Unit-5

UNDERGROUND CABLES

→ Electrical power canbe transmitted or distributed Either by overhead system or by underground Cables.

→ underground have several advantages such as less liable to damage through storms or lighthing, low maintenance cost, less chances of faults, smaller voltage drop and better general apperarance.

→ Drawbacks with this system are greater installation cost and introduce insulation.

→ problems at high voltages compared with the Equivalent overhead systems.

→ For this Reason, underground Cables are employed where it is impracticable to use overhead lines.

→ underground cables are used for transmission of Electric power for short or moderate distances.

underground cables:-

An underground cable consists of one or more conductors covered with suitable insulation and surrounded by a protecting cover.

→ The types of cables to be used will depends upon the working voltage and service Requirement.

→ The necessary Requirements a cable must fulfil are as follows

i) The conductors used in cables should be tinned stranded copper or aluminium of high conductivity. Stranding is done so that conductor may become flexible and carry more current.

ii) The conductor size should be such that the cable carries the desired load current without overheating and causes voltage drop within permissible limits.

iii) The cable must have proper thickness of insulation in order to give high degree of safety and reliability at the voltage for which it is designed.

iv) The cable must be provided with suitable mechanical protection so that it may withstand the rough use in laying it.

v) The materials used in the manufacture of cables should be such that there is complete chemical and physical stability.

Construction of Cables:-

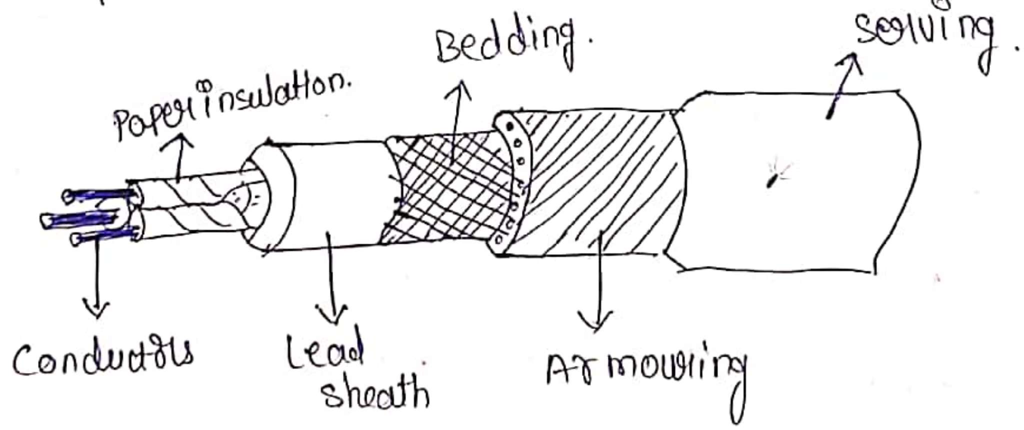
i, Cores or Conductors:- A cables may have one or more than one cable core depending upon the type of service for which it is intended.

→ The 3-conductor cable is used for 3-phase services.

→ The conductors are made of tinned copper or aluminium and are usually stranded in order to provide flexibility to the cable.

ii, Insulation:- Each conductor is provided with a suitable thickness of insulation, the thickness of layer depending upon the withstand voltage.

→ The commonly used insulation materials are impregnated paper, varnished cambric or rubber mineral compound.



iii, Metallic sheath:- In order to protect the cable from moisture, gases or other damaging liquids in the soil and atmosphere, a metallic sheath of lead or aluminium is provided over the insulation.

iv, **Bedding**:- over the metallic sheath is applied a Layer of bedding which consists of a fibrous material like jute & hessian tape.

→ The purpose of bedding is to protect the metallic sheath against corrosion and from mechanical injury due to armouring.

v, **Armouring**:- over the bedding, Armouring is provided which consists of one & two layers of galvanised steel wire & steel tape.

→ Its purpose is to protect the cable from mechanical injury while laying it and during course of handling.

→ Armouring may not be done in case of some cables.

vi, **serving**:- In order to protect armouring from atmospheric conditions, a layer of fibrous material (jute) simil to bedding is provided over the armouring. This is known as serving.

Insulating materials for cables:-

The insulating materials have some properties.

i, High insulation Resistance to avoid leakage currents.

ii, High Dielectric strength to avoid Electrical break down of the cables.

→ Insulating materials which are generally used are.

i. Rubber:- Rubber is either natural or synthetic which is obtained from the milky sap of tropical tree or may produced from alcohol or oil products

→ The Relative permittivity of rubber is b/w 2 & 3, dielectric strength of about 30kV/mm, specific Resistance is $10^{15}\Omega m$.

→ pure rubber cannot be used as an insulating material because it absorbs moisture and temp is low (38°c).

2. Vulcanized India Rubber (VIR):-

→ This VIR is known for high durability, high mechanical strength & good wear Resistant properties which have better qualities than pure Rubber.

→ Mineral matters like sulphur, Red lead, zinc oxide Etc., are mixed with pure rubber to prepare VIR.

→ It has dielectric strength of about 10-20kV/mm, and dielectric constant of about 2.5.

3. Impregnated paper:-

→ This is prepared by impregnating chemically pulped paper with paraffinic or napthenic materials.

→ Rubber insulation is completely Replaced by This Impregnated paper because it has some advantages like ` low cost, low capacitance, high dielectric strength (30kV/mm), high thermal conductivity and high insulation Resistance.

→ This hygroscopic in nature, it absorbs moisture, Thus Reducing the insulating strength of material, This is the major drawback

→ Their Ends are covered with tar or wax when not in use.

→ This type of cables are used for low voltage distribution.

3. varnished cambric :- varnished cambric or Empire tape is prepared by using cambric, a thin white cotton cloth, impregnating and coating it with varnish.

→ This varnished cambric is then rolled on the conductor in the form of a tape, petroleum jelly is then coated on cambric surface of the conductor which helps in Easy sliding of conductors inside the cable.

→ The dielectric strength is 4kv/mm and its dielectric constant ranges b/w 2.5 & 3.8

5. poly vinyl chloride (PVC):- It is synthetic compound.

→ It is obtained from the polymerisation of acetylene and is in the form of white power.

→ For obtaining this material as a cable insulating it is compounded with certain materials known as plasticizers which are liquids with high boiling point.

→ It has high insulation Resistance, good dielectric strength and mechanical toughness over high temperature.

→ so, this type is used for low, medium domestic lights and power installations.

Classification of cables:- These are classified into two ways according to.

i, Type of insulation material used in manufacturing.

ii, the voltage for which they are operated.

→ Another classification is.

i, Low-Tension (LT) Cables — upto 1000V
ii, High-tension (HT) cables - upto 11,000V
iii, super tension (ST) Cables — 22kV to 33kV.
iv, Extra high tension (EHT) — 33kV to 66kV
v, Extra super voltage Cables — beyond 132kV.

→ Cable may be one or more than one depending upon the type of service

i, One core.
ii, two core.
iii, Three core.
iv, Four core ; For 3-phase service, either 3-single core cables or three-core cable can be used depending upon the operating voltage and load demand.

Cables for 3-phase service :- These are of Three types.

1. Belted cables — upto 11kV
2. screened Cables — from 22kV to 66kV
3. Pressure Cables — beyond 66kV.

For Answer Refere

Insulation Resistance of a single core cable :-

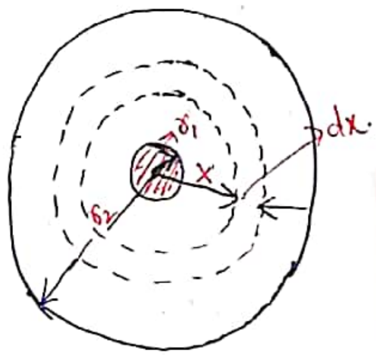
→ The cable conductor is provided with a suitable thickness of insulating material in order to prevent leakage current.

→ The path for leakage current is radial through the insulation.

→ The opposition offered by insulation to leakage current is known as insulation Resistance of the cable.

→ Insulation Resistance should be very high for satisfactory operation.

→ Let us consider a single core cable of conductor radius r_1 and internal sheath radius r_2. Let l be the length of the cable and ρ be the Resistivity of the insulation.



→ Consider a very small layer of insulation of thickness dx at a radius x, the length through which leakage current tends to flows is dx and the area of x-section offered in this flow is $2\pi x l$.

∴ Insulation Resistance of considered layer

$$= \rho \frac{dx}{2\pi x l}$$

Insulation Resistance of the whole cable is

$$R = \int_{r_1}^{r_2} \rho \frac{dx}{2\pi x l} = \frac{\rho}{2\pi l} \int_{r_1}^{r_2} \frac{1}{x} dx.$$

$$\therefore R = \frac{\rho}{2\pi l} \log_e \frac{r_2}{r_1}$$

∴ Eqn shows that Resistance of cable is inversely proportional to its length. In other words, if the length of cable increases, its insulation Resistance decreases.

1. A single core cable has a conductor diameter of 1cm and insulation thickness of 0.4cm. If the specific Resistance of insulation is $5 \times 10^{14}\ \Omega$-cm, then Calculate the Insulation Resistance for a 2km length of the cable.

Sol:- Conductor Radius $r_1 = 1/2 = 0.5$ cm

length of cable $l = 2$ km $= 2000$ m.

Resistivity $\rho = 5 \times 10^{14}\ \Omega$-cm

$= 5 \times 10^{12}\ \Omega$-m

Internal sheat $r_2 = 0.5 + 0.4 = 0.9$ cm

∴ Insulation Resistance $R = \frac{\rho}{2\pi l} \log_e \frac{r_2}{r_1}$

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$$= \frac{5\times10^{12}}{2\pi\times2000} \log_e \frac{0.9}{0.5}$$

$$= 0.234 \times 10^{9}\,\Omega.$$

$$= 234\,M\Omega.$$

2. The insulation Resistance of a single core cable is 495 MΩ/km. If the core diameter is 2.5cm and Resistivity of insulation is $4.5\times10^{14}\,\Omega$-cm, find the insulation thickness.

sol:- Length of cable. $l = 1km = 1000m.$

Cable Resistance, $R = 495M\Omega = 495\times10^{6}\,\Omega$

Conductor Radius $r_1 = 2.5/2 = 1.25\,cm.$

$$\rho = 4.5\times10^{14}\,\Omega\text{-cm}$$

$$= 4.5\times10^{12}\,\Omega\text{-m}.$$

Let r_2 cm be the internal sheath radius.

$$R = \frac{\rho}{2\pi l} \log_e \frac{r_2}{r_1}$$

$$\log_e \frac{r_2}{r_1} = \frac{2\pi l \times R}{\rho} = \frac{2\pi\times1000\times495\times10^{6}}{4.5\times10^{12}}$$

$$= 0.69$$

$$2.3 \log_{10} r_2/r_1 = 0.69.$$

$$r_2/r_1 = \text{Anilog } 0.69/2.3$$

$$= 2.$$

$$r_2 = 2r_1 = 2\times1.25$$

$$= 2.5cm$$

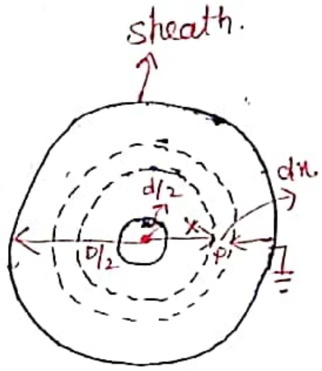
∴ Insulation thickness ⇒ $r_2 - r_1 = 2.5 - 1.25 = 1.25cm$

Capacitance of a single-core cable:-

→ A single-core cable can be considered to be equivalent to two long co-axial cylinders.

→ The conductor of the cable is the inner cylinder while the outer cylinder is Represented by lead sheath which is at Earth potential.

→ Consider a core cable with conductor diameter 'd' and inner sheath diameter 'D'.



→ Let the charge per metre axial length of the cable be Q coulombs and ε be the permitivity of the insulation material b/w core and lead sheath.

→ Then $\varepsilon = \varepsilon_0 \varepsilon_r$ wher ε_r is the Relative permitivity of the insulation.

→ Consider a cylinder of radius x metres and axial length 1m. The surface Area of this cylinder is $= 2\pi x \times 1 = 2\pi x \ m^2$

∴ Electric flux density at any point 'P' on the considered cylinder is.

$$D_x = \frac{Q}{2\pi x} \ C/m^2$$

Electric intensity at point P, $E_x = \frac{D_x}{\varepsilon} = \frac{Q}{2\pi x \varepsilon} \ V/m$

→ The work done in moving a unit positive charge from poin p through a distance dx in the direction of electric field is $E_x dx$

→ Hence, the work done in moving a unit +ve from one conductor to sheath, which is potential difference 'V' b/w Conductor and sheath, is given by.

$$V = \int_{d/2}^{D/2} E_x \, dx = \int_{d/2}^{D/2} \frac{Q}{2\pi\varepsilon_0\varepsilon_r} dx$$

$$= \frac{Q}{2\pi\varepsilon_0\varepsilon_r} \log_e \frac{D}{d}$$

Capacitance of the cable is

$$C = \frac{Q}{V} = \frac{Q}{\frac{Q}{2\pi\varepsilon_0\varepsilon_r} \log_e \frac{D}{d}} \text{ F/m.}$$

$$= \frac{2\pi\varepsilon_0\varepsilon_r}{\log_e (D/d)} \text{ F/m}$$

$$= \frac{2\pi \times 8.854 \times 10^{-12} \times \varepsilon_r}{2.303 \log_{10}(D/d)} \text{ F/m}$$

$$= \frac{\varepsilon_r}{41.4 \log_{10}(D/d)} \times 10^{-9} \text{ F/m}$$

If the cable has a length of 'l' metres, then capacitance of the cable is.

$$\boxed{C = \frac{\varepsilon_r l}{41.4 \log_{10} D/d} \times 10^{-9} \text{ F}}$$

1. A 33kV, 50 Hz, 3-ϕ underground cable, 4km long uses three single core cables. Each of the conductor has a diameter of 2.5cm and the radial thickness of insulation is 0.5cm. Determine i, capacitance of the cable/ph. ii, charging current/ph, iii, Total charging kVAR, The Relative permittivity of insulation is 3.

Sol: i, Capacitance of cable/ph

$$C = \frac{\varepsilon_r l}{41.4 \log_{10}(D/d)} \times 10^{-9} F.$$

$\varepsilon_r = 3$; $l = 4km = 4000m$; $d = 2.5cm$; $D = 2.5 + 2 \times 0.5 = 3.5cm$

$$\therefore C = \frac{3 \times 4000 \times 10^{-9}}{41.4 \times \log_{10}(3.5/2.5)} = 1984 \times 10^{-9} F.$$

ii, voltage/ph, $V_{ph} = \frac{33 \times 10^3}{\sqrt{3}} = 19.05 \times 10^3 V.$

iii charging current/ph $I_c = \frac{V_{ph}}{X_c} = 2\pi f C V_{ph}$

$= 2\pi \times 50 \times 1984 \times 10^{-9} \times 19.05 \times 10^3$

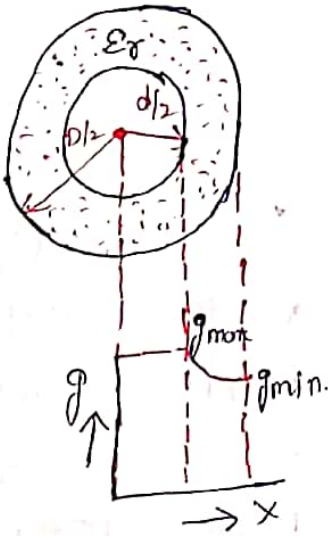
$= 11.87 A$

iii, Total charging kVAR $= 3 V_{ph} I_c$

$= 3 \times 19.05 \times 10^3 \times 11.87$

$= 678.5 \times 10^3$ kVAR.

Dielectric stress in a single core cable:-



→ Under operating conditions, the insulation of a cable is subjected to electrostatic field.

→ This is known as dielectric stress.

→ The dielectric stress at any point in a cable is infact the potential gradient (electric intesity) at that point.

→ Consider a single core cable with core diameter d and internal sheath diameter D. we thus know that, The electric intensity at a point 'x' meters from the centre of the cable is.

$$E_x = \frac{Q}{2\pi\varepsilon_0\varepsilon_r x} \; V/m.$$

where electric intensity is equal to potential gradient. so, potential gradient 'g' at a point 'x' metres from the centre of cable is

$$g = E_x$$

$$g = \frac{Q}{2\pi\varepsilon_0\varepsilon_r x} \; V/m \longrightarrow (1)$$

we know that potential difference 'V' b/w conductor and sheath is.

$$V = \frac{Q}{2\pi\varepsilon_0\varepsilon_r} \log_e \frac{D}{d} \; V.$$

$$Q = \frac{2\pi\varepsilon_0\varepsilon_r V}{\log_e D/d} \longrightarrow (2)$$

substitute the value of Q from Eqn ② in Eqn ①

$$g = \frac{\dfrac{2\pi\varepsilon_0\varepsilon_r V}{\log_e D/d}}{2\pi\varepsilon_0\varepsilon_r x} = \frac{V}{x \log_e D/d} \text{ V/m} \rightarrow ③$$

from Eqn ③ potential gradient varies inversely as the distance x. so, potential gradient will be maximum when x is minimum i.e., when $x = d/2$ or at the surface of the conductor. on the other hand, potential gradient will be minimum at $x = D/2$ or at sheath surface.

∴ maximum potential Gradient is

$$g_{max} = \frac{2V}{d \log_e D/d} \text{ V/m} \quad [\because x = d/2]$$

∴ minimum potential gradient is

$$g_{min} = \frac{2V}{D \log_e D/d} \text{ V/m} \quad [\because x = D/2]$$

$$\therefore \frac{g_{max}}{g_{min}} = \frac{\dfrac{2V}{d \log_e D/d}}{\dfrac{2V}{D \log_e D/d}} = \frac{D}{d}.$$

→ The variation of stress in dielectric is shown in fig. it is clear that dielectric stress is max at the conductor surface and its value goes on decreasing as we move away from the conductor.

→ It may be noted that maximum stress is an important consideration in the design of a cable. i.e., maximum stress is 5 kV/mm, then the insulation used must have a dielectric strength of at least 5 kV/mm.

1. A single core cable for use on 11 kV, 50 Hz system has conductor area of 0.645 cm^2 and internal diameter of sheath is 2.18 cm. The permittivity of the dielectric used in the cable is 3.5. Find.
   i, The maximum electrostatic stress in the cable
   ii, minimum electrostatic stress in the cable.
   iii, capacitance of the cable per km length.
   iv, charging current.

Sol:- Area of cross-section of conductor

$$a = 0.645 \, cm^2$$

Diameter of the conductor $d = \sqrt{\frac{4a}{\pi}}$

$$= \sqrt{\frac{4 \times 0.645}{\pi}}$$

$$= 0.906 \text{ cm}$$

Internal diameter of sheath $D = 2.18$ cm

i, Maximum electrostatic stress in the cable is

$$g_{max} = \frac{2V}{d \log_e\left[\frac{D}{d}\right]} = \frac{2 \times 11}{0.906 \log_e \frac{2.18}{0.906}} \text{ kV/cm}$$

$= 27.65 \text{ kV/cm r.m.s}$

ii) minimum electrostatic stress in the cable is

$$g_{min} = \frac{2V}{D \log_e \left(\frac{D}{d}\right)} = \frac{2 \times 11}{2.18 \log_e \frac{2.18}{0.906}} \text{ kV/cm}$$

$$= 11.5 \text{ kV/cm r.m.s.}$$

iii) Capacitance of cable $C = \frac{\varepsilon_r l}{41.4 \log_{10} \frac{D}{d}} \times 10^{-9} F$

$\varepsilon_r = 3.5$; $l = 1 km = 1000 m$

$$C = \frac{3.5 \times 1000}{41.4 \log_{10} \left[\frac{2.18}{0.906}\right]} \times 10^{-9}$$

$$= 0.22 \times 10^{-6} F.$$

iv) charging current $I_c = \frac{V}{X_c}$

$$= 2\pi f C X_c$$

$$= 2\pi \times 50 \times 0.22 \times 10^{-6} \times 11000$$

$$= 0.76 A.$$

Capacitance of 3-core Cables:-

The Capacitance of cables are most important than overhead lines because in cables.

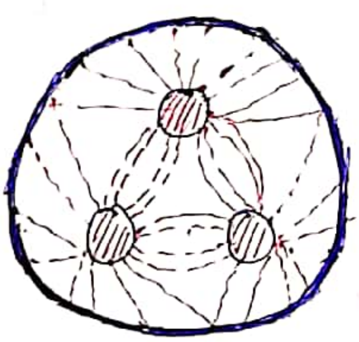
i) conductors are nearer to each other and to the earthed sheath.

i.e., They are separated by a dielectric of permittivity much greater than of air.

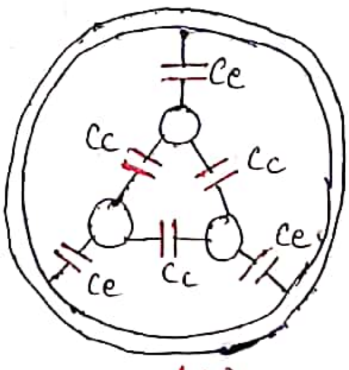
→ The potential difference is exists b/w pairs of conductors and b/w each conductor and the sheath, electrostatic fields are setup in the cable which is shown in fig (a).

→ These electrostatic field give rise to core-core capacitance "Cc" and conductor-Earth capacitance "Ce". which is shown in fig (b).

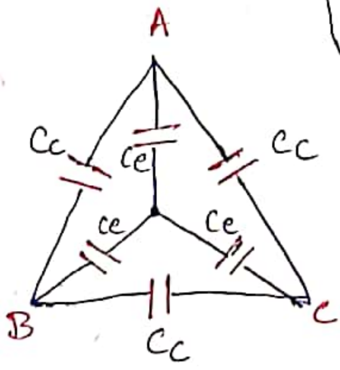
→ The three "Cc" are delta connected whereas the three "Ce" are star connected, the sheath forming the star point shown in fig (c).



(a)



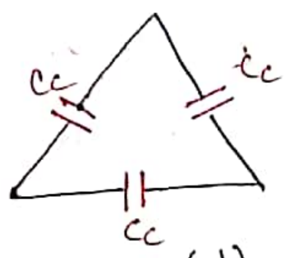
(b)

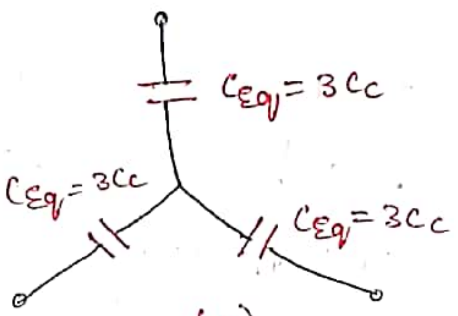


(c)

→ They lay of belted cable makes it reasonable to assume equality of each C_c and each C_e.

→ The three delta connected capacitances C_c shown in fig (d) can be converted into equivalent star connected capacitance shown in fig (e)

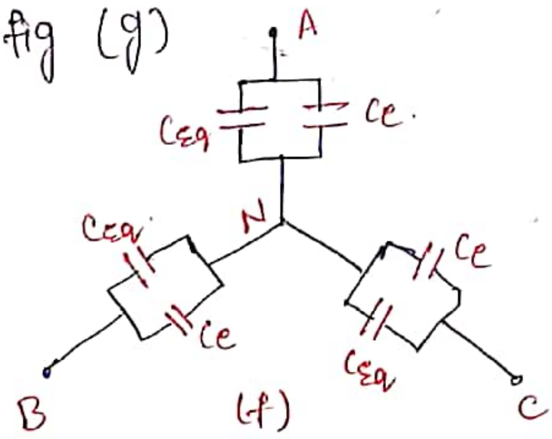


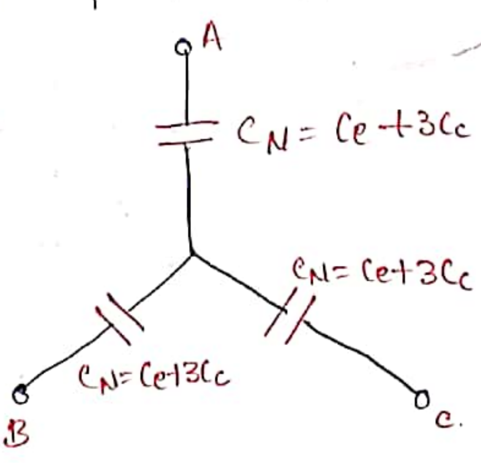


→ Then the equivalent star capacitance C_{Eq} is equal to three times the delta capacitance C_c i.e., $C_{Eq} = 3C_c$.

→ The system capacitance shown in fig (e) reduces to the equivalent circuit shown in fig (f)

so, the whole cable is equivalent to three star-connected capacitors each of capacitances shown in fig (g)





$$C_N = C_e + C_{Eq}$$
$$= C_e + 3C_c.$$

If V_{ph} is the phase voltage, then charging current I_c is given by.

$$I_c = \frac{V_{ph}}{\text{Capacitance Reactance per phase}}$$

$$= 2\pi f V_{ph} C_N.$$
$$\therefore I_c = 2\pi f V_{ph} (C_e + 3C_c)$$

Measurement of C_e and C_c :- C_c & C_e Can be obtained from the formulas for belted Cables, their values can also be determined by measurement. The following two measurements are Required.

i, In the First measurement, the three cores are bunched together (i.e., conioned) & the capacitance is measured b/w bunched cores and sheath.
→ the bunching eliminates all the three Capacitors C_c, leaving the three Capacitors C_e in parallel. So, if C_1 is the measured Capacitance, this test yields

$$C_1 = 3C_e$$
$$C_e = C_1/3$$

ii, In the 2nd measurement, two cores are bunched with the sheath and capacitance is measured b/w them and the third core. This test gives $2C_c + C_e$. If C_2 is the measured capacitance then

$$C_2 = 2C_c + C_e.$$

→ from 1st test C_e is measured and C_2 is found experimentally, then C_c can be determined.

→ value of $C_N (= C_e + 3C_c)$ is desired, it can be found directly by another test, in this test, the capacitance b/w two cores or lines is measured with the 3rd core free or connected to sheath.

→ This eliminates one of the capacitors C_e so that if C_3 is the measured capacitance then.

$$C_3 = C_c + \frac{C_c}{2} + \frac{C_e}{2}$$

$$= \frac{1}{2}[C_e + 3C_c]$$

$$= \frac{1}{2}C_N.$$

1. the capacitance of a 3-φ belted cable are 12.6 μF b/w the three cores bunched together and the lead sheath and 7.4 μF b/w one core and the other two ~~cores~~ connected to sheath. Find the charging current drawn by the cable when connected to 66kV. 50Hz supply.

Sol:- $V_{ph} = \frac{66 \times 10^3}{\sqrt{3}} = 38105V$; $f = 50Hz$, $C_1 = 12.6\mu F$

$C_2 = 7.4\mu F$

Let core-core and core-earth capacitances of the cable be C_c and C_e.

$$C_1 = 3C_e.$$

$$C_e = C_1/3 = 12.6/3 = 4.2\mu F$$

$$C_2 = 2C_c + C_e.$$

$$C_c = \frac{C_2 - C_e}{2} = \frac{7.4 - 4.2}{2}$$

$$= 1.6\mu F$$

∴ core to neutral capacitance is

$$C_N = C_e + 3C_c = 4.2 + 3 \times 1.6$$

$$= 9\mu F$$

charging current, $I_c = 2\pi f V_{ph} C_N$

$$= 2\pi \times 50 \times 38105 \times 9 \times 10^{-6}$$

$$= 107.74A$$

Grading of cables:- The process of achieving uniform electrostatic stress in the dielectric of cables is known as grading of cables.

→ We know that electrostatic stress in a single core has maximum value (g_{max}) at the conductor surface and it is decreasing as we move away from conductor and minimum at sheath.

→ For safe working of a cable having homogeneous dielectric, the strength of dielectric must be more than g_{max}.

→ The unequal stress distribution in a cable is for two Reasons, one is insulation of greater thickness is Required which increases the cable size.

→ second is it may be lead to breakdown of insulation.

→ inorder to overcome these two disadvantages it is necessary to have a uniform stress distribution in cables.

→ This can be achieved by distributing the stress in such a way that its value is increased in the outer layers of dielectric. This is known as grading of cables.

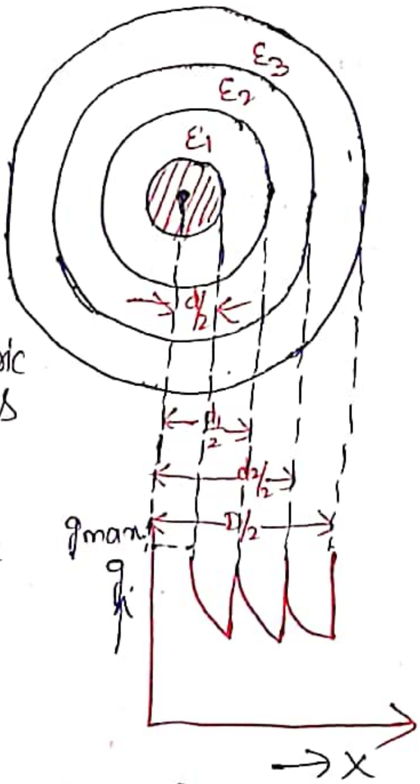
→ There are two main methods of grading of cable. i, capacitance grading.
ii, Intersheath grading.

i. Capacitance grading:- The process of achieving uniformly in the dielectric stress by using layers of different dielectrics is known as capacitance grading.

→ In this, the homogeneous dielectric is replaced by a composite dielectric.

→ The composite dielectric consists of various layers of different dielectrics in such a manner that relative permittivity ε_r of any layer is inversely proportional to its distance from the centre.

→ In this conditions, the value of potential gradient at any point in the dielectric is constant and is independent of its distance from the centre.



→ If the grading is ideal one then the dielectric stress in the cable is same everywhere.

→ The ideal grading Requires the use of an infinite num of dielectric which is an impossible task.

→ In practice, two or three dielectrics are used in the decreasing order of permittivity, the dielectric of highest permittivity being used near the core.

→ Fig. shows three dielectrics of outer diameter d_1, d_2 and D and of relative permittivity of $\varepsilon_1, \varepsilon_2, \varepsilon_3$.

→ If the permittivities are $\varepsilon_1 > \varepsilon_2 > \varepsilon_3$ and the three dielectrics are worked at the same maximum stress, then.

$$\frac{1}{\varepsilon_1 d} = \frac{1}{\varepsilon_2 d_1} = \frac{1}{\varepsilon_3 d_2}$$

$$\varepsilon_1 d = \varepsilon_2 d_1 = \varepsilon_3 d_2$$

→ potential difference across the inner layer is

$$V_1 = \int_{d/2}^{d_1/2} g\, dx = \int_{d/2}^{d_1/2} \frac{Q}{2\pi\varepsilon_0\varepsilon_1 x}\, dx$$

$$= \frac{Q}{2\pi\varepsilon_0\varepsilon_1} \log_e \frac{d_1}{d}$$

$$= \frac{g_{max}}{2} d \log_e \frac{d_1}{d} \left[\because \frac{Q}{2\pi\varepsilon_0\varepsilon_1} = \frac{g_{max}}{2} d \right]$$

→ similarly potential across 2nd layer (V_2) & 3rd layer (V_3) is given by ;

$$V_2 = \frac{g_{max}}{2} d_1 \log_e \frac{d_2}{d_1}$$

$$V_3 = \frac{g_{max}}{2} d_2 \log_e \frac{D}{d_2}.$$

∴ Total potential difference core & earthed sheath is

$$V = V_1 + V_2 + V_3.$$

$$= \frac{g_{max}}{2} \left[d \log_e \frac{d_1}{d} + d_1 \log_e \frac{d_2}{d_1} + d_2 \log_e \frac{d_3}{d_2} \right]$$

→ If the cable had homogeneous dielectric, then for the same values of d, D and g_{max}, the permissible potential difference b/w core and earthed sheath would have been.

$$V' = \frac{g_{max}}{2} d \log_e \frac{D}{d}.$$

→ $V > V'$, for given dimensions of the cable, a graded cable can be worked at a greater potential than non-graded cable.

→ For the same safe potential, the size of graded cable will be less than that of non-graded cable.

i, As the permissible value of g_{max} are peak values so, all the voltages in all expressions should be taken as peak values and not the R.M.S values.

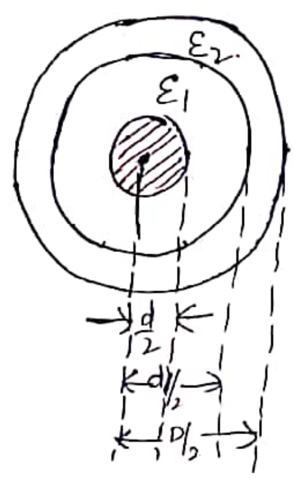
ii, If the max stress in Three dielectrics is not the same then.

$$V = \frac{g_{1max}}{2} d \log_e \frac{d_1}{d} + \frac{g_{2max}}{2} d_1 \log_e \frac{d_2}{d_1} + \frac{g_{3max}}{2} d_2 \log_e \frac{D}{d_2}$$

→ The disadvantage of this method is that there are a few grade dielectrics of Reasonable cost whose permitivities vary over the Required range.

1. A 66kV single core lead sheathed cable is graded by using two dielectrics of relative permitivity 5 & 3. thickness of each being 1cm. The core diameter is 2cm. Determine the maximum stress in the two dielectrics.

Sol:- The potential difference V b/w conductor and earthed sheath is given by.



$$V = \int_{d/2}^{d_1/2} g_1\,dx + \int_{d_1/2}^{D/2} g_2\,dx.$$

$$= \int_{d/2}^{d_1/2} \frac{Q}{2\pi\varepsilon_0\varepsilon_1 x}\,dx + \int_{d_1/2}^{D/2} \frac{Q}{2\pi\varepsilon_0\varepsilon_2 x}\,dx.$$

$$= \frac{Q}{2\pi\varepsilon_0}\left[\frac{1}{\varepsilon_1}\log_e\frac{d_1}{d} + \frac{1}{\varepsilon_2}\log_e\frac{D}{d_1}\right] \rightarrow (1)$$

$$g_1\,max = \frac{Q}{\pi\varepsilon_0\varepsilon_1 d} \rightarrow (2).$$

Put the value of $Q = g_{1max}\pi\varepsilon_0\varepsilon_1 d$ from Eq (2) in Eqn (1) then.

$$V = \frac{g_{1max}\,\varepsilon_1 d}{2}\left[\frac{1}{\varepsilon_1}\log_e\frac{d_1}{d} + \frac{1}{\varepsilon_2}\log_e\frac{D}{d_1}\right]$$

$$g_1\,max = \frac{2V}{d\left[\frac{\varepsilon_1}{\varepsilon_2}\log_e\frac{D}{d_1} + \log_e\frac{d_1}{d}\right]}$$

where $d = 2cm$, $d_1 = 4cm$, $D = 6cm$; $V = \frac{66}{\sqrt{3}} \times \sqrt{2}$
$= 53.9\,kV$

$\varepsilon_1 = 5$; $\varepsilon_2 = 3$.

Substitute the values, we get

$$g_1 max = \frac{2 \times 53.9}{2\left[\log_e 4/2 + 5/3 \log_e 6/4\right]} \text{ kV/cm.}$$

$$= \frac{2 \times 53.9}{2\left[0.6931 + 0.6757\right]}$$

$$= 39.38 \text{ kV/cm.}$$

similarly

$$g_2 max = \frac{2V}{d_1\left[\frac{\varepsilon_2}{\varepsilon_1}\log_e \frac{d_1}{d} + \log_e \frac{D}{d_1}\right]}$$

$$= \frac{2 \times 53.9}{4\left[\frac{3}{5}\log_e 4/2 + \log_e 6/4\right]} \text{ kV/cm}$$

$$= \frac{2 \times 53.9}{4\left[0.4158 + 0.4054\right]}$$

$$= 32.81 \text{ kV/cm.}$$

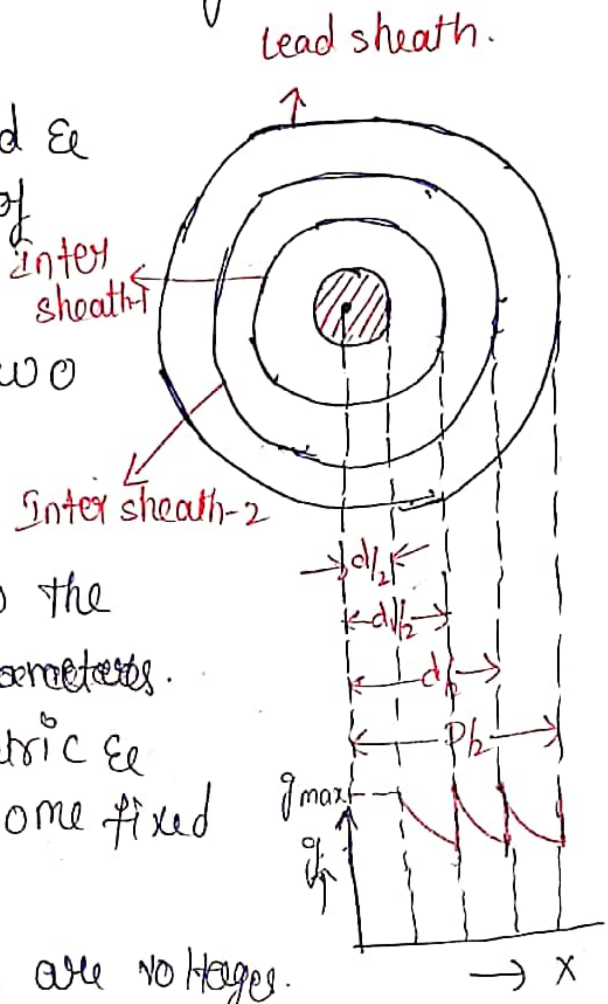
Intersheath grading:-

→ In this method of cable grading, a homogeneous dielectric is used, but it is divided into various layers by placing metallic intersheats b/w the core and lead sheath.

→ The intersheaths are held at suitable potentials which are in b/w the core potential and earth potential.

→ This arrangement improves voltage distribution in the dielectric of the cable and consequently more uniform potential gradient is obtained.

→ consider a cable of core diameter d & outer lead sheath of Diameter D.



→ suppose that two inter sheaths of diameters d_1 & d_2 are inserted into the homogeneous diameters. defects on dielectric & maintained at some fixed potential.

→ let V_1, V_2 & V_3 are voltages b/w core & intersheath 1, b/w intersheath 1 & 2 and b/w intersheath 2 & outer lead sheath.

→ There is a definite potential difference b/w the inner and outer layers of each intersheath,

→ Each sheath can be treated like a homogeneous single core cable.

maximum stress b/w core & intersheath-1 is.

$$g_{1max} = \frac{V_1}{\frac{d}{2}\log_e d_1/d}.$$

$$g_2 max = \frac{V_2}{\frac{d_1}{2} \log_e \frac{d_2}{d_1}}$$

$$g_3 max = \frac{V_3}{\frac{d_2}{2} \log_e \frac{D}{d_2}}$$

→ since the dielectric is homogeneous, the max. stress in each layer is same i.e.,

$$g_1 max = g_2 max = g_3 max = g\, max \text{ (say)}$$

$$\frac{V_1}{\frac{d}{2} \log_e \frac{d_1}{d}} = \frac{V_2}{\frac{d_1}{2} \log_e \frac{d_2}{d_1}} = \frac{V_3}{\frac{d_2}{2} \log_e \frac{D}{d_2}}$$

→ The cable behave like three capacitors in series, so, all the potentials are in phase i.e., voltage b/w conductor & earthed lead sheath is

$$V = V_1 + V_2 + V_3$$

→ This method have three disadvantages, i.e., there are complications in fixing sheath potentials.

→ another one is intersheaths are likely to be damaged during transportation & installation.

→ Third one is due to charging current there are considerable losses in intersheaths, so, it is rarely used.