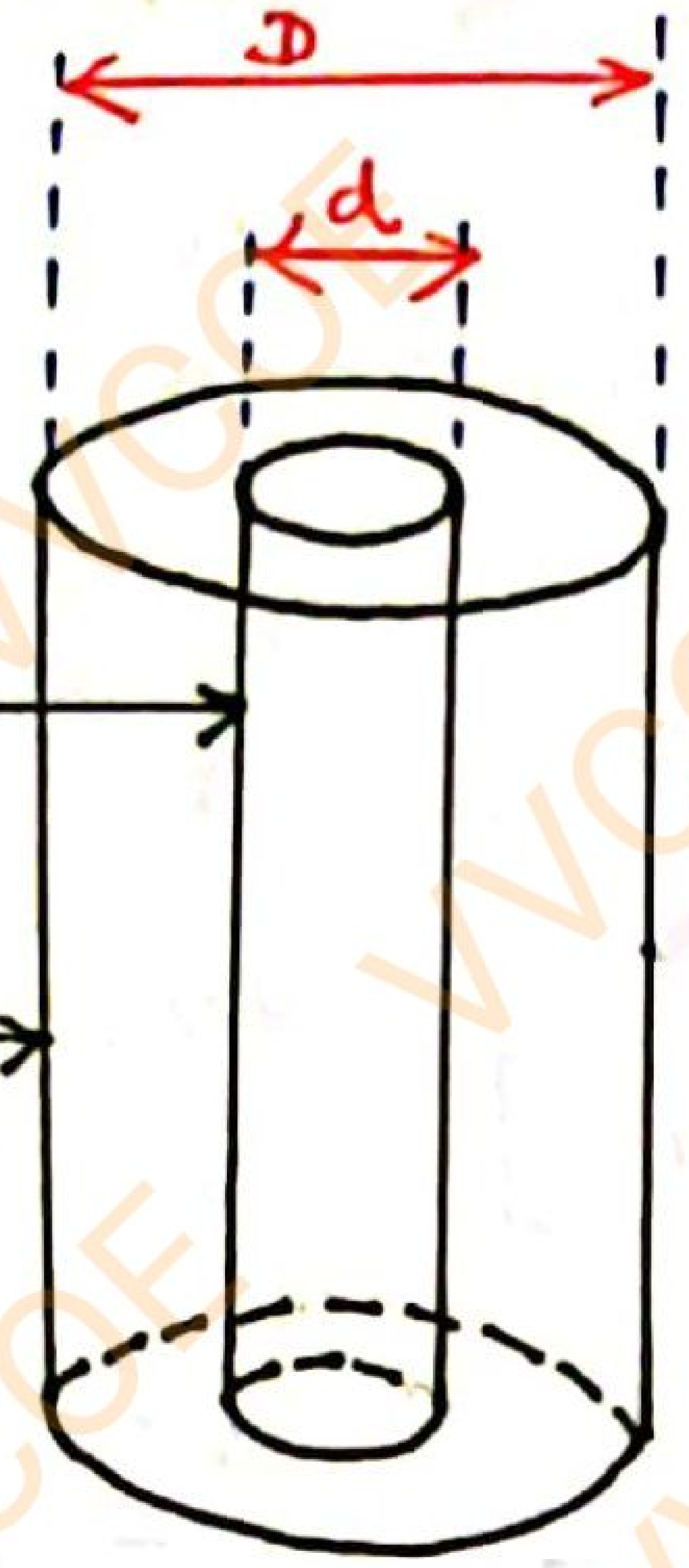
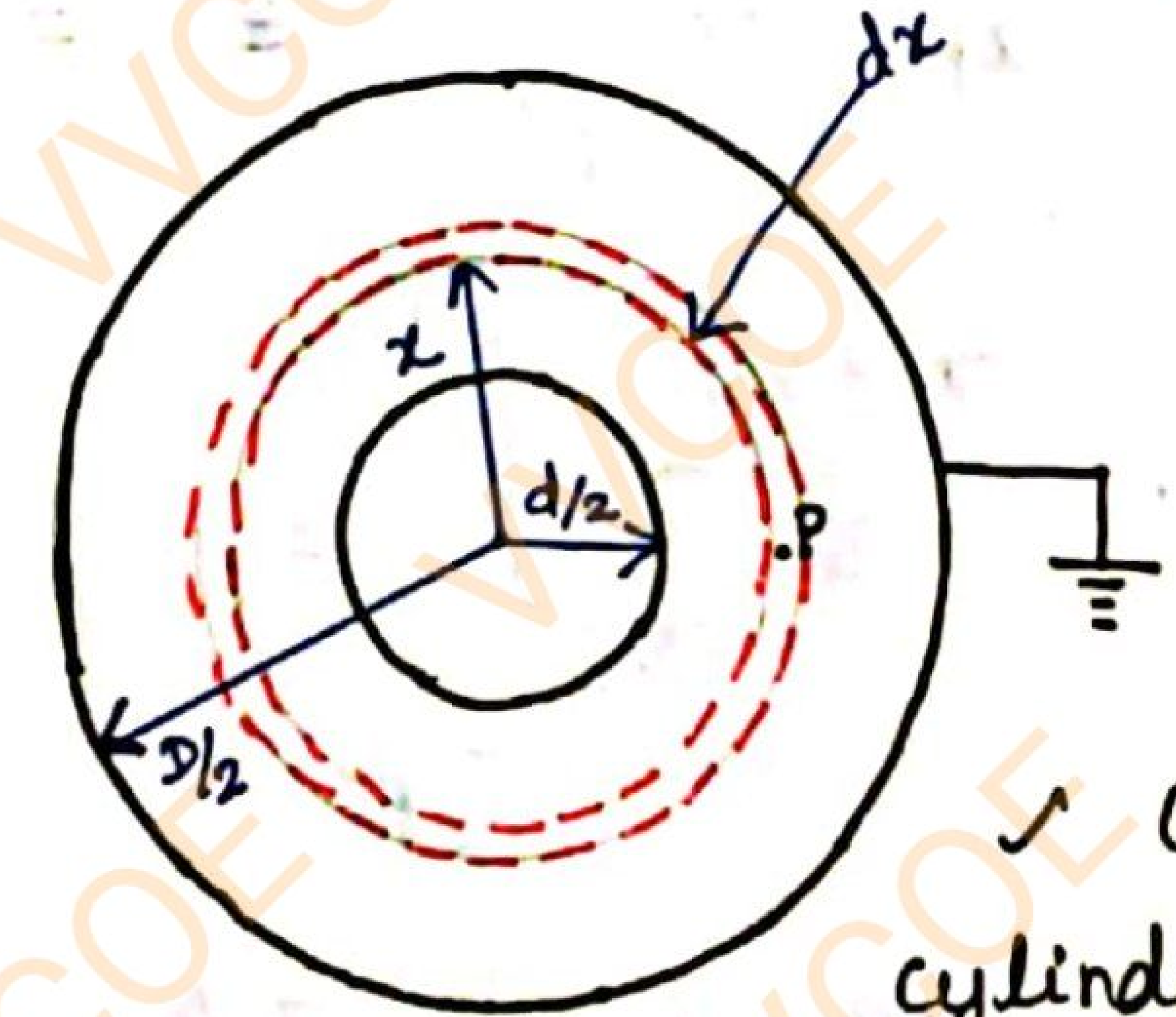
CAPACITANCE OF A SINGLE CORE CABLE



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

→ Inner cylinder ⇒ core
outer cylinder ⇒ lead sheath



- consider
  - Q → charge per unit length in coulomb
  - ε → permittivity of the material b/w core & sheath

- Consider an elementary cylinder with radius x and axial length metre. The surface area of this cylinder is $2\pi x \times 1 = 2\pi x$

- According to Gauss's law, the lines of flux due to charge Q on the conductor are in radial direction. and total flux lines are equal to the total charge possessed

$$\therefore \text{Flux density} = \frac{Q}{2\pi x} \quad c/m^2$$

Electric field Intensity at any point P (at distance x) on the elementary cylinder is given by

$$E = \frac{Q}{2\pi \varepsilon x} \quad V/m$$

Potential difference between the conductor and sheath is

$$V = \int_{d/2}^{D/2} E \, . \, dx$$

$$= \int_{d/2}^{D/2} \frac{Q}{2\pi \varepsilon x} \, . \, dx$$

$$= \int_{d/2}^{D/2} \frac{1}{x} \, . \, dx$$

$$= \frac{Q}{2\pi \varepsilon} \left[\ln x \right]_{d/2}^{D/2}$$

$$= \frac{Q}{2\pi \varepsilon} \left[\ln \frac{D}{2} - \ln \frac{d}{2} \right]$$

$$= \frac{Q}{2\pi \varepsilon} \left[\ln \frac{D/2}{d/2} \right]$$

$$V = \frac{Q}{2\pi \varepsilon} \ln \left(\frac{D}{d} \right)$$

capacitance of a cable is , $C = \frac{Q}{V}$

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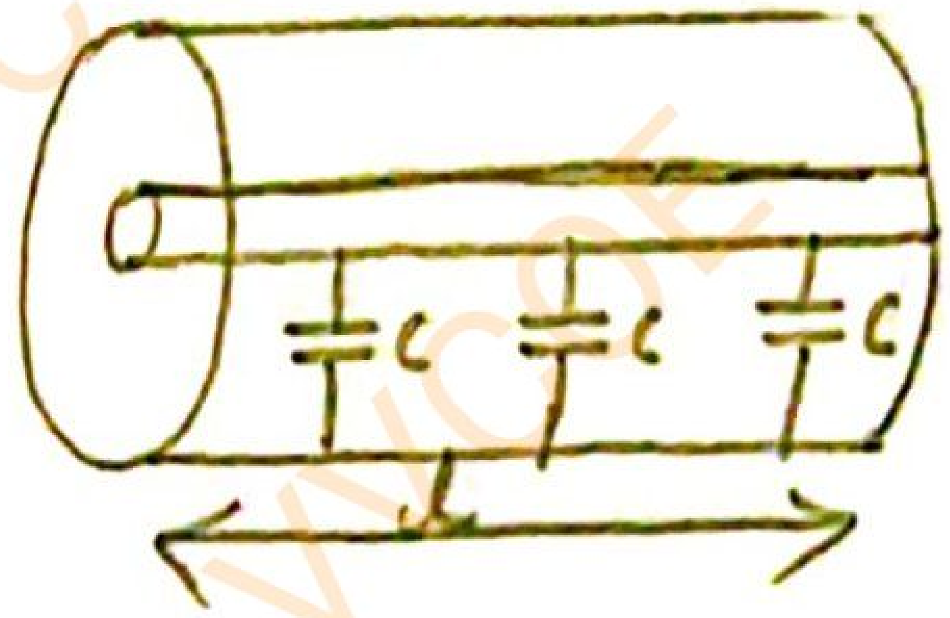
$$C = \frac{q}{\frac{q}{2\pi\varepsilon} \ln\left(\frac{D}{d}\right)}$$

$$C = \frac{2\pi\varepsilon}{\ln\left(\frac{D}{d}\right)} \quad F/m$$

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



$$\boxed{C = \frac{2\pi\varepsilon l}{\ln\left(\frac{D}{d}\right)}} \quad F$$

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 cable has a maximum value (g_{max}) at the conductor surface and goes on decreasing as we move towards the sheath. (minimum at sheath). This results in, the section of dielectric near the conductor surface may breakdown and may cause damage to the complete dielectric in the cable.

- If a dielectric of high-strength is used in a cable, then no doubt it is useful just over the conductor where the stress is maximum, but as we go away from the conductor surface, the value of dielectric stress decreases. So the dielectric will be unnecessarily strong and expensive.

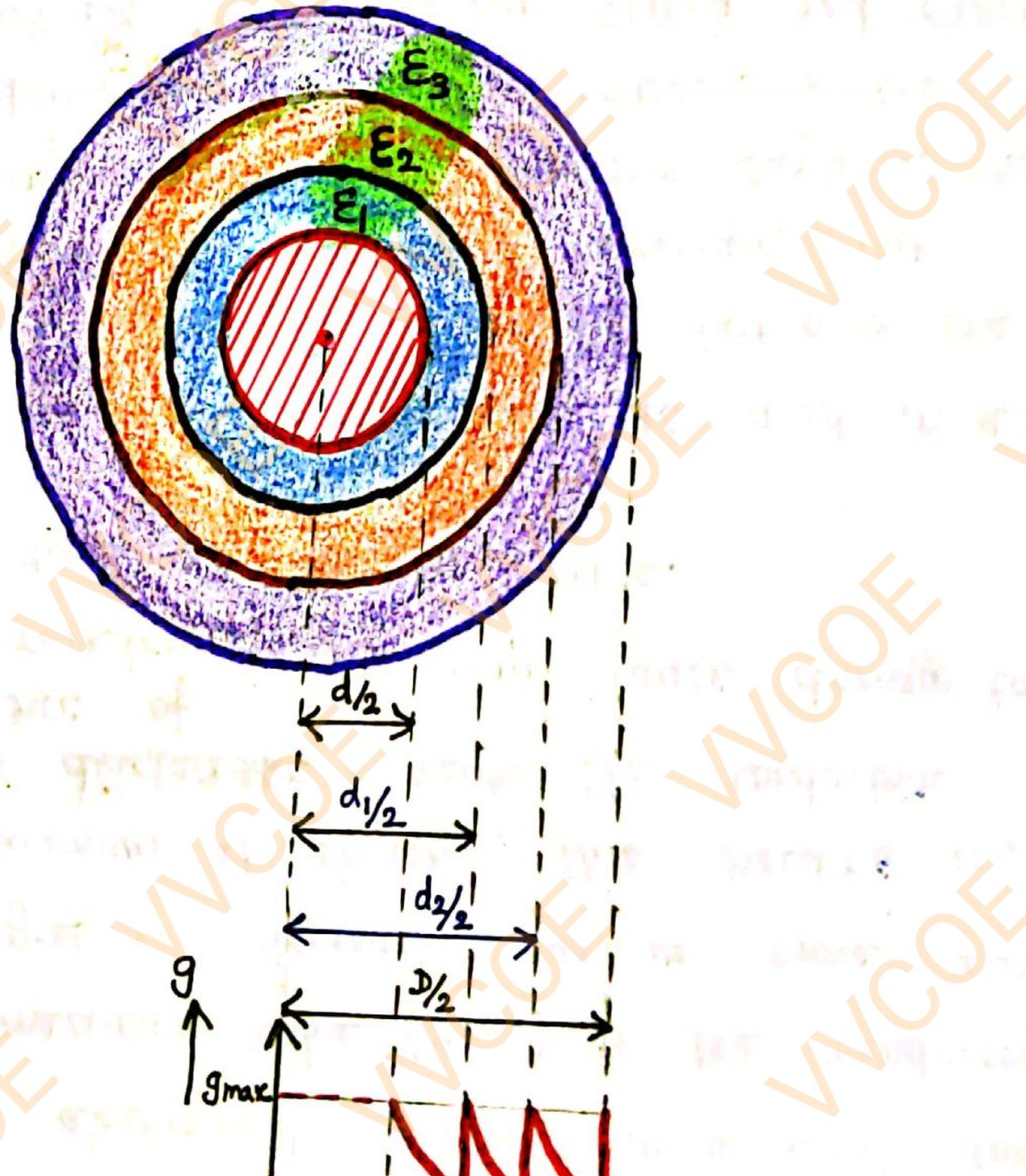
- However, by some means we must equalize the dielectric stress in the insulation of cable. This process of equalizing the dielectric stress is called grading of cable.

There are two methods of grading the cables.

1) Capcitance grading.
2) Intersheath grading.

CAPACITANCE GRADING

✓ In this method of cable grading, the uniformity in dielectric stress is achieved by using different layers of dielectrics having different permittivities ($\varepsilon_r \propto \frac{1}{x}$) between the core and sheath. where $x \rightarrow$ radius distance of dielectric layer from centre.



The gradient at point x from the centre of the cable is given by $g = \frac{Q}{2\pi\varepsilon x}$

Now, consider a cable in which there are three dielectrics of relative permittivity $\varepsilon_1, \varepsilon_2, \varepsilon_3$ respectively. Also, $\varepsilon_1 > \varepsilon_2 > \varepsilon_3$

let $d_1 \rightarrow$ outer diameter of dielectric 1

$d_2 \rightarrow$ outer diameter up to dielectric 2

$D \rightarrow$ Outer diameter up to dielectric 3.

Maximum stress of dielectrics are

$$g_{1max} = \frac{Q}{2\pi\varepsilon_0\varepsilon_1\left(\frac{d}{2}\right)} \quad ; \quad g_{2max} = \frac{Q}{2\pi\varepsilon_0\varepsilon_2\left(\frac{d_1}{2}\right)} \quad ; \quad g_{3max} = \frac{Q}{2\pi\varepsilon_0\varepsilon_3\left(\frac{d_2}{2}\right)}$$

$$g_{1max} = \frac{Q}{\pi\varepsilon_0\varepsilon_1 d} \text{ —— (1)} \quad ; \quad g_{2max} = \frac{Q}{\pi\varepsilon_0\varepsilon_2 d_1} \quad ; \quad g_{3max} = \frac{Q}{\pi\varepsilon_0\varepsilon_3 d_2}$$

When maximum stress for the three dielectrics are same then

$$g_{1max} = g_{2max} = g_{3max} = g_{max}$$

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

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

Potential difference across the inner layer is

$$V_1 = \int_{d/2}^{d_1/2} g \, dx$$

$$= \int_{d/2}^{d_1/2} \frac{Q}{2\pi\varepsilon x} \cdot dx$$

$$= \frac{Q}{2\pi \varepsilon_0 \varepsilon_1} \int_{d/2}^{d_1/2} \frac{1}{x} \cdot dx$$

$$= \frac{Q}{2\pi \varepsilon_0 \varepsilon_1} \left[\ln x \right]_{d/2}^{d_1/2}$$

$$= \frac{Q}{2\pi \varepsilon_0 \varepsilon_1} \left[\ln\left(\frac{d_1}{2}\right) - \ln\left(\frac{d}{2}\right) \right]$$

$$= \frac{Q}{2\pi \varepsilon_0 \varepsilon_1} \left[\ln\left(\frac{\frac{d_1}{2}}{\frac{d}{2}}\right) \right]$$

$$V_1 = \frac{Q}{2\pi \varepsilon_0 \varepsilon_1} \ln\left(\frac{d_1}{d}\right) \quad \text{——— (2)}$$

$$(1) \Rightarrow \quad g_{max} = \frac{Q}{\pi \varepsilon_0 \varepsilon_1 d}$$

$$\Rightarrow \quad g_{max} \cdot d = \frac{Q}{\pi \varepsilon_0 \varepsilon_1}$$

$$\frac{g_{max} \cdot d}{2} = \frac{Q}{2\pi \varepsilon_0 \varepsilon_1} \quad \text{——— (3)}$$

sub (3) in (2) we get

$$\boxed{V_1 = \frac{g_{max} \cdot d}{2} \ln\left(\frac{d_1}{d}\right)}$$

similarly potential difference across second layer (V_2) and third layer (V_3) is given by.

$$\boxed{V_2 = \frac{g_{max}}{2} \cdot d_1 \ln\left(\frac{d_2}{d_1}\right)}$$

$$\boxed{V_3 = \frac{g_{max}}{2} \cdot d_2 \ln\left(\frac{D}{d_2}\right)}$$

Total potential difference across core and sheath is

$$V = V_1 + V_2 + V_3$$

$$\boxed{V = \frac{g_{max}}{2}\left[d \ln \frac{d_1}{d} + d_1 \ln \frac{d_2}{d_1} + d_2 \ln \frac{D}{d_2}\right]}$$

If the cable had homogeneous dielectric, then for the same values of d, D and g_{max}, the permissible potential difference between core and earthed sheath is

$$V' = \frac{g_{max}}{2} d \ln\left(\frac{D}{d}\right)$$

Always,

$V > V'$ ie) a graded cable can be worked at a greater potential than that of non-graded. Alternatively, for the same safe potential, the size of graded cable will be less than that of non graded cable.

Note: (For problems) X

(i) As the permissible value of g_{max} are peak values, therefore, all the voltages in the above expressions should be taken as peak and not the r.m.s values.

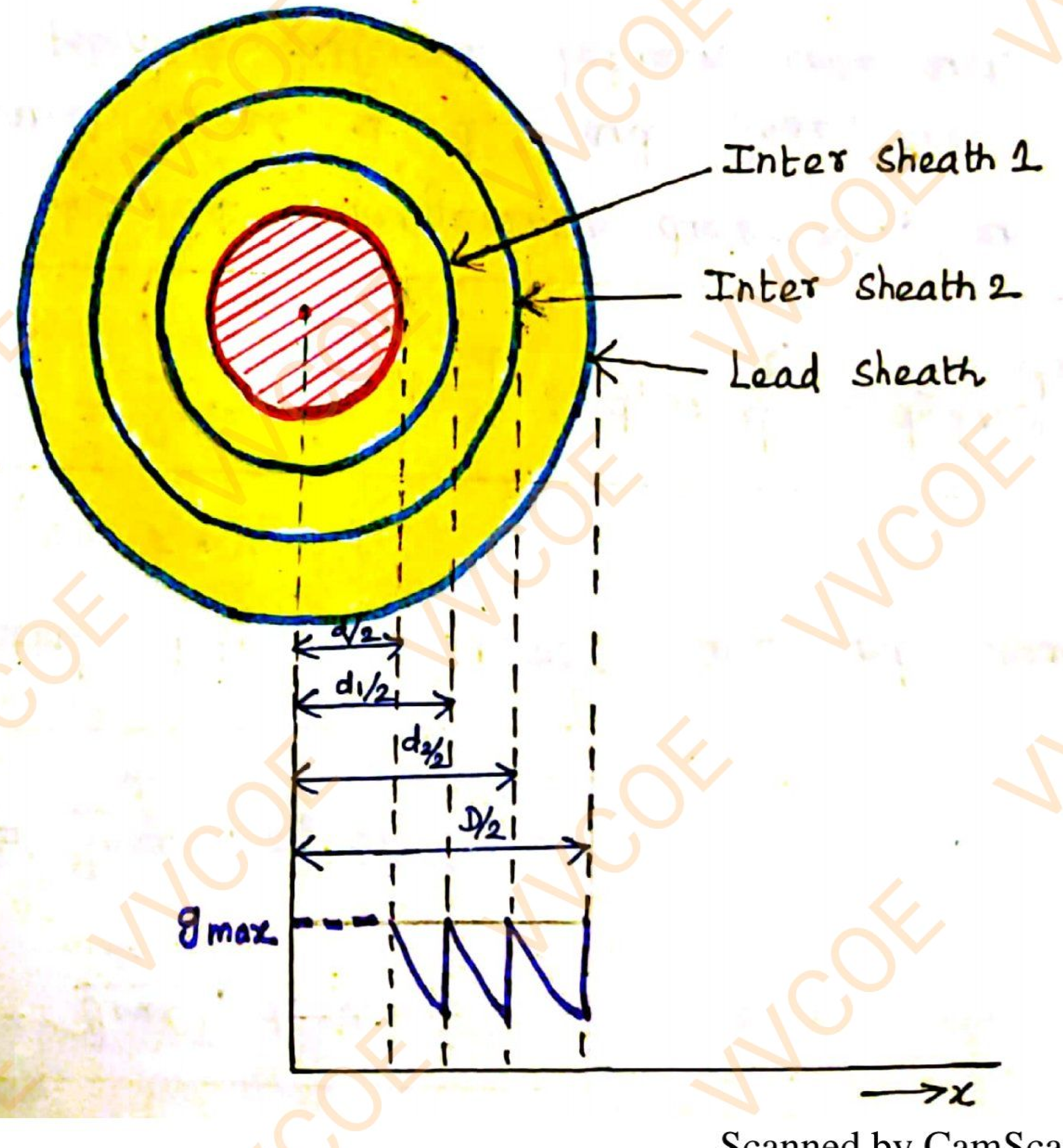
(ii) If max. stress in the 3 dielectrics is not same, then

$$V = \frac{g_{1max}}{2} d \ln\left(\frac{d_1}{d}\right) + \frac{g_{2max}}{2} d_1 \ln \frac{d_2}{d_1} + \frac{g_{3max}}{2} d_2 \ln \frac{D}{d_2}$$

INTERSHEATH GRADING.

- ✓ In this method of cable grading a homogeneous dielectric is used, but it is divided into various layers by placing metallic intersheaths at different positions (i.e between core and sheath). Each intersheath is maintained at some potential by connecting them to the tappings of the transformer.

- ✓ Hence each layer is maintained at such a potential that the maximum stress across each layer is the same.



*Consider a cable of core diameter d

Outer lead sheath of diameter D

Two intersheaths of diameter d_1 and d_2 are inserted into the homogeneous dielectric and maintained at some fixed potentials.

* Let V_1, V_2 and V_3 respectively be the voltage between core and intersheath 1, between intersheath 1 and intersheath 2, intersheath 2 and outer lead sheath.

maximum stress between core and intersheath 1

$$g_{1max} = \frac{V_1}{\frac{d}{2} \ln\left(\frac{d_1}{d}\right)}$$

maximum stress between intersheath 1 and intersheath 2

$$g_{2max} = \frac{V_2}{\frac{d_1}{2} \ln\left(\frac{d_2}{d_1}\right)}$$

maximum stress between intersheath 2 and outermost sheath is

$$g_{3max} = \frac{V_3}{\frac{d_2}{2} \ln\left(\frac{D}{d_2}\right)}$$

Since the dielectric is homogeneous, the maximum stress in each layer is the same.

$$g_{1max} = g_{2max} = g_{3max}$$

$$\frac{V_1}{\frac{d}{2} \ln\left(\frac{d_1}{d}\right)} = \frac{V_2}{\frac{d_1}{2} \ln\left(\frac{d_2}{d_1}\right)} = \frac{V_3}{\frac{d_2}{2} \ln\left(\frac{D}{d_2}\right)}$$

As the cable behaves like 3 capacitors in series, therefore, all the potentials are in phase

ie. Voltage between conductor and earthed lead sheath is, $V = V_1 + V_2 + V_3$

Disadvantages of Intersheath grading

Intersheath grading is rarely used because.

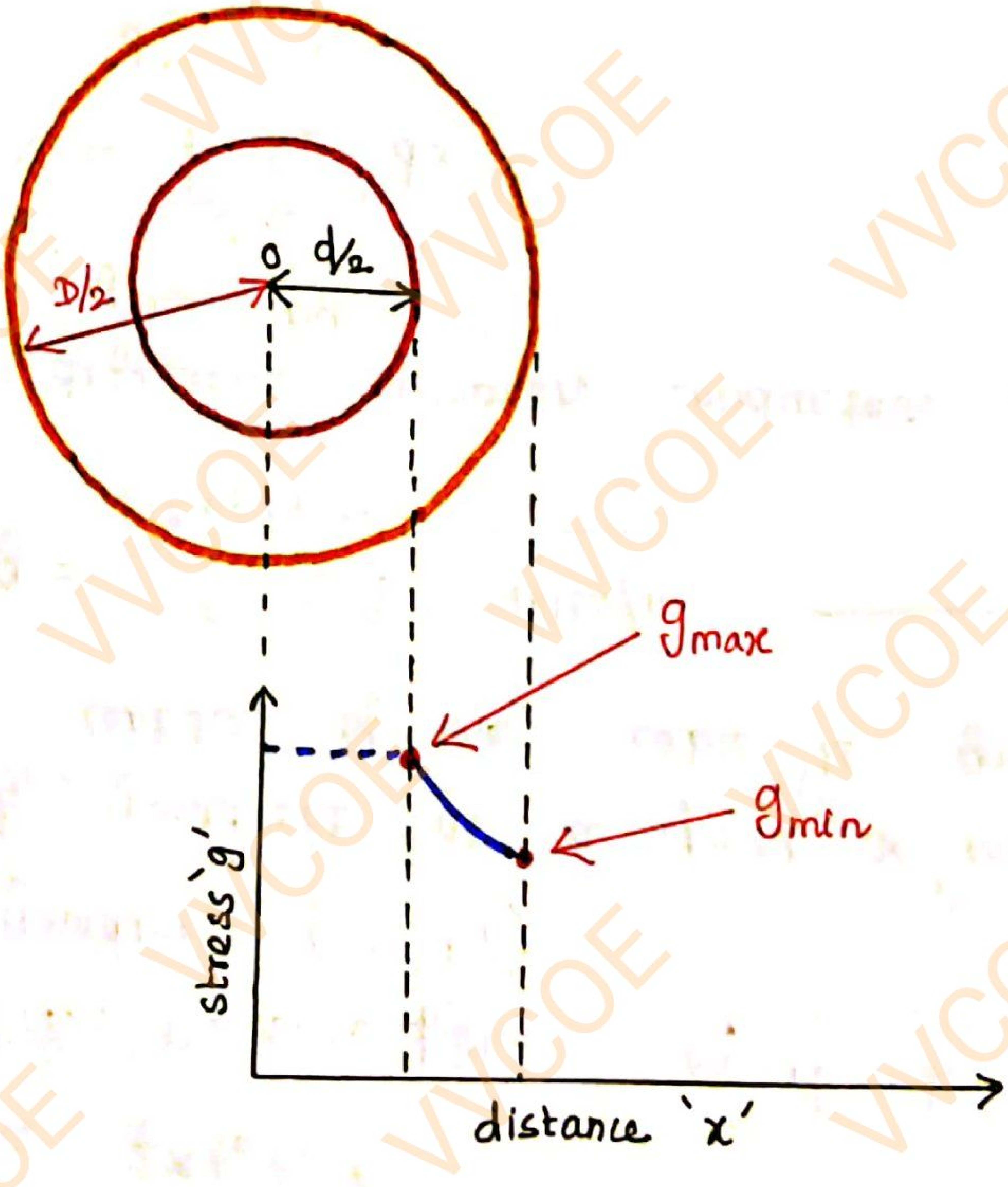
1) Complications in fixing the sheath potentials
2) intersheaths are likely to be damaged during transportation.
3) There are considerable loss in the intersheaths due to charging currents.

POTENTIAL GRADIENT

(or)

DIELECTRIC STRESS IN A SINGLE CORE CABLE (or) Electrostatic stress in Insulation.

Under operating conditions, the insulation of a cable is subjected to electrostatic stress. This is known as dielectric stress. The dielectric stress at any point in a cable is nothing but the potential gradient



Consider a single core cable with core diameter 'd' and sheath diameter 'D'

Electric field intensity at a distance 'x' meters from the centre of the cable is given by

$$E_x = \frac{Q}{2\pi \varepsilon_0 \varepsilon_r x} \quad \text{volts/m.}$$

By definition, electric field is equal to potential gradient $(g = E_x)$

$\therefore$ Potential gradient at a point 'x' metres from the centre of the cable is given by

$$g = \frac{Q}{2\pi \varepsilon_0 \varepsilon_r x} \quad \text{volts/m} \qquad \text{——— (1)}$$

Potential difference between conductor and sheath is given by

$$V = \int_{d/2}^{D/2} E_x \, . \, dx$$

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

$$= \frac{Q}{2\pi \varepsilon_0 \varepsilon_r} \int_{d/2}^{D/2} \frac{1}{x} \, . \, dx$$

$$= \frac{Q}{2\pi \varepsilon_0 \varepsilon_r} \Big[\ln x \Big]_{d/2}^{D/2}$$

$$= \frac{Q}{2\pi \varepsilon_0 \varepsilon_r} \left[\ln (D/2) - \ln (d/2) \right]$$

$$= \frac{Q}{2\pi \varepsilon_0 \varepsilon_r} \left[\ln \frac{D/2}{d/2} \right]$$

$$V = \frac{Q}{2\pi \varepsilon_0 \varepsilon_r} \left(\ln \frac{D}{d} \right)$$

$$\Rightarrow \quad Q = \frac{2\pi \varepsilon_0 \varepsilon_r . V}{\ln \left(\frac{D}{d} \right)} \quad \text{———} (2)$$

sub (2) in (1) we get

$$g = \frac{\dfrac{\cancel{2\pi \varepsilon_0 \varepsilon_r} . V}{\ln \left(\frac{D}{d} \right)}}{\cancel{2\pi \varepsilon_0 \varepsilon_r} . x}$$

$$\boxed{g = \frac{V}{x . \ln \left(\frac{D}{d} \right)}} \quad \text{volts/m} \quad \text{———} (3)$$

From (3) $\Rightarrow$ Potential gradient is proportional to distance 'x'

$\therefore$ The stress is maximum at the surface of the conductor ie. when $x = \frac{d}{2}$

$$\Rightarrow \boxed{g_{max} = \frac{V}{\frac{d}{2} \ln \left(\frac{D}{d} \right)}}$$

Minimum potential gradient is (at $x = D/2$)

$$\boxed{g_{min} = \frac{V}{\frac{D}{2} \ln \frac{D}{d}}}$$

$$\frac{g_{max}}{g_{min}} = \frac{\dfrac{\cancel{V}}{\frac{d}{\cancel{2}} \cancel{\ln \frac{D}{d}}}}{\dfrac{\cancel{V}}{\frac{D}{\cancel{2}} \cancel{\ln \frac{D}{d}}}}$$

$$= \frac{\frac{1}{d}}{\frac{1}{D}}$$

$$\boxed{\frac{g_{max}}{g_{min}} = \frac{D}{d}}$$

THE MOST ECONOMICAL DIAMETER OF CONDUCTOR

- We know that, the maximum stress occurs at the surface of the conductor.
- In practice, the maximum stress value should be kept as low as possible. Also, for safe working of cable, the dielectric strength of the insulation should be kept more than the g_{max}.

Rewriting the expression for maximum stress, we get

$$g_{max} = \frac{2V}{d \ln\left(\frac{D}{d}\right)} \quad \text{volts/m} \quad \text{—— (1)}$$

when voltage 'V', sheath diameter 'D' are fixed. The only parameter to be selected is the core diameter 'd'

The minimum value of g_{max} can be obtained when the denominator of (1) is maximum.

The maximum value of the denominator is obtained by differentiating it with respect to 'd' and equating it to zero.

(slope = 0)
point of

$$\frac{d}{d(d)}\left[d \ln\left(\frac{D}{d}\right)\right] = 0$$

$$d \cdot \frac{1}{\frac{D}{d}} \cdot \left(\frac{-D}{d^2}\right) + \ln\left(\frac{D}{d}\right) \cdot (1) = 0.$$

Note
$d(\ln x) = \frac{1}{x}$

$$\cancel{d} \cdot \frac{\cancel{d}}{\cancel{D}} \left(\frac{-\cancel{D}}{\cancel{d^2}}\right) + \ln\left(\frac{D}{d}\right) = 0$$

$$-1 + \ln\left(\frac{D}{d}\right) = 0$$

$$\boxed{\ln \frac{D}{d} = 1} \quad \text{——(2)}$$

Applying A. log on both sides we get

$$\frac{D}{d} = e^1$$

$$\frac{D}{d} = 2.718$$

$$\boxed{d = \frac{D}{2.718}} \quad \text{——(3)}$$

ie) The core diameter must be $\frac{1}{2.718}$ times the sheath diameter D so as to give the minimum value of g_{max}.

sub (2) in (1) we get,

$$\text{minimum } g_{max} = \frac{2V}{d}$$

$$\Rightarrow \quad d = \frac{2V}{g_{max}} \quad \text{——— (4)}$$

The main criterion for determining conductor diameter is current carrying capacity.

But using the above expressing (4). for high voltage cables, the value of core diameter 'd' determined gives very large value. than required for current carrying capacity. And such extra copper required can increase the cost tremendously. Hence to increase 'd' without the use of an extra copper. following methods are used.

1. Aluminium is used instead of copper as. the aluminium size is more than the copper for the same current carrying capacity.
2. Using stranded copper conductors around a dummy core of jute or hemp.
3. Using stranded copper conductors around a lead tube instead of hemp.

CAPACITANCE OF THREE CORE CABLES

The capacitance of a cable system is much more important than that of overhead line because in cables

(i) conductors are nearer to each other and to the earthed sheath.
(ii) They are seperated by a dielectric of permittivity much greater than that of air.

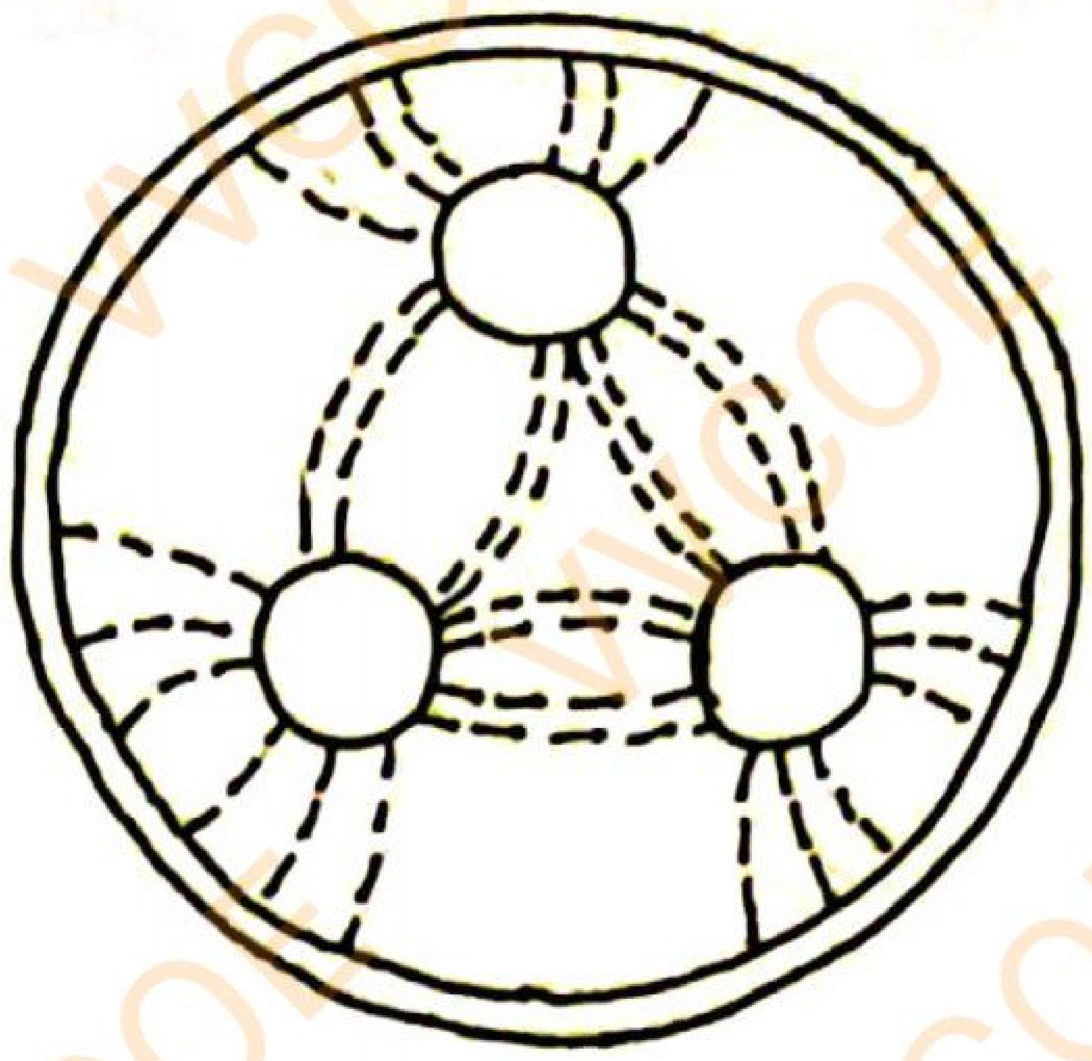
Since there is a potential difference between pairs of conductors and between each conductor and sheath, there will be a system of electrostatic fields in the cross-section of the cable as shown in Fig. Consequently the three core cable has capacitance between the cores and each core has capaitance with sheath as shown in Fig.

Let

$C_c \rightarrow$ core to core capacitance

$C_s \rightarrow$ core to sheath capacitance.

✓ Here, the three C_c are delta connected where as the three C_s are star connected.



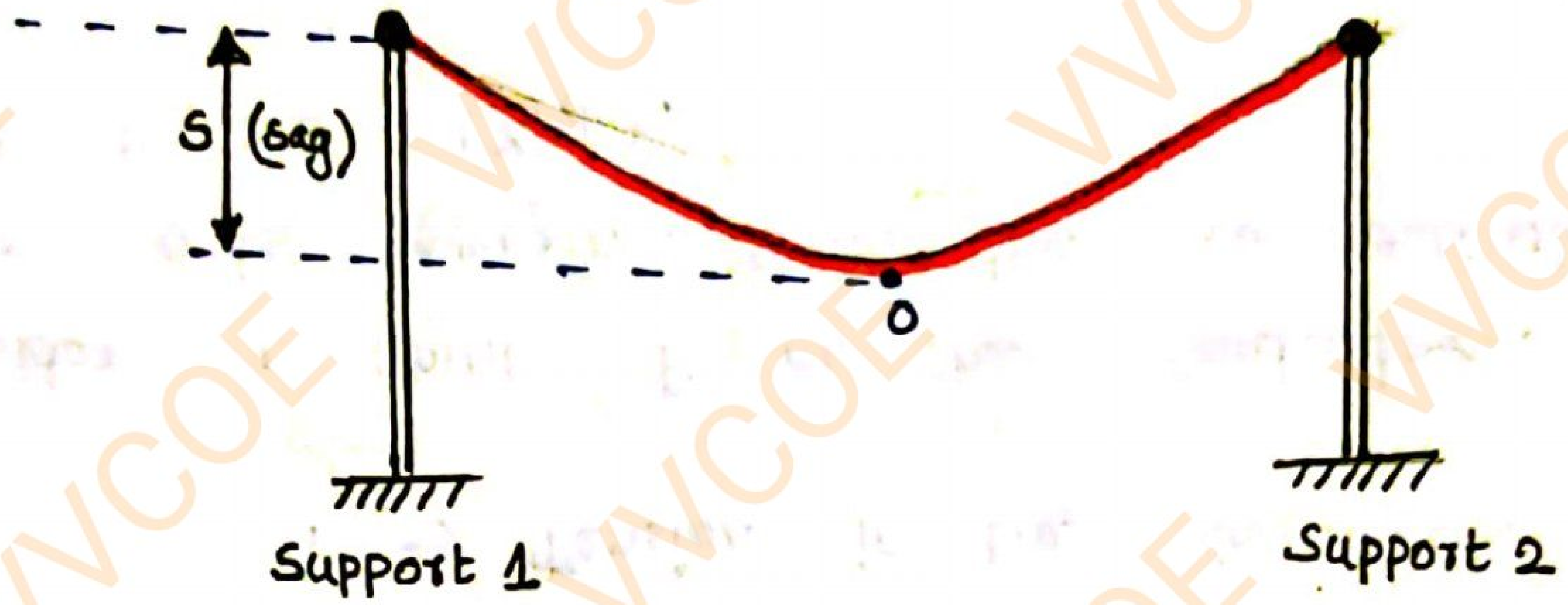
MECHANICAL DESIGN OF LINES

Mechanical design of OH lines – Line supports – Types of towers – stress and sag calculation – Effects of wind and Ice loading.

Insulators: Types, Voltage distribution in insulator string, improvement of string efficiency, testing of Insulators.

CALCULATION OF SAG AND TENSION

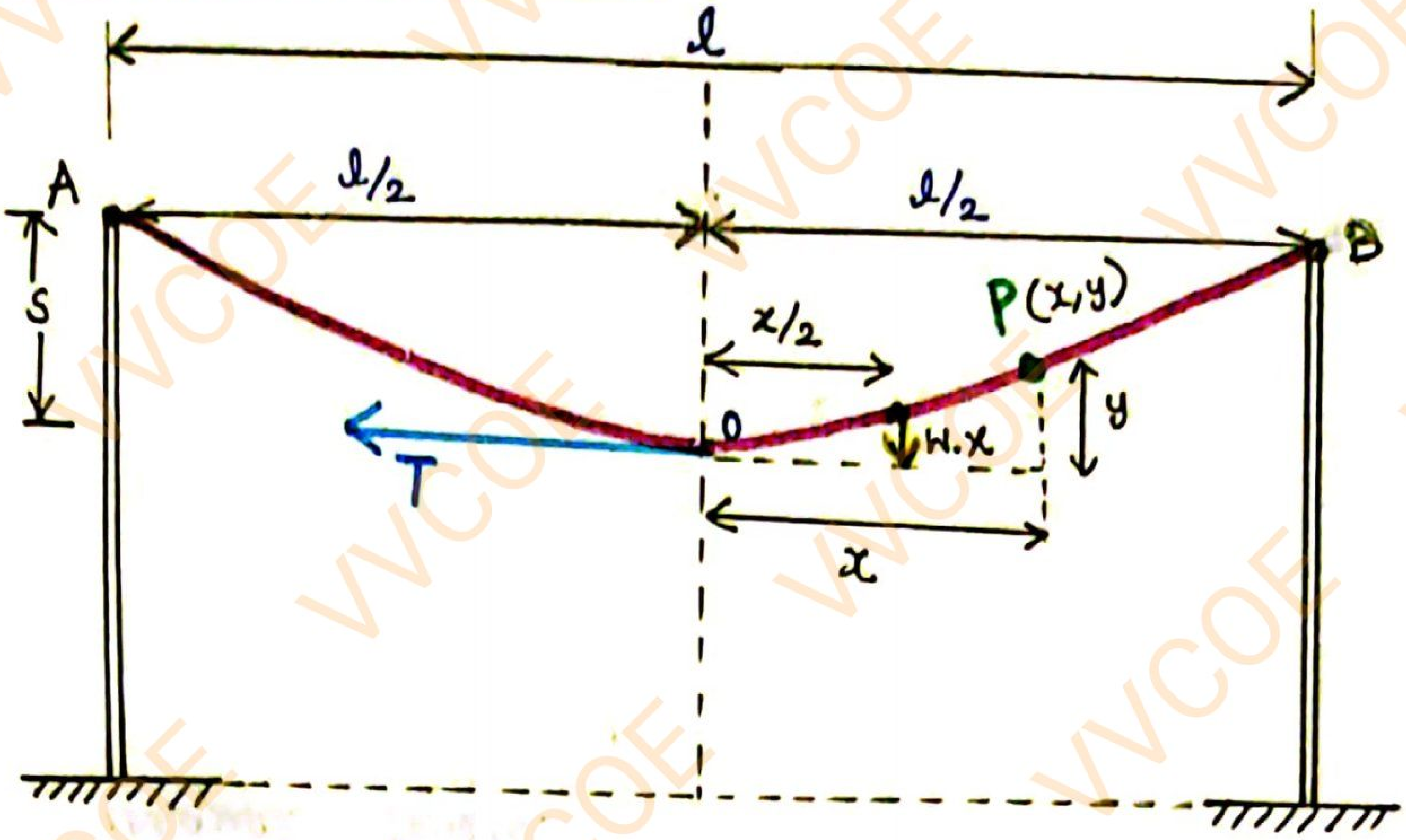
SAG :- The difference in levels between point of support and the lowest point on the conductor is called sag.



In practice there are two cases in which sag calculation differs.

1. The supports supporting the conductor are located at equal level.
2. The supports supporting the conductor at unequal levels.

Supports at Equal Level



✓ Consider a conductor between two equal level supports A and B with O as the lowest point as shown in Fig.

Let,

$l \rightarrow$ length of the span.

$W \rightarrow$ weigh per unit length of the conductor.

$T \rightarrow$ Tension in the conductor in kg

✓ Consider a point P on the conductor. and let point O is origin. Hence the co-ordinate of point P are (x,y).

✓ Assume the curvature to be so small. so that curved length is equal to x co-ordinate of point P, ie) $l(OP) = x$

✓ There are two forces acting on OP of the conductor.

1) The tension 'T'.

2) Weight 'wx' of the conductor acting at a distance $\frac{x}{2}$ from O.

Equating the moments of these two forces about P we get

Note : Moment of force = Force × ⊥r distance

$$Ty = wx \cdot \frac{x}{2}$$

$$\boxed{y = \frac{wx^2}{2T}} \quad \text{—(1)}$$

The equation shows that the trajectory is parabolic in nature.

Now at point A or B, $x = l/2$ and $y = S$

Now

$$(1) \Rightarrow \quad S = \frac{w\,(l/2)^2}{2T}$$

The maximum sag, $\boxed{S = \dfrac{w l^2}{8T}}$

The sag at any point of the conductor is, $= S - y$

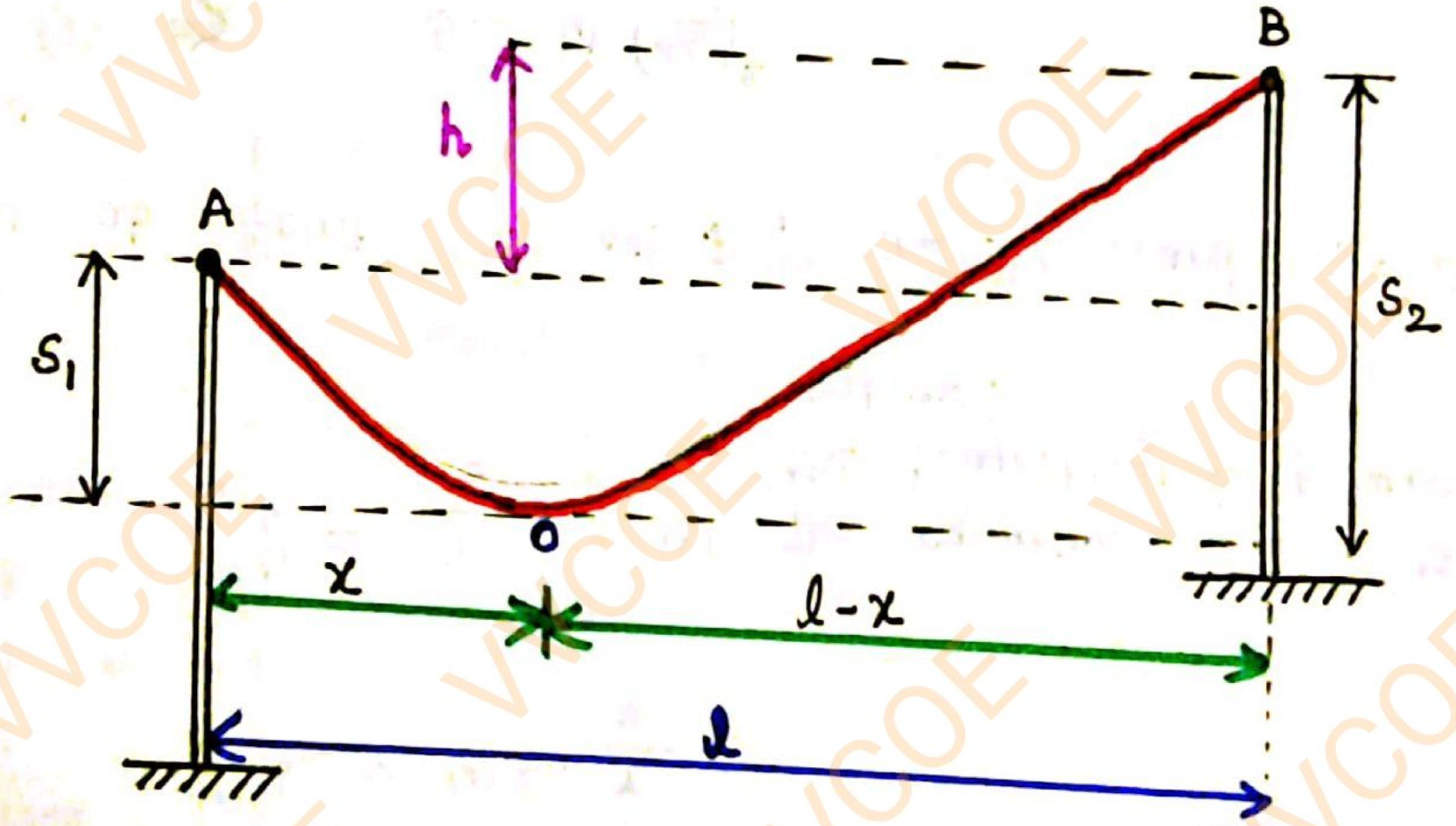
$$\Rightarrow \frac{wl^2}{8T} - \frac{wx^2}{2T}$$

$$\boxed{\text{Sag at any point P} = \frac{w}{8T}\left[l^2 - 4x^2\right]}$$

Supports at Unequal Levels

In situations like hilly areas, it is not possible to have supports at the same level. It is necessary to use supports at the different levels in the areas including small hills, river etc.

✓Consider a conductor suspended between two supports A and B which are at the unequal levels.



Let O → lowest point on the conductor.
l → span length
h → difference in the levels between two supports.
x → distance of point O from support A
l-x → distance of point O from support B
T → tension in the conductor
W → weight per unit length of the conductor.

The sag at x is, $\boxed{S_1 = \frac{wx^2}{2T}}$

The sag at $l-x$ is, $\boxed{S_2 = \frac{w(l-x)^2}{2T}}$

Difference in two levels of supports,

$$h = S_2 - S_1$$

$$= \frac{w(l-x)^2}{2T} - \frac{wx^2}{2T}$$

$$= \frac{w}{2T}\left[(l-x)^2 - x^2\right]$$

$$= \frac{w}{2T}\left[l^2 + \cancel{x^2} - 2lx - \cancel{x^2}\right]$$

$$h = \frac{w}{2T}\left[l^2 - 2lx\right]$$

$$\Rightarrow T = \frac{wl^2}{2h} - \frac{2wlx}{2h}.$$

$$2Th = wl^2 - 2wlx$$

$$2wlx = wl^2 - 2Th$$

$$x = \frac{\cancel{w}l^{\cancel{2}}}{2\cancel{w}\cancel{l}} - \frac{\cancel{2}Th}{\cancel{2}wl}$$

$$\boxed{x = \frac{l}{2} - \frac{Th}{wl}}$$

The values of S_1 and S_2 can be determined if the value of x is known.

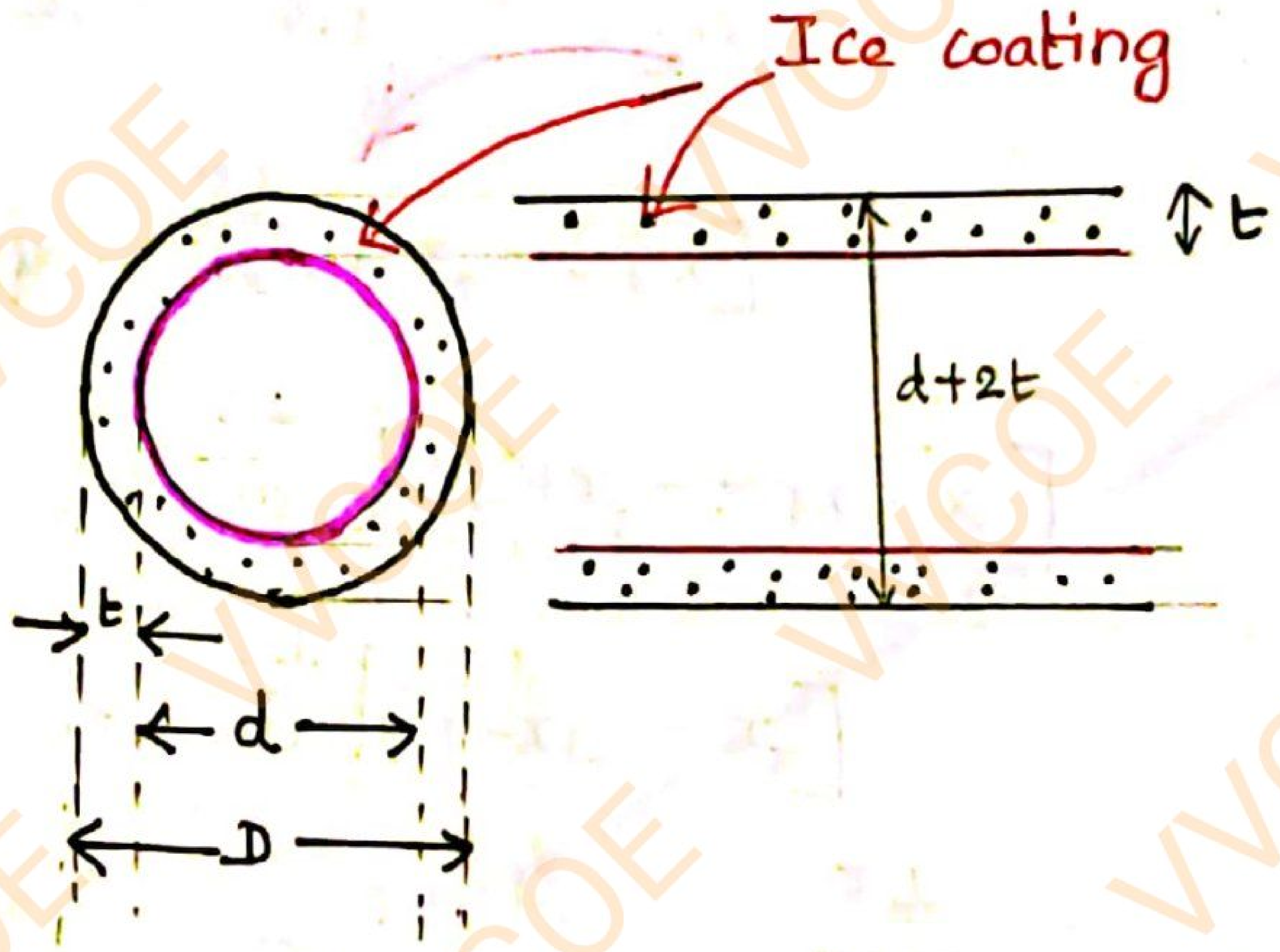
EFFECT OF WIND AND ICE LOADING

EFFECT OF ICE :-

Ice loading is the formation of ice coating over the transmission line due to severe winter and snowfalls.

As a result of ice loading,

(i) effective diameter of conductor increases.
(ii) weight of the conductor increases.
(ie. ice weight added)



Consider,

$d \rightarrow$ diameter of conductor
$t \rightarrow$ thickness of ice covering
$D \rightarrow$ over all diameter (conductor + ice coating)

$$\therefore \quad D = d + 2t \quad \text{——— (1)}$$

Area of over all conductor $= \dfrac{\pi D^2}{4}$

Area of Ice covering $= \dfrac{\pi D^2}{4} - \dfrac{\pi d^2}{4}$

$$A_i = \frac{\pi}{4}(D^2 - d^2) \quad \text{———} (2)$$

sub (1) in (2)

$$A_i = \frac{\pi}{4}\left[(d+2t)^2 - d^2\right]$$

$$= \frac{\pi}{4}\left[\cancel{d^2} + 4t^2 + 4dt - \cancel{d^2}\right]$$

$$A_i = \frac{\cancel{4}\pi t}{\cancel{4}}\left[t+d\right]$$

Volume of Ice covering = $A_i \times$ length

For unit length, $l = 1$

Now,

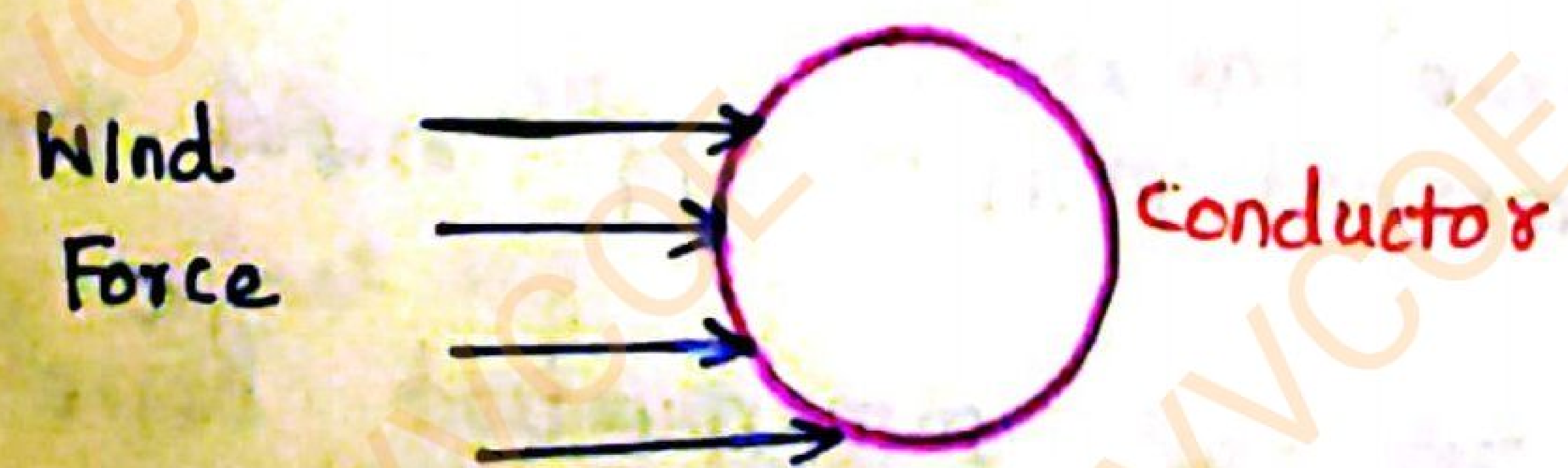
Volume of Ice covering per metre length of conductor, $V_i = \pi t\left[t+d\right]$

Weight of ice covering per unit length, W_i = Density of Ice $\times \pi t\left[t+d\right]$

density of Ice = 915 kg/m^3

$$\boxed{W_i = 915\,\pi t\left[d+t\right]}$$

EFFECT OF WIND PRESSURE



The wind flows horizontally and hence the wind pressure on the conductor is considered to be acting perpendicular to the conductor.

The wind force W_w = wind pressure per unit area $\times$ Projected surface area per unit length.

$$W_\omega = P\left[(d+2t)\times 1\right]$$

$$\boxed{W_\omega = P\ (d+2t)}$$

where

$P \rightarrow$ wind pressure in kg/m^2

COMBINED EFFCT OF WIND AND ICE

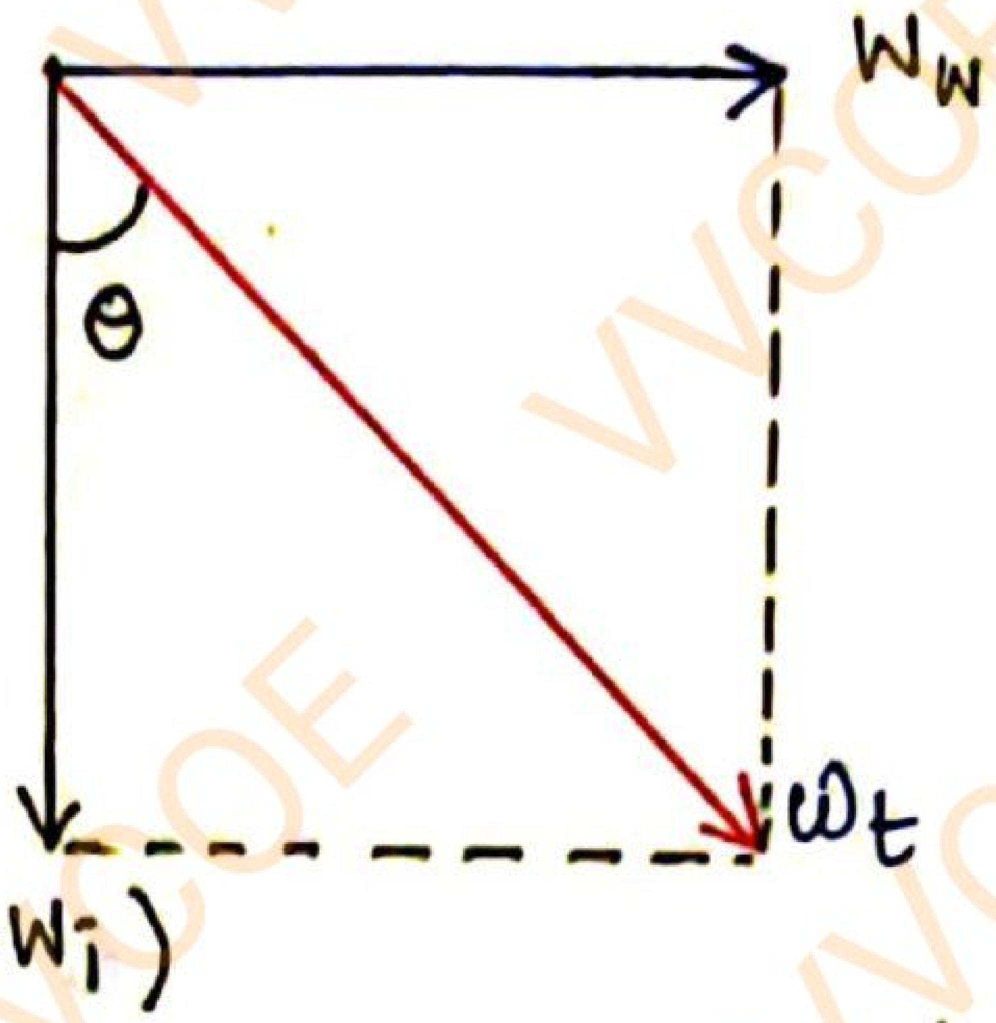
Due to the weight of ice deposits on the line and the wind pressure, the mechanical stress increases in the conductor and therefore, the line must be designed to withstand these stresses and tensions.

let

$W \rightarrow$ weight of the conductor itself acting vertically down.

$W_i \rightarrow$ weight of ice acting vertically down.

$W_\omega \rightarrow$ wind force acting horizontally.



Resultant weight acting on conductor

$$\boxed{\omega_t = \sqrt{(\omega + W_i)^2 + (W_W)^2}}$$

When the Ice and wind are acting simultaneously, the sag direction is at an angle θ measured with respect to vertical. Hence the sag is called slant sag.

Slant sag $\boxed{S = \dfrac{\omega_t l^2}{8T}}$

$$\boxed{\tan\theta = \frac{W_\omega}{(W+W_i)}}$$

Vertical sag :-

The vertical sag is the cosine component of the slag sag S. Obtained by resolving slant sag.

$$\text{Vertical sag} = S.\cos\theta.$$

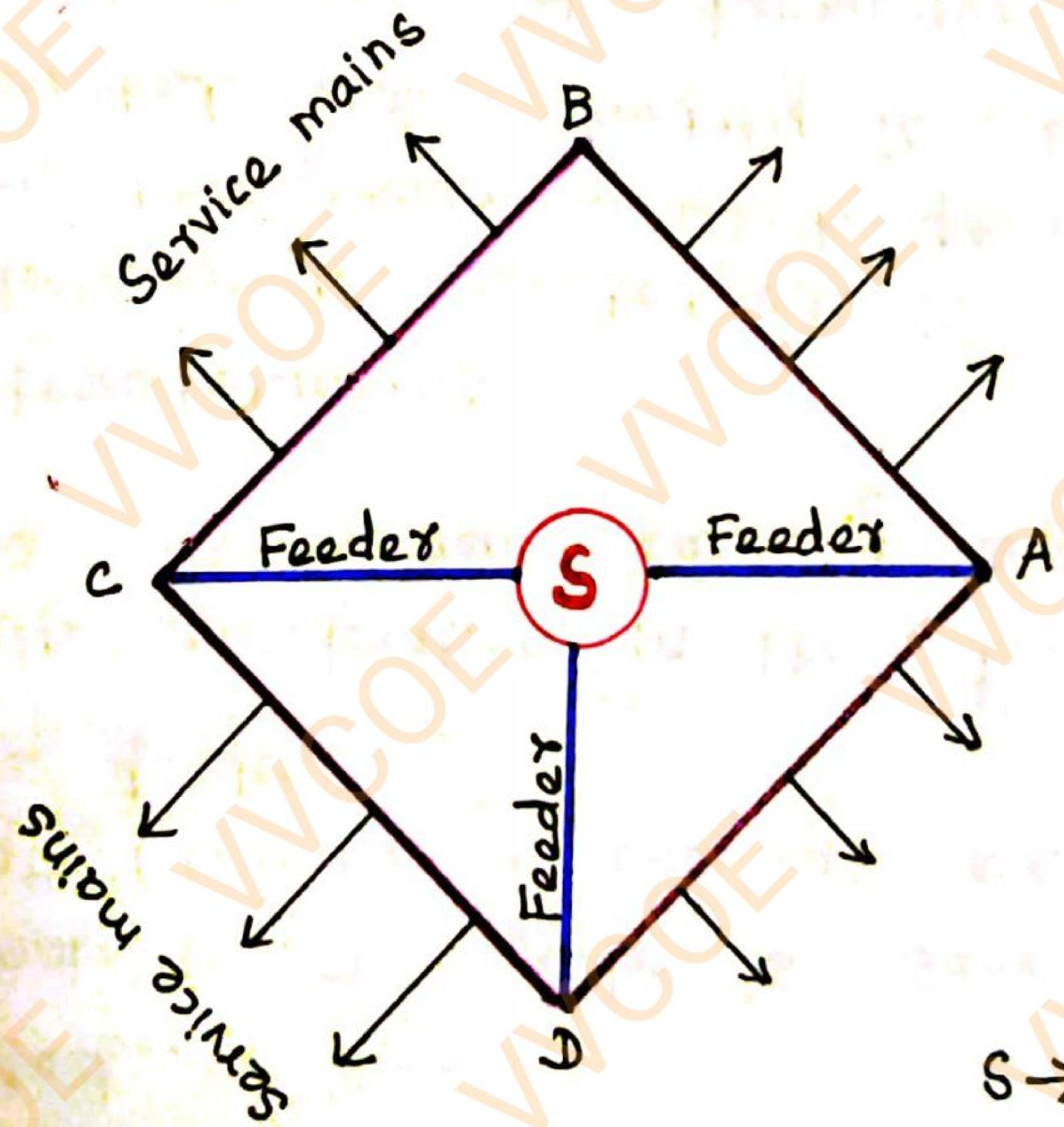
$$= \frac{\omega_t l^2}{8T}.\cos\theta$$

DISTRIBUTION SYSTEMS - GENERAL ASPECTS

✓ The part of the power system (conductor system) by means of which electrical energy is conveyed from substations to the consumer is known as distribution systems.

✓ In general, the distribution system is the electrical system between the sub-station fed by the transmission system and the consumers meters.

✓ Distribution system generally consists of
a 1) feeders 2) distributors 3) service mains.



S → substation (or) localised generating station.

Fig. Typical distribution system - Line diagram.

Feeders :-

- Feeders are conductors of large current carrying capacity. It connects the substation (or localised generating station) to the area where power is to be distributed.
- The current in the feeder is same throughout its length because no tappings are taken from the feeder.
- The main consideration in the design of a feeder is the current carrying capacity.

Distribution transformers :-

- The distribution transformer is a stepdown transformer in which primary is Delta connected and secondary is star connected.
- The output voltage of distribution transformer is 440 V for 3ϕ and 230V for 1ϕ in India.

Distributor :-

- A distributor is a conductor from which tappings are taken for supply to the customers.
- Because of tappings, that are taken at various places along the length of distributor, the current is not same throughout its length.
- The main consideration of a distributor, while designing, is the voltage drop across its length.
- In Fig. AB, BC, CD and DA are the distributors.

Service Mains :-

- A service mains is generally a small cable which connects the distributor to the consumers terminals.
- service mains are tapped from distributors as shown in Fig.

CLASSIFICATION OF DISTRIBUTION SYSTEMS

A distribution system can be classified according to

(i) Nature of current :-

According to nature of current, distribution system may be classified as

(a) D.C distribution system.
(b) A.C distribution system.

Now-a-days, A.C distribution system is universally adopted for distribution of electric power as it is simpler and more economical than direct current method.

(ii) character of service :-

According to the character of service, the distribution system may be classified as.

(a) General light and power
(b) Industrial power
(c) railway
(d) street lighting etc...

(III) Type of construction:-

According to the type of construction, the distribution system may be classified as

(a) over head distribution system and

(b) Underground distribution system.

- over head system is generally employed for distribution as it is 5 to 10 times cheaper than equivalent underground system.

- In general, the underground system is used at places where overhead construction is impracticable or prohibited by local laws.

(IV) Number of wires:-

According to number of wires the distribution systems may be classified as

(a) two wire distribution system.

(b) Three wire distribution system.

(c) Four wire distribution system.

(V) Scheme of connection:-

According to scheme of connection, the distribution system may be classified as

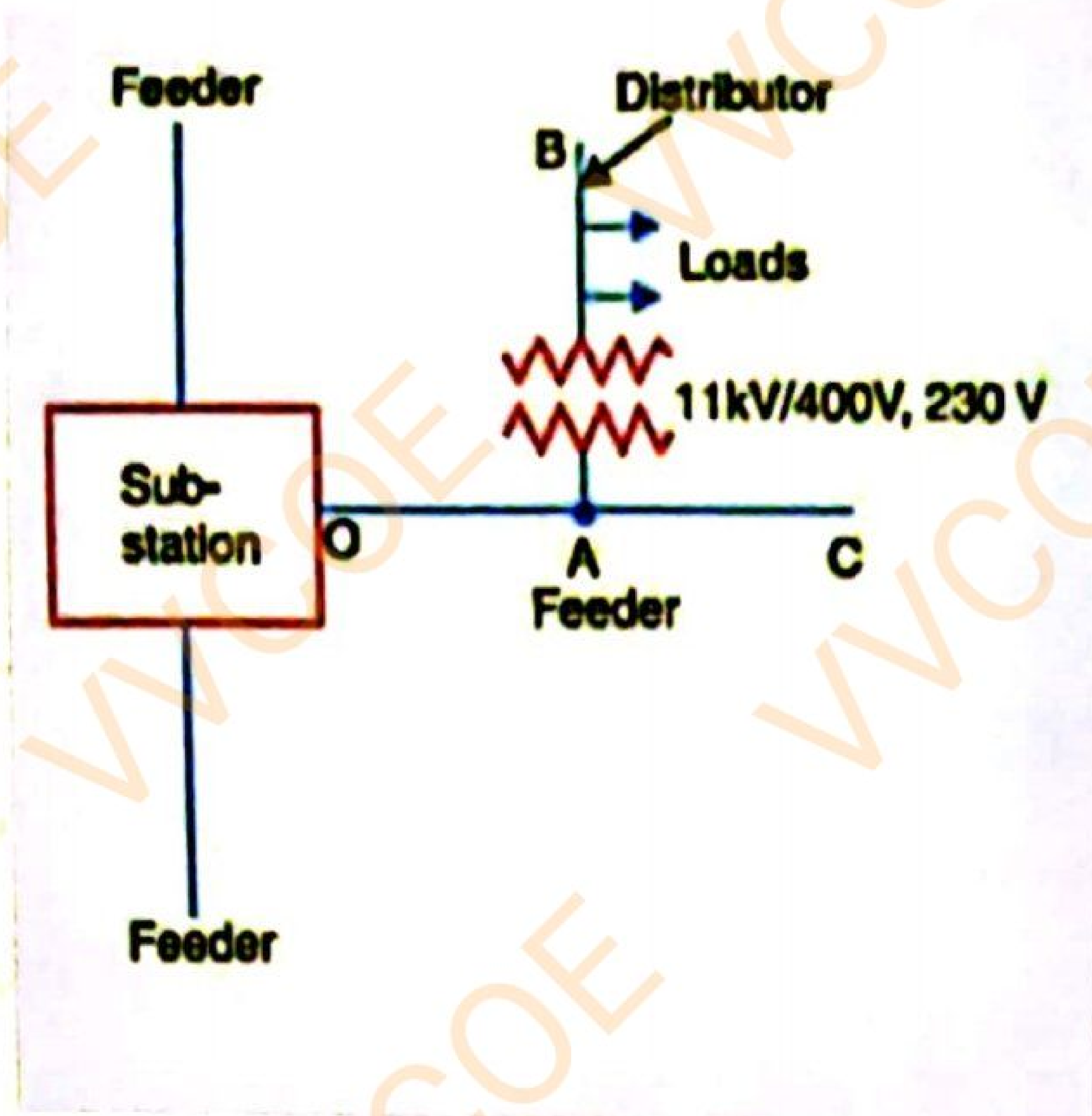
(a) radial

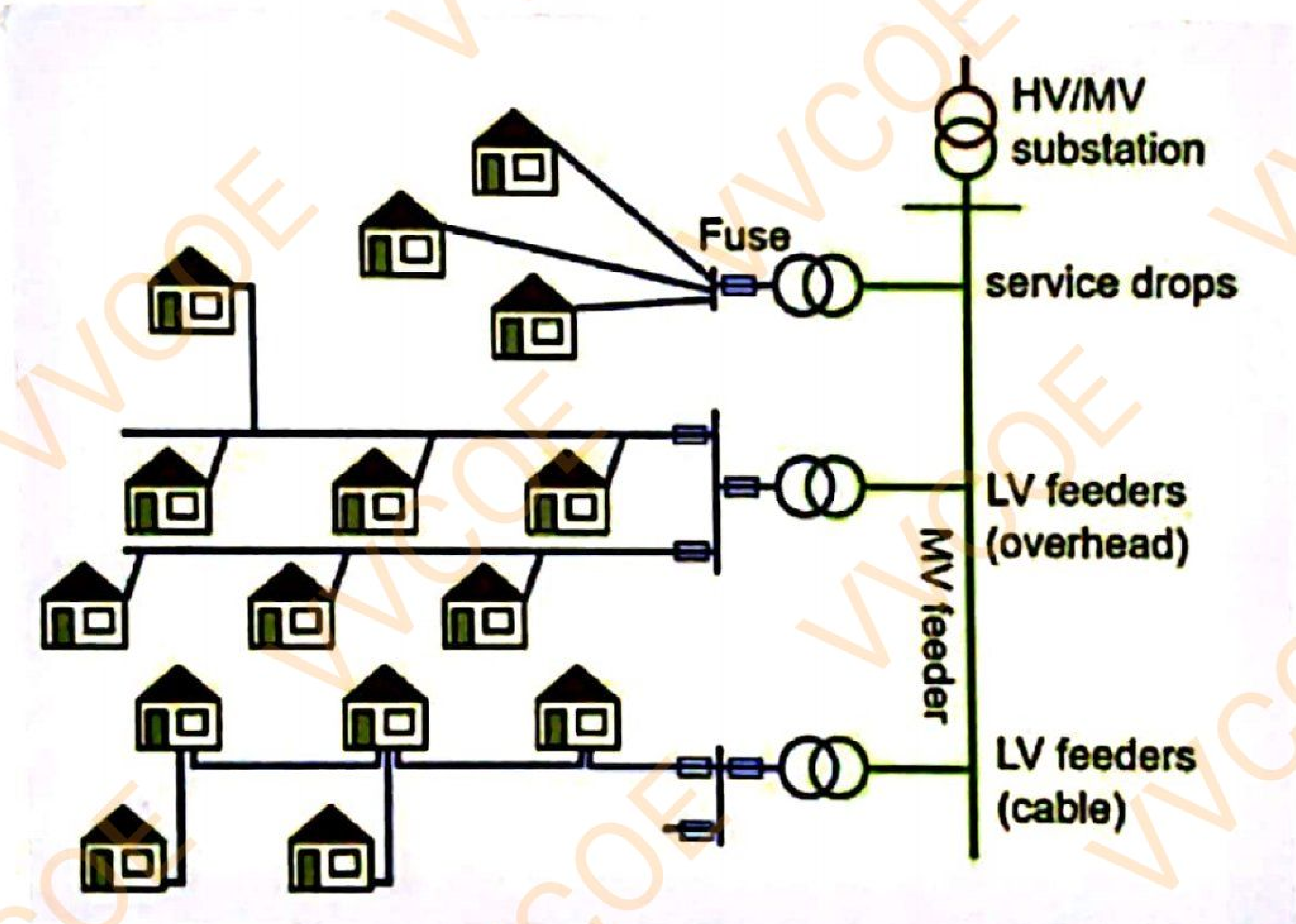
(b) ring main system

(c) Inter connected system.

CONNECTION SCHEMES OF DISTRIBUTION SYSTEM

1. **Radial system :-** Feeders radiate from one single substation





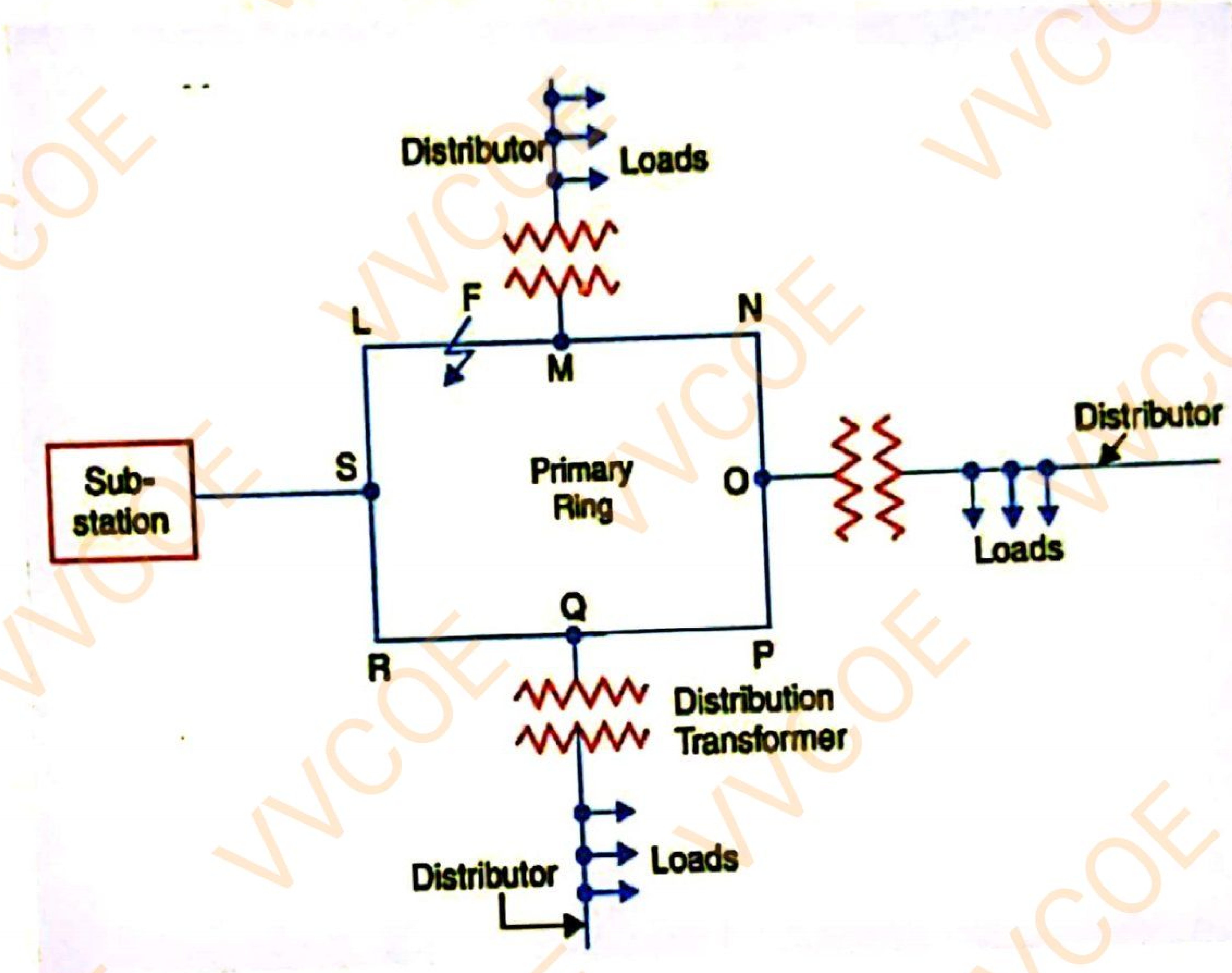
→ In this type, the distributor is connected to supply mains at one end and loads are tapped at different points along the length of the distributor.

→ In this type of distribution system, voltage across the load away from the feeding point goes on decreasing. The minimum voltage occurs on the farthest load point and distributor nearest to the feeding point is heavily loaded.

→ so cusumer at the distant end would be subjected to serious voltage fluctuations.

→ This is the simplest distribution circuit and has the lowest initial cost. However, If fault occurs in any section of feeder or distributor, the whole distributor gets cuts off. The supply continuity is disturbed.

2. Ring main System:



→ In this system, The feeder is in closed loop form and looks like a ring. Hence the name.

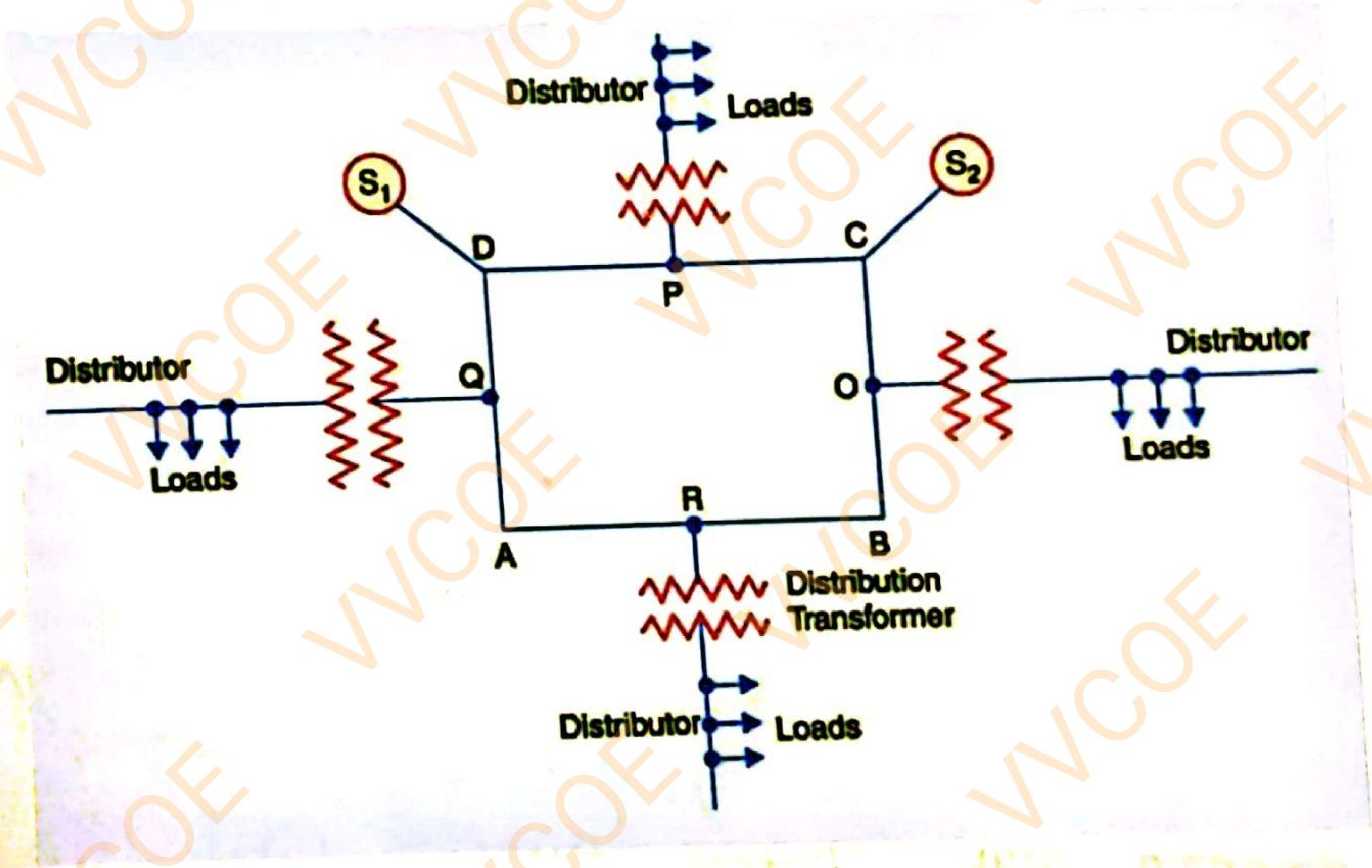
→ The loop circuit starts from the substation bus-bars, makes a loop through the area to be served, and returns to the substation.

→ The distributors are tapped at different points M, O, Q of the feeder through distribution transformers.

→ The system is very reliable because each distributor is fed through two feeders.

✓ Suppose fault occurs at any point F of section SLM of the feeder. The section SLM of the feeder can be isolated for repairs and at the same time continuity of the supply is maintained to all the consumers through SRQPONM.

3. Inter connected system :-



→ When the feeder ring is energised by two or more generating stations or substations, it is called inter-connected system.

→ The single line diagram of interconnected system is shown in Fig. The closed feeder ring is ABCD is supplied by two substations S_1 and S_2 at points D and C respectively

→ Distributors are connected to points O, P, Q & and R of the feeder ring through distribution transformers.

→ The interconnected system has the following advantages.

✓ It increases the service reliability.

✓ Any area fed from one generating station during peak load hours can be fed from the other generating station.

✓ It improves efficiency of the system.

KELVIN'S LAW

The economic size of the conductor is selected by using Kelvin's law.

The economic design of the conductor is that when the total annual cost is minimum.

Total Annual cost = annual charge on the capital investment + annual charge due to loss of energy.

charge on capital investment :- cost of depreciation, interest on capital cost of the conductor, maintenance cost.

charge due to loss of energy :- I^2R loss (due to resistance).

let,

$a \rightarrow$ area of cross-section of conductor

$C_1 \rightarrow$ annual charge on capital investment

$C_2 \rightarrow$ annual charge due to loss of energy.

Annual charge on capital investment is directly proportional to the area of cross-section of the conductor.

$$\therefore \quad C_1 \propto a$$

$$C_1 = K_1 a \quad \text{— (1)}$$

where, $K_1 \rightarrow$ proportionality constant.

✓ Annual charge due to loss of energy is inversely proportional to the area of cross-section of the conductor. $\left[\because R = \frac{\rho l}{a}\right]$

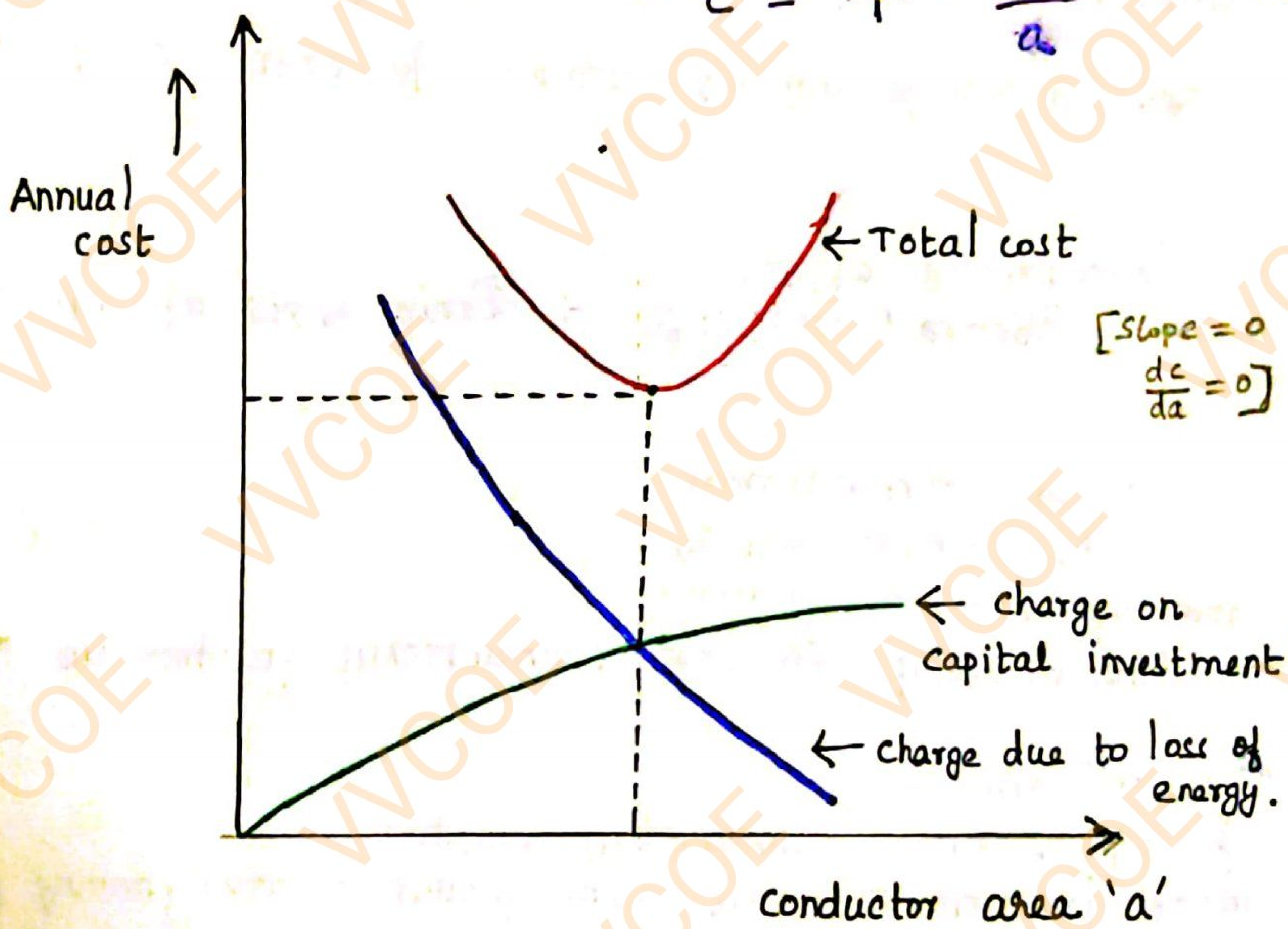
$$\therefore \; C_2 \propto \frac{1}{a}$$

$$C_2 = \frac{K_2}{a} \quad \text{——(2)}$$

$K_2 \rightarrow$ Proportionality constant.

Total annual charges, $C = C_1 + C_2$

$$C = K_1 a + \frac{K_2}{a} \quad \text{——(3)}$$



For C to be minimum, differentiate total cost with respect to area of cross section and equate it to zero.

$$\frac{d}{da}\left[K_1 a + \frac{K_2}{a}\right] = 0$$

$$K_1 - \frac{K_2}{a^2} = 0$$

$$K_1 = \frac{K_2}{a^2}$$

$$a K_1 = \frac{K_2}{a} \qquad [(1) \text{ and } (2)]$$

$$C_1 = C_2$$

Hence, the most economical area of conductor is when,

Annual charge on capital Investment = Annual charge due to loss of energy.

D.C DISTRIBUTION

→ In the beginning, electricity was generated as direct current (D.c). (but had many practical drawbacks).

→ With the development of transformer, A.c has overtaken D.C.

→ Now-a-days electrical energy is generated, transmitted and distributed in the form of A.c. Because A.c voltage can be efficiently and conveniently raised or lowered for economic transmission and distribution.

→ However, for certain applications, D.c supply is absolutely necessary.

eg) ✓ DC supply is required for operation of variable speed machinery (D.c motors).

✓ Electrochemical work.

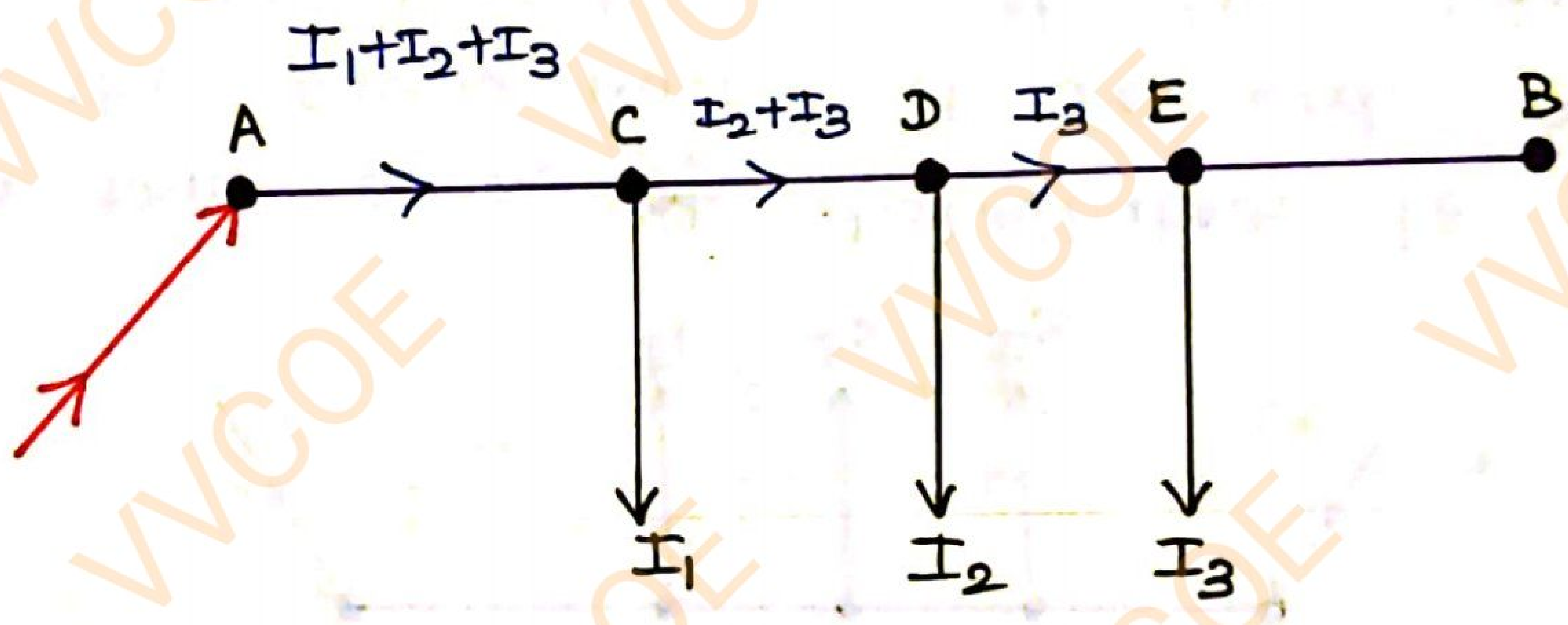
✓ Electric traction.

TYPES OF D.C DISTRIBUTORS

The D.C distributors are classified as
(i) Distributor fed at one end.
(ii) Distributor fed at both ends.
(III) Distributor fed at the centre
(IV) Ring distributor.

(i) DISTRIBUTOR FED AT ONE END :-

(Also known as → Singly fed Distributor.)



→ In this type, the distributor (AB) is connected to supply at one end only (A).

→ The loads are tapped at different points along the length of distributor.
(ie loads I_1, I_2, I_3 tapped off at points C, D, and E respectively)

Here,

✓ The current in the various sections of the distributor away from the feeding point goes on decreasing.

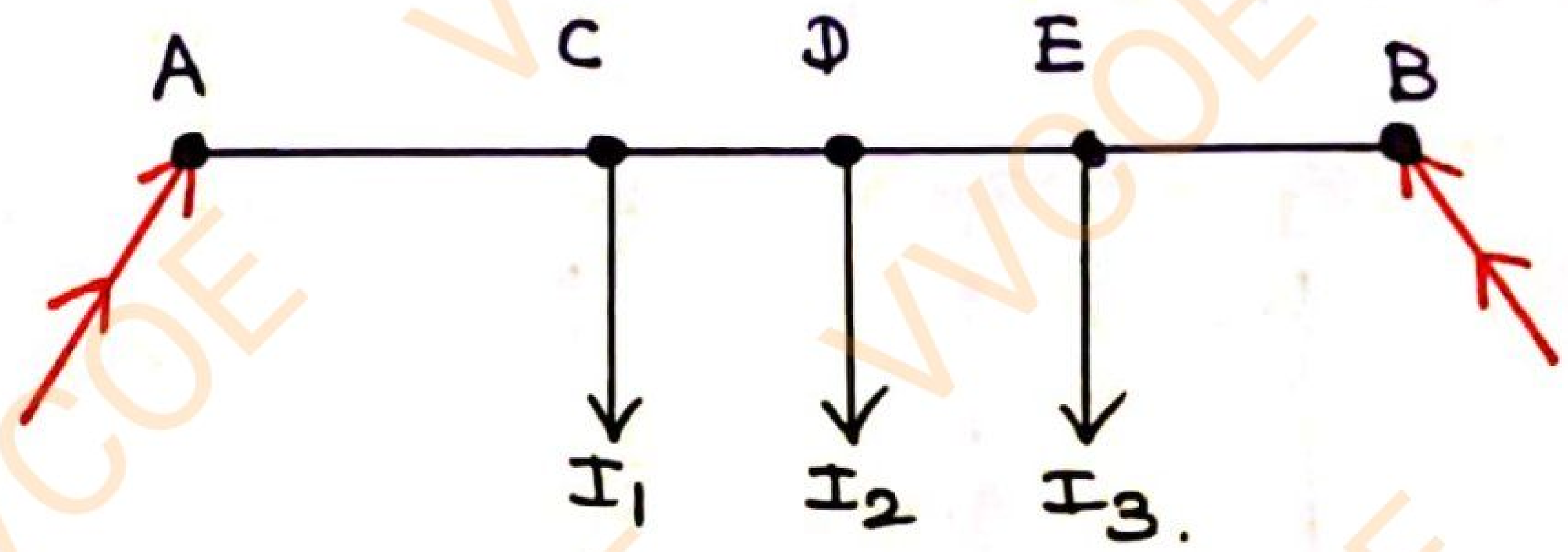
ie) current in.

Section AC > Section CD > Section DE.

✓ The voltage across the loads away from feeding point goes on decreasing ie) minimum voltage occurs on the farthest load point.

✓ In case a fault occurs on any section of the distributor, the whole distributor will have to be disconnected from the supply.

(ii) DISTRIBUTOR FED AT BOTH ENDS



→ In this case, the distributor is connected to the supply mains at both ends and loads are tapped off at the different points along the length of the distributor.

→ The voltage at both feeding points may be different or equal.

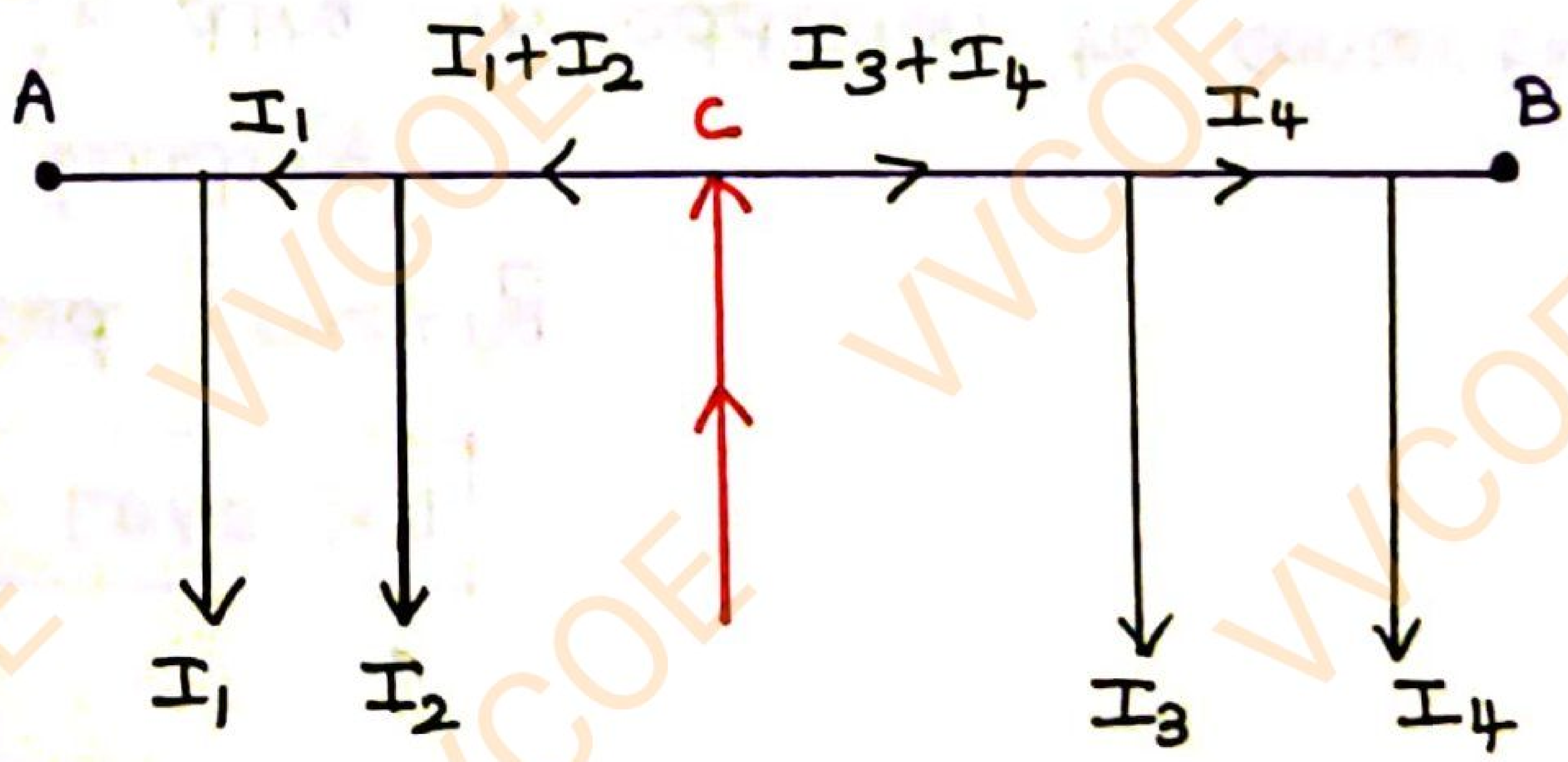
→ Here, the load voltage goes on decreasing as we move away from one feeding point say A, reaches minimum value and then again starts rising and reaches maximum value when we reach the other feeding point B.

→ The minimum voltage occurs at some load point and is never fixed. It is shifted with the variation of load on different sections of the distributor.

✓ If a fault occurs at any feeding point of the distributor, the continuity of the supply is maintained from the supply.

✓ In case of fault on any section of the distributor, the continuity of supply is maintained at other feeding point.

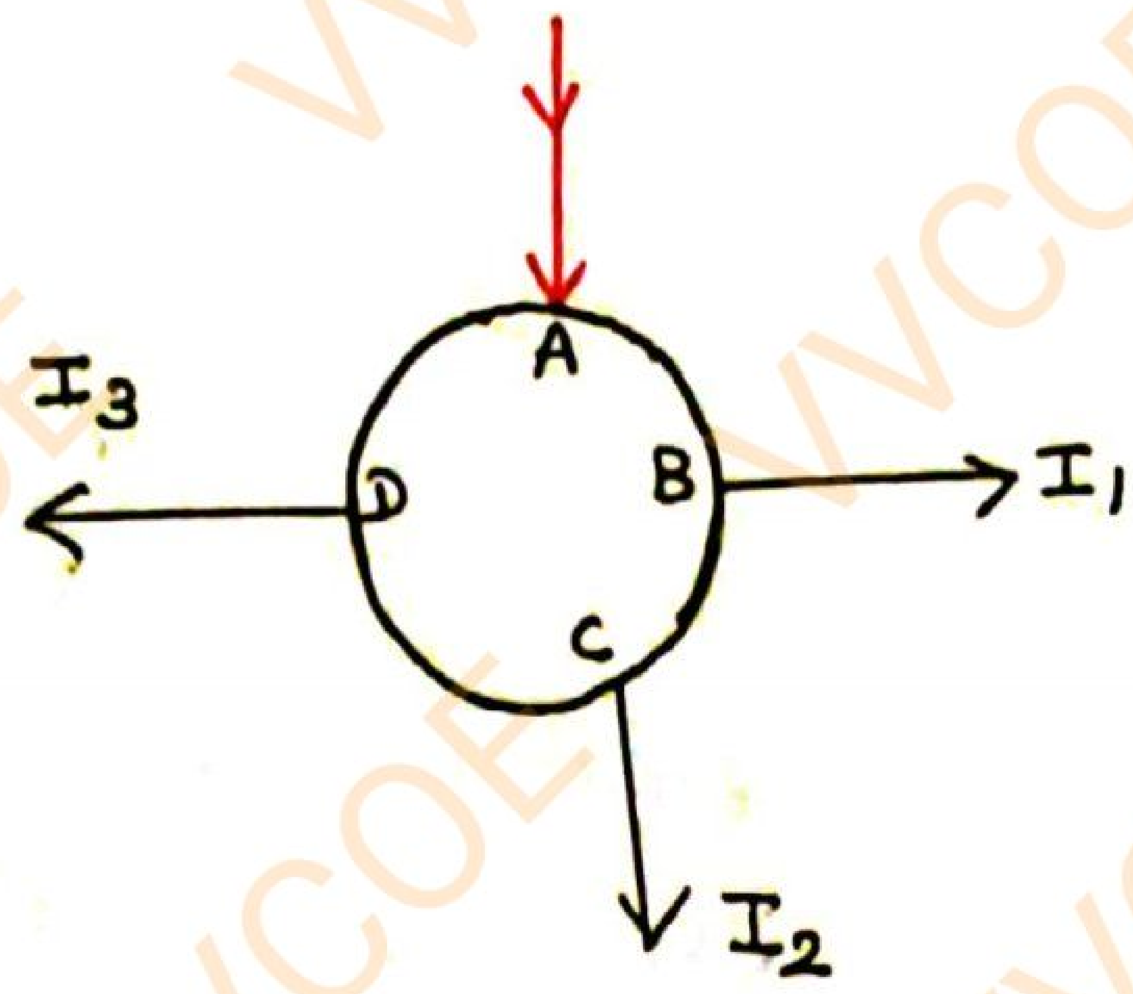
(III) DISTRIBUTOR FED AT THE CENTRE :-



→ In this type, the centre of the distributor is connected to the supply mains

→ This type of distributor is equivalen to two singly fed distributor.

(iv) RING MAIN DISTRIBUTOR



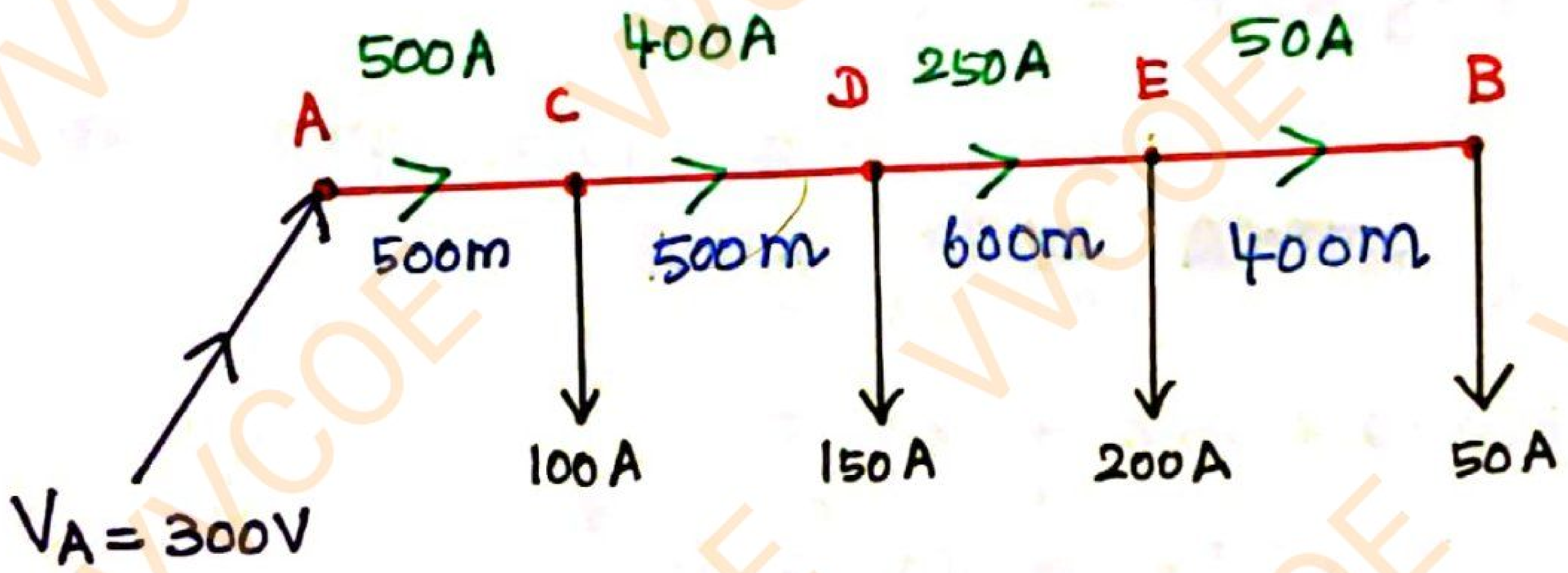
→ In this type, the distributor is in the form of ring.

TYPES OF LOADING

1. Concentrated loading
2. Uniform loading
3. Uniform loading in addition to concentrated loading.

1. A 2-wire D.C distributor cable AB is 2km long and supplies loads of 100A, 150A, 200A and 50A situated 500m, 1000m, 1600m and 2000m from the feeding point A. Each Conductor has a resistance of 0.01Ω per 1000m. Calculate the P.d at each load point if a P.d of 300V is maintained at point A.

Solution:-



given, ⟹ resistance of each conductor = 0.01 m per 1000m

Resistance of section AC, $R_{AC} = 0.02 \times \frac{500}{1000} = 0.01\ \Omega$

Resistance of section CD, $R_{CD} = 0.02 \times \frac{500}{1000} = 0.01\ \Omega$.

Resistance of Section DE, $R_{DE} = 0.02 \times \frac{600}{1000} = 0.012\ \Omega$

Resistance of section EB, $R_{EB} = 0.02 \times \frac{400}{1000} = 0.008\ \Omega$

P.D at load point C,

V_C = Voltage at A − Voltage drop in AC

$= V_A - I_{AC} R_{AC}$

$= 300 - 500 \times 0.01$

$= 295\ V.$

P.D at load point D,

$V_D = V_C - I_{CD} R_{CD}$

$= 295 - 400 \times 0.01$

$= 291\ V.$

P.D at load point E,

$V_E = V_D - I_{DE} R_{DE}$

$= 291 - 250 \times 0.012$

$= 288\ V$

P.D at load point B,

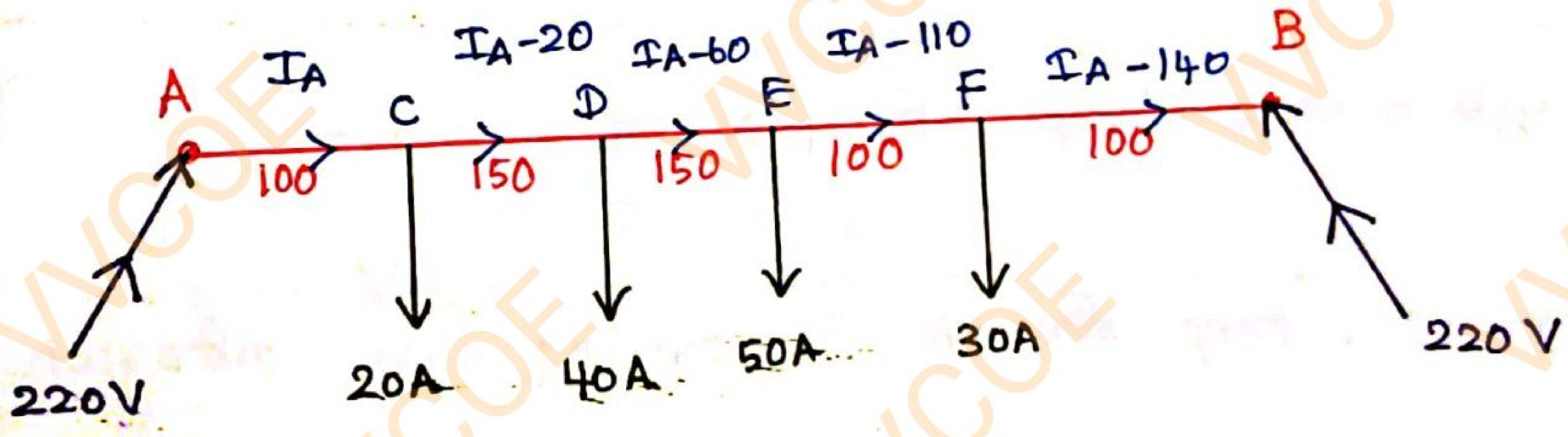
$V_B = V_E - I_{EB} R_{EB}$

$= 288 - 50 \times 0.008$

$= 287.6\ V$

A 2-wire DC street mains AB, 600m long is fed from both ends at 220 V. Loads of 20 A, 40 A, 50 A and 30 A are tapped at distances of 100m, 250m, 400m and 500m from end A respectively. If the area of X-section of distributor conductor is $1 cm^2$, find the minimum consumer voltage. Take $\rho = 1.7 \times 10^{-6}\ \Omega\ cm$.

Solution-



Resistance/m

$$R = \frac{\rho l}{A}$$

$$= \frac{1.7 \times 10^{-6} \times 100}{1}$$

$$= 1.7 \times 10^{-4}\ \Omega/m$$

For 2 wire $\Rightarrow$ $R = 1.7 \times 10^{-4} \times 2$

$$= 3.4 \times 10^{-4}\ \Omega/m$$

Resistance of section AC, $R_{AC} = 3.4 \times 10^{-4} \times 100$
$= 0.034\,\Omega$

Resistance of section CD, $R_{CD} = 3.4 \times 10^{-4} \times 150$
$= 0.051\,\Omega$

Resistance of section DE, $R_{DE} = 3.4 \times 10^{-4} \times 150$
$= 0.051\,\Omega$

Resistance of section EF, $R_{EF} = 3.4 \times 10^{-4} \times 100$
$= 0.034\,\Omega$

Resistance of section FB, $R_{FB} = 3.4 \times 10^{-4} \times 100$
$= 0.034\,\Omega$.

For understanding only

Voltage drop between A & B = Voltage drop over AB.

$V - V$ = voltage drop over length AB

$$\boxed{\text{Voltage at B} = \text{Voltage at A} - \text{Drop over length AB}}$$

$$V_B = V_A - \left[I_A R_{AC} + (I_A - 20) R_{CD} + (I_A - 60) R_{DE} + (I_A - 110) R_{EF} + (I_A - 140) R_{FB} \right]$$

$$220 = 220 - \left[0.034\, I_A + 0.051 (I_A - 20) + 0.051 (I_A - 60) + 0.034 (I_A - 110) + 0.034 (I_A - 140) \right]$$

$$= 220 - \left[0.204\, I_A - 12.58 \right]$$

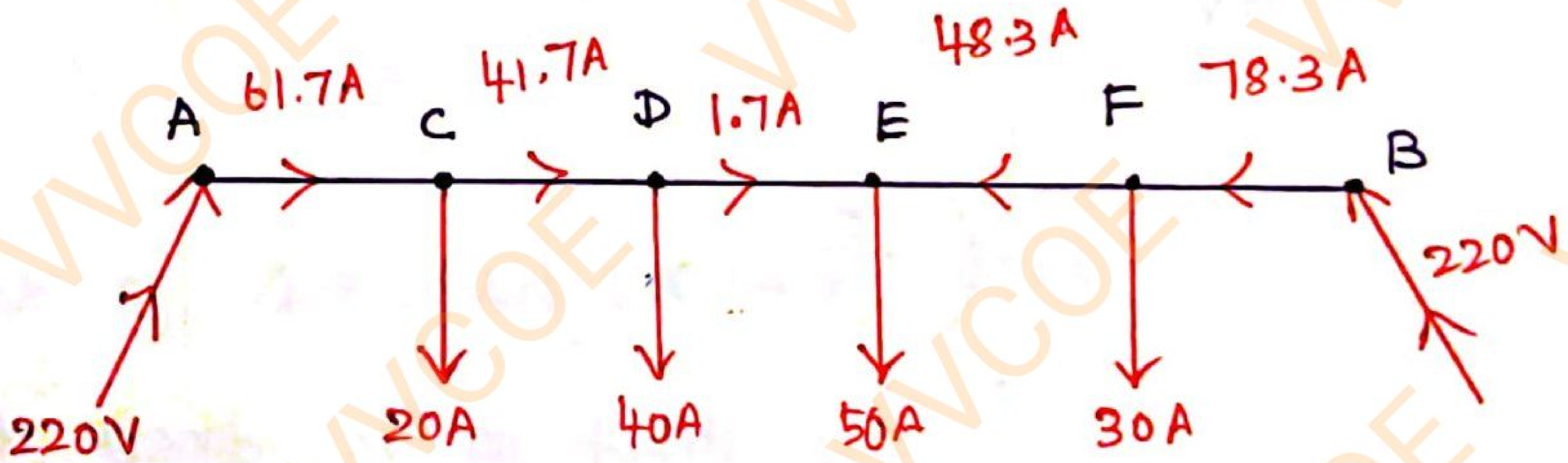
$$I_A = \frac{12.58}{0.204}$$

$$I_A = 61.7$$

→ It is clear that currents are coming to load point E from both sides

$\boxed{\text{Hence, E is the point of minimum Potential.}}$

Minimum consumer voltage,



Minimum consumer voltage,

$$V_E = V_A - [I_{AC} R_{AC} + I_{CD} R_{CD} + I_{DE} R_{DE}]$$

$$= 220 - [61.7 \times 0.034 + 41.7 \times 0.051 + 1.7 \times 0.051]$$

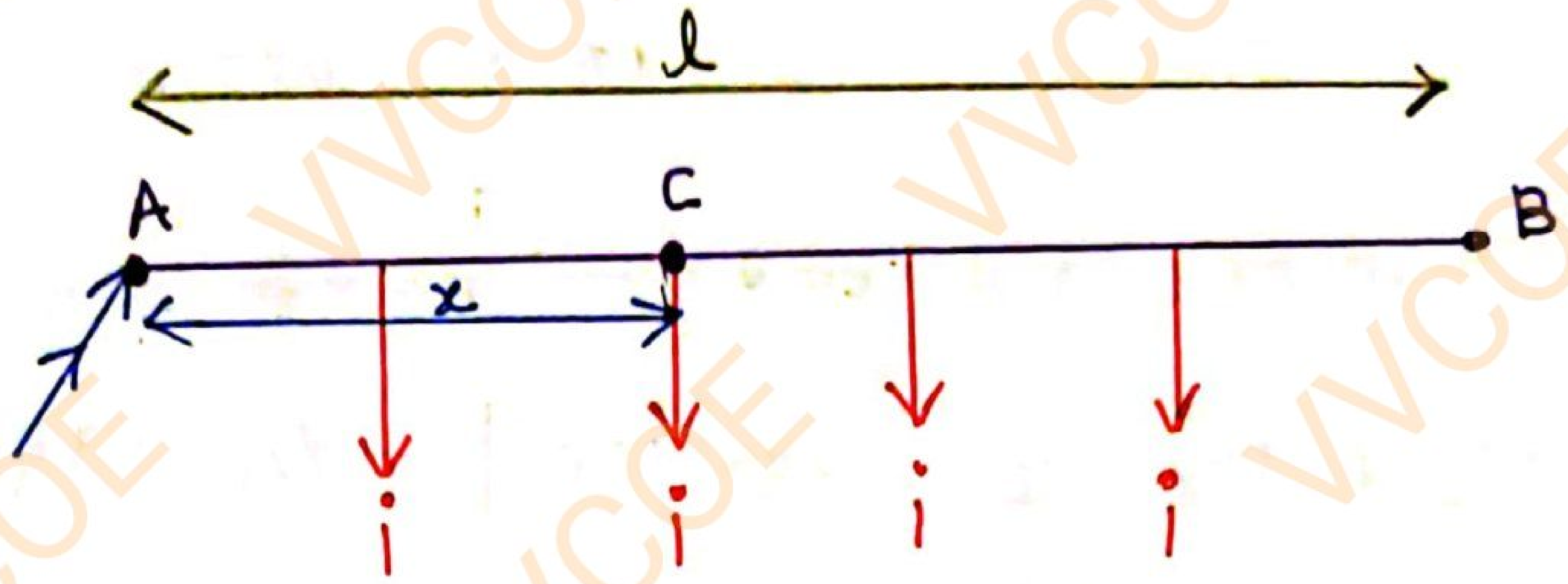
$$= 220 - 4.31$$

$$= 215.69V$$

UNIFORMLY LOADED DISTRIBUTOR FED AT ONE END.

$r \rightarrow$ resistance of distributor / m

$i \rightarrow$ current / m



Voltage drop up to point C

$$\boxed{v = ir\left(lx - \frac{x^2}{2}\right)}$$

Voltage drop over the distributor AB.

$$v = \frac{1}{2} I R$$

$I \rightarrow il$

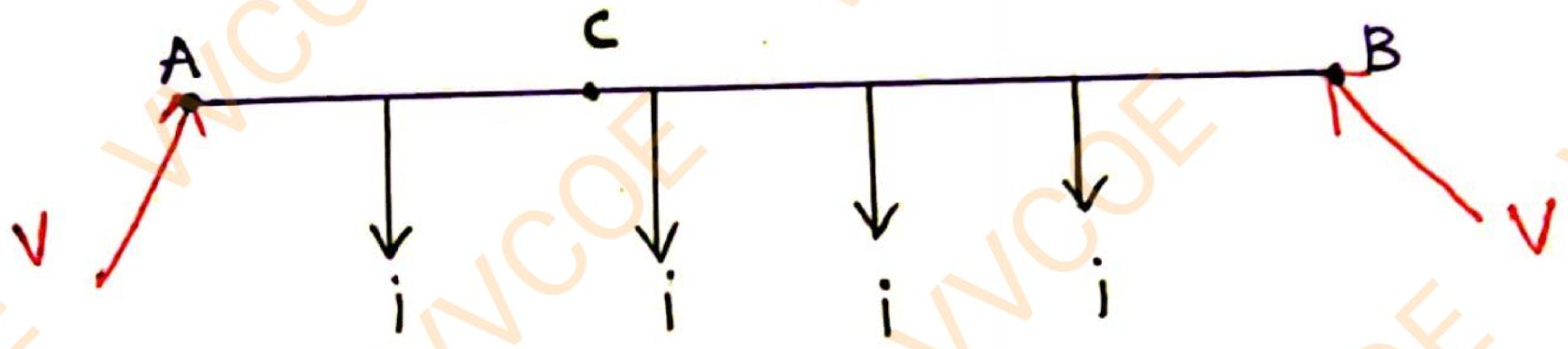
$R \rightarrow rl$

Power loss in the distributor

$$\boxed{P = \frac{i^2 r l^3}{3}}$$

UNIFORMLY LOADED DISTRIBUTOR FED AT BOTH ENDS

(a) Distributor fed at both ends with equal voltages:-



✓ Voltage drop up to point C

$$\boxed{v = \frac{ir}{2}(lx - x^2)}$$

✓ Point of maximum voltage drop.

$$\boxed{v_{max} = \frac{IR}{8}}$$

✓ Point of minimum voltage drop

$$\boxed{v_{min} = V - \frac{IR}{8}}$$