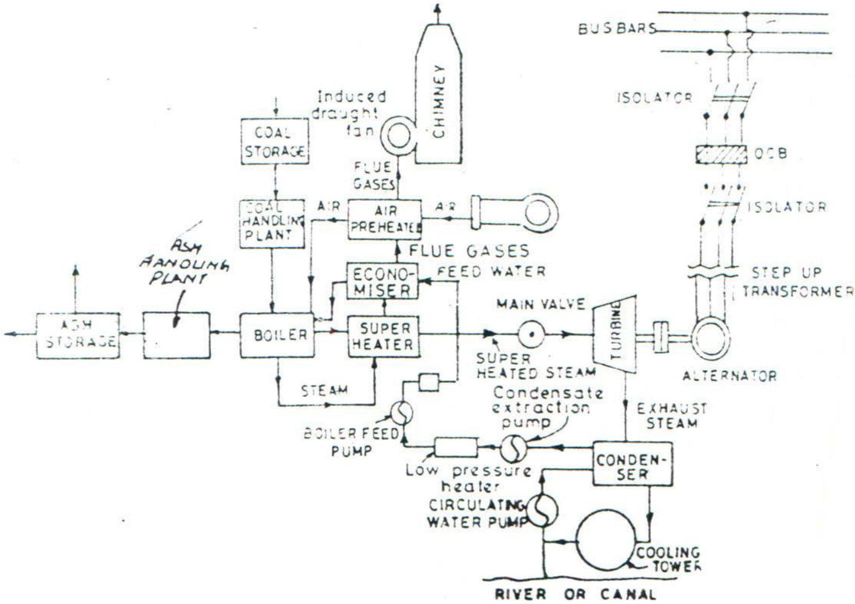


Fig. 11.1. The Schematic Arrangement of a Modern Coal Fed Plant.

way, such as a canal, river or sea, transportation is done by boat or ship. However, in most cases transportation of coal by rail, road is the most common. In the case of small power plants, the quantity of coal being small, manual unloading from rail car may be used but for large power station the unloading from the railway siding is done with the help of wagon tipplers and then the coal is conveyed to the coal handling plant. The coal having been good enough to be burnt into boilers is taken into the boiler bunkers by means of bucket coveyers. The coal is thus stored inthe bunkers from where it falls into the hoppers by gravity and finally the requisite quantity of coal either goes on falling directly on the grate, or where the coal spreaders are provided, coal is spread in the grate up to the rear end. When use of spreaders is made, most of the coal burns in air and remaining falls at the rear end of the grate. Any unburnt coal particles in the middle of the grate are collected in a pipe and are again refired by cinder-refiring fan. The grate in such types of boilers, where use of spreaders is made, moves from rear end to front end, and without spreaders, the movement of the grate is from front to rear end. Combustion is controlled by controlling the grate speed, quantity of coal entering the grate, the damper openings. The ash is collected after complete combustion of fuel at the back of the boiler and is removed to the ash storage by means of scrap conveyors.

(*ii*) *Air and Flue Gas Circuit.* Air is drawn from the atmosphere by a forced draught fan through the air preheater, in which it is heated by the heat of flue-gases passing to chimney, and then admitted to the furnaces. The flue-gases after passing around boiler tubes and superheater tubes are drawn by the induced draught fan through economiser and air pre-heater and finally exhausted to the atmosphere through chimney.

(*iii*) *Feed Water and Steam Circuit.* The condensed water is extracted from the condenser by the condensate pump and is then forced to the high pressure feed water heater, where its temperature is raised by the heat from bled steam. The feed water is now pumped to high pressure water heater, where it gets heated by the heat from bled steam extracted at suitable point of steam turbine. It is then pumped into boiler through economiser, in which it is further heated by the heat of flue gases. In boiler, water is converted into high pressure steam, which is wet. Wet steam is passed through super-heater, where it is further superheated, and then supplied to the steam turbine through the main valve. After giving out its heat energy to the turbine, it is exhausted to the condenser where its latent heat is extracted and steam is converted into feed water. At one or more stages, a quantity of steam is bled or withdrawn for heating of feed water. Making up water for boiler is taken through the evaporator, where it is heated by low pressure steam extracted at suitable point of turbine.

(*iv*) *Cooling Water Circuit.* Cooling water is supplied from a river, canal, or lake or cooling towers through screens to remove the matter, that might choke the condenser tubes. It is circulated through the condenser for condensing the steam and finally discharged to the suitable position near the source of supply. During the passage, its temperature rises and in the case of cooling towers the heat must be extracted before the water is again pumped to the condenser. A low pressure in the condenser is maintained with the circulation of cooling water to the condenser.

Factors Influencing the Choice of Site For Thermal Plants. The following factors should be considered while selecting a site for steam power station for economical and efficient generation :

(*i*) *Nearness to the load centre.* The power station should be as near as possible to the centre of the load to reduce the transmission cost and losses. This factor is most important when d.c. supply system is adopted. However, in case of a.c. supply system where transformation of energy from lower voltage to higher voltage and *vice-versa* is possible, power station can be erected at places other than that of centre of load provided other conditions are favourable.

(*ii*) *Supply of water.* The power station should be near to the source of water. Since large quantity of cooling water (500 tonnes of cooling water for every tonne of coal burnt) is required for the condenser.

(*iii*) *Supply of Fuels.* The power station should be near to the coal mines if possible to reduce the transportation cost of fuel.

(*iv*) *Transportation Facilities.* The facilities like railway station must be available for transportation of heavy equipment and fuels.

(*v*) *Cost of land.* Land should be available at a reasonable price.

(*vi*) *Type of land.* Soil of land should be very stiff to bear the weight of the large building and heavy machinery.

(*vii*) *Available area.* Sufficient area must be available to keep the land in reserve for future expansions.

(*viii*) *Distance from populated area.* The site for the power station should be away from the populated area so that there may be no effect of pulverised fuel, residues and fumes on the population.

All the factors given above make us to select the site for the thermal power station away from the towns. Now-a-days more importance is given to the facilities for generation than those of distribution and a site for steam power station near by river side, where ample water is available, no pollution of atmosphere occurs and fuel can be transported easily, is an ideal choice.

Constitutents of Steam Power Station and Layout. The important parts and auxiliaries of steam power stations are discussed below :

(*i*) *Steam Generating Equipments.*

(*a*) *Boilers.* Steam boilers used in steam plants are of two types namely fire tube and water tube. In fire tube boilers, the tubes containing hot gases of combustion inside are surrounded with while in water tube boiler, the water is inside the tubes and hot gases outside the tubes. Fire tube boilers use is limited to low cost, small size and low pressure (to about 10 kg/cm^2) plants. For central steam plants of large capacity, water tube boilers are usually used. The water tube boilers have following advantages over fire tube boilers.

1. It has high evaporative capacity due to having a large heating surface ;
2. Owing to rapid and uniform circulation of water in tubes, it has better heat transfer to the mass of water and better efficiency.
3. It has high working pressure due to small size of drum.
4. Owing to large ratio of heating surface to water volume, it has quick raising of steam.
5. It has got safety in operation.
6. It occupies less space.
7. Overall control is better.
8. Easy removal of scale from inside the tubes.

Fire tube boilers for low pressure are cheaper and capable of meeting large fluctuation in steam demands due to greater water storage in the drum.

The design of boiler depends upon weight, height, portability, safety, bulk, character of operating labour life, efficiency and cost. The boilers may be straight or bent tube of diameter ranging from 25 mm to 100 mm; longitudinal or cross drum, horizontal, vertical or inclined tube, forced or natural circulation, single or multi-drum, sectional or box header, cross or parallel baffles, marine or stationary. Header boilers, using straight tubes are superseded by curved-tube drum type. Natural circulation (by density difference) of water is used with pressure upto 175 kg/cm^2. Pumps giving controlled circulation, are often preferred on design delivering more than 3,40,000 kgm of steam per hour at pressures above 100 kg/cm^2.

(*b*) *Boiler Furnaces*. The construction of boiler furnace varies from plain refractory walls to completely water cooled walls, depending upon characteristics of fuel used and ash produced, firing methods, nature of load demand, combustion space required, excess air used, operating temperature, initial and operating cost. Water walls are built of tubes of diameter from 25 mm to 100 mm variously spaced, with or without fins or studs, and bare or with different thickness of moldable refractory on the inner face. Heat transfer rates run from 50,000 to 150,000 B. Th. U. per hour cubic ft. of surface. To meet these requirements of heat transmission, circulation on the water side should be adequate, obtained by convection or by pumps. Air cooled walls are no more preferred. Surrounding the furnace, and the rest of the boiler, is the insulated casing which may be finished in plastic or with a sheet-metal sheath. The boiler is supported on its own structural steel with provision for expansion.

There are two methods of firing coal in boiler furnaces *i.e.* hand firing and mechanical firing. Hand firing of coal is limited to small or transient services (less than 4,500 kg of stream per hour) where the inefficiency of poor combustion control is acceptable. Stokers give mechanical feeding of coal. Mechanical stoker receive fuel by gravity, carry it to the furnace for combustion and after combustion, discharge the ash at the appropriate point. The advantages of stoker or mechanical firing over hand firing are given below :

(*i*) There is uniform feeding of fuel into the furnace.

(*ii*) There is better regulation and efficient combustion due to easy control of firing.

(*iii*) Lobour cost is less.

(*iv*) There is a possibility of use of poor grades of coal due to better control.

(*v*) Combustion capacity is more.

Mechanical stokers are of two types namely over feed stokers and under feed stokers. In the over feed stokers, the fresh fuel is added to the top of the burning fuel bed while in the under feed stokers the fresh fuel is introduced from below the burning fuel. Underfeed stokers are suitable for cooking type coals and run with fuel bed thicknesses upto 60 cm. Travelling or chain grate stokers are used for burning middle-western bituminous coals with fuel beds less than 15 cm in thickness and grate travel rates of 30 to 60 cm per minute. Spreader stokers, with dumping or travelling grates, are suitable for a wide variety of coals using thin fires (5 to 7 cm).

Solid fuels can be used in a powdered form and burn like oil and gases. The coal is first dried usually by the flue gases and then ground to a fine powder in pulverised mill. The pulverised fuel has the following advantages.

(*i*) It enables the boilers to operate for longer period at maximum capacity

(*ii*) Steam can be raised rapidly.

(*iii*) There is possibility of high rates of combustion.

(*iv*) Quantity of air required for combustion is less.

(*v*) Efficiency can be increased if fuel and air are adjusted accurately.

(*vi*) Fuel used may be of low grade.

(*vii*) Ash removing troubles are not more.

However the pulverised fuels have the following disadvantages:

(*i*) Initial and running costs of pulverisation plant are high.

(*ii*) Higher thermal losses in the flue gases are caused by higher combustion temperatures

(*iii*) There is a risk of explosion.

(c) *Superheater and Re-heaters.* These consist of groups of tubes made of special steel (carbon steel for steam temperature up to 950°F, carbon-molybdenum steel for steam temperature of 1050°F and stainless steel for steam temperature of 1200°F) with an outside diametér from 25 mm to 64 mm. Tube bundle location and arrangement, with counter current, and/or parallel flow is dictated by type of firing, required steam temperature, and steam-temperature characteristic. The superheater tubes are heated by the heat of combustion gases during their passage from the furnace to the chimney.

Superheaters are of two types : (*i*) Radiant super-heaters and convection super heaters. Radiant type superheater is located in the furnace between the furnace water-walls, absorbs heat from the burning fuel through radiation and gives drooping characteristics—the temperature of superheat falls with the increase in steam output. Convection superheater is located well back in the boiler tube bank, receives its heat entirely from flue gases through convection and gives rising characteristics—the temperature of super-heat increase with the increase in steam out put. Convection super-heaters are more commonly used. Desired control of characteristic is obtained by :

(*i*) proportioning and locating surfaces in series.

(*ii*) using internal dampers on boiler gas side.

(*iii*) temp. rating by water or

(*iv*) supplementary burners. Heat transfer rates of 10 to 12 B.T.U. per hour per square ft per degree temperature difference are representative.

The steam is superheated to the highest economical temperature not only to increase the efficiency but also to have following advantages :

(*i*) Owing to its high internal energy, there is reduction in requirement of steam quantity for a given output of energy which reduces the turbine size.

(ii) Superheated steam being dry, turbine blades remain dry so the mechanical resistance to the flow of steam over them is small which increases the efficiency.

(iii) There is no corrosion and pitting at the turbine blades due to dryness of steam.

(d) *Econqmisers and Air pre-heaters.* It consists of a large number of closely spaced parallel tubes with thin walls and small diameter (about 50 mm) connected by, headers or drums. The tubes rate sometimes finned to increase the heat transfer surface. Economiser and air pre-heater are used to recover a part of heat that would otherwise be lost. These raise boiler efficiency lowering the stack temperature and saving the fuel but involve extra cost of installation and maintenance and additional requirement of floor space. Either one or both may be used or they may be omitted entirely. Economisers recover heat from the flue gases by adding it to the feed water on its way to the boiler, thus raising the temperature of water usually without evaporation. The feed water should be sufficiently pure which may not form scales and cause internal corrosion.

Air pre-heaters recover the heat from the flue gases by adding it to the air suppiied for combustion. This raises the temperature of the furnace gases, improves combustion rates and efficiency, and lowers the stack temperature, thus the overall efficiency of the boiler is increased. Air preheaters are of to types namely recuperative and regenerative types. The recuperative type uses a bank of straight light gauge steel tubes 25 mm to 75 mm. in diameter usually with the flue gases inside the tubes and air outside. The regenerative types transfers the heat by using slowly revolving drum (1 or 2 rpm) of corrugated metal which moves alternately through the hot gas and cold air streams.

(ii) *Condensers.* The condensers are used to create a suction at very low pressure at the exhaust of turbines to permit expansion of steam in the prime mover to a very low pressure and thus the efficiency is increased. The condensers also facilitate in removal of exhausted steam for use as feed water, air and non-condensable gases from steam when passing through them.

Condensers are of two types. The *jet type and surface type.* Jet type condensers which mix up steam and circulating water, are limited to small industrial applications (1,000 kW.), where best vacuum are not required (50 mm. to 125 mm. Hg abs). In jet type condensers, as the steam mixes with cooling water, so can not be used as feed water. So the jet type condensers being low in cost even are not used in modern power plants. Surface condensers, in which steam and cooling mediums are separated by a surface, prevail in large installations for best vacuum (12 mm. to 50 mm. Hg. abs.) and condensate must be conserved.

Surface condensers use welded steel plate for the shell with cast iron water boxes. Horizontal tube banks using 25 mm. diameter nonferrous tubes and tube sheets prevail. Tubes are generally rolled at both ends with a slight bowing or with a joint in the shell for expansion. Straight tubes, rolled at one end and with a packing ferrule at the other end, are used. For fresh water, tubes sheets are commonly Muntz or Admiralty metal, while tubes are brass, copper, arsenical copper or aluminium brass. Tubes support plates are of copper bearing steel. Divided water boxes and water flow reversal arrangements facilitate in cleaning and maintenance. The condenser is attached to turbine by :

(*a*) direct bolting to turbine exhaust flange (up to 20 MW).

(*b*) direct bolting to turbine exhaust flange with spring supports under the condenser.

(*c*) Solid support of condenser with expansion joint between the turbine and the condenser.

(*iii*) *Prime-Movers.* Steam prime movers are either reciprocating engines or turbines. Due to reciprocating motion steam engines have become obsolete in these days and steam turbines are usually used as prime movers. Steam turbines give high speed (1,800 to 5,000 r.p.m.), maximum size (275 MW), minimum floor space, bulk in weight, maximum efficiencies (80%) in large sizes, suitability for highest steam pressures (350 kg/cm^2), steam temperatures (1,200 °F), vacua (12.7 mm. mercury). All large units (above 1,000 kW.) are steam turbines.

According to the action of steam on moving blades, the steam turbines are of two types namely *impulse* and *reaction* types. These two types differ in working. In impulse turbines, the steam expands in nozzles only and when passing over the blades, its pressure remains constant. The jet passes over several rings of moving blades until its kinetic energy is expanded. In reaction type turbines, the steam does not expand in nozzles but expands as it flows over the blades, the blades will, therefore, act also as nozzles. The expansion of steam as it flows over the blades is adiabatic, any friction losses between the steam and blades are converted into heat, which, in turn will reheat the steam. The effect of this is to dry or superheat the steam as it flows over the blades.

The final velocity of steam will be extremely high if the steam is expanded in a single nozzle from the boiler pressure down to the condenser pressure. If this jet is now passed over a single blade rin and its kinetic energy is absorbed by this ring, it will be found tha the speed of this blade ring is too high for practical purpose. One o the chief objects in steam turbines development has been to devis of overcoming this high speed of turbine wheels. No reduction gea is required for the reaction type turbine because the speed bein relatively low.

The steam turbines used are of two types namely axial flow an radial flow type according to the type of flow of steam. In axial flo type turbines, the steam flows over the blades in a direction paralle to the axis of the wheel. In radial flow turbines, the blades ar arranged radially so that the steam enters at the blade tip nearest the axis of the wheel and flows towards the circumference.

The steam turbines having horizontal shaft are used. These may be :

(*i*) condensing or non-condensing.

(*ii*) single shaft or multiple shaft.

(*iii*) single or multiple cylinder.

(*iv*) single or double flow.

(*v*) extracting or non extracting.

(*vi*) controlled (automatic) or uncontrolled extraction.

(*vii*) reheat or non-reheat.

(*viii*) throttle or multiple nozzle governed.

(*ix*) constant or variable speed.

(*x*) single or double shell.

As regards the size of units to be installed, it depends upon several factors such as capital cost, spares required, load factor and the peak load of the system.

(*iv*) *Water Treatment Chamber*. The boilers require clean and soft water for their long lives. The water taken from a river or from other source of supply is stored in storage tanks. Water is sucke from storage tanks by pumps, purified and softened by chemical and then delivered to the boilers by means of feed pumps.

(*v*) *Control Room*. In case of remote control, the control room houses all the necessary measuring instruments for each panel of alternator and feeder, synchronising gear, protective gear, automatic voltage regulator, communication arrangement etc. A separate battery room and a motor generator set or a rectifier is also installed for supplying to make and trip circuit of switchgear. In case of outdoor switchgear, normally compressed air is used for operation.

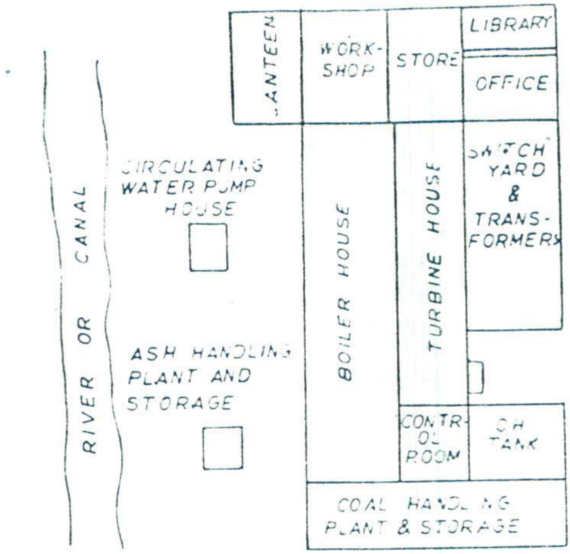


Fig. 11.2. The Layout of Thermal Power Station.

(*vi*) *Switch Yard.* The switchyard houses transformers, circuit breakers and switches for connecting and disconnecting the transformers and circuit breakers. It also has lightning arrestor for the protection of the power station against lightning strokes.

The supply to the bus-bàrs from alternators is taken through transformers and circuit brèakers of suitable ratings.

The power station over and above this requires workshop, store, labour canteen, library and also residential accommodation for the operating staff.

Example 1. *A thermal station has an overall efficiency of 21% and 0.7 kg. of coal is burnt per kWh of energy generated. Determine the calorific value of coal.*

(S.B.T.E. Final Year. (Elec. Engg.) 1973 Supp.)

Solution. Heat produced by 0.7 kgm of coal

$$=\frac{\text{Output in heat units}}{\text{Overall efficiency}}=\frac{1\times 860}{0.21}=4,095 \text{ k. cals}$$

Since $1 kWh = 860$ k. cals.

Heat produced by 1 kgm of coal

$$=\frac{4,095}{0.7}=5,850 \text{ k. cals}$$

Hence calorific value of coal = 5,850 k. cals/kgm Ans.

Example 2. *Determine the thermal efficiency of a power station and its coal bill per annum from the following data :*

Maximum demand	*20,000 kW*
Load factor	*40%*
Coal consumption	*1.93 lb/unit generated*
Boiler efficiency	*85%*
Turbine efficiency	*90%*
Price of 1 ton of coal	*Rs. 30*

[A.M.I.E. Sec. B. Nov. 1965]

Solution. Thermal efficiency of power station

= Boiler efficiency × Turbine efficiency

$= 0.85 \times 0.9 = 0.765$ or 76.5% **Ans.**

Units generated per annum = Maximum demand in kW. × load factor × 8,760

$= 20,000 \times 0.4 \times 8760 = 7,008 \times 10^4$ kWh.

$$\text{Coal consumption per annum} = \frac{7,008 \times 10^4 \times 1.93}{2,240} \text{ tons}$$

$$\text{Cost of coal/annum} = \text{Rs.} \frac{7008 \times 10^4 \times 1.93 \times 30}{2,240} = \text{Rs.} 18,11,443 \textbf{ Ans.}$$

2. Hydro-electric Power Stations. For hydro-electric power stations water collected in natural lakes and reservoirs at high altitude is utilised or water may be artificially stored by constructing dams across flowing streams. The pressure head of water or kinetic energy of water is utilised to drive the water turbines coupled to the alternators which generates the electric power.

Due to limited reserves of fuels and increasing demand of electric power the hydro-electric power stations are becoming more and more popular in these days. The hydro-electric power stations are generally located in hilly areas, where dam can be built easily and large reservoirs can be obtained.

The operating cost of hydro-electric power plant is about Rs. 200 per kW of installed capacity and Rs. 0.01 per unit generated.

The hydro-electric power stations have the following advantages ad disadvantages.

Advantages. (*i*) No fuel other than water is the source of energy required in it.

(*ii*) It can be put into service instantly

(*iii*) Cheapest in operation and maintenance.

(*iv*) Such power stations have constant speed and hence constant frequency as very acute governing is possible with water turbines.

(*v*) No standby losses are there.

(*vi*) Such plants have got longer life.

(*vii*) It is very neat and clean plant as there is no smoke or ash.

(*viii*) Highly skilled engineers are required only at the time of construction but later a few experienced persons will be sufficient.

(*ix*) In addition to generation of electric power such plants also serve other purposes such as irrigation and flood control.

Disadvantages. (*i*) Large area is required for its installation.

(*ii*) It has very high construction cost.

(*iii*) Very longer period is required for its erection *i.e.* from 5 to 7 years.

(*iv*) Transmission lines cost more.

(*v*) The power supply may be effected due to long dry seasons.

Factors to be considered for the location of hydro-electric power stations.

The following factors should be taken into consideration for the location of hydroelectric power stations.

(*i*) Such power stations should be built where there is adequate water available at good head or huge quantity of water is flowing across a given point as generation of electric power depends upon the potential energy of water fall or kinetic energy of flowing stream.

(*ii*) Convenient accommodation for the erection of a-dam or reservoir must be available because storage of water in a suitable reservoir at a height or building of dam across the river is essential in order to have continuous and perennial supply during the dry season.

(*iii*) The reservoir must have a large catchment area to maintain the level of water in the reservoir required in the dry season.

(*iv*) The land should be of reasonable cost and rocky to withstand the weight of large building and heavy machinery.

(*v*) Adequate transportation facilities must be available nearby.

(*vi*) There should be possibility of stream diversion at the time of construction.

Elements of a Hydroelectric Plant. An hydro-electric plant consists of a diversion dam, a conduit to carry the water to the water wheel, the power house and its equipment, and a tail race. The size, location, and type of each of these essential elements depend upon the topography and geological conditions and the amount of water to be used. The height to which the dam is to be built is usually limited by the extent of flowage damage. Pondage may have great value, particularly for peak load power plants. The spillway section of the dam must be long enough to pass safely the maximum amount of water to be expected. Likewise the abutments and other short structures must be built to withstand successfully the greatest freshet conceivable on the river.

(*i*) *Dams.* The dam may be either impounding (or non-overflow type) or spillway (or flow type). In case of non-overflow type dams, means are provided to release excess flow, by a separate spillway section by regulating valves, or by large spillway gates. Non-overflow type dams are earth dams, rock-fill dams, and high-reservoir arch dams.

(*ii*) *Spillway.* This is constructed to act as a safety valve. It discharges the overflow water to the down stream side when the reservoir is full. These are generally constructed of concrete and provided with water discharge opening shut off by metal control gates. By changing the degree to which the gates are opened, the discharge of the head water to the tail race can be regulated to maintain the water level in the reservoir.

(*iii*) *Intakes.* It may consist of canals, flumes, pipe lines, and pressure tunnels with or without *forebays*, which provide a small amount of reservoir capacity to take care of variations in load. When long flow lines in close conduits are used and a forebay cannot be constructed, *surge tanks* are usually provided to care for the fluctuations in load.

(*iv*) *Penstocks.* Penstocks are built of steel or reinforced concrete. Steel penstocks are almost always welded on the longitudinal seam. The circumferential seam may be welded also. It is a closed conduit which connects the forebay or surge tank to the scroll case of the turbine. In case of medium head power plants, each unit is usually provided with its own penstock. In case of high head plants, a single penstock is frequently used, and branch connections are provided at the lower end to supply two or more units. In long penstocks great care is to be taken to protect the conduit against water hammer. The thickness should be adequate to bear both the normal hydrostatic pressure and also the sudden surges both above and below normal caused by fluctuations in load and by emergency conditions.

(*v*) *Valves and Gates.* In low head plants gates are needed at the entrance to the turbine casing to close the flow of water for inspection and repairs. Individual hoist-operated gates are provided in cases where frequent shut downs are required and where the time available for inspection is limited. Other plants use stop gates or stop logs placed in sections by means of travelling crane. While using medium or longer length penstocks or a common penstock for more than one unit, it is necessary to install valves at or near the entrance to the turbine casing. These are usually of the *butterfly or pivot* type for low and medium heads.

(*vi*) *Rocks.* These are built up from long, flat bars set vertically or nearly and spaced in accordance with the minimum width of water passage through the turbine. The clear space between the bars varies from 25 mm or 40 mm to 150 or 200 mm on very large installations. These are used to prevent the ingress of floating and other material to the turbine. In some cases where large diameter turbines are used, the racks are omitted, but provision is made for skimmer walls or booms to prevent ice and other material from entering the unit.

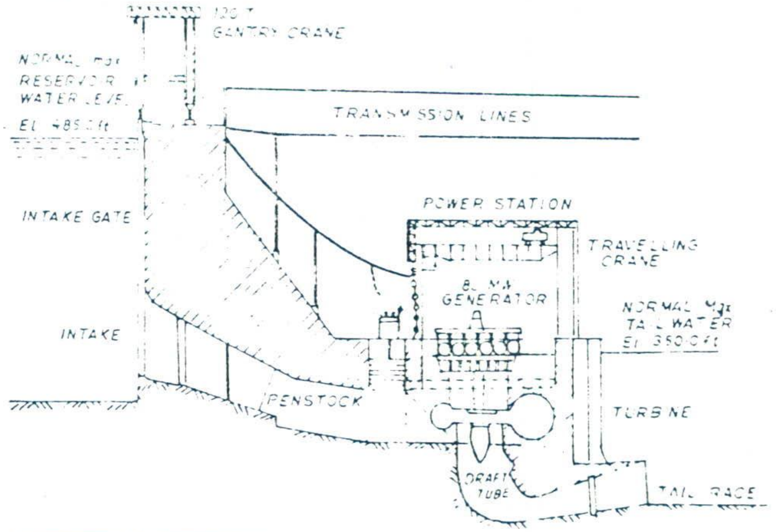


Fig. 11.3. The Hydro-Electric Schemes.

(*vii*) *Tail Race.* The water after having done its usual work in the turbine is discharged to the tail race which may lead it to the same stream or to another one.

(*viii*) *Draft Tubes.* An air tight pipe of suitable diameter connected to the runner outlet and conducting water down from the wheel and discharging it under the surface of the water in the tail race is known as *draft tube*. It is provided to increase the head acting on the water wheel.

(*xi*) *Prime Mover or Water Turbines.* According to the type of flow of water, the water turbines used as prime movers in hydro-electric power stations, are of four types, namely (*i*) *axial flow turbines* having flow of water along the shaft axis such as propeller and Kaplan turbine (*ii*) *inward radial flow turbines* having flow of water along the radius such as Francis turbine (*iii*) *tangential flow turbine* having flow of water along the tangential directions such as Pelton wheel and (*iv*) *mixed flow* (radial inlet and axial outlet) such as Francis turbine. According to the action of water on moving blades, water turbines are of two types *viz impulse and reaction type turbines. In the impulse type turbine* the entire pressure of water is converted into kinetic energy in a nozzle and the jet thus formed drives the wheel. Whereas in *reaction type turbine,* the water pressure combined with its velocity, work on the runner.

According to the name of the originator water turbines are of three types, *viz* Pelton wheel, Francis turbine and Kaplan turbine.

The Pelton Wheel. It is an impulse type turbine and is suitable for high head and low flow plants. It consists of a rotor equipped with elliptical shaped buckets along the periphery of the turbine. The rotor starts turning due to impact of the jet on the buckets. The quantity of water discharged by the nozzle is controlled by controlling the nozzle opening by means of a needle placed in the tip of nozzle. The movement of the needle is controlled by the governor. Deflectors are used for control of speed in addition to the needle.

Francis Turbine. In these turbines water glides over the blades of a turbine with a small and fairly constant velocity and exerts a pressure varying from maximum at the top to a small value at the bottom. The water flows radially inward towards the centre. The guide blades of the turbine are each pivoted about an axis in parallel with the turbine axis so that quantity of water entering the turbine may be regulated by turning them simultaneously in one direction or the other. It is a reaction type turbine and is suitable for low to medium head and water flow plants. It essentially consists of "guide apparatus" consisting of an outer ring of stationary guide blades fixed to the casing of the turbine and an "inner ring" consisting of rotating blades forming a wheel or a runner. Like Pelton wheel their motion is automatically controlled by governors.

The full load efficiency of this type of turbine is about 92 per cent. Francis type turbines can be constructed in vertical or horizontal forms. The horizontal constructions are more accessible and have higher speed ; but for large machines generally vertical construction is preferred.

Kaplan Turbine. In this type of turbine the drawback of considerable loss at low loads due to rotary motion of water in Francis turbine is overcome and uniform efficiency at all loads is maintained. It is also a reaction type turbine and has gate and governing mechanism similar to that of a Francis turbine. The difference between Kaplan turbine and Francis turbine is that in the former runner, the water strikes the turbine blades axially whereas the latter receives water radially. This type of turbine is suitable for low head and large flow plants. Kaplan turbine gives high speed than ordinary Francis turbines. The characteristic features of Kaplan turbine is that the gate opening and blade angle are adjusted simultaneously by the governing mechanism. Its efficiency is about 90 per cent at all loads.

Propeller Turbine. In these turbines, the blades are casted integrally with the hub. It is an axial flow turbine and has got no provision for changing the runner blade angles while the turbine is in motion. Its efficiency is about 92 per cent at full load and drops to 65 per cent at half full load.

Classification of Hydro-electric Plants.

On the basis of operating head, Hydro-electric power plants may be classified as (*i*) low head (*ii*) medium head, and (*iii*) high head plants. Though there is no definite line of demarcation for low, medium and high heads but the head below 60 metres is considered as low head, the head above 60 metres and below 300 metres is considered as medium head and the head above 300 metres is considered as high head.

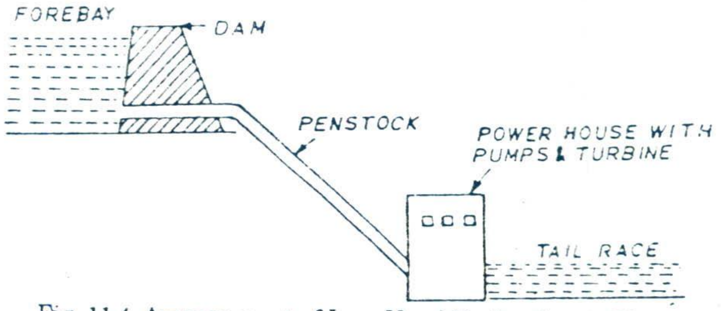


Fig. 11.4. Arrangement of Low Head Hydro-electric Plant.

In low head plants Kaplan turbines are used. In these plants a pipe of large diameters and short lengths are required. Head being low, and large quantity of water is required for a given output. Structure of such plants is extensive and expensive. Generators used in such plants are of low speed and large diameters.

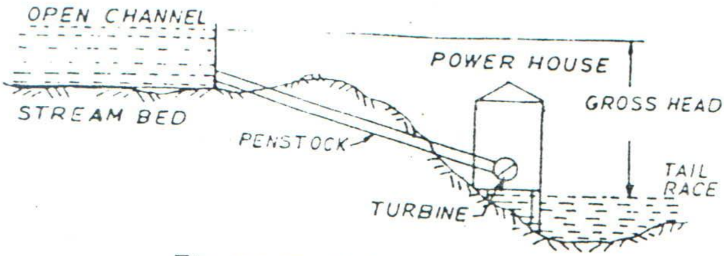


Fig. 11.5. The Medium Head Plant.

Medium Head Hydro Electric Plants. In such plants horizontal shaft Francis turbines are used. The characteristic of medium head plant may be either of high head or of low head plants according to its working head nearer to high head or low head.

High Head Hydro-Electric Plants. For the installation of such plants, a site may be chosen, where a stream descending a steep lateral valley can be dammed and a reservoir for storage of water is formed. A pressure tunnel is constructed between reservoir to valve house at the start of penstock to carry water from reservoir to valve house. Surge tank (a tank open from the top) is built just in between the start of penstock and the valve house so that the severity of water hammer effect on penstock can be reduced in case of sudden closing of fixed gates of the water turbine. When there is sudden increase in demand, surge tank serves as a ready reservoir from which the turbine can draw water temporarily. The valve house consists of main sluice valves and automatic isolating valves, which operate on bursting of penstock and cut off further supply of water to penstock. Penstocks are steel pipes and carry the water from the valve house to the turbines.

In such plants Pelton wheels or jet impulse turbines are employed. The generators employed are of high speed and small diameter. Penstocks are of large length and of comparatively smaller cross section.

Hydro-plant Auxiliaries. The auxiliaries required for hydro-electric plant are governor, cranes lubricating oil pumps, air compressors, high pressure oil pumps for generator motor jacking system, fans, cooling water pumps, drainage and dewatering pumps, gate hoists, valves, battery charging units, CO_2 cylinders etc. These auxiliaries are generally electrically driven. Water is used to cool the bearings of the turbines and generators and the transformer and is circulated through water pumps. Air compressors maintain a supply of air under pressure for operation of generator brakes and other uses in the power station. Fans are used for ventilation of the turbine and switchgear room or for cooling transformers. Oil pumps handle transformer oil through the cleaning and cooling system. Cranes are used to lift heavy parts or replace them in position during repairs. Water pumps are used for unwatering of turbine pits during repairs or inspection. Storage batteries are used to supply low voltage d.c. power for switchgear control. These batteries are constantly charged through a battery charging equipment using a rectifier or motor generator set. Carbon-di-oxide cylinders and other fire extinguishing equipment are used in case the fire breaks out. The supply for the above auxiliaries is usually obtained from the station transformer, which is installed solely for this purpose.

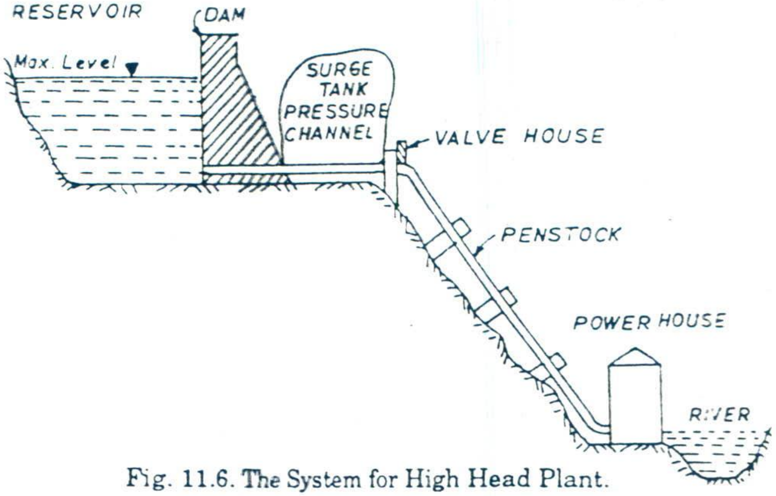


Fig. 11.6. The System for High Head Plant.

Example 1. *A hydro-electric generating station is supplied from a reservoir of capacity 20 million cubic metres at a head of 180 metres. Calculate the total electrical energy generated in kWh if the hydraulic efficiency be 0.8 and the electrical efficiency 0.9.*

(A.M.I.E. Sec. B. Hydro-Power Engg. Nov., 1967)

Solution. Volume of water. $V = 20 \times 10^6$ cubic metres

Weight of water available, $W = 20 \times 10^6 \times 1,000 = 20 \times 10^9$ kgm

Head of water, $H = 180$ metres

Total electrical energy generated

$$= W \times H \times \eta_h \times \eta_e$$

$$= 20 \times 10^9 \times 180 \times 0.8 \times 0.9 \text{ kgm}$$

$= 2,592 \times 10^9 \times 9.81$ Nw-m or Joules or watt-secs

$$= \frac{2,592 \times 10^9 \times 9.81}{1,000 \times 3,600} \text{ kWh}$$

$= 70,63,200$ **kWh Ans.**

Example 2. *Determine the power that can be generated in a hydro-station having an available head of 40 metres, a catchment area of 6×10^8 sq. metres. The rainfall per annum is 1.5 metres. Given that 65% of the total rainfall can be collected. Assume the following efficiencies :*

Penstock 95% ; turbine 85% and generator 90%

[S.B.T.E UP Final Year (Elec. Engg.) 1973]

Solution. Catchment area, $A = 6 \times 10^8 \text{ m}^2$

Annual rain fall, $F = 1.5$ metres

Volume of water available per annum

$= A \times F \times K$

$= 6 \times 10^8 \times 1.5 \times 0.65 = 585 \times 10^6 \text{ m}^3$

Where k is the yield factor to allow for run off and loss by operation and is equal to 0.65

Weight of water available per annum,

$= 585 \times 10^6 \times 1000$ kg]

$= 585 \times 10^9$ kg [Since 1m^3 of water weighs 1000 kg

Weight of water available per second

$$W = \frac{585 \times 10^9}{8760 \times 3600} = 18,571 \text{ kg}$$

Head of water, $H = 40$ metres

$$\text{Average power in kW} = \frac{WH \times 9.81}{1000} \times \eta_p \times \eta_t \times \eta_g$$

$$= \frac{18571 \times 40 \times 9.81 \times 0.95 \times 0.85 \times 0.9}{1000}$$

$= 5340$ **Ans.**

Example 3. *An hydro-electric station is supplied from a catchment area of 150 square km with an annual rainfall of 150 cm. and effective head of 300 metres. Assume a yield factor of 50%, overall efficiency of 80% and a load factor of 40%, calculate the available continuous power and the rating of the generator installed.*

[D.T.E. Final Year. (Elec. Engg.) 1959]

Solution.

Volume of water available per annum = Catchment area × rain fall

$$= 150 \times 10^6 \times 1.5 = 225 \times 10^6 \text{ m}^2$$

Volume of water utilised = Volume of water available × yield factor

$$= 225 \times 10^6 \times 0.5 = 112.5 \times 10^6 \text{ metres}^3$$

Weight of water utilised per annum, $W = 112.5 \times 10^6 \times 1,000$ kg

$$= 112.5 \times 10^9 \text{ kgm}$$

since 1m^2 of water weighs 1,000 kgm

Head of water, $H = 300$ metres

Stored energy in catchment area = WH

$$= 112.5 \times 10^9 \times 300 \text{ kg-m}$$

$$= 3,375 \times 10^{10} \times 9.81 \text{ Joules or watt-secs}$$

Total electrical energy available = stored energy × overall efficiency

$$= 3,375 \times 10^{10} = 9.81 \times 0.8 \text{ Joules or watt-secs}$$

$$= 26,487 \times 10^{10} \text{ watt-secs}$$

$$= \frac{26,487 \times 10^{10}}{3,600 \times 1,000} \text{ kWh}$$

$$= 73.6 \times 10^6 \text{ kWh}$$

$$= \frac{\text{Total energy available}}{8,760}$$

$$= \frac{73.6 \times 10^6}{8,760} = 8,400 \text{ kW Ans.}$$

$$\text{Installed capacity of the plant} = \frac{\text{Average load}}{\text{load factor}} = \frac{8,400}{0.4}$$

$$= 21,000 \text{ kW} \textbf{ Ans.}$$

3. Diesel Power Stations. Diesel power stations are installed where supply of coal and water is not available in sufficient quantity or where power is to be generated in small quantity or where standby sets are required for continuity of supply such as in hospitals, telephone exchanges, radio stations and cinemas. One or more diesel engine driven generators may be installed in a medium size power stations either to supply the peak loads for small duration or for seasonal loads. These may be used for supplying power to auxiliaries in the event of a failure of the main working units in a steam plant. The advantages and disadvantages of diesel-electric power stations are follows :

Advantages. (*i*) Such plants are very simple in design and installation.

(*ii*) The efficiency of such plants at part loads is not reduced so much as that of a steam plant.

(*iii*) Such plants give good response to varying loads without any difficulty.

(*iv*) Such-plants occupy less space because of using minimum auxiliaries.

(*v*) Low cost of building and civil engineering works.

(*vi*) The standby losses are less.

(*vii*) Less quantity of water required for cooling purpose.

(*viii*) Such plants can be started and put on load without wasting any time.

(*ix*) The overall capital cost including installation per unit of installed capacity is lesser in comparison to steam plant.

(*x*) Being simpler in operation such plants requires lesser operating and supervising staff as compared to that for steam plants.

Disadvantages. (*i*) Due to high cost of diesel oil as fuel, the operating cost is very high.

(*ii*) Maintenance and lubrication cost is also high in comparison to other plants.

(*iii*) Diesel plants are unable to supply overloads continuously whereas steam plants can work under 25% overload continuously.

(*iv*) These units cannot be constructed in large size because of limited capacity.

Diesel Plant Elements. A diesel-electric power plant consists of the engine proper and the auxiliary equipment as given below.

(*i*) *Engine air intake system including air filters, ducts, supercharger (integral with the engine).* The air required for compression purposes in each cycle is supplied through the air filters to prevent the dust particles from ingress to the cylinder.

(*ii*) *Engine fuel system including fuel storage tanks, fuel transfer pumps, strainers, heaters and connecting pipe work.* The fuel oil for the whole day is transferred to the all day tank by means of transfer pump. The fuel is passed through the strain to remove suspended impurities. From this tank the fuel oil is fired into the engine through fuel filter and fuel injection pump.

(*iii*) *Engine exhaust system including silencers and connecting ducts.* This system is provided to discharge the engine exhaust to the atmosphere outside the building. The exhaust manifold connects the engine cylinder exhaust to the exhaust pipe provided with a muffler in order to reduce pressure in the exhaust line and eliminate most of the noise which may result if the waste gases are discharged directly into the atmosphere. In case of diesel-electric generating units installed in steam plants, exhaust system also includes water heaters and steam boilers to utilise the heat of waste gases.

(*iv*) *Engine cooling system including cooling pumps towers or spray ponds, water treatment or filtration plant and connecting pipe.* For cooling of engine cylinder, the cooling water is passed through the jacket. The water used for cooling engine cylinder is softened by water treatment or water filtration plant to avoid formation of scales etc. in it. Hot well is provided in the surge tank to make a provision of jacket water.

(*v*) *Engine lubricating oil system including lubricating oil pumps, oil tanks, filters, coolers, purifiers and connecting pipe work.* The lubricating oil is drawn from the sump by means of a pump and is passed through a strainer and filter. Usually the lubricating oil is hot when drawn from the sump, if it is not, it should be heated, first before passing through the filters, to increase its viscosity and make the filtration easy. The oil is then cooled through a heat exchanger and then sent into engine.

(*vi*) *Engine starting system including battery, starter, compressed air supply etc.*

Small sets are usually started manually by handles but for sets

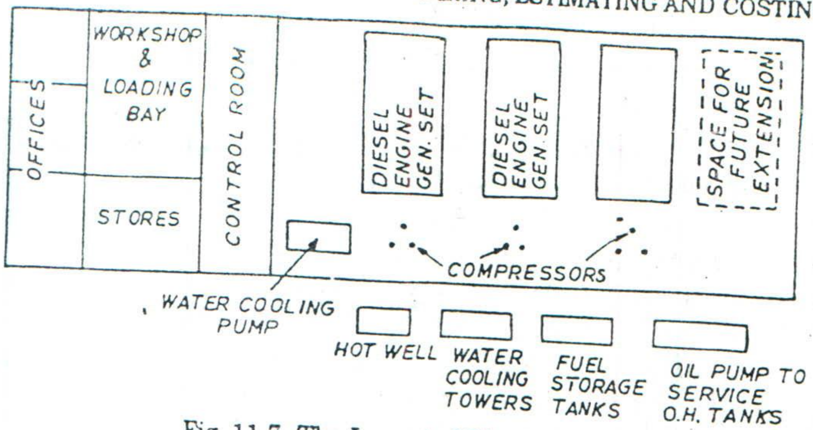


Fig. 11.7. The Layout of Diesel Plant

of large capacity say above 75 kW, the compressed air is required to be sent into the engine for starting purpose. Battery driven motors can also be used for starting purposes.

Example. *A diesel power station has fuel consumption of 0.25 kg. per kWh, the calorific value of the oil being 10,000 k.cals per kgm. Estimate the overall efficiency of the power station.*

Solution. When output = 1 kWh = 860 K. cals

Input = fuel consumption per kWh output × calorfic value of fuel

$$= 0.25 \times 10{,}000 \text{ K. cals} = 2{,}500 \text{ K. cals}$$

$$\text{Overall efficiency} = \frac{\text{output}}{\text{input}} \times 100 = \frac{860}{2500} \times 100 = 34.4\% \textbf{ Ans.}$$

4. Nuclear Power Stations. The nuclear power station has been developed due to attention of scientists towards the peaceful applications of atomic energy. The first atomic power plant was commissioned in U.S.S.R. on June 27, 1954 and after that a number of atomic power plants have been commissioned in many countries like U.S.A, Canada, Great Britain, Japan and France. In our country also two atomic power plants are working. The first one is Tarapur Atomic Power Station and the other is Rana Partap Atomic Power in Rajasthan. The atomic energy commission has plans to generate 2,700 MW of electricity from nuclear power stations by 1978-79. To generate 2,700 MW some more stations have yet to be installed in various states.

According to the atomic energy commission, the generation from the coal based station located with in 80 km of the coal mines is cheaper than that from nuclear power plant. The most suitable area for nuclear stations are Western U.P., Northern and Western Rajasthan, Punjab and Haryana. According to experts of the atomic energy commission power generation from 1,000 MW nuclear station will be one paisa/unit cheaper than the coal based power station. A 1,000 MW power station will feed 560 crore units/year into the system excluding the spinning and cold reserve. The saving in the energy bill of a nuclear power station will be Rs. 5.6 crores per year.

The basic requirements for the location of a nuclear power station (*i*) The adequate supply of water for cooling should be available (*ii*) adequate land away from habitation (*iii*) Safety of the area is essential from the danger of floods and (*iv*) accessibility of site by rail and roads.

Fuel used. The main fuels used to produce the atomic energy are Uranium (U_{235}), Thorium (Th_{237}) and Plutonium (PU_{232}). It has been estimated that uranium alone contains far more energy than all the world's resources of coal and petroleum put together.

Fig. below shows a flow diagram of a nuclear power station.

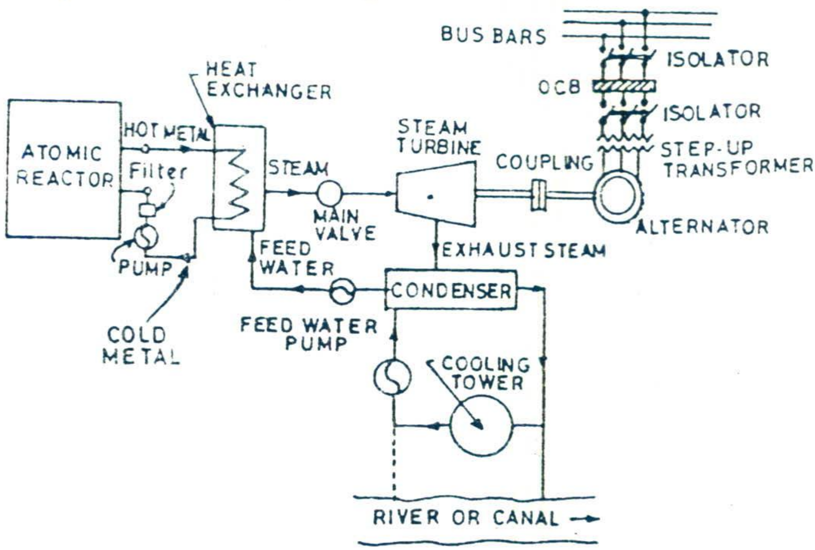


Fig. 11.8. System of Atomatic Power Station.

The above metals become unstable and transformed to metals of lower atomic weights like silicon, nickel etc. by Fission Process. The splitting of 1 kg of Uranium (U_{235}) atoms yields 25×10^6 kWh in heat form, which when conveyed to gas turbine or steam turbine through molten metal and heat exchanger results in about 6.5×10^6 kWh of electrical energy. Thus energy obtained by fission of 1 kg of uranium is roughly equivalent to that obtained by burning about 2,500 tonnes of high grade coal.

By Fission Process, in an atomic reactor, when the atoms of Uranium or other similar metals of large atomic weight are broken into metals of lower atomic weight, the tremendous amount of heat energy produced is extracted by pumping fluid or molten metal like liquid sodium or gas through the pile. The heated metal or gas is the allowed to exchange its heat to the heat exchanger by circulation. In heat exchanger, the gas is heated or steam is generated which are utilised to drive gas turbine or steam turbine coupled to an alternator, thereby, generating electrical energy.

Characteristics of Nuclear Power Plants. (*i*) These plants are most economical in large capacity. The capital cost of such power plants is Rs. 3,000 per kW excluding the investment on fuel process, which is about Rs. 500 per kW.

(*ii*) There is no transportation difficulty as the quantity of fuel required is very small.

(*iii*) The primary distribution cost is less because these plants can be located near the load centre.

(*iv*) Such plants are very useful to be employed as base load plants because the running cost is quite low and is independent of loading of the station though the capital cost is very high.

(*v*) The ouput control is extermely flexible.

5. The Gas Turbine Power Plant. The gas turbine utilises the heat developed by the combustion of gaseous and liquid fuels. The principle is that a turbo-compressor compresses pure air or air and gas to a high compression and then it is burnt in the combustion chamber where combustion takes place at a constant pressure and the products of combustion expands down to atmospheric pressure in the turbine. Gas turbine sizes vary from 40 to 30,000 kW.

Advantages of gas Turbine Power Plant. 1. simplicity and flexibility of design and installation, 2. compactness, 3. low initial cost, 4. require small building space 5. require little cooling water. 6. The delivery and installation time for these power plants is much less than for steam plants. 7. The gas turbines can be started quickly and can be put to share full load within a few minutes. 8. Efficiency can be improved considerably by using heat economy devices. 9. Maintenance costs are lower than for diesel power plants. 10. Petroleum distillate fuels are quite suitable though expensive. 11. Natural gas is also a very suitable fuel and cheap as it is an ideal source of power for gas turbines.

Disadvantages. 1. The main draw back of gas turbines in that coal or heavy residual petroleum can not be easily used in the combustion chamber and life of the chamber is considerably reduced due to high temperature sodium-vanadium attack. 2. The fuel costs in such plants are usually higher than in other plants.

Application of Gas Power Plants. (*i*) It can be used for driving generators and supplying peak loads in other types of power plants.

(*ii*) It can be used for supplying mechanical drive for auxiliaries

(*iii*) It can be used for operating as combination plants with conventional steam boilers.

Elements of Simple Gas Turbine Plant. A simple gas turbine plant consists of the reaction type non-condensing turbine, a compressor mounted on the same shaft or coupled to the turbine, the combustion chamber, generator coupled to turbine itself and auxiliaries such as starting device, auxiliary lubrication pumps, oil system, fuel system and the duct system etc. The air is sucked in by the compressor from the atmosphere and discharges it at high pressure and temperature into the combustion chamber and burns in the stream of air supplied from the compressor outlet. A part of the air is delivered ahead of the burning fuel to cool the very hot combustion products (at temperature of about 3,000° F) and brings them to a temperature of about 1350°F which is allowed to enter the turbine without causing damage to the first few rows of blades. The gases ensuing are then expanded in the turbine resulting in motion of rotor and finally discharged to the atmosphere at a temperature of about 1000°F. The power developed, in the turbine due to expansion of gases is sufficient to drive the compressor, generator and auxiliaries.

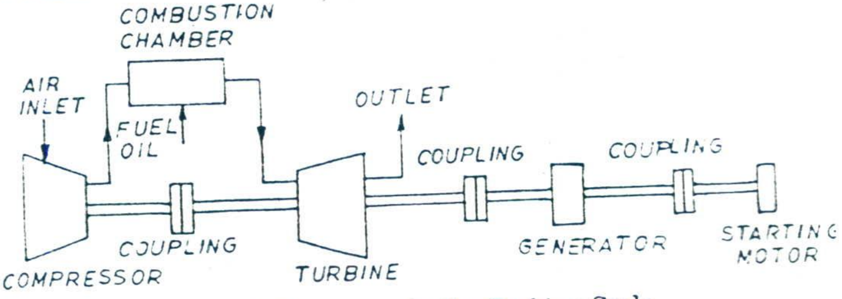


Fig. 11.9. The system for Gas Turbine Cycle.

The overall efficiency of such plants is very low (about 20%) as compared to that of a diesel engine plant (about 35%). However, by using regenerator, intercooler and reheater, the efficiency of the plant can be improved.

Comparison Between Various Types of Power Stations.

Particulars	*Hydro electric power stations*	*Steam power stations*	*Atomic power stations*	*Diesel-electric power stations*
1. Site	The site with sufficient area is available, water in huge quantity and at a sufficient head is available, the land is cheap and rocky and transportation facilities are available. These power stations are usually far from the load centres.	These plants are located near the load centre but other factors such as supply of fuel and water, cost of land, available area and transportation facilities are also taken into consideration. Location of steam power stations to some extent is flexible as compared with that of hydro-electric plants.	These plants are located near the centre of load.	These plants can be installed anywhere.
2. Transmission and distribution cost.	Long transmission lines are required and hence transmission and distribution cost is very high to some extent.	Short transmission lines are required and so transmission and distribution cost is low as compared to Hydro-electric Power station.	Transmission and distribution cost is very low.	Transmission cost is nil and distribution cost is also very small.
3. Initial cost	Initial cost is very high as compared to thermal power stations due to large amount of excavation work and heavy cost of transportation of the plant and machinery.	Initial cost is low as compared to the hydro-electric and atomic power plants.	The capital cost is very high as compared to all other types of power stations due to heavy cost of nuclear reactors and heavy cost of erection as highly specialised and expert engineers are required for its erection work.	The initial cost is the minimum.

Particulars	Hydro-electric power stations	Steam power stations	Atomic power stations	Diesel-electric power stations
4. Operating cost.	Since no fuel is required, so cost of operation is practically nil.	Operating cost of these plants is very high as compared to hydro-electric plants and atomic power plants but low as compared to diesel electric power station.	The operating cost is very low as compared to all other types of stations except that o˘ hydro-electric plants.	The operating cost is very high as compared to all other types of power stations.
5. Cost of transportation of fuel.	Cost of transportation of fuel is nil as no fuel is required.	Cost of transmission of fuel is very high especially when the power plants are away from the coal mines and has no railway siding.	Cost of transportation of fuel is very low because fuel in very small quantity is required (in terms of kgms.)	Cost of transportation of fuel is higher than that for hydro-electric plants and atomic power plants but lower than that for steam power plants.
6. Limit of source of power.	Source of power, *i.e.* water in case of hydro-electric plants is not dependable because it depends upon the rain fall, which is at the whim of nature.	Source of fuel *i.e.* coal reserve all over the world is considered to be fixed and therefore coal mines are being exhausted and the time may come when there may be scarcity of coal.	The source of power is unlimited since large deposits of fissionable materials all over the world are available.	Source of fuel *i.e.* diesel is not available in plenty.
7. Reliability	Hydro-electric plant is simple, robust and more reliable.	Steam power plants are less reliable.	These plants are reliable.	Diesel electric power plants are less reliable.

(Contd.)

Particulars	*Hydro-electric power stations*	*Steam power stations*	*Atomic power stations*	*Diesel-electric power stations*
8. Simplicity and cleanliness.	Hydro-electric plants are most simple and clean.	Atmosphere is polluted by fumes and residues of pulverised fuels.	The handling of atomic power station is quite complicated as radiation hazards are involved in it. Special outfits are designed and employed by the operating staff.	These plants are simple and clean than steam plants and atomic power plants.
9. Maintenance cost.	Maintenance cost is comparatively low as few skilled engineers and small operating staff is employed.	Maintenance cost is higher as compared with that of hydro-electric plants and diesel electric power plants because large operating staff and more skilled engineers are employed.	Maintenance cost is comparatively higher because skilled and well trained staff is employed for its operation and maintenance.	Maintenance cost is comparatively lower because lesser operating and supervising staff is kept.
10. Field of application.	These plants are most economical where water source is available at a sufficient head.	These plants are most economical near coal mines and by the side of river or canal.	Where neither water nor coal as a source of power is available, as in Rajasthan, these plants are more feasible and adopted.	These plants are installed to supply power in emergency.

Regenerator is usually of shell and the tube construction. The exhaust gases are made to flow inside the nest of tubes while air flows outside the tubes in the shell in counterflow and is heated up by the heat given out by the exhaust gases. Thus the regenerator utilises the heat of exhaust gases to heat the compressed air before it is sent to the combustion chamber which reduces the fuel combustion of the plant and improves thermal efficiency of the cycle. However, for short time operation such as peak loads, the cost of regenerator may not justify its use in gas cycle. The inter cooler is another heat exchanger which cools the partly compressed air to reduce volume and increase density. Intercooling improves the thermal efficiency, and reduces the size of turbine and compressor for the given output. Reheater is used to reheat the gases after partial expansion in the turbine so that its further expansion yields more work.

Sub-Stations

1. Introduction. The sub-station may be defined as assembly of apparatus which transforms the characteristics of electrical energy from one form to another, say for example, from alternating current to direct current and from one voltage to another.

It has already been said that the a.c. electrical energy is generated at low voltage but for transmission the voltage is stepped up. Similarly the consumers do not use high voltage and so the same must be stepped down to low voltage. The stepping up and stepping down of voltage is done in the sub-stations.

As already explained that it is economical to transmit electrical energy in the form of alternating current. This form of energy is converted into d.c. in the substation where required.

2. Classification of Substations. The substation can be classified as follows :

(*a*) **In accordance with the service.** In accordance with the service performed by them, the substations can be of following types:

(*i*) *Static.* In this type of substations static equipments to change the characteristics of electrical energy are used. So in these substations the voltage of the a.c. energy is changed.

(*ii*) *Converting.* In this type of substations the a.c. energy is changed to d.c. form of energy.

(*b*) **In accordance with the service voltage.** Usually these are alternating current substations. The various types are given below :

(*i*) *Extra high voltage transmission substation.* In this substation, the voltage is transformed to extra-high voltage (above 66 KV) for the purpose of transmission of electrical energy.

(*ii*) *Distribution Substation.* In this substation the voltage is stepped down to low tension *i.e.* 400 volts for supplying the users.

(*iii*) *Industrial Substation.* The big industrial consumers, who need bulk supply are fed at high voltage *viz.* 11 KV or 66 KV. The voltage is stepped down at the substation installed in their premises. These substations are known as industrial substations.

(*iv*) *Substation for Power Factor Correction.* Due to line inductance, the power factor at the end of the transmission line decreases. To improve the power factor, it is necessary to install the synchronous condensers at the end of the line. Such installations are known as power factor correction substations.

(*v*) *Frequency Changing Substation.* Sometimes for utilization purposes, different frequencies are to be used than the normal generation frequency. Such substations which convert frequency are known as frequency changing substations.

(*c*) **In accordance with mounting.**

(*i*) *Indoor Type Substations.* The substations consist of a series of open and enclosed chambers or compartments. The main equipments needed for this type of sub-station are arranged in these compartments. The chamber space in which the equipment of any one main bus bar connection is mounted, as a whole, is called as a cell, cubicle or compartment.

Such Substations are usually erected for a voltage upto 11000 volts but can be erected for 33000 volts and 66000 volts. When the surrounding atmosphere is contaminated with impurities such as metal corroding gases and fumes, conductive dust etc.

According to construction, these types of sub-station are further subdivided into :

(*i*) *Substations of the integrally built type*—In which the apparatus is installed on site. In these substations the cell structures are constructed with concrete or brick.

(*ii*) *Substations of the composite built up type*—In these substations, the assemblies and prefabricated parts are assembled on site within a substations switchgear room. The compartments of these sub station take form of metal cabinets or enclosures, each of which contains the equipment of one main connection cell. Within the cabinets or enclosures, an oil circuit breaker, a load interrupter switch, one or more voltage transformers are mounted.

(*iii*) *Unit type factory fabricated substations and metal clad switch Boards* —In such type of substations, the equipments are built in electrical engineering workshops and are shifted to site of installation fully pre-assembled. After installation, only connections to the incoming and outgoing power circuits are required to be made. Cubicles for unit type switch boards or substations take the form of fully enclosed metal clad cabinets.

Metal clad cubicles designed with withdrawable trucks and divided into number of compartments are usually used.

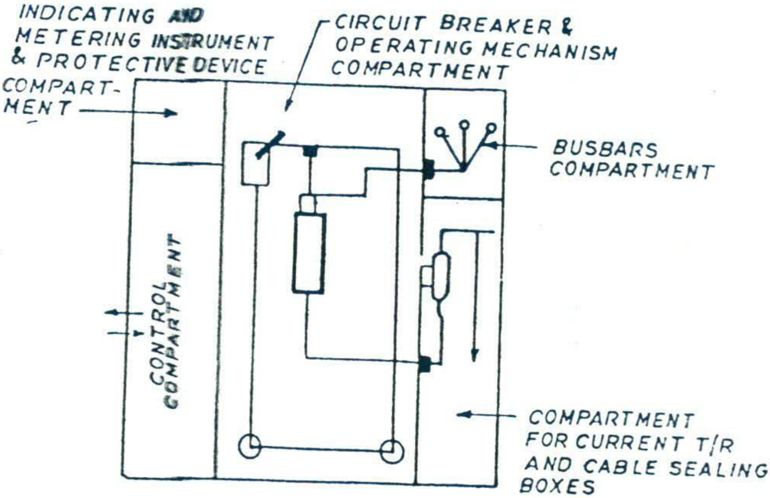


Fig. 11.18 The system of metal clad cubicles designed with several compartments.

The compartments in which the cubicle is divided are control compartment, indicating and metering instrument, protective device compartment, circuit breaker and operating mechanism compartment, main bus-bars compartment, current transformers, cable sealing boxes compartment.

To prevent any possible opening or closing of the disconnecting devices when the circuit breaker is closed, these cubicles are designed with interlocks which prevent the truck from being rolled in or withdrawn when the circuit breaker is closed.

(*ii*) *Out-door Substations*

These are of two types :

(*a*) *Pole-mounted Substations*. These types of substations are erected for distribution of power in localities. Single stout poles or

H-pole and 4-pole structures with suitable platforms are used for transformers of capacity upto 200 KVA. These substations are cheapest, simple and smallest in size. All the equipment is of outdoor type and mounted on the supporting structure of H.T. distribution lines. Gang operating (G.O.) switch is used for switching "ON" and "OFF" of H.T. transmission line. H.T. fuse unit is installed for protection of H.T. side. To control L.T. side iron clad low tension switch with fuses of suitable capacity is installed. Lightning arrestors are installed over the H.T. line to protect the transformers from the surges. The substations is earthed at two or more places.

The maintenance cost of substation is low and by using a large number of such substations in a town, it is possible to lay the distributions at a lower cost. But owning to increase in number of transformers, total KVA is increased, no-load losses increases and the cost per KVA thus increased.

(*b*) *Foundation Mounted Substation.* These types of substations are used for primary and secondary transmission. Since equipments required for such substations are very heavy, therefore, site selected for these substations must have a good access for heavy transport. Owing to exposed bus-bars and other associated equipment the clearances and the spacings are not only to be governed by the operating voltage but also from the consideration of the encroachment from outside.

The switchgear consists of circuit breakers of suitable type on both the sides but now a days, the circuit breaker is dispersed on the incoming side of the modern transformers from economy paint of view. The isolating switches thus solve purpose.

3. Transformer. It is an essential part of a voltage conversion substation. The transformer consists of two coils which are insulated with each other and are placed on steel core. The steel core is made of laminations. The steel cores with windings are placed in a container. Insulating material *viz.* transformer oil is placed in the container which provides insulation between the windings on the core and the container. This oil also radiates out the heat of the windings. For radiating the heat, tubes are provided along with two side of the container. The oil after heating expands and circulates in the tubes and the container. When the hot oil is in the tubes, the heat is radiated to the surroundings. The terminals of the windings are brought out into porcelain-oil filled or condenser type bushings.

Transformer can be classified in various categories as below, depending upon the type of core or type of cooling employed :

(*a*) **In accordance with the type of core.** Transformer can be of the following types in accordance with the type of core.

(i) *Core-type transformer.* In this type of transformer cylindrical coils wound on a rectangular core as shown in Fig. 11.11 are used.

It will be seen that the low voltage winding is placed near the cores, it is because of the fact that insulation between the core and winding can be easily provided.

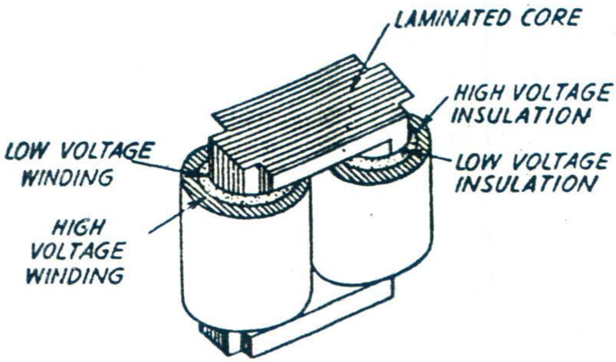


Fig. 11.11. Section of a core-type transformer.

(ii) *Shell-type transformer.* In Fig. 11.12 the section of the core and winding of a shell-type transformer is shown.

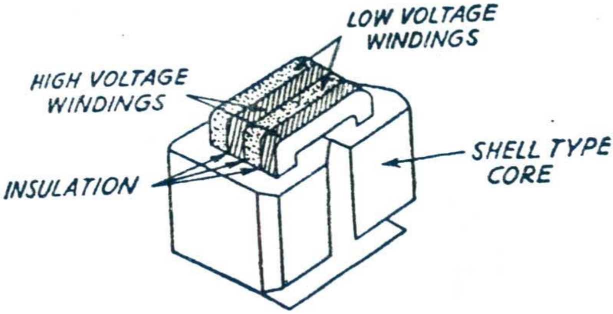


Fig. 11.12. Section of a shell-type transformer.

(b) **In accordance with type of cooling.** Transformer can be of the following types in accordance with type of cooling employed:

(i) *Oil-filled Self-cooled.* In this type of transformer, the assembled windings after putting on the core are placed in the container. The container is filled with high quality insulating oil. The oil radiates out heat to the surroundings. On its two sides pipes are provided to increase the dissipation area. *Only this type of cooling is adopted for outdoor transformer.*

(*ii*) *Oil-filled Water-cooled.* In this type of transformer, coils through which cold water is circulated, are placed inside the container in which oil is placed. The heat from oil is conveyed through the water circulating in the coil.

(*iii*) **Air Blast type.** This type of cooling is adopted in high voltage transformer of 33 KV or above. The transformer core and windings are placed in a container which is open at two opposite sides. The air is blown through it with the help of blower for cooling purposes.

4. Advantages and Disadvantages of Outdoor Substations as compared to Indoor Substations. The outdoor substation has the following advantages :

(*i*) The constructional work needed is much smaller than the indoor substation.

(*ii*) Less quantity of building material is needed.

(*iii*) Installation cost of switchgear is low.

(*iv*) Adequate space between two adjoining equipment can be provided without incurring much cost.

(*v*) Erection can be completed in much less time.

(*vi*) Whole of the equipment can be viewed, which makes fault location easier.

(*vii*) The extension of the scheme is easier, whenever needed.

Following are the disadvantages of the outdoor substations.

(*i*) The dirt and dust deposit on the contact switches and thus the maintenance cost increases.

(*ii*) The chances of leakage increase during rainy and snow falling seasons and thus the switching operation becomes difficult.

(*iii*) The installation is not safe from unauthorised entry of a person.

5. Design of Substation. When a substation is to be designed the following procedure should be adopted :

1. Prepare a single line diagram of main electric connections showing bus-bar arrangement, circuit breakers and reactors.

2. Decide the layout of the switch gear keeping in view capacity of substation, method of control, number of feeders, reliability, safety, flexibility, simplicity, space needed and cost.

3. The individual circuit should be so designed that there is a minimum amount of risk involved in its failure.

4. The layout should be such that it should be possible to isolate any section during fault without affecting the service to the healthy section.

5. It should be possible to have an easy and safe access for maintenance and inspection for different equipments.

6. In order to avoid serious troubles from spreading one unit to the other, partitions or barriers should be provided between units.

7. Reactors may be used to limit the short circuit current, so that rupturing capacity of the circuit breaker becomes adequate.

8. In order to avoid very large capacity circuit breakers, the current per circuit should be limited to about 2,000 A.

9. An arrangement should be made for extinguishing fire.

10. The earth conductor should be of sufficient cross-sectional area to carry the fault current in severe conditions.

11. A proper and very efficient automatic electrical protective gear should be used.

12. Power cables should be separated from control cables.

13. In order to avoid fire hazard, fire proof switch room and cable room should be provided.

14. An adequate arrangement should be made for oil handling.

6. Main Connection Schemes

In substations and switch gears, the electric power is received and distributed by means of main bus-bars to which the equipment is connected according to some given main circuit scheme.

In the substations, special types of apparatus like isolators (or disconnecting switches), circuit breakers, instrument transformers etc. are used for interconnecting high voltage power lines, (overhead or cable), with the main bus-bars.

Connections may be divided as incoming (power feeder connections), tie (lines interconnecting two substations or switchgear installations, each of which is fed through its own incoming feeder connection), outgoing (feeder connections for feeding other subsequent substations or switchgear installations), voltage transformers (connections made in a given substation), voltage transformer connections for control and metering).

The main connection diagram drawn for a substation shows the arrangements of all the circuits with its main bus-bars.

For simplicity and to facilitate reading, all the electrical connections of a substation can be shown by a single-line diagram. It is understood that all the phases are connected identically.

The main elements of the installations ; circuit breakers, isolators, fuses, instrument transformers, power transformers etc. are shown by standard graphical symbols on the single line diagrams.

7. Graphical Symbols for various types of apparatus and circuit elements on substation main connection diagram.

(*a*) *Circuit Elements* — *Symbols*

(*i*) Bus-bars

(*ii*) Electrical connection or bus-bars or wires.

(*iii*) Earthing (connection to earth).

(*iv*) Apparatus terminal or terminal in an installation.

(*v*) Cable termination

(*vi*) Current transformer with one core

(*vii*) Current transformer with two cores (two secondary windings)

(*viii*) Fuse

(*ix*) Fixed resistor

(*x*) Variable resistor with sliding contact and no break in the circuit.

(*xi*) Plug in connection in withdrawable contact arrangements and in apparatus.

Circuit Elements — *Symbols*

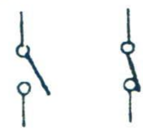
(*xii*) Lightning arrestor (general Symbol)

(*xiii*) Valve type lightning arrestor

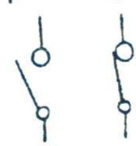
(*xiv*) Gap fuse arrestor

(*b*) *Switching Apparatus* — *Position*: *open*, *closed*

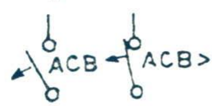
(*i*) Isolator (disconnecting switch)



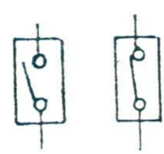
(*ii*) Load-interrupter switch incorporating with arc extinguishing device



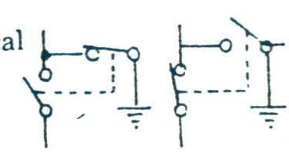
(*iii*) Air circuit breaker with over current trip or release



(*iv*) High voltage circuit breaker (oil, air blast, hard gas etc.)



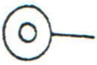
(*v*) Isolator with earthing knife mechanical inter lock



(*c*) *Electric Machines and Transformers*

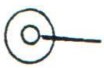
(*i*) Three phase squirrel-cage induction motor

(*ii*) Three phase slip ring induction motor



(*iii*) D.C. Generator

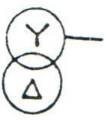
(*iv*) Three phase synchronous generator



(*v*) Three phase synchronous generator, simplified representation

(*vi*) Single phase steel core transformer

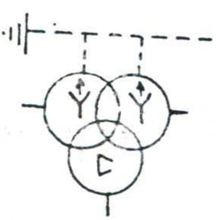
(*vii*) Three phase steel core transformer with star delta connected windings and brought out neutral



(*viii*) Three-phase steel-core auto-transformer with star connected winding

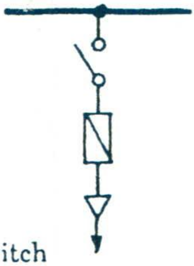
(*ix*) Two single phase voltage transformers in open delta (V) connections

(*x*) Three-phase, three winding potential transformer having two star connected windings, each with the neutral brought out and earth, and one winding connected as an open delta.

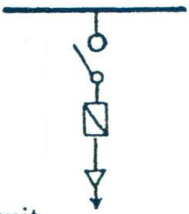


8. Main connection diagrams showing the arrangements of various typical connections and of the simplest substation schemes.

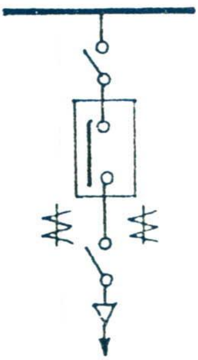
(*i*) Connection with isolator and fuse



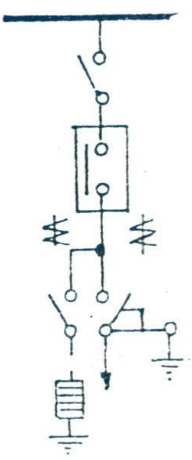
(*ii*) Connection with load interrupter switch and fuse



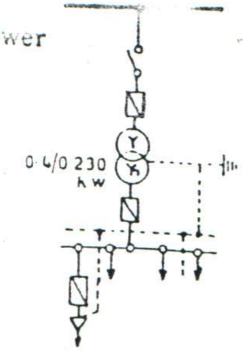
(*iii*) Connection with bus isolator, circuit breaker and line isolator.



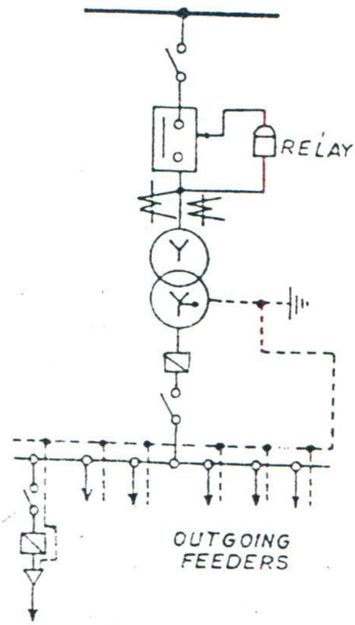
(*iv*) Connection with bus isolator, circuit breaker and a line isolator having earthing knives, the main connection also in corporating a valve type lightning arrestor connected through an isolator.



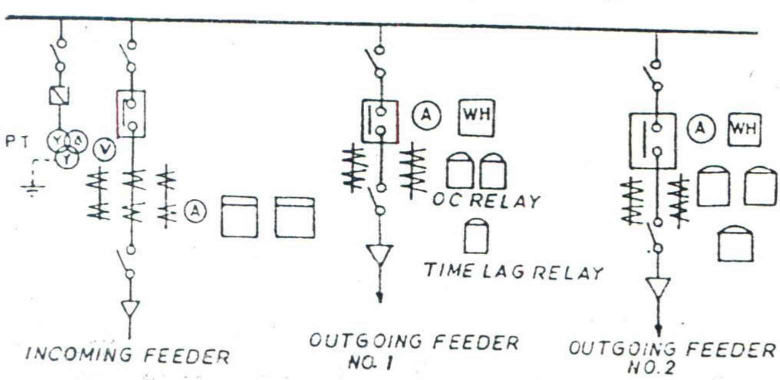
(*v*) Connections of typical forms of power transformers (11 KV)



For Transformer of Lower Ratings



(*vi*) *For Transformer of Higher Ratings*



(*vii*) Fig. shows *Complete Single Line Main Connection Diagram of An 11 KV Substation.*

9. (*i*) **Insulators.** The porcelain insulators used in substations are of the post and bushing (through) type. They serve as supports and insulation of the bus-bars.

A post insulator consists of porcelain body, cast iron cap and flanged cast iron base, as shown in Fig. 11.13.

The hole in the cap is threaded so that the bus-bars are either bolted to the cap directly or fixed by means of a bus-bar clamp. Post insulators are available with round, oval and square flanged bases and used for fixing with one, two or four bolts. Each base has also an earthing bolt.

Fig. 11.13. The post insulation

A bushing or through insulator consists of porcelain-shell body, upper and lower locating washers used for fixing the position of bus bar or rod in the shell, and mounting flange with holes drilled for fixing bolts and supplied with an earthing bolt, as shown in Fig. 11.14.

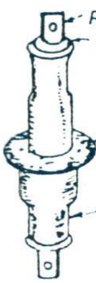


Fig. 11.14. Shows bushing.

For current rating above 2,000 A, the bushings are designed to allow the main bus-bars to be passed through them directly.

Each phase of the bus-bars is coated with paint according to a fixed colour code-red, yellow and blue to identify the phase of the main bus-bars.

(*ii*) *Conductors*. The substation **buses** can be of the following types :

(*a*) rigid buses of solid conductor or tubing.

(*b*) strain buses of cables.

They can be of copper or aluminium. The rigid type of buses are most commonly used, for small substations they may be of 4/0 hard drawn solid copper conductor ; but with higher capacities copper tubes may be used.

For the last 5 to 10 years the use of aluminium as an electric conductor has been greatly accelerated. The advantages of aluminium over copper are well known : higher conductivity on weight basis, lower cost for equal current-carrying capacity, excellent corrosion resistance and ease of formability. These advantages have given aluminium undisputed lead in electric transmission systems. For proper reliable electrical connection in cases of aluminium buses, they can be coated with silver.

(iii) Isolators. An isolator or disconnecting switch is used to open some given part of a power circuit after switching off the load by means of a circuit breaker.

Thus isolators serve only for preventing the voltage from being applied to some given section of the busbar in a switchgear installation or to one or another piece of apparatus in the installation.

In some cases isolators are used as a circuit breaking device but their use for this purpose is strictly limited by definite conditions, such as the power rating of the given circuit.

There are two types of isolators.

(1) Single pole isolators and (2) Three pole isolators.

(iv) Circuit Breakers. Circuit breakers are installed to perform the following duties :

(*i*) To carry the full load current continuously.

(*ii*) To open and close the circuit on no load.

(*iii*) To make and break the normal operating current.

(*iv*) To make and break the short circuit currents of magnitude up to which it is designed for.

Circuit brokers of various types have been discussed in this chapter ahead.

(v) Load-Interrupter Switches. The switches are designed and used to close and open high voltage circuits under normal working conditions (at normal load). The arc extinguishing device of the load interrupter is made in the form of a split, moulded plastic chute fitted with organic glass inserts. This chute surrounds the moving knife of the arc extinguishing system. The stationary arcing contact is located in the lower part of the chute.

When the switch is opened, the arc drawn between the working contact is separated and acted upon by the high temperature of arc, the walls of the organic material inserts generated gasses (mainly hydrogen), which create a longitudinal blast serving to extinguish the arc. Lever-arm manually operating mechanism are used for closing and opening the load-interrupter switches.

(vi) Power Transformers. Power transformers are used for stepping up the voltage for transmission at generating stations and

for stepping down the voltage for further distribution at main step down transformer substations. Usually naturally cooled, oil immersed, known as ON type, two windings three phase transformers are used up to the rating of 10 MVA. The transformers of rating higher than 10 MVA are usually air blast cooled. For very high rating, the forced oil, water cooling and air blast cooling are used. The transformers used are provided with on load tap changer for regulating the voltage.

The transformers are generally installed upon lengths of rails fixed on concrete slabs having foundation 1 to $1\frac{1}{2}$ metres deep.

(vii) (a) Current Transformers (C.T's). These instrument transformers are connected in a.c. power circuits to feed the current coils of indicating and metering instruments (ammeters, wattmeters, watt-hour meters) and protective relays. Thus the CTs broaden the limits of measurements and maintain a watch over the curents flowing in the circuits and over the power loads. In high voltage installations, CTs, also isolate the indicating and metering instruments from high voltage. The current transformer basically consists of an iron core on which the primary winding is usually single turn winding and the number of turns on secondary winding depending upon the power circuit current to be measured. The primary is directly inserted in the power circuit (the circuit in which current is to be measured) and to the secondary winding or windings, the indicating and metering instruments and relays are connected. When the rated current of CT flows through its primary winding a current of 5 amperes will appear in its secondary winding. The larger the current to be measured, more the number of turns on secondary. The ratio of primary current to the secondary current is known as *transformation ratio of the CT.*

The current transformers are rated for rated voltage of the insulation, the rated currents of the primary and secondary windings and the accuracy class. The accuracy class indicates the limit of the error in percentage of the rated turns ratio of the given current transformer. Current transformers are available in the accuracy classes 0.5 ; 1 ; 3 and 10.

(b) Potential Transformers (PT's). The potential transformers are used for voltages above 380 volts to feed the potential coils of indicating and metering instruments (volt meters, wattmeters, watt-hour meters) and relays. These transformers make the ordinary low voltage instruments suitable for measurement of high voltage and isolate them from high voltage.

The primary winding of the potential transformers is connected to the main bus-bars of the switch gear installation and the secondary windings is connected to various indicating and metering instruments and relays also.

When the rated high voltage is applied to the primary of a P. T., the voltage of 110 volts appears across the secondary winding. The ratio of the rated primary voltage to the rated secondary voltage is known as *turns or transformation ratio.*

The potential transformers are rated for primary and secondary rated voltages accuracy class, number of phases, system of cooling.

(*viii*) *Indicating and Metering Instruments.* (ammeters, voltmetres, wattmetres, kWh metres) are installed in the substations to control and maintain a watch over the currents flowing in the circuits and over the power loads.

(*ix*) *Carrier-Current Equipment.* Such equipment is installed in the substation for communication, relaying, telemetering or for supervisory control. This equipment is suitably mounted in a room known as *carrier room* and connected to the high voltage power circuit. Sometimes the communication equipment is installed adjacent to the breaker and connected above the breaker terminals.

(*x*) *Control Cables.* The control cables and conduit system is required for affecting automatic controls. The control system generally operates at 110 V or 220 V and the cables employed for this purpose are multi-core cables having 10 or 37 or 61 conductors according to requirement. For laying these cables, generally duct are run from control room basement to centrally located junction boths from where the conduits are run to the required points.

(*xi*) *Air Break and Disconnect Switches.* They are generally manually operated, but can also be motorized if they are to be of remote controlled type. The modern trend is to have automatic sectionalizing switches.

The disconnect switches for 46 KV and below are generally of single pole and have hook-stick operated mechanism, but they can also be of group-operated mechanism. The 110 KV and higher voltage disconnect switches are group-operated *i.e.* all the six poles are operated with one handle.

However, it may be pointed that these air-break switches are opened only after the circuit breaker had made the circuit dead.

(*xii*) *Protective Fuses and Relays.* The fuses are very commonly provided on the high voltage side alongwith the other protective devices. It serves to protect the transformer from the system or it can also be said that the fuse protects the system from transformer. The relays are also used to protect the power system equipment from damage against fault at any point *en route*.

(xiii) Switch Boards. The switch board consists of meters, relays and control equipment as illustrated in Fig. 11.15 (*a*). The essential meters are placed at the bottom. The control equipment is generally half-way between top and bottom, so as to facilitate the operation A control desk may also be provided as shown in Fig. 11.15 (*b*).

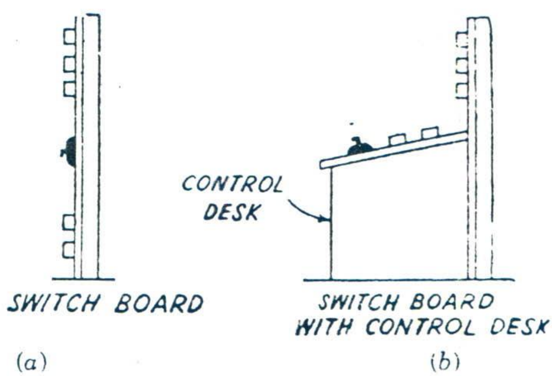


Fig. 11.15

The materials generally used for switch board panels are slate and asbestos ebony, although all steel switch boards can also be used only where voltage is not more than 11 KV.

(xiv) Control Room. All equipments such as switch board, carrier current equipment, batteries etc. are housed in the control room, which generally also has a basement hatch way (2 m × 1.5 m approx.) left in the floor for facilitating the installation. Below the switch board, a slot of about 10 cm. may be provided for control cables etc. Fig. 11.16 represents layout of the control room, which is about 10 cm × 7 m. The basement may be used as a battery room, or for storage etc.

10. Substation Auxiliaries Supply. In small unattended substations only a small amount of power for electric lighting during regular periods of inspection, maintenance and repair is required.

In regional substations, the electric power is required for the auxiliaries--the lighting circuits, air blast fans of power transformers, battery charging sets, oil servicing facilities, compressor units in case of air blast circuit breakers, ventilating fans of the substation buildings, water supply and heating system equipment etc.

In substations, incorporating synchronous condensers, the supply is also required for the operation of auxiliary equipment of the synchronous condensers.

In large substations it is wide practice to connect two transformers to the 11 KV main bus-bars for supply of the auxiliaries at a voltage of 400/230 V.

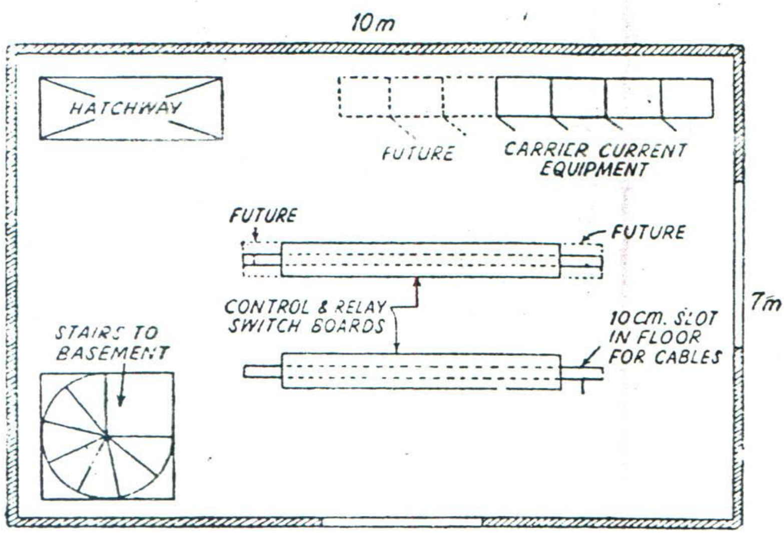


Fig. 11.16. Layout of the control room.

11. Complete Bus Bar Arrangements on High and Low Voltage Side for a Substation. The static transformers can be further subdivided into primary substations and substations of local significance. The primary substation may form a part of national grid, it may operate at 400, or 220, or 110, or 66 KV on the H. T. side, while it may have 66 or 33 or 11 KV on the L. T. side. The sub-station of local significance may convert the 66 or 33 or 11 KV voltage to 0.4/0.23 KV for local consumers.

In order to have thorough understanding, first single line diagrams are given for both high and low voltage sides (for two-phases only) and in the next articles the bus bar arrangements are dealt with in general.

Fig. 11.17 represents most simple connections for primary substation having two step down transformers which are fed through two sections of single bar, similarly there are two sections of low voltage bus bar. The two sections (both on high and low voltage sides) can be connected together through sectionalizing circuit breakers SCB_1 and SCB_2 ; in which case both the transformers can be operated in parallel or independently. The advantage of operating the transformers independently is that in case of fault, the fault current will be smaller.

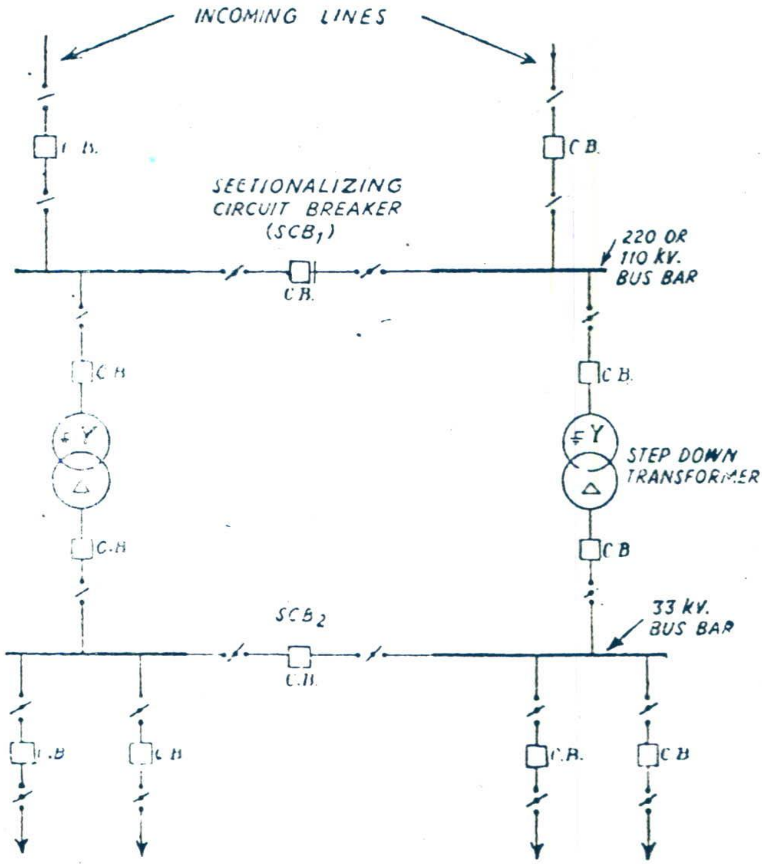


Fig. 11.17. Single bus-bar arrangement of primary substation.

As the primary substations have key position in a national supply system, so, it is most important to ensure reliability of supply, during normal as well as during severe weather conditions etc. Both low and high voltage sides are provided with double bus bars as shown in Fig. 11.18. Bus coupler breakers BC_1 and BC_2 are used in order to transfer the load from one bus to other. With the help of sectionalizing circuit breakers SCB_1 and SCB_2, the two transformers can be operated in parallel, if required.

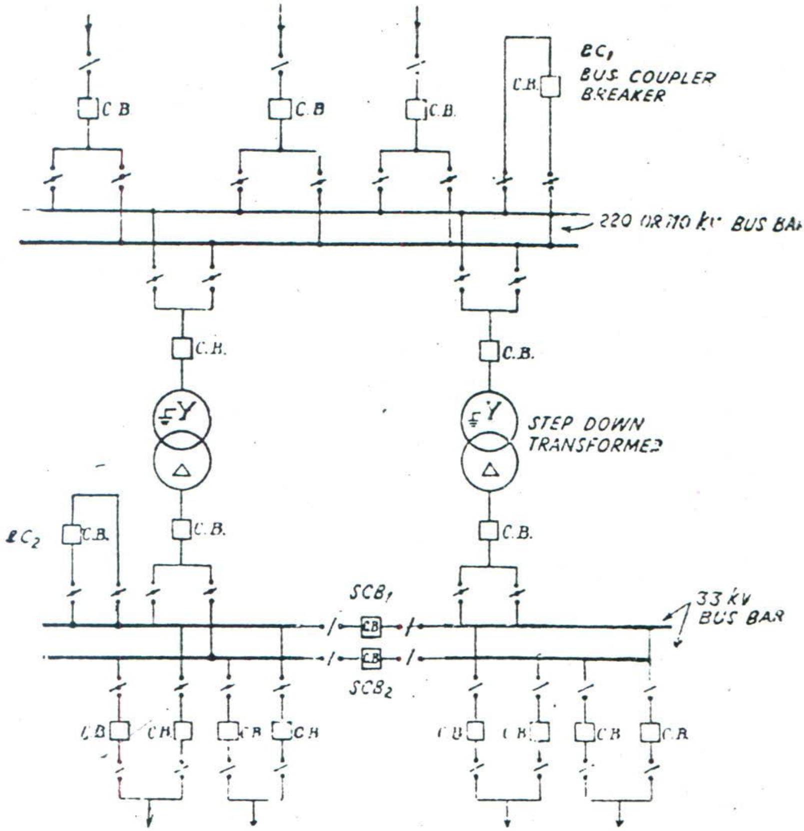
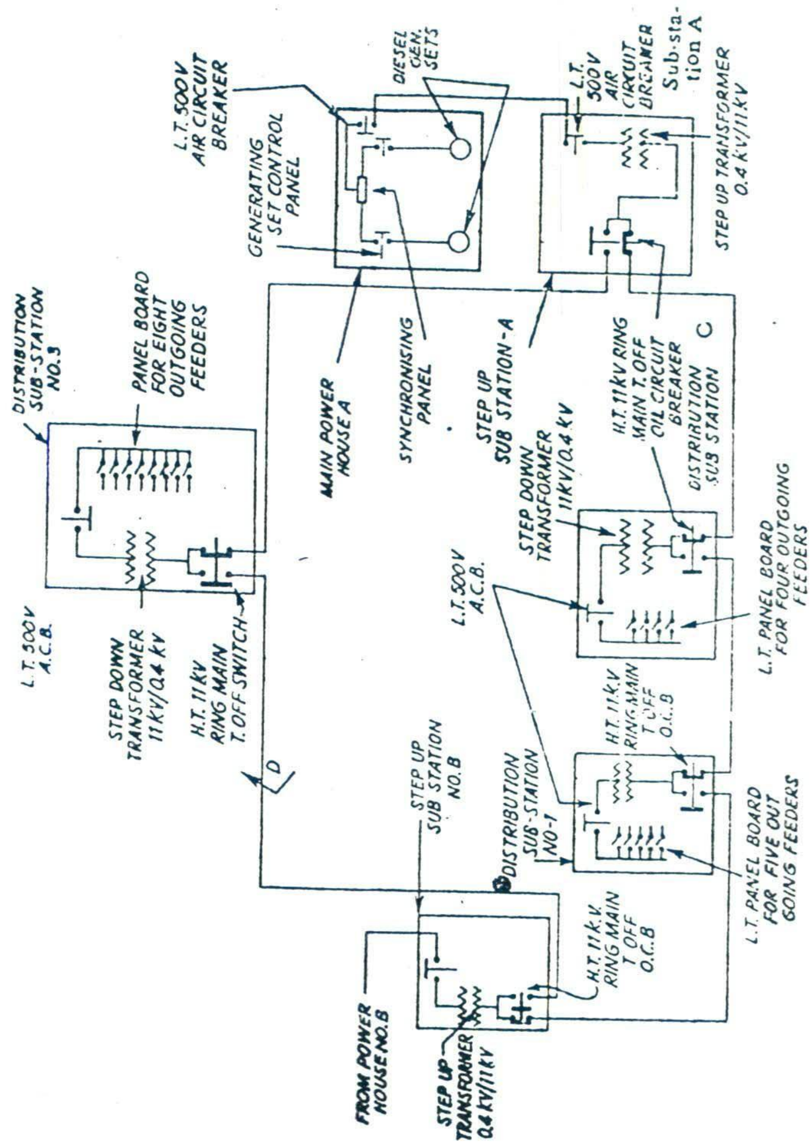


Fig. 11.18. Double bus arrangement of primary substation.

12. Ring Main System. In this system two or more power houses are connected in a fashion as shown in Fig. 11.19. The generated supply at 400 V is taken to step-up substations.

The voltage is stepped up to 11 KV in these substations. Two step-up substations are connected to various distribution (step down) substations as shown in Fig. 11.19 through a ring main system. The distribution and step-up substations are provided with ring main T. off switch. The ring main T. off switch can be connected to any of the two power houses and thus increase the reliability. Even if there is a fault at any point in the cable, the distribution substations can be fed. For example let there be a fault at points *C* and *D* shown in Fig. 11.19. Distribution sub-station No. 1 and No. 2 can be fed from step-up substation *B* and distribution substation No. 3 can be fed from step-up sub-station *A*.



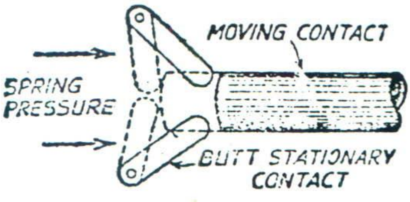
11.19. 11 KV Ring main system

13. Circuit Breaker. Circuit breaker has the following essential components :

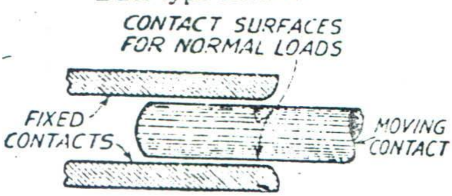
(*a*) Circuit breaker contacts,
(*b*) Bushings,
(*c*) Busbars and conductors,
(*d*) Instrument transformers.

Busbars, conductors and instrument transformers have already been discussed in art. 11 and 9. Circuit breaker contacts and bushings are discussed in the following articles.

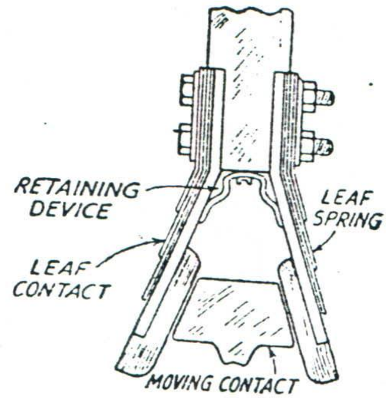
14. Circuit Breaker Contacts. The circuit breaker contacts are required to carry normal as well as short circuit current. The normal current should be carried by without any rise in temperature of contacts and drop in voltage. To ensure that temperature does not rise, the contacts are placed in oil. *If the contacts are placed in oil, the breaker is known as* **oil circuit breaker** *otherwise it is known* **as air circuit breaker.** Various types of contacts are shown in Fig. 11.20.



Butt type contact



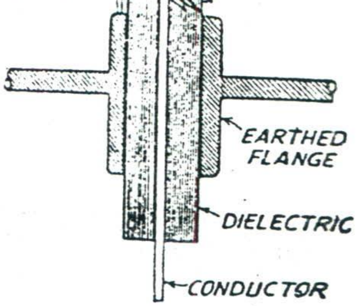
Tulip type contact



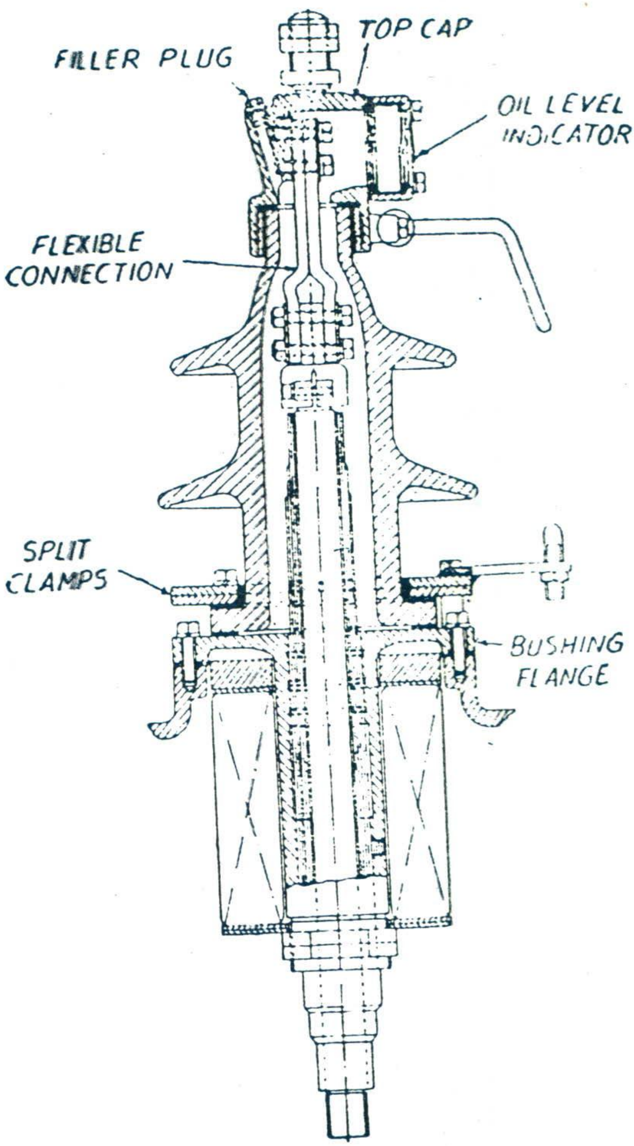
Finger and wedge type contact

Fig. 11.20

15. Bushings. Bushings are used as an insulating material around a high voltage conductor when the conductor is passed through the metal sheath or the plate of the tank of the circuit



(*a*) Indoor Bushings



(b) Outdoor Bushings

Fig. 11.21

breaker. Most common types of bushings used for indoor and outdoor purposes are shown in Fig. 11.21

16. Oil Circuit Breaker. In this type, contacts are placed in oil. The oil prevents restriking of the arc after the current reaches zero point of the cycle. The oil moves into the zone of arc after the current reaches zero point by the following actions :

(1) By the pressure generated by the arc itself. Circuit working on this principle is known as plain break oil circuit breaker.

(2) By the pressure caused by the natural head of the oil, circuit breaker working on this principle is known as **self blast circuit breaker.**

(3) By pressure earthed by the external forces, circuit breakers working on this principle are known as **Forced blast circuit breakers.**

Following are the advantages and disadvantages of the oil circuit breaker.

Advantages :

1. The oil used (such as transformer oil) is a very good insulator and allows smaller clearance between live conductors and earth conductor.

2. The cold oil is capable of entering into arc space and act as an insulator when the arc current goes to zero.

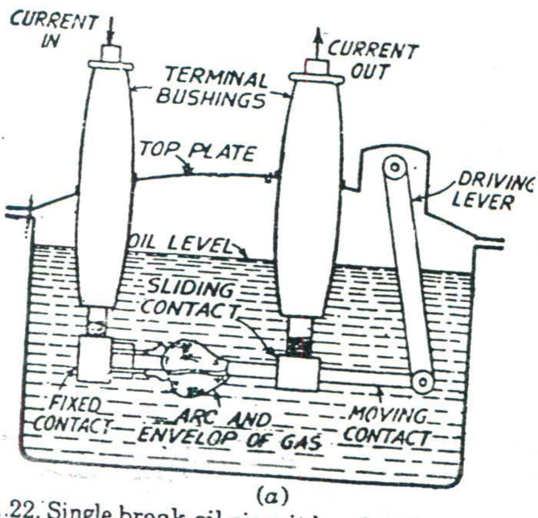
3. The oil has a high dielectric strength.

4. It absorbs the heat energy of the arc as the oil has great heat dissipating properties.

5. The gases so formed by decomposition of oil caused by arc energy have good cooling properties.

Disadvantages :

1. It is inflammable.



(a)

Fig. 11.22. Single break oil circuit breaker for indoor purposes.

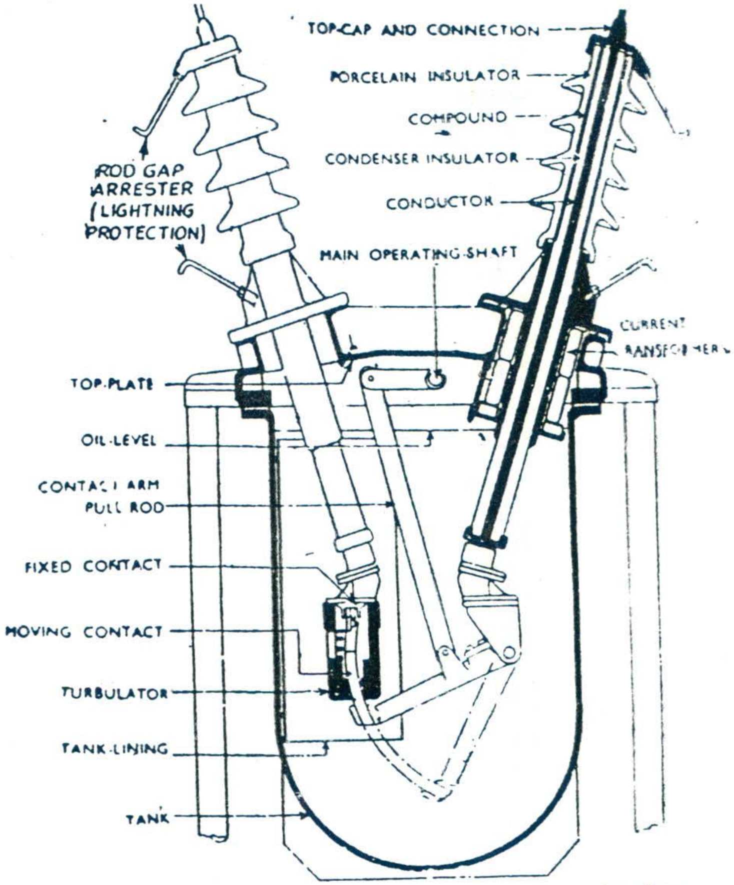


Fig. 11.22. (*b*) Single break outdoor type circuit breaker

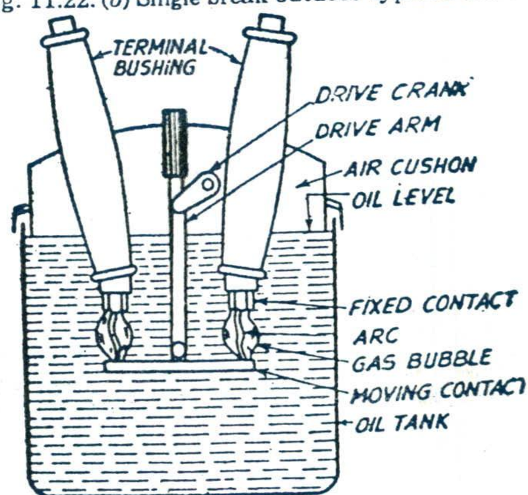
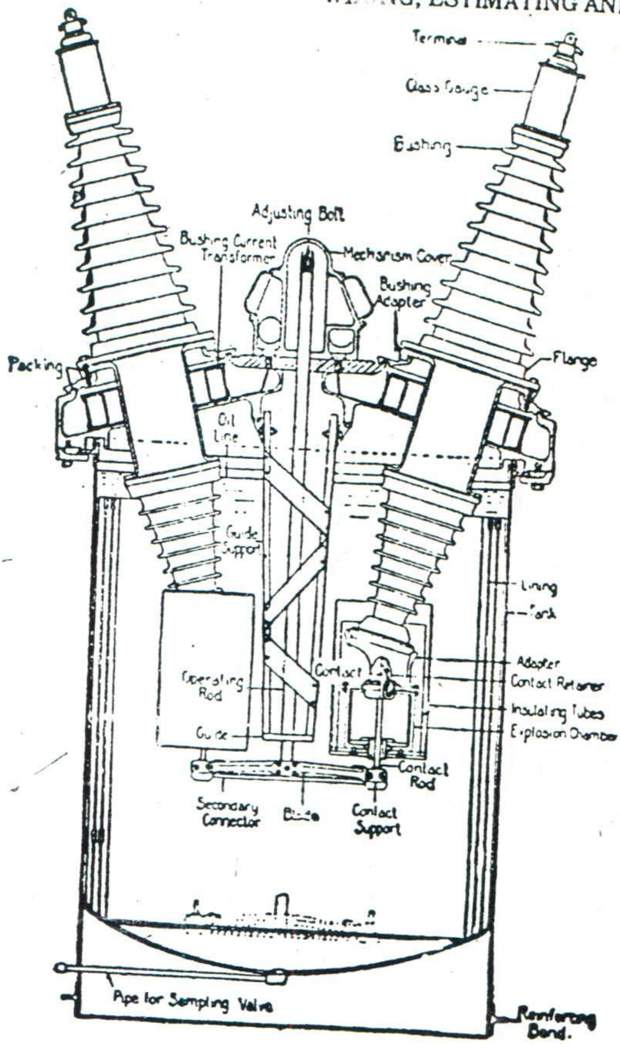


Fig. 11.23 (*a*). Double break oil circuit breaker for indoor purposes.



(*b*)

Fig. 11.23. Double break outdoor type circuit breaker.

2. It forms an explosive mixture with air.

3. Due to composition etc., the oil has to be kept clear and requires maintenance.

17. Description of Oil Circuit Breaker. In this type of circuit breaker, a system of levers, toggles and rollers is utilised to close the circuit breaker by raising the moving contacts against the action of strong spring which open the contacts when the circuit breaker is tripped mechanically or by action of relays and current transformers.

These types of circuit breaker have high rupturing capacity and are designed for remote action by employing a solenoid coil or pneumatic gear. The automatic losing gear is the best possible for mineral oil free from alkali, acid and moisture.

Fig. 11.22 and 11.23 (*a*) and (*b*) represent the various important parts of single break oil circuit breaker and double break oil circuit breaker.

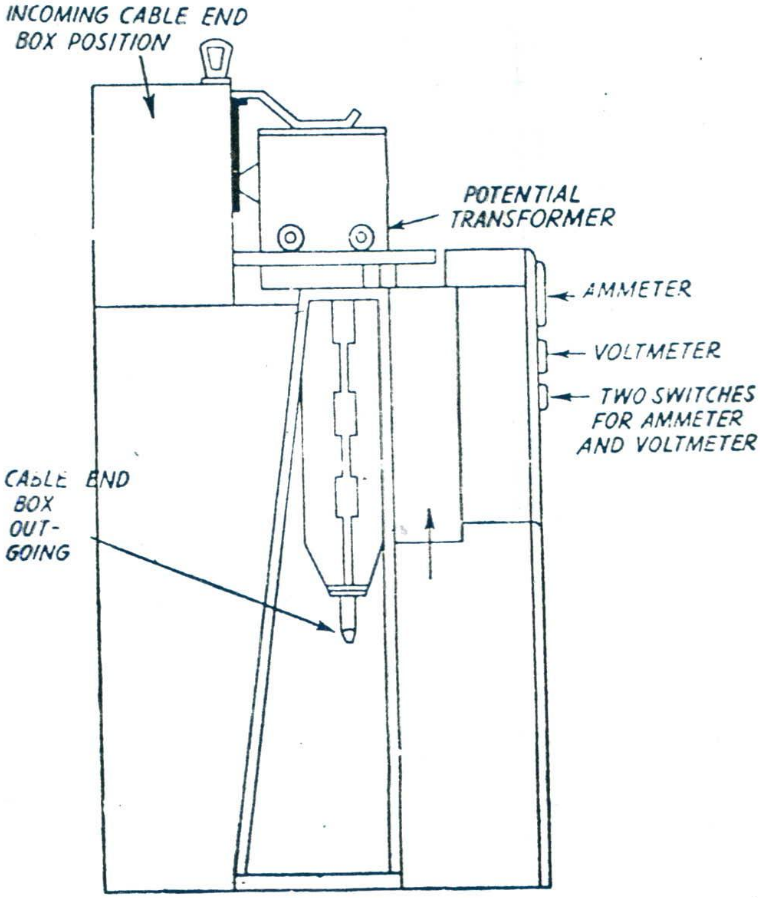


Fig. 11.24. Side view of H.T. 11 KV, 3-phase 3-wire oil circuit breaker.

Fig. 11.24 represents the general outlook of H.T. 11 KV oil circuit breaker. In Fig. 11.25 general outlook of H.T. 11 KV, HRC fuse switch is represented.

In Fig. 11.26, the general outlook of an L.T. feeder panel having draw-out type incoming O.C.B. and many outgoing switches panel has been shown.

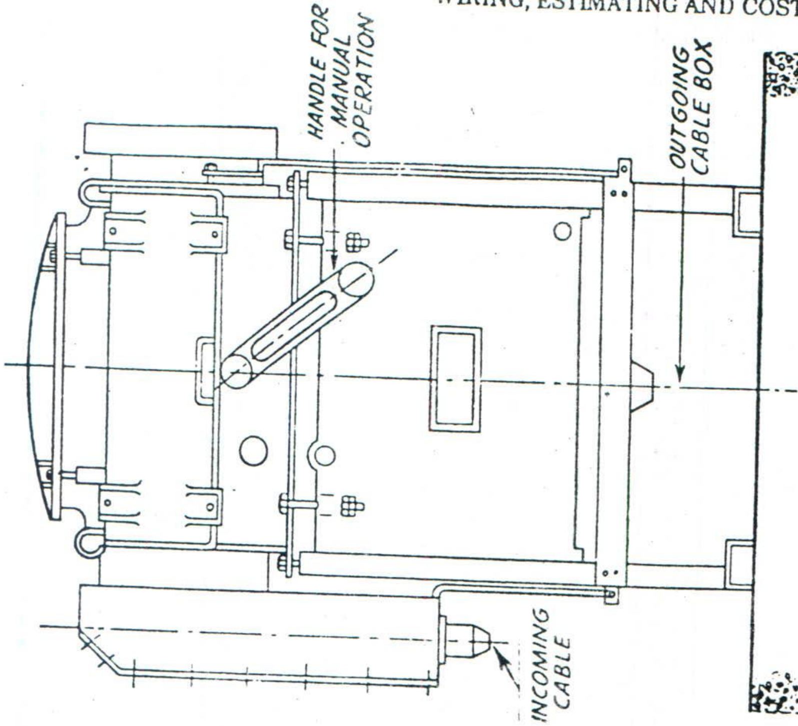


Fig. 11.25. H.T. 11 KV H.R.C. fuse switch.

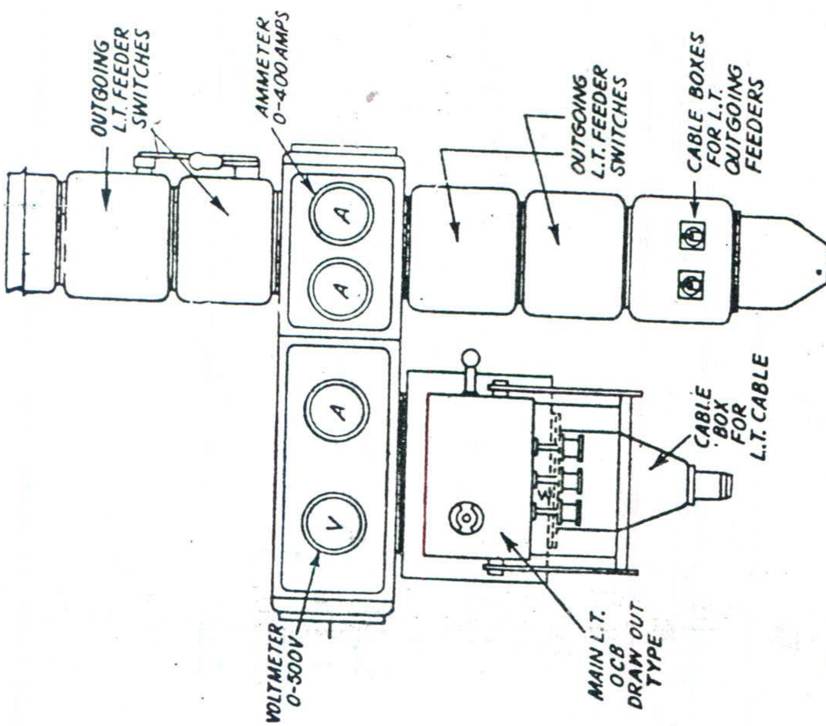


Fig. 11.26. L.T. Feeder Panel.

... ection Diagrams.

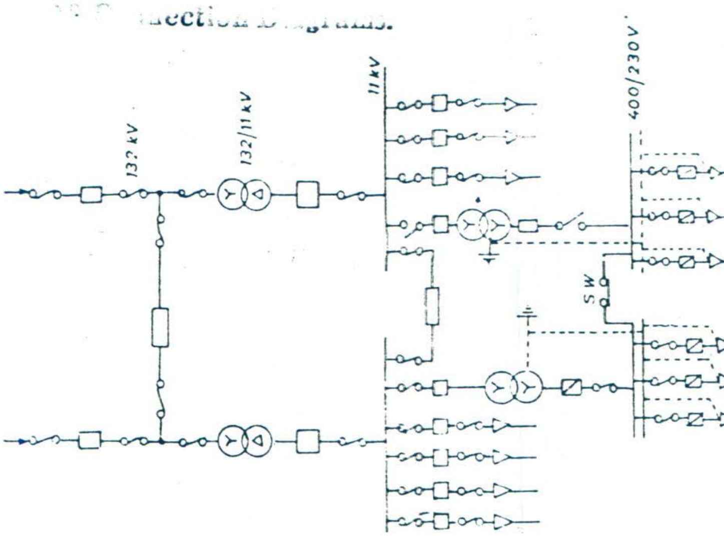


Fig. 11.27. The Main Connections for Auxiliaric Supply in 132/11 KV Step Down Substation.

Key Diagrams of Typical 33 KV Substations.

The key diagrams of typical 33 KV substations are given in Figs. below :

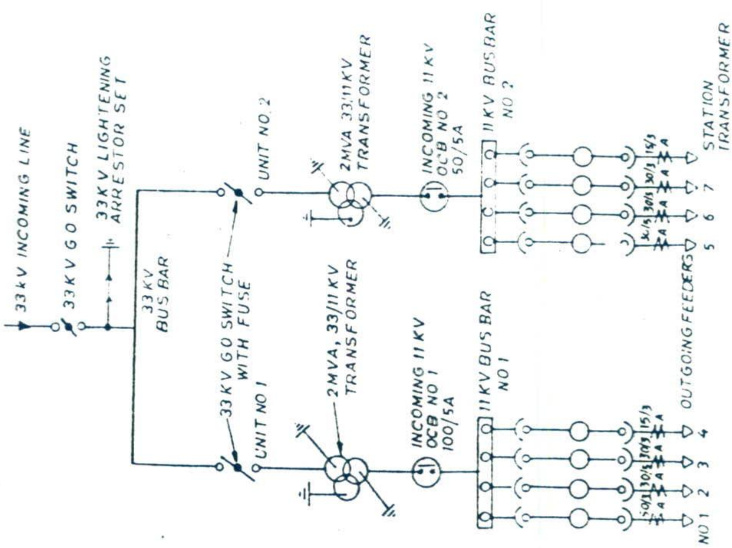


Fig. 11.28. Key Diagram of Typical 33 KV, 3 MVA Substation.

(a) Type of fuse : Copper tinned or lead or aluminium.

(b) Capacity in amperes : 3 amps or 5 amps or 10 amps or 20 amps or 50 amps or 100 amps.

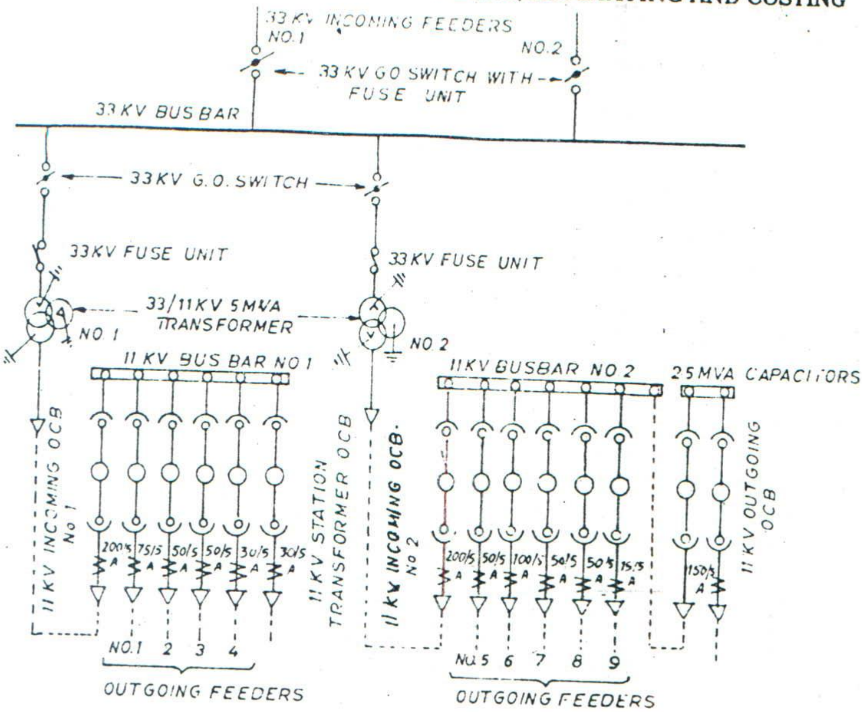


Fig. 11.29. The Key Diagram of Typical 33 KV, 10 MVA Substation.

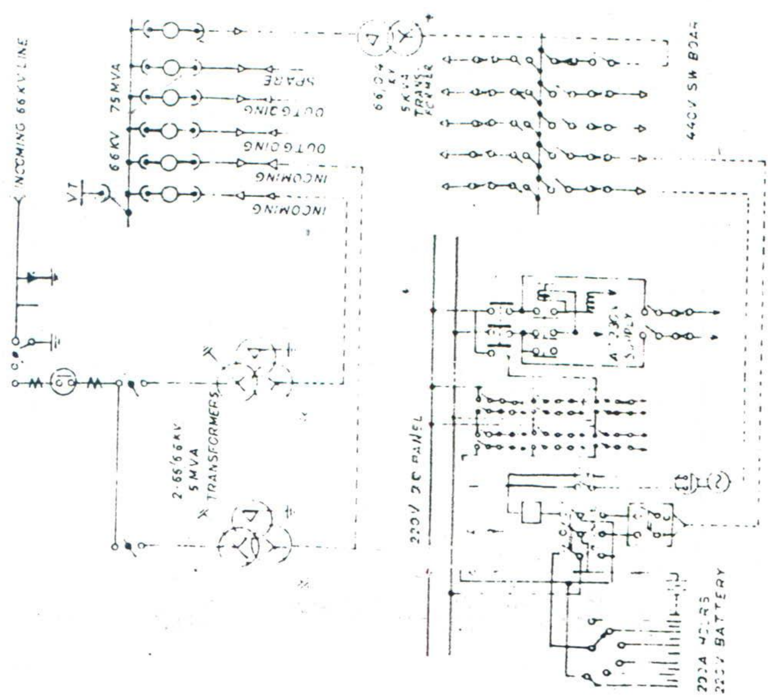


Fig. 11.30. The Lay out of a typical 66 KV Substation.

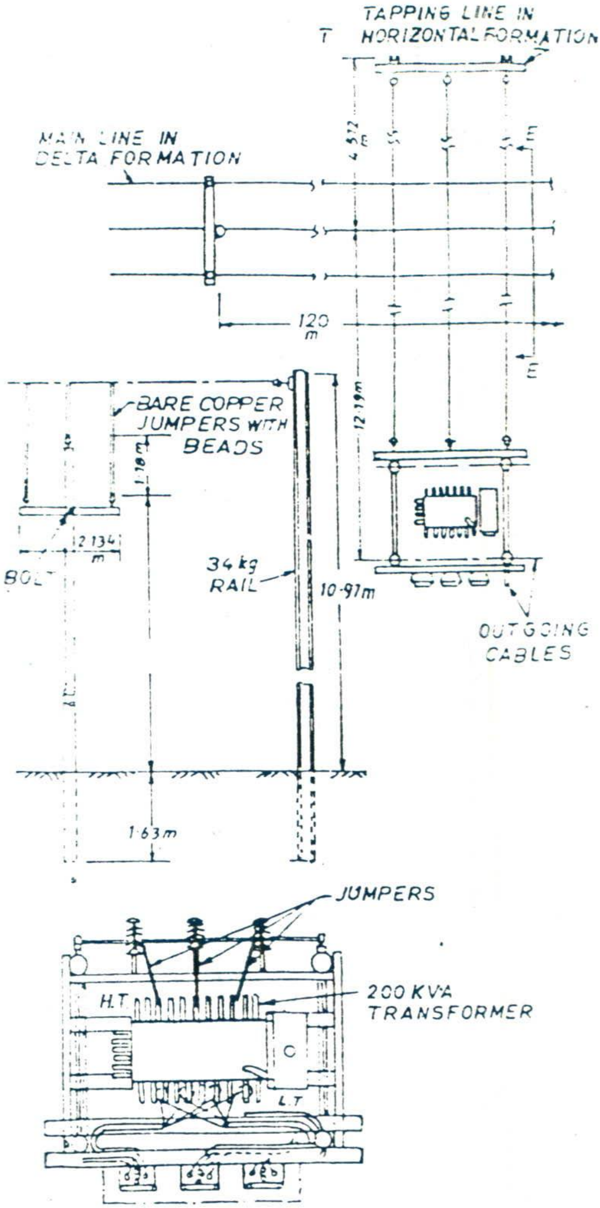

TAPPING LINE IN HORIZONTAL FORMATION
MAIN LINE IN DELTA FORMATION
120 m
BARE COPPER JUMPERS WITH BEADS
1·78 m
12·19 m
2·134 m
BOLT
34 kg RAIL
10·97m
OUTGOING CABLES
1·63 m
JUMPERS
H.T
200 KVA TRANSFORMER
L.T

Fig. 11.31

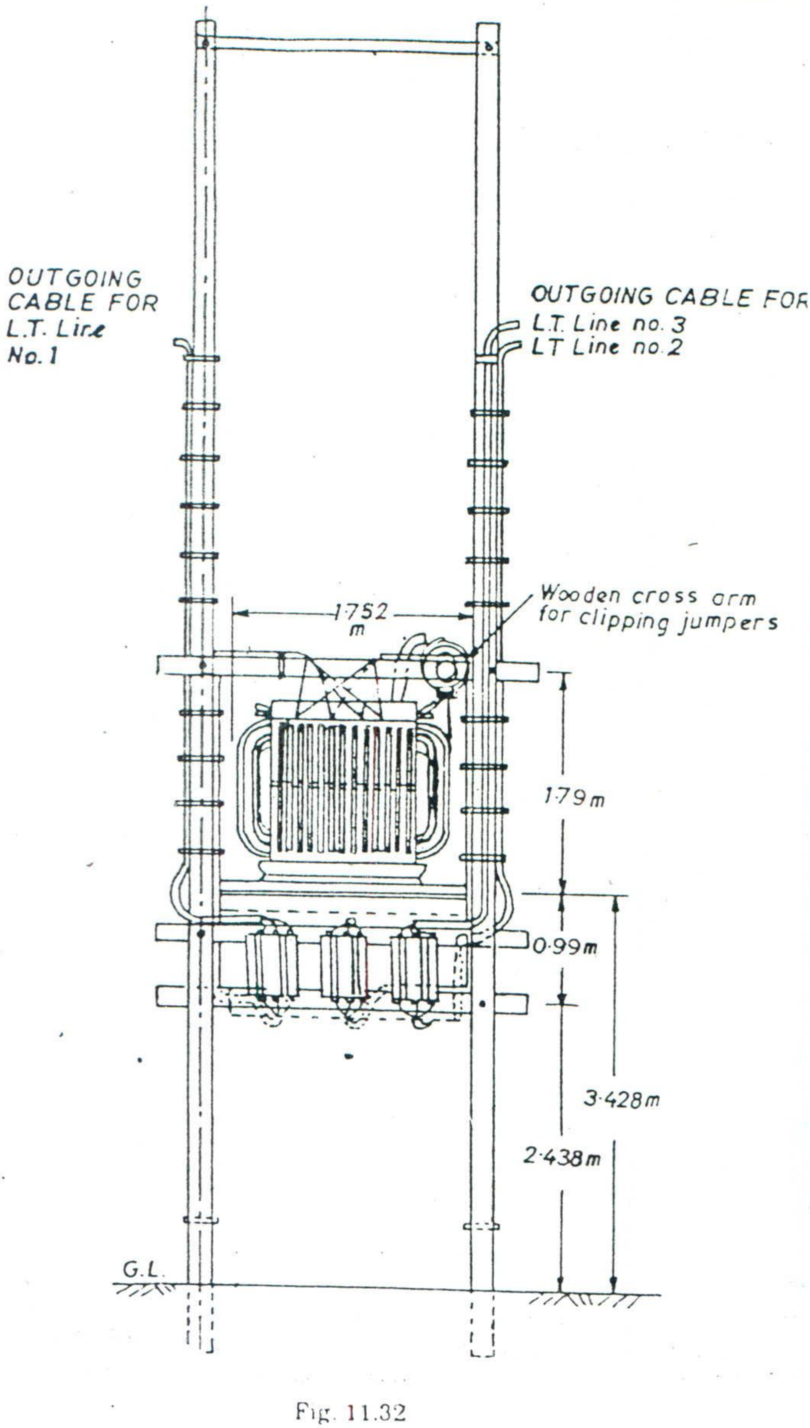
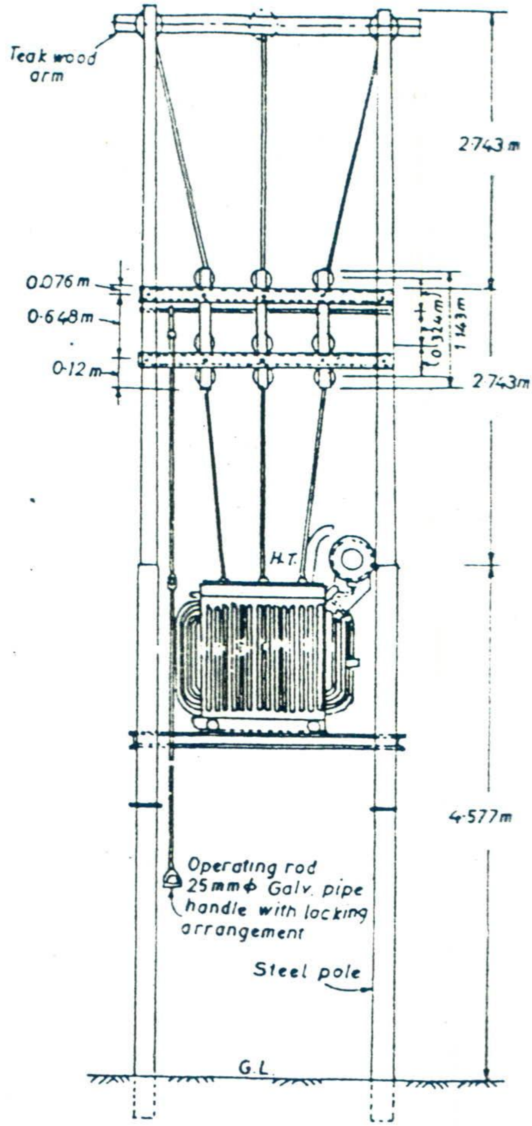

OUTGOING CABLE FOR L.T. Line No. 1
OUTGOING CABLE FOR
L.T. Line no. 3
LT Line no. 2
1·752 m
Wooden cross arm for clipping jumpers
1·79 m
0·99 m
3·428 m
2·438 m
G.L.

Fig. 11.32



Teak wood arm
2·743 m
0.076 m
0·648 m
0·12 m
0·324 m
1·143 m
2·743m
H.T.
4·577m
Operating rod 25mmϕ Galv. pipe handle with locking arrangement
Steel pole
G.L.

Fig. 11.33

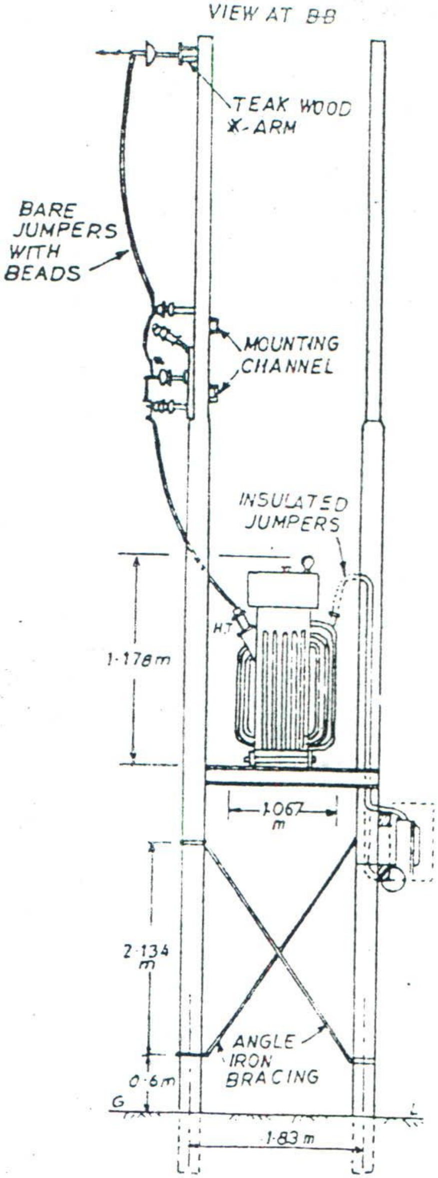

VIEW AT BB
TEAK WOOD
X-ARM
BARE
JUMPERS
WITH
BEADS
MOUNTING
CHANNEL
INSULATED
JUMPERS
H.T
1·178m
1·067
m
2·134
m
ANGLE
IRON
BRACING
0·6m
G
1·83 m

Fig. 11.34

TYPICAL QUESTIONS

1. What are different types of power stations ? Write the advantages and disadvantages of each type of power station.

2. In how many main circuits, a modern coal fed power plant can be divided ? Explain about each circuit and give the schematic arrangement of the same.

3. What are the factors which influence the choice of site for thermal plants and give the layout diagram ?

4. Explain about the constituents of steam power station.

5. Explain about the Hydro-electric Power station and what are the factors to be considered for the location of hydro-electric power station ?

6. What are the elements of hydro-electric plant ? Explain about them.

7. What are the types of water turbines ? Explain about them.

8. How are the Hydroelectric plant classified ? Explain them with diagrams.

9. What auxiliaries are used with a Hydro-electric plant ?

10. Explain about the Diesel power station and their elements.

11. Explain about the nuclear power station and what are the basic requirements for the location of a nuclear power station ?

12. Explain about the characteristics of a Nuclear power plant.

13. Explain about the gas turbine power plant and their elements.

14. Give the comparison chart of each power plant.

15. What do you understand by oil circuit breaker, explain its description with the help of sketches ?

16. What are the advantages and disadvantages of oil circuit breaker?

17. Give the key diagram of two 11 KV substations connected to various distribution substations through a ring main system. Point out various equipment used in all substations connected through ring main.

18. Why ring main system is used ?

19. What are the advantages and disadvantages of the outdoor sub-stations as compared to indoor substation ?

20. What are the points to be considered while designing the substations ?

21. Describe the various equipments required for (*a*) indoor substation and (*b*) outdoor substation.

22. What are the various types of substations.

23. Describe with sketch the arrangement of bus bar on high and low voltage scale of substation.

24. Explain the various parts of a circuit Breaker.

25. Explain about the connection scheme of substation.
26. Describe about the indoor and outdoor substations.
27. Draw the diagrams for the following.
    (*a*) Connection with isolator and fuse.
    (*b*) Connection with bus-isolator, circuit breaker and line isolator.
    (*c*) Connection of 11 KV power transformer.
    (*d*) Single line diagram of 11 KV substation.
28. Explain about the design of substation.
29. What do you understand by sub-station auxiliaries supply ?
30. Draw the main connections
    (*a*) For Auxiliaries supply in 132/11 KV step down sub-station.
    (*b*) Key diagram of typical 33 KV, 3MVA/10 MVA substation.
    (*c*) Lay out of a typical 66 KV substation.

12

General Specifications

1. Introduction. 2. Generating set (diesel engine driven) 3. Switches and O.C.B. 4. L.T. O.C.B. indoor type with time limits fuse. 5. H.T. 11 KV switch with H.R.C. Fuses. 6. Ring main T. off switch. 7. H.T. Feeder panel. 8. L.T. Feeder panel. 9. Transformer. 10. Specifications for items of overhead lines. 11. Poles or struts. 12. Pin Insulators. 13. Shackle Insulators. 14. Disc type Insulators. 15. Stay assembly 16. Stay wire. 17. Aluminium Conductor steel reinforced. 18. G.I. wire. 19. Specifications for items of internal wiring. 20. V.I.R. Cable. 21. Weather proof Cable. 22. Cord flexible. 23. V.I.R. L.C. Cable. 24. P.V.C. Cable. 25. T.R.S. wire. 26. Fuse Board distribution. 27. Energy Meter. 28. Fuse wire. 29. Fuse Carrier. 30. Conduits. 31. Conduits Boxes. 32. Screws. 33. Tumbler Switch. 34. Water-Tight Swatch. 35. Socket outlet. 36. Metal Shades. 37. Glass Shades. 38. Lamp Holder. 39. Ceiling Roses. 40. Main Switch. 41. Underground Cable (low tension). 42. Underground Cable (high tension).

1. **Introduction.** It is very essential to specify the items requird correctly as otherwise there is going to be confusion while commencing the work on completion of the initial formalities of estimating and costing. In addition, until and unless the specifications are drawn correctly, it is not possible to assess its correct price.

2. **Generating sets (diesel engine driven).** Diesel engine driven generating sets are available with automatic excitation and as well as with shunt field regulator. If required automatic voltage regulator is also provided for automatic control of voltage on various loads after the initial excitation is given by hand on no load. The general specification of diesel engine generating sets are as under:

(*i*) **Diesel Engine.**

(*a*) B.H.P.—191 at 1,000 r.p.m.

(*b*) Overload capacity : 12% for one hour after every 12 hours working.

(*c*) No of cylinders : 6

(*d*) No of strokes : 6

(*e*) Rotation : Anticlockwise

(f) Method of starting : Battery or Pneumatic

(ii) **Alternator**

(a) Rating : 160 KVA at 1,000 r.p.m. at 0.8 p.f.

(b) Voltage : 420 ± 5%

(c) No of phases : 3-phase 4-wire

(d) Cycles : 50

(e) Type of excitation : Hand excited

(f) Requirement of parallel operation : To be provided with damper windings

(g) Coupling : Flexible coupling or Rigid coupling

The diesel engine and alternator as specified above are to be mounted on a common base plate. The base plate supplied is to be fabricated out of sheet steel and angle iron for the engine and alternator. Suitable foundation bolts for keeping the base plate in position on the foundation are to be provided. Further suitable engine alternator and coupling bolts to tight them on the base plate should also be provided.

(iii) **Alternator control panel.**

(a) Totally enclosed sheet cubical type with door at the back

(b) Bus bars : Copper or aluminium of sufficient rating for the above set

(c) Circuit breaker : Air circuit breaker complete with overload and short circuit release

(d) Working voltage : 500 V

(e) Voltmeter : 0—500 V (moving iron.)

(f) Ammeter : 0—300 A (moving iron.)

(g) Other meter : kWh meter, KW meter, frequency meter, power factor meter, moving coil ammeter for exciter.

(e) Arrangement for synchronising and excitation : Set of synchronising sockets and plug to be provided for parallel operation of sets. Shunt field regulator with hand wheel for varying the excitation also is to be provided.

3. Switches and O. C. B. Specifications for various switches and O.C.B. are given below :

4. L.T. O.C.B. Indoor type with time limit Switch. L.T. 400 amps enclosed oil circuit breaker fitted with :

(a) S. P. neutral link.

(b) 5 amps overload trips calibrated 100/200%.

(c) Time limit fuse totally enclosed.

(d) C.T. of rating 400/5 amps.

(e) Mechanical on and off handle with indicator.

(f) Cable box suitable for $3\frac{1}{2}$ core, 150 sq. mm. paper insulated lead covered underground cable.

(g) 3 Nos. 500-Amp copper or aluminium bus-bars placed in a metal clad enclosures.

5. H.T. 11KV Switch with H.R.C. Fuses. 11 KV A.C. metal clad extensible automatic manually operated indoor oil fuse switch unit of the tripping all phase type and breaking capacity 300 M.V.A. with the following attachment :

(a) Withdrawal fuse carrier complete with 3 Nos, 11KV suitable rated HRC (High Rupturing capacity) oil tight striker pin cartridges fuses.

(b) 3—300 Amps bus bars copper or aluminium, placed in a metal clad chamber filled with compound.

(c) Mechanical off and on handle with indicator and pad locking arrangement.

(d) Suitable oil level indicator.

(e) Two cable boxes for 3 core 25 sq. mm. H.T. underground PILCADSTA cable.

6. Ring Main T. off Switch. It should have the following specifications.

H. T. 11 KV extensible type ring main T. off switch indoor type comprises of one transformer control panel and 2 Nos. isolator panel each fitted with :

(A) **Transformer Control Panel.** Consists of Automatic manually operated oil fuse switch unit 300 Amps capacity having following parts :

(a) Withdrawal fuse carrier complete with 3 Nos H.R.C. oil tight striker pin cartridges fuses.

(b) Three, 500 Amp bus bars, copper aluminium placed in a metal clad chamber filled with compound.

(c) Mechanical on and off handle with indicator and padlocking arrangement.

(d) Suitable oil level indicator.

(e) Two cable boxes each suitable for 25 mm^2 **PILCADSTA**, HT underground cable.

(B) **Isolator pannel 2 Nos. for each unit.** It should comprise of the following :

(a) Metal clad non automatic type load breaking, fault making oil immersed isolator assisted with spring.

(b) Three 500 Amp bus bars of copper or aluminium placed in a metal clad chamber filled with compound.

(c) Mechanical operating handle with devices to bring it in the positions—On, Off, Earth and Test.

(d) One no. cable box suitable for 25 mm^2 **PILCADSTA**, H.T. underground cable.

7. H.T. Feeder Panel. It can be specified as under :

(a) Type : Indoor.

(b) System : 11 KV, 50 cycles, 3-phase ; 3-wire.

(c) Incoming panel with following accessories attachment.

(i) Vertical dropdown drawout free handle mechanism oil circuit breaker capacity 40 amps.

(ii) 3 Nos. of 5 amps. overload trips calibrated 100/200%.

(iii) 3 Nos. of time limit fuses.

(iv) 3 Nos. of current transformer ratio 40/5 amps accuracy.

(v) Voltmeter : 0-15 KV.

(vi) Ammeter : 0-40 amps.

(vii) Rotary selector switch.

(viii) 3-phase draw-out type oil immersed potential transformer ratio 11,000V/110V with H.V. and L.V. fuses.

(ix) Cable Box indoor type suitable for 3-core PILCADSTA 50 sq. mm U/G cable.

(x) Metal clad air insulated 3 Nos. bus bars suitable for working voltage 11 KV, capacity 50 amps.

(d) 3 Nos. outgoing pannel each with following accessories attachment.

(i) Vertical dropdown drawout free handle mechanism oil circuit breaker, capacity 40 amp.

(*ii*) 3 Nos. of 5 amps. overload trips calibrated 100/200%.

(*iii*) 3 Nos. of time limit fuses.

(*iv*) 3 Nos. of current transformer ratio 40/5 amps accuracy.

(*v*) Ammeter 0-44 amps.

(*vi*) Rotary selector switch.

(*vii*) Cable box indoor type suitable, for 3-core PILCADSTA 25 sq. mm U/G cable.

(*viii*) Metal clad air insulated 3 Nos. bus-bars suitable for working voltage 11 KV, capacity 50 amps.

8. L.T. Feeder Panel. It can be specified as under :

Metal clad indoor floor mounting type L. T. distribution board suitable for operation on 3-phase, 4-wire 50 c/s 400/440 volts. The panel should be equipped with the following :

(*a*) *Bus bars.* It should consist of :

(*i*) 3 Nos. bas-bars capacity 200 amps and mounted on porcelain support.

(*ii*) 1 No. bus bar capacity 100 amps and mounted on porcelain support.

(*b*) *Incoming.* It should consist of :

(*i*) 200 amps, 400/440 volts tripple pole, trip fuse, horizontal draw-out type oil circuit breaker with rupturing capacity as 10 MVA.

(*ii*) 3 Nos. of current transformers operated oil dash pot time lags system for over load trips.

(*iii*) 1 No. of neutral link.

(*iv*) 1 No. of under-voltage release.

(*v*) 1 No. mechanical on-off indicator.

(*vi*) 1 No. trip lever for emergency.

(*vii*) 1 No. ammeter 0–300 amps with selector switch.

(*viii*) 3 Nos. of current transformers ratio 200/5 Amps.

(*ix*) 1 No. voltmeter 0–500 V with selector switch and protective fuse.

(*x*) 1 cable box indoor type suitable for PILC $3\frac{1}{2}$ core 225 sq. mm underground cable.

(*c*) *3 Nos. outgoing.* Each should consists of :

(*i*) 3 Nos. of iron clad tripple pole and neutral link H. R. C. type fuse switch units, complete with H. R. C. fuse.

(*ii*) 1 No. ammeter 0–200 Amps with selector switch.

(*iii*) 3 Nos. of current transformers ratio 100/5 Amps.

(*iv*) 1 Cable box indoor type suitable for PILC, $3\frac{1}{2}$ core 185 sq., mm underground cable.

9. Transformers. The step-up transformer is used for stepping up the voltage after generation for the purpose of transmission upto the distribution substation. At the distribution substation, the voltage is again stepped down to 400 V. The step-up transformer can be specified as udner :

Capacity : 300 KVA.

(*a*) Type of transformer : Indoor or outdoor.

(*b*) Type of cooling : Natural oil cooled, or oil-filled water cooled or air Blast type (for 33 KV or above).

(*c*) Type of core : Shell or core.

(*d*) Type of wiring : Double wound or autowound.

(*e*) No. of phases and neutral.

(*i*) L. V. Side : 3 phases with neutrals for step-down transformer or 3-phase only for step-up transformer.

(*ii*) H. V. Side : 3 phases only.

(*f*) Voltage : between phases on :

(*i*) H. V. Side : 11 KV.

(*ii*) L. V. Side : 0.4 KV.

(*g*) Vector Group : Dy-11

(*h*) Tapping on H. V. side or on L.V. side depending upon if the transformer $2\frac{1}{2}$%, ±5%, $\pm 7\frac{1}{2}$% is step-up or stepdown

(*j*) Permissible temp. side of the core : 50°C

(*k*) Permissible temp. side of the oil : 45°C

(*m*) Efficiency at 0.8 p.f.

(*i*) At full load = 99% or 98.2%

(*ii*) At $\frac{1}{2}$ load = 99.2% or 98.4%

(*n*) Iron losses : 700 watts.

(*o*) Copper loss at full load : 4050 watts.

(*p*) Regulation at 0.8 p.f. : 3.88%

(*q*) Cable joints an H. V. side : Should be in a position to accommodate **PILCADSTA** H. T. U/G cable 25 sq. mm.

(*r*) Cable joint on L. V. Side : Should be in a position to accommodate L. T. U/G PILC cable 150 sq. mm.

10. Specifications for Items of Overhead Lines. Various items specified below :

11. Poles or struts. The poles can be of wood, R.C.C. or steel tubular. *The length of the struts should be 8.55 metres.* These can be specified as under :

(A) *Wooden Poles or Struts :*

(*a*) Girth of butt : 61 cm. or 76 cm.

(*b*) Girth of tip : 38 cm. or 53 cm.

(*c*) Length : 8.55 metres or 9.15 metres or 11 metres.

(B) *Reinforced Concerte Pole Struts.*

(*a*) Section at bottom : 22.86 cm. × 22.86 cm. or 30.50 cm × 30.50 cm.

(*b*) Length: 8.55 metres or 9.15 metres or 11 metres.

(C) *Steel Tubular Poles / Struts.* The steel tubular poles/struts should be of cast iron one piece with base flanges and bolts and nuts, the length should be 8.55 metres or 9.15 metres or 11 metres.

12. Pin Insulators. The pin insulators should be made of porcelain vitreous, white or brown with mild steel galvanized spindle, with galvanized iron nut and washer. Its dimensions for various voltages should be as shown in Table 12.1.

Table 12.1

Working Voltage	*Insulator size in mm*				*Size of galvanised mild steel spindle in mm.*	
	Height	*Maximum dia.*	*Dia. of groove*		*Dia. of shank*	*Top cordon thread*
			Side	*Top*		
500 V	63.50	57.15	9.52		15.885	15.885
1100 V	82.55	69.85	15.885	15.885	15.885	15.885
3,300 V	82.55	85.52	15.885	15.885	28.575	19.05
6,600 V	131.70	120.65	19.05	19.05	28.575	19.05
11,000 V	168.285	146.05	19.05	19.05	28.575	19.05

13. Shackle Insulators. The shackle insulator should be made of porcelain vitreous, white or brown including galvanised mild steel straps (2 Nos.) and bolt. Its dimensions for various voltages should be as shown in Table 12.2.

Table 12.2

Working Pressure	*Size of shackle insulator in mm*			*Size of galvanised steel straps and bolts in mm.*	
	Height	*Maximum dia.*	*Dia. of groove for conductor*	*Section of strap*	*Dia. of bolt*
500 V	52.39	63.50	6.35	25.40 × 1.60	9.52
1,100 V	66.76	78.21	14.29	31.75 × 3.18	12.70
3,300 V	101.60	106.36	25.40	41.36 × 4.80	19.05
6,600 V	139.70	127.00	12.70	38.10 × 4.80	19.05
11,000 V	152.40	127.00	16.00	38.10 × 4.80	19.05

14. Disc type Insulators. Disc type insulators are made of porcelain, vitreous white or brown in colour and each disc of size 152.40 mm dia. should be in a position to withstand 11,000 volts. The no. of disc used depends upon the working voltage. These car be specified as under :

Working voltage: 11 KV or 33 KV

Dia. of disc : 152.40 mm

No. of discs : 1 or 3

Other fittings : Equipped with tension clamps.

15. Stay Assembly. It can be specified as under :

(*a*) *Stay bow.*

(*i*) Dia. of rod : 15 mm

(*ii*) Length : 37.5 cm.

(*b*) *Stay plate.*

(*i*) Cross-section : 22.5 cm × 22.5 cm or 30 cm × 30 cm

(*ii*) Thickness of the plate : 6.5 mm

(*c*) *Stay or Anchor rod*

(*i*) Dia. of rod : 16 mm or 19 mm

(*ii*) Length : 60 cm.

One end of the stay rod should be threaded and have a suitable bolt and the other end should be joined with the stay plate by means of forged head as shown in Fig. 8.18.

(*d*) *Stay Insulator*. It should be made of porcelain viterous white or brown and should be specified as follows :

(*a*) Size : 7.62 cm. × 3.81 cm. or 10.8 cm. × 5.72 cm.

(*b*) Working load : 900 kg. or 1360 kg.

16. Stay Wire. *The stay wire should be of galvanised iron and should have 7 strands either of G.I wire 8 S.W.G. or of 10 S.W.G.*

17. Aluminium Conductor Steel Rod. The aluminium conductor is to be specified by number of aluminium and steel strands and their diameter in mm. The various sizes are indicated in Table 8.3. These conductors also have trade name. Few important sizes and trade names are given in Table 12.3.

Table 12.3

Stranding no. and wire dia.						*Method of specifying by size*	*Method of specifying by trade name*
	Aluminium		*Steel*				
No.	*Dia.*		*Dia*				
	mm	*inch*	*No.*	*mm.*	*inch*		
6	2.11	0.083	1	2.11	0.083	6/1 × .083	Squirrel
6	2.59	0.102	1	2.59	0.102	6/1 × .102	Weasel
6	3.00	0.118	1	3.00	0.118	6/1 × .118	Ferrot
6	3.35	0.132	1	3.35	0.132	6/1 × .132	Rabbit
6	3.66	0.144	1	3.66	0.144	6/1 × .144	Mink
6	3.99	0.157	1	3.99	0.157	6/1 × .157	Beaver
6	4.19	0.166	1	4.19	0.166	6/1 × .166	Other
26	2.54	0.100	1	2.54	0.100	26/7 × .100	Coyote
30	3.00	0.118	7	3.00	0.118	30/7 × .118	Panther

18. G. I. Wire. G.I. wire SWG No. 8 or 10 are used in over head transmission and distribution lines for earth wire. This can be specified as under :

Gauge : SWG 8 or 10

Weight per 100 metre length : 11.40 kg. or 6.00 kg.

19. Specifications for Items of Internal Wiring. Various items of internal wiring are specified as under :

20. V.I.R. Wires. V.I.R. wires have high conductivity conductor, single strand of aluminium, insulated with vulcanised rubber, tapped, braided and compounded to conform I.S.I. specifications. These wires can be specified as under :

(*a*) Type of insulation : V.I.R.

(b) Voltage grading : 250 V or 660 V

(c) No. of cores : Single or twin core.

(d) Metal : Aluminium.

(e) Size : 1 sq. mm, 1.5 sq mm, 2 sq mm, or 3 sq. mm or 4 sq. mm or 6 sq. mm or 10 sq. mm or 15 sq. mm or 20 sq. mm or 25 sq. mm.

21. Weather Proof Cables. Weather proof cables have high conductivity, single strand of aluminium conductor, insulated with vulcanised rubber tapped, braided and weather resisted compounded.

These cables are either twin core or single core and are of various sizes. These can be specified as under :

(a) Type of insulation : V.I.R.

(b) Voltage grading : 250 V or 660 V.

(c) No. of cores : Single or twin.

(d) Metal : Aluminium.

(e) Size : 1 sq. mm or 1.5 sq. mm or 2 sq. mm or 3 sq. mm or 4 sq. mm or 6 sq. mm or 10 sq. mm or 15 sq. mm or 20 sq. mm.

22. Cord Flexible. Flexible cords have high conductivity stranded copper wire insulated with vulcanised rubber and sheathed with tough rubber. These cords are available in twin core. These cords can be specified as under :

(a) Type of insulation : Flexible.

(b) Voltage grading : 250 V.

(c) No. of cores : twin.

(d) Metal : aluminium/Copper

(e) Size : 0.4 sq. mm or 0.6 sq. mm, 1 sq. mm, 2 sq. mm, 3 sq. mm or 4 sq. mm.

23. V.I.R. L. C. Cable. These cables have high conductivity conductor, single strand of aluminium insulated with vulcanised rubber, tapped, braided and covered with lead. These are twin core cables of 250 v or 660 V grade and various sizes available are as for V.I.R. wires. These wires can be specified in similar fashion as *V.I.R. wire except for insulation.*

24. P.V.C. Cable. The aluminium conductors of such cable are covered by polyvenyl compounded insulation. These are available in 250 V or 660 V grade and are either single or twin core. The various sizes available are as for V.I.R. wires. *These wires can be specified in similar fashion as V.I.R. wires except for insulation.*

25. T.R.S. Wires. These cables have high conductivity single strand of aluminium conductor, insulated with vulcanised rubber tapped, braided and weather and sheathed with tough rubber. These cables are either twin core or single core and are of various sizes as for V.I.R. wires. *Except for insulation, these wires can be specified in a similar fashion as V.I.R. wires.*

26. Fuse Board Distribution. The fuse board should be made of hardwood or metal clad with hinged front vitreous fuse bases and carriers mounted on frame. It can be specified as follows :

(*a*) Rating : 15 amps or 20 amps or 25 amps etc.

(*b*) No. of phases : Single pole or double pole or three pole.

(*c*) Arrangement of neutral : Neutral link.

(*d*) Nos. of circuits : 2-way or 3-way or 4-way or 6-way or 8-way.

(*e*) Working voltage : 250 V or 500 V.

(*f*) Type of fittings : Flame proof or wooden.

27. Energy Meter : A.C. energy meter can be induction type, single-phase, three-phase or three-phase 4-wire. These can be specified as follows :

(*a*) Working voltage : 230 V or 400 V or 6.6 KV or 11 KV.

(*b*) No. of phases : Single phase or three-phase, three-wire or three-phase four-wire.

(*c*) R.P.M. : 450 or 600 or 900 or 1000 or 1200 etc.

(*d*) Rating : 5 amps or 10 amps or 20 amps or 25 amps or 50 amps or 100 amps or 500 amps.

(*e*) Any other attachment :

(*i*) P.T. of suitable size for high voltage energy meter.

(*ii*) C.T. for suitable size meters having rating more than 100 amps.

28. Fuse Wire. The fuse wire to be inserted should be in accordance with I.E. Regulations. It may be of copper tinned, lead or aluminium. The fuse wire has been already discussed in a separate chapter in details. The fuse wire is to be specified as under :

(*a*) Type of fuse : Copper tinned or lead or aluminium.

(*b*) Capacity in amperes : 3 amps or 5 amps or 10 amps or 20 amps or 50 amps or 100 amps.

29. Fuse Carrier. The fuse carrier has already been discussed in a separate chapter. It is made of ceramic which is ignitable under normal condition. The fuse carrier may be specified as under :

(*a*) Working voltage : 3 amps or 5 amps or 10 amps or 20 amps or 50 amps. or 100 amps.

30. Conduits. The conduit should be black or silver enamelled or galvanised with screwed from right hand thread. The conduit can be specified as under :

(*a*) Material : Welded or solid drawn steel.

(*b*) Type of painting : Black or silver enamelled or galvanised.

(*c*) Size : 15 mm or 20 mm or 25 mm or 30 mm or 35 mm.

(*d*) Gauge : 16 S.W.G.

31. Conduit Boxes. These should be of malleable cast iron and *draw in-type*. These can be specified as under :

(*a*) Size : Suitable for conduit size 15 mm or 20 mm or 25 mm or 30 mm or 35 mm.

(*b*) Material : Malleable cast iron.

(*c*) Size of tapping : 31.75 mm.

32. Screws. *The screws of any size should be of brass.*

33. Tumbler Switch. Can be specified as under :

(*a*) Material : Backelite.

(*b*) Capacity : 5 amps or 15 amps.

(*c*) Working voltage : 250 V.

(*d*) Other important requirements :

(*i*) The holes at the base of switch should be filled with hygroscopic insulating compound. This compound should remain hard even at 75°C.

(*ii*) Switch cover should comply with I.S. 1087 of 1957.

(*iii*) Operating dollies should be made of insulating material and of sufficient strength.

34. Water-tight Switch. This can be specified as under :

(*a*) Capacity : 5 amps or 15 amps.

(*b*) Base : The base should be of galvanised cast iron or malleable iron.

(*c*) Cover : Should be of cast iron or malleable iron and should be provided with rubber washer.

(*d*) Working voltage : 250 V.

35. Socket Outlet. It can be specified as under :

(*a*) Capacity : 5 amps or 15 amps.

(*b*) Working voltage : 250 V.

(*c*) Bottom material : The bottom should be made of white.

(*d*) Well glazed, non-absorbent vitreous porcelain with recessed back for proper seating.

(*e*) Contacts : The contacts should be made of brass.

(*f*) Cover : The cover should be of backelite having minium 3.2 mm thickness.

36. Metal Shades. These can be specified as under :

(*a*) Shape : Conical

(*b*) Metal : Enamelled iron.

(c) Dia. or holes : (*i*) 28.58 mm. (*ii*) 254 mm or 300 mm.

37. Glass Shades. These can be specified as under :

(*a*) Shape : Conical
(*b*) Metal : Opal glass
(*c*) Dia. of holes (*i*) 28.58 mm (*ii*) 254 mm.

38. Lamp holders. These can be specified as under :

(*a*) Type : Pendent or Bracket or Batten.

(*b*) Material : Brass or Backelite.

39. Ceiling Rose. These can be specified as under :

(*a*) Material : Backelite.

(*b*) Material of terminals : Brass, the contact should be separated with porcelain or backelite.

(*c*) Type : 2-way or 3-way.

40. Main Switch. These can be specified as under :

(*a*) Capacity : 15 amps or 30 amps or 60 amps or 100 amps or 200 amps.

(*b*) Working voltage : 230 V or 400 V.

(*c*) No. or phases : Single phase or three-phase four-wire.

(*d*) Arrangement of neutral : Neutral link.

(*e*) Operating handle : Should be of sufficient strength and controlled by spring.

(*f*) Fuse base or carrier : The base should be of high grade vitreous porcelain.

41. Underground Cables (Low Tension.) These cables should confirm to I.S. 692-1957 and these can be specified as under:

Insulator and Conductor : Paper insulated lead alloy sheathed and served with aluminium conductor.

Grading : 660 volts or 1,100 volts

No. of Cores : Two or three or four or three and half cores.

Size : 25 sq. mm. or 35 sq. mm, 50 sq. mm, 95 sq. mm or 185 sq. mm or 300 sq. mm or 500 sq. mm.

Note :-*It should be noted that three and half-core cables are not being manufactured for sizes below 50 sq. mm., therefore for cables below 50 sq. mm four-core cables are used. Three and half-core cables are used for sizes above 50 sq. mm.*

42. Underground Cable (High Tension). These cables should confirm to IS-692-1957 and these can be specified as udner:

Insulation : Paper insulated lead alloy sheathed double steel tape armoured and served with aluminium conductor.

Grading : 6.6 KV or 11 KV or 33 KV.
No. of Cores : Three.

Size : 25 sq. mm or 35 sq. mm or 50 sq. mm or 185 sq. mm or 225 sq. mm or 300 sq mm.

42. Boxes, Cable Jointing (Low and Medium and High Tension): Cables boxes are of various types as given below :

(*i*) *End dividing*

(*a*) Indoor

(*b*) Outdoor

(*ii*) *Straight through type*

(*iii*) *Tee type.*

The cable boxes should be specified as under :

Type : End dividing (indoor or outdoor) or straight through or Tee type.

Working voltage : 400 Volts or 6.6 KV or 11 KV, or 33 KV.

Size, insulation and cores of cable : Suitable for PILC or PILCADSTA three or three and half or four-core cables of required size.

TYPICAL QUESTIONS

1. What do you understand by the term 'specifications'?
2. What are the various equipments used in a substation ? Specify any of the equipment.
3. Draw out the specifications of a 0.4/11 KV transformer 300 KVA capacity.
4. Draw out the specifications of a diesel generating set.
5. It is required to procure a L.T. feeder panel, capacity 400 Amp. for four outgoing feeders each of capcity 200 Amps. Chalk out the specifications for the same.
6. Chalk out the specifications for L.T. and H.T. underground cable.
7. How would you specify (*a*) stay assembly and (*b*) A.C.S.R.
8. Write down the specifications of a main switch to control consumer two-wire mains for his connected light and fan load of 1 kW at 230 V.
9. Write down brief specifications of a switch for controlling 100 watts 230 volts lamp in cleat wiring.
10. How would you specify (*a*) Energy Meter (*b*) Fuse wire (*c*) Conduit (*d*) Metal shades.
11. Write down brief specifications of the following material :
    (*a*) Earth plate required for earthing L.T. lines.
    (*b*) 5 Amp plug used in concealed conduit.
    (*c*) 500 Amp 3-phase A.C. kWh meter 400 volts for use in a factory.
    (*d*) V.I.R. wire used in domestic purposes.
12. Write down brief specifications for :
    (*a*) Insulator for 11 KV.
    (*b*) Stay rod.
13. Write down brief specifications for :
    (*i*) Transformer.
    (*ii*) Generator.
    (*iii*) Energy meter for domestic use.
    (*iv*) Switch.
14. Write down brief specifications for :
    (*a*) Earthing material for grounding a small workshop.
    (*b*) Stay Insulator for L.T. lines.
    (*c*) Insulator for 11 KV line.
    (*d*) Lighting arrestors for 11 KV line.
    (*e*) Circuit breaker for L.T. line.