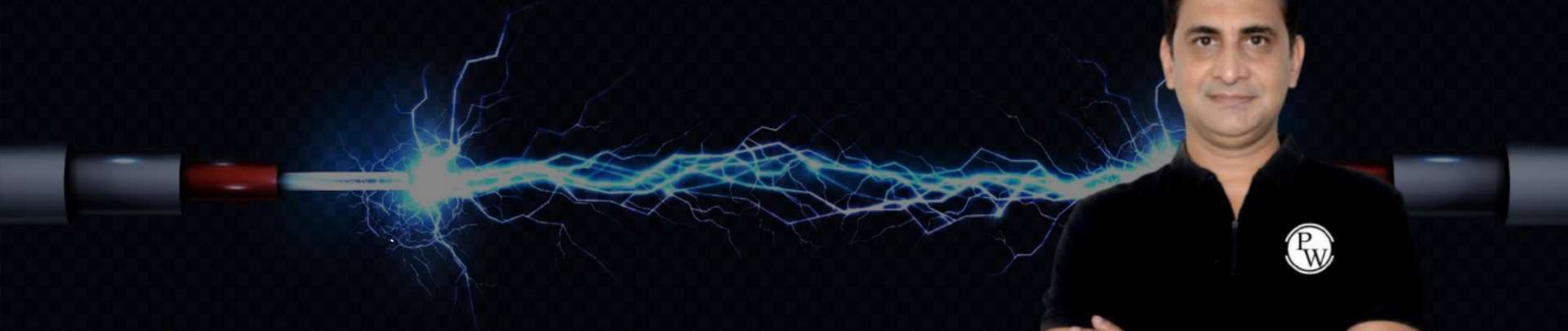


# Electrical Engineering

## Power System



Lecture No.-1  
Underground Cables

By- Ajay Gupta Sir



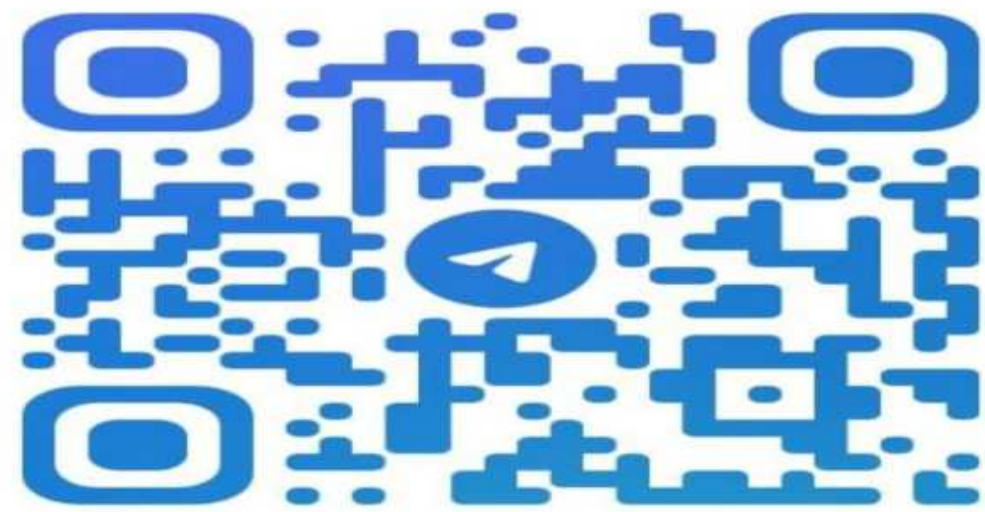
## Recap of previous class

- ✓ 1. Radial distribution uniform loading  
Fed both end by different voltage
- ✓ 2. Ring distribution
- ✓ 3. Interconnected network
- ✓ 4. a.c distribution



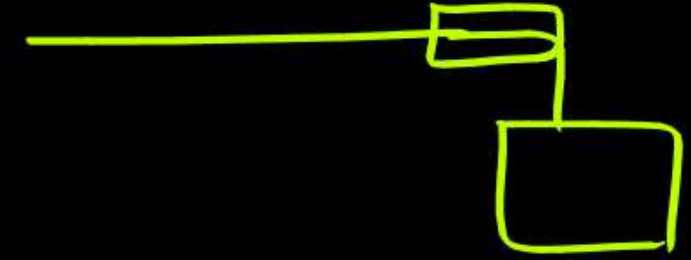
# Topics to be Covered

- ✓ 1. Underground cable component
- ✓ 2. Classification of cable
- ✓ 3. Electrostatic stress on cable
- ✓ 4. Most economical radius of conductor



@AJAYGUPTASIRPW

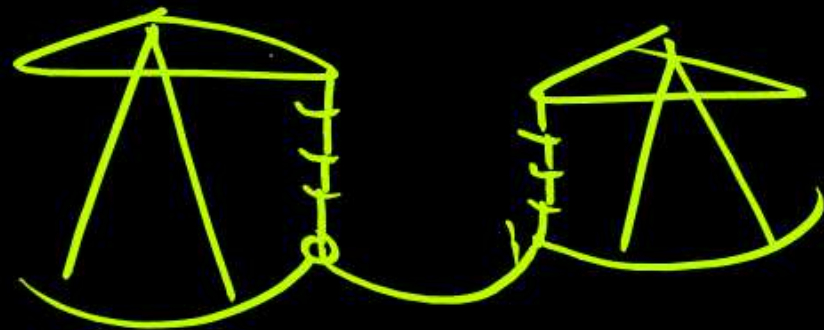
## Under Ground Cables

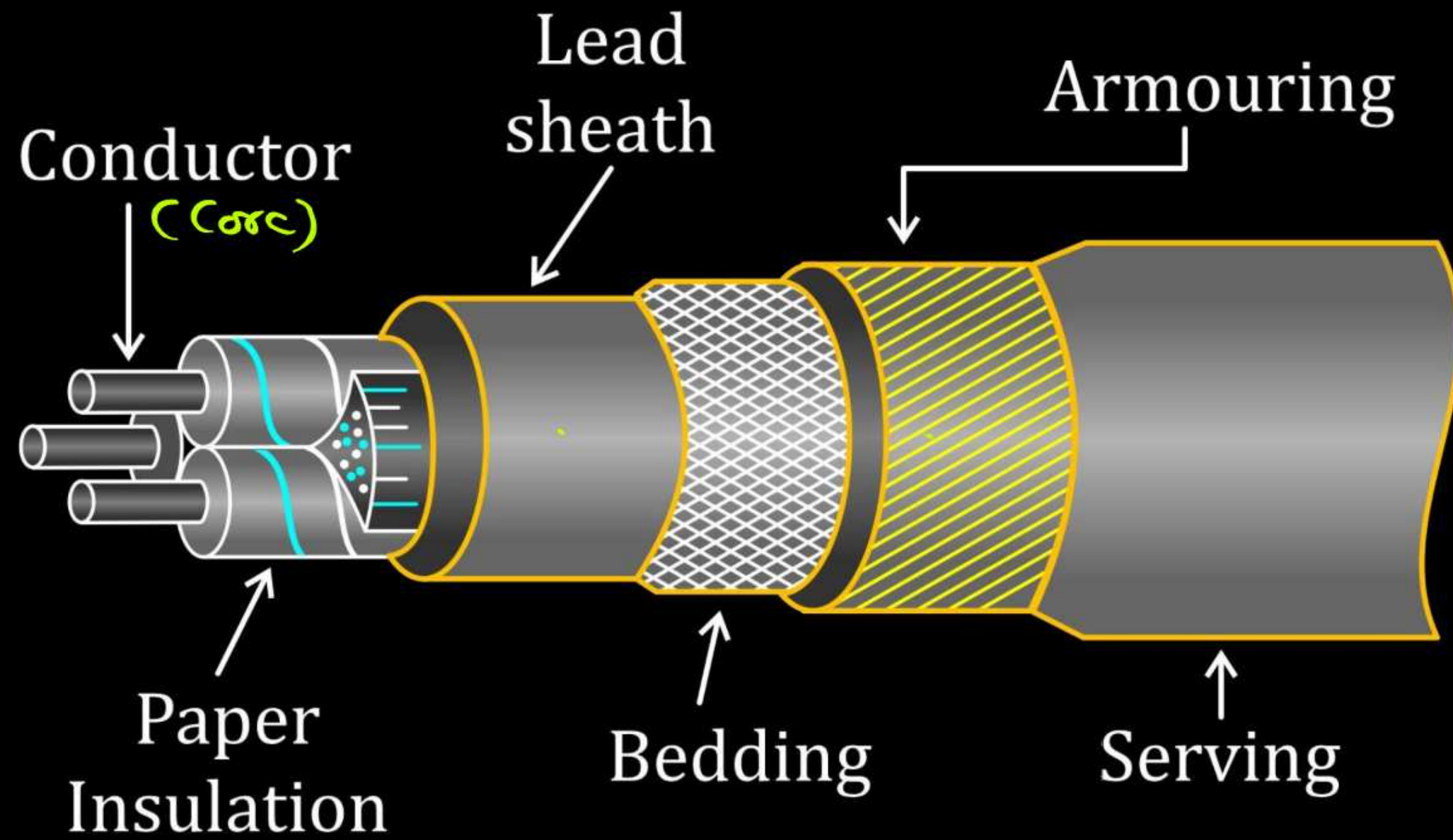


### Application: -

- (i) It is mainly used in transmission & distribution of electrical energy in densely populated region.
- (ii) To connect the overhead line with indoor sub-station equipment
- (iii) Cable is used inside water body
- (iv) At the Railway track crossing
- (v) At the road crossing

| OHL           | UGC                   |
|---------------|-----------------------|
| (1) Conductor | (1) Conductor ✓       |
| (2) Tower ✓   | (2) Insulation ✓      |
| (3) Insulator | (3) Metallic Sheath ✓ |
|               | (4) Bedding ✓         |
|               | (5) Armoring ✓        |
|               | (6) Serving ✓         |





## 1. Conductor:

- Copper conductor is used in control cable, signaling and communication
- In power cable, we use stranded Al conductor

## 2. Insulation:

- It prevent leakage current from conductor to ground
  - (a) The resistance of insulation should be high.
  - (b) It should have high dielectric strength, so thickness of insulation should be reduced.
  - (c) Non hygroscopic, so it should not absorb the moisture
  - (d) Chemically & electrically inert

(e) Free from impurities

e.g. **Vulcanized rubber** ✓

**Impregnated paper** ✓

**PVC** ✓

**Polythene** ✓

**XLPE (Cross linked polythene cable)** ✓



### 3. **Metallic Sheath:**

➤ It prevent the cable from moisture gases or other damaging liquids (acids or alkalies) in the soil and atmosphere

➤ It also protect the insulation.

✓(a) Lead

✓(b) Aluminum

#### 4. Bedding:

- The purpose of bedding is to protect the metallic sheath against corrosion and from mechanical injury due to armoring so, It provided a cushion between sheath and armoring.
- It is made of cotton, jute, Hessian tape

#### 5. Armoring :

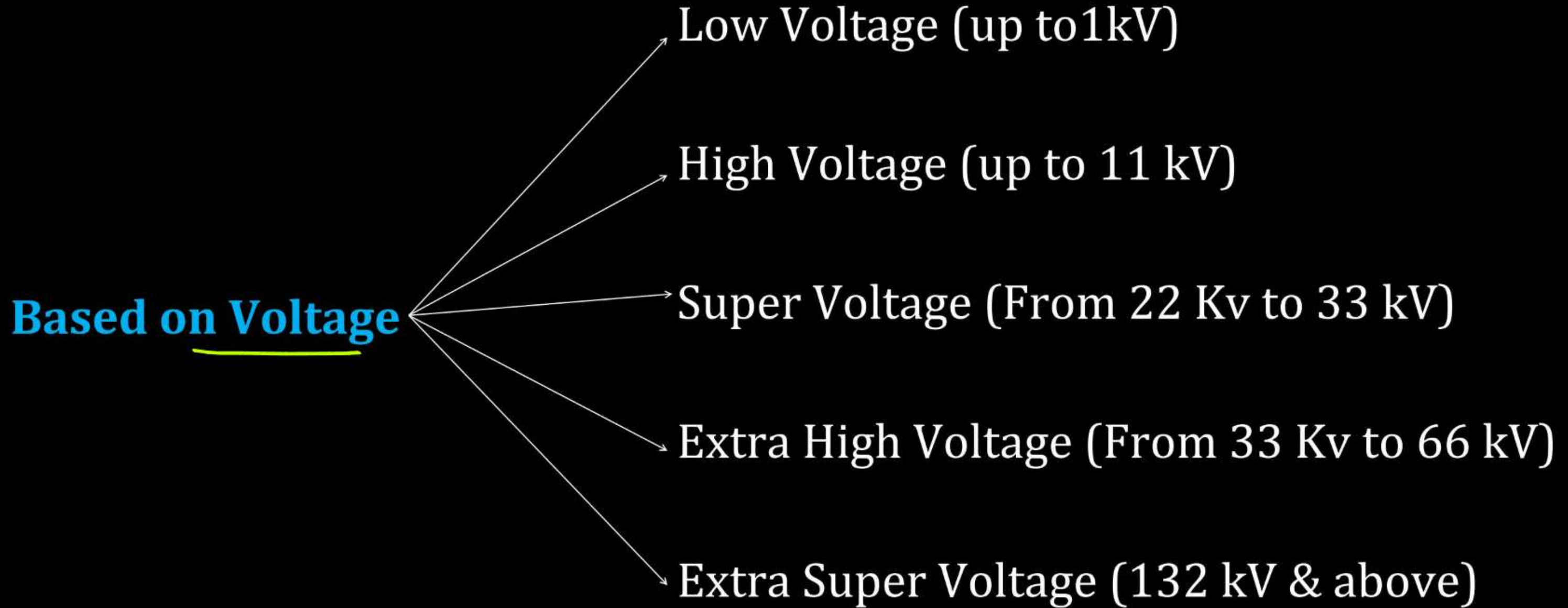
- It provide protection cover, which protect the cable during transportation and laying.
- Steel tape and steel galvanized wire is used.

## Serving :

- It protect the armour from corrosion, fibrous material is used for serving.
- Single <sup>Conductor</sup>core cable is generally not provided with armoring as it increase the loss.
- Aluminum sheath cable do not required armoring.

Note : Bedding, armouring and serving are only applied to the cables for the protection of conductor insulation and to protect the metallic sheath from mechanical injury.

## Classification of Cable:



# Based on Insulation



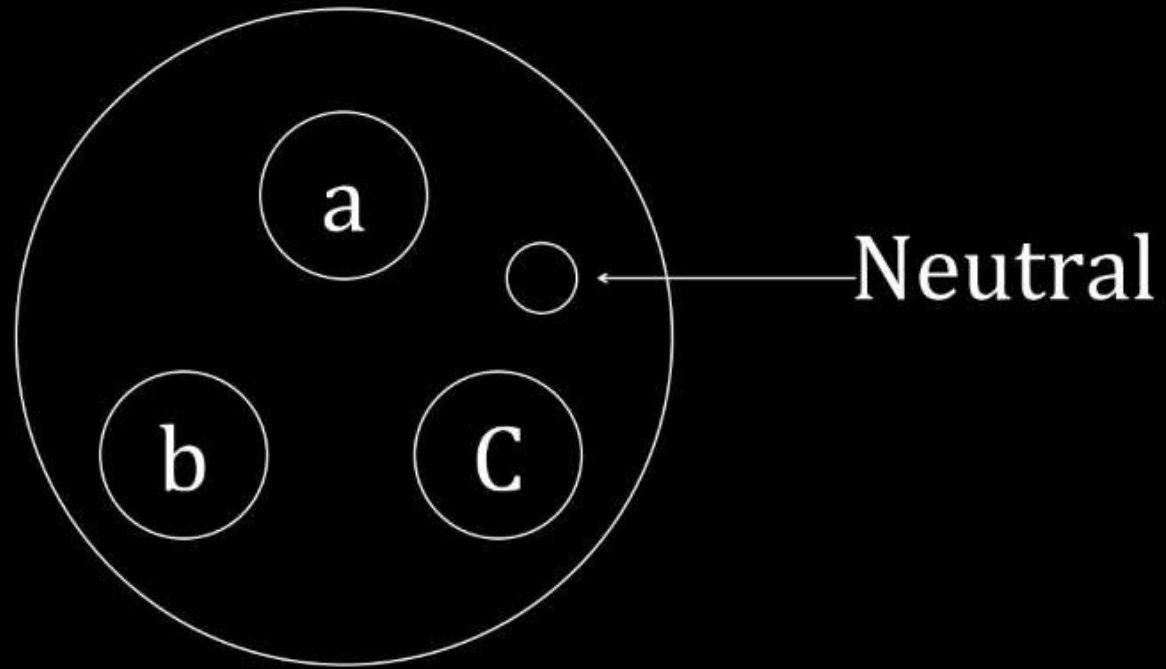
## Based on number of core

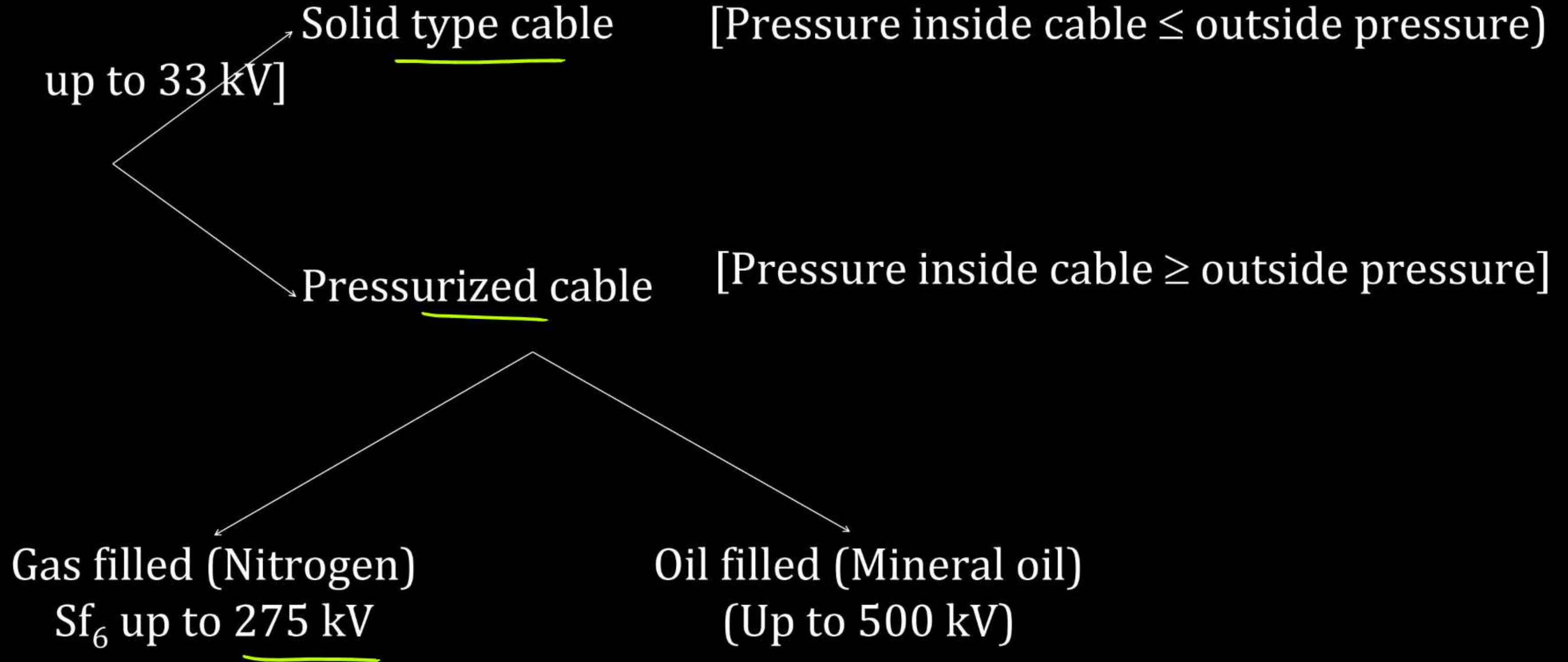
(Conductor)

Single core ( $\geq 66$  kV)

3 Core ( $\leq 33$  kV)

3 & half core (LV Distribution)





## Advantages of Pressurised Cable

The various advantages of gas pressure cables are,

1. Gas pressure cables can carry 1.5 times the normal load current and can withstand double the voltage. Hence such cables can be used for ultra high voltage (UHV) levels.
2. Maintenance cost is small.
3. The nitrogen in the steel tube, helps in quenching any fire or flame.
4. No reservoir or tanks required.
5. In oil-filled cables, the circulating oil helps remove heat from the conductor
6. The steel tubes used make the cable laying easy.
7. The ionization and possibility of voids is completely eliminated.

## Single Core Wire :



## 3 Core Wire :



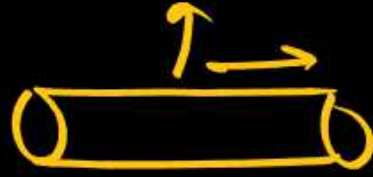
### 3 Core Cable

Belted cable (Up to 11 kV)

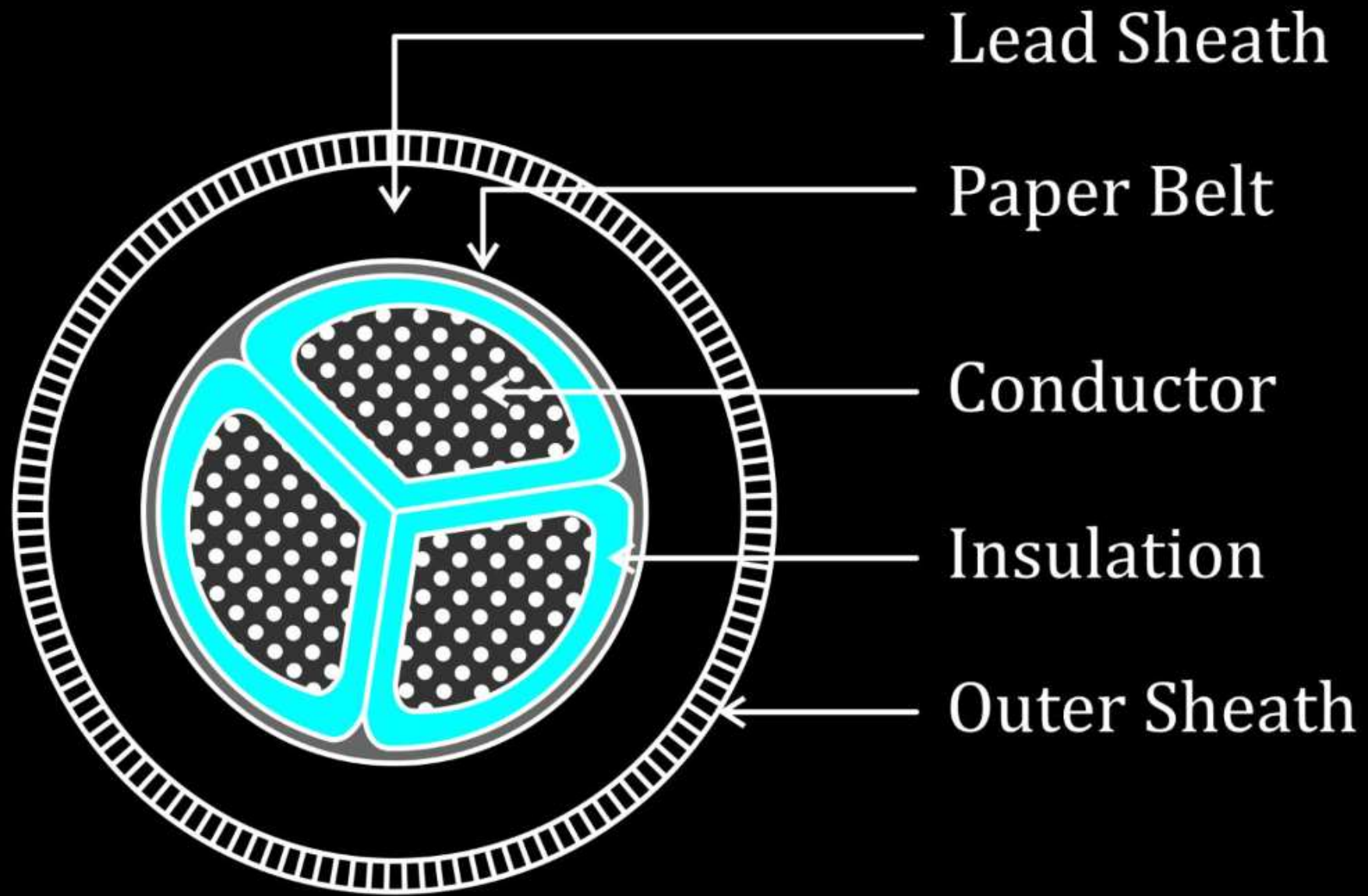
Shielded(Screened) cable (from 22KV to 66 kV)

Oil and gas filled cable (66 kV & above)

- In belted cable each conductor is insulated ( by impregnated paper) separately, and then overall belt insulation is used, and then finally metallic sheath is used.

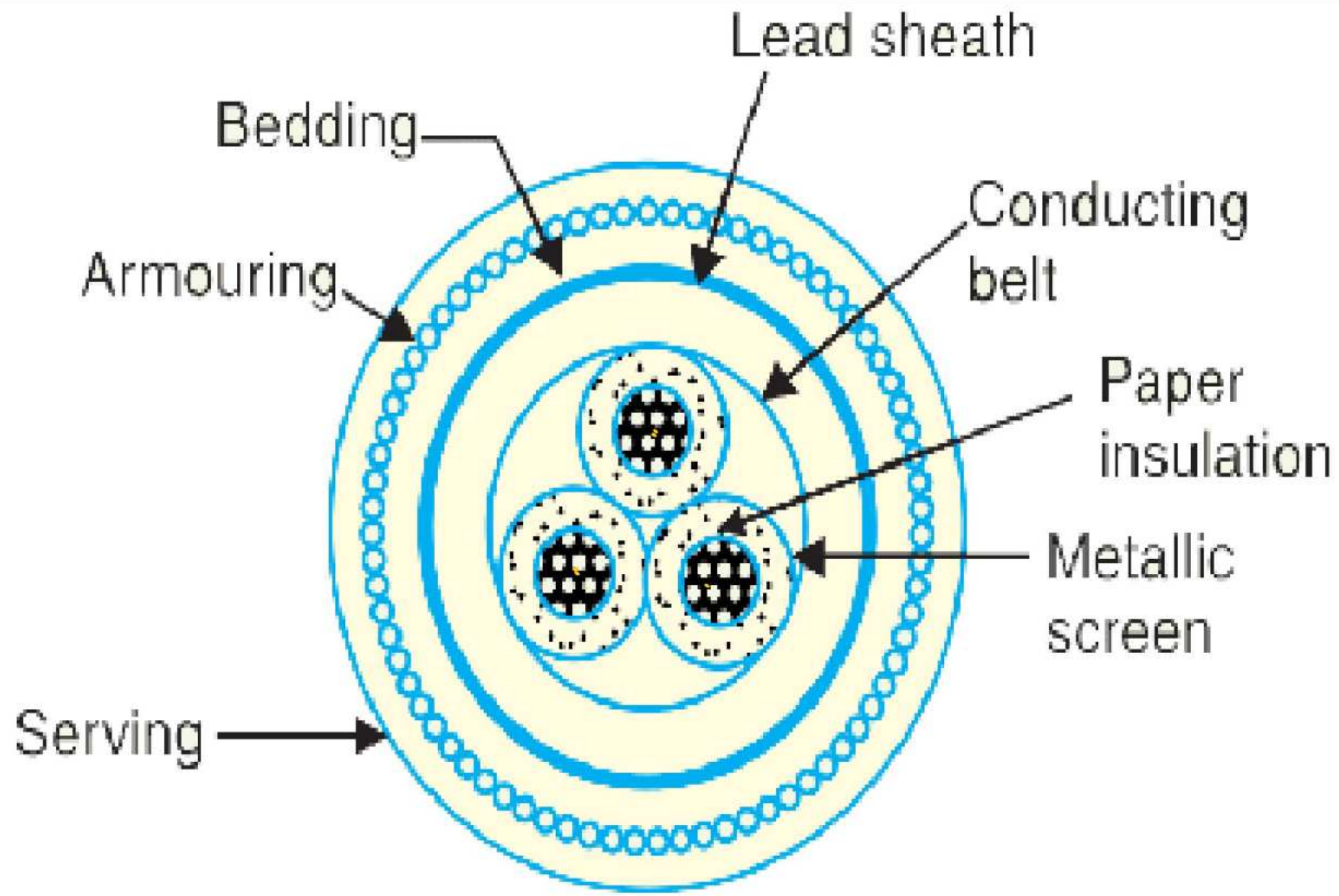


- In this cable tangential electric stress also exist. Which force leakage current along the length of insulation. Which may lead to its breakdown.
- In shielded cable each conductor is individually insulated and cover with metallic sheath. Then an additional sheath is used.
- All four sheath are at the earth potential, so electric stress is radial only

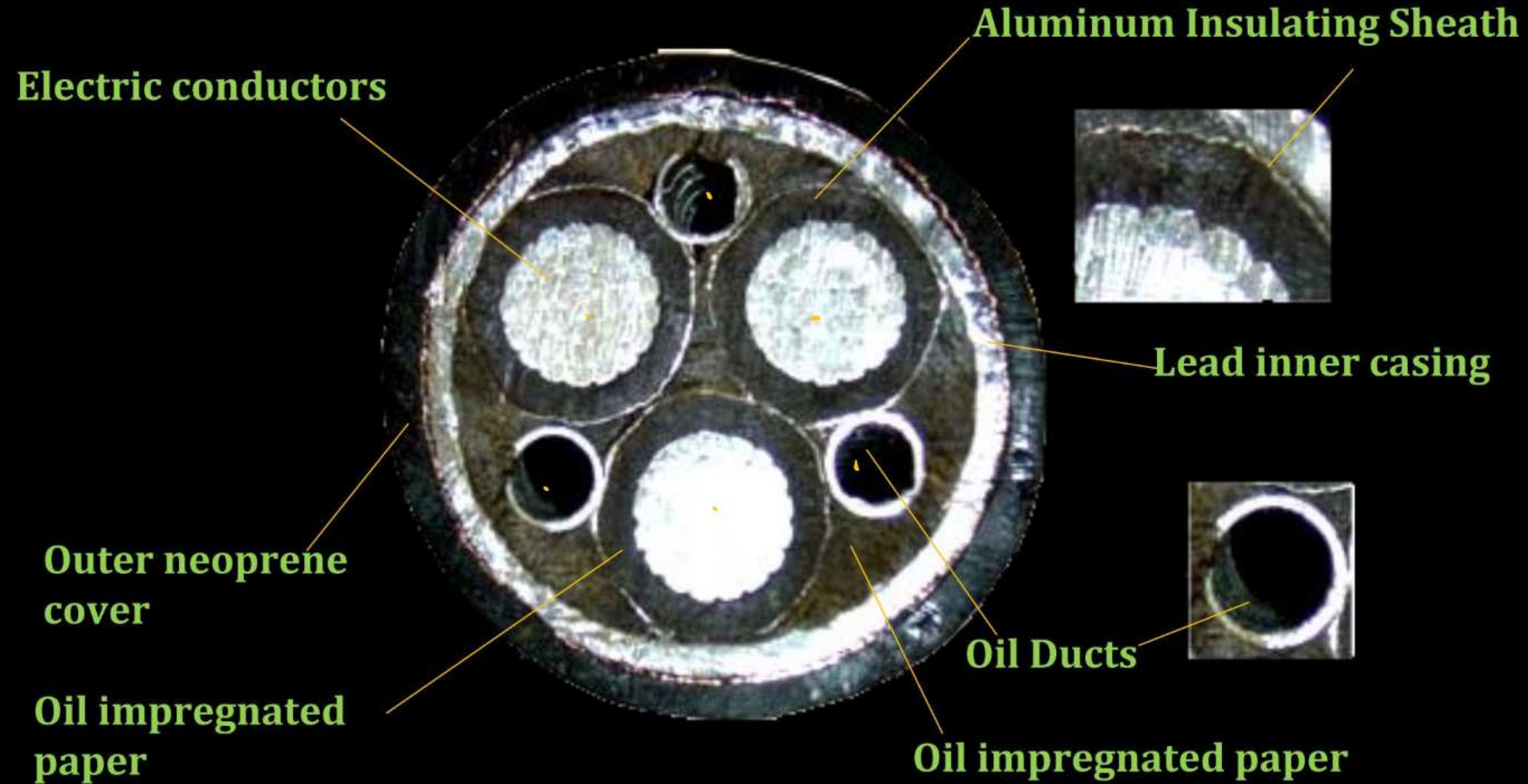


**Belted Cable**





# Internal view of 3 core 33kV oil filled cable



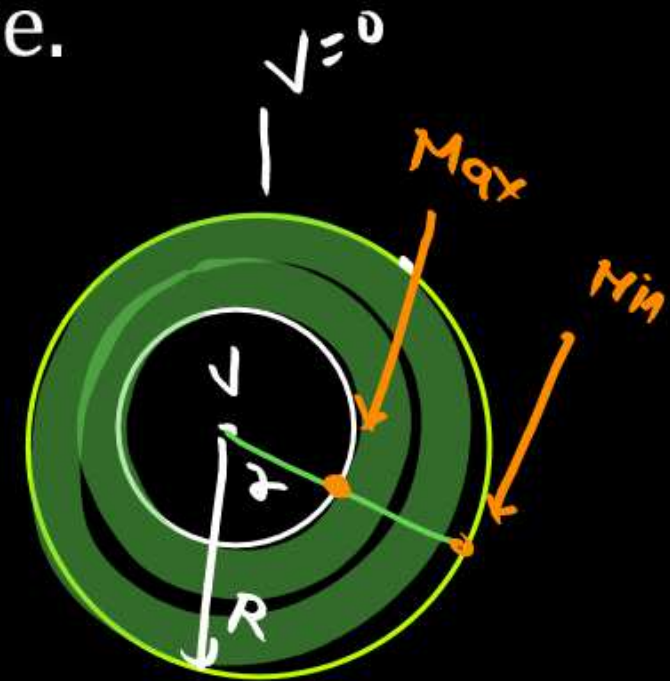
# Electrostatic stress on single core cable:

Electric stress = Electrical field = Potential Gradient,

$$E = g.$$

- Electrical field inside the conductor is zero. So, it is also zero at conducting Sheath.
- Now suppose in insulator electrical field at x distance.

$$g = E = \frac{q}{2\pi\epsilon x} \quad - (1)$$



$$V = - \int_R^r E \, dx$$

$$V = - \int \frac{q_v}{2\pi\epsilon x} \, dx$$

$$V = \frac{q_v}{2\pi\epsilon} [-\ln x]_R^r$$

$$V = \frac{q_v}{2\pi\epsilon} [\ln R - \ln r]$$

$$V = \frac{q_v}{2\pi\epsilon} \ln \frac{R}{r}$$

$$\frac{q_v}{2\pi\epsilon} = \frac{V}{\ln(R/r)}$$

Put value of  $\frac{q}{2\pi\epsilon}$  in eqn (1)

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

→ Electric Stress is inversely proportional to distance

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

$$g = \frac{V}{x \ln \frac{D}{d}}$$

- So electrical field will be maximum at the outer surface of conductor,  $x = r$

$$J_{mx} = E_{\max} = \frac{V}{r \ln\left(\frac{R}{r}\right)}$$

- The Minimum value of electrical field occur at the inner surface of sheath,  $x = R$

$$J_{m\eta} = E_{\min} = \frac{V}{R \ln\left(\frac{R}{r}\right)}$$

$$\frac{g_{mx}}{g_{mn}} = \frac{R}{\gamma}$$

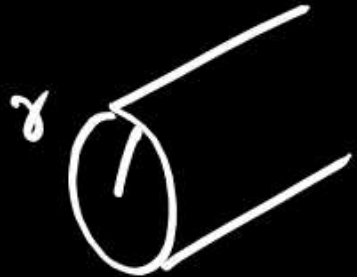
$$\frac{g_{mx}}{g_{mn}} = \frac{D}{d}$$

Q.



A single core cable for use on 11 kV, 50 Hz system has conductor area of  $0.645 \text{ cm}^2$  and internal diameter of sheath is  $2.18 \text{ cm}$ . The permittivity of the dielectric used in the cable is  $3.5$ . Find (i) the maximum electrostatic stress in the cable

- A** ~~27.65~~ kV/cms (RMS)
- B** 20.65 kV/cms (RMS)
- C** 17.65 kV/cms (RMS)
- D** 22.65 kV/cms (RMS)



Given

$$a = 0.645 \text{ cm}^2$$

$$D = 2.18 \text{ cm}$$

$$\epsilon_r = 3.5$$

$$R = 1.09 \text{ cm}$$

Formula

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

$$a = \pi r^2$$

$$r = \sqrt{\frac{a}{\pi}} = \sqrt{\frac{0.645}{\pi}} = 0.453 \text{ cm}$$

$$g_{mx} = \frac{11}{0.453 \ln \frac{1.09}{0.453}} = \frac{11}{0.3977} = 27.66 \text{ kv/cm (RMS)}$$

Q.



A single core cable for use on 11 kV, 50 Hz system has conductor area of  $0.645 \text{ cm}^2$  and internal diameter of sheath is  $2.18 \text{ cm}$ . The permittivity of the dielectric used in the cable is  $3.5$ . Find (i) minimum electrostatic stress in the cable

- A 15.65 kV/cms (RMS)
- B 13.65 kV/cms (RMS)
- C 11.49 kV/cms (RMS)
- D 22.65 kV/cms (RMS)

$$g_{\min} = \frac{V}{R \ln R/r}$$
$$= \frac{11}{1.09 \ln \frac{1.09}{0.453}} = 11.49$$

II Method

$$\frac{g_{\max}}{g_{\min}} = \frac{R}{r}$$
$$\frac{27.66}{g_{\min}} = \frac{1.09}{0.453} \Rightarrow g_{\min} = 11.49$$

Q.



The maximum and minimum stresses in the dielectric of a single core cable are 40 kV/cm (r.m.s.) and 10 kV/cm (r.m.s.) respectively. If the conductor diameter is 2 cm, find :

(i) thickness of insulation

$$\gamma = 1$$

- A 2 cm
- B 3 cm
- C 4 cm
- D 5 cm

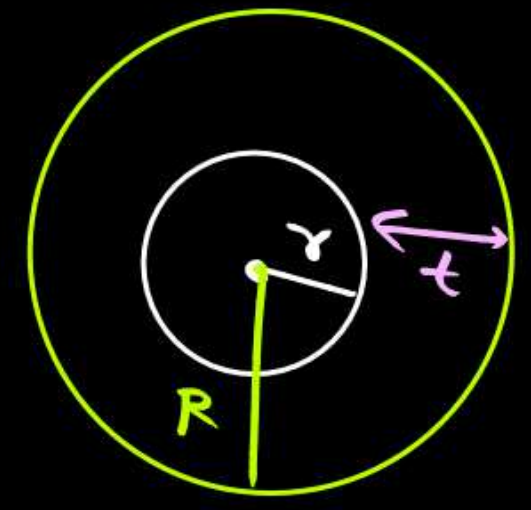
$$t = R - \gamma$$

$$t = R - 1$$

$$\frac{g_{mx}}{g_{mn}} = \frac{R}{\gamma}$$

$$\frac{40}{10} = \frac{R}{1} \Rightarrow R = 4 \text{ cm}$$

$$t = 4 - 1 = 3$$



Q.



The maximum and minimum stresses in the dielectric of a single core cable are 40 kV/cm (r.m.s.) and 10 kV/cm (r.m.s.) respectively. If the conductor diameter is 2 cm, find :  $\gamma = 1$

(i) Operating voltage in RMS

- A 52.3 kv
- B 49.8 kv
- ☒ C 55.45 kv
- D 78.3 kv

$$g_{mx} = \frac{V}{\gamma \ln \frac{R}{\gamma}} \qquad g_{mn} = \frac{V}{R \ln \frac{R}{\gamma}}$$

$$\frac{g_{mx}}{g_{mn}} = \frac{R}{\gamma}$$

$$40 = \frac{V}{1 \ln \frac{4}{1}}$$

$$\frac{40}{10} = \frac{R}{1}$$

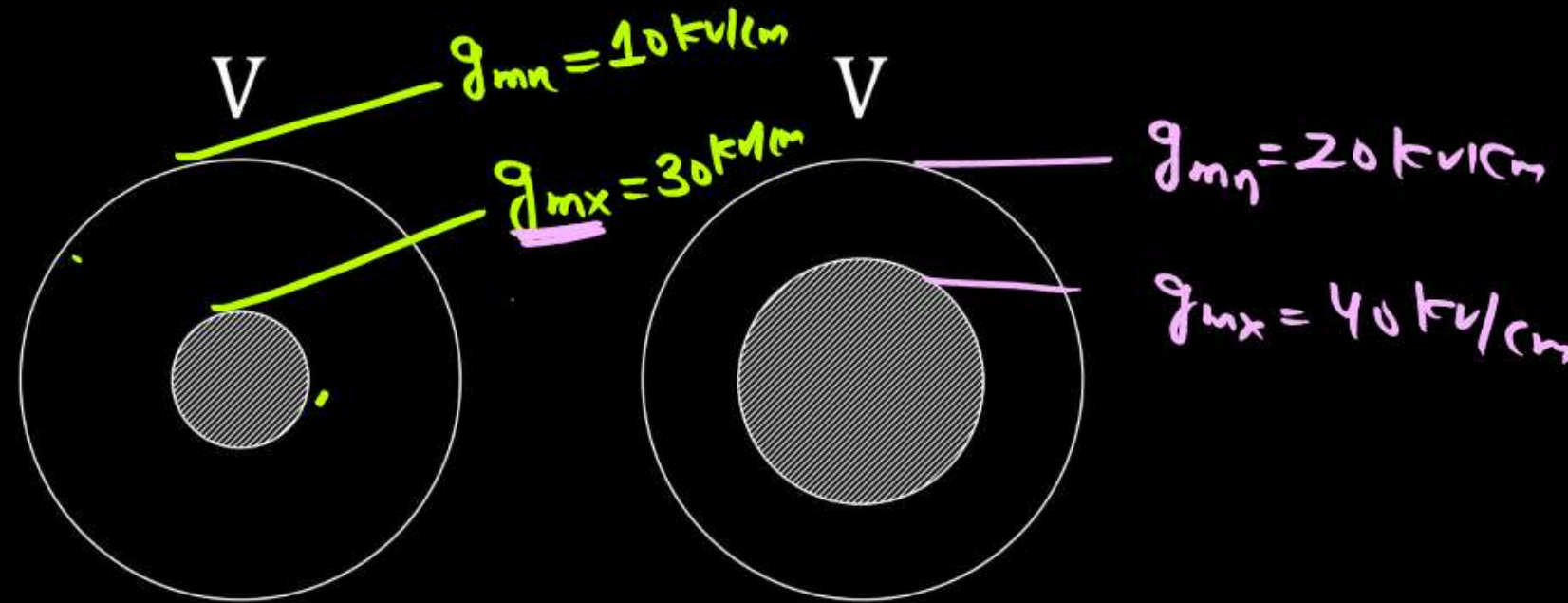
$$\underline{R = 4}$$

$$V = 55.45$$

## Most economical radius of conductor:

- So dielectric strength of insulation should be higher than  $E_{\max}$ .

For a fixed voltage application, if over all size of cable (R). We will determine radius of conductor (r) for which electrical field of surface of conductor ( $E_{\max}$  should be minimum).



It will reduce the cost of insulation, so it will be most economical radius.

# Electrical field at surface of conductor.



$$g_{mx} = \frac{V}{\gamma \ln \frac{R}{\gamma}}$$

$$\frac{d(g_{mx})}{d\gamma} = 0$$

$$\frac{\gamma \ln \frac{R}{\gamma} (0) - V \left[ \cancel{\gamma} \frac{\cancel{\gamma}}{R} \left( -\frac{R}{\cancel{\gamma}^2} \right) + \ln \frac{R}{\gamma} (1) \right]}{\left[ \gamma \ln \frac{R}{\gamma} \right]^2} = 0$$

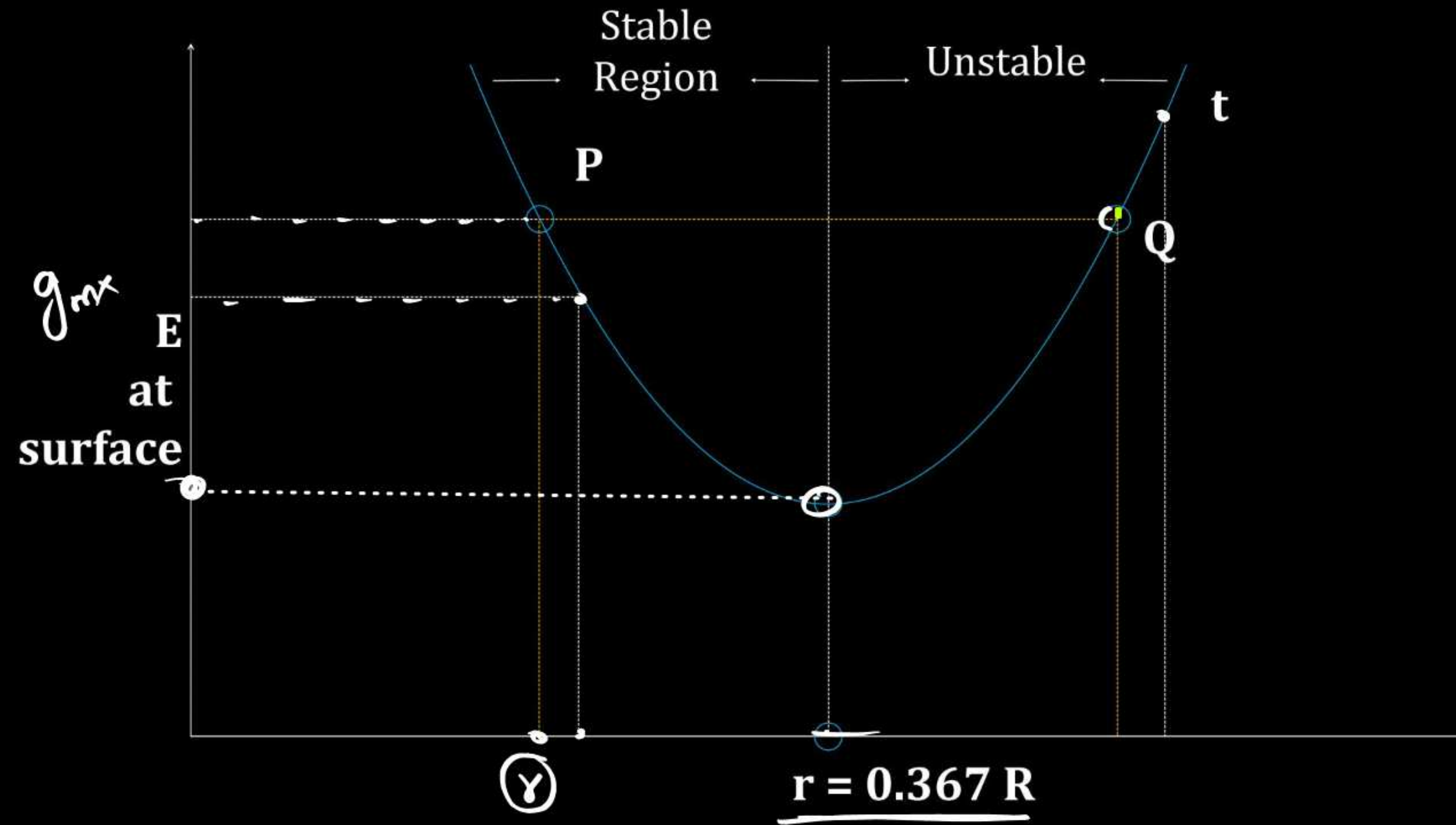
$$-1 + \ln \left( \frac{R}{\gamma} \right) = 0$$

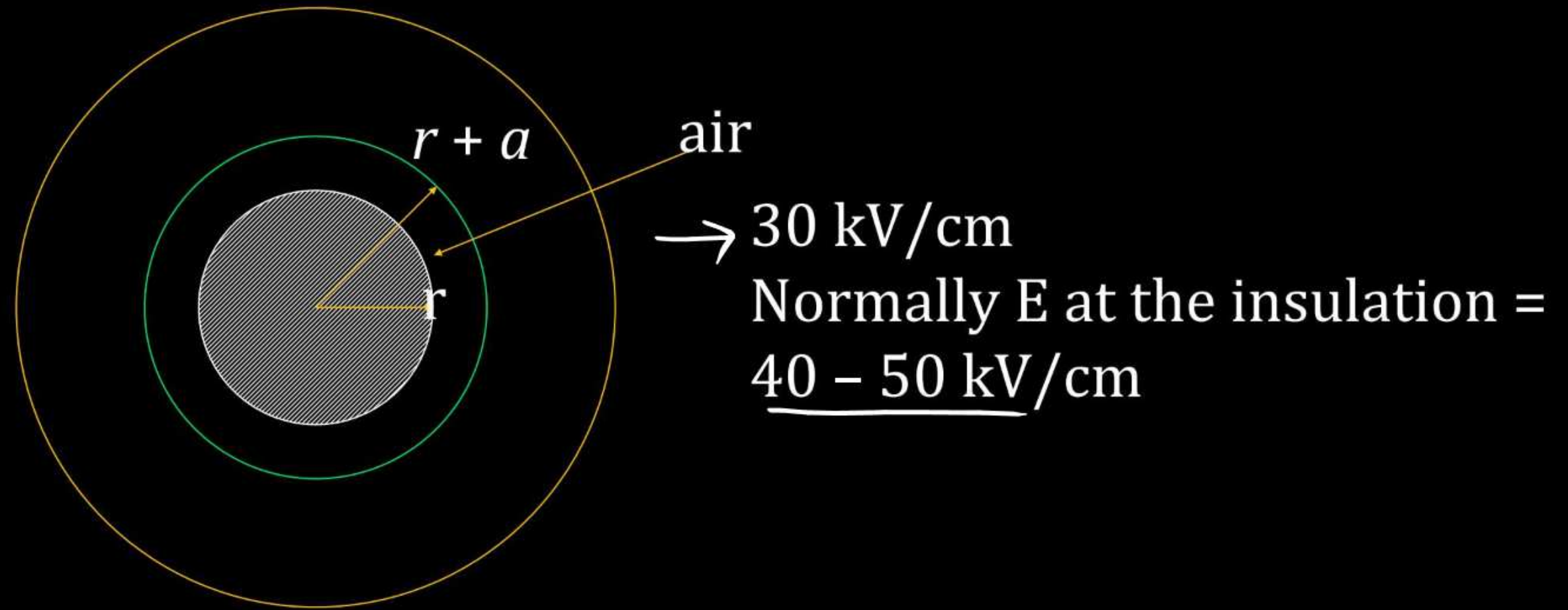
$$\ln \left( \frac{R}{\gamma} \right) = 1$$

$$\rightarrow \boxed{\frac{R}{\gamma} = e}$$

$$\frac{R}{\gamma} = 2.718$$

$$\gamma = \frac{R}{2.718} = 0.368 R.$$





For min insulation  $\frac{r}{R} = \frac{1}{e}$

$$\frac{R}{r} = e$$

$$\gamma \leq 0.367 R$$

Q.



Find the most economical size of a single-core cable working on a 132 kV 3-phase system, if a dielectric stress of 60 kV/cm(peak) can be allowed.



- A R=10.2, r= 4.2 cm
- B R=7.2, r= 3.2 cm
- C R=12.2, r= 6.1 cm
- D D=9.78, d= 3.6 cm

Given

$$V(\text{line}) = 132 \text{ (RMS)}$$

$$g_{\text{mx}}(\text{Peak}) = 60 \text{ kV/cm}$$

(3 ph system

$$g_{\text{mx}}(\text{RMS}) = \frac{60}{\sqrt{2}} \text{ kV/cm}$$

$$\frac{R}{r} = e^1$$

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

$$g_{mx} = \frac{V}{\gamma \ln \frac{R}{\gamma}}$$

$$\frac{60}{\sqrt{2}} = \frac{132/\sqrt{3}}{\gamma \times 1}$$

$$\gamma = 1.796$$

$$d = 2 \times 1.796$$

$$\underline{d = 3.6}$$

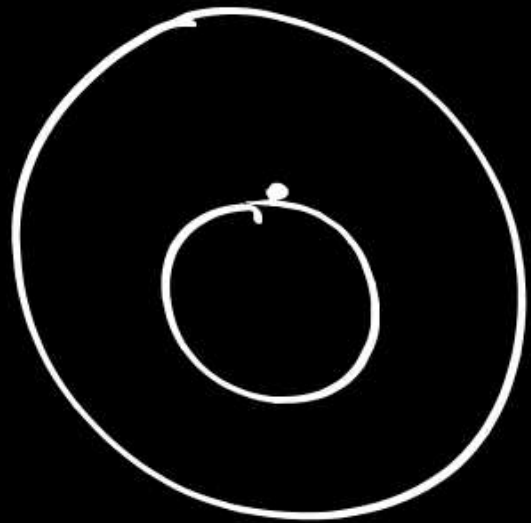
$$\frac{2R}{2\gamma} = e$$

$$\frac{D}{d} = e$$

$$D = \underline{9.78}$$

Q.

Determine the economic overall diameter of a 1-core cable metal sheathed for a working voltage of 85 kV if the dielectric strength of the insulating material is 65 kV/cm(peak).



$$g_{mx}(RMS) = \frac{65}{\sqrt{2}}$$

$$g_{mx} = \frac{V}{\gamma \ln \frac{R}{r}}$$

$$\frac{65}{\sqrt{2}} = \frac{85}{\gamma \times 1}$$

$$\gamma = 1.849$$

For economic  $\frac{R}{r} = e$

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

$$\frac{R}{r} = e$$

$$R = 1.84 \times e^1 = 5.02$$

$$D = 2R = 10.04$$



## 2 Minutes Summary

- Cable classification
- Electrostatic stress in insulation
- Economic radius of conductor

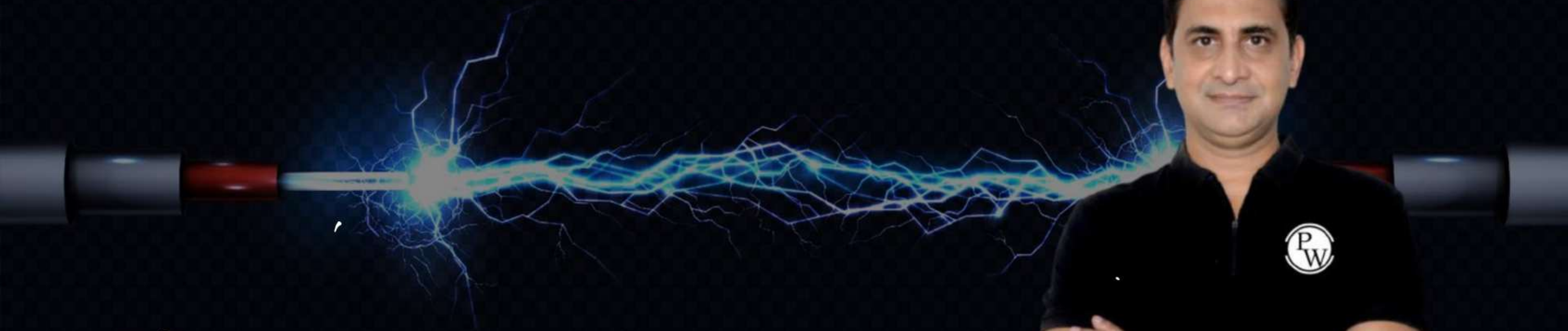
**Thank you**

**GW**  
*Soldiers !*



# Electrical Engineering

## Power System



Lecture No.-2  
Underground Cables

By- Ajay Gupta Sir



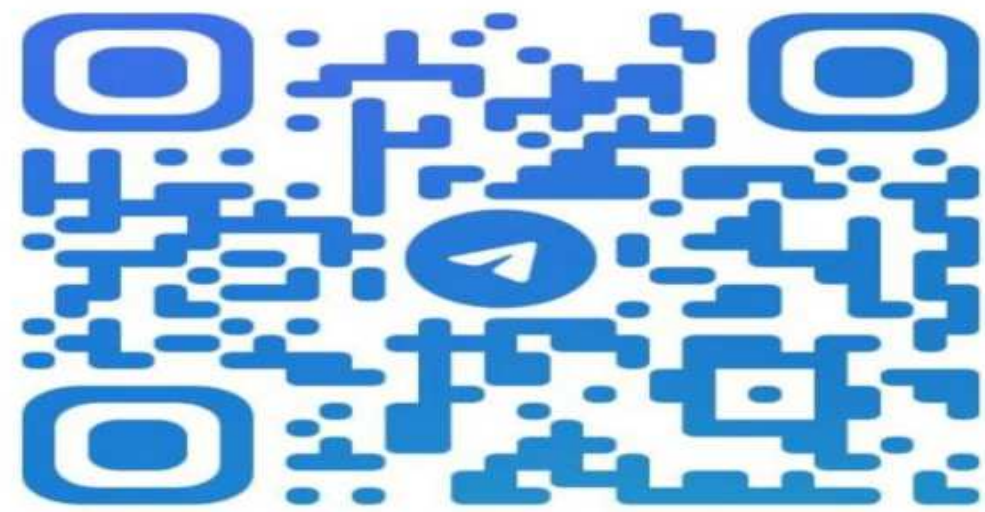
# Recap Of previous class

- ✓ 1. Underground cable component
- ✓ 2. Classification of cable
- ✓ 3. Electrostatic stress on cable
- ✓ 4. Most economical radius of conductor



# Topics to be Covered

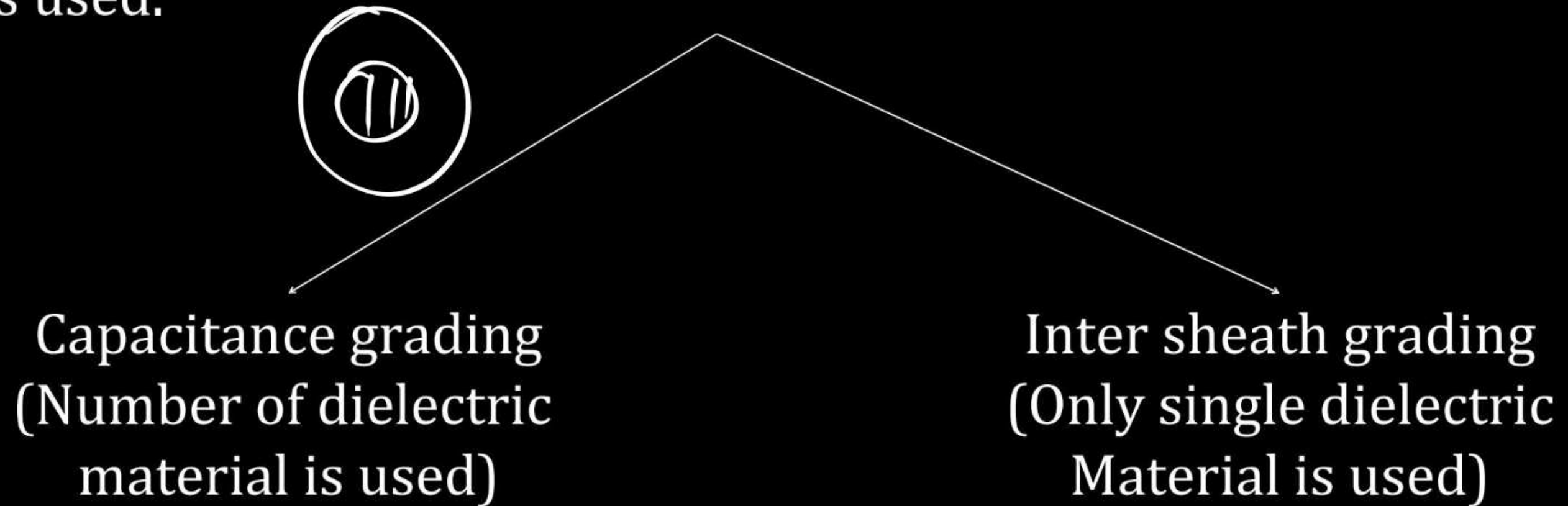
- ✓ 1. Grading of Cable
- ✓ 2. Capacitance grading
- ✓ 3. Inter-sheath Grading
- ✓ 4. Insulation Resistance

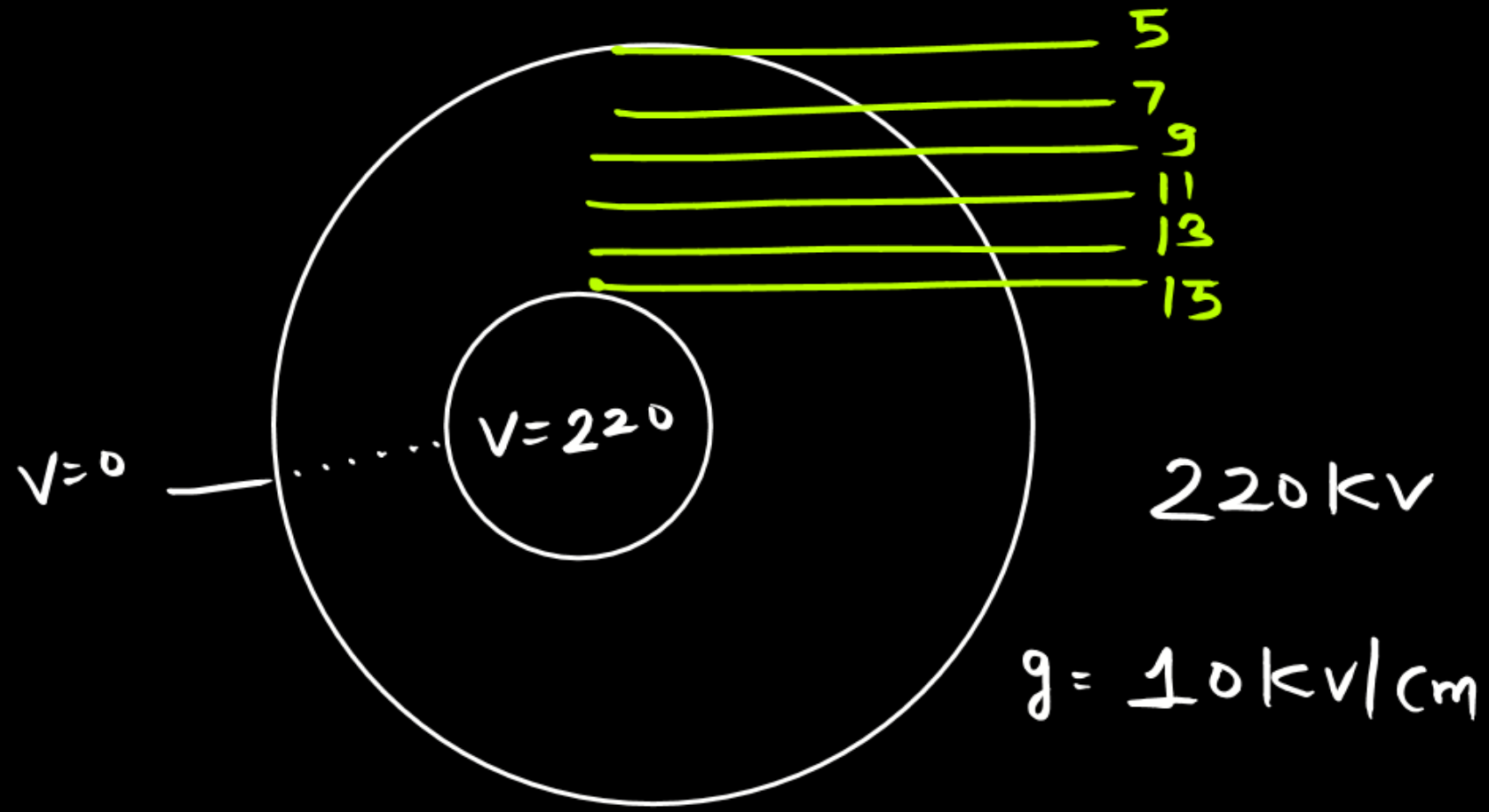


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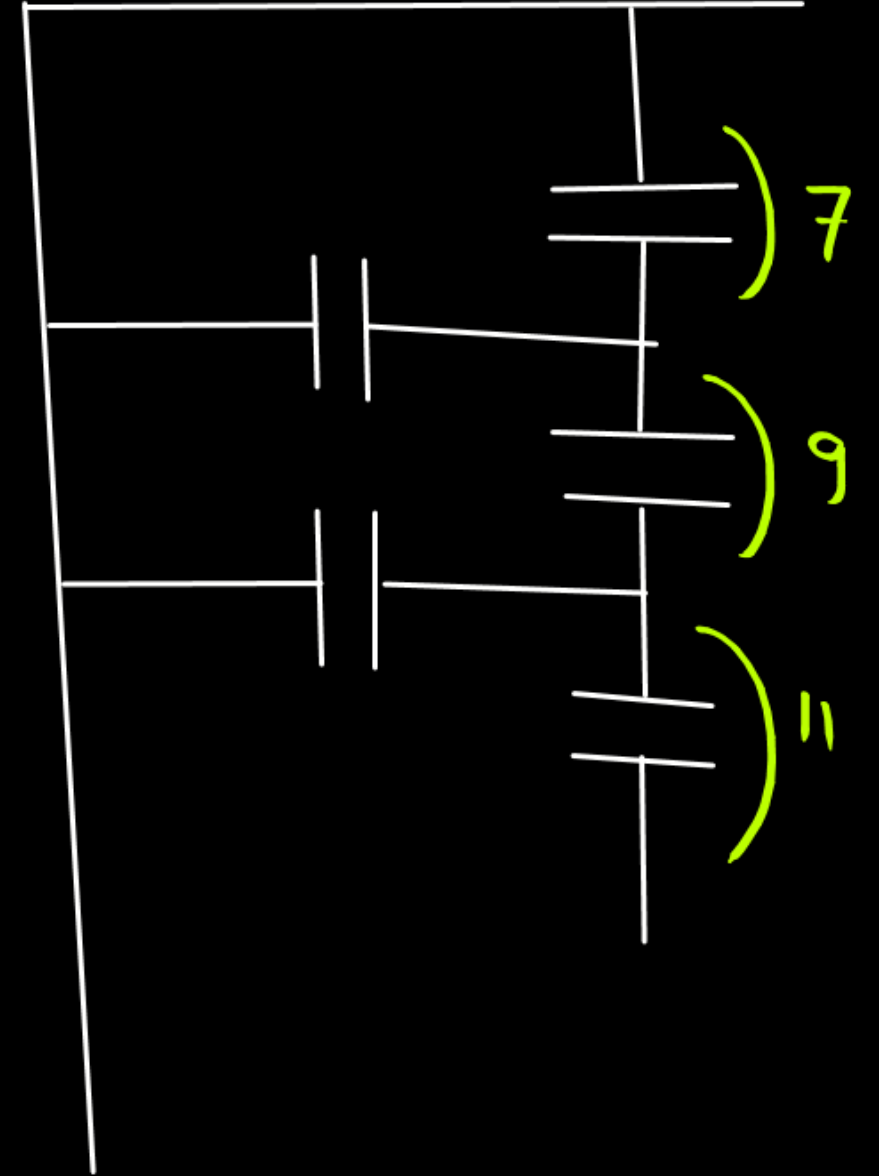
## Grading of Cable:

- Grading means distribution of dielectric material such that difference between maximum and minimum electrical field is reduce. So same size cable can be used for high voltage or <sup>for</sup> same operating voltage smaller size of cable is used.





$$\text{Thickness} = \frac{220 \text{ kV cm}}{10 \text{ kV}} = 22 \text{ cm}$$

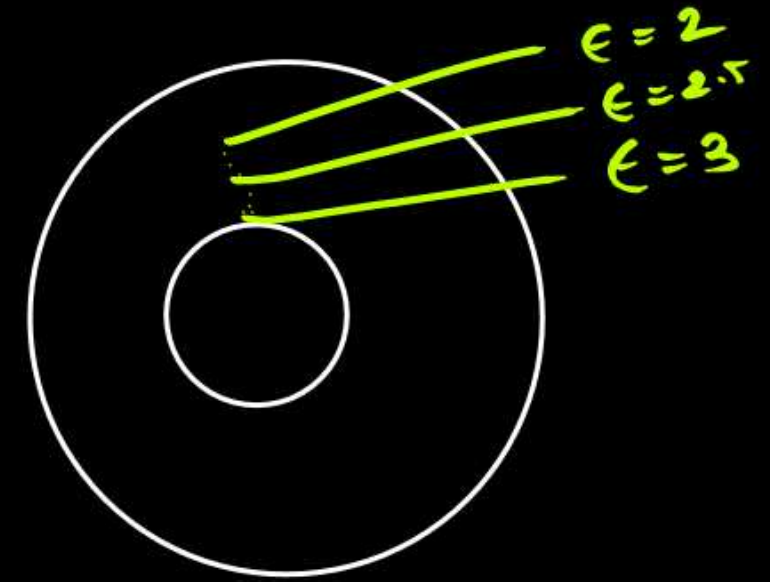
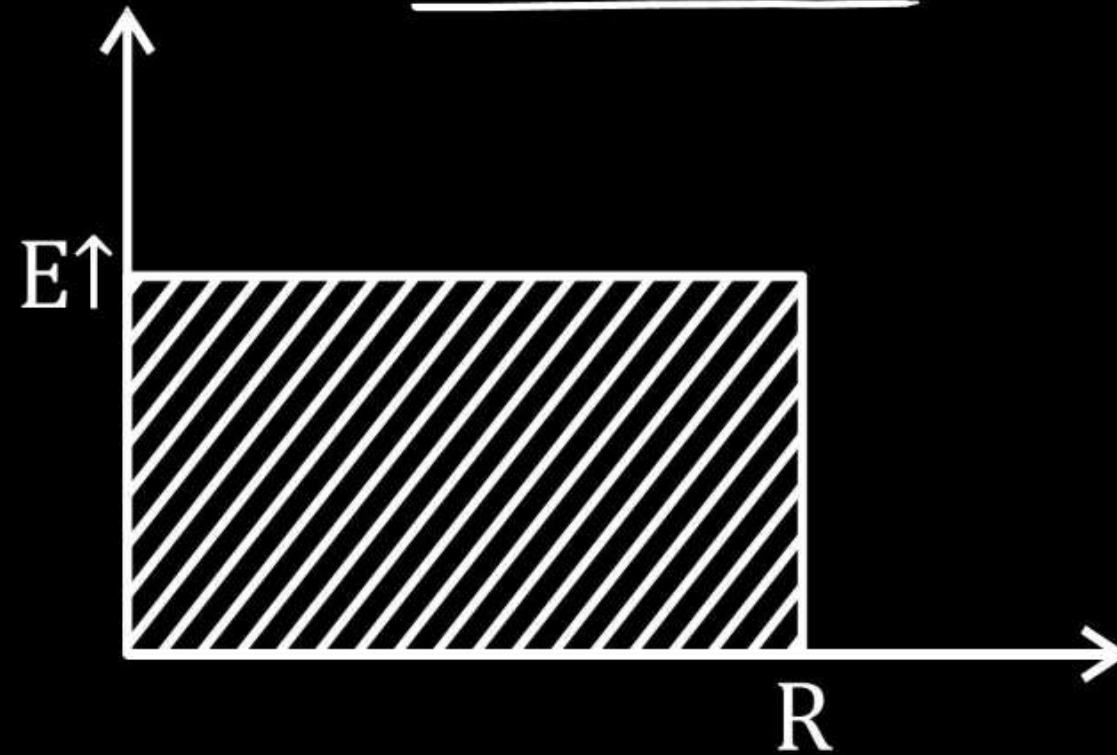


## Capacitance Grading:

- Electrical field at  $x$  distance  $\underline{E_x} = \frac{\lambda}{2\pi(\epsilon x)}$   $\lambda = q$

So,  $E_x$  will be independent of  $x$ ,  $\epsilon x = \text{constant} = k$

$$\epsilon \downarrow = \frac{k}{x \uparrow}$$



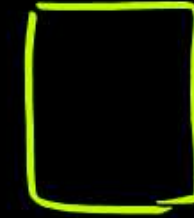
- So infinite amount of dielectric material is required normally we use 2-3 dielectric material with permittivity of  $\epsilon_1, \epsilon_2, \epsilon_3$  & radius  $r_1, r_2$  &  $r_3$
- Now to find out the location of different dielectric material.

## Case-I :



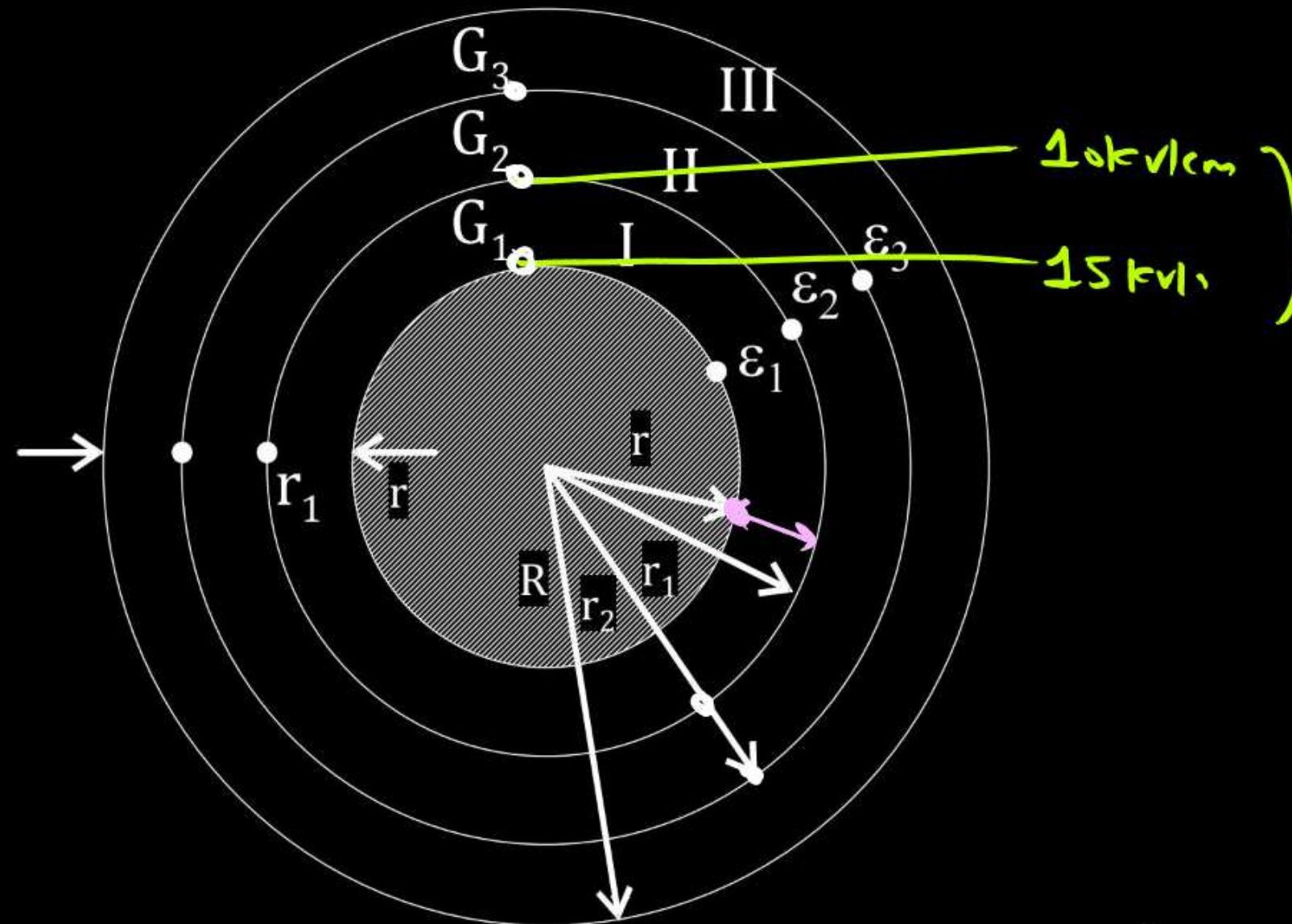
(1) If factor of safety of all dielectric material is same.

$$F = \frac{\text{Dielectric strength}}{E \text{ at surface}}$$



$$\frac{450}{250} = 2$$

Suppose if dielectric strength of insulating material is  $G_1$ ,  $G_2$  and  $G_3$



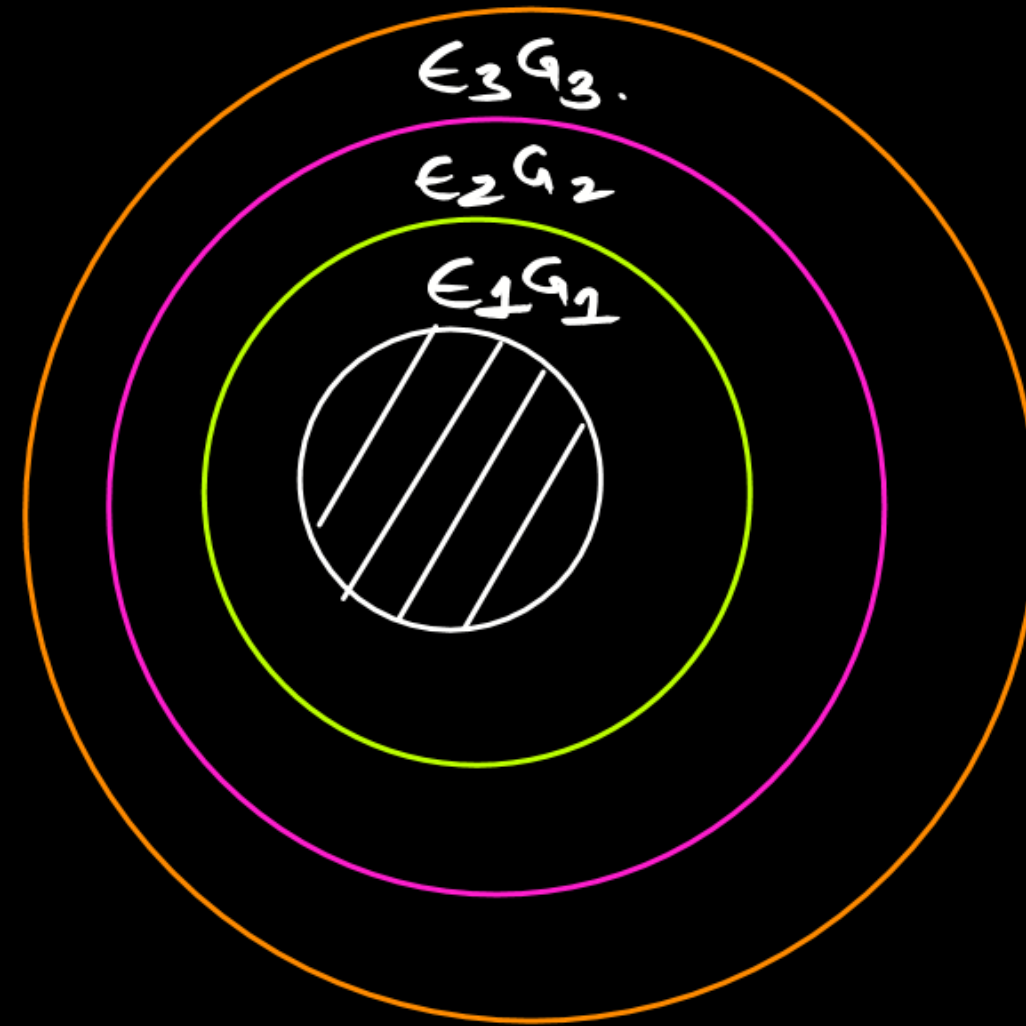
$$\frac{30 \text{ kV/cm}}{15} = 2$$

$$F = \frac{G_1}{\frac{\cancel{\lambda}}{2\pi\epsilon_0\epsilon_1\cancel{\lambda}}} = \frac{G_2}{\frac{\cancel{\lambda}}{2\pi\epsilon_0\epsilon_2\cancel{\lambda}_1}} = \frac{G_3}{\frac{\cancel{\lambda}}{2\pi\epsilon_0\epsilon_3\cancel{\lambda}_2}}$$

$$G_1\epsilon_1\cancel{\lambda} = G_2\epsilon_2\cancel{\lambda}_1 = G_3\epsilon_3\cancel{\lambda}_2$$

$$\cancel{\lambda} < \cancel{\lambda}_1 < \cancel{\lambda}_2$$

$$\boxed{\epsilon_1 G_1 > \epsilon_2 G_2 > \epsilon_3 G_3}$$

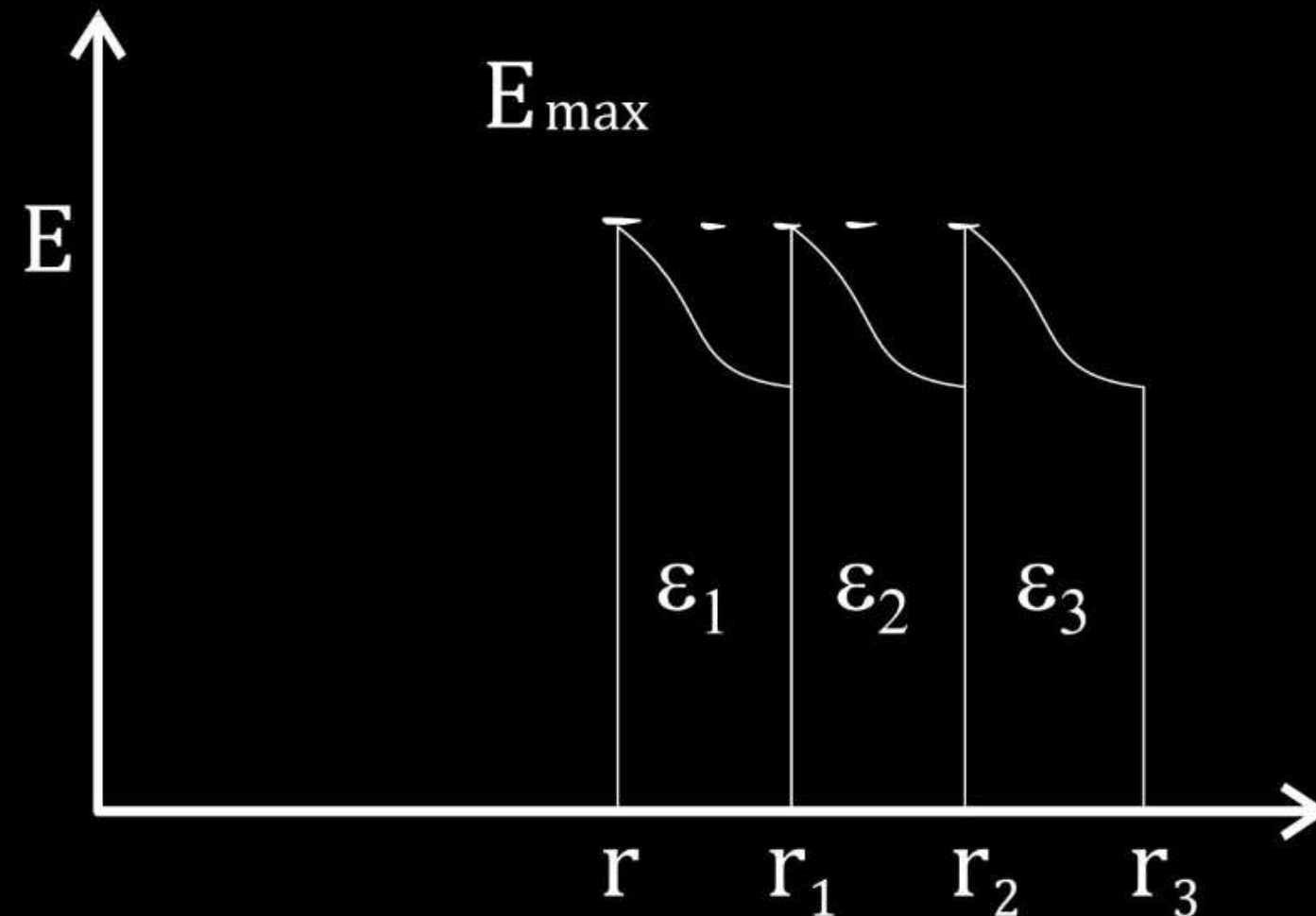


So, material with highest  $\epsilon G$  should be placed near to conductor & outer layer should be in descending order of product of  $\epsilon G$ .

So, material with highest  $\epsilon G$  should be placed near to conductor & outer layer should be in descending order of product of  $\epsilon G$ .

**Case-II :** If maximum value of electric field is same.

So dielectric material with high permittivity should be placed near to conductor.

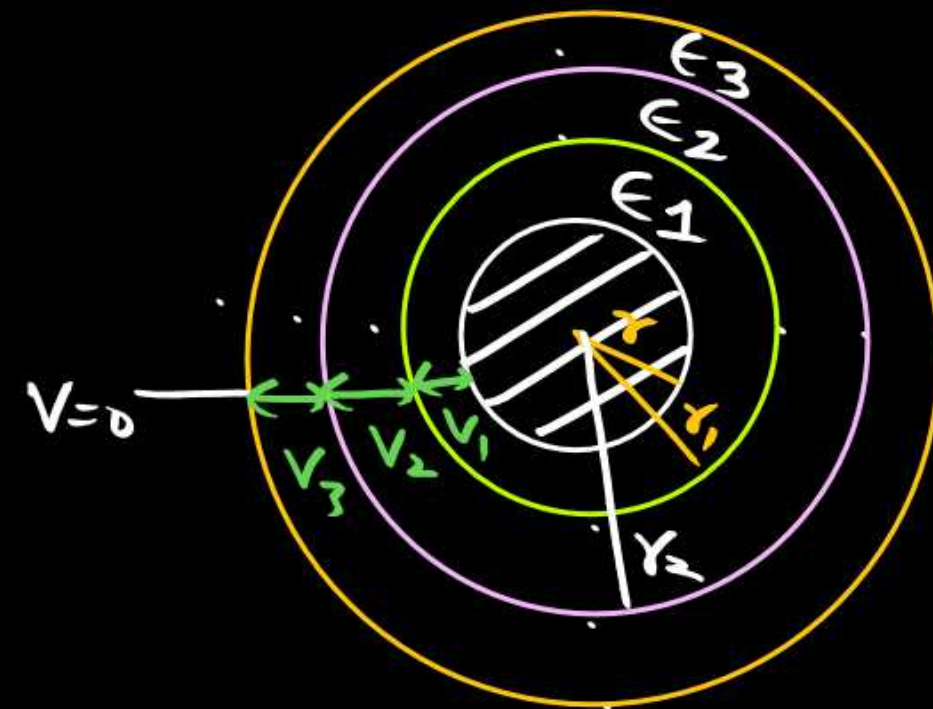


$$g_{\max} = \frac{\cancel{\lambda}}{\cancel{2\pi\epsilon_0}\epsilon_1\cancel{\gamma}} = \frac{\cancel{\lambda}}{\cancel{2\pi\epsilon_0}\epsilon_2\cancel{\gamma_1}} = \frac{\cancel{\lambda}}{\cancel{2\pi\epsilon_0}\epsilon_3\cancel{\gamma_2}}$$

$$\epsilon_1\gamma = \epsilon_2\gamma_1 = \epsilon_3\gamma_2$$

$$\gamma < \gamma_1 < \gamma_2$$

So  $\boxed{\epsilon_1 > \epsilon_2 > \epsilon_3}$

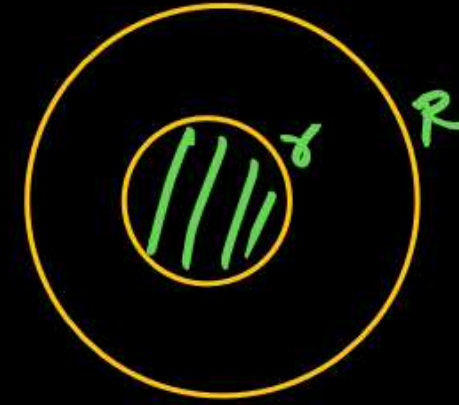




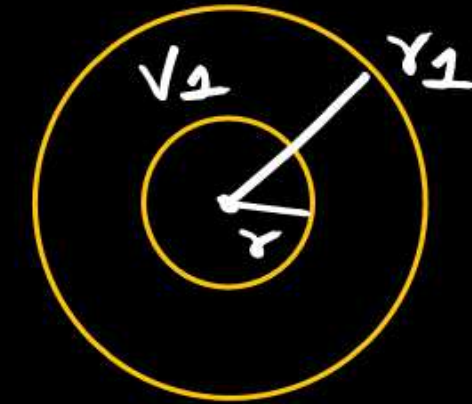
If maximum working stress is  $g_{mx}$  then operating voltage of cable.



$$g_{mx} = \frac{V}{r \ln \left( \frac{R}{r} \right)}$$



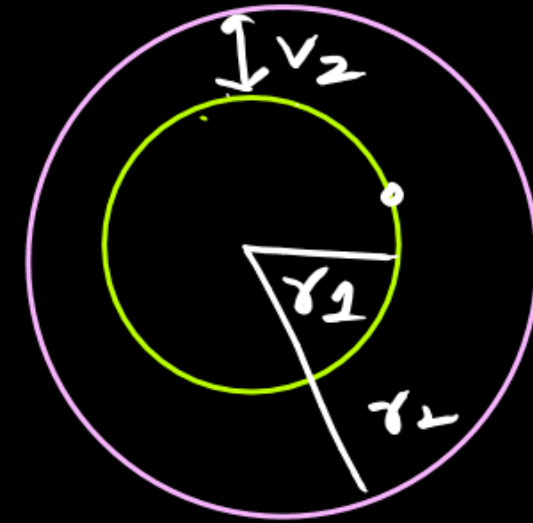
$$g_{mx} = \frac{V_1}{\gamma \ln \frac{\gamma_1}{\gamma}}$$



$$V_1 = g_{mx} \gamma \ln \frac{\gamma_1}{\gamma} \quad \text{--- (1)}$$

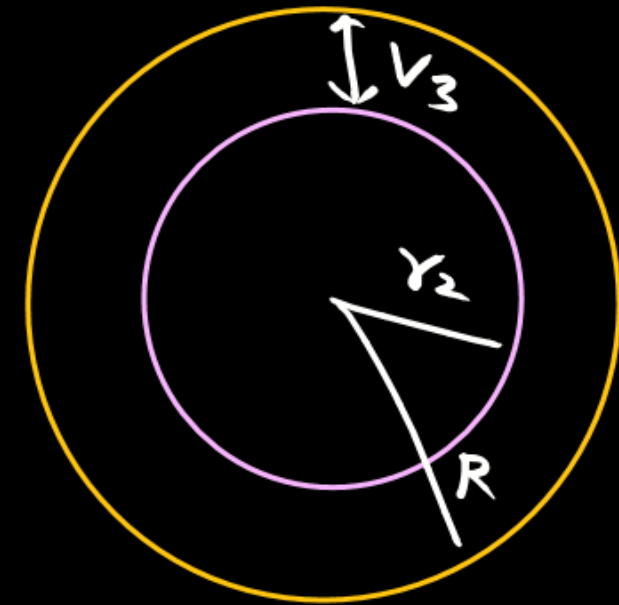
$$\rightarrow g_{mx} = \frac{V_2}{\gamma_1 \ln \frac{\gamma_2}{\gamma_1}}$$

$$V_2 = g_{mx} \gamma_1 \ln \frac{\gamma_2}{\gamma_1} \quad - (2)$$



$$\rightarrow g_{mx} = \frac{V_3}{\gamma_2 \ln \frac{R}{\gamma_2}}$$

$$V_3 = g_{mx} \gamma_2 \ln \frac{R}{\gamma_2}$$



Total voltage of cable  $V = V_1 + V_2 + V_3$

$$V = g_{mx} \gamma \ln \frac{\gamma_1}{\gamma} + g_{mx} \gamma_1 \ln \frac{\gamma_2}{\gamma_1} + g_{mx} \gamma_2 \ln \frac{R}{\gamma_2}$$

$$V = g_{mx} \left[ \gamma \ln \frac{\gamma_1}{\gamma} + \gamma_1 \ln \frac{\gamma_2}{\gamma_1} + \gamma_2 \ln \frac{R}{\gamma_2} \right]$$

**Q.**

A single-core lead sheathed cable is graded by using three dielectrics of relative permittivity 4, 3 and 2, respectively. The conductor diameter is 2 cm, and overall diameter is 8 cm. If the three dielectrics are worked at the same maximum stress of 40 kV/cm, find the safe working voltage of the cable?

What will be the value of safe working voltage for an ungraded cable, assuming the same conductor and overall diameter and the maximum dielectric stress?

$$r = \frac{2}{2} = 1 \text{ cm}$$

$$R = \frac{8}{2} = 4 \text{ cm}$$

$$g_{mx} = \frac{\lambda}{2\pi\epsilon_0\epsilon_1 r} = \frac{\lambda}{2\pi\epsilon_0\epsilon_2 r_1} = \frac{\lambda}{2\pi\epsilon_0\epsilon_3 r_2}$$

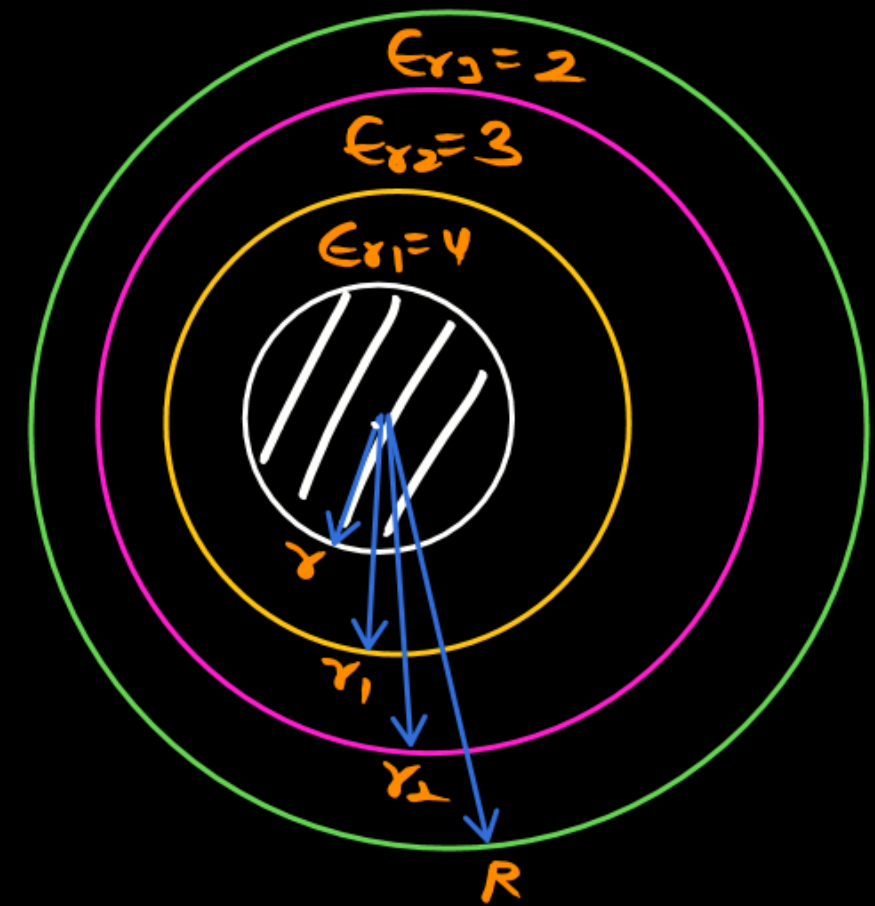
$$\epsilon_1 r = \epsilon_2 r_1 = \epsilon_3 r_2$$

$$4(1) = (3)r_1 = (2)r_2$$

$$r_1 = \frac{4}{3} = 1.33 \quad r_2 = \frac{4}{2} = 2$$

$$V = g_{mx} \left[ r \ln \frac{r_1}{r} + r_1 \ln \frac{r_2}{r_1} + r_2 \ln \frac{R}{r_2} \right]$$

$$V = 40 \left[ 1 \ln \frac{1.33}{1} + 1.33 \ln \frac{2}{1.33} + 2 \ln \frac{4}{2} \right] = \underline{88.56 \text{ kV}}$$



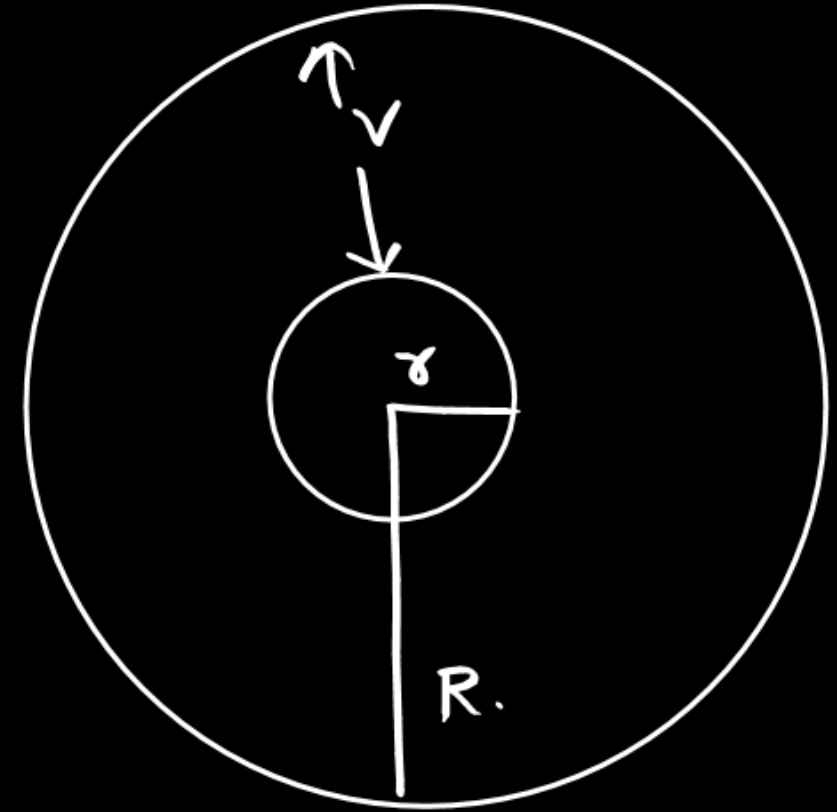
(11)

$$g_{mx} = \frac{V}{\gamma \ln \frac{R}{\gamma}}$$

$$V = g_{mx} \gamma \ln \frac{R}{\gamma}$$

$$V = 40 \times 1 \ln \frac{4}{1}$$

$$V = \underline{55.45 \text{ kV}}$$



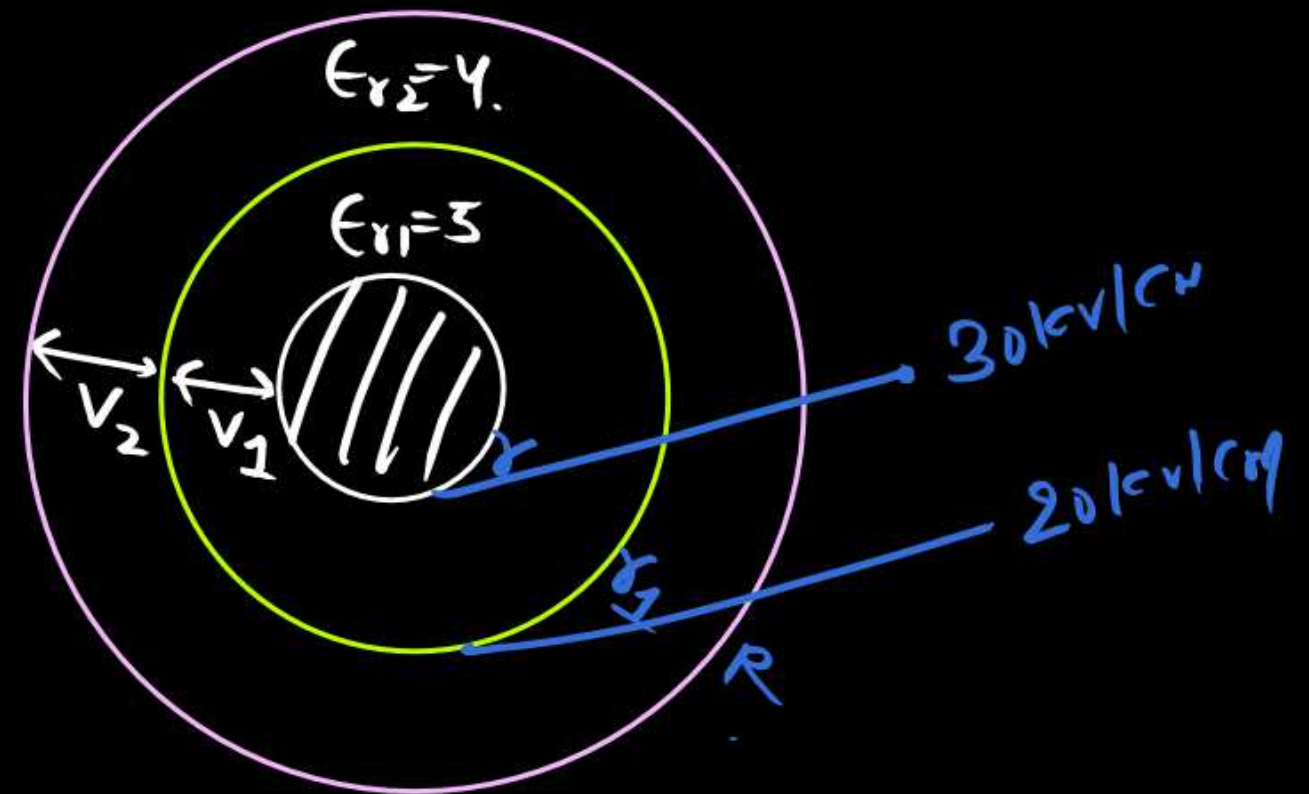
Q.



A single core lead sheathed cable has a conductor diameter of 2 cm; the diameter of the cable being 8 cm. The cable is graded by using two dielectrics of relative permittivity 5 and 4 respectively with corresponding safe working stresses of 30 kV/cm and 20 kV/cm. (Peak)  
Calculate the radial thickness of each insulation and the safe working voltage of the cable ?

$$r = \frac{2}{2} = 1 \text{ cm}$$

$$R = \frac{8}{2} = 4 \text{ cm}$$



$$g_{mx1} = \frac{\lambda}{2\pi\epsilon_0\epsilon_1 r}$$

$$g_{mx2} = \frac{\lambda}{2\pi\epsilon_0\epsilon_2 r_1}$$

$$\frac{g_{mx1}}{g_{mx2}} = \frac{\epsilon_2 r_1}{\epsilon_1 r}$$

$$\frac{3\phi}{2\phi} = \frac{4r_1}{5(1)}$$

$$r_1 = \frac{15}{8} = 1.875.$$

$$g_{mx1} = \frac{V_1}{\gamma \ln \frac{\gamma_1}{\gamma}}$$

$$g_{mx2} = \frac{V_2}{\gamma_1 \ln \frac{R}{\gamma_1}}$$

$$V_1 = g_{mx1} \gamma \ln \frac{\gamma_1}{\gamma}$$

$$V_2 = g_{mx2} \gamma_1 \ln \frac{R}{\gamma_1}$$

$$\text{Total Voltage (Peak)} = g_{mx1} \gamma \ln \frac{\gamma_1}{\gamma} + g_{mx2} \gamma_1 \ln \frac{R}{\gamma_1}$$

$$= 30 \times 1 \ln \frac{1.875}{1} + 20 \times 1.875 \ln \frac{4}{1.875}$$

$$= 18.85 + 28.41$$

$$= 47.26 \text{ kv(Peak)} = \frac{47.26}{\sqrt{2}} = 33.41 \text{ (RMS)}$$

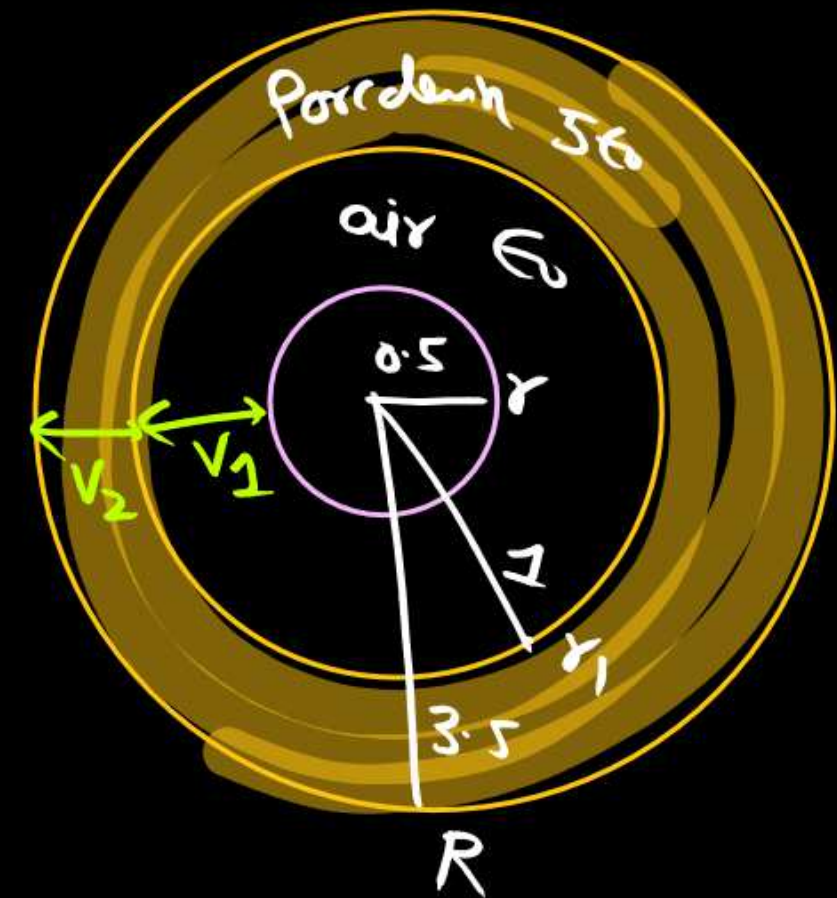
Q.

A conductor of 1 cm diameter pass centrally through a porcelain cylinder of internal diameter of 2cm & outer diameter of 7 cm. The cylinder is surround by metal sheath. The permittivity of porcelain is 5 and peak voltage gradient in air should not exceed 34 kV/cm. Determine Max safe working voltage.

$$r = \frac{1}{2} = 0.5 \text{ cm}$$

$$\epsilon_1 = 1$$

$$R = 3.5 \text{ cm}$$



For Air  $g_{mx1} = \frac{\lambda}{2\pi\epsilon_0\gamma}$

For Porcelain  $g_{mx2} = \frac{\lambda}{2\pi\epsilon_0(5)\gamma_1}$

$$\frac{g_{mx1}}{g_{mx2}} = \frac{5\gamma_1}{\gamma}$$

$$\frac{34}{g_{mx2}} = \frac{5 \times 1}{0.5}$$

$$g_{mx} = 3.4 \text{ KV/cm}$$

$$V = V_1 + V_2$$

$$V = g_{mx1} \gamma \ln \frac{\gamma_1}{\gamma} + g_{mx2} \gamma_1 \ln \frac{R}{\gamma_1}$$

$$V = 34(0.5) \ln \frac{1}{0.5} + 3.4 \times 1 \ln \frac{3.5}{1}$$

$$V = 16.04 \text{ (Peak)}$$

$$V = \frac{16.04}{\sqrt{2}} = 11.34 \text{ (RMS)}$$

## Inter Sheath Grading

- Here we use a single dielectric Material, but no. of sheath will be more.
- By using auxiliary transformer, to maintain the potential of sheath at a particular value. So, the value of Maximum stress of the surface of each sheath is remain same.



$$g_{mx} = \frac{V - V_2}{\gamma \ln \frac{r_1}{\gamma}} = \frac{V_2 - V_1}{\gamma_1 \ln \frac{r_2}{\gamma_1}} = \frac{V_1}{\gamma_2 \ln \frac{R}{\gamma_2}} \quad - (1)$$

$$\text{Let } \frac{\gamma_1}{\gamma} = \frac{\gamma_2}{\gamma_1} = \frac{R}{\gamma_2} = \alpha \quad \rightarrow \quad \begin{aligned} \gamma_2 &= \gamma_1 \alpha \\ \gamma_1 &= (\gamma \alpha) \alpha = \alpha^2 \gamma \end{aligned}$$

$$\frac{V - V_2}{\gamma \ln \alpha} = \frac{V_2 - V_1}{\gamma_1 \ln \alpha} = \frac{V_1}{\gamma_2 \ln \alpha}$$

$$\rightarrow \frac{V_2 - V_1}{V_1} = \frac{\gamma_1}{\gamma_2} = \frac{1}{\alpha}$$

$$\frac{V_2}{V_1} - 1 = \frac{1}{\alpha}$$

$$\frac{V_2}{V_1} = 1 + \frac{1}{\alpha}$$

$$\frac{V_2}{V_1} = \frac{\alpha + 1}{\alpha}$$

$$V_2 = \frac{\alpha + 1}{\alpha} \cdot V_1$$

$$\frac{V_2 - V_1}{V - V_2} = \frac{V_1}{V} = \alpha$$

$$\frac{\frac{\alpha + 1}{\alpha} V_1 - V_1}{V - \left(\frac{\alpha + 1}{\alpha}\right) V_1} = \alpha$$

$$\frac{V_1}{\alpha} = V\alpha - (\alpha + 1)V_1$$

$$V_1 \left[ \frac{1}{\alpha} + (\alpha + 1) \right] = V\alpha$$

$$V_1 \left[ \frac{\alpha^2 + \alpha + 1}{\alpha} \right] = V\alpha$$

$$V_1 = \frac{\alpha^2}{\alpha^2 + \alpha + 1} \cdot V$$

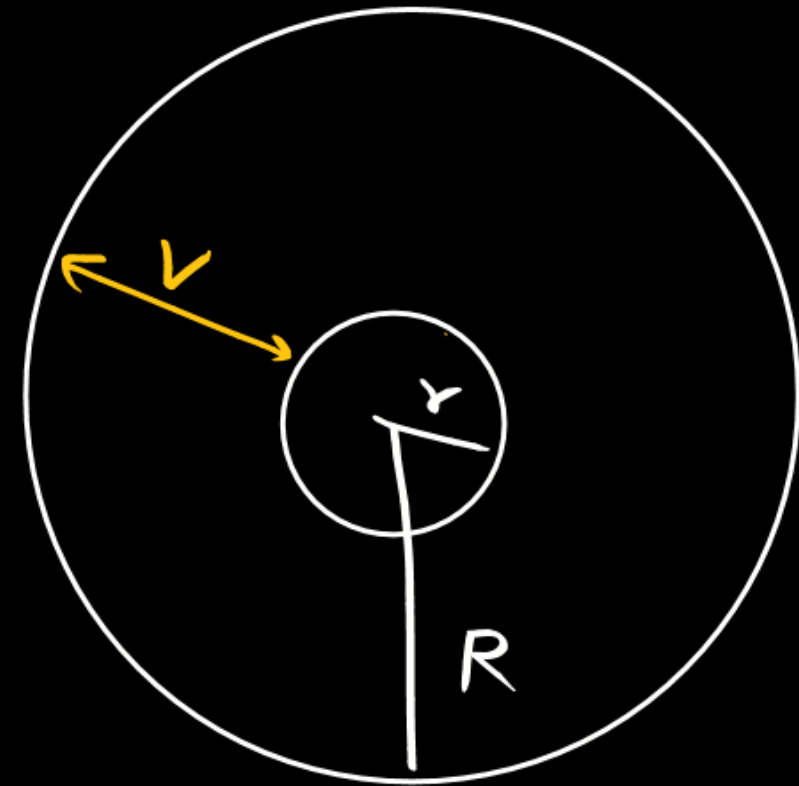
From eq<sup>n</sup> (1) 
$$g_{mx} = \frac{V_1}{\gamma_2 \ln \frac{R}{\gamma_2}} = \frac{\frac{\cancel{\alpha^2}}{\alpha^2 + \alpha + 1} \cdot V}{\cancel{\alpha^2} \gamma \ln \alpha}$$

$$g_{mx} = \frac{V}{\gamma (\alpha^2 + \alpha + 1) \ln \alpha}$$

(with)

→ if intersheath grading were not used

$$g_{mx} = \frac{V}{\gamma \ln \frac{R}{\gamma}}$$



$$\frac{R}{\gamma} = \frac{R}{\gamma_2} \cdot \frac{\gamma_2}{\gamma_1} \cdot \frac{\gamma_1}{\gamma} = \alpha \cdot \alpha \cdot \alpha = \alpha^3 \quad (\alpha > 1)$$

$$g_{mx} = \frac{V}{\gamma \ln \alpha^3}$$

(without)

$$\frac{g_{mx}(\text{with})}{g_{mx}(\text{without})} = \frac{\cancel{\gamma}}{\cancel{\gamma}(\alpha^2 + \alpha + 1) \ln \alpha} \times \frac{\cancel{\gamma} \ln \alpha^3}{\cancel{\gamma}} = \frac{\ln \alpha^3}{(\alpha^2 + \alpha + 1) \ln \alpha}$$

$$= \frac{3 \cancel{\ln \alpha}}{\cancel{\ln \alpha} (\alpha^2 + \alpha + 1)} = \frac{3}{\alpha^2 + \alpha + 1} < 1$$

$$g_{mx}(\text{with}) < g_{mx}(\text{without})$$

So, we can say by using multiple inter sheath the electrical stressed is  reduced.

So, voltage of cable with the Inter sheath is

$$V = (V - V_2) + (V_2 - V_1) + (V_1 - 0)$$

$$= g_{mx} \gamma \ln \frac{r_1}{\gamma} + g_{mx} \gamma_1 \ln \frac{r_2}{r_1} + g_{mx} \gamma_2 \ln \frac{R}{r_2}$$

$$= g_{mx} \left[ \gamma \ln \alpha + \gamma_1 \ln \alpha + \gamma_2 \ln \alpha \right]$$

$$V = g_{mx} \ln \alpha [\gamma + \gamma_1 + \gamma_2]$$

➤ Grading theory is mostly theoretical method of does not have practical approach.



## 2 Minutes Summary

- Capacitance grading
- Intersheath grading

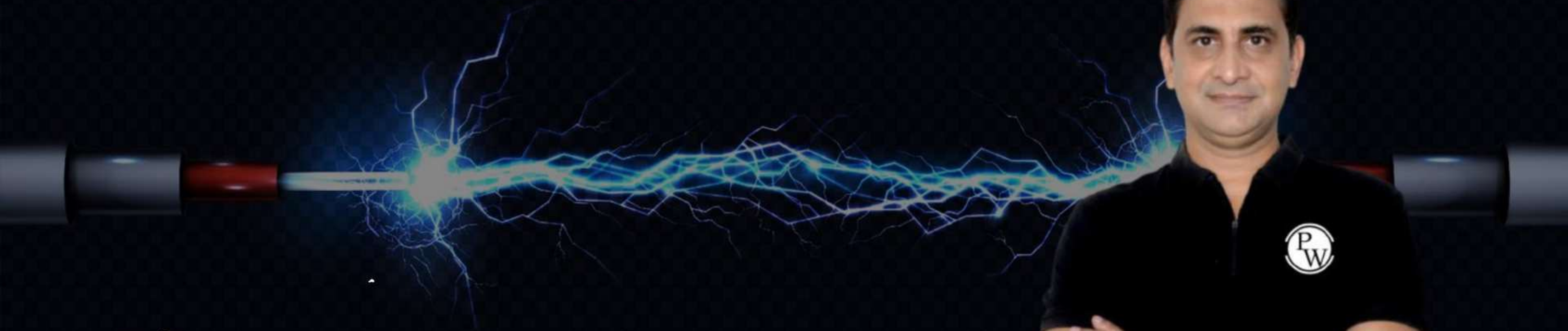
**Thank you**

**GW**  
*Soldiers !*



# Electrical Engineering

## Power System



Lecture No.-3  
Underground Cables

**By- Ajay Gupta Sir**



# Recap Of previous class

✓ 1. Grading of Cable

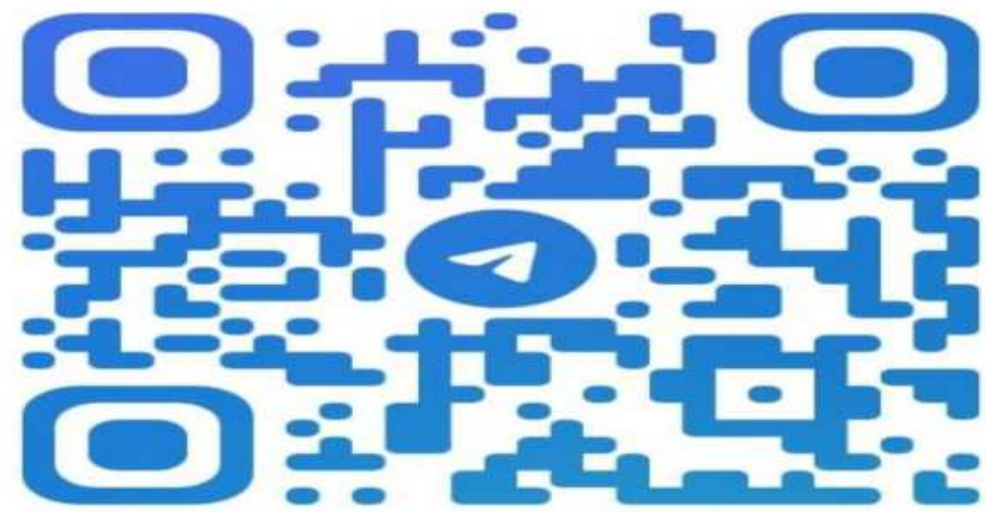
✓ 2. Capacitance grading

✓ 3. Inter-sheath Grading



# Topics to be Covered

- ✓ 1. Capacitance of 1 phase cable
- ✓ 2. Capacitance of 3 phase cable
- ✓ 3. Measurement of capacitance
- ✓ 4. Losses in cable



@AJAYGUPTASIRPW

Q.



A single core cable of conductor diameter 2 cm and lead sheath of diameter 5.0 cm is to be used on a 66 kV, 3-phase system. Two inter-sheaths of diameter 3.0 cm and 4.0 cm are introduced between the core and lead sheath. If the maximum stress in the layers is the same, find the voltages on the inter-sheaths

$$r = \frac{2}{2} = 1 \text{ cm}$$

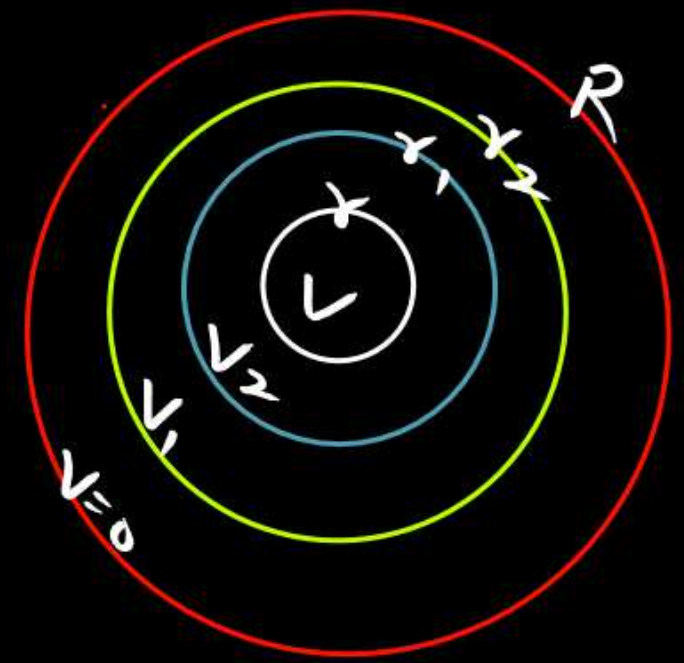
$$r_1 = \frac{3}{2} = 1.5$$

$$R = \frac{5}{2} = 2.5 \text{ cm}$$

$$r_2 = \frac{4}{2} = 2 \text{ cm}$$

$$g_{mx} = \text{same}$$

$$V = \frac{66}{\sqrt{3}} = 38.105$$



- A 37.02 kv, 18.88 Kv
- B 39.23 Kv, 20.23 kv
- C 45 Kv, 23.20 Kv
- D ✓ None

$$g_{mx} = \frac{V - V_2}{\gamma \ln \frac{\gamma_1}{\gamma}} = \frac{V_2 - V_1}{\gamma_1 \ln \frac{\gamma_2}{\gamma_1}} = \frac{V_1 - 0}{\gamma_2 \ln \frac{R}{\gamma_2}}$$

$$\frac{V - V_2}{1 \ln \frac{1.5}{1}} = \frac{V_2 - V_1}{1.5 \ln \frac{2}{1.5}} = \frac{V_1}{2 \ln \frac{2.5}{2}}$$

$$\frac{V - V_2}{0.4054} = \frac{V_2 - V_1}{0.4315} = \frac{V_1}{0.4462}$$

$$\frac{V_2 - V_1}{V_1} = \frac{0.4315}{0.4462}$$

$$\frac{V_2}{V_1} - 1 = 0.967$$

$$V_2 = 1.967 V_1$$

$$V_2 = 1.967 \times 13.249$$

$$V_2 = \underline{26.06}$$

$$\frac{V - V_2}{V_2 - V_1} = \frac{0.4054}{0.4315}$$

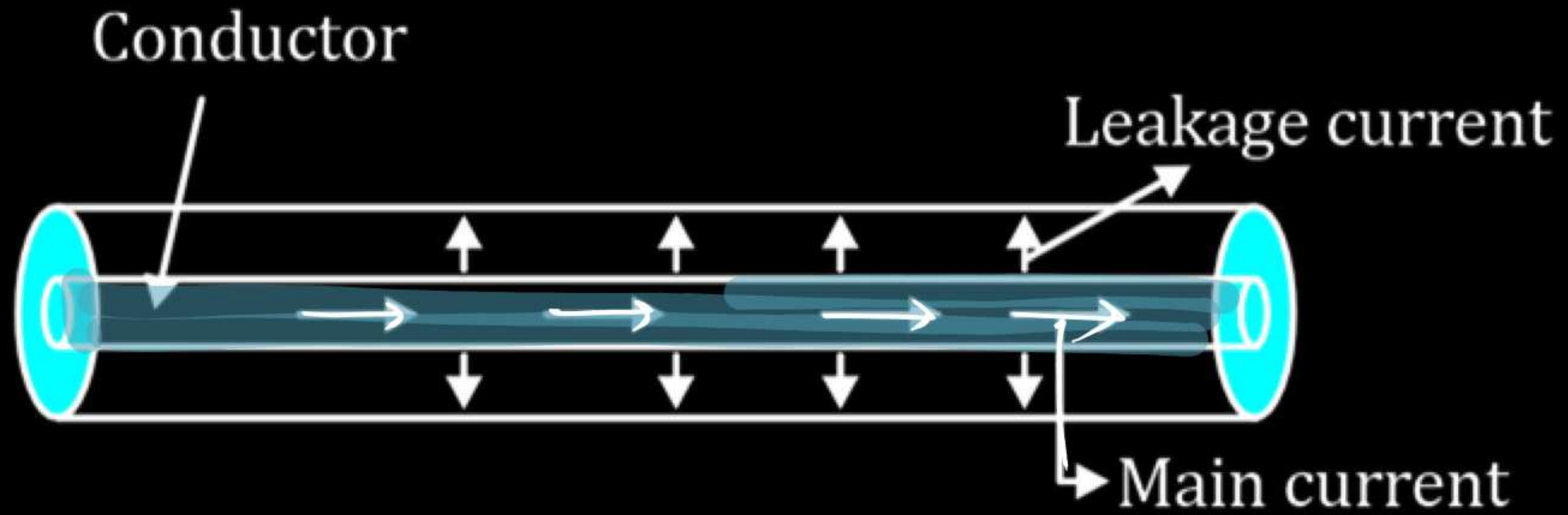
$$\frac{V - 1.967 V_1}{1.967 V_1 - V_1} = 0.94$$

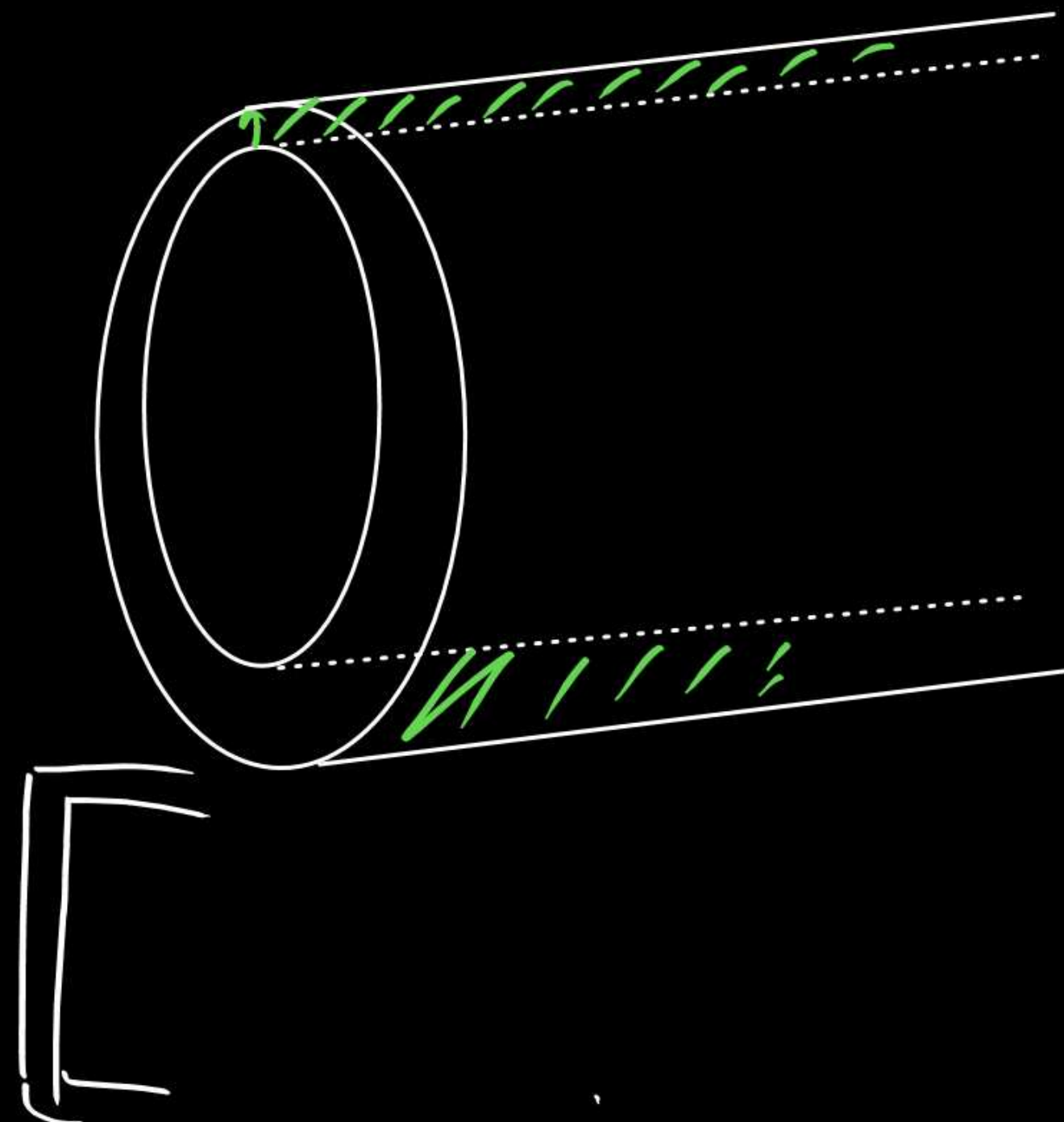
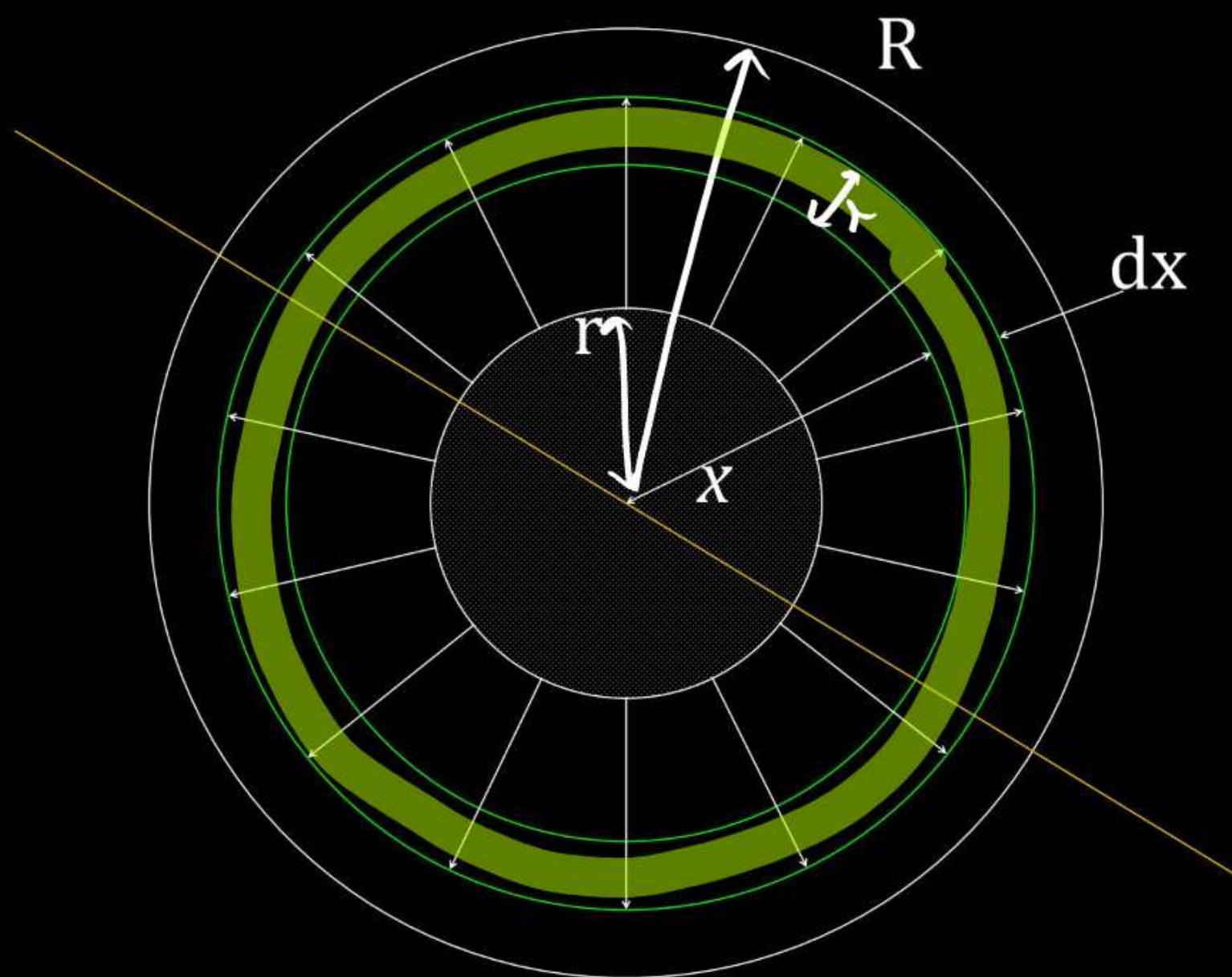
$$V - 1.967 V_1 = 0.967 V_1 \times 0.94$$

$$2.876 V_1 = V$$

$$V_1 = \frac{38.105}{2.876} = \underline{13.249}$$

# Insulation resistance of a Cable





Suppose we take a differential elements  $dx$  at a  $x$  distance away from center. 

The resistance of differential element is

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

$$R_{ins} = \int_r^R \frac{\rho dx}{2\pi x l}$$

$$R_{ins} = \frac{\rho}{2\pi l} \int_r^R \frac{dx}{x}$$

$$R_{ins} = \frac{\rho}{2\pi l} [\ln x]_r^R$$

$$R_{ins} = \frac{\rho}{2\pi l} [\ln R - \ln r]$$

$$R_{ins} = \frac{\rho}{2\pi l} \ln \frac{R}{r}$$

$$R_{ins} \propto \frac{1}{l}$$

Q.



The Insulation Resistance of the cable of length 10 km is 1 MΩ. For a length of 100 km. The Insulation Resistance will be

$$R_{ins} \propto \frac{1}{l}$$

$$\frac{R_{ins1}}{R_{ins2}} = \frac{l_2}{l_1}$$

$$\frac{1}{R_{ins2}} = \frac{100}{10}$$

$$R_{ins} = \frac{1}{10} = \underline{0.1}$$

- A 1 MΩ
- B 10 MΩ
- C 0.1 MΩ
- D 0.01 MΩ

Q.



The insulation resistance of a single-core cable is 495 MΩ per km. If the core diameter is 2.5 cm and resistivity of insulation is  $4.5 \times 10^{14} \Omega\text{-cm}$ , find the insulation thickness

$$r = \frac{2.5}{2} = 1.25 \text{ cm}$$

$$l = 1 \text{ km} = 1000 \times 100$$

$$R_{ins} = 495 \text{ M}\Omega$$

$$R_{ins} = \frac{\rho}{2\pi l} \ln\left(\frac{R}{r}\right)$$

$$495 \times 10^6 = \frac{4.5 \times 10^{14}}{2\pi \times 10^5} \ln\left(\frac{R}{r}\right)$$

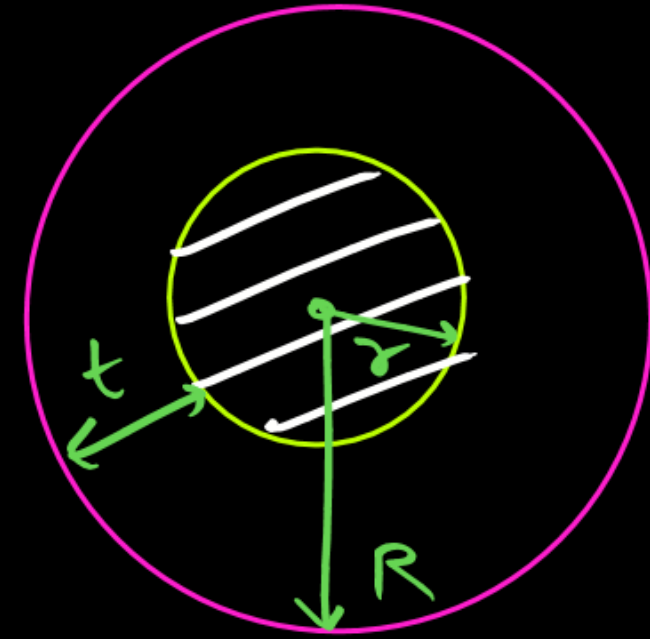
- A** ☒ 1.25 cm
- B** ☐ 2.05 Cm
- C** ☐ 2.15 Cm
- D** ☐ None

$$\ln\left(\frac{R}{r}\right) = \frac{495 \times 2\pi}{4.5 \times 10^3} = 0.691$$

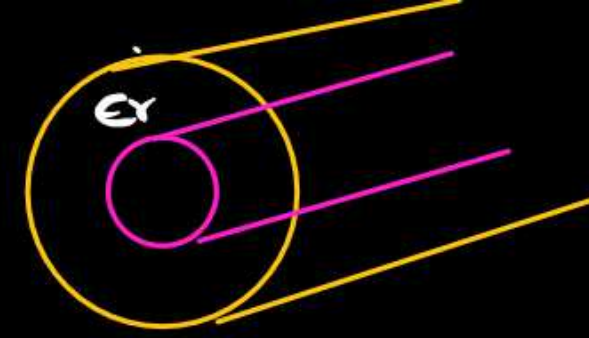
$$\frac{R}{r} = 1.996$$

$$R = 2.495$$

$$\begin{aligned} t = R - r &= 2.495 - 1.25 \\ &= 1.25 \text{ cm} \end{aligned}$$



## Capacitance of Cable:



### 1. Capacitance of a single core cable.

- A single-core cable can be considered to be equivalent to two long co-axial cylinders.
- The conductor (or core) of the cable is the inner cylinder while the outer cylinder is represented by lead sheath which is at earth potential.
- Consider a single core cable with conductor radius  $r$  and inner sheath radius  $R$ .
- Let the charge per meter axial length of the cable be  $q$  coulombs and  $\epsilon$  be the permittivity of the insulation material between core and lead sheath.

$$E = \frac{q}{2\pi\epsilon_0\epsilon_r x}$$

$$V = - \int_R^r E dx$$

$$V = - \int_R^r \frac{q}{2\pi\epsilon_0\epsilon_r x} dx$$

$$V = \frac{q}{2\pi\epsilon_0\epsilon_r} \left[ -\ln x \right]_R^r$$

$$V = \frac{q}{2\pi\epsilon_0\epsilon_r} [\ln R - \ln r]$$

$$V = \frac{q}{2\pi\epsilon_0\epsilon_r} \ln \frac{R}{r}$$

$$C = \frac{q}{V}$$

$$C = \frac{q}{V} = \frac{2\pi\epsilon_0\epsilon_r}{\ln(R/r)}$$

F/m

The capacitance of cable is higher than that of OH line.

1. The permittivity of Insulation is higher than permittivity of air.
2. The Distance between conductor and sheath is less.

$$C_{\text{cable}} = \frac{2\pi\epsilon_0 \epsilon_r}{\ln(R/r)}$$

$$C_{\text{OH}} = \frac{2\pi\epsilon_0}{\ln(D/r)} \text{ F/m}$$

$$C_{\text{cable}} > C_{\text{OH}}$$

$$I_{Ph} = \frac{V_{Ph}}{X_c} = j\omega C V_{Ph}$$

$$VAR = V_{Ph} I_{Ph} = j\omega C V_{Ph}^2$$

$$\text{For 3 phase} = 3 V_{Ph} I_{Ph}$$

Q.

A 33 kV, 50 Hz, 3-phase underground cable, 4 km long uses three single core cables. Each of the conductor has a radius of 2.5 cm and the radial thickness of insulation is 0.5 cm. Determine ?

(i) capacitance of the cable/phase

(ii) charging current/phase

(iii) total charging KVAR. ✓

The relative permittivity of insulation is 3

$$r = 2.5 \text{ cm}$$

$$R = 2.5 + 0.5 = 3 \text{ cm}$$

$$C = \frac{2\pi \epsilon_0 \epsilon_r}{\ln(R/r)} = \frac{2\pi \times 8.854 \times 10^{-12} \times 3}{\ln\left(\frac{3}{2.5}\right)} \text{ F/m}$$

$$= 9.153 \times 10^{-10} \text{ F/m}$$

$$= 9.153 \times 10^{-10} \times 4 \times 10^3 = 36.61 \times 10^{-7} \text{ F}$$



$$\begin{aligned} \text{(iv)} \quad I_{ph} &= j\omega C V_{ph} \\ &= 2\pi(50) \times (36.61 \times 10^{-7}) \left( \frac{33000}{\sqrt{3}} \right) \\ &= 21.91 \end{aligned}$$

$$\begin{aligned} \text{(iii)} \quad VAR &= 3V_{ph} I_{ph} \\ &= 3 \times \frac{33000}{\sqrt{3}} \times 21.91 \\ &= 1252.32 \end{aligned}$$

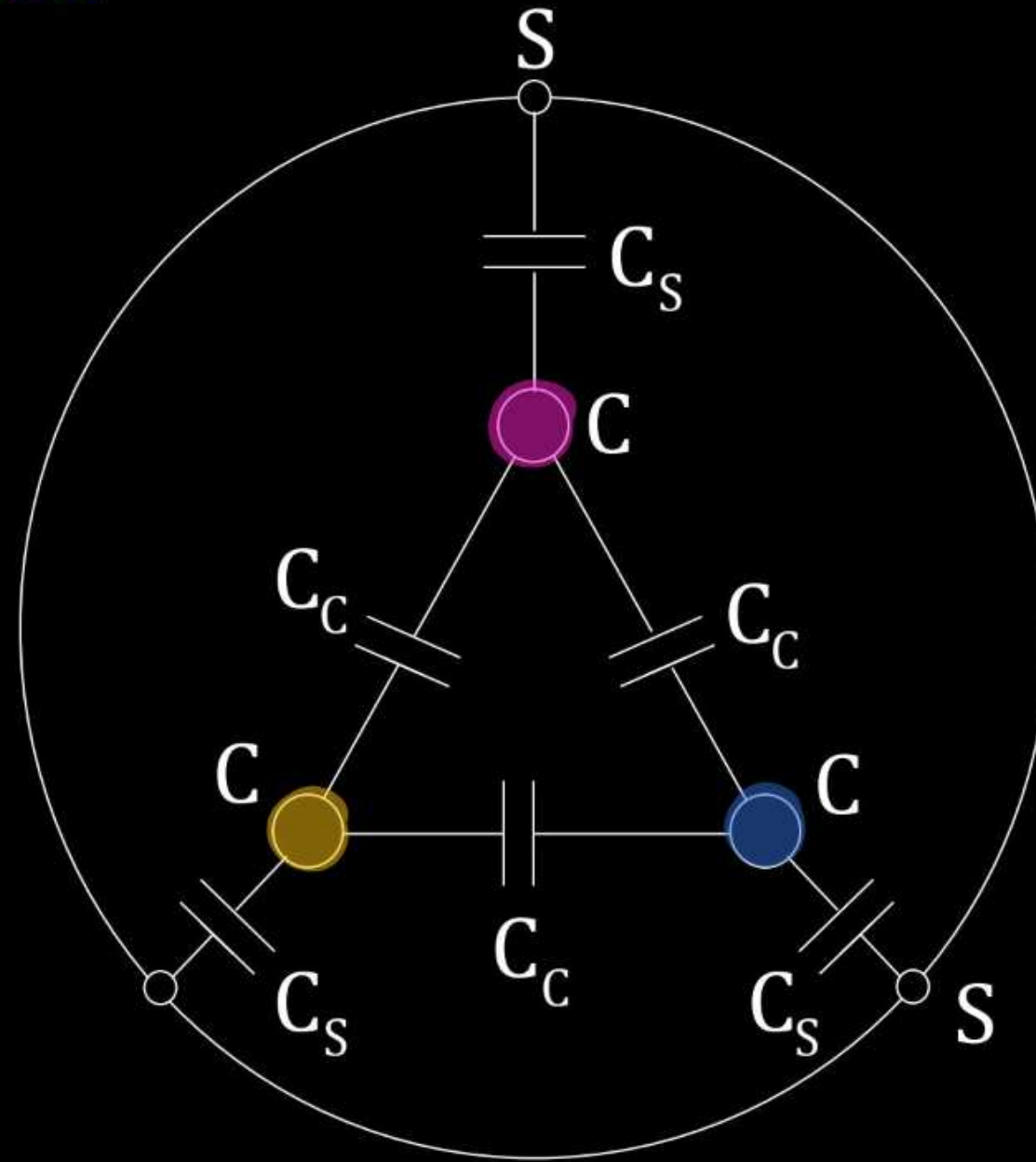
Q.

A single core cable has a conductor diameter of 1 cm and internal sheath diameter of 1.8 cm. If impregnated paper of relative permittivity 2 is used as the insulation, calculate the capacitance for 1 km length of the cable?



# Capacitance of Cable

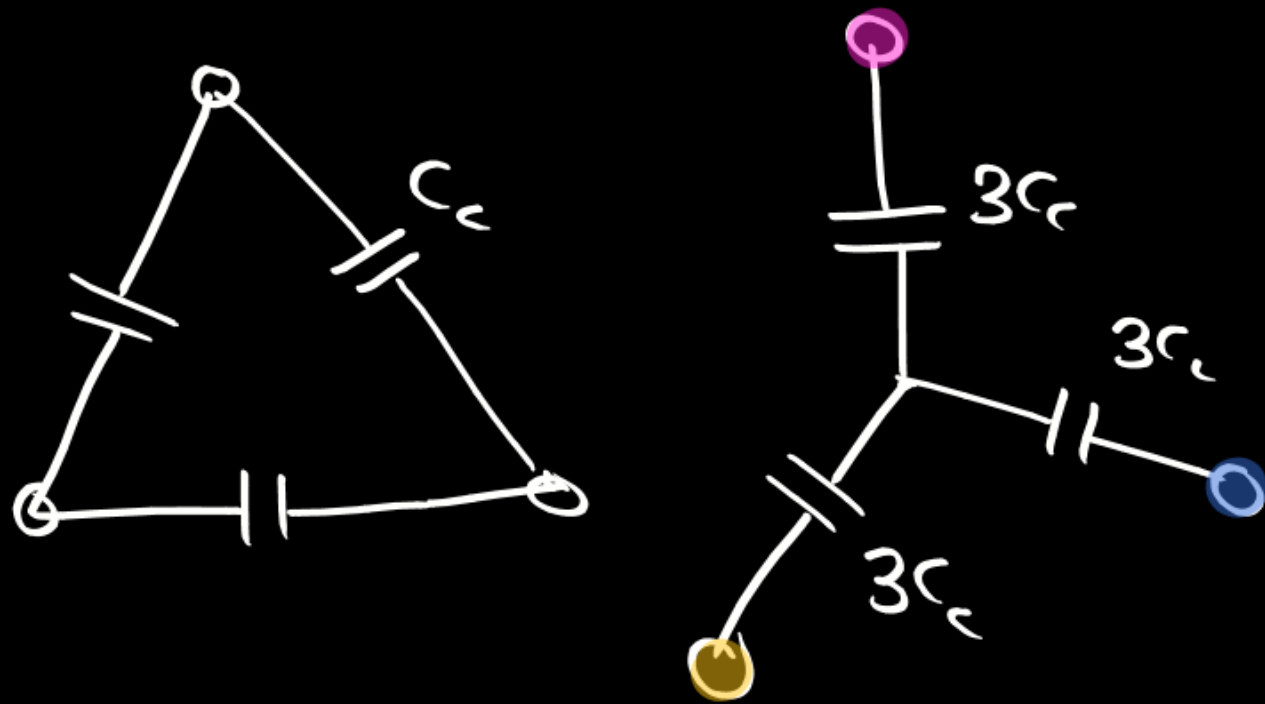
## Capacitance 3 core Cable:



In 3 core cable overall 6 capacitance is formed

$C_s$  = Capacitance between conductor & sheath

$C_c$  = Capacitance between the conductors.

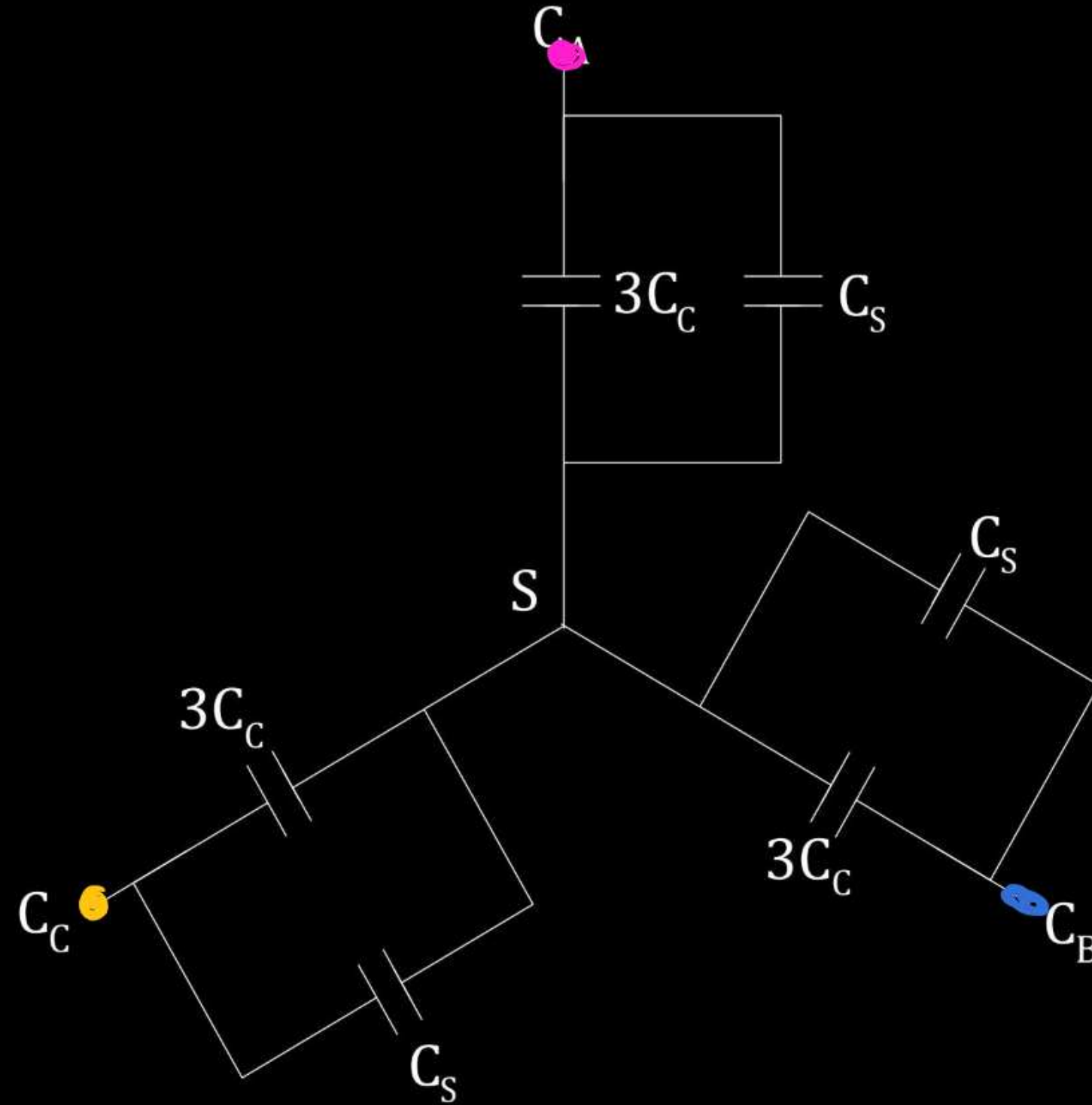


$$Z_Y = \frac{Z_\Delta}{3}$$

$$\frac{1}{j\omega C_Y} = \frac{1}{j\omega C_\Delta 3}$$

$$C_Y = 3C_\Delta$$

Now Total Capacitance



So per phase capacitance,

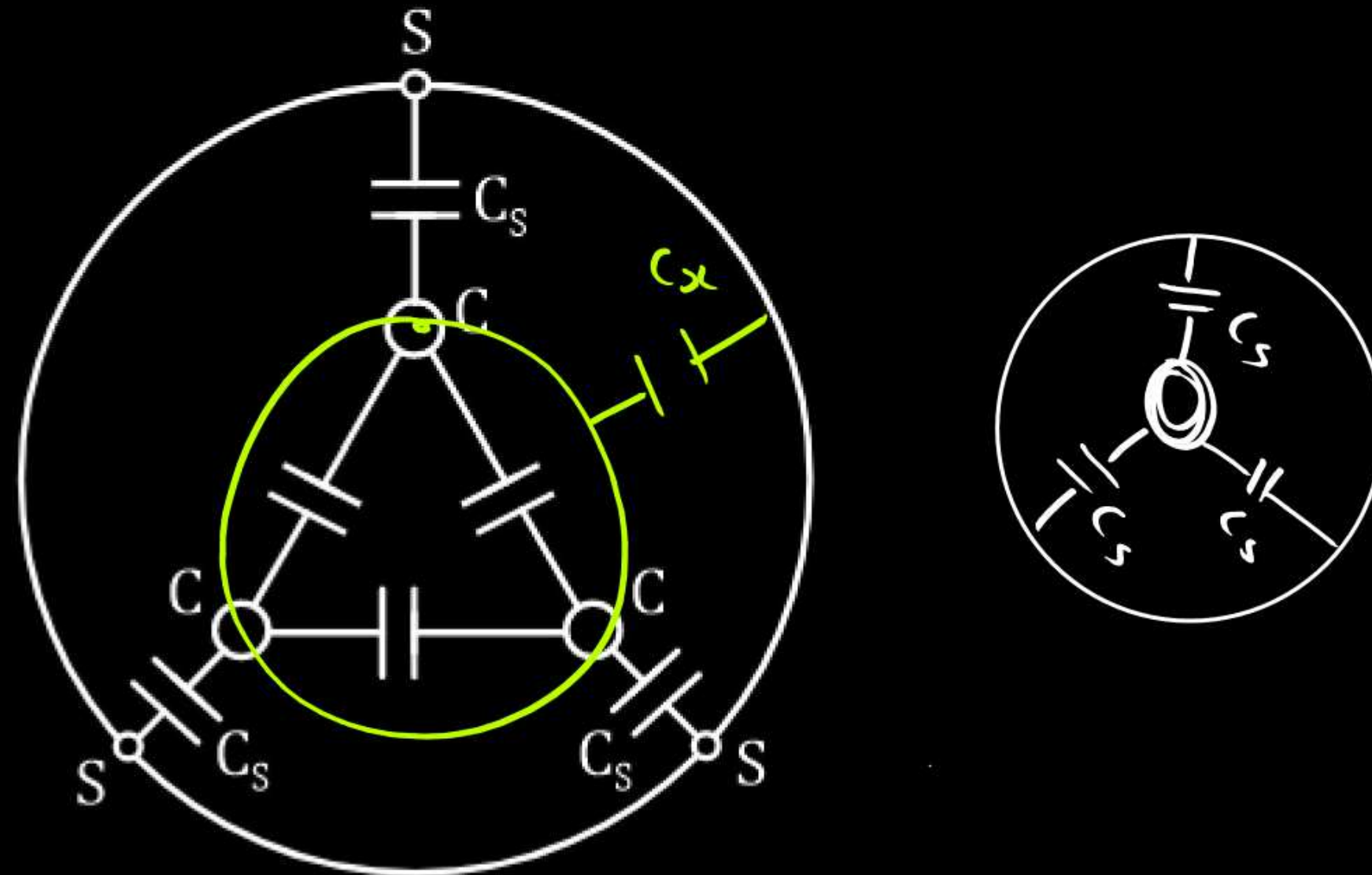
$$C_{ph} = C_s + 3C_c$$

The charging current per phase,

$$I_c = j\omega C_{ph} V_{ph}$$

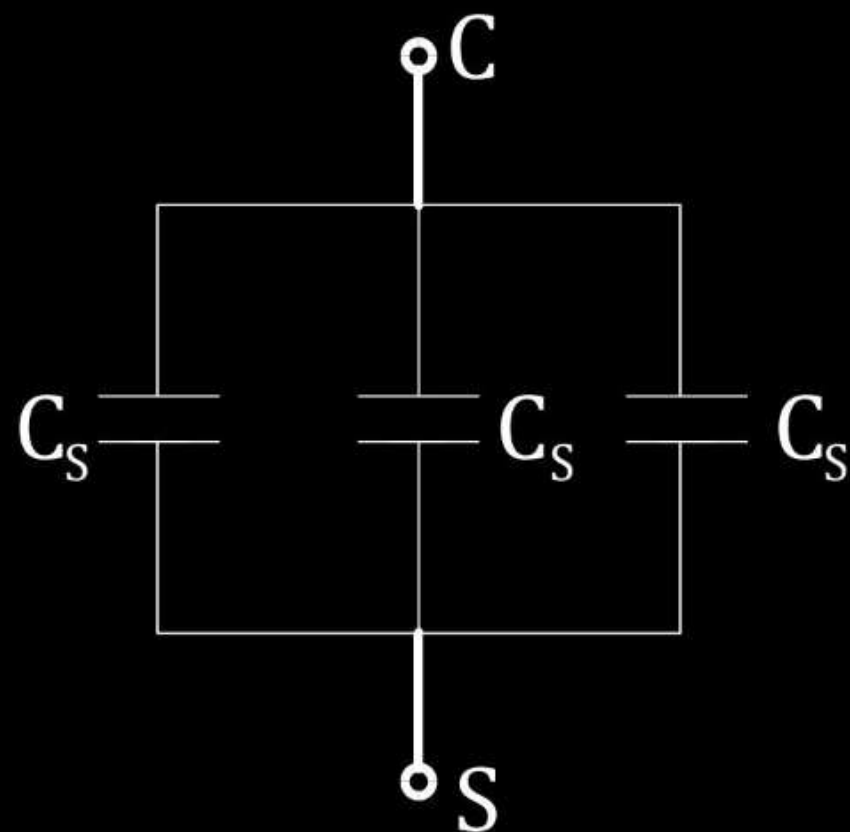
# The Measurement of $C_{ph}$

**Step 1:** Bunch all 3 conductors (core) & Measure the capacitance between bunched conductor & sheath. Suppose it is  $C_x$

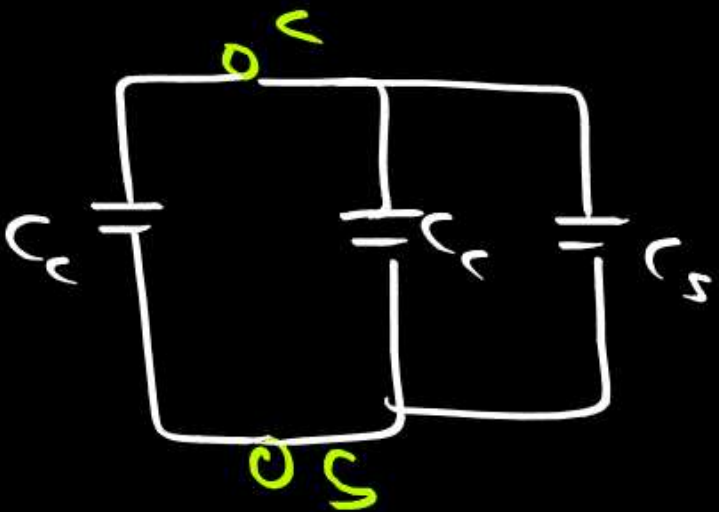
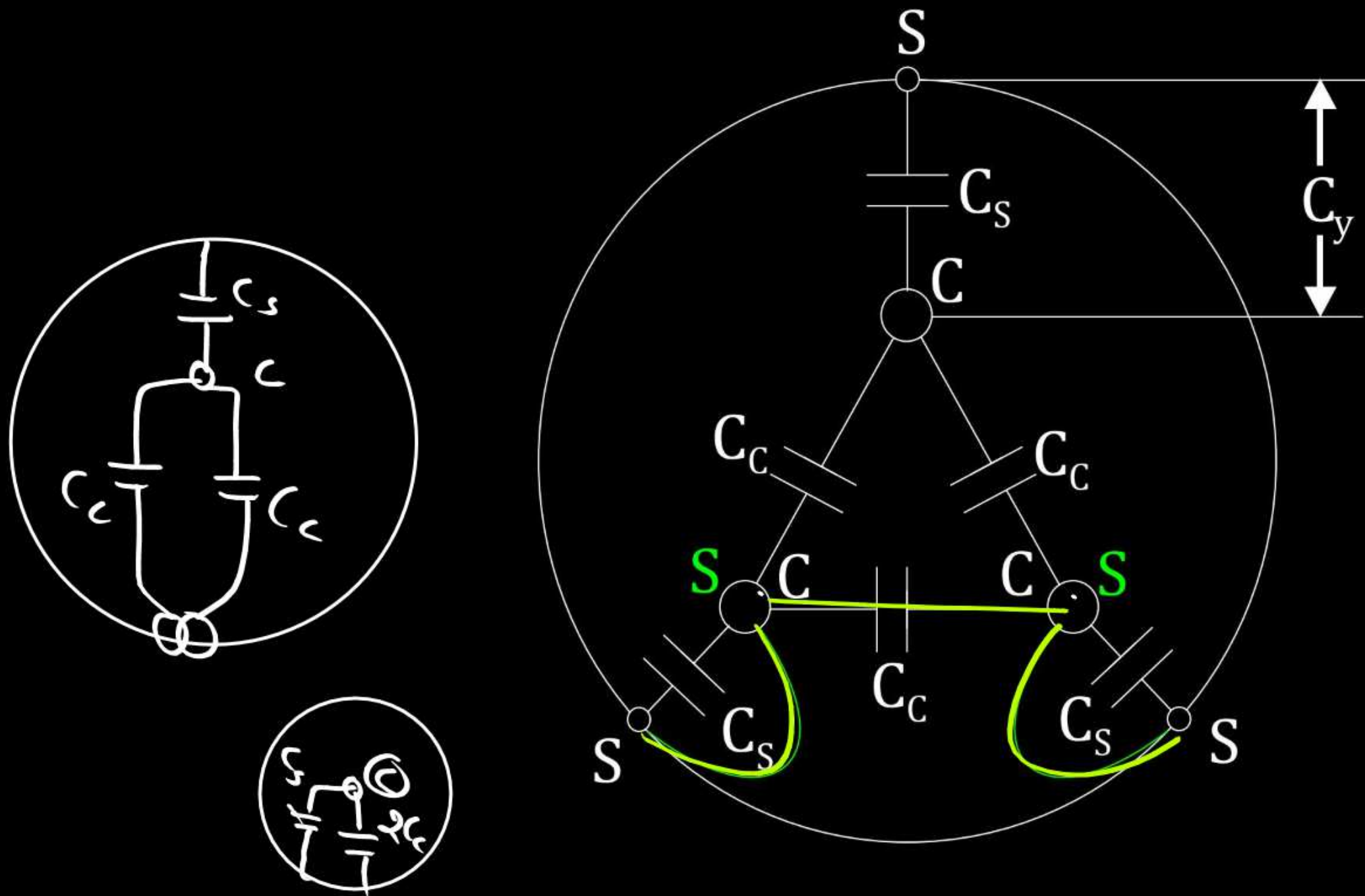


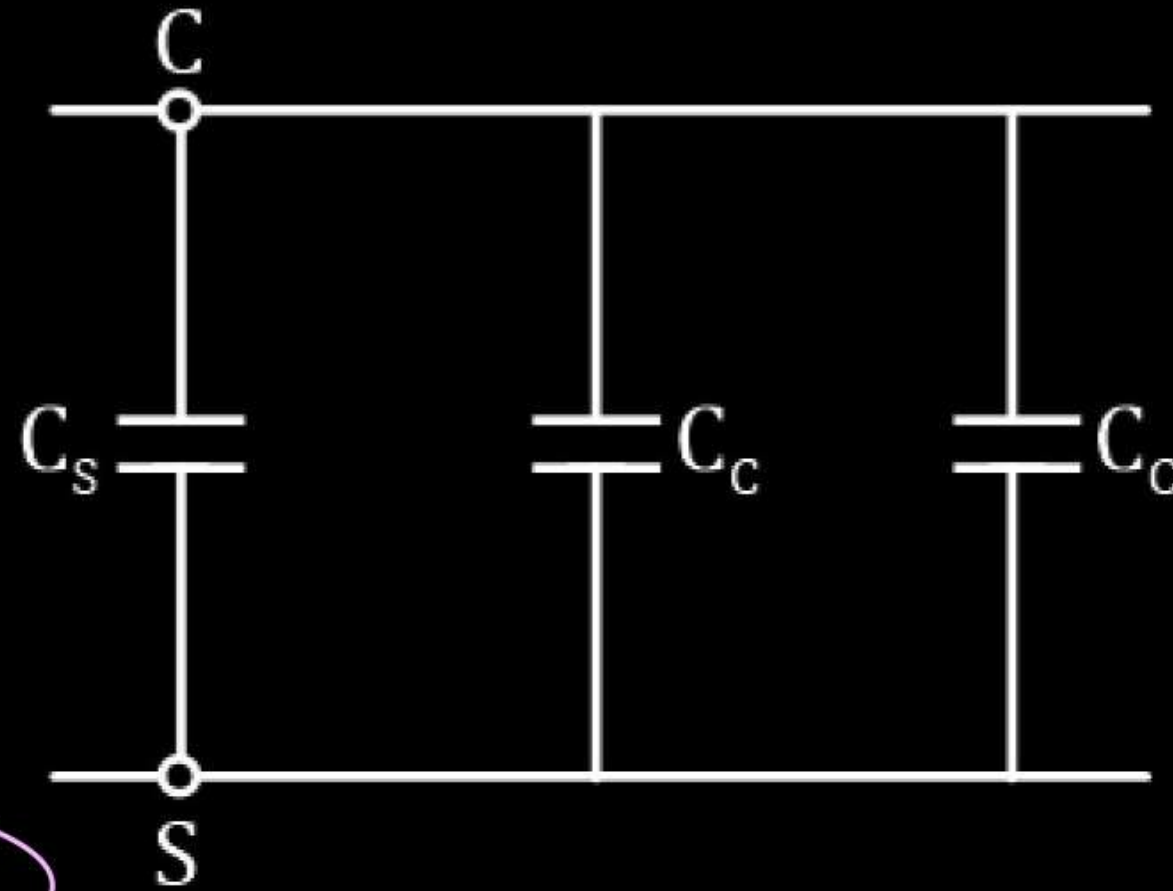
$$C_x = 3C_s$$

$$C_s = \frac{C_x}{3}$$



**Step 2:** Connect any two conductor to sheath & Measure Capacitance between remaining conductor & sheath. Suppose it is  $C_y$ .





$$C_Y = C_s + 2C_c \leftarrow$$

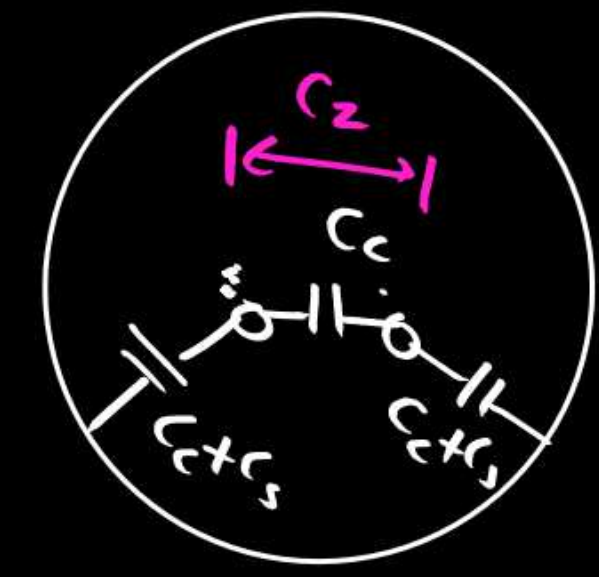
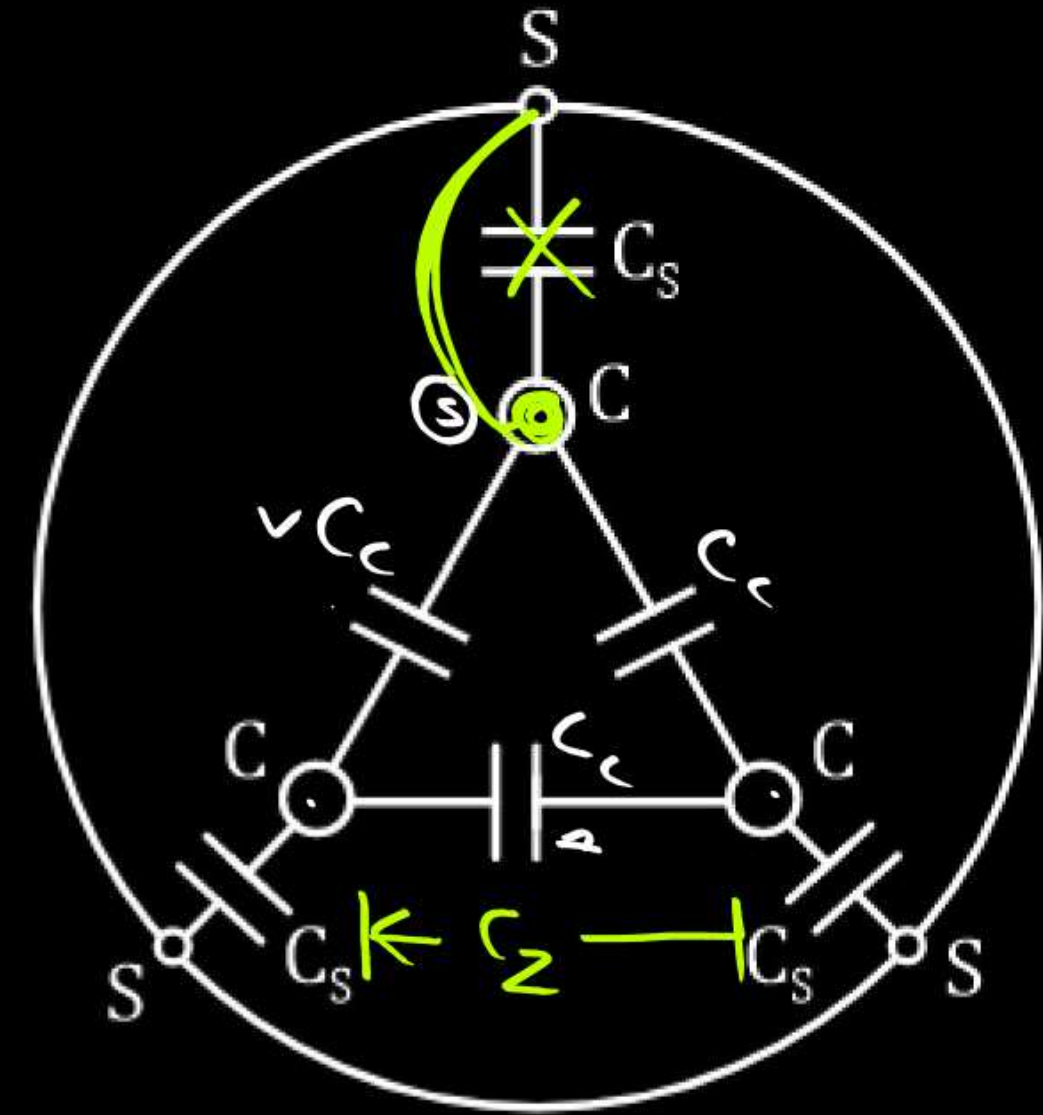
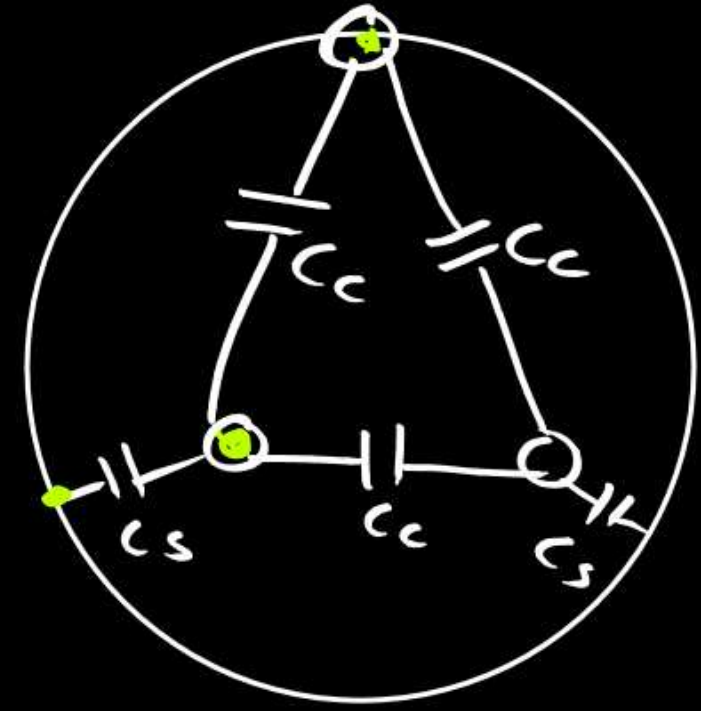
$$C_Y = \frac{C_X}{3} + 2C_c$$

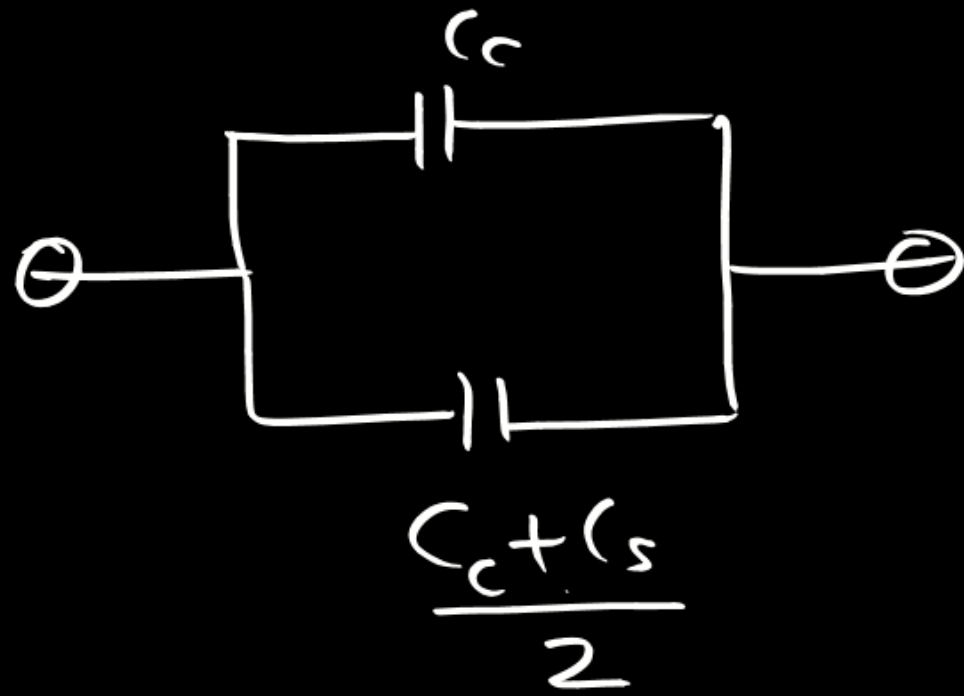
$$C_c = \frac{C_Y - \frac{C_X}{3}}{2}$$

$$C_{Pn} = 3C_c + C_s$$

## The Measurement of $C_{ph}$

- It may be noted here that if value of  $C_{ph}$  ( $= C_s + 3C_c$ ) is desired, it can be found directly by another test.
- In this test, the capacitance between two cores or lines is measured with the third core free or connected to the sheath.
- This eliminates one of the capacitors  $C_s$  so that if  $C_z$  is the measured capacitance, then





$$C_Z = C_c + \frac{C_c + C_s}{2}$$

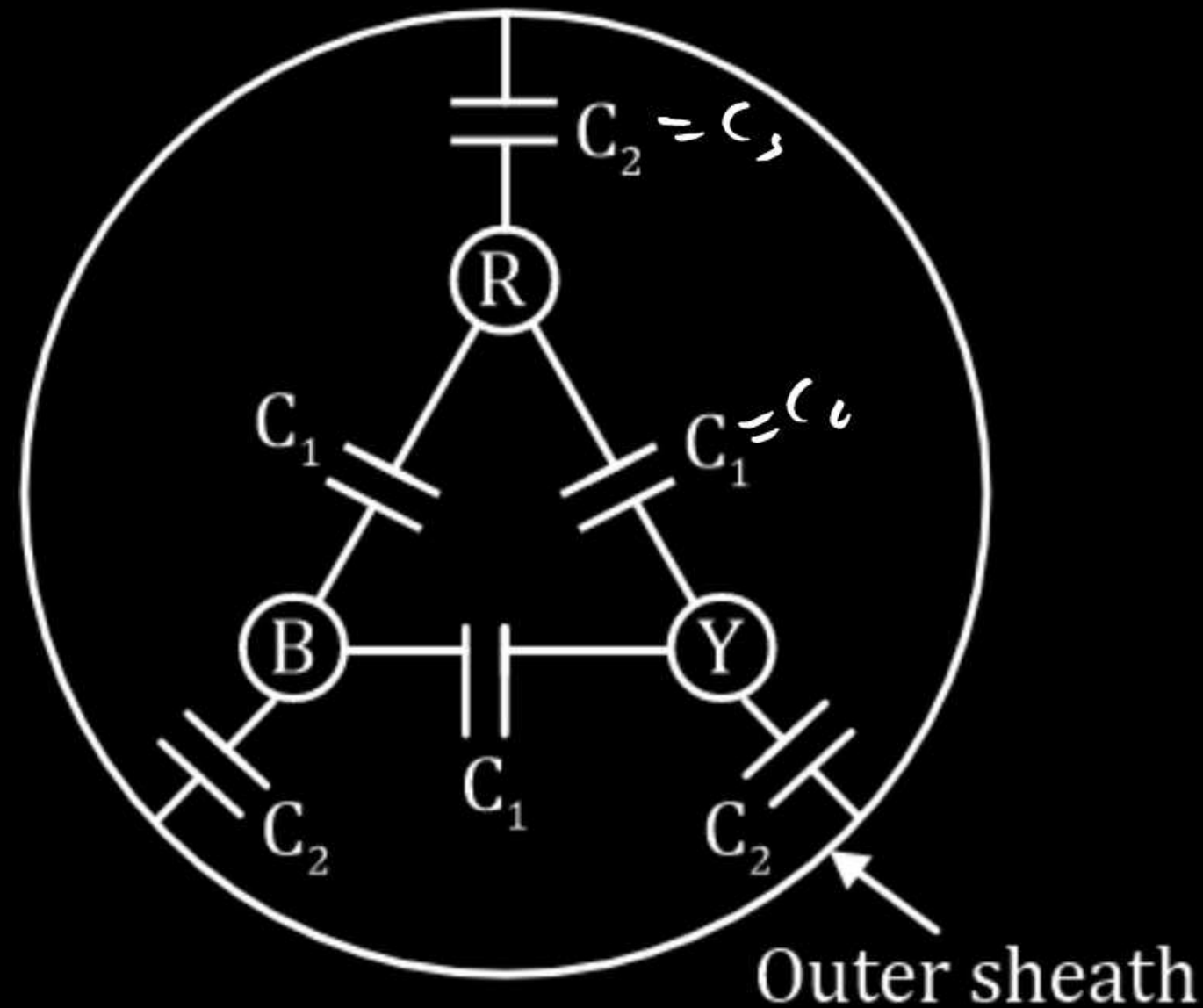
$$C_Z = \frac{3C_c + C_s}{2}$$

$$C_Z = \frac{C_{Ph}}{2}$$

$$C_{Ph} = 2C_Z$$

**Q.**

Consider a three-core, three-phase, 50 Hz 33 kV cable whose conductors are denoted as R, Y and B in the figure. The inter-phase capacitance ( $C_1$ ) between each pair of conductors is  $0.2 \mu\text{F}$  and the capacitance between each line conductor and the sheath is  $0.4 \mu\text{F}$ . The per-phase charging current is



$$C_{ph} = 3C_c + C_s$$

$$C_{ph} = 3C_1 + C_2$$

$$C_{ph} = 3(0.2) + 0.4$$

$$C_{ph} = 1 \mu F$$

$$\begin{aligned} I_{ph} &= \frac{V_{ph}}{X} = j\omega C_{ph} V_{ph} \\ &= 2\pi \cdot 50 \times 1 \times 10^{-6} \times \frac{33000}{\sqrt{3}} \\ &= 5.98 \text{ Amp} \end{aligned}$$

## Heating of cable/Losses of Cable

If Generation of heat > Dissipation of heat

⇒ Temp will Increase

If Generation of heat < dissipation of heat

⇒ Temp will decrease

Heating in cable occur due to loss

The Main losses in cable are

1. Core loss (Ohmic loss) [Conductor]
2. Dielectric loss
3. Sheath loss

Core → Insulation → Sheath → Ground (Heat Dissipated)

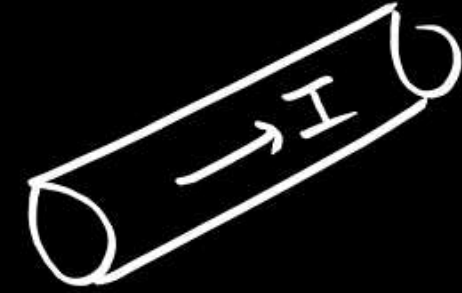
**1. Core loss:** The Main loss is ohmic loss in conductor.

1 Core cable =  $I^2R$

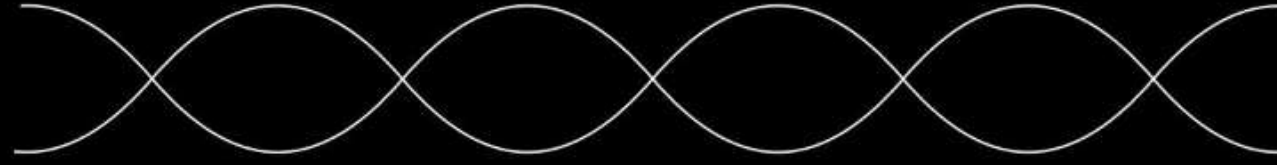
3 Core cable =  $3I^2R$ .

- If Resistance is given at ambient temperature ( $20^\circ$ ). So, first find out resistance at operating temperature. (e.g. 60)

$$\checkmark \underline{R_{60}} = \underline{R_{20}}(1 + \alpha t)$$

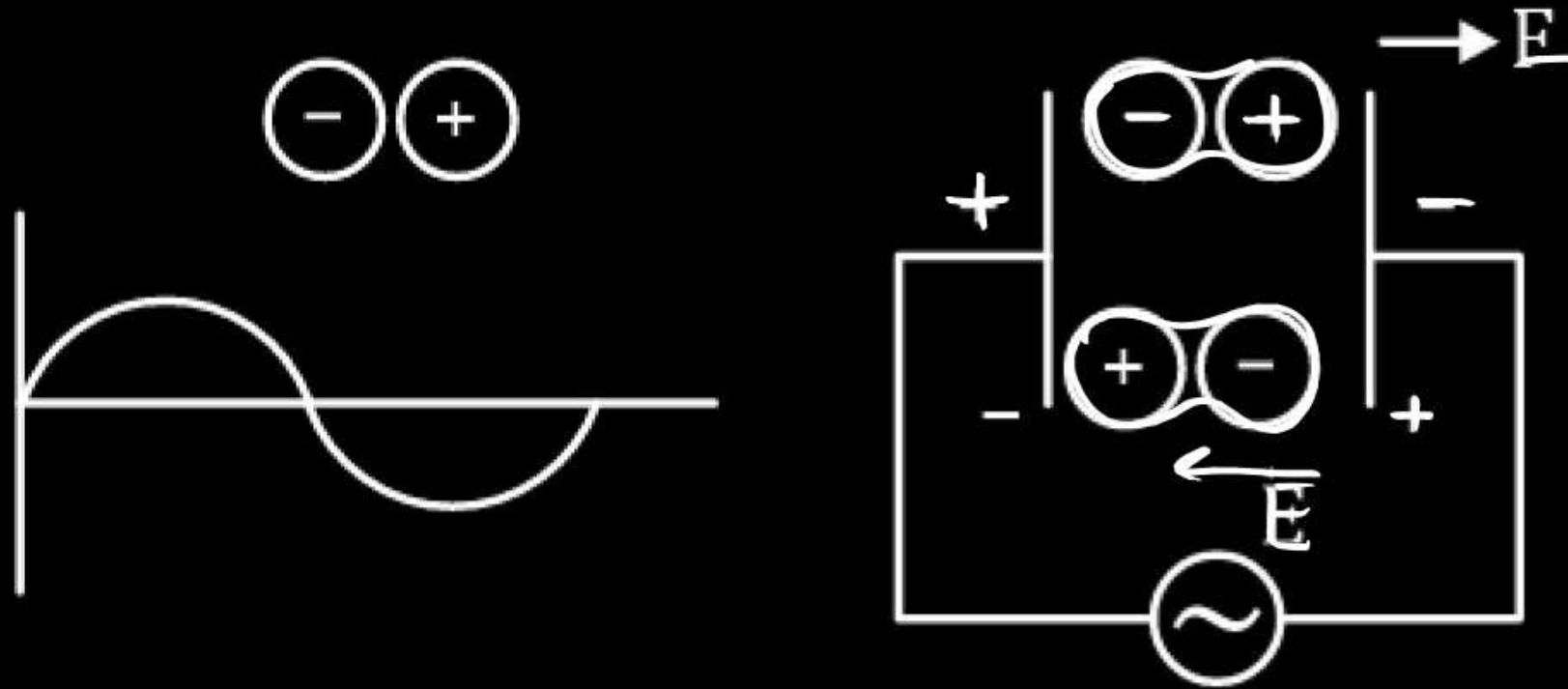


➤  $\underline{R} = \underline{\dot{R}_{60}} \times \underline{1.02} \times \underline{1.02}$



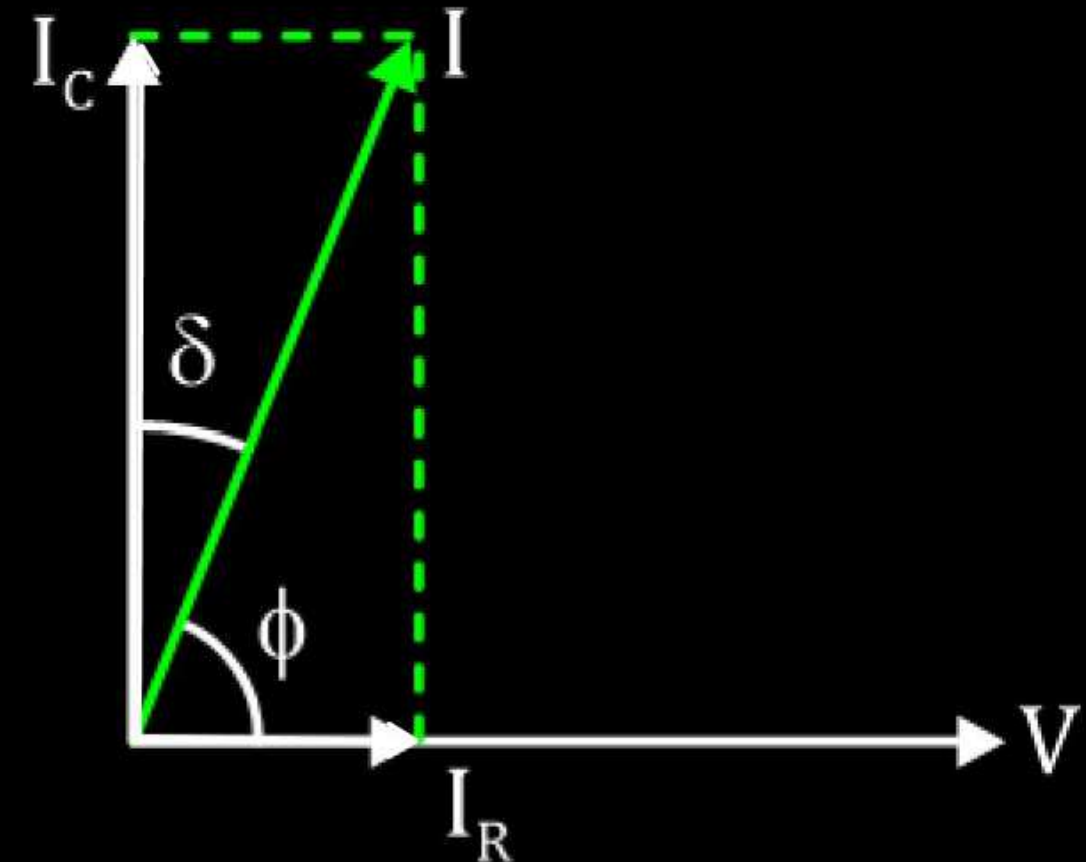
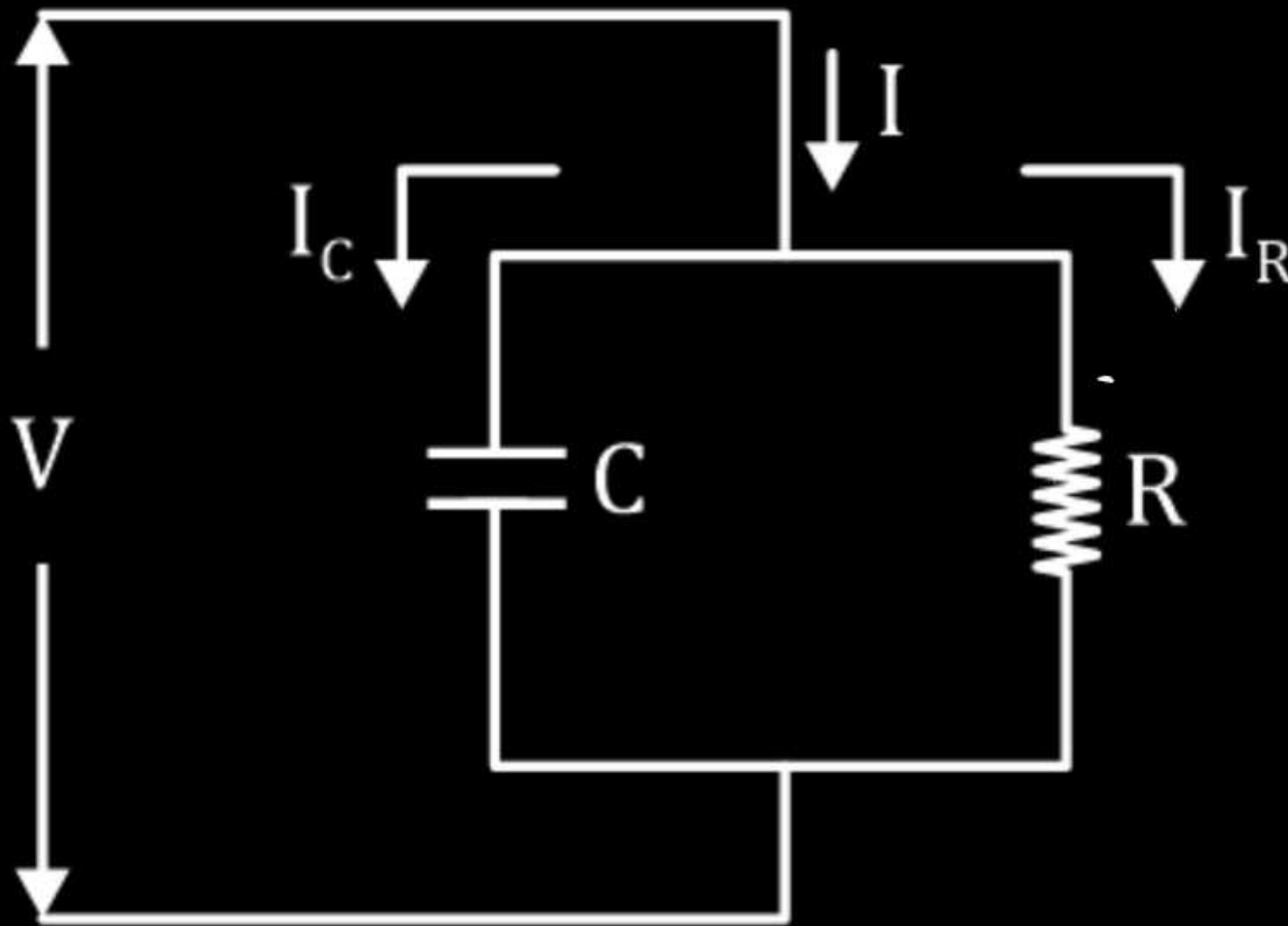
Due to skin effect. Effective AC resistance will be higher than D.C resistance. Factor for increment of R due to length of outer most conductor more than central strand.

## 2. Dielectric loss:



- The Dielectric is subjected to alternating electrical field, which is changing its direction.
- Due to electric field Dipole, try to align as per  $E$ .
- So, After every half cycle, The Dipole change its direction. The energy loss in this process is caused dielectric loss.

- It is also occurred due to leakage current flowing in Insulator.
- The lossy Dielectric Material can be represented as



$$P = \frac{V^2}{R} = V \times \frac{V}{R}$$

$$P = V \times \frac{V}{R}$$

$$P = V \times \omega C V \tan \delta$$

$$P = \omega C V^2 \tan \delta$$

$$\tan \delta = \frac{I_R}{I_C}$$

$$\tan \delta = \frac{V/R}{V/X_C}$$

$$\frac{V}{R} = \frac{V}{X_C} \tan \delta$$

$$\frac{V}{R} = \omega C V \tan \delta$$

$\tan \delta$  is the characteristic of Insulating Material.

It is called loss tangent.

Loss tangent  $\downarrow$  = Better Insulating Material

For 3 phase cable

$$\begin{aligned} \text{Total dielectric loss} &= 3 W C_{ph} V_{ph}^2 \tan \delta \\ &= W C_{ph} (\sqrt{3} V_{ph})^2 \tan \delta \\ &= W C_{ph} V_L^2 \tan \delta \end{aligned}$$

$$\delta = 90 - \phi$$

$\phi$  = P.f. angle.

## Sheath loss:

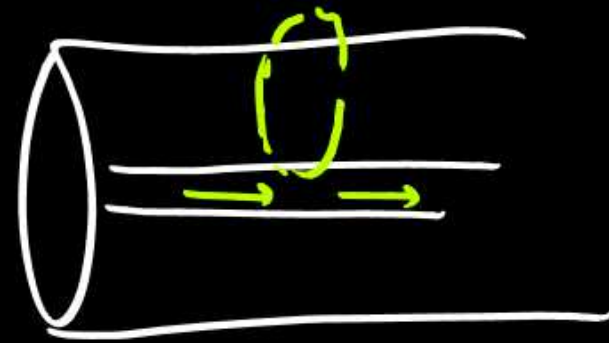
Suppose in single core cable. The AC current is flowing. A pulsating nature of Magnetic field is created.



it will link the sheath, so EMF will be Induced as per faraday law. (take core as a Primary winding. & sheath as a secondary winding.



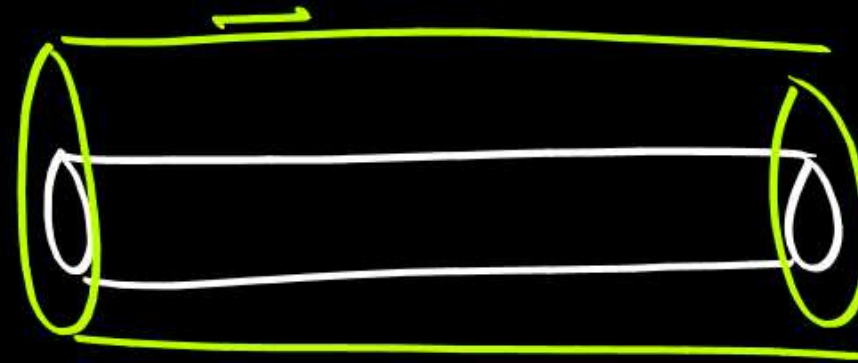
Due to this EMF (voltage). The current will start flowing, which create sheath loss.

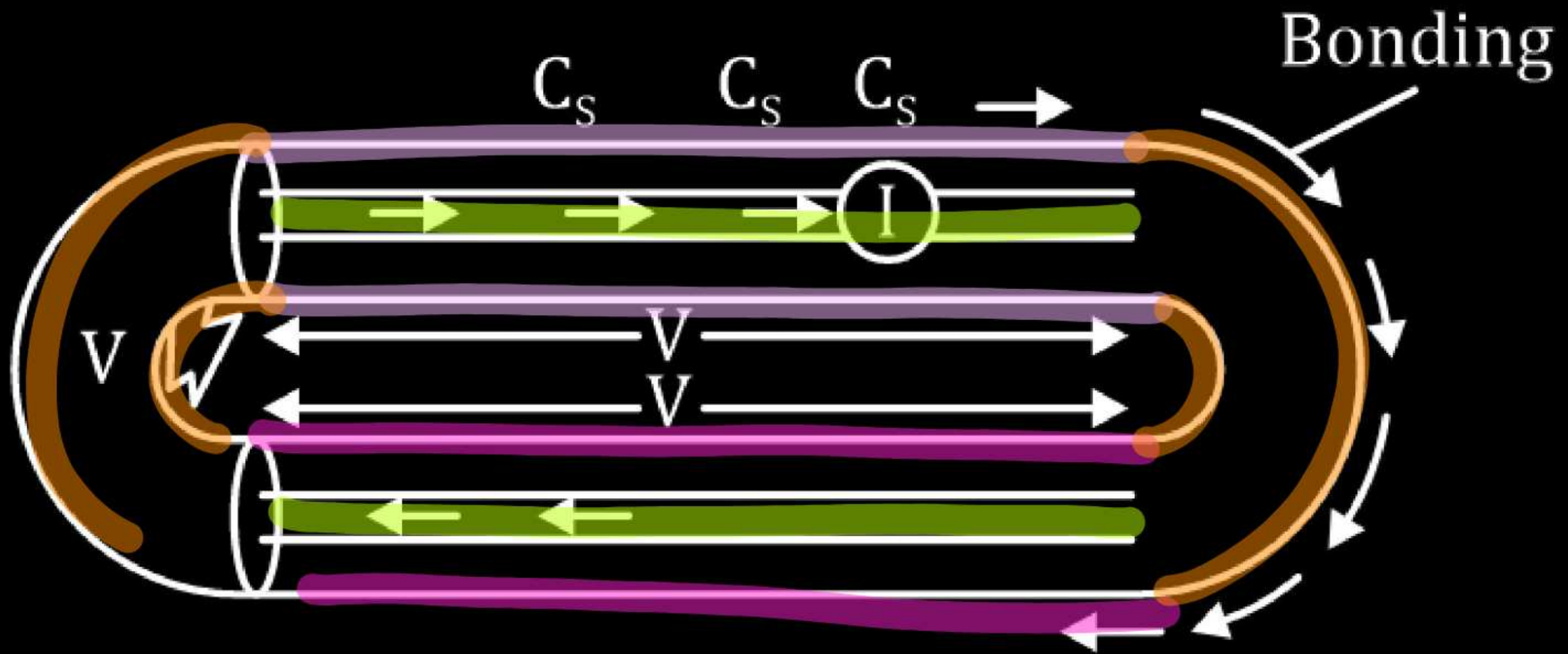


Sheath loss  $\propto$  core loss.

Sheath loss may be two type

1. Sheath eddy current loss  $\rightarrow$  it flow sheath of same cable.
2. Sheath circuit current  $\rightarrow$  From sheath of one cable to sheath of second cable.  
(This current flow, when Sheath of two cable is connected at both end. This is known as bonding)





Q.



A 11 KV, 50 Hz, single phase cable has radius of 10 mm and internal sheath radius of 25 mm. If relative permeability of insulator is 1.5 and loss tangent is 0.036. Find out the dielectric loss of a cable if cable length is 10 KM

$$P = \omega C V^2 \tan \delta$$

$$C = \frac{2\pi \epsilon_0 \epsilon_r}{\ln(R/r)} = \frac{2\pi \times 8.854 \times 10^{-12} \times 1.5}{\ln\left(\frac{25}{10}\right)}$$

$$= 200.6 \times 10^{-12} \text{ F/m}$$

$$= 200.6 \times 10^{-12} \times 10 \times 1000$$

$$= 200.6 \times 10^{-8}$$

- A 2.74 KW
- B 20.12 KW
- C 30.19 KW
- D None

$$P = \omega C V^2 \tan \delta$$

$$P = 2\pi \cdot 50 \times 250.6 \times 10^{-8} \times (11000)^2 \times 0.036$$

$$P = 2745.16 \text{ Watt}$$

$$P = 2.74 \text{ kW}$$



## 2 Minutes Summary

- Capacitance of  $1\phi$  Cable
- Capacitance of  $3\phi$  Cable
- losses in the cable.

**Thank you**

**GW**  
*Soldiers !*



# PRACTICE SHEET-1

## EE Power Systems

### Distribution and Underground Cables

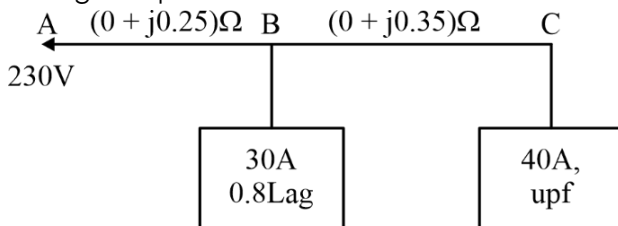
**Q1** A 2-wire dc ring distributor is 250 m long and is fed at 240 V at point A. At point B, 120 m from A, a load of 100 A is taken and at C, 80 m in the opposite direction, a load of 100 A is taken. If resistance per 100 m of single conductor is  $0.02 \Omega$ , then the current in the section BC of feeder is :

- (A) 16 A (B) 24 A  
(C) 32 A (D) 48 A

**Q2** A 2-wire dc distributor is 500 m long and is fed at 250 V at point A and 240 V at another end (Point D). At point B, 200 m from point A, a load of 50 A is taken and at C, 150 m from B, a load of 100 A is taken. If resistance per 100 m of single conductor is  $0.05 \Omega$ , then the current in the section CD of feeder is :

- (A) 30 A (B) 40 A  
(C) 70 A (D) 80 A

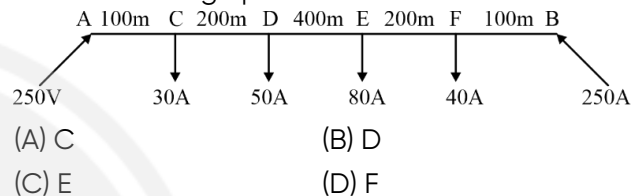
**Q3** A single-phase AC distributor supplies two single phase loads as shown in figure. The voltage drop from A to B is :



- (A) 6.62 V  
(B) 16.62 V  
(C) 20.56 V

(D) 33.33 V

**Q4** A two-conductor cable 1000 m long is loaded as shown. Both ends are supplied at 250 V. The minimum voltage point is :



**Q5** A 2-wire distributor is uniformly loaded at the rate 1 A/m and is fed at both the ends. The point of minimum potential occurs at 550 m from end A and the minimum potential is 220 V. If the length of the distributor is 1000 m, calculate the voltages at the feeding ends A and B. The resistance of each conductor is  $0.01 \Omega/\text{km}$ .

- (A) 223.025 V, 222.025 V  
(B) 224.025 V, 223.025 V  
(C) 225.025 V, 224.025 V  
(D) 226.025 V, 225.025 V

**Q6** The insulation resistance of a single core cable is  $100 \text{ M}\Omega/\text{km}$ . The insulation resistance for 10 km length is \_\_\_\_\_  $\text{M}\Omega$ .

**Q7** An 11 kV, 50 Hz, single phase cable has a diameter of 10 mm, an internal sheath radius of 20 mm. If the dielectric has a relative permittivity of 2.6 and a loss angle of  $0.036$



radian, the dielectric loss for 3 km length of the cable is :

- (A) 910 watts
- (B) 938 watts
- (C) 869 watts
- (D) 857 watts

**Q8** A 3-phase, 3 core, metal sheathed cable gave the following test for capacitance.

1. Capacitance between two conductors bunched with the sheath and the third conductor is  $0.45 \mu\text{F}$  per km.
2. Capacitance between bunched conductors and sheath is  $0.75 \mu\text{F}/\text{km}$ .

The value of capacitance per phase is \_\_\_ $\mu\text{F}/\text{km}$ .

**Q9** A single core cable 10 km long has an insulation resistance of  $2 \text{ M}\Omega$ . The core diameter is 12 mm and the diameter of the cable over the insulation is 30 mm. The resistivity of the insulating material is :

- (A)  $137.44 \text{ G}\Omega \cdot \text{m}$
- (B)  $152.44 \text{ G}\Omega \cdot \text{m}$

- (C)  $126.12 \text{ G}\Omega \cdot \text{m}$
- (D)  $148.12 \text{ G}\Omega \cdot \text{m}$

**Q10** When  $7/0.029 \text{ V.I.R}$  cable is carrying 20 A, a drop of 1 V occurs every 12 m. The voltage drops in a 100 m run of this cable when it is carrying 10 A is nearly :

- (A) 4.2 V
- (B) 3.2 V
- (C) 1.2 V
- (D) 0.42 V

**Q11** A drawn wire of resistance of  $5 \Omega$  is further drawn so that its diameter becomes one-fifth of the original. What is its resistance with volume remaining the same ?

- (A)  $25 \Omega$
- (B)  $125 \Omega$
- (C)  $625 \Omega$
- (D)  $3125 \Omega$

**Q12** A concentric cable has a conductor diameter of 1 cm and an insulation thickness of 1.5 cm. When the cable is subjected to a test pressure of 33 kV, the maximum field strength will be nearly :

- (A)  $41,000 \text{ V/cm}$
- (B)  $43,200 \text{ V/cm}$
- (C)  $45,400 \text{ V/cm}$
- (D)  $47,600 \text{ V/cm}$



## Answer Key

Q1 (A)

Q2 (C)

Q3 (B)

Q4 (C)

Q5 (A)

Q6 10~10

Q7 (D)

Q8 0.54~0.56

Q9 (A)

Q10 (A)

Q11 (D)

Q12 (D)





## Power Systems



Distribution and Under ground Cables

Practice Sheet 01  
Discussion Notes

**By- Ajay Gupta Sir**

Q.

A 2-wire dc ring distributor is 250 m long and is fed at 240 V at point A. At point B, 120 m from A, a load of 100 A is taken and at C, 80 m in the opposite direction, a load of 100 A is taken. If resistance per 100 m of single conductor is  $0.02 \Omega$ , then the current in the section BC of feeder is

A 16 A

B 24 A

C 32 A

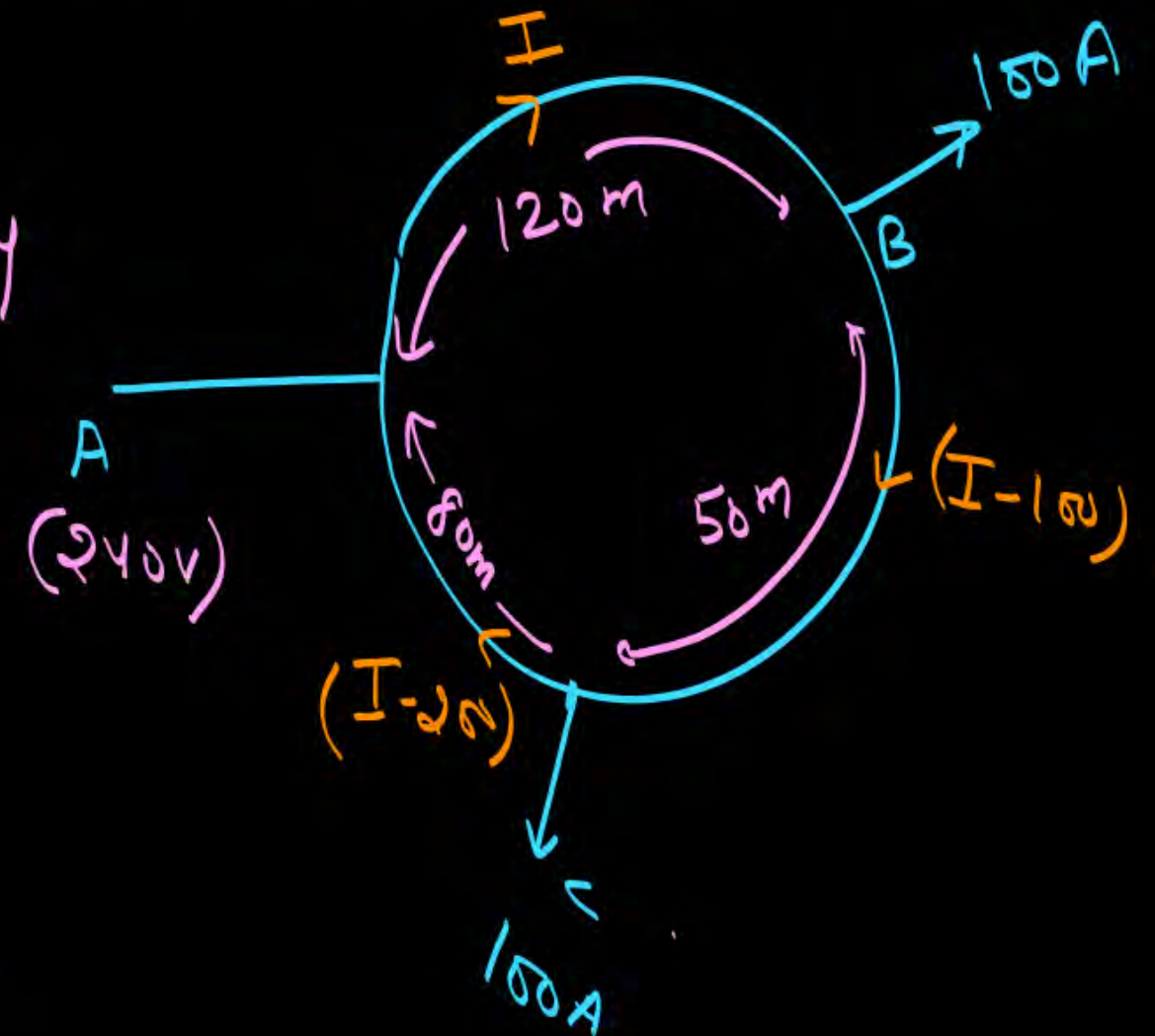
D 48 A

$$\text{Resistance per } 100 \text{ m} = 0.02 \times 2 = 0.04$$

$$\text{Resistance of } AB = \frac{120}{100} \times 0.04 = 0.048$$

$$BC = \frac{50}{100} \times 0.04 = 0.02$$

$$CA = \frac{80}{100} \times 0.04 = 0.032$$



KVL

$$I(0.048) + (I - 100) 0.02 + (I - 200) 0.032 = 0$$

$$0.1 I = 8.4$$

$$I = 84 \text{ A}$$

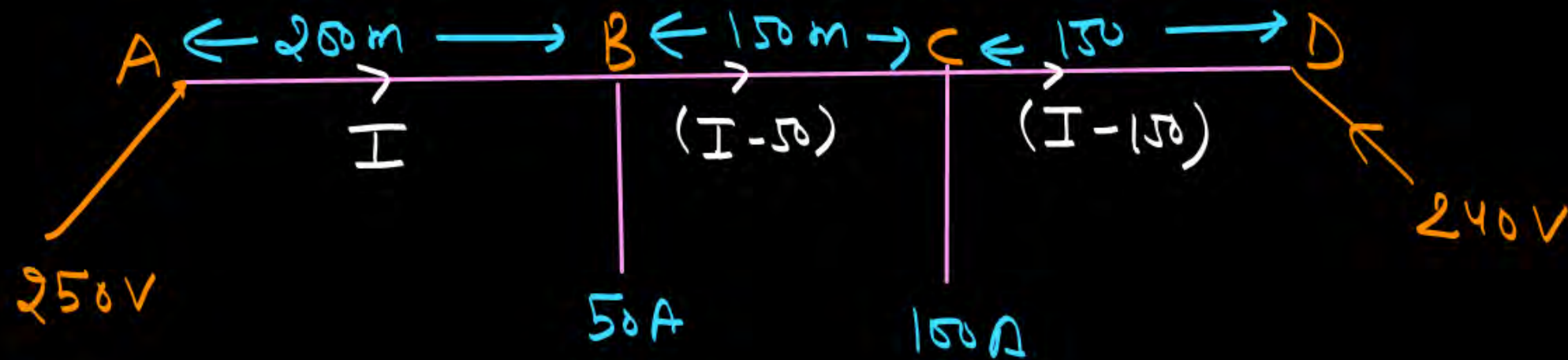
Current in  $B_c$

$$B_c = 84 - 100$$
$$= \underline{\underline{-16}}$$

**Q.**

A 2-wire dc distributor is 500 m long and is fed at 250 V at point A and 240 V at another end (Point D). At point B, 200 m from point A, a load of 50 A is taken and at C, 150 m from B, a load of 100 A is taken. If resistance per 100 m of single conductor is  $0.05 \Omega$ , then the current in the section CD of feeder is

- A** 30 A
- B** 40 A
- C** 70 A ✓
- D** 80 A



$$\text{Resistance of Both Conductor} = 2 \times 0.05 = 0.1$$

$$AB = 0.2 \Omega$$

$$BC = 1.5 \times 0.1 = 0.15 \Omega$$

$$CD = 0.15$$

$$I(0.2) + (I - 50)(0.15) + (I - 150)(0.15) = 10$$

$$0.5I - 30 = 10$$

$$0.5I = 40$$

$$I = 80$$

$$CD = I - 150$$

$$= 80 - 150 = -70$$

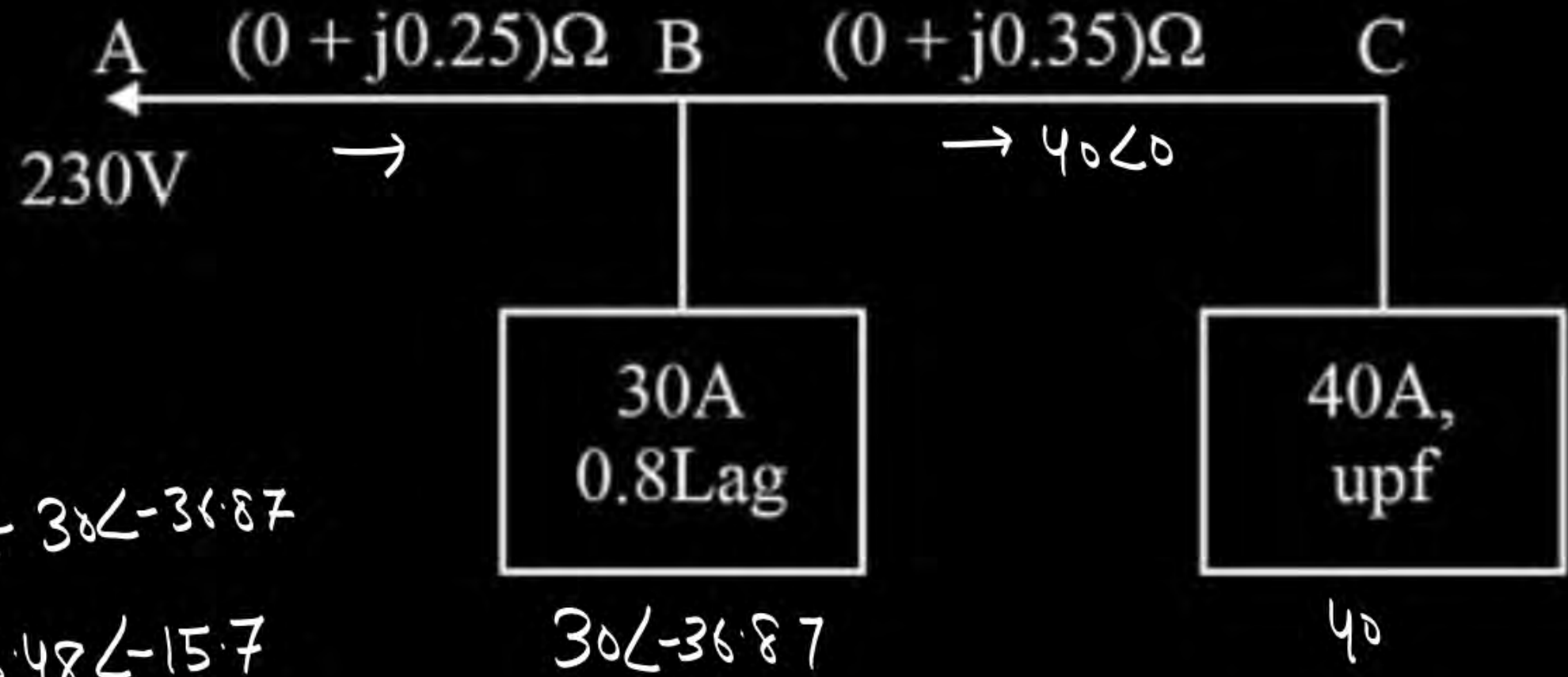
**Q.**

A single-phase AC distributor supplies two single phase loads as shown in figure. The voltage drop from A to B is

- A** 6.62 V
- B** 16.62 V
- C** 20.56 V
- D** 33.33 V

$$I = 40\angle 0 + 30\angle -36.87^\circ$$

$$= 66.48\angle -15.7^\circ$$



$$\begin{aligned}\text{Total voltage drop in AB} &= [66.48 \angle -15.7] [j0.25] \\ &= 16.62 \angle 74.3\end{aligned}$$

Q.

A two-conductor cable 1000 m long is loaded as shown. Both ends are supplied at 250 V. The minimum voltage point is

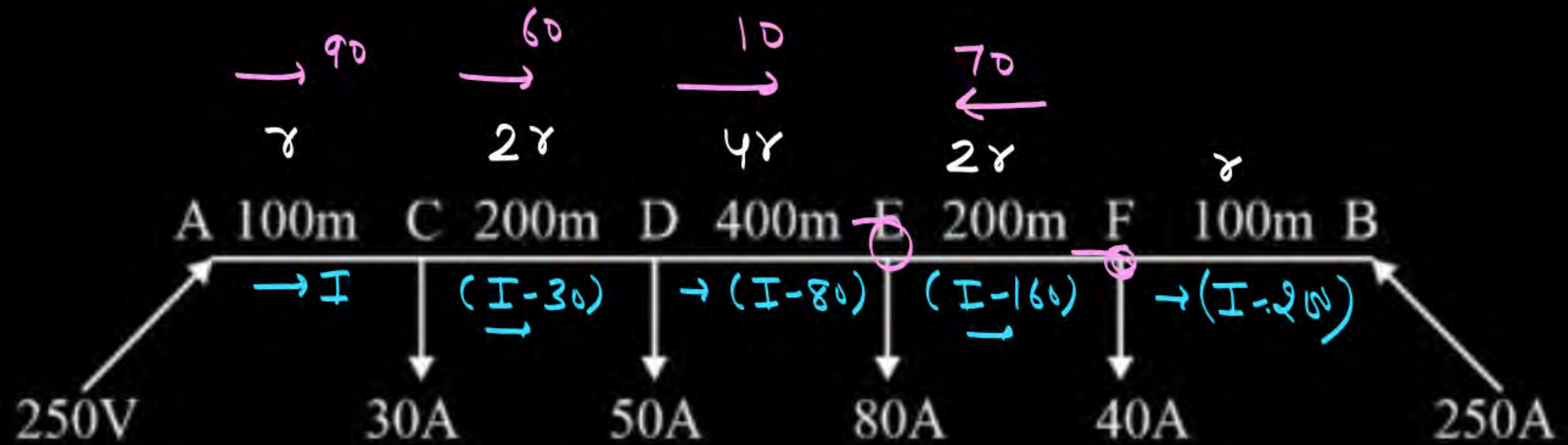


A C

B D

C E ✓

D F



$$I + (I-30)(2) + (I-80)(4) + (I-160)(2) + (I-200)(1) = 0$$

$$10I - 900$$

$$I = 90$$

**Q.**

A 2-wire distributor is uniformly loaded at the rate 1 A/m and is fed at both the ends. The point of minimum potential occurs at 550 m from end A and the minimum potential is 220 V, If the length of the distributor is 1000 m, calculate the voltages at the feeding ends A and B. The resistance of each conductor is 0.01  $\Omega$ /km.

$$r = 0.01 \Omega / \text{km}$$

$$i = 1 \text{ A/m}$$

**A**

223.025 V, ~~222.025 V~~ <sup>223.025</sup>

**B**

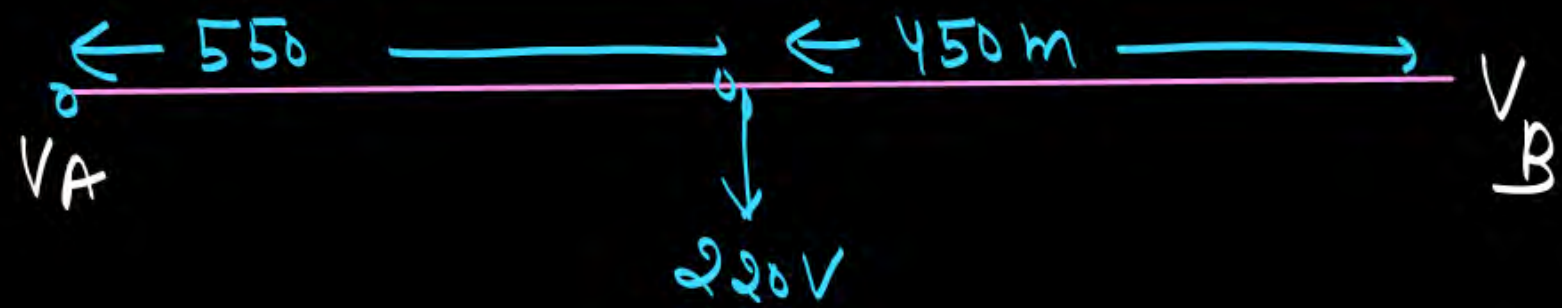
224.025 V, 223.025 V

**C**

225.025 V, 224.025 V

**D**

226.025 V, 225.025 V



$$V_A - 220 = 18 \frac{l^2}{2}$$

$$= 1 \times \frac{0.02 \Omega}{1000 m} \times \frac{(550)^2}{2}$$

$$= 3.025$$

$$V_A = 223.025$$

$$V_A - V_B = 1 \times \frac{0.02}{1000} \times \frac{(1000)^2}{2}$$

$$V_A - V_B = 10$$

$$V_B = V_A - 10 = 213.025$$

**Q.**

The insulation resistance of a single core cable is  $100 \text{ M}\Omega/\text{km}$ . The insulation resistance for 10 km length is \_\_\_\_  $\text{M}\Omega$ .

$$R \propto \frac{1}{l}$$

$$\text{for } 10 \text{ km} = \frac{100}{10} = 10 \text{ M}\Omega$$

**Q.**

An 11 kV, 50 Hz, single phase cable has a diameter of 10 mm, an internal sheath radius of 20 mm. If the dielectric has a relative permittivity of 2.6 and a loss angle of 0.036 radian, the dielectric loss for 3 km length of the cable is

**A** 910 watts

**B** <sup>428 W</sup>  
~~938 watts~~

**C** 869 watts

**D** 857 watts

$$r = 5 \text{ mm}$$

$$R = 20 \text{ mm}$$

$$\epsilon_r = 2.6$$

$$\theta = 0.036 \times \frac{180}{\pi}$$

$$l = 3 \text{ km}$$

$$11 \text{ kV, } 50 \text{ Hz}$$

$$C = \frac{2\pi\epsilon_0\epsilon_r}{\ln R/r} = \frac{2\pi \times 8.85 \times 10^{-12} \times 2.6}{\ln 4} = 104.336 \times 10^{-12} \text{ F/m}$$

$$= \omega C V^2 \tan \delta$$

$$= 100 \pi \times 104.336 \times 10^{-12} \times (11000)^2 \times \tan\left(0.036 \times \frac{180}{\pi}\right)$$

$$= 100 \pi \times 104.336 \times (11000)^2 \times 0.036 \times 10^{-12} \times 3000$$

$$= 428.34 \text{ W}$$

**Q.**

A 3-phase, 3 core, metal sheathed cable gave the following test for capacitance.

1. Capacitance between two conductors bunched with the sheath and the third conductor is  $0.45 \mu\text{F}$  per km.

2. Capacitance between bunched conductors and sheath is  $0.75 \mu\text{F/km}$ .

The value of capacitance per phase is \_\_\_\_\_  $\mu\text{F/km}$ .

$$3C_s = 0.75$$

$$C_s = 0.25$$

$$C_s + 2C_c = 0.45$$

$$0.25 + 2C_c = 0.45$$

$$2C_c = 0.2$$

$$C_c = 0.1$$

$$C_{ph} = C_s + 3C_c$$

$$= 0.25 + 0.3$$

$$= 0.55$$

**Q.**

A single core cable 10 km long has an insulation resistance of 2 MΩ. The core diameter is 12 mm and the diameter of the cable over the insulation is 30 mm. The resistivity of the insulating material is

- A** 137.44 GΩ-m ✓
- B** 152.24 GΩ-m
- C** 126.12 MΩ-m
- D** 148.12 MΩ-m

$$r = 6 \text{ mm}$$

$$R = 15 \text{ mm}$$

$$R = 2 \text{ M}\Omega \text{ for } 10 \text{ km}$$

$$R = \frac{\rho}{2\pi l} \ln \frac{R}{r}$$

$$2 \times 10^6 = \frac{\rho}{2\pi \times 10 \times 1000} \ln \frac{15}{6}$$

$$\rho = \frac{12.566 \times 10^{10}}{0.916} = 137.1 \times 10^9 \Omega\text{-m}$$

**Q.**

When 7/0.029 V.I.R cable is carrying 20 A, a drop of 1 V occurs every 12 m. The voltage drop in a 100 m run of this cable when it is carrying 10 A is nearly

**A** 4.2 V ✓

**B** 3.2 V

**C** 1.2 V

**D** 0.42 V

$$\begin{aligned}
 20 \text{ A, in } 12 \text{ m} &= 1 \text{ V} \\
 10 \text{ A, } 100 \text{ m} &= \frac{1}{20} \times 10 \times \frac{100}{12} = 4.16
 \end{aligned}$$

**Q.**

A drawn wire of resistance of  $5\Omega$  is further drawn so that its diameter becomes one-fifth of the original. What is its resistance with volume remaining the same?

**A**  $25\Omega$

**B**  $125\Omega$

**C**  $625\Omega$

**D**  $3125\Omega$  ✓

$$a_1 = \pi r^2$$

$$a_2 = \pi \left(\frac{r}{5}\right)^2 = \frac{a_1}{25}$$

$$a_1 l_1 = a_2 l_2$$

$$\cancel{a}_1 l_1 = \frac{\cancel{a}_1}{25} \cdot l_2$$

$$l_2 = 25 l_1$$

$$\frac{R_1}{R_2} = \frac{l_1}{a_1} \cdot \frac{a_2}{l_2} = \frac{1}{25} \cdot \frac{1}{25}$$

$$R_2 = 5 \times 625 = 3125$$

**Q.** A concentric cable has a conductor diameter of 1 cm and an insulation thickness of 1.5 cm. When the cable is subjected to a test pressure of 33 kV, the maximum field strength will be nearly

- A** 41,000 V/cm
- B** 43,200 V/cm
- C** 45,400 V/cm
- D** 47,600 V/cm ✓

$$r = 0.5 \text{ cm}$$

$$R = 0.5 + 1.5 = 2$$

$$g_{\max} = \frac{V}{r \ln R/r} = \frac{33 \times 10^3}{0.5 \ln \frac{2}{0.5}} = 47.608 \times 10^3 \text{ V/m}$$

Thank  
you