EDUCATION

To those who have been an endless source of inspiration who have spared no effort to provide me with the best education, me how to rely upon my self & surmount all obstracles & hardships.

TO

FATHER & MOTHER

1996/6/28

BB

I would like to extend my appreciation's and regards to my supervisor Prof. Haldun Gürmen for his generous help during the work on this project. I would like to express my thanks for many useful comments and suggestions provided by Assoc. Prof. Dr. Şenol BEKTAŞ. I am also indebted to my family for their support in all aspects.

PAGE

Overhead and Underground

Transmission and Distribution Lines

1. INTRODUCTION

Transmission and distribution lines are vital links between generating stations and consumers. Transmission lines carry power at high voltages such as 132 kV or 220 kV over a long distance from the generating stations to the major load centres. The power is supplied to the various consumers, both domestic and industrial, from the secondary substations, by means of distribution lines. Distribution of power is carried out also by underground four-wire-cables. In this chapter, we shall discuss the different materials used, and the design and installation of overhead and underground lines.

SUPPORTS FOR TRANSMISSION LINES

Transmission lines are generally carried on steel towers. The line conductors are supported on the tower by means of insulators while the earth wire is directly supported by means of a clamp. The usual span of tower line is 250 m. The supports used in practice for transmission lines of various voltages are given in Table 1.1.

Table 1.1: Supports used for Transmission Lines

Sr. No.	*Voltage*	*Type of support*
1.	1000kV	Tower
2.	800kV	Tower
3.	600kV	Tower
4.	220kV	Tower
5.	132kV	Tower
6.	66kV	Tower of H pole structure
7.	33kV	Tower if the conductors to be carried are heavy,

DISTRIBUTION LINES - MATERIALS USED

The main material used for HT (11kV) and LT (415 V) distribution lines are listed as follows:

1. Poles and their fittings
2. Conductors and their accessories
3. Earthwire and its accessories
4. Insulators and their fittings
5. Stays (or guys) and the associated arrangement
6. Anticlimbing devices
7. Danger sign boards
8. Guarding wires

1.1 Poles and Their Fittings

Poles are used as supports for crossarms, insulators, and conductors for overhead lines. The different types of poles used for erecting overhead lines in urban and rural areas are:

1. Wooden poles
2. Steel poles
    (a) tubular poles
    (b) rail poles
3. Re-inforced Cement Concrete (RCC) and Pre-stressed Cement Concrete (PCC) poles.

As a thumb rule, in the depth of the pole to be planted in the ground is taken as 1/6 of the pole length. Since PCC poles are lighter, their transportation, handling, erection are easier. PCC poles are of 9m and 8m length.

Cross arms are cross-pieces mounted on poles to support the insulators and conductors of a line. Cross-arms may be made either of wood or steel. The usual lengths and cross-sections of wooden cross-arms in use are:

1. 1.52 m x 125 mm x 125 mm for 11 kV lines

2. 2.14 m x 125 mm x 125 mm for 33 kV lines

MS channel iron sizes 75 mm x 37 mm and 100 mm x 50 mm are usually used as steel cross arms.

A pole top bracket is required for fixing the pin insulator on the top of the pole, and is manufactured from MS flat of size 60 mm x 8 mm.

1.2 Conductors and Their Accessories

As the availability of copper has become scare in India, copper is not used as conductor material for transmission and distribution and is now being replaced by aluminium.

All aluminium stranded conductors (AASC) are mainly used on low voltage distribution systems employing relatively short spans of upto 67 m.

Steel Reinforced Aluminium Conductors (ACSR) are made up of galvanized steel core surrounded by stranded aluminium wires. Due to the higher strength of ACSR, the span length can increased. Hence ACSR conductors are widely used in transmission and distribution of electrical energy.

Galvanised steel conductors do not corrode, and possess high resistance. Hence such wires are used in telecommunication circuits, earth wires, guard wires, guy wires etc.

The following accessories are required for the conductor to be installed on poles:

1. binding tape
2. binding wire
3. parallel groove (PG) clamp
4. jointing sleeve
5. repair sleeve
6. tension clamp
7. suspension clamp

The conductors are bound to pin insulators using binding tape and binding wire. Electrical connection between straight run line conductors can be made with the help of parallel groove (PG) clamps made of aluminium alloy. When two conductors have to be joined a jointing sleeve is sued. Repair sleeves are used for the reinforcement of ACRS or AAC conductors which have a few of the aluminium strands damaged or broken. At the terminal pole, the conductor is suspended by the disc insulator by means of suspension clamps.

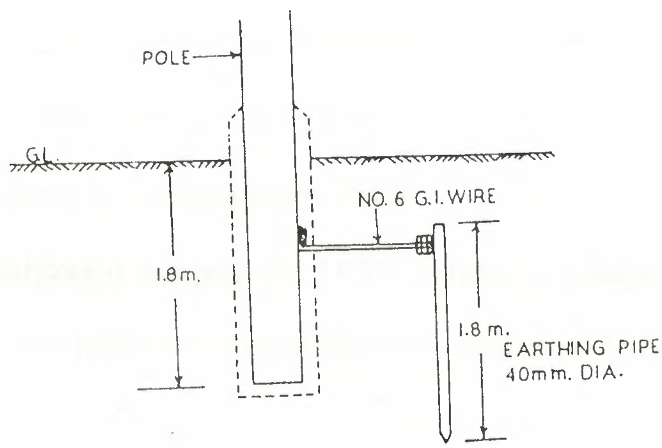
1.3 Earth Wire and Its Accessories

All metal supports of overhead lines and metallic fitting attached thereto should be permanently and efficiently earthed. Earthing can be done in two ways.

1. A continuous earth wire is run over the supports and then connected to earth at fours points in every 1.6 km, the spacing between the points being as nearly equal as possible. The earth wire is usually of galvanised steel. (GSL 8 SWG or 4 SWG). Double earth wire is used at those places where guarding is to be provided for a three-phase three wire system. The earth

wire is placed in J-bolt or screw-eye bolt. At other places on 11 kV lines, the earth wire is placed on reels.

2. In the second method, every pole is earthed and the earth wire is run along the pole to the ground connected to the earth rod/pipe. A galvanised iron rod of diameter 20 mm or a pipe of diameter 40 mm is driven into the ground for its full length with top at least 0.6 meter below the ground level, as shown in Figure 1.1. Earth wire is connected to the rod/pipe with the help of clamp. Water is poured into sump to keep the soil surrounding the pipe moist. However, where the soil is hard, charcoal and salt layers are provided around the pipe/rod in alternate to reduce earth resistance which should not exceed 10 ohms.



For steel tubular poles, a hole of 14 mm diameter is provided in each pole at a height of 300 mm above the planting depth for connecting the earth wire to the earth electrode. For PCC and RCC poles, the wire fore earthing is brought from the top along the pole and should be properly clamped and connected to earth electrode. The earth wire (GSL No. 6) is connected to the pipes with GI bolts, nuts and washers, employing GI lugs of suitable sizes.

1.4 Insulators and Their Fittings

In order to prevent short circuit between the different phase conductors of the line and also to prevent leakage of current to earth through cross-arms on poles and towers, insulators are provided between conductors and supporting structures.

Pin insulators are commonly used on rural and urban 11 kV primary distribution lines. These can be used upto 33 kV. Pin insulators can be of single piece or multipiece.

Pin insulators cannot take conductor load in tension which often occurs at angles and at dead ends. To meet this requirement, disc insulators are used. Besides being used at angles and at dead ends, disc insulators are also used as suspension insulators in straight runs for line voltages of 66 kV and above. Suspension insulators are also used on straight runs on 11 kV and 33 kV lines if the conductor size is heavy i.e. 48 mm^2 and above. But pin insulators are never used in tension, and never for voltages above 33 kV.

One disc insulators is adequate for 11 kV. When the voltage is higher, more than one disc insulators are joined together to form a straight of insulators. The number of disc insulators needed to form strains for different voltages are given in table 1.2

Table 1.2: Minimum Number of Insulator Discs for Transmission Lines

System voltage (kV)	*Number of insulators in string assemblies*	
	Suspension Assemble	*tension or dead-end assembly*
11	1	1
22	2	3
66	5	6
132	9	10
220	14	15
400	21	22

For low and medium voltage lines pin type and shackle type insulators are used. Shackle insulators take tension of conductors at dead ends, junctions of overhead lines with cables, road crossings and at angle poles. Egg type insulators, also called strain insulators or guy insulators are generally used with pole guys on low voltage lines, where it is necessary to insulate the lower part of the guy wire from the pole for the safety of people and animals on the ground.

1.5 Guys (stays) and the Associated Arrangement

In the case of an overhead line using poles, unlike intermediate poles, a terminal pole experiences a pull on one side only and tends to tilt the pole in the direction of line. To prevent this, a stay or guy is provided.

There is also a tendency for the pole to tilt where the line takes a turn. A guy is required to counteract the resultant pull on the angle pole owing to the line.

Under abnormal weather conditions the pole and conductors may be subjected to high velocity winds in the transverse direction to the line which may tilt or uproot the poles. As a safeguards against this, every fifth pole in a straight run is provided with two wind guys on either side in the transverse direction.

A guy may be strut guy or a stranded steel wire guy, as shown in Figure 1.2. Stranded steel wire guys are fixed on the opposite side of conductor and they remain in tension. The strut guys which are made of lines poles, are installed on the same side as conductors and take compressive loads.

Stranded guy (stay) wires commonly used on overhead lines are galvanised steel of 70^2 kgf/mm quality. Stayrods are manufactured from round mild steel with a diameter of 16 mm or 20 mm. The stay plate is fitted to one end of the stayrod and to the other end, the stay bow is fixed. Stay plates are of cast iron or reinforced concrete and it holds the stay (guy) assembly firmly in the ground. Stay bow is fixture which connects the stay (guy) wire to the stay rod. GI thimbles are used at both ends of the stay (guy) wire to avoid damage to the stands of the stay wire. The stay is fixed with the pole through a stay people clamp. A large egg-type insulator is inserted in each stay to insulate to upper part of the stay wire from the lower part. It is provided on the stay-wire at a minimum height of 3 m from the ground.

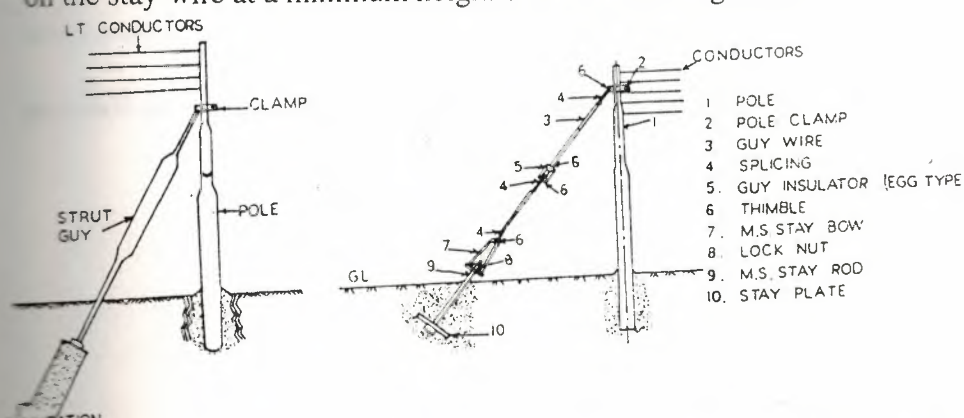


Figure 1.2: Different types of guy (stay) arrangements

1.6 Anticlimbing Devices

Barbed wire is wrapped on poles at a height of about 2.5 m from the ground for at least 1 meter. This is to prevent climbing by unauthorised persons.

1.7 Danger Sign Boards

A danger plate is provided on each pole, as a warning measure indicating the working voltage of the line and the word "danger". It is provided at a height of 2.5 metres from the ground.

1.8 Guarding Wires

A guarding is provided for the safety of life, installations and of the communication circuits. The guarding for 11 kV lines is provided at road crossings, canal crossings, railway crossings, crossings over LT lines or telegraph and telephone lines. For LT lines, the guarding is provided throughout. When guard wires are provided, if a line conductor breaks, it becomes earthed before falling on the ground.

There are two types of guards (a) cradle guard and (b) box or cage guard. In 11 kV lines, when conductors are in horizontal or delta formation, cradle guard is provided. Cage guarding is provided on LT lines with a vertical formation. Both the types are shown in Figure 1.3.

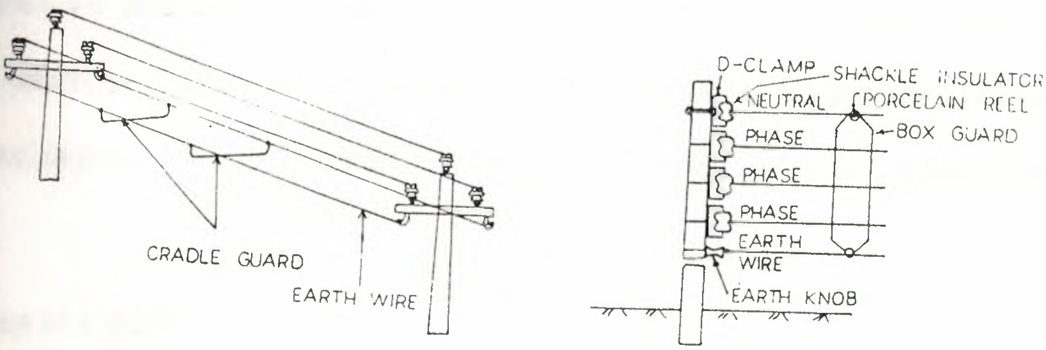


Figure 1.3. (a) Cradle guarding (b) Cage guarding

When an LT line is in horizontal formation, a cradle guard is provided. Guards should be made of the same material as used for the earth wire, i.e., GSL 8 SEG or GSL 6 SWG. Guards should be uniformly spaced.

CHAPTER 2

UNDERGROUND CABLES

Cables are used for giving service connection from the nearest overhead distributor to domestic, commercial, agricultural or industrial consumers. Cables are also used in electrical installations, in power stations, distribution systems, in substations and in large industrial units.

2.1. Types of Cables

Cables are classified according to the voltage range for which they near used :

1. Low - Tension Cables	(1)	250 - 440 V
	(2)	650 - 1100 V
2. High - tension Cables	(1)	unto 3.3 kV
	(2)	unto 6.6 kV
	(3)	unto 11 kV
	(4)	22 kV and 33 kV cables.
3. Extra - High - Tension Cables	66 kV and 132 kV oil filled and gas filled cables.	

2.2. Construction of Cables

One of the major component of a cable is the conductor. Since the conductor is under tension, it is necessary to insulate the conductor. Hence another component of a cable is the insulation.

aluminium is used. The aluminium conductors upto 10 sq.mm size are circular and solid, and above that size are circular and stranded.

The insulation is an extremely important part of a cable. The materials used for insulation may be one of the following :

(1) Vulcanized India Rubber (VIR)

(2) Paper

(3) Polyvinyl Chloride (PVC)

PVC cables are used in India upto 11 kV. They have completely replaced VIR and paper insulated cables upto 11 kV operation.

2.3 Low Tension Cables

Low tension cables are those that are used upto 1.1 kV. They are almost invariably PVC cables. The various sizes of LT cables are given below:

(1) Single-core cable with aluminium conductors: 1.5 sq.mm to 625 sq.mm.

(2) Two, three, three-and-a-half, and four core cables with aluminium conductors: 1.5 sq.mm to 625 sq.mm.

(3) Control cables upto 61 cores with copper conductors: 1.5sq.mm and 2.5 sqmm.

2.4 High Tension cables

High tension cables are those used for 1.1 kV and above. Cables upto 6.6 kV grade (i.e., 1.1 kV, 3.3 kV) are covered by PVC insulation. Paper insulated cables are manufactured for used on voltages 11, 22 and 33 kV. The range of sizes for paper insulated cables for 11 kV is as follows:

(1) Single-core cable 16 to 1000sq.mm.

(2) Three core cable 16 to 500 sq.mm.

Paper insulated power cables can be classified as follows:

(1) Belted type.

(2) Screened or H-type.

(3) SL type.

CHAPTER 3

MECHANICAL DESIGN OF OVERHEAD LINES

Two important terms connected with mechanical design of lines are sag and span.

Sag: The maximum vertical distance in the span of an overhead line, between conductor and the straight line passing through the two top points of the support of the conductor is called sag.

Span: The part of an overhead line between the consecutive supports is called span.

Length of span: The horizontal distance between two consecutive supports of an overhead line is called length of span.

3.1 Necessity of Sag

A knowledge of the amount of sag of an overhead line is important because it is the sag which determines the minimum ground clearance. The clearances to be provided as permissible under the Indian Electricity Rules are given in Table 3.3 to 3.6

Sr. No.	Voltage	Clearance
1.	Low and medium voltage lines	(a) 1.22 m (4 ft) (for bare conductor). (b) 0.61 m (2 ft) (for insulated conductor)
2.	High voltage lines upto and including 11 kV	1.83 m (6 ft)
3.	High voltage lines above 11 kV	2.44 m (8 ft.)
4.	Extra high voltage lines	3.05 m (10 ft).

Table 3.4: Minimum Clearance between Conductors and Trolley Wires when an Overhead Line is Crossing a Tramway or Trolley Bus Route

Type of roof	*Vertical clearance*	*Horizontal clearance*
Flat roof	2.44 m (8 ft) (from the highest point)	1.22 m (4 ft)
Pitched roof	2.44 m (8 ft) (immediately below the lines)	1.22 m (4 ft)

Table: 3.5: Minimum Clearance from the Accessible Point on Buildings of Low and Medium Voltage Lines and Service Lines, when the Line passes above or adjacent to the Building

Sr. No.	Voltage	*Vertical clearance above the highest point on the basis of maximum sag.*	*Horizontal clearance on the basis of maximum deflection due to wind pressure*
1.	High voltage lines upto and including 11 kV	3.66 m (12 ft)	1.22 m (4 ft)
2.	High voltage lines above 11 kV and upto and including 33 kV		1.83 m (6 ft)
3.	For extra high voltage lines	3.66, (12 ft) plus 0.305 m (1 ft) for every additional 33 kV or part thereof	1.83 m (6 ft) plus 0.305 m (1 ft) for every additional 33 kV or part thereof

Table 3.6: Minimum Clearance from any Accessible Point on Buildings, of High and Extra-high Voltage, when the Line passes above or adjacent to the Building

3.2 Sag Calculation

Let w be the weight of the conductor per unit length,

T the tension at the lowest point and

l the length of the span

The sag of conductor $d = wl^2/8T$

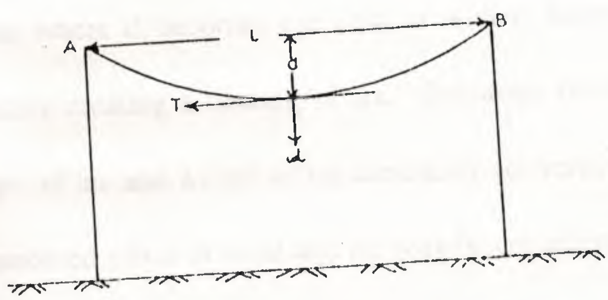


Figure 3.4: Illustration of sag

Because of the sag, the length of the conductor is greater than the length of the span. The length of the conductor

$$l_1 = \frac{l + 8d^2}{3l}$$

3.3 Factors Affecting the Sag

1. *Effect of temperature:* In summer, high temperature causes an increase in the length of the conductor, causing it to sag all the more. This may leaves less clearance to ground than is necessary. In winter, low temperatures cause a reduction in the sag of the conductor which increases the tension in the conductor so as to snap it. To know the actual sag at any temperature at a site, stringing charts are used.

2. *Effect to wind:* When wind blows, its pressure acts horizontally on the length of the wire. Thus the conductor is acted upon by two forces viz., the weight of the conductor w acting

tension T in the conductor will increase under wind pressure. While designing the overhead lines, the sag should be so provided that the tension developed under wind condition is sill within permissible limits.

The values of wind pressure are different at different places. Generally, it may be assumed that the maximum wind pressure in India varies from about 100 kg/m^2 to about 150 kg/m^2.

3. *Effect of ice:* In areas where it becomes too cold in winter, there is a possibility of ice-formation on the conductor creating a coating of ice. -formation on the conductor creating a coating of ice. The weight of ice and weight of the conductor act vertically downwards. To find the effect on sag, the combined effect of wind and ice may be considered. If the total weight per metre of conductor including ice covering and wind force is w_t, the sag is

$$d = \frac{w_t l^2}{8T}$$

4. *Effect of length of span on sag:* Use of long spans necessitates the use of taller supports and larger space between conductors, because increase in the span increases the sag. By using conductors of greater tensile strength, such as ACSR, long spans can be employed without considerable increase in the height of supports.

With wooden poles spans upto 75 m and with steel towers spans upto 250 m can be used.

5. *Effect of sag on overhead conductor configuration:* When overhead lines are in horizontal configuration there is a possibility, when strong wind blows, that a short circuit may occur between conductors or between conductors and supports. Therefore, in areas where heavy wind blows, a vertical configuration for overhead conductors is preferred.

When overhead conductors are in vertical configuration, the ice coating around conductors in cold regions, may sometimes appear or disappear in one conductor but not in all conductors. This cause an unequal sag in the different conductors and may result in a short circuit between them. Therefore, in areas where icy conditions occur, horizontal configuration for overhead conductors is preferred.

CHAPTER 4

DESIGN OF UNDERGROUND CABLES

4.1 Factors Determining Selection of LT Power Cables

The following factors should be taken into account while selecting the correct size and type of cables

1. *System voltage:* When writing out the specifications of a cable, the system voltage and the type of system, i.e., whether the system in single phase, three phase, earthed or unearthed, AC or DC must be stated.

2. *Current carrying capacity:* The current rating is the most important factor. Table 4.1 and 4.2 give the current carrying capacities of various types and sizes of cables under different conditions of laying. Temperature rating factors given in Table 4.2 should be used to multiply values obtained from Table 4.1 and 4.2 for obtaining the current carrying capacity of cables under the condition of installation.

Table 4.1: Current Ratings of 'Insulast' Aluminium Power Cables

Nominal area of conductor (sq.mm)	*Single core cables*				*Twin and multicore cables*			
	Laid in ground		*Laid in air*		*Laid in Ground*		*Laid in air*	
	2 cables (A)	*3 cables (A)*	*2 cables (A)*	*3 cables (A)*	*2 core (A)*	*3, 3.5 and 4 core (A)*	*2 core (A)*	*3, 3.5 and 4 core (A)*
1.5	21	17	18	15	18	16	16	13
2.5	28	24	25	21	25	21	21	18
4	36	31	32	27	32	28	27	23
6	44	39	41	35	40	35	35	30
10	59	51	56	47	55	46	47	40
16	75	66	72	64	70	60	59	51
25	97	86	99	84	90	76	78	70
35	120	100	120	105	110	92	99	86
50	145	120	150	130	135	110	125	105
70	170	140	185	155	160	135	150	130
95	205	175	215	190	190	165	185	155
120	230	195	240	220	210	185	210	180
150	265	220	270	250	240	210	240	205
185	300	240	305	290	275	235	275	240
225	325	260	340	325	300	265	310	270
240	335	270	350	335	320	275	375	280
300	370	295	395	380	355	305	365	315
400	410	325	455	435	385	335	420	375
500	435	345	490	480	405	360	435	380
625	485	390	560	550	460	400	460	420

Table 4.2: Current Rating of Insulast' Copper Controls Cables

No. of cores	1.5 sq.mm		2.5 sq.mm	
	Laid in Ground (A)	Laid in air (A)	Laid in ground (A)	Laid in air (A)
2	23.0	20.0	32.0	27.0
3	21.0	17.0	27.0	24.0
4	21.0	17.0	27.0	24.0
5	17.0	14.5	23.0	19.5
6	15.0	13.5	21.5	18.0
7	14.0	12.5	20.0	17.0
10	13.0	11.0	17.5	15.0
12	12.0	10.5	16.5	14.0
14	11.0	10.0	16.0	13.5
16	10.0	9.5	15.0	12.5
19	9.5	9.0	14.0	12.0
24	9.0	8.0	13.0	11.0
27	8.5	7.5	12.5	10.5
30	8.5	7.5	12.0	10.0
37	8.0	7.0	11.0	9.0
44	7.5	6.5	10.0	8.5
52	7.0	6.0	9.5	8.0
61	6.5	5.5	9.0	7.5

Table: 4.3: Rating Factors for Variation in Ambient Air/Ground Temperature

Ambient air/ground temperature (^0C)	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Air	1.35	.130	1.25	1.16	1.09	1.00	0.90
Ground	1.17	1.12	1.06	1.00	0.94	0.87	0.79

The current rating given in Tables 4.6 and 4.7 are based on the normal laying conditions given below:

1. Ground temperature - 30^0C

2. Ambient air temperature - 40^0C

3. Thermal resistivity of soil - 150^0C cm/W

4. Depth of laying - 750 mm

3. *Mode of installation:* The mode of installation determines the type of cables to be used. For underground installations, armoured cables are used to prevent damage on account of accidental digging. In general, armoured cables are recommended where there is a possibility of mechanical damage. If there is no chance of mechanical damage whatsoever, cheaper unarmoured cables can be sued.

4. *Permissible voltage drop:* The selection of the cable size should be such that the voltage variation in the cable should be within permissible limits i.e., ± 5% of the declared voltage.

5. *Short circuit rating:* If a phase-to-phase or phase-to-earth short circuit occurs, a very high short-circuit current flows. The cable should be so selected that it can withstand the stresses and the resulting increase in temperature caused by the maximum short circuit current produced by the phase to phase short circuit upto a period of one second.

6. *Economic considerations:* While selecting the cable size for a given application, a detailed study is made of three or four approximate sizes which are satisfactory in respect of current carrying capacity and permissible voltage drop. The I^2 R losses, the interest on capital cost, and depreciation are worked for each size of cable. The size which gives minimum running cost is preferred.

4.2 Factors Determining the Size of H. T. Power Cables

Selection of the correct size and type of HT power cable depends on certain factors which are discussed as follows:

1. *System voltage:* While writing out the specifications of an HT cable one must state the system voltage, and specify whether it is an earthed or unearthed system. The HT cable is almost invariably used on three phase system.

2. *Current carrying capacity:* Table 4.4 gives the current carrying capacity of 3.3 kV and 6.6 kV three core belted, armoured cables of various sizes. Tables 4.5 and 4.6 give the current carrying capacities of 11 kV three core belted and screened armoured cables respectively.

Table 4.4: Continuous Current Ratings of 3.3 kV and 6.6 kV Three Core Belted Armoured Cables

Nominal area of conductor (mm^2)	*Current rating (A)*		
	In air	*In ground*	*In duct*
16	75	76	68
25	105	110	93
35	120	120	105
50	145	147	125
70	190	188	163
95	219	213	185
120	264	250	215
150	296	277	240
185	342	315	273
225	395	354	310
240	427	377	335
300	465	402	360
400	562	475	422

Table 4.5: Continuous Current Ratings of 11 kV Three-core Belted Armoured Cables

Nominal area of conductor (mm^2)	*Current rating (A)*		
	In air	*In ground*	*In duct*
16	65	70	61
25	93	95	84
35	104	105	95
50	127	130	114
70	168	168	145
95	191	190	165
120	226	222	194
150	255	246	215
185	291	279	246
225	334	314	280
240	363	337	300
300	394	359	319
400	465	423	376

Table 4.6: Continuous Current Ratings of 11 kV Three-core Screened Armoured Cables

Nominal area of conductor (mm^2)	*Current rating (A)*		
	In air	*In ground*	*In duct*
16	73	76	65
25	101	104	85
35	115	118	97
50	142	145	120
70	183	182	155
95	210	205	175
120	251	241	206
150	278	264	226
185	320	298	256
225	372	336	291
240	405	360	312
300	439	402	334

Temperature rating factors for variations in ambient air temperature and ground temperature are given in Tables 4.7 and 4.8.

Table 4.7: Rating Factors for Variation in Ambient Air Temperature (for Cables in Air)

Air temperature (^{0}C)	25	30	35	40	45
Rating factor for 11 kV	1.30	1.21	1.10	1.00	0.88

Table 4.8: Rating Factors for Variation in Ground Temperature (for Cables laid in the Ground or Ducts)

Ground temperature (^{0}C)	15	20	25	30	35	40	45
Rating factor for 11 kV	1.20	1.13	1.07	1.00	0.93	0.85	0.76

Table 4.9 gives the rating factors for the depth of laying. As the cable is laid progressively deeper under the ground the heat dissipation becomes correspondingly more difficult. Hence as the depth of laying increases, the current carrying capacity decreases.

Table 4.9: Rating Factors for Depth of Laying in Ground for 11 kV Cables

Depth of laying (cm)	*Rating factor*
75	-
90	1.00
105	0.99
120	0.98
150	0.96
180 or more	0.95

The temperature rating factors and the depth of laying factors given in the above tables should be used to multiply the values of current rating obtained from Tables 4.4, and 4.7. The current rating are based on the specific conditions of installations as given below:

(i) ground temperature: 30^0C

(ii) ambient air temperature: 40^0C

(iii) thermal resistivity of soil: 150^0C cm/W

(iv) maximum conductor temperature for 11 kV:65^0C.

(v) maximum conductor temperature owing to short circuit: 160^0C

(vi) standard depth of laying for cables laid directly in the ground for 11 kV: 90 cm.

3. *Mode of installation*: PILC cables are generally installed in following ways:

(1) directly in the ground

(2) in a duct or pipe

(3) in air.

In addition there are special installations such as vertical suspensions, river crossings, under the sea, inside mines etc. While specifying the types of cables, this information should be taken into consideration.

4. *Permissible voltage drop*: The selection the values of the short circuit rating of copper and aluminium conductor cables for a period of one second, the student may refer IS: 1255-1967.

4.3 Laying of Underground Cables

For planning and designing a permanent underground cable system, the first step is to determine the route the cables should follow. As a rule, the shortest possible route having minimum bends is chosen. A trench is dug in the ground along ht planned route of the cable. The exact depth of the trench varies according to the voltage at which the cables is operating. See Table 4.11.

Table 4.10: Depth of Trench for Different Operating Voltages

Operating voltage (kV)	*depth of trench (cm)*
Upto 1.1	45 + radius of complete cable
3.3-11	75 + radius of complete cable
22-33	100 + radius of complete cable

The conventional methods of laying underground cables are:

(a) laying directly in the ground

(b) drawing into pipes or ducts

(c) laying in troughs, and

(d) laying cables on racks and cleats.

The first method involves digging a trench in the ground and directly laying the cable in the trench. In the 'duct system', a number of pipes or ducts are laid in the trench side by side. Then one or more cables, depending upon their sizes, are drawn through each duct. Laying cables in troughs is not used now-a-days. In this method, the cables is laid in troughing made of stoneware, cement concrete or cast iron inside the excavated trench. After the cables is placed in position, the troughing is filled with a bituminous compound and then covered.

Inside buildings, factories, generating stations, substations, cables are sometimes laid on racks or brackets spaced at regular intervals. They may also be cleated directly to the walls or on mild steel structures fixed to walls.

CHAPTER 5

UNDERGROUND CABLES

Underground cables are very often used for transmission and distribution of electrical energy particularly in towns and densely populated areas. Compared with overhead systems, cables have the following advantages-

(i) They do not spoil the beauty of surroundings

(ii) They are not exposed to lightning and other atmospheric hazards.

(Their disadvantages are - comparatively more cost and difficulty in locating faults).

5.1 Classification of Cables

Cables are classified according to the working voltage as follows-

(i) L. T. (Low Tension) cables upto 1,000 volts

(ii) H. T. (High Tension) cables upto 11,000 volts

(iii) S. T. (Super Tension) cables from 22,000 volts

(iv) E. H. T. (Extra High Tension) cables from 33,000 to 66,000 volts.

(v) Oil filled (under pressure) and gas filled cables from 66 to 132 kV and above.

5.2 General Construction of Cables

The general construction of cables is-

(a) Core (s)

(b) Insulation

(c) Metallic Sheath

(d) Bedding

(e) Armouring

(f) Serving.

Core (s) are of stranded copper having highest conductivity.

Insulation. Paper, varnished cambric and vulcanized bitumin may be used for low voltages. But impregnated paper is most common for insulation over core (s).

The purpose of *metallic sheath* (usually of lead, lead alloy or of aluminium) over insulation is to prevent the entry of moisture into the insulating material.

Bedding is provided over the metallic sheath and projects it from mechanical injury due to armouring. It may consist of paper tape compounded with a fibrous material. (Sometimes jute strands or hessian tape may be used for this purpose).

Armouring is provided over bedding to avoid mechanical injury to the cable. It consists of one or two layers of galvanized steel wire or of steel tape.

Serving is similar to bedding but is provided *over* armouring.

5.3 Methods of Laying

Chief methods of laying underground cables are (I) Direct (ii) Draw-in and (iii) Solid Systems.

Direct System. In this method a trench of suitable width and depth is dug in which the cable is laid and covered with soil. The depth of the trench must be uniform and the cables should be laid on an even solid ground. The trench is covered with a bed of sand (about 10 cm) before the cable is laid in that. (This is done to protect the cable from harmful chemicals in the ground which may cause corrosion and electrolysis). After the cables had been laid in the trench it is again covered with another layer of sand (about 10 cm). The cable is protected from mechanical injury by bricks, tiles or concrete slabs etc. Where more than one cable is laid in the same trench a horizontal inter-axial spacing of at least 30 cm is advisable to reduce the effect of mutual heating and also to ensure that a fault on one cable does not involve an adjacent cable. (This does not, of course, apply to individual single core cables forming a three phase circuit).

Direct laying is cheap and simple. It also gives the best conditions for dissipating the heat generated in the cables. There is no trouble due to traffic vibration etc. either. The only difficulty is that an extension of load can be made by a completely new excavation which may cost as much as the original work.

Draw-in System. In this system a line of conduits, ducts or tubes is laid in a trench with manholes at suitable positions, the cables being drawn therein afterwards. The conduits or ducts are of glazed stoneware, cement or concrete. The tubes are usually of stone ware, though sometimes fibre, steel, wrought iron or cast iron may also be employed. (Steel or iron though good for this purpose prove costly and that is why their use is limited). It is not necessary to armour the cable but a serving of hessian tape of jute protects the cable when drawing-in.

This method of cable laying is suitable for congested areas where excavation is expensive and inconvenient, for once the conduits have been laid repairs, additions, alternations etc. can be easily made without reopening the ground. The disadvantages of this method of cable laying are- (i) first cost is high (ii) due to close proximity of cables heat dissipation is unfavourable. (As a result of this current carrying capacity of the cables is reduced).

Solid System. In this the cable is laid in throughing in an open trench. The troughing may be treated wood, glazed stoneware, cast iron or asphalt. (Asphalt troughing appears to be most suitable considering the question of costs, ease of laying and that it can be jointed into one homogenous length). After the cable is laid in position the troughing is filled up solid with bitumin, pitch or asphalt which is poured in after being heated into a fluid state. Cables can be laid with a bare sheath and are immune from electrolysis as he sheath is electrically insulated from earth. After the filling material (which should preferably be pure bitumin) a covering which may be of bricks, tiles or wood is applied to the trough. In the case of cast iron or asphalt troughs the cover is usually of the same material as the trough.

This method of laying cables has the advantage that the cable is protected from breakdown due to electrolysis and corrosion (and is, therefore, suitable for soils having large quantities of salts etc.) but is more expensive than direct laid system. Moreover facilities for heat dissipation are poor. Another disadvantage of the method is that skilled supervision and favourable weather conditions (while the job is proceeding) are essential. In view of these disadvantages this method is little used now-a-days.

5.4 Different Types of Cables

We will consider the following types of cables-

(i) Belted

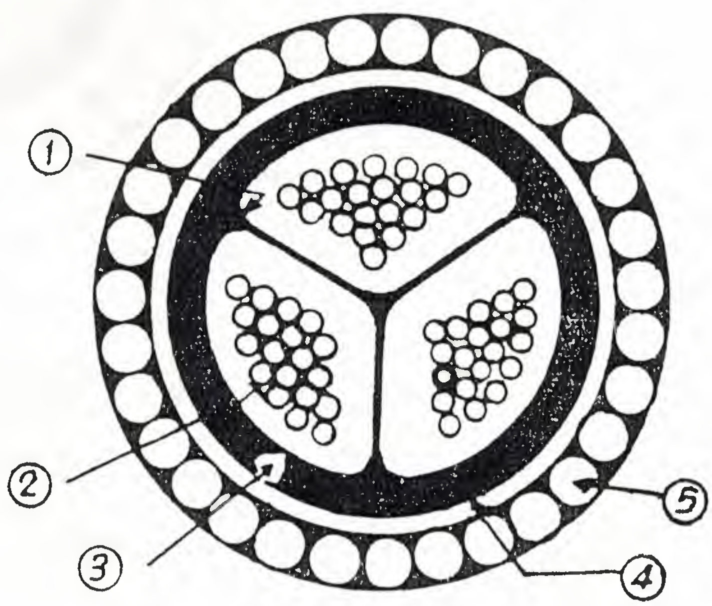
(ii) Screened (H type)

(iii) S. L.

(iv) H. S. L.

(v) Pressure type

Belted Cables. Fig. 4.1 shows such a cable. Each core is insulated with impregnated paper.



1. Jute filling; 2. Paper sheath; 3. Paper belt; 4. Lead sheath; 5. Armouring

Surrounding the cores is a belt of paper, the spaces between the cores being filled with a fibrous insulating material. The cores are sector shaped to avoid large spaces between them. Over the paper belt, lead sheath, braiding, armouring and serving are provided. Such cables are meant for low (and medium) voltages of the order of 10.000 volts. For such voltage ratings electrostatic stresses are small and thermal conductivity is also not of much importance.

H type Cables. These are screened cables (called H type due to M. Hochstadter). This type is an improvement over belted cable and has the important advantage of eliminating all tangential components of electrical stress. (It is purely radial in this type of cable).

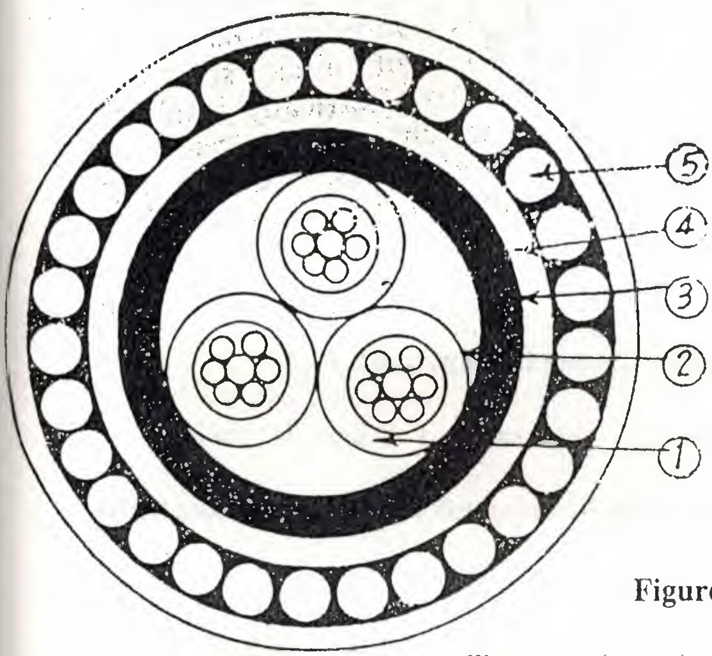


Figure 5.2

1. Paper insulation; 2. Metallic screen (paper); 3. Cotton tape; 4. Lead sheath; 5. Armouring

Figure 5.2 shows such a cable. In this type no belt insulation is used. The cores are insulated with paper and a metallic (perforated) screen is provided over the insulation. All the cores are then surrounded by cotton tape interwoven with fine copper wires. Over this is provided a covering of lead sheath and then armouring. This cable can be used upto 66 kV.

S. L. Cables. S. L. means separate lead. Figure 5.3 shows such a cable. Each core is insulated with impregnated paper and then lead sheath. All the cores are then covered by steel armour but unlike "H" type there is no lead sheath under armour surrounding all the cores. As in "H" type the electrical stresses are radial and are uniformly distributed. This type of cable can also be used upto 66 kV.

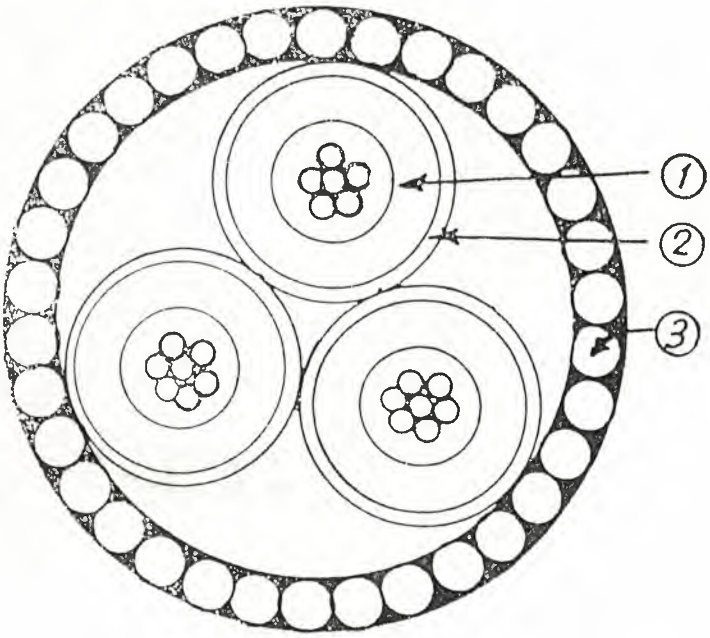


Fig. 5.3

1. Impregnated paper; 2. Lead sheath; 3. Armouring

Both "H" and S. L. types have a greater current carrying capacity than an equivalent belted cable. This is due to better rate of heat dissipation.

H. S. L Cables. This is a combination of "H" type and S. L. type. Fig. 5.4 shows the cross-section of such a cable. Here each core is insulated with paper belting, sheated with metallized paper and is then provided with covering, braiding, armouring and serving. In some cases metallized paper is replaced by copper tape.

Pressure Cables. In the cables for extra high voltage there is a danger of breakdown of dielectric on account of presence of voids. The failure of dielectric results in ionization and associated chemical reactions which damage the insulation.

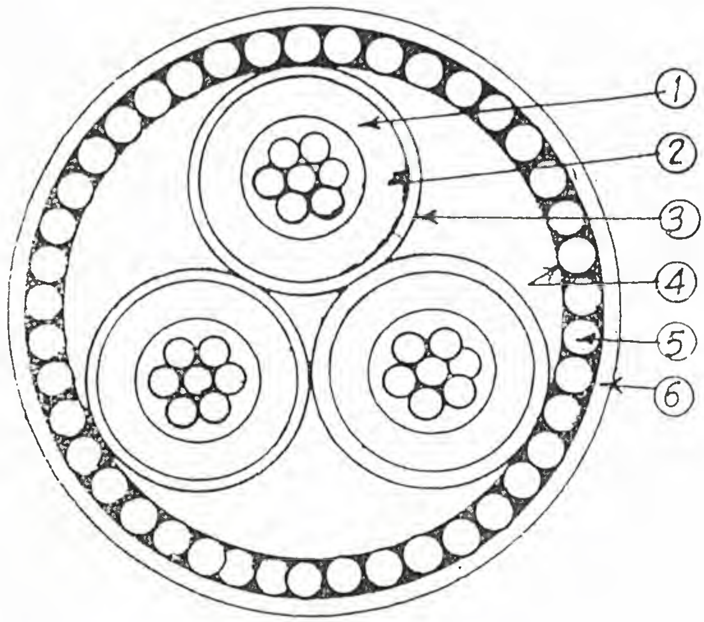


Fig. 5.4

1. Paper insulation; 2. Metallized paper; 3. Lead sheath, 4,5 and 6. Covering, Armouring and Serving

Two methods generally employed to minimise the formation or voids are-

(i) Using oil under pressure

(ii) Using gas pressure.

In the first type the core is made hallow and is supplied from oil reservoirs suitably placed. (It is also called *oil filled cable*). In another design the core is of stranded conductor and the oil channels are provided near the sheath.

In the second (gas pressure) type the cables are placed in metal pipes which are gas tight and are filled with nitrogen at a pressure of 12 to 15 atmospheres. The pressure of gas on account of compression does not permit the formation of voids.

As compared to the normal cables of other designs a pressure cable can be worked at double the voltage and nearly one and a half times to current. Their cost of manufacture is, however, much greater.

5.5 Insulation Resistance of a Cable

Consider a single core cable of conductor radius r and internal sheath radius R as shown in Fig. 5.5 The resistance of a thin shell, between radii x and x + dx and axial length 1 metre is

$$dR = \frac{\rho dx}{2\Pi x.1}$$

where ρ is the specific resistance of the dielectric. [It should be noted that while calculating the insulation resistance, "length of leakage path" is dx and "area of cross-section for leakage path" is 2 π x. 19].

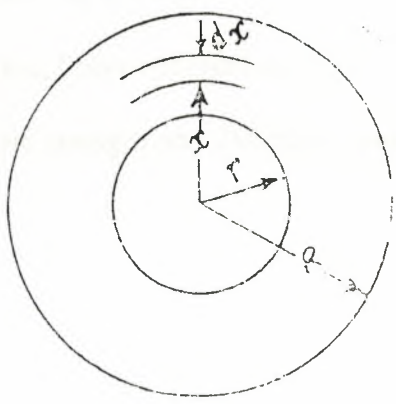


Figure 5.5

Integrating, total resistance

$$R_i = \int_r^R \frac{\rho dx}{2\Pi x.1} = \frac{\rho}{2\Pi} \text{ ohms per metre length of cable.}$$

5.6 Design Considerations in Cable of Different Voltage Ratings

Upto 33 kV, cables are of the solid type and the critical design factor is *ionization.* For cables with voltage ratings between 33 and 132 kV, the critical design factor is *impulse strength* while for voltage ratings above 132 kV *thermal stability* is the critical design factor.

5.7 Cable Insulating Materials.

Dielectric used for cable insulation should have high insulation resistance, high dielectric strength and good mechanical properties. They should not be affected by acids and alkalis and must not be hygroscopic. Also they should not be too costly.

Principal insulating materials used in cables are Impregnated paper, Vulcanized India Rubber (V. I. R.), Varnished cambric, Polyvinyl chloride (P.V.C) and Silicone rubber.

Table below gives dielectric strength and dielectric constants of some of the important materials.

Material	*Dielectric strength kV/mm*	*Dielectric constant*
Impregnated paper	20 to 30	3 · 6
India rubber	10 to 20	2 to 6
Varnished	4	2 · 5 to 3 · 8

5.8 Maximum and Minimum Potential Gradients in the Dielectric and Capacitance of a Cable

Consider a conductor having a charge q (coulombs per metre). Electric flux density (D) at a point x (metres) from this conductor is given by

$$D = \frac{q}{2\Pi x.1} C / m^2$$

(This is as per Gauss's law according to which the flux emanating or emerging from a charge equals the charge)

Electric flux density in the dielectric having a permittivity ε

$$E = \frac{D}{\varepsilon} = \frac{q}{2\Pi \varepsilon x} Nw / C \qquad ...(i)$$

(Potential gradient, g, numerically equals E and is expressed in V/m).

If V is the working voltage of the cable we have

dV = E dx

If r and R are the core radius and overall sheath radius of the cable respectively

$$\text{Then} \quad V = \frac{\int_r^R Edx}{\int_r^R \frac{q}{2\Pi \varepsilon x} dx} = \frac{q}{2\Pi\varepsilon} In \frac{R}{v}$$

$$\text{or} \quad q = \frac{2\Pi\varepsilon}{In \frac{R}{r}} .V$$

We know that capacitance = charge/volt

i.e C = q/V

So that capacitance (per unit length) of cable

$$C = \frac{2\Pi\varepsilon}{In \frac{R}{r}} F / m$$

Further from equations (i) and (ii)

$$g = \frac{V}{x ln \frac{R}{r}}$$

Maximum value of g (i.e. g_{max}) results for x = r and minimum value of g (i.e. g_{min}) results for x=R.

Therefore, $g_{max} = \frac{V}{e \ln \frac{R}{n}}$

and $g_{min} = \frac{V}{r \ln \frac{R}{r}}$

Ratio

$$\frac{g_{max}}{g_{min}} = \frac{Vl(r \ln \frac{R}{r})}{Vl(R \ln \frac{R}{r})} = \frac{R}{r}$$

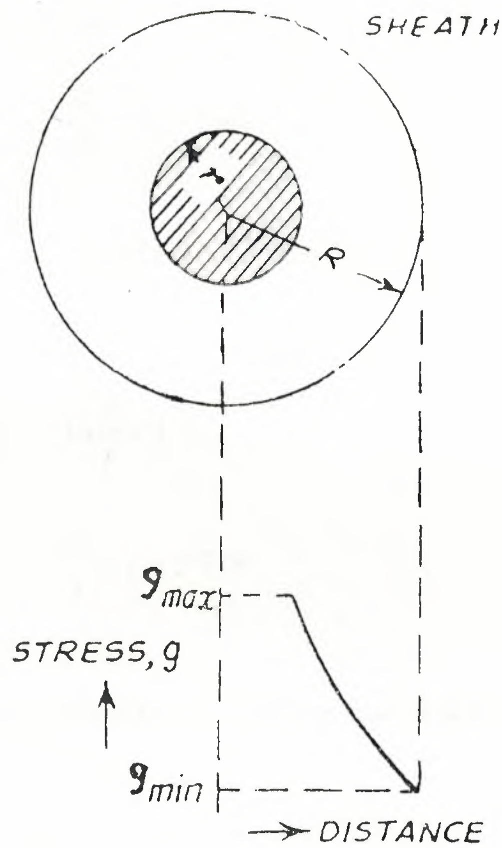


Fig. 5.6

Variation of stress in the dielectric is shown graphically in Fig. 5.6.

5.9 Most Economical Size of Conductor in a Cable

We have seen above that

$$g_{\max} = \frac{V}{r \ln \frac{R}{r}}$$

For a given situation V and (let us suppose) R are fixed. In that case g_{max} will be a minimum when r ln R/r is a maximum. This means

$$\frac{d}{dr}(r \ln \frac{R}{r}) = 0$$

or $$\frac{d}{dr}(r \ln R - r \ln r) = 0$$

or $$\ln R - (\ln r + 1) = 0$$

or $$\ln \frac{R}{r} = 1$$

or $$\frac{R}{r} = e = 2{\cdot}718$$

In other words overall radius should be 2·718 times that of radius of conductor.

5.10 Grading of Cables

We have seen above that stress in the dielectric of a cable varies inversely as the distance (of the point considered) from the center of the core. Cable grading means achieving uniformity in the dielectric stress (potential gradient).

Two methods for this purpose are-

(i) Capacitance grading

(ii) Intersheath grading.

In a capacitance graded cable dielectric consists of a number of layers such that $\varepsilon_r \propto 1/x = k/x$ where k is a constant of proportionality, ε_r is the dielectric constant (relative permittivity) of layer and x is the distance from the center of the core. This makes potential gradient at all points in the dielectric (from the center of the core) equal.

Thus,

$$g_x = \frac{q}{2\Pi\varepsilon x} = \frac{q}{2\Pi\varepsilon_0\varepsilon_r x}$$

$$= \frac{q}{2\Pi\varepsilon_0} \cdot \frac{1}{k(\frac{1}{x}).x}$$

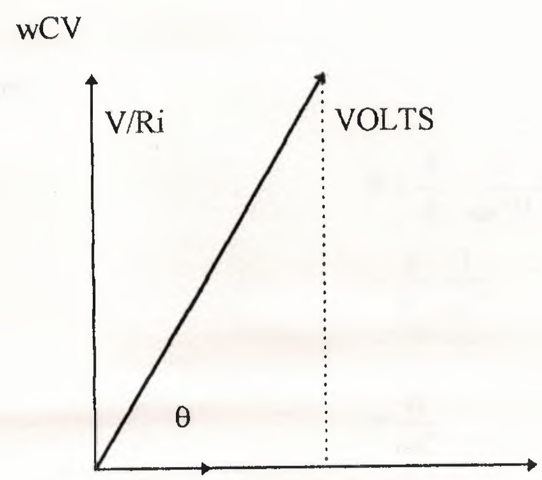
= constant.

To achieve a uniform potential gradient infinite number of dielectrics will be needed. But useful purpose can be served by having two or three dielectrics.

In *intersheat grading*, intersheat [which are metallic sheats held at definite potentials between the core (conductor) and sheath (earth) in a cable] are employed. The object of providing intersheats is to reduce the range of variation between maximum and minimum stress. Thus the method provides a more economical design of cable.

5.11 Power Factor and Dielectric Loss of a Cable

(i) Consider a single core cable. Assuming its insulation resistance to remain constant the impressed voltage V will send a current (V/R_i) through the insulation and this current is in phase with Vδ as shown in Fig. 5.7.



$$\frac{V}{1/\varepsilon C} = \omega CV$$

Figure 5.7

On account of the capacity effect of the dielectric (and the intersheats) a charging current whose magnitude is also flow from the supply. The latter is a 90^0 leading current w.r.t. V (see Fig. 5.7). The total current I is the phasor sum of these two current and leads the voltage by an angle ϕ, where cos ϕ gives the power factor of the cable. (In practice ϕ is very nearly equal to $\Pi/2$)

$$\cos\phi = \cos\left(\frac{\Pi}{2} - \delta\right)$$

$$= \sin\delta$$

$$= \delta(s\sin ce\delta issmall)$$

i.e. power factor of the cable $= \delta$

$$\cos\phi = \cos\left(\frac{\Pi}{2} - \delta\right)$$
$$= \sin\delta$$
$$= \delta(s\sin ce\delta issmall)$$

i.e. power factor of the cable $= \delta$

Now when δ is small, $\sin\delta = \tan\delta = \delta$

Therefore,

$$\delta = \frac{V}{R_i}.\frac{1}{\omega CV} = \frac{1}{\omega CR_i}$$
$$= \frac{1}{R_i}.\frac{1}{\omega C}$$

$$= \frac{G}{\omega C}$$

where $1/R_i$=G= conductance of the cable

Therefore, power factor of the cable = $G/\omega C$

(ii) Dielectric loss of a cables is given by V_2/R_i.

5.12 Ionization in Cables

The insulating material of a cable may enclose some gas filled and vacuous spaces and may not be perfectly homogenous. The spaces may occur between the wrappings of the paper or may be formed during the manufacturing process of the cable by loosely wrapped paper or improper filling with impregnating material. due to heat during normal operation of the cable. A gas or vacuous space is liable to ionization and chemical effects which follow may lead to gradual destruction of the insulation at that point.

5.13 Consider Resistance of a Two Wire Mains

Consider a two wire system as shown in Figure 5.8, the voltage between positive and negative conductors being V. Let the resistance of these conductors to earth be R_1 and R_2 respectively. (Resistance between the mains, R, does not affect the readings).

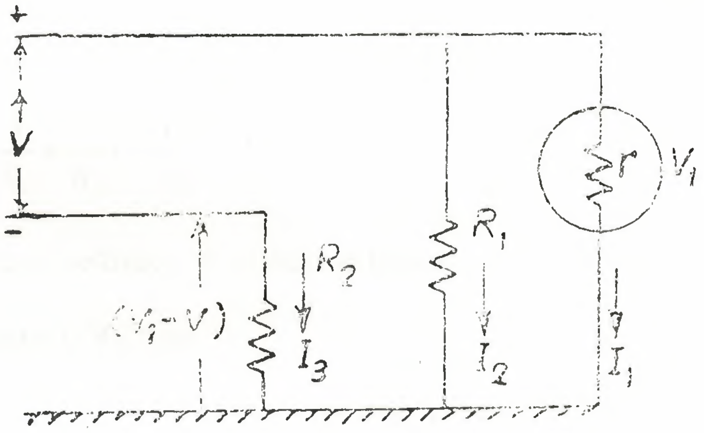


Fig. 5.8

When the volt-meter having a resistance r is connected between positive conductor and earth as shown in Fig. 5.9 let the reading on the voltmeter be V_1 Applying Kirchoff's current law at Q

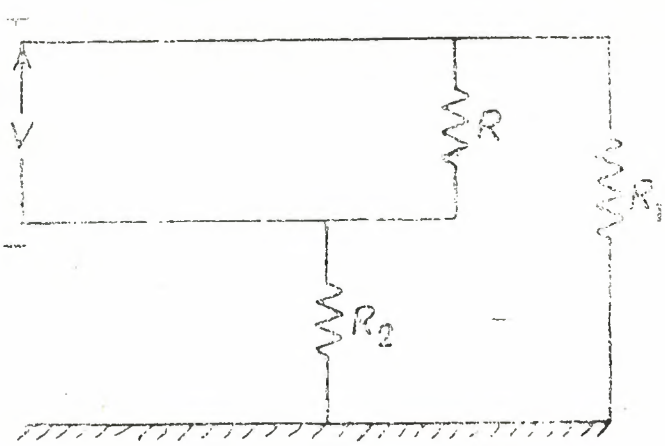


Fig. 5.9

$$I_1 + I_2 + I_3 = 0$$

$$or \frac{V_1}{r} + \frac{V_1}{R_1} + \frac{V_1 - V}{R_2} = 0$$

$$or \frac{V_1}{r} + \frac{V_1}{R_1} = \frac{V - V_1}{R_2}$$

which gives $V_1(\frac{1}{r} + \frac{1}{R_1} + \frac{1}{R_2}) = \frac{V}{R_2}$

If next the same voltmeter is connected between the negative conductor and earth and reading on the voltmeter is V_2, then

$$V_2\left(\frac{1}{r} + \frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{V}{R_1}$$

From equations (i) and (ii), by division

$$V_1/V_2 = R_1/R_2$$

Again from equation (ii)

$$\frac{V}{V_2} = R_1\left(\frac{1}{r} + \frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{R_1}{r} + 1 + \frac{R_1}{R_2} = \frac{R_1}{r} + 1 + \frac{V_1}{V_2}$$

which gives

$$R_1 = r\left(\frac{V}{V_2} - 1 - \frac{V_1}{V_2}\right) = r\left(\frac{V - V_1 - V_2}{V_2}\right)$$

Similarly $R_2 = r\left(\frac{V - V1 - V_2}{V_1}\right)$

and $V_2 = 30$ volts

r = 10,000 ohms

As shown above

$$R_1 = r\left(\frac{V - V_1 - V_2}{V_2}\right) = 10{,}000\left(\frac{250 - 140 - 30}{30}\right) = 10{,}000x\frac{80}{30} = 26{,}667 ohms$$

and

$$R_2 = r\left(\frac{V - V_1 - V_2}{V_1}\right) = 10{,}000x\frac{80}{140} = 5{,}714 ohms$$

5.14 Common Faults in Cables and their Localization

The common causes of faults in cables may be over-heating, absorption of moisture by the insulation etc. The faults which are likely to occur are-

(a) Ground fault - Breakdown of insulation of cable between the core and earth (or cable sheath).

(b) Short circuit fault - Breakdown of insulation between two cables or between two cores of a multi-core cable

(c) Open circuit fault - Conductor becomes broken or a joint gets pulled out.

Blavier and Earth Overlap Tests are used for location of position of fault on a single core cable i.e. when to no other cables run along with a faulty one.

Loop Tests are carried out when one or more sound cores are available. The loop tests are

(a) Murray loop test

(b) Varley loop test

(c) Fisher loop test

Tests for an open circuit fault are based on the principle that the capacity of a cable to ground or to another parallel conductor is proportional to the length of the cable.

[Localization of faults in cables is an important application of measurement of resistance (or capacitance). For a detailed treatment of the subject, any text on Electrical Measurement should be referred to].

IMPORTANT QUESTIONS

(1) Discuss the advantages of using underground cables compared with overhead lines for transmission and distribution of electrical energy.

(2) State how cables are classified according to operating voltage.

(3) Explain the general construction of cables and explain the purpose of insulation, sheath, bedding, armouring and serving over the core.

(4) What are the different methods of laying underground cables? Explain the advantages and disadvantages of various methods.

(5) Explain the constructional features of

(i) Belted

(ii) Screened (H type)

(iii) S. L.

(iv) H. S. L.

(v) Pressure type cables

Summary.

Transmission of power by over head lines is very much cheaper then by underground cables and this is the main advantage of over head transmission. Another advantage is the comparative ease with which repairs can be carried out on an overhead transmission or distribution system. In thinly populated areas over head lines for distribution al power are particulary advantageous.

Against these advantages overhead lines have the disadvantage that these are exposed to lighting and atmospheric hazards like smoke, ice etc. Another disadvantage is the inductive interference between power and telecommunication circuits in the case of over head transmission al power.

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