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Play Narrations
Use Timings
Show Media Controls

Monitor: Automatic

Use Presenter View

Start Slide Show

The Supply System

- It is the interlink between the generating stations and the consumers over which power is transferred.

Or, in a more simple way -

- Power is generated in the generating stations and this power is made available to the consumers by the supply system.
- It consists of network of conductors and associated items/equipment over which the energy is transferred from generating stations to the consumers.

1 Subject: Power Systems I Date: 03/03/2021

Topic: Power Systems

- 1. Supply Systems
- 2. Standard Design of Overhead Lines
- 3. Reinforced Design of Overhead Lines
- 4. Insulators
- 5. Insulated Cables
- 6. Transmission Line Performance
- 7. Codes and
- 8. Interactions with Communication Circuits

2 Books

- 1. The Transmission and Distribution of Electrical Energy By R. Davies & R. Barker
- 2. Power System Analysis By J. D. Kerec & William D. Stevenson
- 3. Power System Engineering By G. R. Barker & J. J. Wiegert
- 4. Electrical Power Systems By G. L. Mathew
- 5. Textbook of Electrical Engineering By S. S. Thakur

3 Characteristics

- 1. It is the interface between the generating systems and the consumers over which power is transferred.
- 2. It is a more simple way.
- 3. Power is generated in the generating stations and this power is made available to the consumers by the supply system.
- 4. A series of networks of conductors and associated components over which the energy is transferred from generating stations to the consumers.

4 Components of a power system

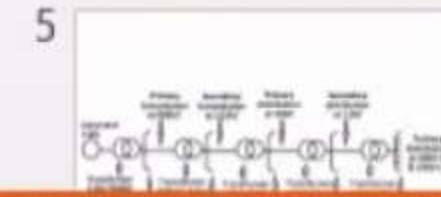
- 1. Transmission system
- 2. Distribution system

- Transmission system may further be subdivided into:

- (i) Primary transmission (765kV, 400kV, 275kV & 220kV)
- (ii) Secondary transmission (132kV & 66kV).

- Distribution system may further be subdivided into:

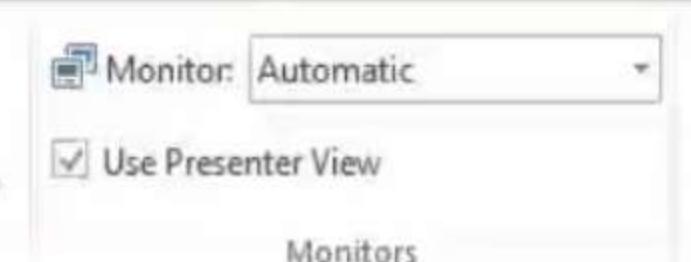
- (i) Primary distribution (33kV),
- (ii) Secondary distribution (11kV & 6.6kV) and
- (iii) Tertiary distribution (400V – Line to line, 230V – Line to neutral).



The supply system is subdivided into two distinct parts:

1. Transmission system and
2. Distribution system.

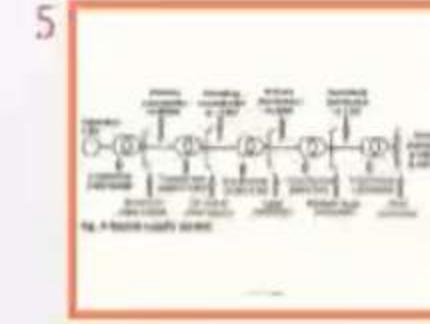
- Transmission system may further be subdivided into:
 - (i) Primary transmission (**765kV, 400kV, 275kV & 220kV**) and
 - (ii) Secondary transmission (**132kV & 66kV**).
- Distribution system may further be subdivided into:
 - (i) Primary distribution (**33kV**),
 - (ii) Secondary distribution (**11kV & 6.6kV**) and
 - (iii) Tertiary distribution (**400V – Line to line, 230V – Line to neutral**).

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- 2
- 1. The Transformer and Distribution of Electrical Energy
 - 2. By W. Goren & M. Barker
 - 3. Power System Analysis
 - 4. By John J. Grainger & William D. Stevenson
 - 5. Power System Engineering
 - 6. By R. D. Barker & J. C. Chapman
 - 7. Electrical Power Systems
 - 8. By G. L. Mathew
 - 9. Transmission & Distribution
 - 10. By S. S. Thakur

- 3
- Ques Answer Boxes**
- 1. It is the interface between the generating stations and the consumers over which power is transferred.
 - 2. Generators in the generating stations and the power is made available to the consumers by the supply system.
 - 3. Process of receiving, utilising and making reasonable arrangements over which the energy is transferred from generating stations to the consumers.

- 4
- Transmission System**
1. Transmission system
 2. Substation system
 3. Transmission system may further be subdivided into:
 - (i) Primary transmission (400kV, 220kV, 132kV & 66kV).
 - (ii) Secondary transmission (220kV & 66kV).
 - (iii) Distribution system may further be subdivided into:
 - (i) Primary distribution (33kV).
 - (ii) Secondary distribution (11kV & 400V).
 - (iii) Tertiary distribution (400V-LL & 230V-LN).



- 6
- Ques Answer Boxes**
- 1. Used for remote monitoring, control and power systems.
 - 2. A computer or digital device which is connected to a communication network for information exchange.
 - 3. Change of voltage conditions in consumer's premises.

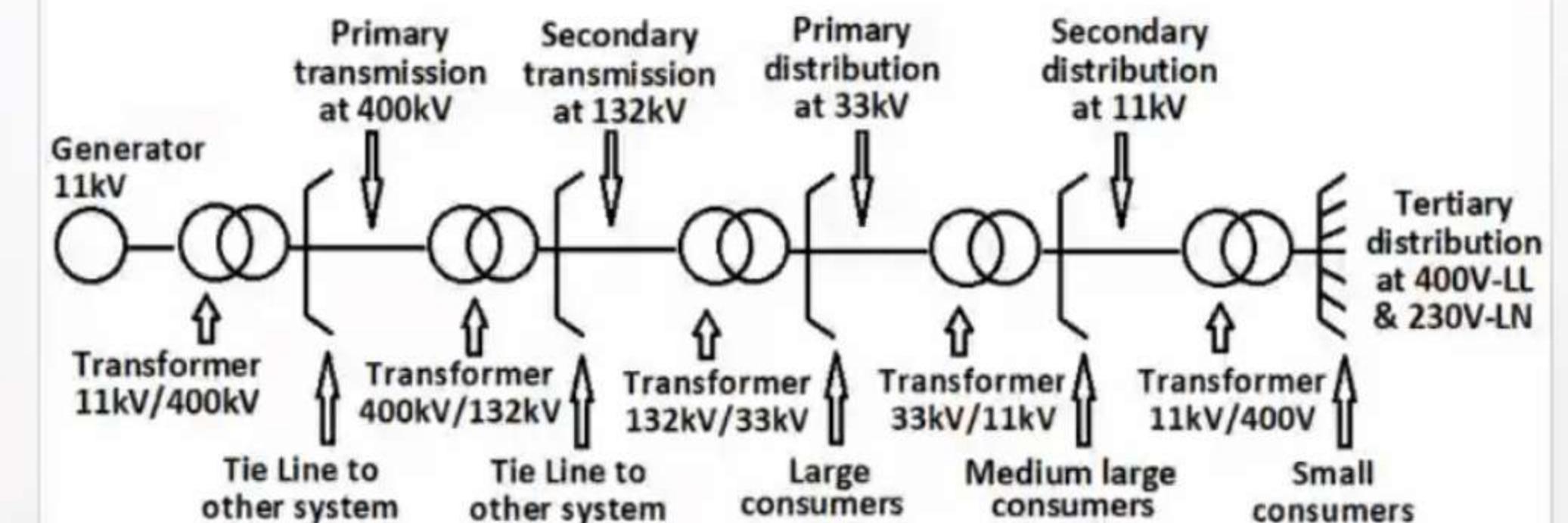


Fig. A typical supply system



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Monitors

3

Transmission system

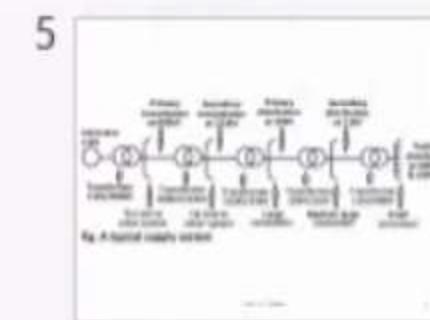
- It is the interface between the generating stations and the consumers over which power is transferred.
- Or in a more simple way:
- Power is generated in the generating stations and this power is made available to the consumers by the supply system.
- Process of transfer of electricity and associated components over which the energy is transferred from generating stations to the consumers.

4

Distribution system

1. Transmission system
2. Distribution system

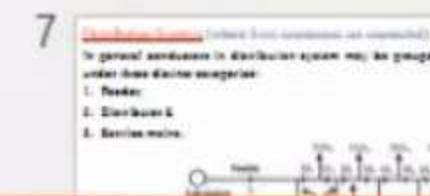
- Transmission system may further be subdivided into:
 - (i) Primary transmission (33KV, 40KV, 66KV, 110KV)
 - (ii) Secondary transmission (11KV & 6KV)
- Distribution system may further be subdivided into:
 - (i) Primary distribution (33KV)
 - (ii) Secondary distribution (11KV & 6KV)
 - (iii) Tertiary distribution (33KV → Distribution, 11KV → Line or feeder)



6

Substation

- There are several working voltages in the same system.
- Change of voltage takes place where in a substation → it is a place known as **substation**.
- Change of voltage is effected by means of a transformer.
- For equipment manufacturing reasons & for interconnections, voltages are standardized.
- Standard frequency in our country is **50Hz**.



➤ Points to note:

- There are several working voltages in the same system.
- Change of voltage takes place where in a substation → it is a place known as **substation**.
- Change of voltage is effected by means of a transformer.
- For equipment manufacturing reasons & for interconnections, voltages are standardized.
- Standard frequency in our country is **50Hz**.

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8

Feeder: Connecting link between the substation and the area served by the system.

- Current feeding of a feeder is same along the whole length.
- Its tapping connection is taken from the feeder along the length.

Distributor: Connecting link between the feeder & the service mains.

- It is characterized by numerous tappings in the form of service mains for connecting the consumers.
- Current feeding of distributor decreases from the feeding point to the terminals.

Service main: Connecting link between the distributor & the terminals of the consumer.

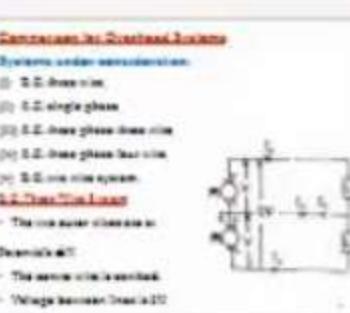
9

Service mains: Connection for various houses

- It is necessary to design the supply system more conveniently & to use of resources as much as possible.
- Geometrically it is necessary to minimize the amount of copper necessary for reducing possible system voltage drop.

Geometric:

- (A) To supply the same power.
- (B) Distance T same for all the systems.
- (C) Efficiency losses in losses are same for all the systems.
- (D) Cost of insulation is same for all the systems.
- For insulated lines maximum voltage "V" across conductor is same for all the systems.
- The underground feeder maximum voltage "V" between the two conductors is same for all the systems.



11

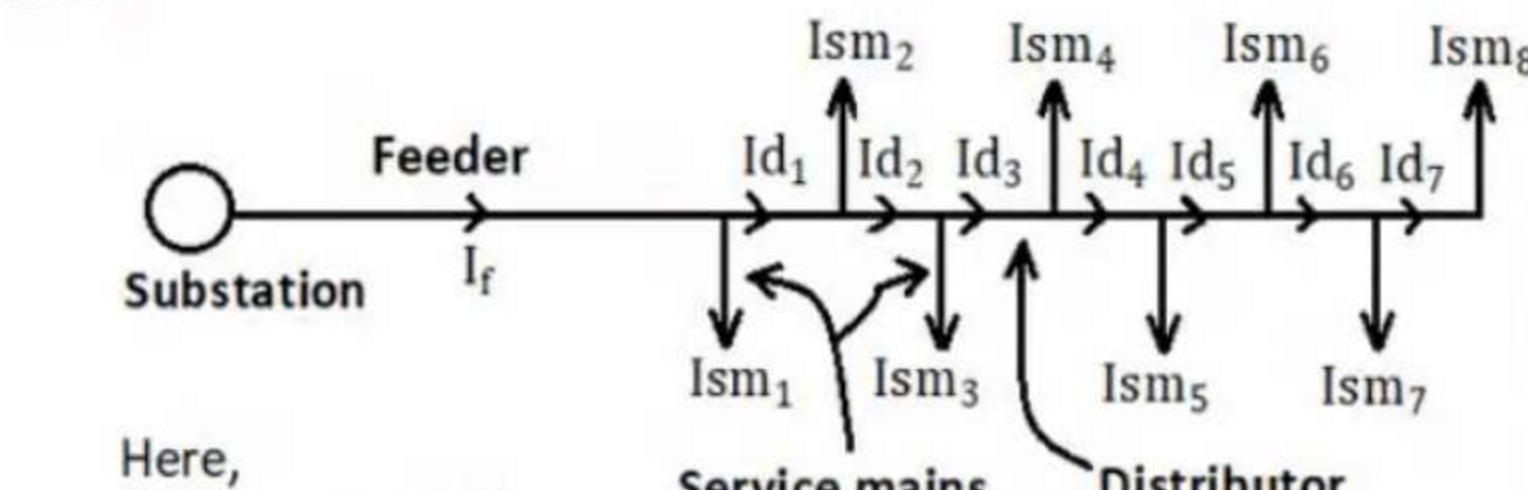
Line current: $I_L = \frac{P}{\sqrt{3}V}$
 $I_L = \frac{P}{\sqrt{3}V} = \frac{P}{\sqrt{3}V_0} (k)$
 $\therefore I_L = \frac{P}{\sqrt{3}V_0} (k)$

A.C. Power Factor:
 $P = V_0 I_0 \cos \phi$

Distribution Systems (where from consumers are connected)

In general conductors in distribution system may be grouped under three distinct categories:

1. Feeder,
2. Distributor &
3. Service mains.



Here,
 Feeder current: I_f
 Distributor currents: $Id_1, Id_2, Id_3, Id_4, Id_5, Id_6, Id_7$
 $(Id_1 > Id_2 > Id_3 \dots > Id_7)$
 Service main currents: $Ism_1, Ism_2, Ism_3, Ism_4, Ism_5, Ism_6, Ism_7, Ism_8$

Fig. A typical distribution system.

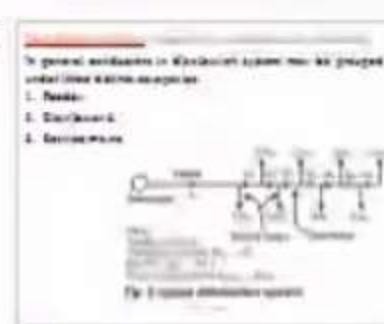
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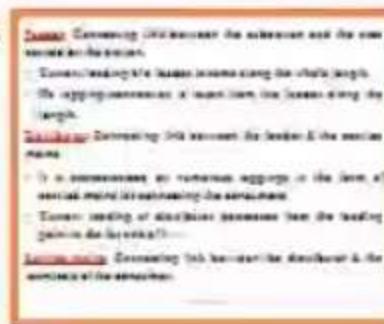
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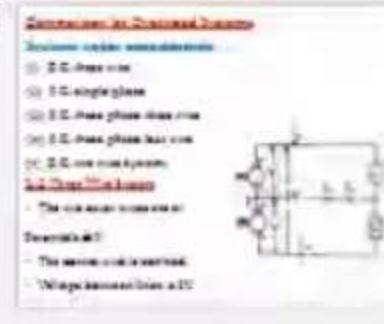
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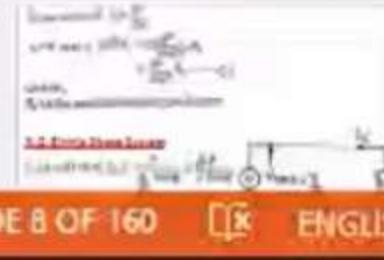
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11 

Feeder: Connecting link between the substation and the area served by the station.

- Current loading of a feeder is same along the whole length.
- No tapping/connection is taken from the feeder along the length.

Distributor: Connecting link between the feeder & the service mains.

- It is characterised by numerous tappings in the form of service mains for connecting the consumers.
- Current loading of distributor decreases from the feeding point to the far end of it.

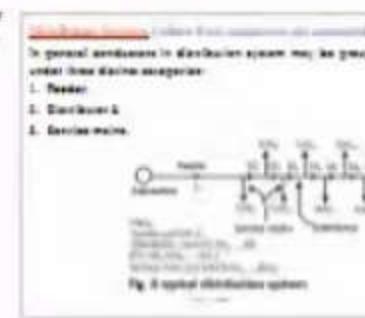
Service mains: Connecting link between the distributor & the terminals of the consumer.

Prof. S. S. Thakur

8

SLIDE 8 OF 160

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Series: Connecting this between the substation and the area served by the system.

- Current flowing in the feeder is same along the whole length.
- No stepping down is taken from the feeder along the length.

Shunt: Connecting this between the feeder & the service meter.

- It is characterized by numerous step-down in the form of service meter for decreasing the voltage.
- Current flowing at different distances from the feeding point is the same.

Delta: Connecting this between the distributor & the consumers at the terminals of the consumers.

9

Assumptions: Common assumptions for various systems

- To supply the same power P .
- Distance 'l' is same for all the systems.
- Efficiency is same for all the systems.
- Cost of insulation is same for all the systems.
- For overhead lines maximum voltage 'V' between conductor to earth is same for all the systems.
- For under ground cables maximum voltage 'V' between the conductors is same for all the systems.



11

Line current $I_L = \frac{P}{\sqrt{3} V}$

$$\text{Line loss} = \frac{I_L^2 R}{\sqrt{3} V} = \frac{\left(\frac{P}{\sqrt{3} V}\right)^2 R}{\sqrt{3} V} = \frac{P^2 R}{3 V^3}$$

D.C. Line Losses:

$$\text{Line current } I_L = \frac{P}{V}$$

$$\text{Line loss} = I_L^2 R = \frac{P^2 R}{V^2}$$

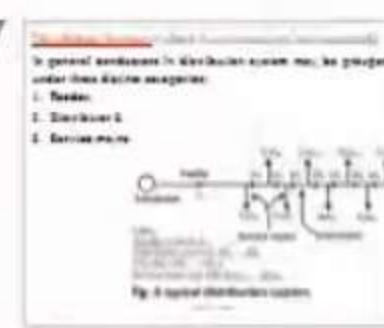
Copper Efficiency Comparison for Various Systems

- It is necessary to design the supply systems most economically → i.e. use of resources as much as possible.
- Accordingly, it is necessary to compare the amounts of copper necessary for various possible systems of supply.

➤ Assumptions:

- (1) To supply the same power P .
- (2) Distance 'l' is same for all the systems.
- (3) Efficiency is same, i.e. losses are same for all the systems.
- (4) Cost of insulation is same for all the systems.
 - For overhead lines maximum voltage 'V' between conductor to earth is same for all the systems.
 - For under ground cables maximum voltage 'V' between the conductors is same for all the systems.

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8

QUESTION: Distinguishing link between the distributor and the consumer
- Current leading off a leader is increasing along the chord length.
- The stepping connection is taken from the leader along the length.

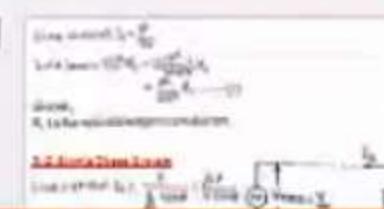
ANSWER: Distinguishing link between the distributor & the service point
- It is characterized by numerous supplies in the form of service meters bypassing the distributor.
- Current leading off distributor decreases from the feeding point to the load end.

ANSWER: Distinguishing link between the distributor & the consumer

9

ANSWER: Comparison for Overhead Systems
- It is necessary to design the supply system more conveniently if the use of transmission facilities possible.
- Increasingly it is necessary to increase the amount of higher voltage to reduce specific system energy.

QUESTION:
(A) Supply the same power? (B) Distribute the same load? (C) Efficiency, losses in lines are same for all the systems... (D) Cost of insulation is same for all the systems...
- For increased line maximum voltage "V" because conductor is much closer to all the systems.
- For underground cables maximum voltage "V" between the conductors is same for all the systems.



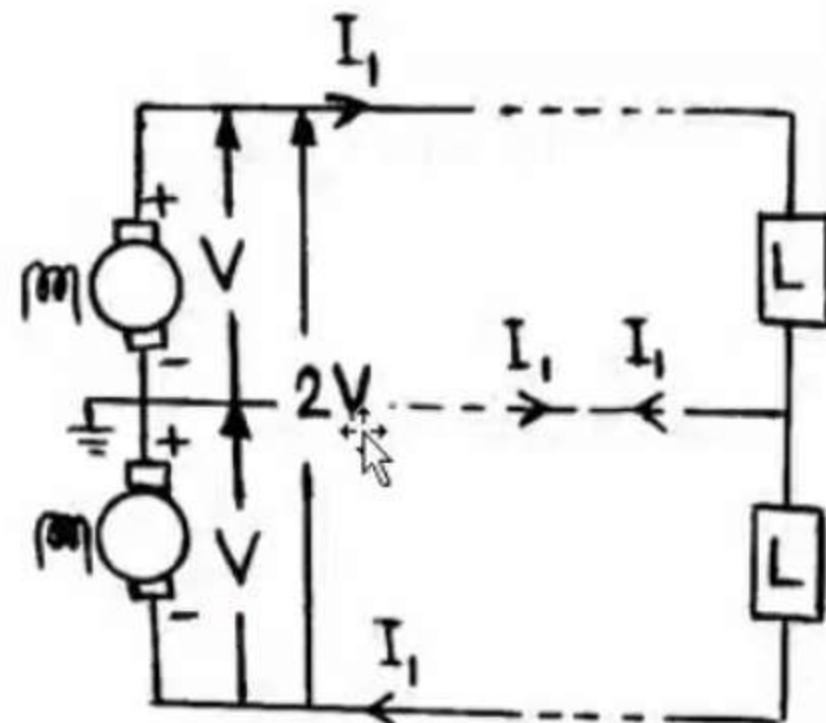
Comparison for Overhead Systems

Systems under consideration:

- (i) D.C. three wire,
- (ii) A.C. single phase,
- (iii) A.C. three phase three wire,
- (iv) A.C. three phase four wire,
- (v) D.C. two wire system.

D.C. Three Wire System

- The two outer wires are at Potentials $\pm V$.
- The centre wire is earthed.
- Voltage between lines is $2V$.



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8 **Series**: Decreasing loss between the subscriber and the area served by the system.
- Current flowing in the leader is maximum along the total length.
- The voltage drop is minimum from the leader along the length.

Shunt: Decreasing loss between the leader & the service meter.
- It is characterized by numerous sagsging in the form of service meter for decreasing the voltage.
- Current flowing in the distributor decreases from the leading point to the load point.

Delta: Decreasing loss between the distributor & the subscriber at the consumer.

9 **General Efficiency**: Consumption for Various Purposes
- It is necessary to design the supply system more automatically & to use of resources as much as possible.
- Accordingly, it is necessary to compare the amount of energy necessary for various possible systems of supply.

Assumptions
(1) To supply the same power.
(2) Efficiency to same level of all the systems.
(3) Efficiency losses in losses are same for all the systems.
(4) Loss of insulation is same for all the systems.
- The calculated line maximum voltage "V" between conductors is same for all the systems.
- The underground medium maximum voltage "V" between the conductors is same for all the systems.

10 **Assumptions for Distribution Systems**
Systems under consideration:
(1) D.C. three wire.
(2) A.C. single phase.
(3) D.C. three phase three wire.
(4) A.C. three phase three wire.
(5) D.C. one wire system.
A.C. Three Phase System
- The three wires are as:
Conductors:
- The outer wires are used.
- Voltage between them is 2V.

11 **Line current** $I_1 = \frac{P}{2V}$
Line loss $= 2I_1^2 R_1 = 2 \left(\frac{P^2}{4V^2} \right) R_1$
where, R_1 is the resistance per conductor.
A.C. Three Phase Line Losses
Line current $I_{L1} = \frac{P}{\sqrt{3}V \cdot \cos\phi}$
Line loss $= 2I_{L1}^2 R_1 = 2 \left(\frac{2P^2}{3V^2 \cdot \cos^2\phi} \right) R_1$
where, R_1 is the resistance per conductor.

12 **A.C. Three Phase Three Wire System**
- In this case neutral is avoided but it is not grounded in the atmosphere.
- Load is assumed to be balanced.
Line current $I_2 = \frac{P}{\sqrt{2}V \cdot \cos\phi}$
 $= \frac{P}{\sqrt{2}R_2 \cdot V \cdot \cos\phi}$

$$\text{Line current } I_1 = \frac{P}{2V}$$

$$\begin{aligned} \text{Line loss} &= 2I_1^2 R_1 = 2 \left(\frac{P^2}{4V^2} \right) R_1 \\ &= \frac{P^2}{2V^2} \cdot R_1 \quad \dots \dots (1) \end{aligned}$$

where,
 R_1 is the resistance per conductor.

A.C. Single Phase System

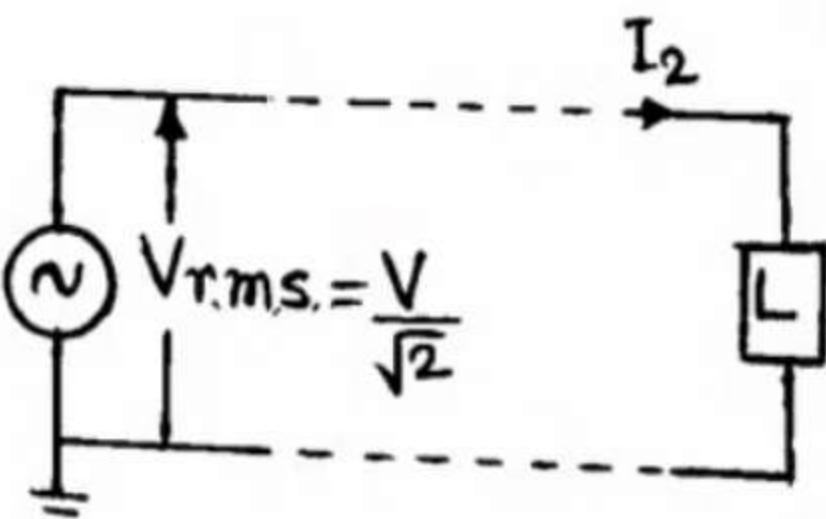
$$\text{Line current } I_2 = \frac{P}{\frac{\sqrt{2}V}{\sqrt{2}} \cdot \cos\phi} = \frac{\sqrt{2}P}{V \cdot \cos\phi}$$

where, $\cos\phi$ is the power factor.

$$\text{Line loss} = 2I_2^2 \cdot R_2 = 2 \left(\frac{2P^2}{V^2 \cdot \cos^2\phi} \right) \cdot R_2$$

$$= \frac{4P^2}{V^2 \cdot \cos^2\phi} \cdot R_2 \quad \dots \dots (2)$$

where,
 R_2 is the resistance per conductor.



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Advantages of Three Phase Systems

- It is necessary to design the supply system more economically & the use of resources is much as possible.
- Economically it is necessary to increase the amount of copper necessary for certain possible systems to supply.

Disadvantages

- 1) To supply the same power.
- 2) Double the cost of the system.
- 3) Efficiency is same as single phase system.
- 4) Cost of insulation is same for all the systems.
- For practical three maximum voltage "V" between conductors is same as for all the systems.
- For underground medium maximum voltage "V" between the conductors is same for all the systems.

Classification by Number of Lines

Systems under consideration:

- 1) D.G. three wire.
- 2) D.G. single phase.
- 3) D.G. three phase three wire.
- 4) D.G. three phase four wire.
- 5) D.G. one line system.
- 6) A.C. three wire system.

The line voltage is same as phase voltage.

Disadvantages

- The source voltage is constant.
- Voltage between lines is $\sqrt{3}V$.

A.C. Line Currents

Line current $I_L = \frac{P}{\sqrt{3}V \cos\phi}$

Line loss $L_L = \frac{I_L^2 R}{1000} = \frac{P^2 R}{3V^2 \cos^2\phi}$

where, R is resistance per conductor.

A.C. Neutral Currents

Neutral current $I_N = \frac{P}{\sqrt{3}V \cos\phi}$

where, V is the potential between neutral and ground.

A.C. Line Losses

Line loss $L_L = \frac{I_L^2 R}{1000} = \frac{P^2 R}{3V^2 \cos^2\phi}$

where, R is resistance per conductor.

A.C. Three Phase Three Wire System

In this case neutral is earthed but it is not provided to the consumers.

Load is assumed to be balanced.

Line current $I_3 = \frac{P}{\sqrt{3}V_{LL} \cos\phi}$

Line loss $L_L = \frac{I_3^2 R}{1000} = \frac{P^2 R}{3V_{LL}^2 \cos^2\phi}$

where, R is resistance per conductor.

A.C. Three Phase Four Wire System

In this case neutral is earthed and it is also provided to the consumers.

Load is assumed to be balanced i.e. no current flows through the neutral.

Line current $I_3 = \frac{P}{\sqrt{3}V_{LL} \cos\phi}$

A.C. Three Phase Three Wire System

- In this case neutral is earthed but it is not provided to the consumers.
- Load is assumed to be balanced.

$$\text{Line current } I_3 = \frac{P}{\sqrt{3}V_{LL} \cos\phi}$$

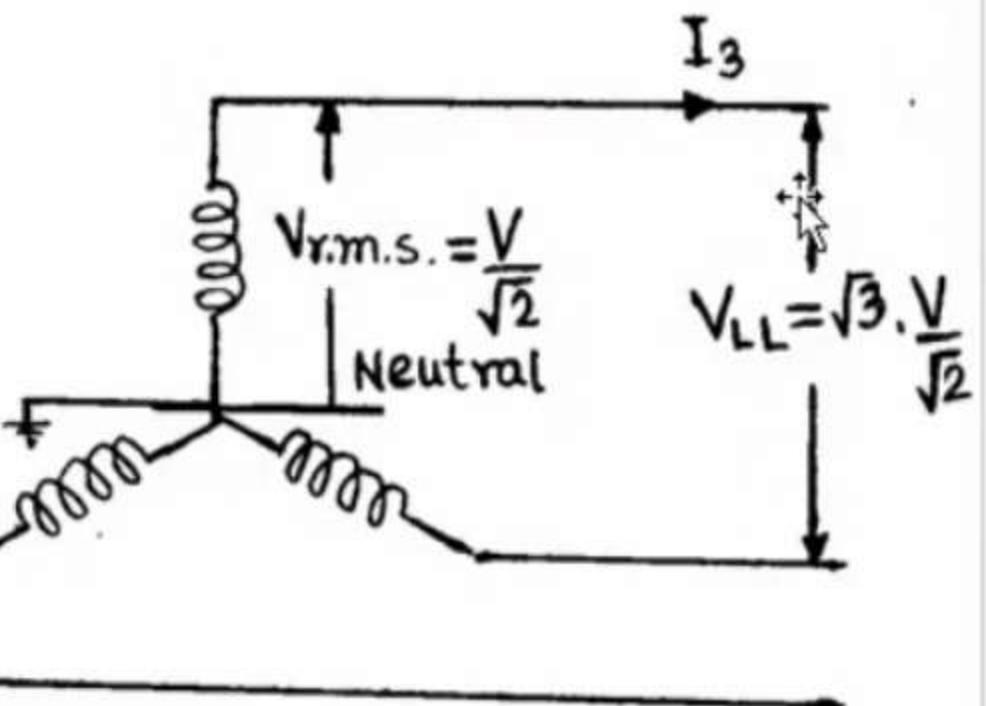
$$= \frac{P}{\sqrt{3} \cdot \sqrt{3} V \cos\phi} = \frac{\sqrt{2} P}{3V \cos\phi}$$

$$\text{Line loss} = 3I_3^2 R_3 = 3 \left(\frac{\sqrt{2} P}{3V \cos\phi} \right)^2 R_3$$

$$= \frac{2 P^2}{3V^2 \cos^2\phi} R_3 \quad \dots \dots (3)$$

where,

R_3 is the resistance per conductor.

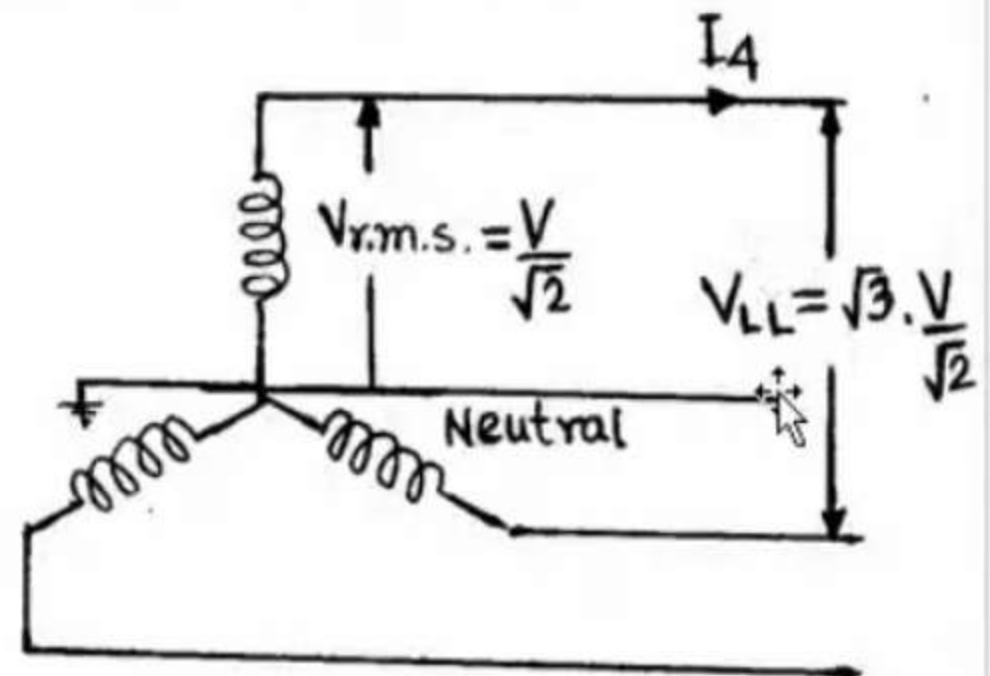


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A.C. Three Phase Four Wire System

- In this case neutral is earthed and is also provided to the consumers.
- Load is assumed to be balanced → i.e. no current flows through the neutral.
- So, loss remains same as in three phase three wire case.

$$\begin{aligned} \text{Line current } I_4 &= \frac{P}{\sqrt{3} \cdot V_{LL} \cdot \cos\phi} \\ &= \frac{P}{\sqrt{3} \cdot \sqrt{3} V \cdot \cos\phi} = \frac{\sqrt{2} P}{3V \cos\phi} \end{aligned}$$



$$\begin{aligned} \text{Line loss} &= 3I_4^2 R_4 = 3 \left(\frac{\sqrt{2} P}{3V \cos\phi} \right)^2 R_4 \\ &= \frac{2 P^2}{3V^2 \cos^2\phi} R_4 \quad \dots \dots (4) \end{aligned}$$

where,

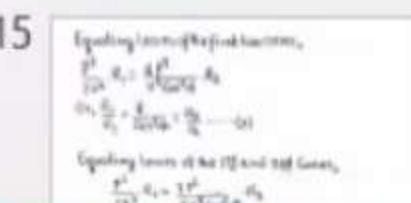
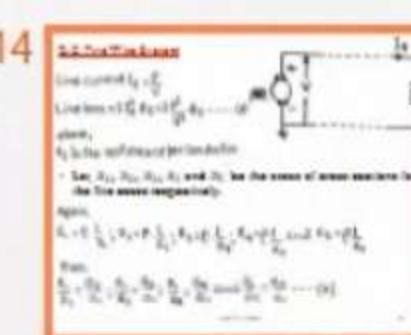
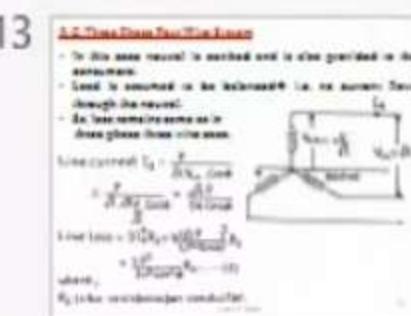
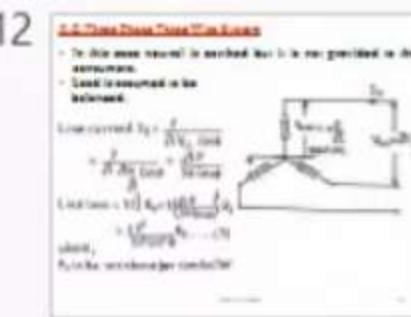
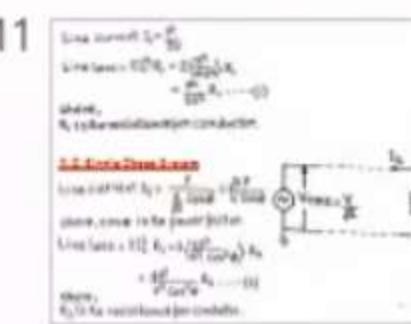
R_4 is the resistance per conductor.

Prof. S. S. Thakur

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D.C. Two Wire System

$$\text{Line current } I_5 = \frac{P}{V}$$

$$\text{Line loss} = 2I_5^2 R_5 = 2 \frac{P^2}{V^2} \cdot R_5 \dots (5)$$

where,

R_5 is the resistance per conductor.

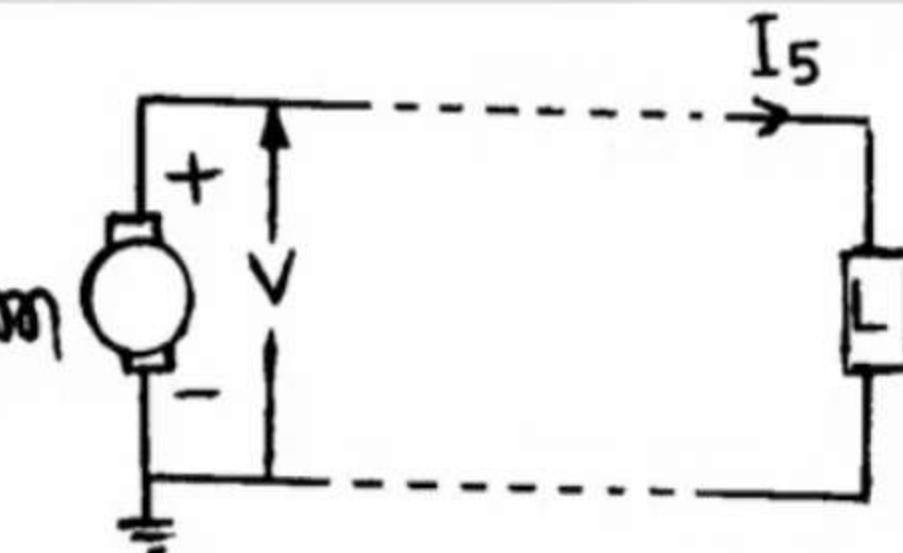
- Let, a_1, a_2, a_3, a_4 and a_5 be the areas of cross sections for the five cases respectively.

Again,

$$R_1 = \rho \cdot \frac{L}{a_1}; R_2 = \rho \cdot \frac{L}{a_2}; R_3 = \rho \cdot \frac{L}{a_3}; R_4 = \rho \cdot \frac{L}{a_4} \text{ and } R_5 = \rho \cdot \frac{L}{a_5}$$

Then,

$$\frac{R_1}{R_2} = \frac{a_2}{a_1}; \frac{R_2}{R_3} = \frac{a_3}{a_2}; \frac{R_3}{R_4} = \frac{a_4}{a_3} \text{ and } \frac{R_4}{R_5} = \frac{a_5}{a_4} \dots (6)$$



Forward 5 sec - [00:09:20 / 22%]



12

Q. A three-phase transmission line has

- To this case current is assumed but it is not provided in the question.
- Load is assumed to be balanced i.e. no current flows through the neutral.
- So three currents same as in three phases three wires case.

Line current $I_1 = \frac{P}{\sqrt{3}V_{ph}}$ and $I_2 = \frac{P}{\sqrt{3}V_{ph}}$

Line loss $= I^2R_1 + I^2R_2 + I^2R_3$

$$= \frac{P^2}{3V_{ph}^2} R_1 + \frac{P^2}{3V_{ph}^2} R_2 + \frac{P^2}{3V_{ph}^2} R_3$$

$$= \frac{P^2}{3V_{ph}^2} (R_1 + R_2 + R_3)$$

where, R_1, R_2, R_3 are resistances per conductor.

13

Q. A three-phase transmission line has

- To this case current is assumed and is also provided in the question.
- Load is assumed to be balanced i.e. no current flows through the neutral.
- So three currents same as in three phases three wires case.

Line current $I_1 = \frac{P}{\sqrt{3}V_{ph}}$ and $I_2 = \frac{P}{\sqrt{3}V_{ph}}$

Line loss $= I^2R_1 + I^2R_2 + I^2R_3$

$$= \frac{P^2}{3V_{ph}^2} R_1 + \frac{P^2}{3V_{ph}^2} R_2 + \frac{P^2}{3V_{ph}^2} R_3$$

$$= \frac{P^2}{3V_{ph}^2} (R_1 + R_2 + R_3)$$

where, R_1, R_2, R_3 are resistances per conductor.

14

Q. A three-phase transmission line has

Line current $I_1 = \frac{P}{\sqrt{3}V_{ph}}$

Line loss $= I^2R_1 + I^2R_2 + I^2R_3$

where, R_1, R_2, R_3 are resistances per conductor.

Let A_1, A_2, A_3, A_4 be the areas of cross sections for the four wires respectively.

Again,

$$\frac{I_1}{A_1} = \frac{I_2}{A_2} = \frac{I_3}{A_3} = \frac{I_4}{A_4}$$

$$I_1 = \frac{A_1}{A_2} I_2 = \frac{A_1}{A_3} I_3 = \frac{A_1}{A_4} I_4$$

Thus,

$$\frac{I_1^2}{A_1^2} = \frac{I_2^2}{A_2^2} = \frac{I_3^2}{A_3^2} = \frac{I_4^2}{A_4^2}$$

15

Equating losses of the first two cases,

$$\frac{P^2}{2V_{ph}^2} \cdot R_1 = \frac{4P^2}{V_{ph}^2 \cos^2 \phi} \cdot R_2$$

Or, $\frac{R_1}{R_2} = \frac{8}{\cos^2 \phi} = \frac{a_2}{a_1} \quad \dots \dots (7)$

Equating losses of the 1st and 3rd Cases,

$$\frac{P^2}{2V_{ph}^2} \cdot R_1 = \frac{2P^2}{3V_{ph}^2 \cos^2 \phi} \cdot R_3$$

Or, $\frac{R_1}{R_3} = \frac{4}{3 \cos^2 \phi} = \frac{a_3}{a_1} \quad \dots \dots (8)$

16

Inputting losses of the 1st and the 4th Options,

$$\frac{P^2}{2V_{ph}^2} \cdot R_1 = \frac{1P^2}{3V_{ph}^2} \cdot R_4$$

$$R_1 \cdot \frac{R_4}{R_4} = \frac{1}{3 \cos^2 \phi} = \frac{a_4}{a_1} \quad \dots \dots (9)$$

Equating losses of the 3rd and the 4th Options,

$$\frac{P^2}{2V_{ph}^2} \cdot R_1 = \frac{1P^2}{3V_{ph}^2} \cdot R_4$$

Equating losses of the first two cases,

$$\frac{P^2}{2V_{ph}^2} \cdot R_1 = \frac{4P^2}{V_{ph}^2 \cos^2 \phi} \cdot R_2$$

$$\text{Or, } \frac{R_1}{R_2} = \frac{8}{\cos^2 \phi} = \frac{a_2}{a_1} \quad \dots \dots (7)$$

Equating losses of the 1st and 3rd Cases,

$$\frac{P^2}{2V_{ph}^2} \cdot R_1 = \frac{2P^2}{3V_{ph}^2 \cos^2 \phi} \cdot R_3$$

$$\text{Or, } \frac{R_1}{R_3} = \frac{4}{3 \cos^2 \phi} = \frac{a_3}{a_1} \quad \dots \dots (8)$$

Forward 5 sec - [00:09:40 / 23%]

Equating losses of the 1st and the 4th Cases,

$$\frac{P^2}{2V^2} \cdot R_1 = \frac{2P^2}{3V^2 \cos^2 \phi} \cdot R_4$$

Or, $\frac{R_1}{R_4} = \frac{4}{3 \cos^2 \phi} = \frac{a_4}{a_1} \dots \dots \dots (9)$

Equating losses of the 1st and the 5th Cases,

$$\frac{P^2}{2V^2} \cdot R_1 = \frac{2P^2}{V^2} \cdot R_5$$

Or, $\frac{R_1}{R_5} = 4 = \frac{a_5}{a_1} \dots \dots \dots (10)$

Therefore,

$$4 \cdot \frac{a_4}{a_1} = \frac{a_5}{a_1}$$

$$4a_4 = a_5$$

$$a_5 = 4a_4$$

Forward 5 sec - [00:09:50 / 23%]

Font

Paragraph

Drawing

Editing

14

Calculation:

Using current $I_1 = I_2 = I_3 = I_4 = I_5$,
 $I_1 = I_2 = I_3 = I_4 = I_5 = 1000 \text{ A}$

Let a_1, a_2, a_3, a_4 and a_5 be the areas of cross sections for
 the five cases respectively.

Again,
 $\frac{I_1}{a_1} = \frac{I_2}{a_2} = \frac{I_3}{a_3} = \frac{I_4}{a_4} = \frac{I_5}{a_5}$

Then,
 $\frac{I_1}{a_1} = \frac{I_2}{a_2} = \frac{I_3}{a_3} = \frac{I_4}{a_4} = \frac{I_5}{a_5} = K$

15

Squaring terms of left-hand side,

$$\left(\frac{I_1}{a_1}\right)^2 = \left(\frac{I_2}{a_2}\right)^2 = \left(\frac{I_3}{a_3}\right)^2 = \left(\frac{I_4}{a_4}\right)^2 = \left(\frac{I_5}{a_5}\right)^2$$

Squaring terms of the L.H.S and R.H.S Given,

$$\left(\frac{I_1}{a_1}\right)^2 = \frac{I_1^2}{a_1^2} = \frac{I_1^2}{a_1^2} = \frac{I_1^2}{a_1^2} = \frac{I_1^2}{a_1^2}$$

16

Squaring terms of the L.H.S and the R.H.S Given,

$$\left(\frac{I_1}{a_1}\right)^2 = \frac{I_1^2}{a_1^2} = \frac{I_1^2}{a_1^2} = \frac{I_1^2}{a_1^2} = \frac{I_1^2}{a_1^2}$$

Squaring terms of the R.H.S and the L.H.S Given,

$$\left(\frac{I_1}{a_1}\right)^2 = \frac{I_1^2}{a_1^2} = \frac{I_1^2}{a_1^2} = \frac{I_1^2}{a_1^2} = \frac{I_1^2}{a_1^2}$$

17

Therefore,

$$\frac{I_1^2}{a_1^2} = \frac{I_2^2}{a_2^2} = \frac{I_3^2}{a_3^2} = \frac{I_4^2}{a_4^2} = \frac{I_5^2}{a_5^2}$$

In the above v_1, v_2, v_3, v_4 and v_5 are volumes of conductors in the five cases.

18

Ques: In assessing the apparent efficiency,

1. D.C. three phase system,
2. D.C. three phase three wire system,
3. D.C. three phase four wire system,
4. D.C. two wire system
5. D.C. single phase one wire system.

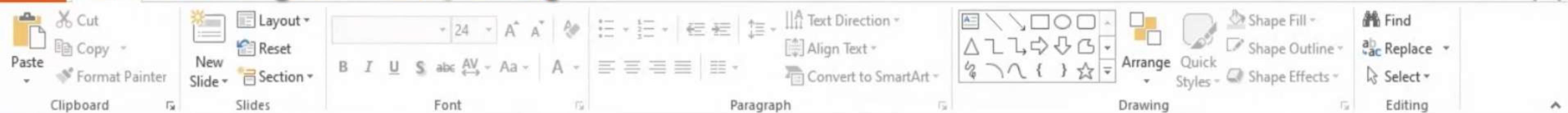
Therefore,

$$\begin{aligned}
 v_1 : v_2 : v_3 : v_4 : v_5 &= 2a_1 l : 2a_2 l : 3a_3 l : 4a_4 l : 2a_5 l \\
 &= 1 : \frac{2a_2 l}{2a_1 l} : \frac{3a_3 l}{2a_1 l} : \frac{4a_4 l}{2a_1 l} : \frac{2a_5 l}{2a_1 l} \\
 &= 1 : \frac{a_2}{a_1} : \frac{3}{2} \frac{a_3}{a_1} : 2 \frac{a_4}{a_1} : \frac{a_5}{a_1} \\
 &= 1 : \frac{8}{\cos^2 \phi} : \frac{3}{2} \cdot \frac{4}{3 \cos^2 \phi} : 2 \cdot \frac{4}{3 \cos^2 \phi} : 4 \\
 &= 1 : \frac{8}{\cos^2 \phi} : \frac{2}{\cos^2 \phi} : \frac{8}{3 \cos^2 \phi} : 4
 \end{aligned}
 \quad \dots \dots \dots (11)$$

1st 5th 2nd 3rd 4th

In the above v_1, v_2, v_3, v_4 and v_5 are volumes of conductors in the five cases.

Forward 5 sec - [00:11:20 / 27%]



15
Equating losses of both the cases,
 $\frac{P_1}{P_2} \cdot R_1 = \frac{P_1^2}{P_2^2} \cdot R_2$
 $R_1 = \frac{R_2}{P_1^2} \cdot \frac{P_2^2}{P_1^2} = R_2 \quad \text{(1)}$
Equating losses of the DC and AC cases,
 $\frac{P_1}{P_2} \cdot R_1 = \frac{P_1^2}{P_2^2} \cdot R_2$
 $R_1 = \frac{R_2}{P_1^2} \cdot \frac{P_2^2}{P_1^2} = R_2 \quad \text{(2)}$

16
Equating losses of AC 3 phase and DC cases,
 $\frac{P_1}{P_2} \cdot R_1 = \frac{P_1^2}{P_2^2} \cdot R_2$
 $R_1 = \frac{R_2}{P_1^2} \cdot \frac{P_2^2}{P_1^2} = R_2 \quad \text{(3)}$
Equating losses of AC 3 phase and the theory,
 $\frac{P_1}{P_2} \cdot R_1 = \frac{P_1^2}{P_2^2} \cdot R_2$
 $R_1 = \frac{R_2}{P_1^2} \cdot \frac{P_2^2}{P_1^2} = R_2 \quad \text{(4)}$

17
Therefore,
 $P_1 \cdot R_1 = P_2 \cdot R_2$
 $P_1 \cdot \left(\frac{R_2}{P_1^2} \cdot \frac{P_2^2}{P_1^2} \right) = P_2 \cdot R_2$
 $P_1 \cdot R_2 = P_2 \cdot R_2$
 $P_1 = P_2$
So the losses P_1, P_2, P_3, P_4 are same in all four cases
in the three phases.

18
Q. connecting in copper efficiency?
1. D.C. three wire system.
2. D.C. three phase three wire system.
3. D.C. three phase four wire system.
4. D.C. two wire system and
5. A.C. single phase two wire system.

19
Statement: A. In case of DC/DCC it is recommended by a pair of balanced resistances. If a third resistance of same value is to be added and it is to supply the three resistances for the required single phase output, then the DC load which can be connected is voltage across resistances and the power supplied in the circuit remains unchanged.
Data: DC 12V generator ($I = 100$ A) and the same for AC system ($I = 100$ A). Further assume:
1) voltage between resistances for both the DC & AC systems.

So, according to copper efficiency,

1. D.C. three wire system,
2. A.C. three phase three wire system,
3. A.C. three phase four wire system,
4. D.C. two wire system and
5. A.C. single phase two wire system.

Forward 5 sec - [00:11:50 / 28%]

The screenshot shows the Microsoft Word ribbon with the 'Home' tab selected. The ribbon includes tabs for File, Home, Insert, Page Layout, References, Mailings, and Review. Below the ribbon, there are several groups of tools: Font (with font size dropdown set to 24), Paragraph (with alignment and spacing controls), and other text-related icons like Bold, Italic, Underline, and Bullets.

The screenshot shows the Microsoft Word ribbon with the 'Home' tab selected. The ribbon includes tabs for File, Home, Insert, Page Layout, References, Mailings, and Review. Below the ribbon is a toolbar with various icons for text and shape manipulation. A floating 'Format' ribbon is visible, containing sections for 'Arrange', 'Quick Styles', 'Shape Fill', 'Shape Outline', and 'Shape Effects'. On the far right of the floating ribbon, there are buttons for 'Find', 'Replace', and 'Select'.

$$16 \quad \begin{aligned} & \text{Equation form of the 1st and the 2nd terms,} \\ & \frac{P_1}{P_2} T_1 = \frac{V_1}{V_2} \frac{T_2}{T_1} V_2 T_1 \\ & \Rightarrow \frac{T_1}{T_2} = \frac{V_1}{V_2} \frac{T_2}{T_1} + \frac{V_1}{V_2} - 1 = 0 \end{aligned}$$

Therefore,
 $\frac{V_1}{V_2} \cdot \frac{V_2}{V_3} \cdot \frac{V_3}{V_4} \cdot \frac{V_4}{V_5} = \frac{V_1}{V_5}$
 $\Rightarrow \frac{V_1}{V_5} = \frac{V_1}{V_2} \cdot \frac{V_2}{V_3} \cdot \frac{V_3}{V_4} \cdot \frac{V_4}{V_5}$
 $\Rightarrow \frac{V_1}{V_5} = \frac{1}{2} \cdot \frac{1}{3} \cdot \frac{1}{4} \cdot \frac{1}{5}$
 $\Rightarrow \frac{V_1}{V_5} = \frac{1}{120}$

In the above V_1, V_2, V_3, V_4 and V_5 are volumes of sand
in the five vessels.

18 In, controlling the copper efficiency:

19 **QUESTION:** If the load of 120VPP is increased by a given amount, which of the following statements is true? Assume no source is added and a 24V supply is also maintained. The original single-phase supply voltage, resistance of the 12V load, and the percentage loss in the system remain unchanged.

SOLN: Let 12 generic k_a = 1/120VPP and the same for 24VPP as k_b. Further assume the voltage between terminals for both the 12V & 24V systems is same.

- (A) Same in 12V system.
- (B) Same in 24V system.
- (C) $k_a = \sqrt{3}k_b$ in both 12V & 24V systems.
- (D) resistance per ammeter.

$$T_0 = \frac{F_0}{\pi D^2 \mu}$$

Problem: A 1Φ load of 10MW is transmitted by a pair of overhead conductors. If a third conductor of same cross section be added and a 3Φ supply be thus substituted for the original single phase supply, calculate the 3Φ load which can now be transmitted if voltage between conductors and the percentage loss in the systems remain unchanged.

Soln.: Let, 1Φ power be $P_1 = 10\text{MW}$ and the same for 3Φ system be $P_2 \text{ MW}$. Further, assume,

V= voltage between conductors for both the 1Φ & 3Φ system.

I_1 = Current in 1Φ system

I_2 = Current in 3Φ system

$\cos\phi$ = p.f. for both 1 ϕ & 3 ϕ systems &

R= resistance per conductor

Forward 5 sec - [00:13:30 / 32%]

17
Therefore,
 $P_1 = V_1 I_1 \cos \phi$
 $I_1 = \frac{P_1}{V_1 \cos \phi}$
 $I_1 = \frac{P_1}{V \cos \phi}$
In the above V_1, V_2, V_3, V_4 and I_1 are values of voltages
in the line source.

18
Ques. According to copper efficiency:
1. D.C. three phase system.
2. D.C. three phase three wire system.
3. D.C. three phase four wire system.
4. D.C. one phase system.
5. D.C. single phase one wire system.

19
Solution: If 100% load at 220V is connected by a pair of balanced condensers. If a third condenser of same value
is added and a DC supply be fed externally for the
original single phase supply, calculate the DC load which can
now be connected. 2 voltage across condensers and the
power supplied in the system remains unchanged.

Soln: Let DC current be $I_1 = 220/220$ and the same for DC system
be $I_2 = 120/220$. Further assume
The voltage across condensers for both DC & AC systems.
1. Current in DC system.
2. Current in DC system.
Given: η_1 for both DC & AC systems &
R = resistance per condenser.

20

21

$$\therefore I_1 = \frac{P_1}{V \cos \phi}$$

$$\text{Loss in } 1\phi \text{ system} = 2 I_1^2 R = 2 \cdot \left(\frac{P_1}{V \cos \phi} \right)^2 R$$

$$= \frac{2 P_1^2}{V^2 \cos^2 \phi} R$$

$$\text{Similarly, } I_2 = \frac{P_2}{\sqrt{3} V \cos \phi}$$

$$\text{Loss in } 3\phi \text{ System} = 3 I_2^2 R = 3 \cdot \left(\frac{P_2}{\sqrt{3} V \cos \phi} \right)^2 R$$

$$= \frac{P_2^2}{V^2 \cos^2 \phi} R$$



Forward 5 sec - [00:15:10 / 36%]

Font

Paragraph

Drawing

Editing

Equating % losses of the two systems,

$$\frac{\frac{2P_1^2}{V^2 \cos^2 \phi} \cdot R}{V \cdot I_1 \cos \phi} = \frac{\frac{P_2^2}{V^2 \cos^2 \phi} \cdot R}{\sqrt{3} V \cdot I_2 \cos \phi}$$

$$\therefore P_2 = 2\sqrt{3} P_1 \cdot \frac{I_2}{I_1} = 2\sqrt{3} P_1 \cdot \frac{\sqrt{3} V \cos \phi}{P_1 \cos \phi}$$

$$= 2\sqrt{3} P_1^2 \cdot \frac{P_2}{\sqrt{3} P_1}$$

$$= 2P_1 P_2$$

$$\therefore P_2 = 2P_1 = 2 \times 10 \text{ MW}$$

$$= 20 \text{ MW}$$

Prof. S. S. Thakur

21

Forward 5 sec - [00:16:49 / 40%]

The image shows the 'Clipboard' tab selected from a ribbon menu. The tab has a blue background with white text. To its left is a small icon of a clipboard with a document. Below the tab, there is a dropdown arrow indicating more options.

Slides

The screenshot shows the Microsoft Word ribbon with the 'Drawing' tab selected. The ribbon tabs include 'File', 'Home', 'Insert', 'Page Layout', 'References', 'Mailings', 'Review', 'View', and 'Drawing'. Below the ribbon, there are several toolbars: a 'Font' toolbar with font and size dropdowns, a 'Text Box' toolbar with orientation and border style options, a 'Text Box' toolbar with alignment and spacing controls, a 'Text Box' toolbar with margin and spacing controls, a 'Text Box' toolbar with border and fill controls, a 'Text Box' toolbar with shadow and 3D effects controls, and a 'Text Box' toolbar with 'Find', 'Replace', and 'Select' buttons.

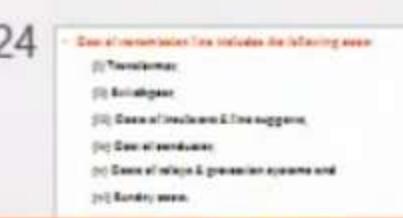
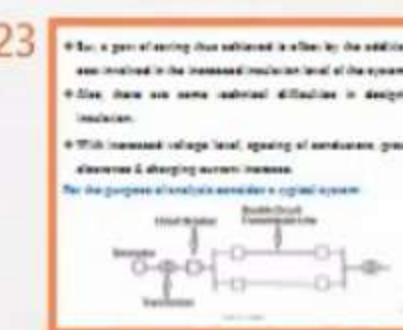
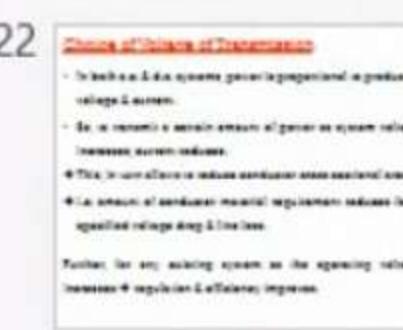
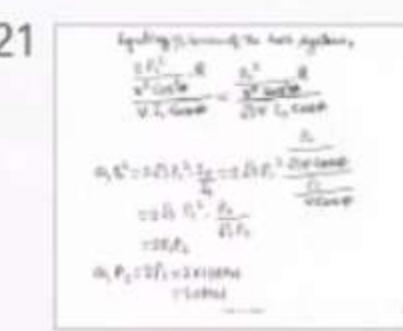
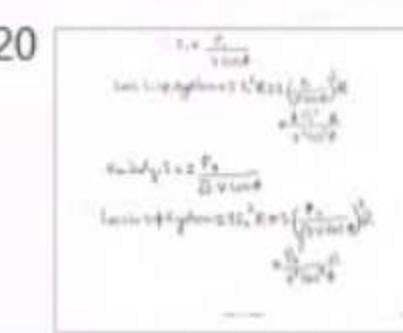
Question: A 10 kV load at 1000 MVA is connected by a pair of overhead transmission lines to three substations at some intermediate locations. It is desired to have the load supplied from the original single-source supply without the 10 kV load which is now to be connected. It is also required that maximum line-to-ground percentage loss in the system remain unchanged.

Choice of Voltage of Transmission

- In both a.c. & d.c. systems, power is proportional to product of voltage & current.
 - So, to transmit a certain amount of power as system voltage increases, current reduces.
 - This, in turn allows to reduce conductor cross sectional area,
 - i.e. amount of conductor material requirement reduces for a specified voltage drop & line loss.

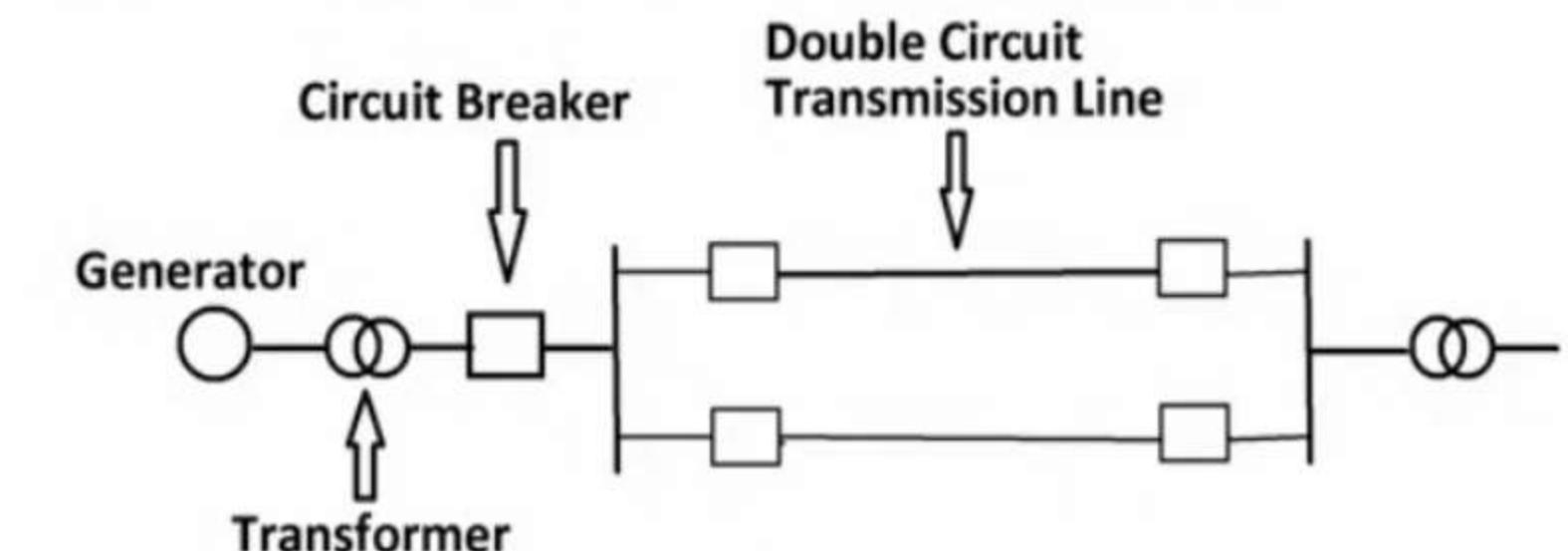
Further, for any existing system as the operating voltage increases \rightarrow regulation & efficiency improves.

Forward 5 sec - [00:20:49 / 50%]



- ❖ But, a part of saving thus achieved is offset by the additional cost involved in the increased insulation level of the system.
- ❖ Also, there are some technical difficulties in designing insulation.
- ❖ With increased voltage level, spacing of conductors, ground clearance & charging current increase.

For the purpose of analysis consider a typical system:



Prof. S. S. Thakur

Forward 5 sec - [00:28:29 / 68%]

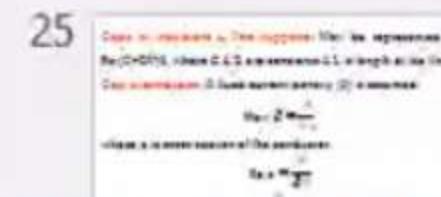
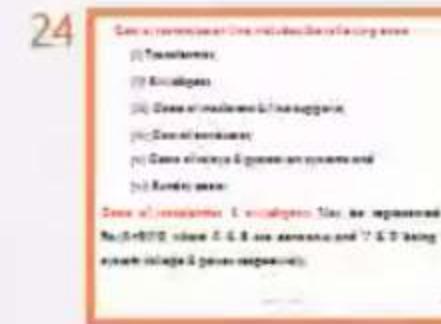
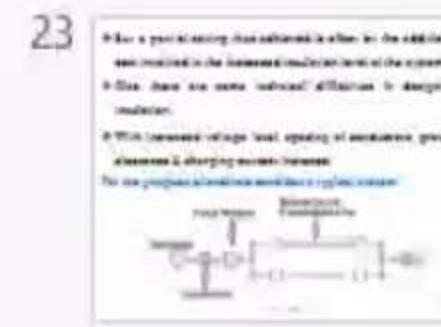
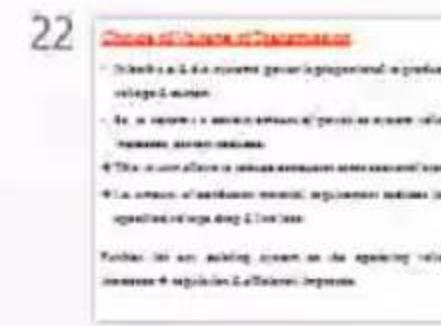
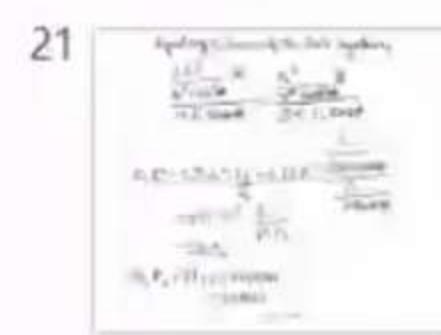
DRAWING TOOLS

Cut Copy Paste Format Painter New Slide Section Layout Reset Rockwell 24 A A Text Direction Align Text Convert to SmartArt

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Microsoft account



- **Cost of transmission line includes the following costs:**

- (i) Transformer,
- (ii) Switchgear,
- (iii) Costs of insulators & line supports,
- (iv) Cost of conductor,
- (v) Costs of relays & protection systems and
- (vi) Sundry costs.

Costs of transformer & switchgear: May be represented as

Rs. $(A + BV)P$, where A & B are constants and V & P being the system voltage & power respectively.

Forward 5 sec - [00:31:39 / 76%]

Home DESIGN TRANSFORMATIONS SLIDE SHOW REVIEW VIEW NITRO PRO 10

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22

Costs of Conductor

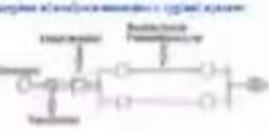
- In conductor losses are proportional to produced voltage & current.
- As in conductor a given amount of power is system voltage increases current reduces.
- Thus, increase in voltage reduces conductor area required.
- In amount of conductor material requirement reduces for a specified voltage drop & line loss.

Further, for any existing system as the operating voltage increases \rightarrow regulation & efficiency improves.

23

Cost of conductor

- For a given loading there is enhanced in either by the additional cost involved in the increased insulation level of the system.
- Or else, there are some technical difficulties in designing insulation.
- With increased voltage level, spacing of conductors ground clearance & charging distance increases.



24

Cost of conductor

- (i) Temperature
- (ii) Reliability
- (iii) Cost of insulation & live supports.
- (iv) Cost of insulation
- (v) Cost of relays & protection systems and
- (vi) Startup costs.

Cost of conductor & insulation may be represented as $P = C + DV$, where C & D are constants and V & D being the system voltage & power respectively.

25

Cost of conductor & live supports

They are represented as $P = C + DV$, where C & D are constants L is length of the conductor and a is cross section of the conductor.

For a fixed current density, $a \propto \frac{P}{V}$

Thus, cost of conductor \propto Volume of conductor ($a \cdot L$)

26

Cost of conductor & protection devices and switchgear

These are represented by a constant percentage of the P .

The total cost of the conductor $P_{total} = P + K \cdot P$

Where K is the factor for protection devices and switchgear.

Costs of insulators & line supports: May be represented as

Rs. $(C + DV)L$, where C & D are constants & L is length of the line.

Cost of conductor: A fixed current density (σ) is assumed.

$$\text{Now, } \sigma \propto \frac{P}{V \cdot a}$$

where, a is cross section of the conductor.

$$\text{So, } a \propto \frac{P}{\sigma \cdot V}$$

For a fixed current density, $a \propto \frac{P}{V}$

So, cost of conductor \propto Volume of conductor ($a \cdot L$).

Thus, cost of conductor = Rs. $E \cdot \frac{PL}{V}$, E being a constant.

Forward 5 sec - [00:33:19 / 80%]

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23

- For a given clearing time achieved is often by the additional cost involved in the increased insulation level of the system.
- There are some technical difficulties in designing insulation.
- With increased voltage level, ageing of insulation, ground clearance & clearing times increase.
- For the purpose of analysis consider a typical system.

24

General transmission line includes the following costs:

- Transformer
- Switchgear
- Cost of insulation & line supports
- Cost of conductors
- Cost of relays & protection systems and
- Survy costs

Cost of insulation & switchgear: They are represented as $R = \alpha V^2$, where α is resistance and V is using the system voltage & power supplied.

25

Cost of insulation & line supports: They are represented as $R = \alpha V^2 L$, where α is resistance & L is length of the line.

Cost of conductors: It is based on current density (J) is assumed.

Where $Z = \frac{V}{I}$

where, I is cross-section of the conductor.

Resistivity $R = \rho \frac{L}{A}$

For a fixed current density, $\rho = \text{constant}$

Ex. area of conductor A (Volume of conductor) $= A$.

Thus, area of conductor $= R = \frac{V}{I}$ (length of conductor).

26

Cost of relay & protection systems and survey: These are represented by a constant component of Rs. F.

The total cost of the transmission line is

$$S = R_0 + (A + BV)P + (C + DV)L + E \cdot \frac{PL}{V} + F$$

To find out the voltage for minimum cost set $\frac{dS}{dV} = 0$.

Costs of relays & protection systems and sundry costs: These are represented by a constant component of Rs. F.

So, total cost of the transmission line is

$$S = \text{Rs. } [(A + BV)P + (C + DV)L + E \cdot \frac{PL}{V} + F]$$

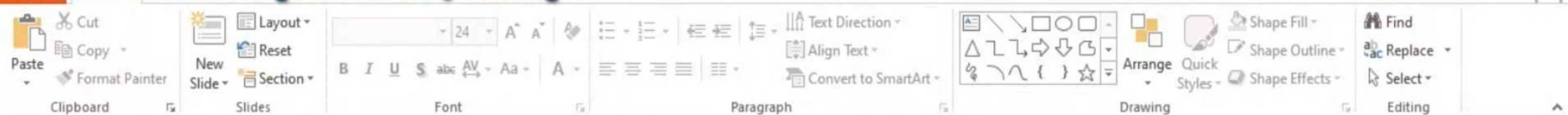
To find out the voltage for minimum cost set $\frac{dS}{dV} = 0$.

$$\text{i.e. } \frac{d}{dV} [(A + BV)P + (C + DV)L + E \cdot \frac{PL}{V} + F] = 0.$$

$$\text{Or, } BP + DL - E \frac{PL}{V^2} = 0$$

$$\text{Or, } E \frac{PL}{V^2} = BP + DL$$

Forward 5 sec - [00:33:29 / 80%]



24
Data of transmission line includes the following areas:
 (i) Transformer.
 (ii) Busbar.
 (iii) Data of insulation & line sugges.
 (iv) Data of conductor.
 (v) Data of relays & protection systems and
 (vi) Boundary areas.
 Data of conductor & insulation may be represented as
 $R = \frac{R_0}{L}$, where R_0 is resistance per unit length of the line.
 Data of insulation & load current density (I) is assumed.

25
Data of insulation & line suggests that it be represented as
 $R = \frac{R_0}{L}$, where R_0 is resistance per unit length of the line.
 Data of conductor & load current density (I) is assumed.
 $R = R_0 \cdot L$
 where L is length of the conductor.
 $R = R_0 \cdot \frac{L}{x}$
 For a fixed current density, $R \propto L$
 For a fixed conductor $R \propto x^{-1}$
 Thus, $R = R_0 \cdot \frac{L}{x}$ is the equation.

26
Data of voltage & generation system and boundary areas. These are represented by a common expression of R_0 .
 By, total area of the transmission line is
 $R = R_0 \cdot \frac{L}{x} = (R_0 \cdot L) \cdot \frac{x}{R_0} = R_0 \cdot x$
 To find out the voltage for minimum loss, $\frac{dV}{dx} = 0$.
 $\therefore \frac{dV}{dx} = \frac{d}{dx} \left[V = R_0 \cdot x + \frac{I^2 R_0}{2} \right] = (R_0 \cdot x) + R_0 \cdot I^2 = 0$
 $\therefore R_0 \cdot x + R_0 \cdot I^2 = 0$
 $\therefore R_0 \cdot x = -R_0 \cdot I^2$

27
Ques: $V = \sqrt{\frac{EPL}{(BP+DL)}}$
While selecting the voltage, the following factors are to be considered:
 1. The standard voltages.
 2. Mechanical strength of the conductor.
 3. Corona loss.
 4. Voltage regulation &
 5. Future growth.

28
Diagram: A diagram of a transmission line system showing a source, transformer, and various components connected in a loop.

$$\text{Or, } V = \sqrt{\frac{EPL}{(BP+DL)}}$$

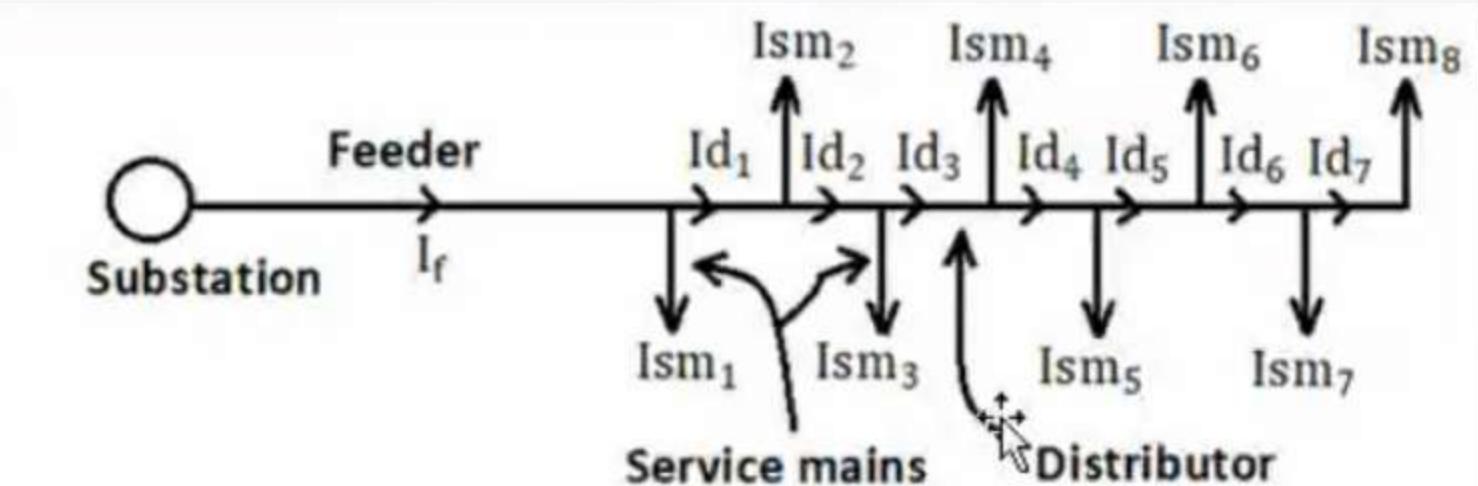
While selecting the voltage, the following factors are to be considered:

1. The standard voltages,
2. Mechanical strength of the conductor,
3. Corona loss,
4. Voltage regulation &
5. Future growth.

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Kelvin's Law



- Voltage drop is an important factor for distributor → since supply voltage to consumer must remain within $\pm 5\%$ for LV distribution & $\pm 12\frac{1}{2}\%$ for HV.
- Connections in the form of service mains are taken from the distributor,
- So, a distributor has variable loading.
- Consumers situated near the feeding point enjoy better voltage compared to those situated at the far end.
- So, the distributor is designed on the basis of voltage drop.**

Forward 5 sec - [00:09:49 / 21%]



On the contrar

- Current loading of feeder is constant throughout whole length.
 - So, feeder is designed on the basis of current carrying capacity & wherever practicable following maximum financial economy as stated in Kelvin's Law.

Statement of Kelvin's law

The most economical cross section of conductor is that which makes annual value of interest & depreciation on the conductor equal to annual cost of energy wasted in conductor resistance.

Forward 5 sec - [00:13:19 / 29%]



28
1. The conductors.
2. Required length of the conductor.
3. Currents.
4. Voltage regulation.
5. Power factor.

28
- Voltage drop is an important factor for conductor & also supply voltage at consumer must remain within 5% for 27 standard & 8% for 110V.
- Connections in the form of service meter are taken from the distribution.
- As a distribution has variable loading.
- Consumers situated near the leading point enjoy lesser voltage compared to those situated on the load end.
- So, the distribution is designed on the basis of voltage drop.

29
On the contrary:
- Current flowing all through the conductor is same throughout its length.
- So, conductor is designed on the basis of current carrying capacity & whenever practicable following minimum financial economy is used in conductor size.
Advantages of Distribution:
The most economical area section of conductor is that which makes annual value of interest & depreciation on the conductor equal to annual cost of energy wasted in conductor resistance.

30
In This:
- Cost of conductor \propto Volume Conductor ($a^2 l$)
 \propto Cross \times length \times
- Annual cost of interest & depreciation \propto Cost of conductor
 \propto Cross section ' a'
So annual cost of interest & depreciation = P_a \propto $a^2 l$
where, P is a constant.
Then, resistance of conductor $R = \rho \frac{l}{a}$, ρ = specific resistance.
So, a given length, $R \propto \frac{1}{a}$

31
Annual energy loss in the $\frac{1}{a}$ \propto $\frac{1}{a}$
where E is energy
Therefore, total annual loss $E = E_0 \left(\frac{1}{a} + \frac{1}{a} \right) \propto \frac{1}{a}$
To find out area required for minimum annual loss $\frac{1}{a} = \frac{1}{2}$
Or, $\frac{1}{a_0} = 2 \Rightarrow a_0 = \frac{1}{2}$
Or, $a_0 = \frac{1}{2}$
Thus for minimum total annual loss $\frac{1}{a} = \frac{1}{2}$
Depreciation \propto annual energy loss \propto $\frac{1}{a}$
So, the most economical section $a_0 = \frac{1}{2}$

➤ Proof

- Cost of conductor \propto Volume Conductor ($a.l$)
 - Cross 'a' \rightarrow for a given length 'l'
- Annual cost of interest & depreciation \propto Cost of conductor

\propto Cross section 'a'

So, annual cost of interest & depreciation = Rs. P.a(1)
where, P is a constant.

Now, resistance of conductor $R = \rho \frac{l}{a}$, ρ = specific resistance.

So, a given length, $R \propto \frac{1}{a}$

Annual energy loss $\propto R \propto \frac{1}{a}$

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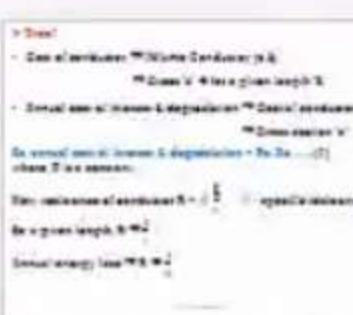
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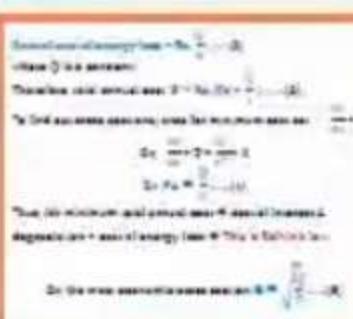
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30



31



$$\text{Annual cost of energy loss} = \text{Rs. } \frac{Q}{a} \dots \dots (2)$$

where Q is a constant.

$$\text{Therefore, total annual cost 'S' } = \text{Rs. } (\text{Pa} + \frac{Q}{a}) \dots \dots (3)$$

To find out cross sectional area for minimum cost set

$$\frac{ds}{da} = 0$$

$$\text{Or, } \frac{ds}{da} = P - \frac{Q}{a^2} = 0$$

$$\text{Or, } Pa = \frac{Q}{a} \dots \dots (4)$$

Thus, for minimum total annual cost \rightarrow cost of interest & depreciation = cost of energy loss \rightarrow This is Kelvin's law.

$$\text{Or, the most economic cross section } a = \sqrt{\frac{Q}{P}} \dots \dots (5)$$

Backward 5 sec -[00:16:49 / 36%]

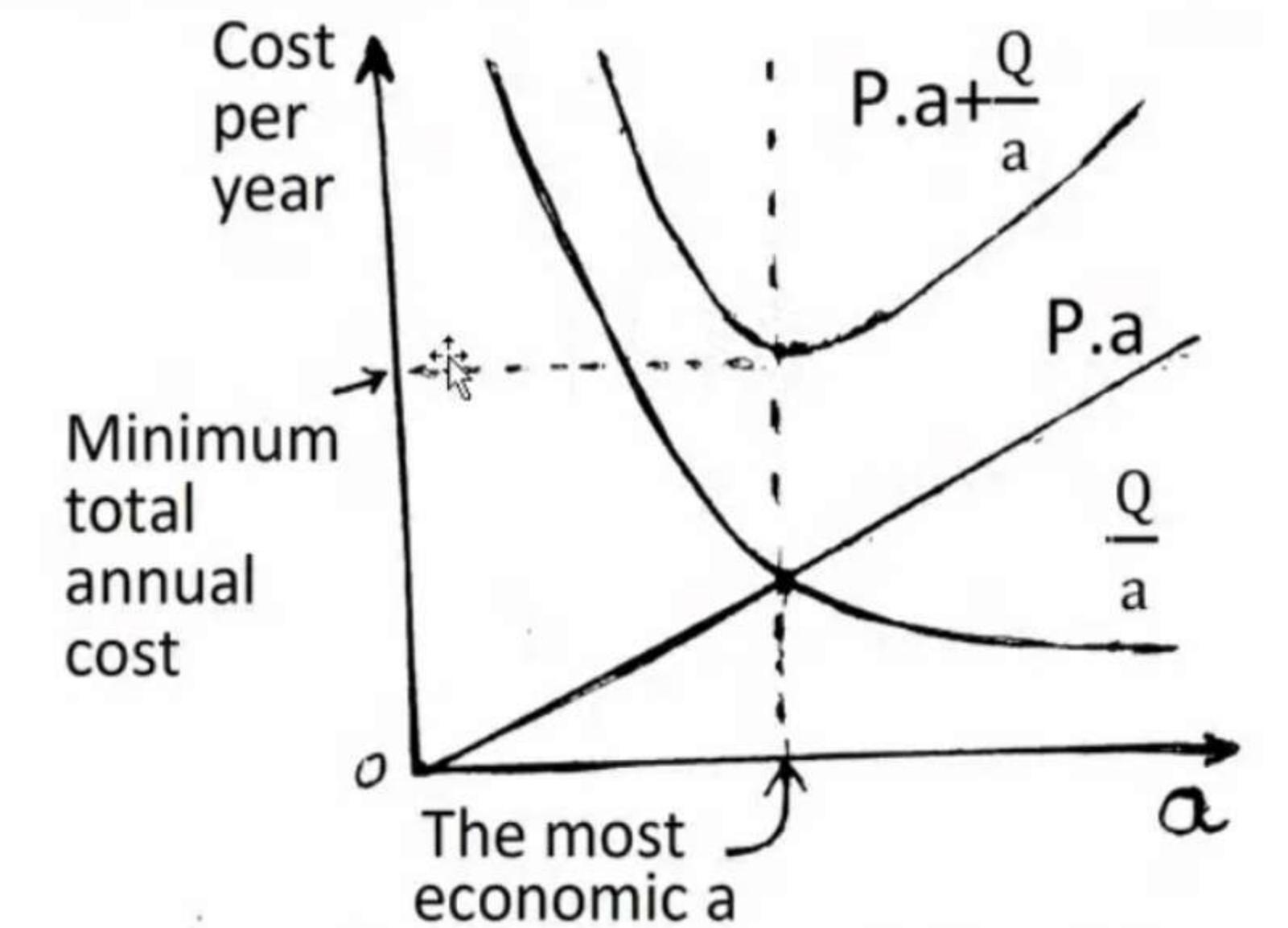
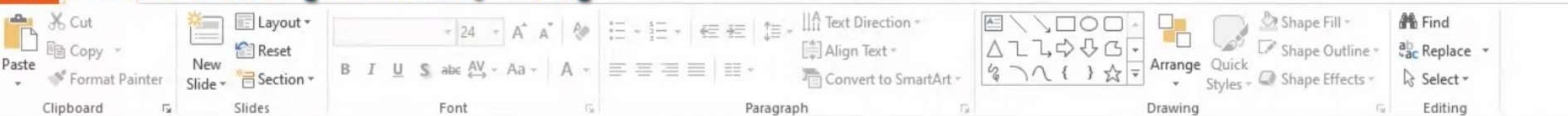
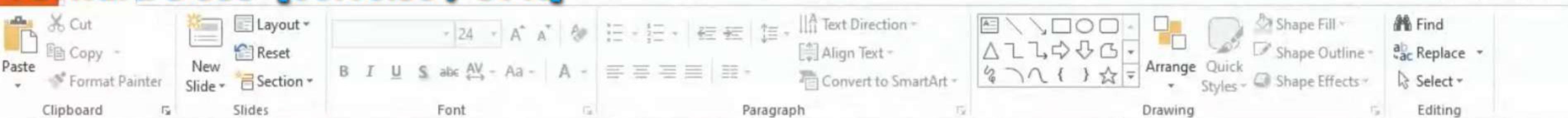


Fig. Illustration of Kelvin's law

Forward 5 sec - [00:16:59 / 37%]



Kelvin's law considering cost of insulation

- If cost of insulation is considered → as for u.g. cables, then
- It is independent of cross section 'a' &
- Insulation (i.e. cost of it) depends mainly on voltage.

Then, annual cost of interest & depreciation = Rs. (P.a + T).....(6)
where T is a constant.

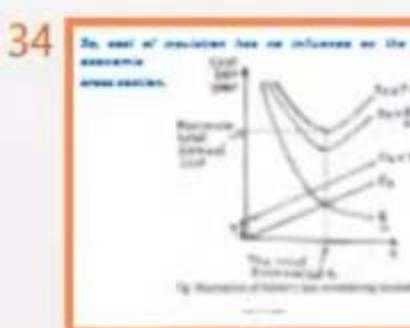
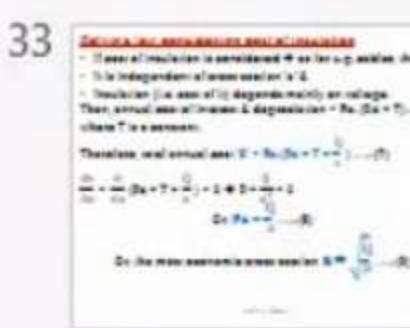
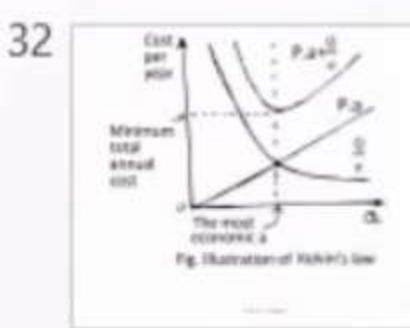
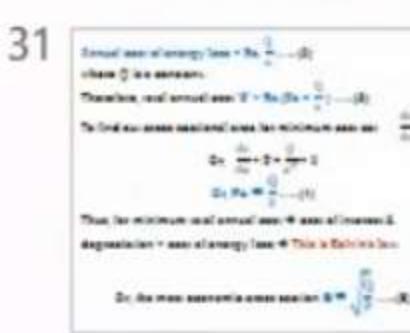
Therefore, total annual cost 'S' = Rs. (P.a + T + $\frac{Q}{a}$)(7)

$$\frac{ds}{da} = \frac{d}{da} (P.a + T + \frac{Q}{a}) = 0 \rightarrow P - \frac{Q}{a^2} = 0$$

$$\text{Or, } Pa = \frac{Q}{a} \quad \dots\dots(8)$$

$$\text{Or, the most economic cross section } a = \sqrt{\frac{Q}{P}} \quad \dots\dots(9)$$

Forward 5 sec - [00:19:49 / 43%]



35

Table 20 (20, pg 283) Determine the most economical cross section for a 20 ft. long air duct carrying a uniform velocity of 100 ft/sec. Air density is 0.0765 lb/ft³. The air is 1.000 ft³/lb. The air is 0.00077 lb/ft³. The time is in use 200 days yearly. The user price of air energy loss = $(2)(0.02 + 100)(20)$, where 'a' = cross section in in^2 of each dimension. Friction = 1% of original cost. Energy loss = 1.00 per 100 ft. The

So, cost of insulation has no influence on the most economic cross section.

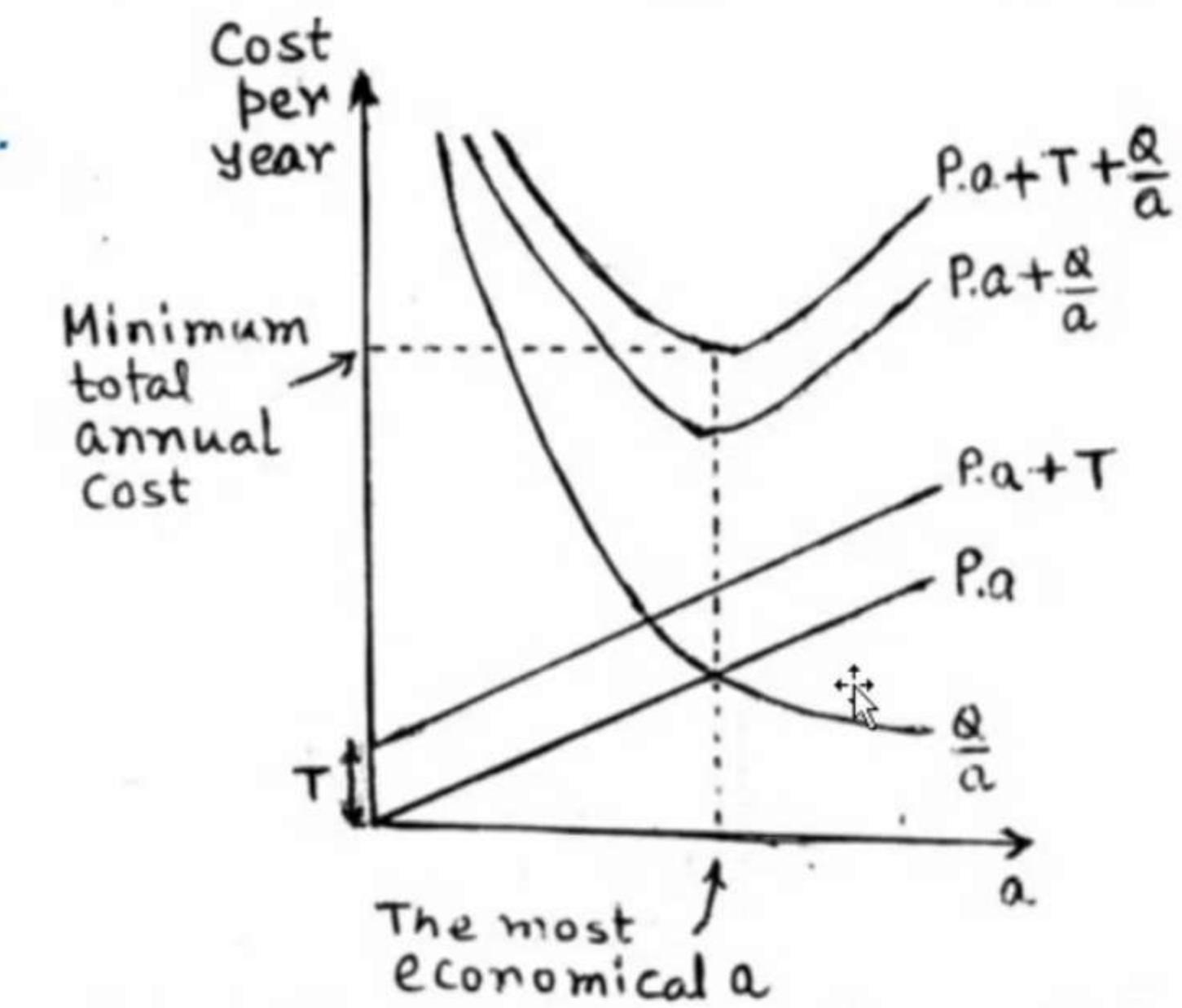
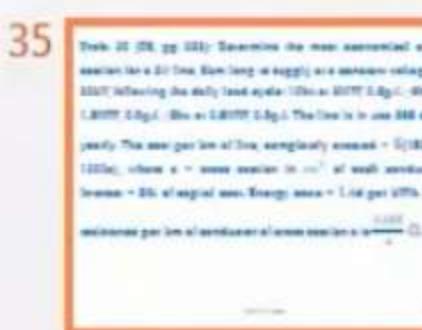
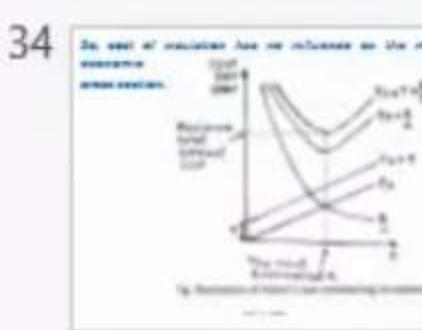
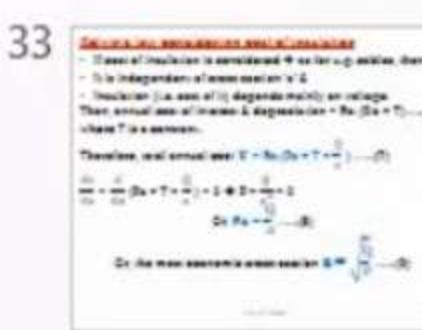
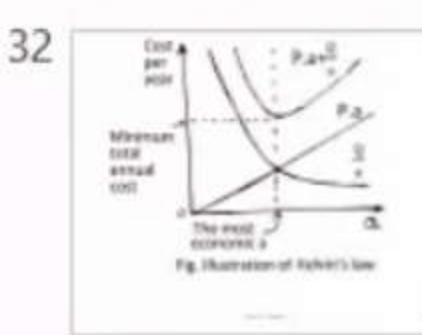


Fig. Illustration of Kelvin's law considering insulation cost

Forward 5 sec - [00:21:39 / 47%]



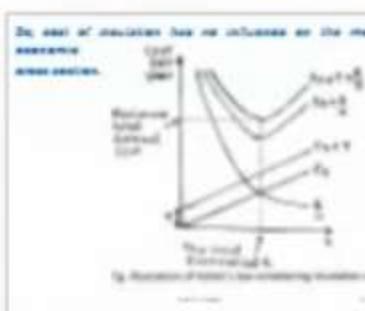
Prob. 20 (PS, pp 233): Determine the most economical cross section for a 3Φ line, 6km long to supply at a constant voltage of 30kV, following the daily load cycle: 10hr. at 3MW, 0.8p.f.; 6hr. at 1.5MW, 0.9p.f.; 8hr. at 0.5MW, 0.9p.f. The line is in use 365 days yearly. The cost per km of line, completely erected = £(1500 + 1200a), where a = cross section in cm² of each conductor. Interest = 8% of capital cost. Energy costs = 1.4d per kWh. The resistance per km of conductor of cross section a is $\frac{0.185}{a} \Omega$.

abhi jeet kumar has left the meeting

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34



35

Data 20 (28, pg. 334) Determine the mean annualized area section for a 21 line, 3 km long at supply voltage of 220V, delivering an daily load average (DOL) of 20000 kVA. The line is in use 300 days yearly. The per unit of line energy loss is 0.185×10^6 , where $a = \text{area section in } \text{cm}^2$ of each conductor. Power = 20000 kVA, average power = 1.0 kVA/kW. The resistance per km of conductor of same section is $\frac{0.001}{a}$.

36

Daily energy loss

$$= \frac{0.185 \times 10^6}{\sqrt{3} \cdot 30 \cdot 10^3 \cdot 0.8} \cdot 10 + \left(\frac{1.5 \cdot 10^6}{\sqrt{3} \cdot 30 \cdot 10^3 \cdot 0.9} \right)^2 \cdot 6 + \left(\frac{0.5 \cdot 10^6}{\sqrt{3} \cdot 30 \cdot 10^3 \cdot 0.9} \right)^2 \cdot 8$$

 $= 177512.033 \text{ R}$

Daily energy loss

$$= 3 \left[\left(\frac{3 \cdot 10^6}{\sqrt{3} \cdot 30 \cdot 10^3 \cdot 0.8} \right)^2 \cdot 10 + \left(\frac{1.5 \cdot 10^6}{\sqrt{3} \cdot 30 \cdot 10^3 \cdot 0.9} \right)^2 \cdot 6 + \left(\frac{0.5 \cdot 10^6}{\sqrt{3} \cdot 30 \cdot 10^3 \cdot 0.9} \right)^2 \cdot 8 \right] \cdot R$$
 $= 177512.033 R$

R = Resistance per conductor for 6 km = $\frac{0.185}{a} \cdot 6$

Energy loss per year = $365 \cdot 177512.033 \cdot \frac{0.185}{a} \cdot 6$

$$= \frac{1918987.90}{a} \text{ Watt-hour}$$

$$= \frac{1918.98790}{a} \text{ kWh}$$

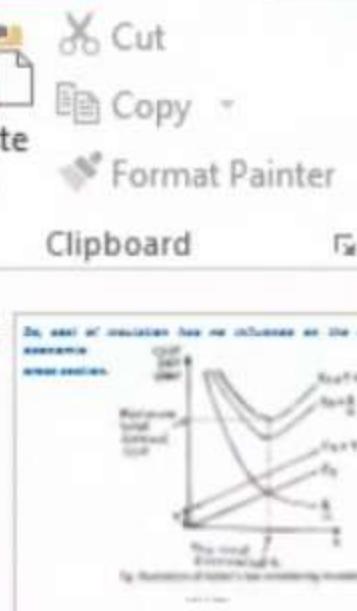
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Cost of annual energy loss = $\frac{1918.98790}{a} \text{ kWh} \cdot \frac{\text{Rs. } 1000 \text{ per kWh}}{240 \text{ hours}}$
 Cost of interest = $\frac{R}{240} \cdot (\text{Rs. } 1000 \text{ per kWh})$
 According to Rutherford's law:
 $\frac{R}{240} \cdot (\text{Rs. } 1000 \text{ per kWh}) = \frac{1918.98790}{a} \cdot \frac{\text{Rs. } 1000 \text{ per kWh}}{240}$
 $a_1 = 0.0014 \text{ cm}^2$

38

- 1. It is difficult to calculate the energy loss correctly as the load varies continuously.
- 2. This loss is actual and has no relation to the physical quantity like average line voltage diagram.
- 3. The value of conductor obtained from Rutherford's law might be smaller than the value obtained by other methods.

Backward 5 sec - [00:28:39 / 62%]



$$\begin{aligned} \text{ballistic energy loss} \\ = & \frac{\sqrt{2\pi}\sigma^2}{(2\pi\ln 2)^{1/2}} \times \frac{(2\pi\sigma^2)}{(2\pi\ln 2)^{1/2}} + \frac{(2\pi\sigma^2)}{(2\pi\ln 2)^{1/2}} \\ = & 1.17755 \text{ eV} \\ R = & \text{Resistivity per conductor for } 1000^\circ K = 0.125 \Omega \cdot m \\ \text{Energy loss per year} & = 1000 \times 1000 \times 1000 \times \frac{0.125}{10^9} \text{ J} \\ & = \frac{1250000}{10^9} \text{ J} \text{ with units} \\ & = \frac{1250000}{10^9} \text{ J} \text{ with units} \end{aligned}$$

$$\begin{aligned} \text{Cost of annual energy loss} &= \frac{15.7100 \times 10^3}{240} \times 6 \\ &= 15.7100 \times 10^3 \times 0.25 \\ \text{Cost of interest} &= \frac{1}{100} (2000 \times 5) \\ \text{According to Rutherford's law,} & \\ \frac{1}{100} (2000 \times 5) &\geq \frac{1.49 \times 10^3 \times 10^3}{240} \times 6 \\ 50 &\geq 3.1734 \text{ cm}^2 \end{aligned}$$

1. The effect is called the energy loss factor or the resistivity.
 2. This law is empirical and has no relation to the physical properties like voltage drop etc.
 3. The use of conductor obtained from Schottky law might be difficult as it have adequate mathematical example.

Cost of annual energy loss

$$= \frac{1.4}{240} \cdot \frac{71918.98790}{a}$$

[Note: 12 Pence = 1 Shilling
20 Shilling = 1 Pound]

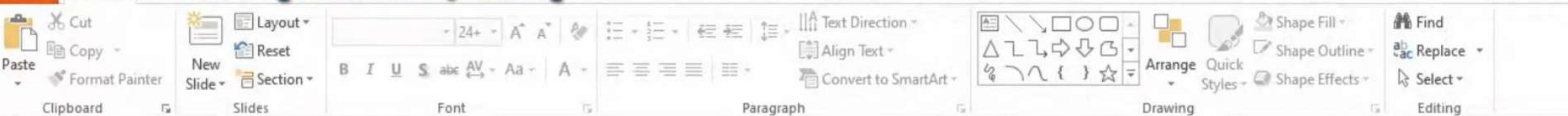
$$\text{Cost of interest} = \frac{8}{100} \cdot (1200 \text{a. } 6)$$

According to Kelvin's law:

$$\frac{8}{100} \cdot (1200a \cdot 6) = \frac{1 \cdot 4}{240} \cdot \frac{71918 \cdot 98790}{a}$$

$$\alpha, \quad a = 0.8534 \text{ cm}^2$$

Forward 5 sec - [00:31:39 / 69%]



35

35 Data #1 (p. 111) Determine the mass associated with one CO_2 molecule. How long will it supply to a person who breathes 10.00 L of air every 10.0 s at 10.0°C and 1.00 atm? The mass per liter of air is approximately equal to $1.29 \times 10^{-3} \text{ g/L}$. The time is equal to 3600 s . This was per liter of air, so multiply instead = $(1.29 \times 10^{-3}) \text{ g/L} \times 10.0 \text{ L} \times 3600 \text{ s} = 4.64 \text{ g}$. Since each CO_2 molecule has a mass of 44.01 g/mol , there are 1.06×10^{22} molecules in 4.64 g .

36

$$= \frac{0.3 \times 10^3}{(0.3 \times 10^3 + 0.4)} = \frac{0.3 \times 10^3}{0.7 \times 10^3} = 0.42857 \approx 0.43$$

B = Resistivity per conductor for case = 0.00016

$$\text{Energy loss per year} = 0.016 \times 0.00016 \times 0.43 \times 10^6 = 1.102 \times 10^{-5} \text{ kWh}$$

$$= 1.102 \times 10^{-5} \text{ kWh}$$

$$= 1.102 \times 10^{-5} \text{ kWh}$$

37

$$\text{Cost of annual depreciation} = \frac{\text{Rs. } 1,000,000}{200} = \text{Rs. } 5,000 \text{ per year}$$

(Note: $1,000,000 \times 1/200 = 5,000,000/200 = \text{Rs. } 5,000$)

Cost of interest $\times \frac{1}{2} \times (\text{Rs. } 200,000 - x)$

According to Kishore's view:

$$\frac{x}{100} (\text{Rs. } 200,000 - x) = 1/2 \times \frac{\text{Rs. } 1,000,000}{200}$$

$$x^2 - 200,000x + 1,000,000 = 0$$

$$x_1 = 100,000 \text{ and } x_2 = 200,000$$

38 |

38. Application of Derivatives

1. It is difficult to calculate the energy functionally as the variables are continuously changing.
2. This law is empirical and has no relation to the physical quantities like temperature, time, voltage, etc.
3. The size of resistance obtained from Ohm's law might be small as we have undergone measured quantity.

39

59. Transformer Primary Calculations

- Voltage drop is an important factor for efficiency.
- Supply voltage or secondary must remain within ±10% tolerance & ±10% for PCT.
- Core losses shared near the leading power angle & voltage降压 at these shared near the load end.
- So, it's necessary to calculate the voltage at the source.

Limitations of Kelvin's law

1. It is difficult to calculate the energy loss correctly as the load varies continuously.
 2. This law is artificial and has no relation to the physical aspects like temperature rise, voltage drop etc.
 3. The size of conductor obtained from Kelvin's law might be too small so as to have adequate mechanical strength.

Forward 5 sec - [00:31:59 / 70%]

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Distribution Systems Calculations

- Voltage drop is an important factor for distributor.
- Supply voltage to consumer must remain within $\pm 5\%$ for LV distribution & $\pm 12\frac{1}{2}\%$ for HV.
- Consumers situated near the feeding point enjoy better voltage compared to those situated near the far end.
- So, it is necessary to calculate the voltage at the consumer's terminals.
- Accordingly, distribution systems calculations are important.

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37
Detailed analysis shows:
Total load current = $\frac{V}{R}$ (where V is the total voltage across the four sections and R is the total resistance of the four sections.)
According to Ohm's law:
 $\frac{V}{R} = \frac{V_1 + V_2 + V_3 + V_4}{R_1 + R_2 + R_3 + R_4}$
 $I = \frac{V}{R} = \frac{V_1 + V_2 + V_3 + V_4}{R_1 + R_2 + R_3 + R_4}$

38
General Features:
1. It is difficult to estimate the energy loss accurately as the load varies continuously.
2. This loss is critical and has no relation to the physical length of the conductor due to voltage drop.
3. The use of conductor selected from Saturation might be economical as it has adequate mechanical strength.

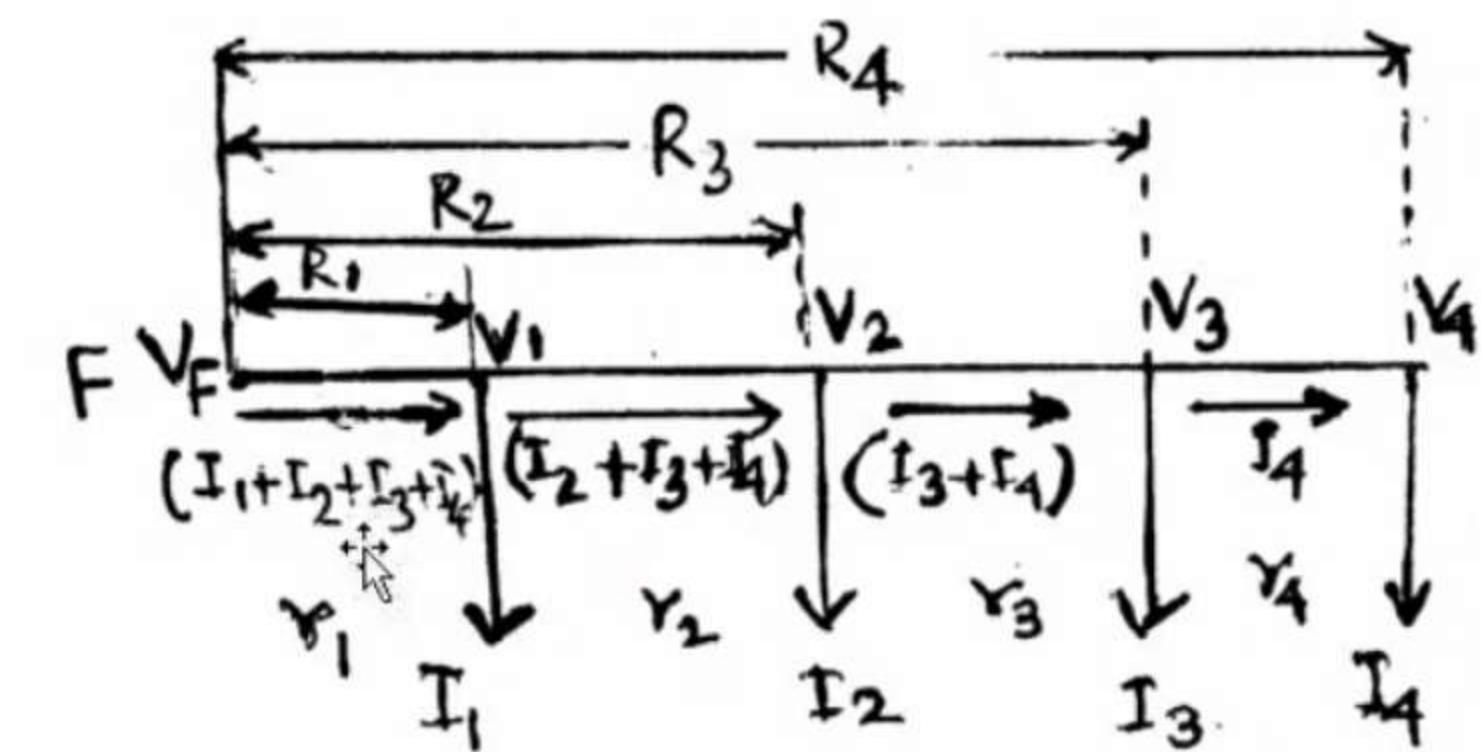
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Distribution System Calculations:
- Designing a distribution system for distribution.
- Supply voltage at consumer must remain within 80% to 120% distribution & lighting load.
- Consumers situated near the feeding point enjoy better voltage compared to those situated near the far end.
- It is necessary to calculate the voltage at the consumers terminals.
- Economically, distribution systems reflect low power losses.

40
D.C. Radial Distributor Fed at One End (for concentrated loads):
- Consider the distributor with four load currents I_1, I_2, I_3, I_4 .
- Voltages of the four load points be V_1, V_2, V_3, V_4 .
- Resistance of each conductor of sections be r_1, r_2, r_3, r_4 .
- Feeding point be F & voltage at feeding point voltage be V_F .

41
Total voltage drop = $V_F - V_1 - V_2 - V_3 - V_4$
= $V_F - (I_1 r_1 + I_2 r_2 + I_3 r_3 + I_4 r_4)$
= $V_F - (I_1 + I_2 + I_3 + I_4) (r_1 + r_2 + r_3 + r_4)$
In the above, 'I' denotes for per unit current.

D.C. Radial Distributor Fed at One End (for concentrated loads)

- Consider the distributor with four load currents $I_1, I_2, I_3 & I_4$.
- Voltages of the four load points be $V_1, V_2, V_3 & V_4$.
- Resistance of each conductor of sections be $r_1, r_2, r_3 & r_4$.
- Feeding point be F & voltage at feeding point voltage be V_F .



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Question 4:

- 1. Is voltage drop across the energy loss directly proportional to the load current?
- 2. The loss is constant and has no relation to the physical quantity like temperature due to aging effect.
- 3. The loss of consumer increases from 50% to 100% might be proportional to the increase in the generated energy.

39

Question 5:

Voltage drop is an important factor for efficiency.

- Supply voltage at consumer must remain within 85% to 105% standard & voltage loss 10%
- Consumers connected near the feeding point enjoy better voltage compared to those located near the load.
- It is necessary to reduce the voltage at the consumer terminals.
- Generally, distribution system efficiency can be improved.

40

Q.5 Total Voltage Drop Due To Four Resistors:

Given the circuit with four load resistors.

- Voltages at the four load points are V_1, V_2, V_3, V_4 .
- Resistance of each load resistor is r_1, r_2, r_3, r_4 .
- Feeding point has T.E voltage or feeding point voltage as V_F .

41

Total Voltage drop = $2.(I_1 + I_2 + I_3 + I_4) \cdot r_1 + 2.(I_2 + I_3 + I_4) \cdot r_2 + 2.(I_3 + I_4) \cdot r_3 + 2.(I_4) \cdot r_4$

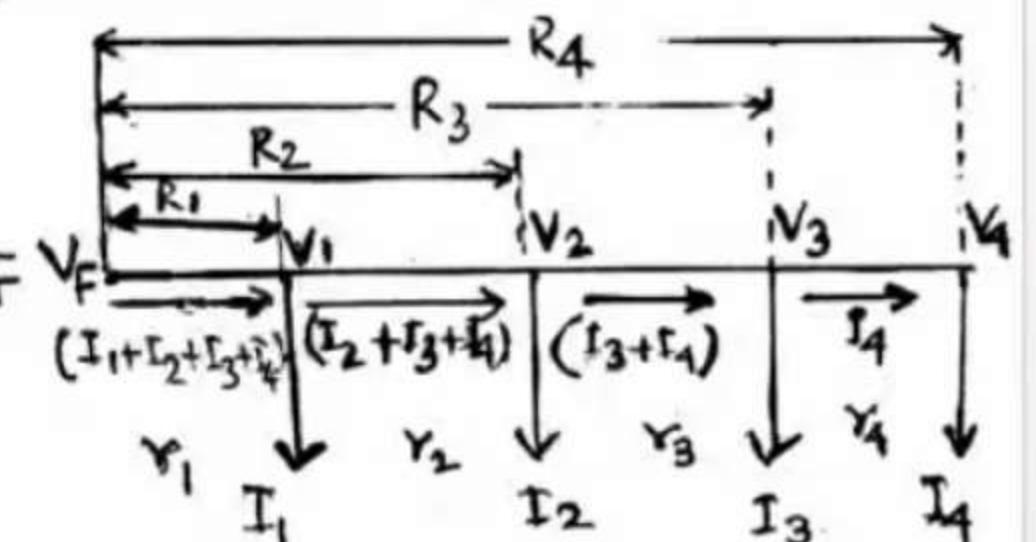
In the above, '2' comes for go & return.

So,

$$V_1 = V_F - 2.(I_1 + I_2 + I_3 + I_4) \cdot r_1$$

$$V_2 = V_1 - 2.(I_2 + I_3 + I_4) \cdot r_2$$

$$V_3 = V_2 - 2.(I_3 + I_4) \cdot r_3$$

$$V_4 = V_3 - 2.(I_4) \cdot r_4$$


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39 Distribution System Calculations

- Voltage drop in long lines is important.
- Supply voltage at consumers must remain within 80% to 120% of the minimum & 10% to 15% of the maximum.
- Consumers situated near the leading point enjoy better voltage compared to those situated near the far end.
- So, it is necessary to calculate the voltage at the consumers.
- Residential distribution systems calculations are important.

40 D.C. Radial Distributor Fed at One End

Consider the distributor with four load consumers L_1, L_2, L_3, L_4 .

- Voltages at the four load points are V_1, V_2, V_3, V_4 .
- Resistance of each conductor of distributor is R_1, R_2, R_3, R_4 .
- Reading gain is P & voltage at leading point voltage is V_1 .

41 Total voltage drop = $(V_1 - V_2) + (V_2 - V_3) + (V_3 - V_4) = V_1 - V_4$

In the above, V_1 remains same due to load.

$$V_1 = V_2 + (I_1 R_1 + I_2 R_2)$$

$$V_2 = V_3 + (I_2 R_2 + I_3 R_3)$$

$$V_3 = V_4 + (I_3 R_3 + I_4 R_4)$$

$$V_4 = V_1 - (I_1 R_1 + I_2 R_2 + I_3 R_3 + I_4 R_4)$$

42 D.C. Radial Distributor Fed at Both Ends

The long distributor carrying heavy loads voltage drop may be appreciably high & may result voltages at the consumers at far end beyond tolerable limits.

Under such situation distributors are fed at both ends.

The point of minimum potential occurs at some point where currents meet from both ends.

Voltage drop up to point of minimum potential is much less compared to the distributor fed at one end only.

43 Consider the distributor with four load consumers L_1, L_2, L_3, L_4 .

Voltages at the four load points are V_1, V_2, V_3, V_4 .

Resistance of each conductor of distributor is R_1, R_2, R_3, R_4 .

The leading point (L1) voltage is V_1 .

I_1, I_2 be the current fed from the two ends.

D.C. Radial Distributor Fed at Both Ends

(For concentrated loads)

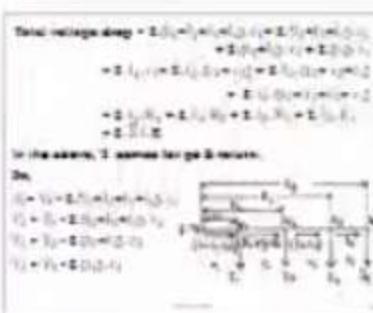
- For long distributors carrying heavy loads voltage drop may be considerably high → may result voltages of the consumers at far end beyond tolerable limits.
- Under such situation distributors are fed at both ends.
- Then, point of minimum potential occurs at some point where currents meet from both ends.
- Voltage drop up to point of minimum potential is much less compared to the distributor fed at one end only.

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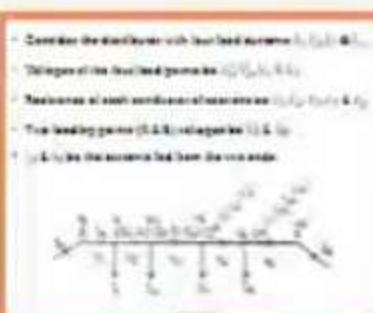
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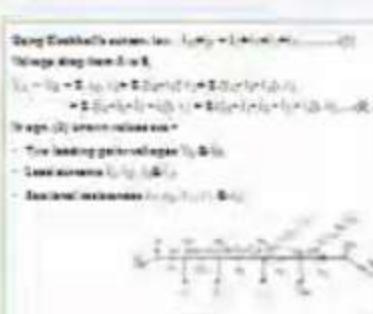
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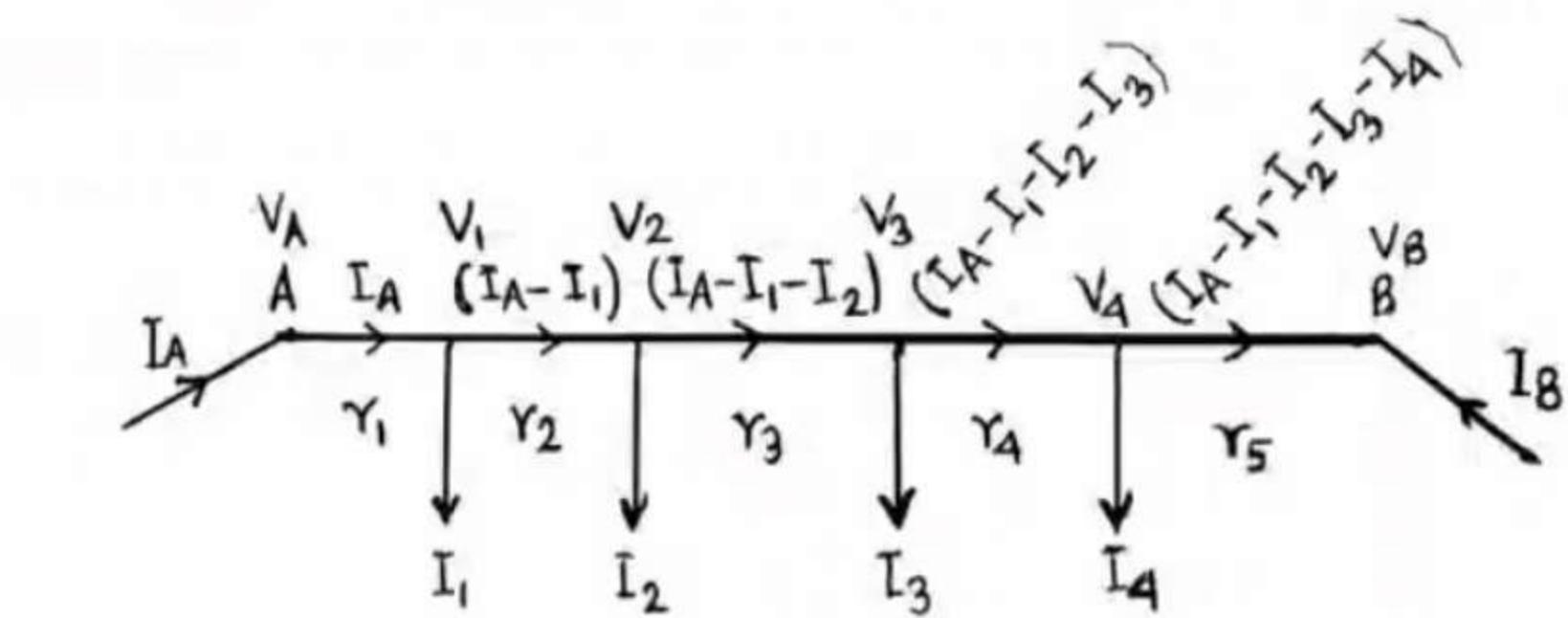
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45



- Consider the distributor with four load currents $I_1, I_2, I_3 \& I_4$.
- Voltages of the four load points be $V_1, V_2, V_3 \& V_4$.
- Resistance of each conductor of sections be $r_1, r_2, r_3, r_4 \& r_5$.
- Two feeding points (A & B) voltages be $V_A \& V_B$.
- $I_A \& I_B$ be the currents fed from the two ends.



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41

Total voltage drop = $V_1 + V_2 + V_3 + V_4 + V_5$
 $= 2I_1r_1 + 2I_2r_2 + 2(I_A - I_1 - I_2)r_3 + 2(I_A - I_1 - I_2 - I_3)r_4 + 2(I_A - I_1 - I_2 - I_3 - I_4)r_5$
 In the above, I_1 remains for one return.
 $I_A = I_1 + I_2 + I_3 + I_4 + I_5$
 $I_2 = I_1 + I_3 + I_4 + I_5$
 $I_3 = I_1 + I_2 + I_4 + I_5$
 $I_4 = I_1 + I_2 + I_3 + I_5$

42

Q.2. Total voltage drop at both ends
 Considerations
 - For long distances carrying heavy load voltage drop may be considerably high & may need voltage at the successive points and beyond short distance.
 - Under such situation distribution can be done in two parts.
 Then, general minimum generation source at some point where voltage must have been constant.
 - Voltage drop at or gain of minimum potential is much less compared to the distribution load area and entry.

43

Consider the distribution with four load sources I_1, I_2, I_3, I_4 .
 - Sources of the four load points be V_1, V_2, V_3, V_4 .
 - Resistances of each section of resistance be r_1, r_2, r_3, r_4 .
 - The feeding gains (S.E.S) voltage be V_A, V_B .
 - I_1, I_2, I_3 be the source fed from the ends.

44

Using Kirchhoff's current law, $I_A + I_B = I_1 + I_2 + I_3 + I_4 \dots \dots \dots (1)$
 Voltage drop from A to B.
 $V_A - V_B = 2. I_A. r_1 + 2.(I_A - I_1) r_2 + 2.(I_A - I_1 - I_2). r_3 + 2.(I_A - I_1 - I_2 - I_3). r_4 + 2.(I_A - I_1 - I_2 - I_3 - I_4). r_5 \dots \dots \dots (2)$
 In eqn. (2) known values are -

Using Kirchhoff's current law, $I_A + I_B = I_1 + I_2 + I_3 + I_4 \dots \dots \dots (1)$

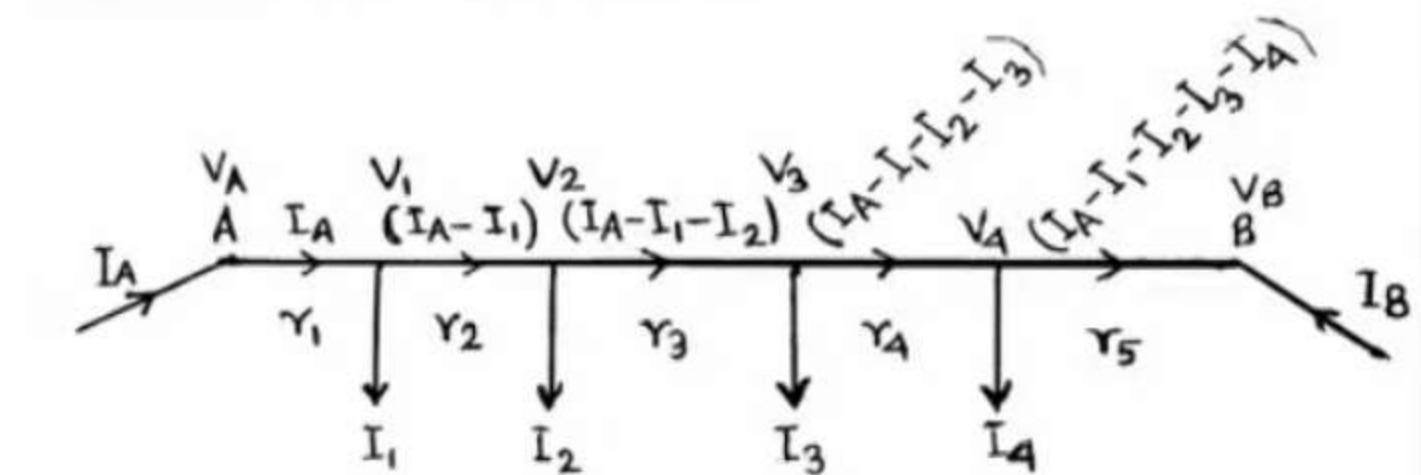
Voltage drop from A to B,

$$V_A - V_B = 2. I_A. r_1 + 2.(I_A - I_1) r_2 + 2.(I_A - I_1 - I_2). r_3$$

$$+ 2.(I_A - I_1 - I_2 - I_3). r_4 + 2.(I_A - I_1 - I_2 - I_3 - I_4). r_5 \dots \dots \dots (2)$$

In eqn. (2) known values are -

- Two feeding point voltages V_A & V_B .
- Load currents I_1, I_2, I_3 & I_4 .
- Sectional resistances r_1, r_2, r_3, r_4 & r_5 .



42

A.C. Digital Distribution Test at Both Ends

- The long distribution carrying heavy loads voltage drop may be appreciably high & it may result in voltage at the extremes either end beyond acceptable limits.

- Under such situation distributions are fed at both ends.

- Then gain of minimum potential occurs when current meets from both ends.

- Voltage drop at point of minimum potential is much less compared to the distribution fed at one end only.

43

Consider the distribution with four load sections I_1, I_2, I_3, I_4 & V_A .

- Voltages at the four load points are V_1, V_2, V_3, V_4 .

- Resistance of each section of section are r_1, r_2, r_3, r_4 .

- Total loading gains (ΔV_A) voltage are I_1, I_2, I_3, I_4 .

- I_1, I_2, I_3 be the currents fed from the two ends.

44

Using Ohm's law we have $V_A = I_1 r_1 + I_2 r_2 + I_3 r_3 + I_4 r_4$

Voltage drop from A to B

$$V_B = V_A - I_1 r_1 - I_2 r_2 - I_3 r_3 - I_4 r_4$$

or $V_B = V_A - 2(I_1 r_1 + I_2 r_2) - (I_3 r_3 + I_4 r_4)$

Diagram (A) shows resistance r_1, r_2, r_3, r_4 .

- Total loading gain voltage $V_A - V_B$.

- Load currents I_1, I_2, I_3, I_4 .

- Sectional resistances r_1, r_2, r_3, r_4 .

45

Now I_1 can be calculated.

- Then I_2 can be calculated from eqn. (1).

Since I_1 is known, one may find -

- Currents in all the sections.
- Voltage at any loading point.

$I_1 = I_2 + 2(I_2 r_2 + I_3 r_3)$

$I_2 = I_3 + 2(I_3 r_3 + I_4 r_4)$

$I_3 = I_4 + 2(I_4 r_4 + I_1 r_1)$

$I_4 = I_1 + 2(I_1 r_1 + I_2 r_2)$

The gain of minimum potential is the load gain where current meets from the two sides.

46

Asymmetric Sectional Distribution Test At Both Ends

- When the distributor supplies either lesser or more than one long section.

- When approximately equal loads are supplied after regular & initial intervals.

- Then loads can be connected in an uniformly distributed.

- Let the uniformly loaded distribution be fed at one end only.

So, I_A can be calculated.

- Then I_B can be calculated from eqn. (1).

Once I_A is known, one may find –

- Currents in all the sections.
- Voltage at any loading point.

$$V_1 = V_A - 2 \cdot I_A \cdot r_1$$

$$V_2 = V_1 - 2 \cdot (I_A - I_1) \cdot r_2$$

$$V_3 = V_2 - 2 \cdot (I_A - I_1 - I_2) \cdot r_3$$

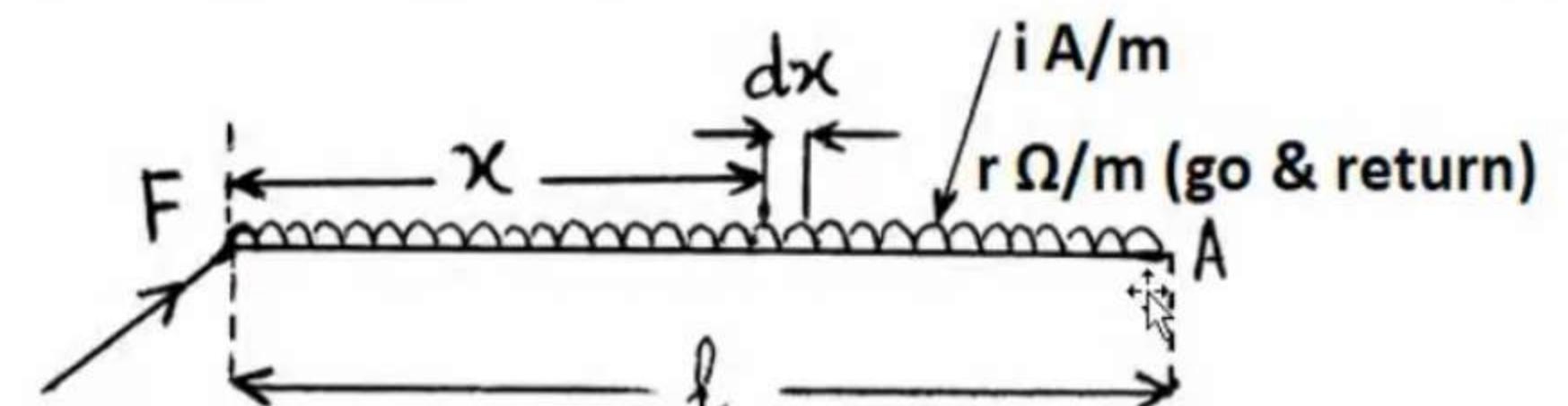
$$V_4 = V_3 - 2 \cdot (I_A - I_1 - I_2 - I_3) \cdot r_4$$

❖ The point of minimum potential is that load point where currents meet from the two sides.

I

Uniformly Loaded Distributor Fed At One End

- When the distributor supplies similar houses or establishments on a long street &
 - When approximately equal loads are tapped off at regular & brief intervals.
 - Then, loads can be considered to be uniformly distributed.
 - Let, the uniformly loaded distributor be fed at one end only.



- Here, current loading is i A/m & $r = \Omega/m$ (go & return).

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44
 Using Ohm's law, $i_1 = i_2 = i$
 Voltage drop from F to A
 $V_F - V_A = \Delta V = i_1 R + i_2 R = 2iR = 2(iL) = 2iL$
 Design of busbar includes:
 - Total leading power consumed $i_1^2 R + i_2^2 R$
 - Load current i_1, i_2, i
 - Additional resistance R_1, R_2, R

45
 At $x = 0$ we have:
 - Then i_x can be calculated from $i = i_0 e^{-Rx/L}$
 Given i_0 is known, we may find:
 - Current in all the sections
 - Voltage across every leading pair.
 $V_x = i_x R$
 $V_x = i_0 e^{-Rx/L} R$
 $V_x = i_0 R e^{-Rx/L}$
 $V_x = i_0 R e^{-2iL} e^{2ix/L}$
 • The point of maximum power in the load pair where
 source meets from the core area.

46
 A.C. Distribution Lines & Their Drop
 When the distributor supplies similar houses or establishments at long interval.
 When approximately equal loads are supplied after regular & short intervals.
 Then loads can be concentrated in the vicinity of distributor.
 i.e. the uniformly loaded distributor has load one and only

 • Bus bar having leading pair & return pair.

47
 Current through the small section $dx = (l - x) \cdot i$.
 Design of busbar includes:
 - Total leading power consumed $i^2 R = (l - x)^2 i^2 R$
 $\Delta V = (l - x) i R = (l - x) i^2 R = (l - x) i^2 R$
 where, $i = (l - x) \cdot i$ = total current in the distributor
 $R = (l - x) \cdot i^2 R$ = total go & return resistance of the distributor
 By any distance 'x' voltage drop is given by
 $i = (l - x) \cdot i^2 R = (l - x) \cdot i^2 R$

48
 A.C. Distribution Lines & Their Drop
 For long uniformly distributed load in one end voltage drop
 may be considerably high & resulting voltage of successive
 series and beyond the returnable lines.
 Under such condition uniformly loaded distributor can't be
 used.
 • Then point of maximum power in the load pair where
 source meets from the core area.

Current through the small section $dx = (l - x) \cdot i$ = $(l - x) \cdot i$ Amp

In small section dx voltage drop $dv = (l - x) \cdot i \cdot (r \cdot dx) = (l - x) \cdot i \cdot r \cdot dx$

So, total voltage drop from the feeding point F to far end A

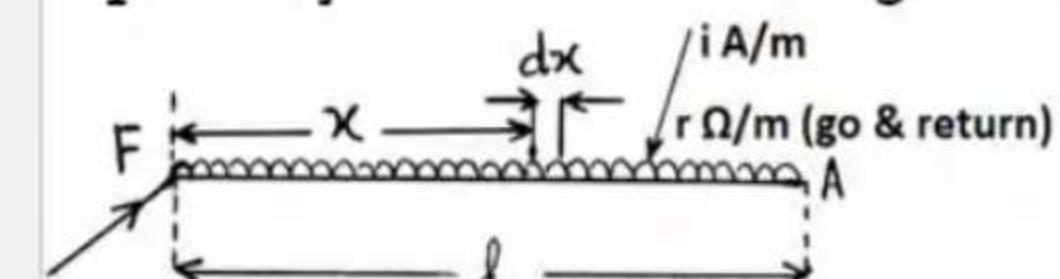
$$\int_0^l dv = \int_0^l (l - x) \cdot i \cdot r \cdot dx = \int_0^l l \cdot i \cdot r \cdot dx - \int_0^l i \cdot r \cdot x \cdot dx$$

$$= l^2 \cdot i \cdot r - i \cdot r \left[\frac{x^2}{2} \right]_0^l = \frac{1}{2} l^2 \cdot i \cdot r = \frac{1}{2} (l \cdot i) \cdot (l \cdot r) = \frac{1}{2} I \cdot R \text{ Volt}$$

where, $I = (l \cdot i)$ = total consumption in the distributor &

$R = (l \cdot r)$ = total go & return resistance of the distributor.

Up to any distance 'x' voltage drop is given by



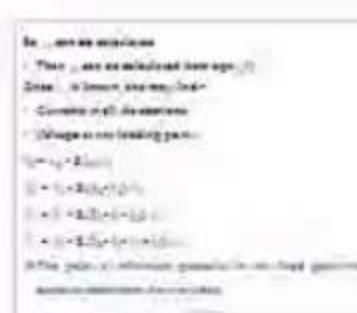
$$v_x = (l \cdot i \cdot r \cdot x - i \cdot r \cdot \frac{x^2}{2}) \text{ Volt}$$

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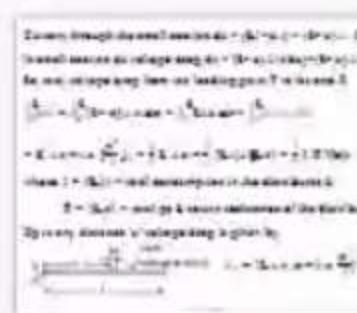
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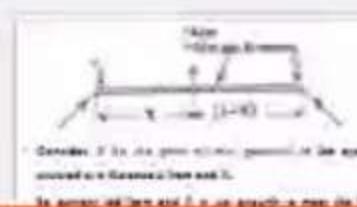
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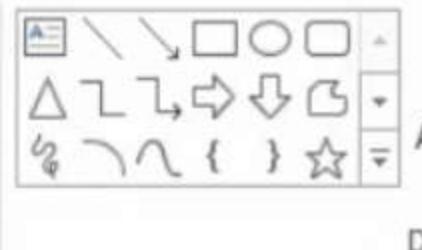
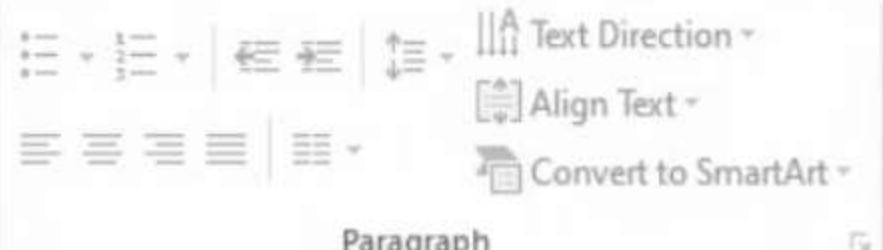
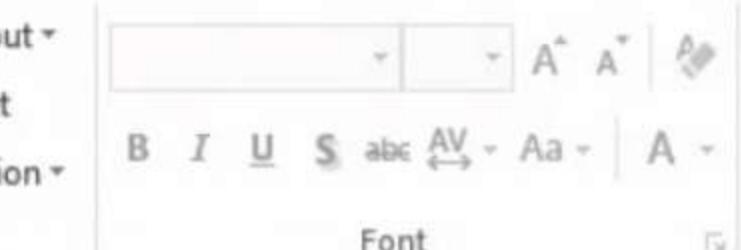
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Uniformly Loaded Distributor Fed At Both Ends

- For long uniformly distributors (fed at one end) voltage drop may be considerably high → resulting voltage of consumers at far end beyond the tolerable limits.
- Under such situation Uniformly loaded distributors are fed at both ends.**
- Then, point of minimum potential occurs at some point where currents meet from both the ends.
- Voltage drop up to point of minimum potential is much less compared to the case when distributor fed at one end only.





46
Ammeter across Considered load at Point P

- Then the Ammeter supplies similar losses or available losses at a long end.
- When approximately equal loads are supplied at regular & short intervals.
- Then losses can be considered to be uniformly distributed.
- i.e., the uniformly loaded distribution can be fed at one end only.

More about feeding at one end (go & return)

47
Current through the small section $dx = (S_1 \rho dx) + (S_2 \rho dx)$. Neglecting the small section voltage drop $dx = (S_1 \rho dx) + (S_2 \rho dx)$ leads to total voltage drop from the feeding point P to load P.

$$dx = \frac{V_A - V_B}{\rho} dx = \frac{V_A - V_B}{\rho l}$$

$$\therefore S_1 \rho dx = \frac{V_A - V_B}{\rho l} dx = \frac{V_A - V_B}{\rho l} dx$$

$$\text{where, } S_1 = \frac{V_A}{\rho l} = \text{load current in the short bus.}$$

$$S_2 = \frac{V_B}{\rho l} = \text{load current in the short bus.}$$

$$S = (S_1 + S_2) = \text{total load current of the distribution.}$$

$$S_1 = \frac{V_A}{\rho l} = \text{load current in the short bus.}$$

$$S_2 = \frac{V_B}{\rho l} = \text{load current in the short bus.}$$

48
Ammeter across Considered load at Point P

- The long uniformly distributed (load at one end) voltage drop may be considerably high & resulting voltage of zero current at the end beyond the ammeter.
- Stable with minimum uniformly loaded distribution can be fed at both ends.
- Then general minimum potential occurs at some point where current flows from both the ends.
- Voltage drop at point of minimum potential is much less compared to the case when distributed load at one end only.

49

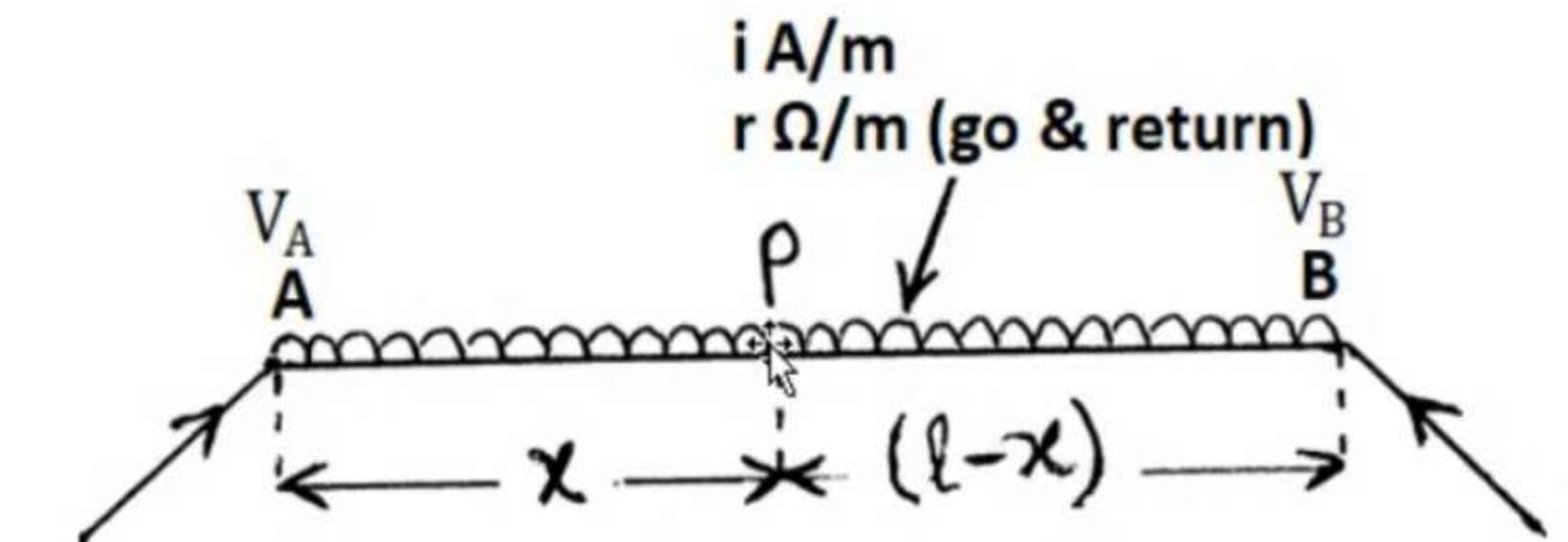
- Consider P be the point of min. potential in the system situated at a distance x from end A.
- So, current fed from end A is just enough to meet the load from A to P.
- Likewise, current fed from end B is just enough to meet the load from B to P.

50

Voltage drop from A to P = $\frac{V_A - V_P}{\rho l} dx^2$
 Voltage drop from B to P = $\frac{V_B - V_P}{\rho l} dx^2$

$$\text{Voltage drop from A to P} = \frac{V_A - V_P}{\rho l} dx^2 = \frac{V_A - V_P}{\rho l} dx^2$$

$$\text{Voltage drop from B to P} = \frac{V_B - V_P}{\rho l} dx^2 = \frac{V_B - V_P}{\rho l} dx^2$$



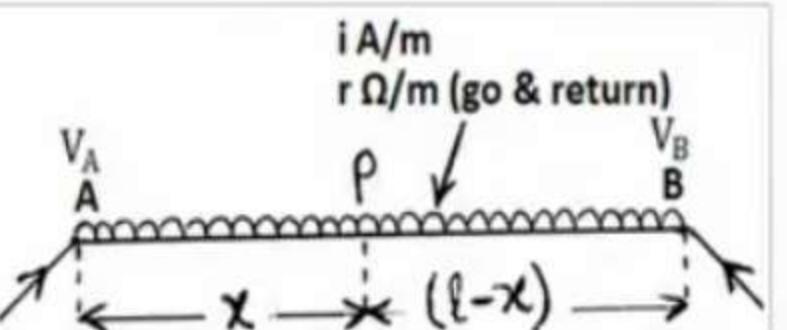
- Consider, P be the point of min. potential in the system situated at a distance x from end A.
- So, current fed from end A is just enough to meet the load from A to P.
- Likewise, current fed from end B is just enough to meet the load from B to P.

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Voltage drop from A to P = $v_1 = i r \frac{x^2}{2}$

$$\text{Voltage drop from B to P} = v_2 = i_r \frac{(l-x)^2}{2}$$



Voltage drop from A to B = $V_A - V_B = \vartheta_1 - \vartheta_2 = \vartheta$ (say)

$$\text{So, } v = i\gamma \frac{x^2}{2} - i\gamma \frac{(l-x)^2}{2} = i\frac{\gamma}{2} [x^2 - (l-x)^2] \\ = -i\frac{\gamma}{2} \cdot l^2 + i\gamma l x$$

Therefore, point of minimum potential

$$x = \left[\frac{l}{2} + \frac{v}{\omega_1 l} \right]$$

Knowing x , voltage drop up to P may be calculated.

If $V_A = V_B$, $v = 0$ and $x = \frac{l}{2}$, i.e. at the mid point.

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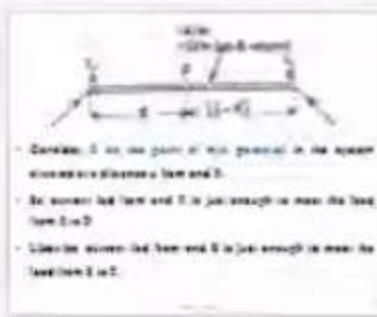
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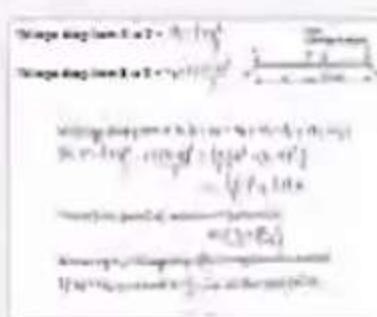
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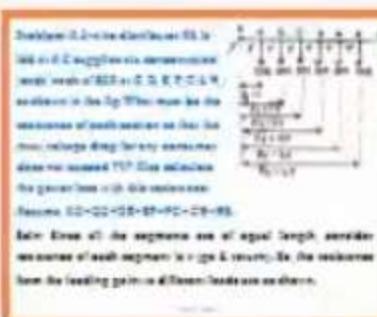
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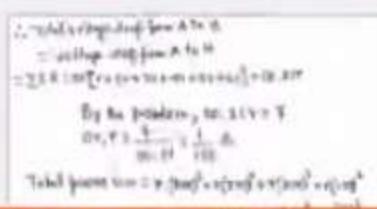
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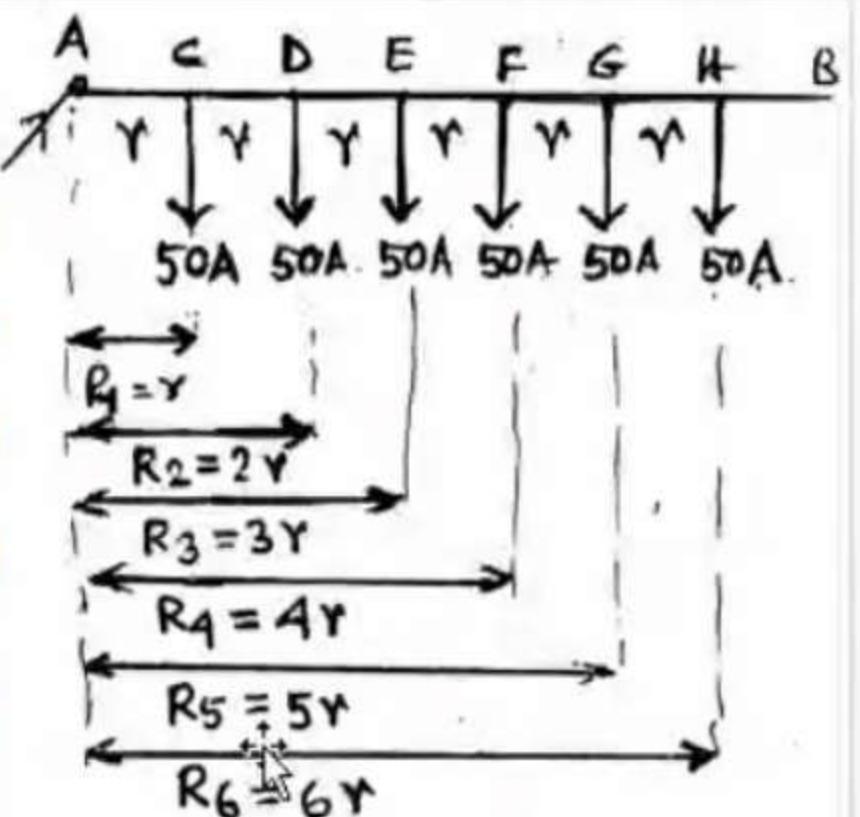
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Problem: A 2-wire distributor AB is fed at A & supplies six concentrated loads, each of 50A at C, D, E, F, G & H, as shown in the fig. What must be the resistance of each section so that the max. voltage drop for any consumer does not exceed 7V? Also calculate the power loss with this resistance.

Assume, AC=CD=DE=EF=FG=GH=HB.

Soln: Since all the segments are of equal length, consider resistance of each segment is r (go & return). So, the resistance from the feeding point to different loads are as shown.

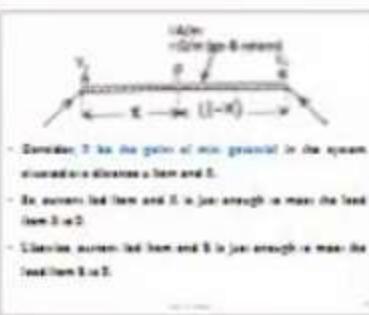


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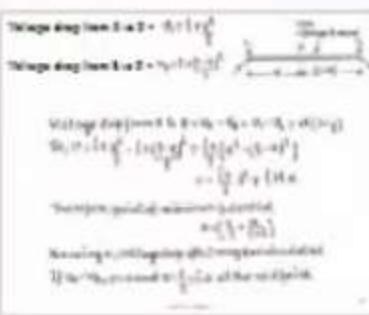
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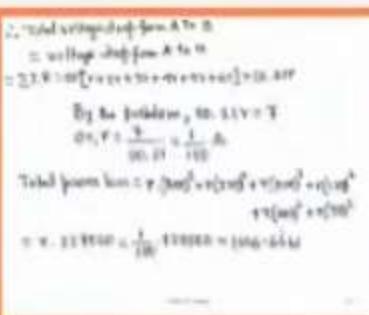
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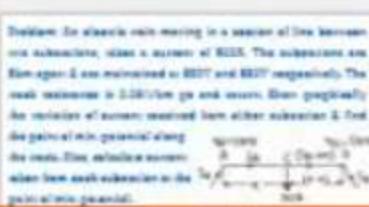
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52



53



∴ Total voltage drop from A to B

= voltage drop from A to H

$$= \sum I \cdot R = 50 [r + 2r + 3r + 4r + 5r + 6r] = 50.21r$$

By the problem, $50.21r = 7$

$$\text{or, } r = \frac{7}{50.21} = \frac{1}{150} \Omega$$

$$\begin{aligned} \text{Total power loss} &= r \cdot (300)^2 + r \cdot (250)^2 + r \cdot (200)^2 + r \cdot (150)^2 \\ &\quad + r \cdot (100)^2 + r \cdot (50)^2 \end{aligned}$$

$$= r \cdot 227500 = \frac{1}{150} \cdot 227500 = 1516.66 \text{ W}$$

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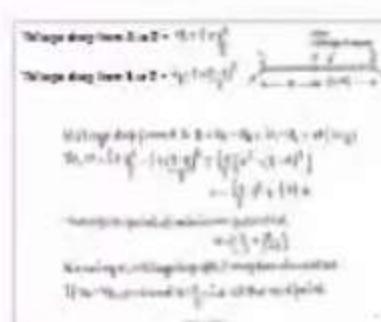
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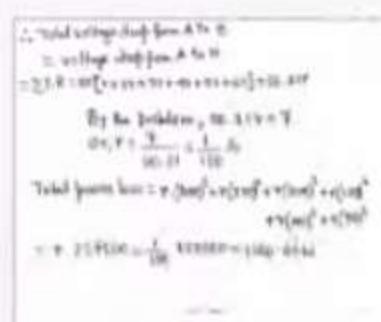
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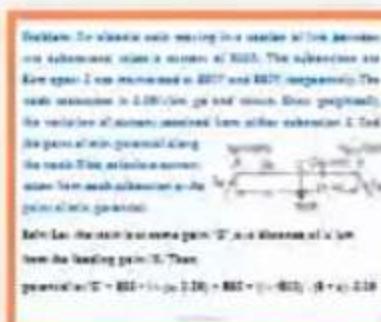
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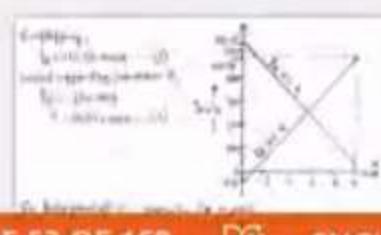
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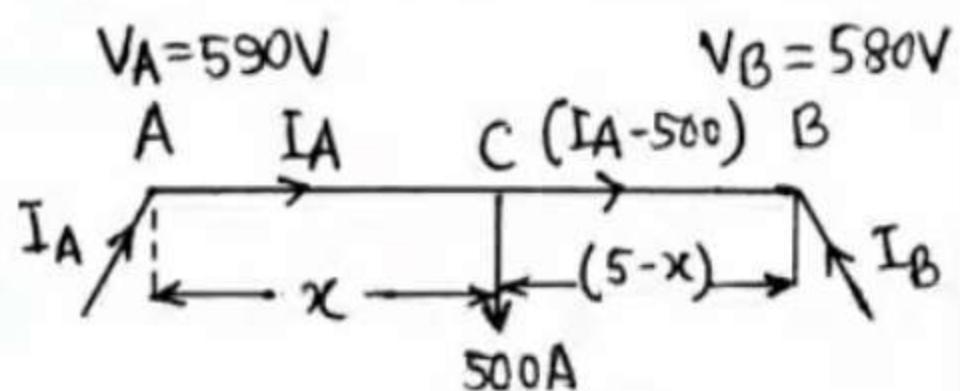
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54



Problem: An electric train moving in a section of line between two substations, takes a current of 500A. The substations are 5km apart & are maintained at 590V and 580V respectively. The track resistance is $0.06\Omega/\text{km}$ go and return. Show graphically the variation of current received from either substation & find the point of min. potential along the track. Also, calculate current taken from each substation at the point of min. potential.



Soln: Let, the train is at some point 'C', at a distance of 'x' km from the feeding point 'A.' Then,

potential at 'C' = $590 - I_A \cdot (x \cdot 0.06) = 580 + (I_A - 500) \cdot (5 - x) \cdot 0.06$

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51 Problem: A 2-phase short circuit at C is fed at B. It supplies two substations. Sub. A feeds at 500 V. Sub. B feeds at 533.33 V. The voltage drop in the line between the substations is 100 V. The resistance of each section is 0.06 ohm/km. The total length of the line is 5 km. The load at point C is 500+j500 ohm. The load at point D is 100+j100 ohm. The load at point E is 100+j100 ohm. The load at point F is 100+j100 ohm.

52 Total voltage drop from A to C = voltage drop from A to B + voltage drop from B to C = $500 \times 0.06 \times 5 + 533.33 \times 0.06 \times 5 = 33.33 + 166.66 = 200$ V. By load flow, $\frac{V_A - V_C}{Z_{AC}} = \frac{I_A}{Z_{AC}}$. Total power loss = $(200)^2 / (500 \times 500) + (200)^2 / (533.33 \times 533.33) + (200)^2 / (100 \times 100) = 1.28 + 0.128 + 0.4 = 1.808$ kW.

53 Problem: An electric train moving in a sector of one between two substations, where a current of 500 A. The substations are fed from B and C are maintained at 500 V and 533.33 V respectively. The load resistance is 0.06 ohm/km and occurs. Then calculate the resistance of current measured from either substation A. The load power at point C is 500+j500 ohm. The load at point D is 100+j100 ohm. The load at point E is 100+j100 ohm. The load at point F is 100+j100 ohm.

54 Current at A: $I_A = 500 / (500 + 500) = 0.5$ A. Current supplied by substation B: $I_B = 0.5 - 500 / 533.33 = 0.06666666666666666$. Power at point C: $P_C = 500 \times 0.5 \times 0.06666666666666666 = 16.666666666666666$ W. Power at point D: $P_D = 500 \times 0.5 \times 0.06666666666666666 = 16.666666666666666$ W. Power at point E: $P_E = 500 \times 0.5 \times 0.06666666666666666 = 16.666666666666666$ W. Power at point F: $P_F = 500 \times 0.5 \times 0.06666666666666666 = 16.666666666666666$ W.

Simplifying,

$$I_A = 533.33 - 100x \quad \dots \dots (1)$$

Current supplied by substation B,

$$\begin{aligned} I_B &= -(I_A - 500) \\ &= -33.33 + 100x \quad \dots \dots (2) \end{aligned}$$

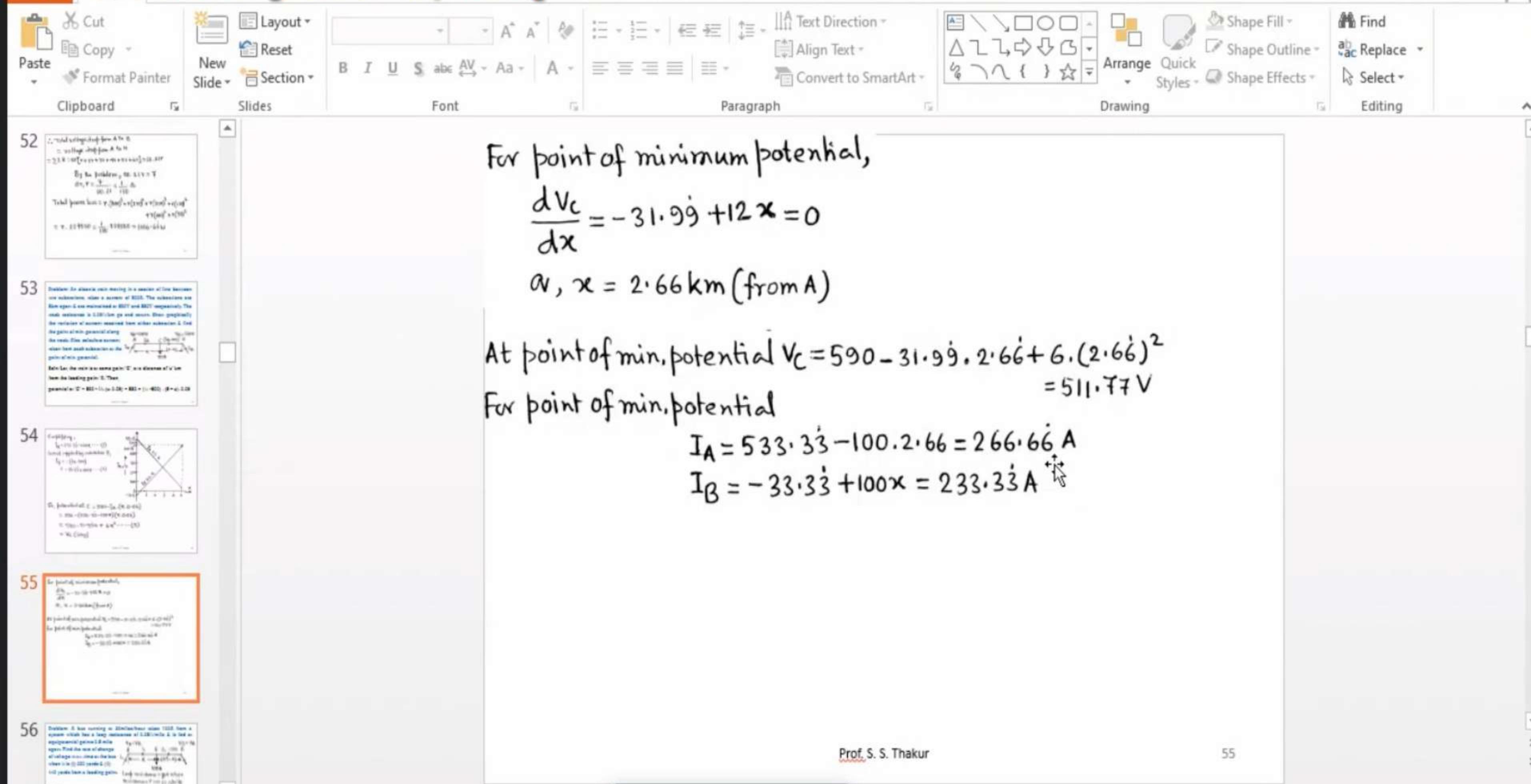
So, potential at C = $590 - I_A \cdot (x, 0, 0.06)$

$$\begin{aligned} &= 590 - (533.33 - 100x)(x, 0, 0.06) \\ &= 590 - 31.99x + 6x^2 \quad \dots \dots (3) \\ &= V_C (\text{say}) \end{aligned}$$

Prof. S. S. Thakur

55

Forward 5 sec - [00:20:10 / 529]



Forward 5 sec - [00:20:50 / 53]



53

Example: An ultrasonic wave moving in a medium of low density has a wavelength of 0.023. The velocities are given as $v = 3000$ and $\lambda = 0.023$ respectively. The wave frequency is $f = 130000$ Hz and we are then prompted to calculate the distance of a source measured from another ultrasonic wave if the two waves travel parallel along the same axis. The reference source emits sound waves with a wavelength of 0.023 m and the source emits waves with a wavelength of 0.023 m.

54

55

```

for i=1:n-1 do
    if max(i) > max(i+1) then
        swap(i,i+1)
    end
end
return max(n)

```

56

Problem 5: You are running on a flat track from point A to point B. Your average velocity is 10 m/s . You run at a constant speed of 12 m/s for the first 100 m , then slow down to 8 m/s for the next 100 m . Finally, you run at 10 m/s for the final 100 m . Find the total time taken.

57

$$\begin{aligned} \text{Distance} &= 100 - 100 \times \frac{1}{10} = 90 \text{ m} \quad (1) \\ \text{Time, in sec} &= \frac{90}{10} = 9 \text{ sec} \quad (2) \\ \text{Speed} &= \frac{90}{9} = 10 \text{ m/sec} \quad (3) \end{aligned}$$

Problem: A bus running at 30 miles/hour takes 100A from a system which has a loop resistance of $0.25\Omega/\text{mile}$ & is fed at equipotential points 0.5 mile apart. Find the rate of change of voltage w.r.t. time at the bus when it is (i) 220 yards & (ii) 440 yards from a feeding point.

A bridge circuit diagram with four resistors labeled A, B, E, and 100 ohms. Resistor A is on the left, resistor B is on the right, resistor E is at the top center, and a 100 ohm resistor is at the bottom center. Current I_A flows through resistor A from left to right. Current $(I_A - 100)$ flows through resistor B from right to left. Current E flows through resistor E from left to right. The voltage across the 100 ohm resistor is labeled x on the left and $(0.5 - x)$ on the right.

Loop resistance = go & return
resistance = $r = 0.25 \Omega/\text{mile}$

Sol

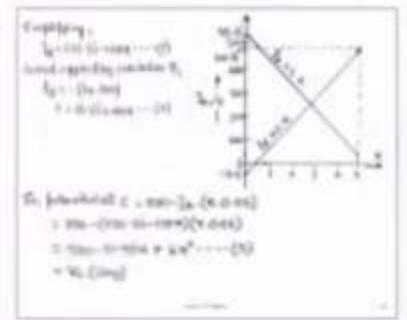
Consider, the bus is at a distance x mile from the feeding point A.

$$\begin{aligned} \text{Voltage drop from A to B} &= V_A - V_B \\ &= I_A \cdot (r \cdot x) + (I_A - 100) \{ r \cdot (0.5 - x) \} = 0 \end{aligned}$$

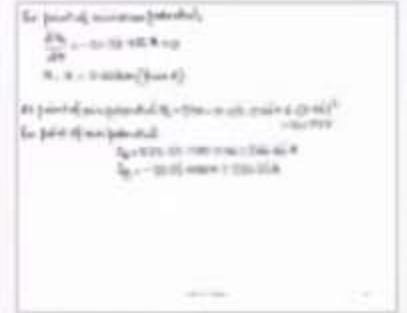
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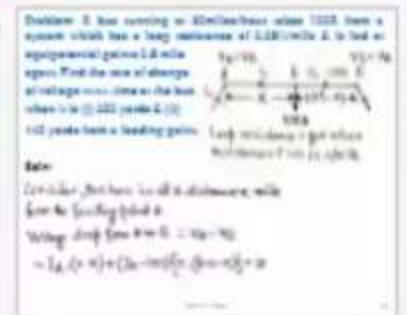
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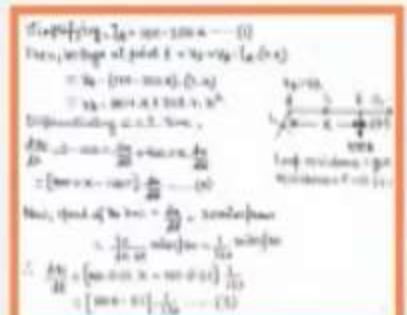
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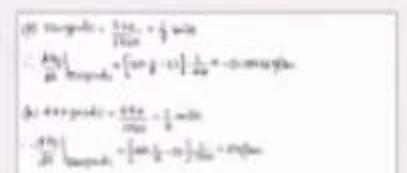
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57



58



Simplifying, $I_A = 100 - 200x \dots\dots (1)$

Then, Voltage at point E = $V_E = V_A - I_A \cdot (r \cdot x)$

$$= V_A - (100 - 200x) \cdot (r \cdot x)$$

$$= V_A - 100r \cdot x + 200 \cdot r \cdot x^2$$

Differentiating w.r.t. time,

$$\frac{dV_E}{dt} = 0 - 100 \cdot r \cdot \frac{dx}{dt} + 400 \cdot r \cdot x \cdot \frac{dx}{dt}$$

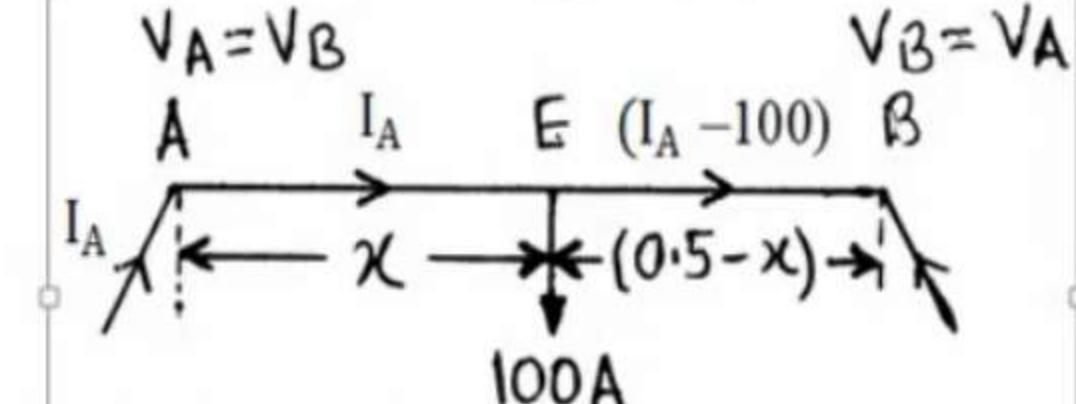
$$= [400 \cdot r \cdot x - 100r] \cdot \frac{dx}{dt} \dots\dots (2)$$

Now, speed of the bus = $\frac{dx}{dt} \approx 30 \text{ miles/hour}$

$$= \frac{30}{60 \cdot 60} \text{ miles/sec} = \frac{1}{120} \text{ miles/sec}$$

$$\therefore \frac{dV_E}{dt} = [400 \cdot 0.25 \cdot x - 100 \cdot 0.25] \cdot \frac{1}{120}$$

$$= [100x - 25] \cdot \frac{1}{120} \dots\dots (3)$$



$V_A = V_B$
 $V_B = V_A$
 I_A E $(I_A - 100)$ B
 I_A x $(0.5 - x)$
 $100A$

Loop resistance = r & return
 resistance = $r = 0.25 \Omega/\text{mile}$

Forward 5 sec -[00:27:50 / 72%]

55

For problem 55, assume that the car's
initial velocity is 25 m/sec.
The car's deceleration is constant at 10 m/sec².
Find the time taken by the car to stop.

Initial velocity = 25 m/sec
Deceleration = 10 m/sec²
Final velocity = 0 m/sec

56

Problem 56: A car running at 100 km/h stops in a distance of 100 m. If the car has a constant deceleration, find the time taken by the car to stop.

Initial velocity = 100 km/h
Final velocity = 0 km/h
Distance = 100 m
Time = ?

57

Given: Initial velocity, $v_0 = 100 \text{ m/sec}$ --- (1)
Deceleration of point A = $a_A = v_{A2} - v_A / t_A$ (from 1)
= $a_A = (v_0 - v_{A2}) / t_A$
 $v_{A2} = v_0 + a_A t_A$, $v_{A2}^2 = v_0^2 + 2 a_A t_A$
 $\frac{dV_E}{dt} = v_{A2} \frac{dv_{A2}}{dt} = v_{A2} \cdot a_A$
 $\frac{dV_E}{dt} = [v_0 + a_A t_A] \frac{dv_{A2}}{dt} = [v_0 + a_A t_A] \frac{dt}{dt} = [v_0 + a_A t_A]$
Now, time of deceleration = $\frac{100}{a_A}$ sec
 $\frac{dV_E}{dt} = \frac{100}{a_A} \cdot a_A = \frac{100}{a_A} \text{ m/sec}^2$
 $\frac{dV_E}{dt} = \frac{100}{a_A} \cdot 10 = \frac{1000}{a_A} \text{ m/sec}^2$

58

(a) Initial velocity = $100 \text{ m/sec} = \frac{1}{18} \text{ miles/sec}$
 $\frac{dV_E}{dt} = \frac{1}{18} \cdot 10 = \frac{10}{18} \text{ miles/sec}^2 = 0.5556 \text{ miles/sec}^2$
Final velocity = $0 \text{ m/sec} = \frac{1}{18} \text{ miles/sec}$
 $\frac{dV_E}{dt} = \frac{0 - \frac{1}{18}}{t} = -\frac{1}{18t} \text{ miles/sec}^2$

59

Given: Initial velocity = 100 m/sec
Deceleration = 10 m/sec²
Find the time taken by the car to stop.

$$(a) 220 \text{ yards} = \frac{220}{1760} = \frac{1}{8} \text{ mile}$$

$$\therefore \frac{dV_E}{dt} \Big|_{220 \text{ yards}} = [100 \cdot \frac{1}{8} - 25] \cdot \frac{1}{120} = -0.10416 \text{ V/sec}$$

$$(b) 440 \text{ yards} = \frac{440}{1760} = \frac{1}{4} \text{ mile}$$

$$\therefore \frac{dV_E}{dt} \Big|_{440 \text{ yards}} = [100 \cdot \frac{1}{4} - 25] \cdot \frac{1}{120} = 0 \text{ V/sec}$$

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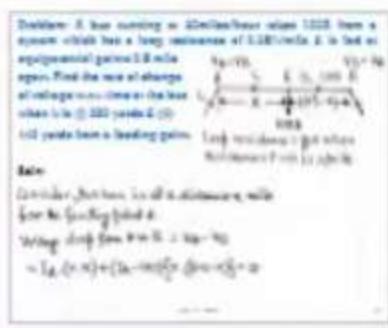
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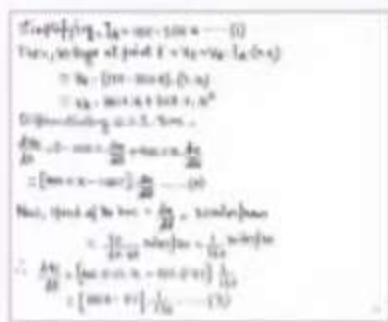
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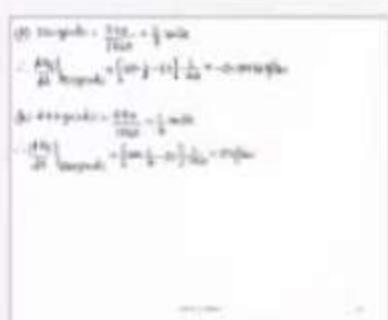
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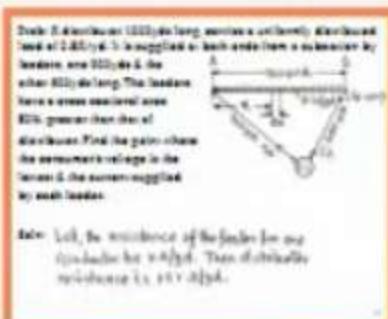
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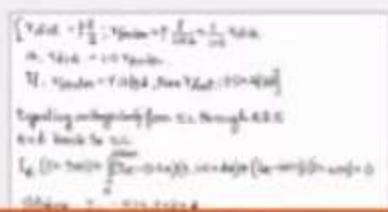
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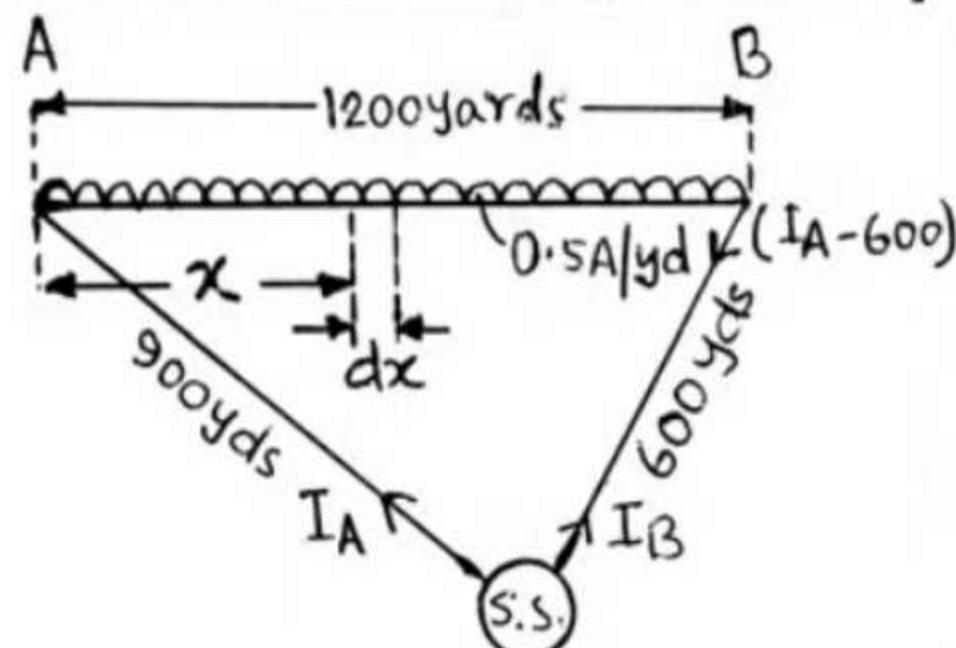
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60



Prob: A distributor 1200yds long, carries a uniformly distributed load of 0.5A/yd. It is supplied at both ends from a substation by feeders, one 900yds & the other 600yds long. The feeders have a cross sectional area 50% greater than that of distributor. Find the point where the consumer's voltage is the lowest & the current supplied by each feeder.



Soln: Let, the resistance of the feeder for one conductor be $r_s/2/\text{yd}$. Then distributor resistance is $1.5 r_s/2/\text{yd}$.

Forward 5 sec - [00:31:39 / 81]

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57

$\gamma_{\text{dist.}} = \rho \frac{l}{a}; \gamma_{\text{feeder}} = \rho \frac{l}{1.5a} = \frac{1}{1.5} \gamma_{\text{dist.}}$

or, $\gamma_{\text{dist.}} = 1.5 \gamma_{\text{feeder}}$.

If, $\gamma_{\text{feeder}} = \gamma_{\text{R2/yd}}$, then $\gamma_{\text{dist.}} = 1.5 \gamma_{\text{R2/yd}}$

Equating voltage drop from S.S. through A & B and back to S.S.

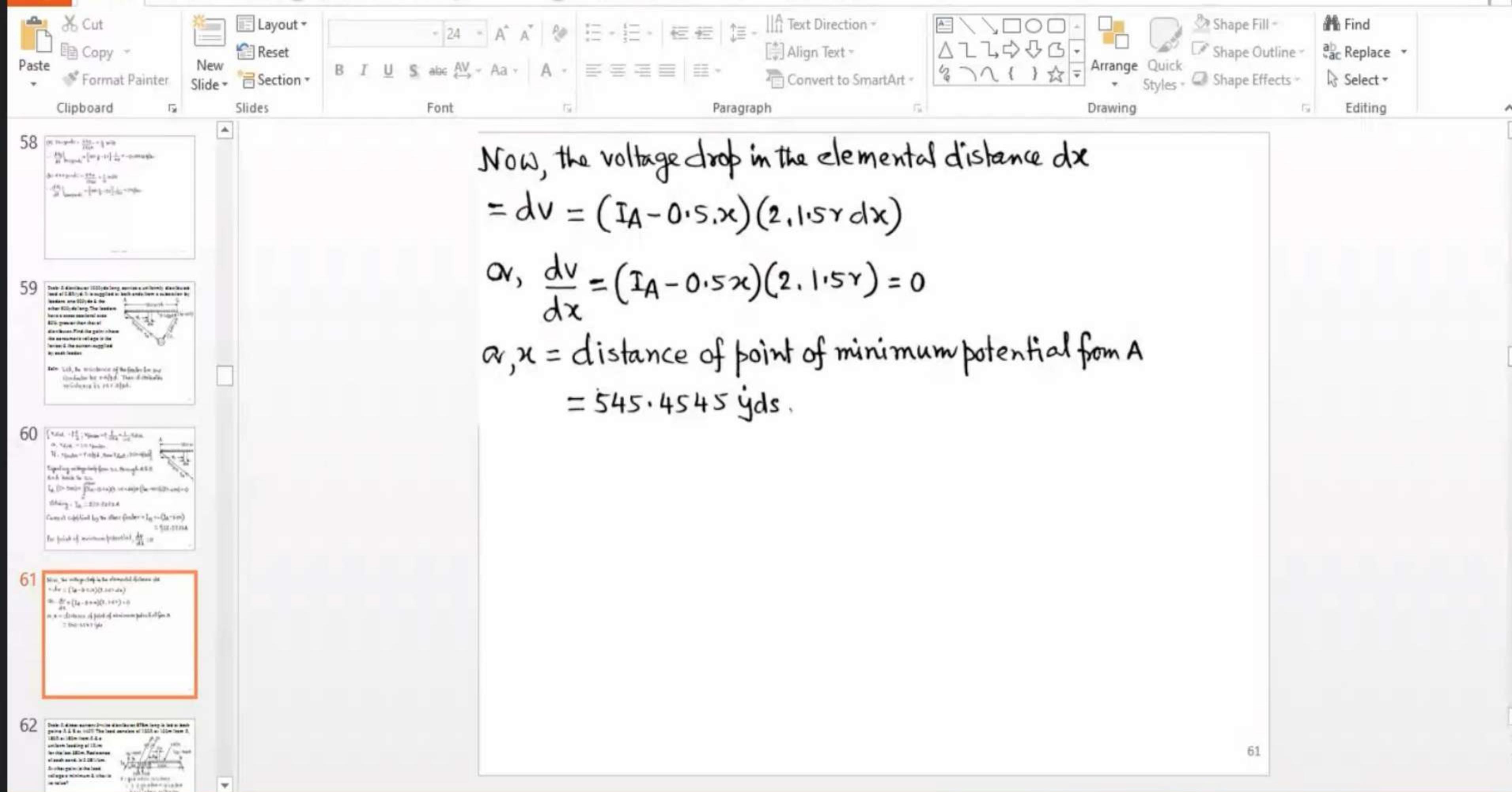
$I_A \cdot (2\gamma_{\text{R2}}) + \int_0^{1200} (I_A - 0.5x)(2.15\gamma_{\text{dx}}) + (I_A - 600) \cdot (2\gamma_{\text{R3}}) = 0$

Solving, $I_A = 272.7272 \text{ A}$

Current supplied by the other feeder = $I_B = -(I_A - 600)$
= 327.2727 A

For point of minimum potential, $\frac{dv}{dx} = 0$

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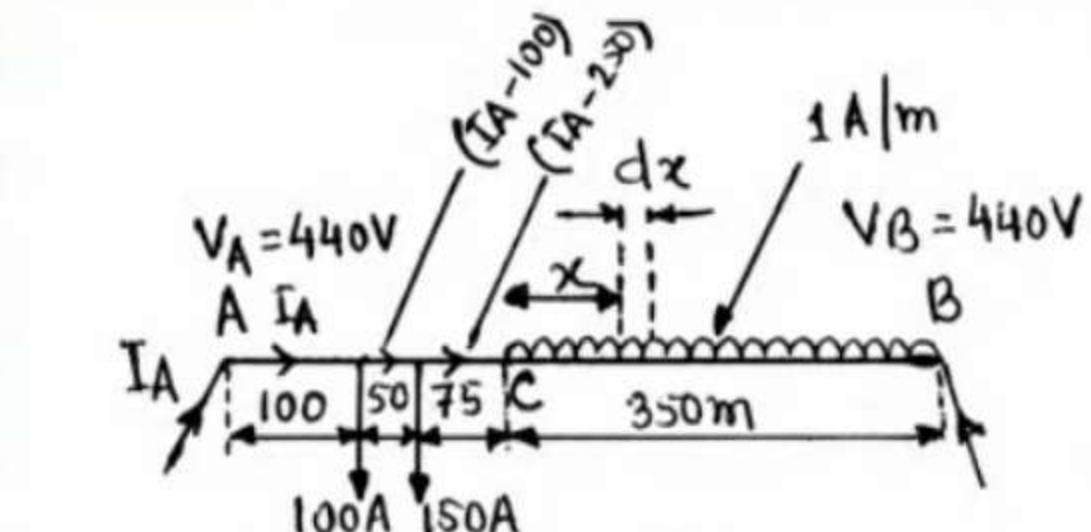
Problem: A direct current 2-wire distributor 575m long is fed at both points A & B at 440V. The load consists of 100A at 100m from A, 150A at 150m from A & a uniform loading of 1A/m for the last 350m. Resistance of each cond. is $0.05\Omega/\text{km}$.

At what point is the load voltage a minimum & what is its value?

Soln: Let, I_A be the current supplied from end A.

Then, voltage drop from A to B

$$\begin{aligned} = V_A - V_B &= I_A \cdot 100\gamma + (I_A - 100) \cdot 50\gamma + (I_A - 250) \cdot 75\gamma \\ &\quad + \int_0^{350} (I_A - 250 - x \cdot 1) \cdot \gamma dx = 0 \end{aligned}$$



$$\begin{aligned} \gamma &= \text{return resistance} \\ &= 2 \cdot 0.05 \Omega/\text{km} = 0.1 \Omega/\text{km} \\ &= 0.1 \cdot 10^{-3} \Omega/\text{m} = 10^{-4} \Omega/\text{m} \end{aligned}$$

Spelling
Aluminium
Resume

Aluminum
Aluminums

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Simplifying, $I_A = 300A$

Since $I_A = 300A$, the point of minimum potential occurs in between C & B.

Now, the voltage drop in the elemental distance dx at a distance 'x' from C = $dv = (I_A - 250 - x) \cdot r \cdot dx$

- For point of minimum potential $\frac{dv}{dx} = 0$

$$\text{or, } \frac{dv}{dx} = (I_A - 250 - x) \cdot r = 0$$

$$\text{or, } x = I_A - 250 = 50\text{m (from C towards B)}$$

Therefore, distance of point of minimum potential from end A = $(100 + 50 + 75) + 50 = 275\text{m}$

Spelling

Aluminium

Resume

Aluminum

Aluminums

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Similarly, distance of point of minimum potential from end B
 $= 350 - 50 = 300\text{m}$

Load voltage at point of minimum potential
 $= \text{Voltage at end B} - \text{Voltage drop in distributed load for } 300\text{m}$
 from end B

$= 440 - \frac{1}{2} \cdot 300^2 \cdot 1 \cdot 10^{-4} = 435.5\text{V}$

Spelling Aluminium Resume Aluminum Aluminums

Sanjit Kumar Swain 64 English (United States)

Forward 5 sec - [00:17:40 / 47%]

Microsoft account

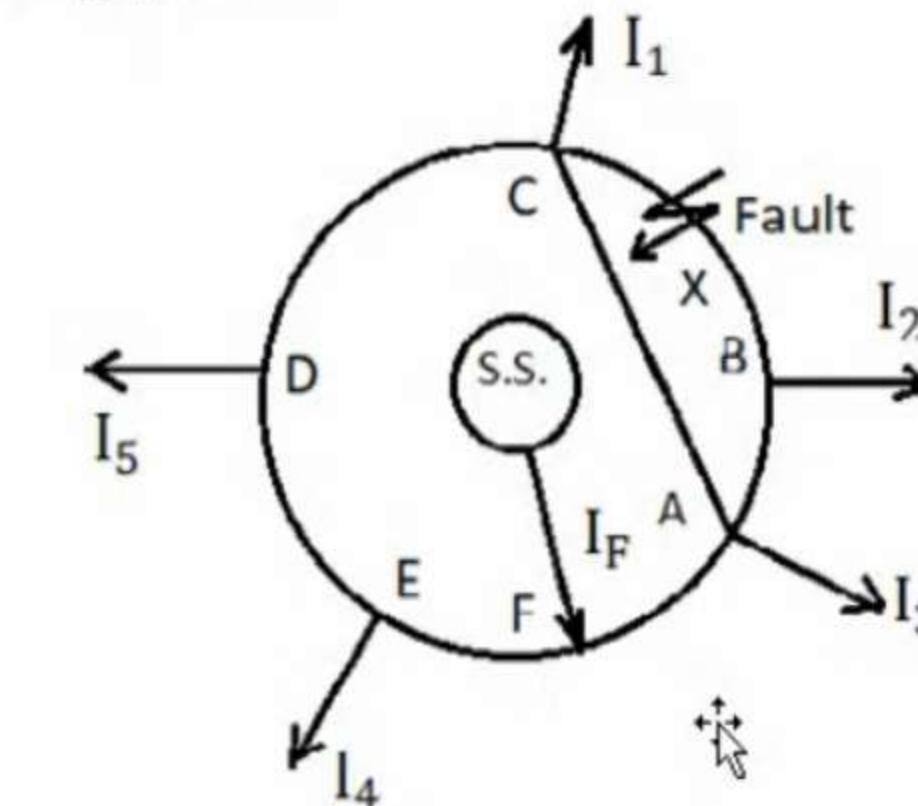
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Ring Distributor

- It employs a distributor which after covering the whole area of supply returns back to starting point.
- It is closed on itself.
- ABCDEFA forms a complete ring.
- Loads are connected at A, B, C, D & E; F is feeding point.
- For any load, there are two parallel paths → greater reliability of supply.
- For fault at 'X', 'BC' is isolated for continuity of supply.
- More saving in conductor compared to a radial distributor.
- Often, two points are joined to reduce voltage drop further.



Spelling

i.r.dx

Resume

(No Suggestions)

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- Two examples of ring distributors are shown in the figures.
- In second fig. current directions are chosen arbitrarily.
- Let, $r \Omega/m$ be go & return of distributor.
- Applying Kirchhoff's law in closed path FABCF,

$$I \cdot (l_1 \cdot r) + (I - I_1) \cdot (l_2 \cdot r) + (I - I_1 - I_2) \cdot (l_3 \cdot r) - I_A \cdot (l_7 \cdot r) = 0 \dots \dots (1)$$

- Applying Kirchhoff's law in closed path FEDCF,

$$(I_F - I - I_A) \cdot (l_6 \cdot r) + (I_F - I - I_A - I_5) \cdot (l_5 \cdot r) + I_F \cdot I \cdot I_A \cdot (l_7 \cdot r) + (I_F - I - I_A - I_5 - I_4) \cdot (l_4 \cdot r) - I_A \cdot (l_7 \cdot r) = 0 \dots (2)$$

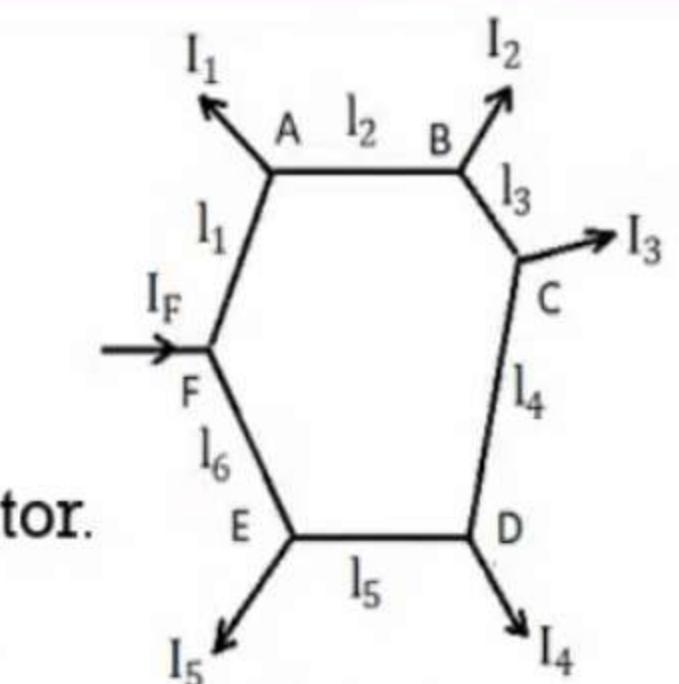


Fig. Simple ring distributor.

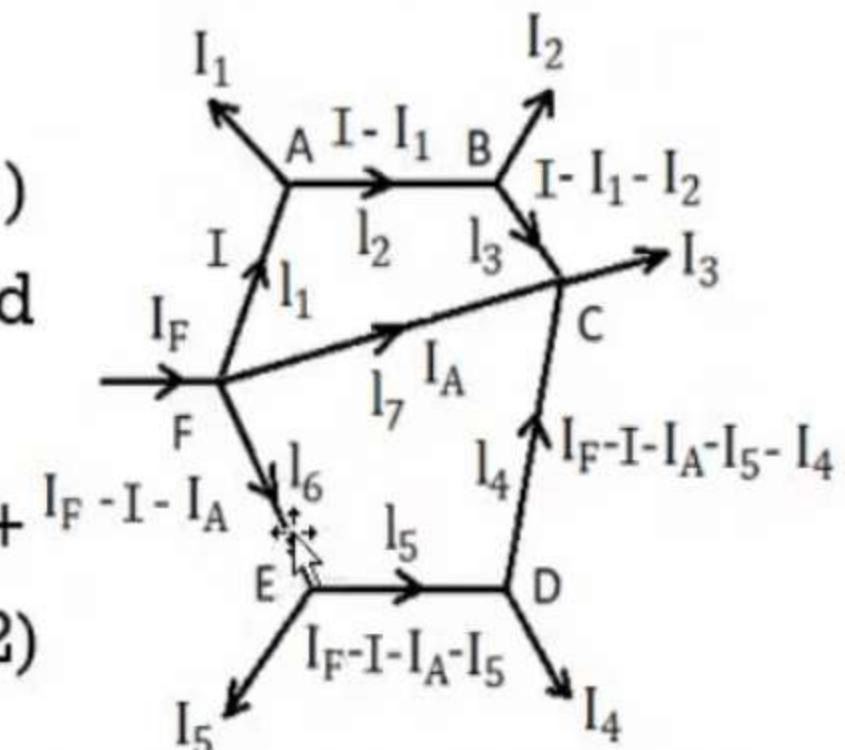


Fig. Ring distributor with inter-connection.

Spelling

i.r.dx

Resume

(No Suggestions)

English (India)

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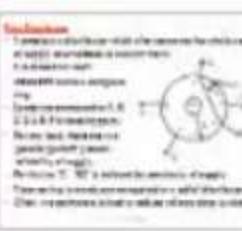
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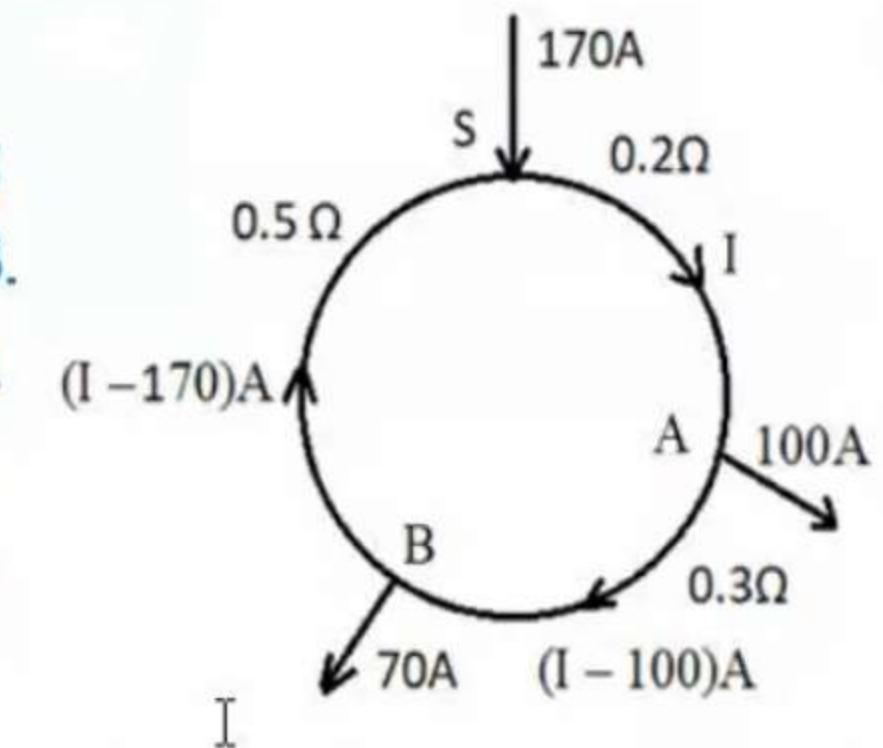
68



69



Problem: A ring main is supplied at point S and is loaded at point A with 100A & at point B with 70A. The sectional resistances are: SA, 0.2Ω; AB, 0.3 Ω; BS, 0.5 Ω. (a) Find the current in AB. (b) Find the voltage drop between S & each Load point. (c) Find the voltage drop between S & A when load at B is removed.



Soln: Considering the current directions, voltage drop in the closed path,

$$I \cdot 0.2 + (I - 100) \cdot 0.3 + (I - 170) \cdot 0.5 = 0$$

Solving, $I = \text{Current from S to A} = 115A$.

Spelling

i.r.dx

Resume

(No Suggestions)

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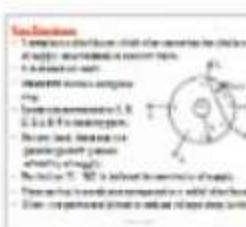
64



(a) Current in AB = $(115 - 100)A = 15A$ (from A to B).

$$\text{Current from S to B} = -(I - 170) = 55A \quad I$$

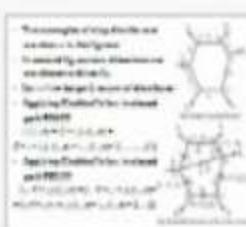
65



(b) Voltage drop between S & A = $I \cdot 0.2 = 23V$ (from S to A).

Voltage drop between S & B = $55 \cdot 0.5 = 27.5V$ (from S to B).

66



(c) When load at B is removed, then current at A is received through two parallel paths: S - A & S - B - A.

67



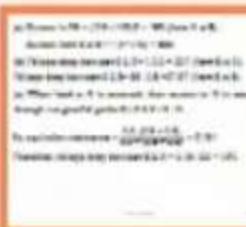
$$\text{So, equivalent resistance} = \frac{0.2 \cdot (0.5 + 0.3)}{0.2 + (0.5 + 0.3)} = 0.16\Omega$$

68



Therefore, voltage drop between S & A = $0.16 \cdot 100 = 16V$.

69



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67
Prob: In the direct-current ring distributor shown, a voltage of 500V is maintained at A. At B, a load of 150A is taken & at C, a load of 200A is taken. Find voltages at B & C. Resistance of each conductor of the main is $0.03\Omega/\text{km}$.

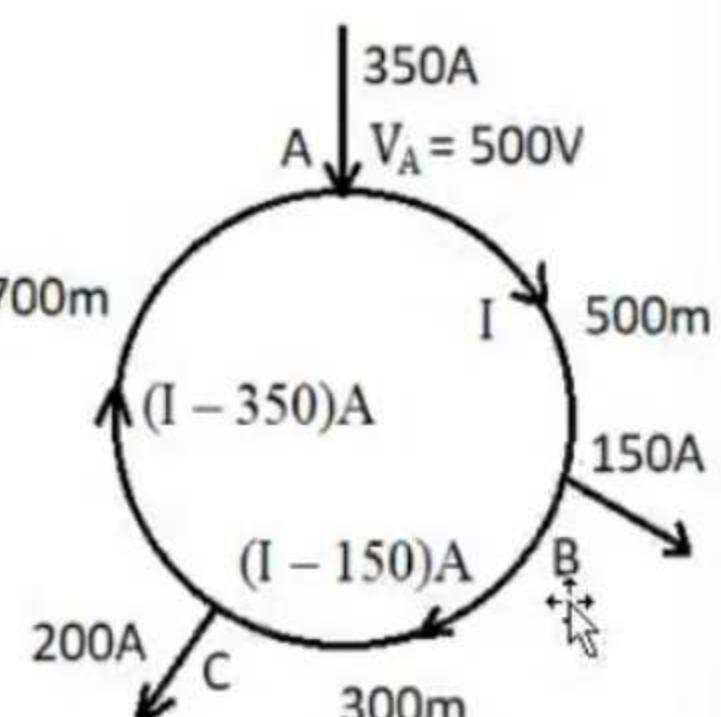
68
Soln: Applying Kirchhoff's Voltage law,

69
 $I \cdot (0.03 \cdot 10^{-3} \cdot 2 \cdot 500) + (I - 150) \cdot (0.03 \cdot 10^{-3} \cdot 2 \cdot 300) + (I - 350) \cdot (0.03 \cdot 10^{-3} \cdot 2 \cdot 700) = 0$

70
Solving, $I = 193.3333\text{A}$

71
Voltage at B = $V_A - \{I \cdot (0.03 \cdot 10^{-3} \cdot 2 \cdot 500)\} = 494.2\text{V}$ (A - B).

Voltage at C = $V_A - \{(I - 350) \cdot (0.03 \cdot 10^{-3} \cdot 2 \cdot 700)\} = 493.42\text{V}$ (A - C)



Resistance of each conductor
 $= 0.03\Omega/\text{km} = 0.03 \cdot 10^{-3} \Omega/\text{m}$

Forward 5 sec -[00:15:30 / 47%]

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Prob: Find the current supplied to the ring main from A & B (a) for equal voltages at A & B, (b) for the voltage at B higher than that at A by 5V.

$$\text{Soln: } I_A + I_B = 100 + 20 + 50 + 30 \\ = 200 \text{A}$$

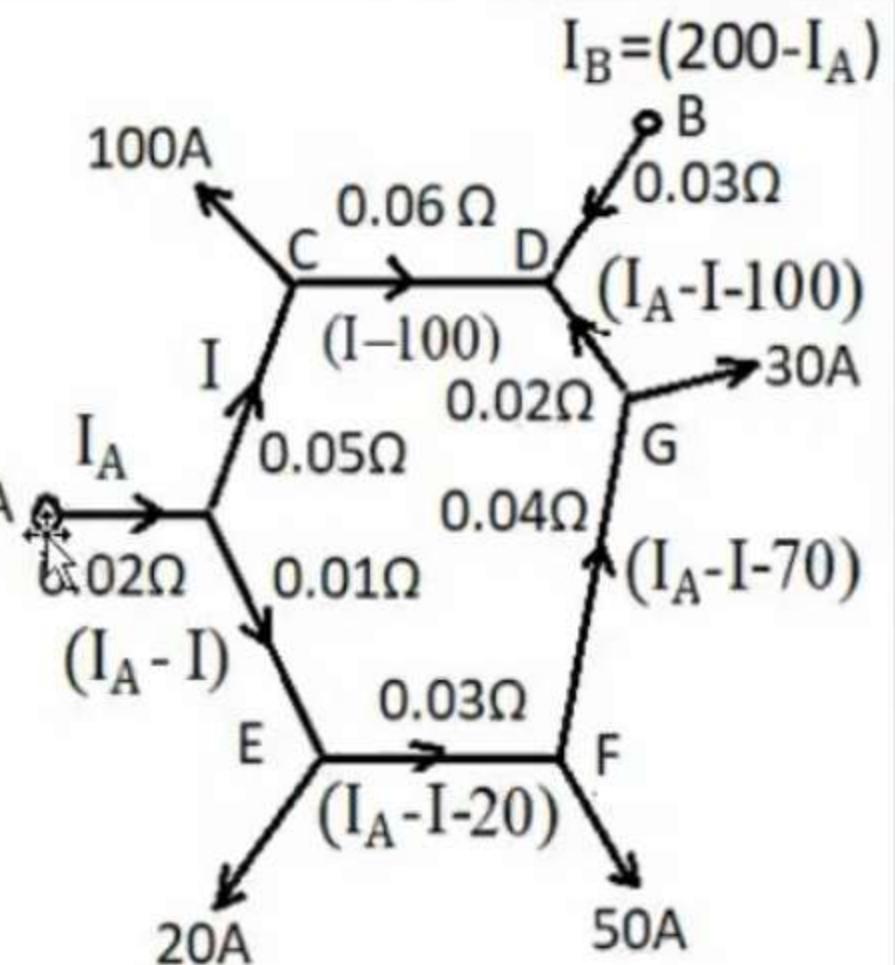
$$\text{Or, } I_B = 200 - I_A \dots\dots(1)$$

(a) Voltage drop from A to B, via C & D,

$$I_A \cdot 0.02 + I \cdot 0.05 + (I - 100) \cdot 0.06 - (200 - I_A) \cdot 0.03 = 0$$

Simplifying,

$$5. I_A + 11. I = 1200 \dots\dots(2)$$



Forward 5 sec - [00:20:03 / 61%]

69
[Text content related to question 69]

70
[Text content related to question 70]

71
[Text content related to question 71]

72
[Text content related to question 72]

73
[Text content related to question 73]

Similarly, Voltage drop from A to B, via E, F & G,

$$I_A \cdot 0.02 + (I_A - I) \cdot 0.01 + (I_A - I - 20) \cdot 0.03 + (I_A - I - 70) \cdot 0.04 \\ + (I_A - I - 100) \cdot 0.02 - (200 - I_A) \cdot 0.03 = 0$$

Simplifying,

$$15. I_A - 10. I = 1140 \dots\dots(3)$$

Solving eqns. (2) & (3),

$$I = 57.2093A \text{ & } I_A = 114.1395A$$

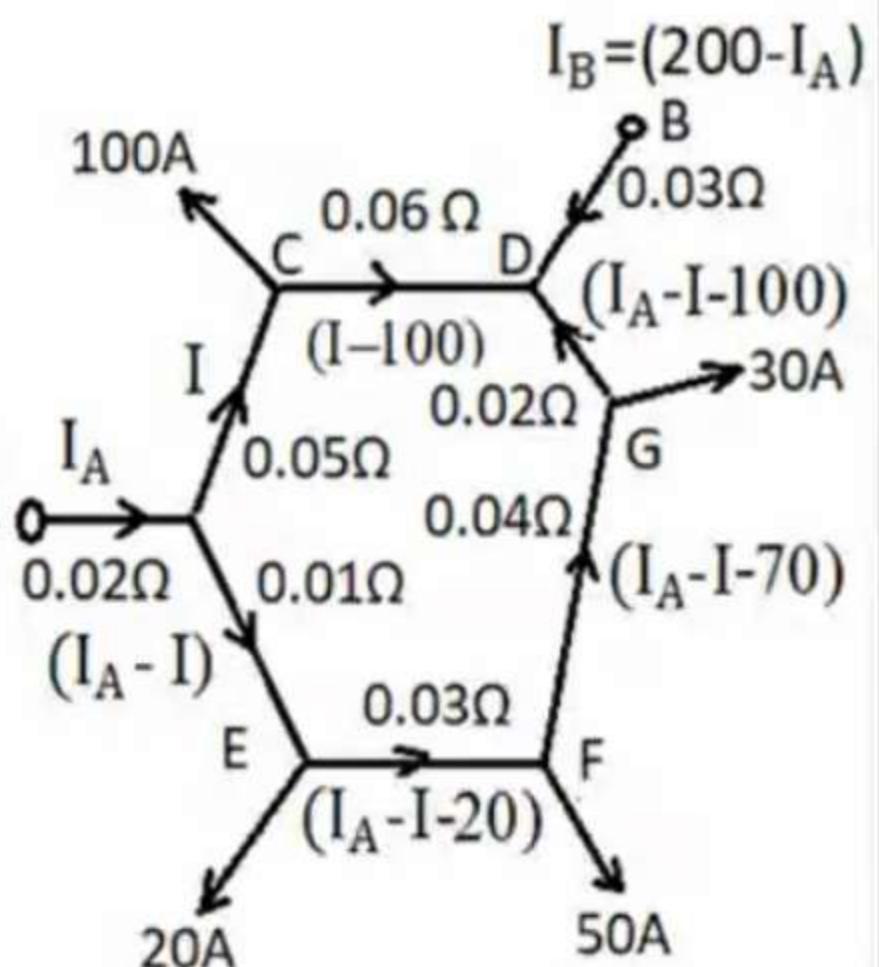
$$\text{Therefore, } I_B = 200 - I_A = 85.8605A$$

$$(b) V_B = V_A + 5 \dots\dots(4)$$

So, from eqn. (2),

$$5. I_A + 11. I - 1200 = -500$$

$$\text{Or, } 5. I_A + 11. I = 700 \dots\dots(5)$$



Backward 5 sec -[00:22:04 / 67%]

A yellow clipboard icon with a white document paper on it.

A row of four icons: a yellow sun-like icon for 'New', a document icon for 'Layout', a blue document icon for 'Reset', and a yellow star icon for 'Section'.

The ribbon bar at the top of the screen shows the 'Home' tab selected. The 'Font' dropdown is set to '24'. The 'Font Style' dropdown shows 'A' with a superscript '2' and a subscript '1'. The 'Font Color' dropdown shows a blue square. The 'Font Size' dropdown shows '24'. The 'Font' dropdown shows 'Times New Roman'. The 'Font' dropdown has a 'Text Direction' button with an arrow pointing right. The 'Font' dropdown has an 'Align Text' button with an arrow pointing down. The 'Font' dropdown has a 'Convert to SmartArt' button with an arrow pointing down.

The image shows the Microsoft Word ribbon interface. The 'Home' tab is currently selected, indicated by a blue background. Other tabs like 'Insert', 'Page Layout', 'Design', 'Layout', 'Text', 'References', 'Mailings', 'Review', and 'View' are visible but not selected. Below the ribbon, there's a toolbar with icons for text orientation, text boxes, shapes, and other drawing tools. A large 'Format' tab is open, displaying options for 'Shape Fill', 'Shape Outline', and 'Shape Effects'. On the far right, there are buttons for 'Find', 'Replace', and 'Select'.

Drawing Editing

70 State the expression for the maximum electric voltage of 800V in terms of
 a) E , R , L when $\omega = \pi$
 b) E , R , L when $\omega = 2\pi$.
 c) E , R , L , resistance of each conductor
 of the main is $0.02\,\Omega$.

Soln: Applying Faraday's Voltage law
 $V = \frac{d\Phi}{dt} = \frac{d(BA)}{dt} =$
 $= 100 \times (0.24 - 0.14) \times 1.4 \times 10^{-3} =$
 $= 100 \times 0.1 \times 1.4 \times 10^{-3} = 1.4 \times 10^{-2} = 14\text{mV}$

Solving: $1 = 14 \times 10^{-3} / R$
 Voltage in $R_1 = 1 / (14 \times 10^{-3}) \times 1.4 \times 10^{-3} = 14 \times 10^{-3} \times 10^3 = 14\text{mV}$
 Voltage in $R_2 = 1 / (14 \times 10^{-3}) \times (0.14 - 0.1) \times 1.4 \times 10^{-3} = 14 \times 10^{-3} \times 4 \times 10^{-3} = 56\text{mV}$

71. Find the current supplied by the battery from 2.5 A to 0. For equal voltage across 2.5 A to 0 for the voltage is higher than current is 0.5 by 0.5.

Soln: $i_1 = i_2 = 100 \times 25 = 25 \times 40$
 $= 250$

$2i_1 + 100 = 250 \Rightarrow i_1 = 125$

(g) Voltage drop from 0 to 2 is 2.5 A.

$i_1 = 2.50 + 2.50 = 50 \Rightarrow 2.50 = (250 - i_1) \cdot 2.50 = 2$

$\log(2) \log$
 $i_1 = 12.5 + 12.5 \Rightarrow 0$

72 Einheit 1: Winkelmaß Formeln für Bsp. via E, P & Z.
 $\angle 1 = 180^\circ - \angle 2$ $\Rightarrow \angle 2 = 180^\circ - \angle 1$
 $\angle 3 = 180^\circ - \angle 4$ $\Rightarrow \angle 4 = 180^\circ - \angle 3$
 $\angle 5 = 180^\circ - \angle 6$ $\Rightarrow \angle 6 = 180^\circ - \angle 5$

Einheit 2:
 $\angle 1 = 180^\circ - 2 \cdot \angle 2 = 180^\circ - 2 \cdot \angle 3$
Solving eqn. (2) & (3):
 $\angle 1 = 180^\circ - 2 \cdot \angle 2$ $\Rightarrow \angle 2 = 90^\circ - \frac{1}{2} \angle 1$
 $\angle 1 = 180^\circ - 2 \cdot \angle 3$ $\Rightarrow \angle 3 = 90^\circ - \frac{1}{2} \angle 1$
Theorem: $\angle 2 = \angle 3 = 90^\circ$
 $\angle 1 = 180^\circ - 2 \cdot 90^\circ = 0^\circ$
Re. form eqn. (2):
 $\angle 1 = 180^\circ - 2 \cdot \angle 2 \Rightarrow \angle 2 = 90^\circ - \frac{1}{2} \angle 1$
Re. form eqn. (3):
 $\angle 1 = 180^\circ - 2 \cdot \angle 3 \Rightarrow \angle 3 = 90^\circ - \frac{1}{2} \angle 1$

73 From step (3)
 $10L_1 + 10.2 + 21x5 + 410 = 410 \dots (2)$
 Solving step (2) & (3),
 $1 + 10.20000L_1 + 21x5 = 41.00000$
 $L_1 = 200 - L_2 = 200 - 88.7775$

Answers: Current Distributions

From eqn. (3)

$$15. I_A - 10. I = 1140 - 500 = 640 \dots\dots(6)$$

Solving eqns. (5) & (6)

$$I = 33.9535A \text{ & } l_A = 65.3023A$$

$$l_B = 200 - l_A = 134.6977A$$

Forward 5 sec - [00:23:15 / 71%]

Microsoft account

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71

72

73

74

75

Alternating Current Distribution

Differences of a.c. & d.c. distributions are

1. Unlike **d.c.** distribution where **only conductor resistance** is considered, in **a.c.** distribution the conductor **reactance**, along with conductor **resistance** are considered.
2. The **different loads** that are tapped off the distributor will, in general, be at **different power factors**.
3. There are **two components of voltage drops**, the in phase voltage drop **due to conductor resistance** & a quadrature voltage drop due to conductor **reactance**.

❖ Keeping in mind these differences, all the techniques used for **d.c.** distribution may be used in **a.c.** distribution.

Prof. S. S. Thakur

74

NOTES COMMENTS

SLIDE 74 OF 159 ENGLISH (INDIA) 74%

Forward 5 sec - [00:26:27 / 80%]

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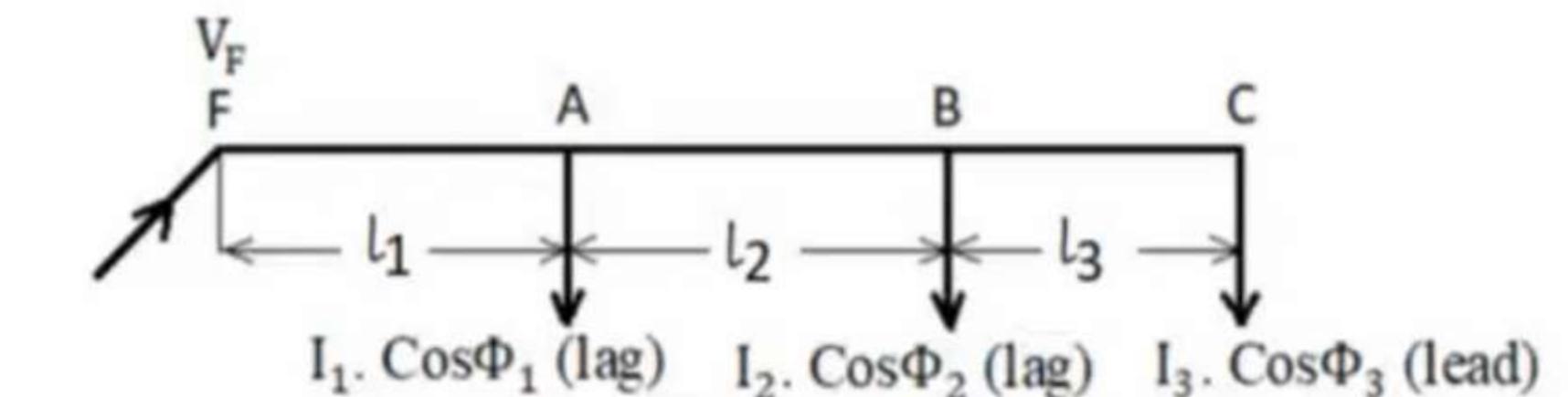
72
Example: Two-wire line from F to C via A & B.
Given:
1. $I_1 = 10 \text{ A}$, $\cos\phi_1 = 0.8$, $\sin\phi_1 = 0.6$
2. $I_2 = 10 \text{ A}$, $\cos\phi_2 = 0.8$, $\sin\phi_2 = 0.6$
3. $I_3 = 10 \text{ A}$, $\cos\phi_3 = 0.8$, $\sin\phi_3 = 0.6$
4. $Z = 0.2 \Omega/\text{km}$

73
Known:
1. $I_1 = 10 \text{ A}$, $\cos\phi_1 = 0.8$, $\sin\phi_1 = 0.6$
2. $I_2 = 10 \text{ A}$, $\cos\phi_2 = 0.8$, $\sin\phi_2 = 0.6$
3. $I_3 = 10 \text{ A}$, $\cos\phi_3 = 0.8$, $\sin\phi_3 = 0.6$
4. $Z = 0.2 \Omega/\text{km}$

74
Alternating Current Distribution
Difference in a.c. two-wire distribution
1. Unlike d.c. distribution where only conductor resistances are considered, in a.c. distribution the conductor resistances along with conductor inductances are considered.
2. The different loads that are supplied off the distributor will, in general, be at different power factors.
3. There are two components of voltage drop, one is phase voltage drop due to conductor resistance & a quadrature voltage drop due to conductor inductance.
Voltage drop due to these differences of the conductor resistances in a.c. distribution may be used to a.c. distributor.

75
Example: Consider the a.c. two-wire distributor fed at one end. Then, the total voltage drop from F to C = $V_{FC} =$
$$l_1 \cdot (R + jX) \cdot (I_1 \cdot \cos\phi_1 - j \cdot I_1 \cdot \sin\phi_1) + (l_1 + l_2) \cdot (R + jX) \cdot (I_2 \cdot \cos\phi_2 - j \cdot I_2 \cdot \sin\phi_2) + (l_1 + l_2 + l_3) \cdot (R + jX) \cdot (I_3 \cdot \cos\phi_3 + j \cdot I_3 \cdot \sin\phi_3)$$

76
Sag & Tension



Distributor impedance = $Z = (R + jX) \Omega/\text{unit length}$

Example: Consider the a.c. two-wire distributor fed at one end.

Then, the total voltage drop from F to C = $V_{FC} =$

$$l_1 \cdot (R + jX) \cdot (I_1 \cdot \cos\phi_1 - j \cdot I_1 \cdot \sin\phi_1) + (l_1 + l_2) \cdot (R + jX) \cdot (I_2 \cdot \cos\phi_2 - j \cdot I_2 \cdot \sin\phi_2) + (l_1 + l_2 + l_3) \cdot (R + jX) \cdot (I_3 \cdot \cos\phi_3 + j \cdot I_3 \cdot \sin\phi_3)$$

So, consumer voltage at C = $V_C = V_F - V_{FC}$

Similarly, consumer voltages at A & B may also be calculated.

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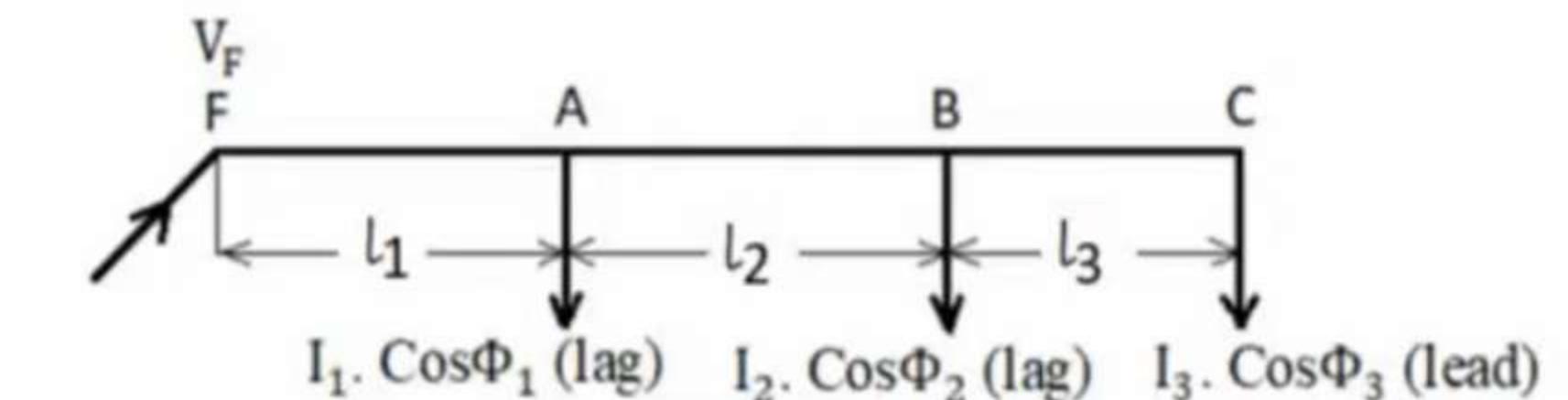
73
New slide (R)
 $100 \times 100 = 10000$
Existing slide (R) A (R)
 $100 \times 10000 = 1000000$
 $1000000 \times 100 = 100000000$

74
Assignment Question Distribution
1. Distribute voltage drop only between sections & connected to a.c. distribution the consumer voltages along with consumer voltages are calculated.
2. The different loads that are supplied at the distributor will, in general, be distributed proportionately.
3. These are the components of voltage drops due to passive resistances & reactive voltages due to inductive reactances.
4. Adding up all these differences all the voltages need to be distributed may be used in a distributor.

75
Example Consider the a.c. two wire distributor fed at one end.
Then, the total voltage drop from F to C = $V_{FC} = I$
 $I_1 \cdot (R + jX) \cdot (I_1 \cdot \text{Cos}\Phi_1 - j \cdot I_1 \cdot \text{Sin}\Phi_1) + (l_1 + l_2) \cdot (R + jX) \cdot (I_2 \cdot \text{Cos}\Phi_2 - j \cdot I_2 \cdot \text{Sin}\Phi_2) + (l_1 + l_2 + l_3) \cdot (R + jX) \cdot (I_3 \cdot \text{Cos}\Phi_3 + j \cdot I_3 \cdot \text{Sin}\Phi_3)$

76
Sag & Tension

77
Open electrical distance between the adjacent supports.
Under normal conditions, the vertical height of the conductor at various stages is less than that of the supports.
Difference between the wire & known sag (D)
Degradation in sag for conductors of different materials
Material of conductor
Wire insulation
Temperature change
Wind load



Distributor impedance = $Z = (R + jX) \Omega/\text{unit length}$

Example: Consider the a.c. two wire distributor fed at one end.

Then, the total voltage drop from F to C = $V_{FC} = I$

$$l_1 \cdot (R + jX) \cdot (I_1 \cdot \text{Cos}\Phi_1 - j \cdot I_1 \cdot \text{Sin}\Phi_1) + (l_1 + l_2) \cdot (R + jX) \cdot (I_2 \cdot \text{Cos}\Phi_2 - j \cdot I_2 \cdot \text{Sin}\Phi_2) + (l_1 + l_2 + l_3) \cdot (R + jX) \cdot (I_3 \cdot \text{Cos}\Phi_3 + j \cdot I_3 \cdot \text{Sin}\Phi_3)$$

So, consumer voltage at C = $V_C = V_F - V_{FC}$

Similarly, consumer voltages at A & B may also be calculated.

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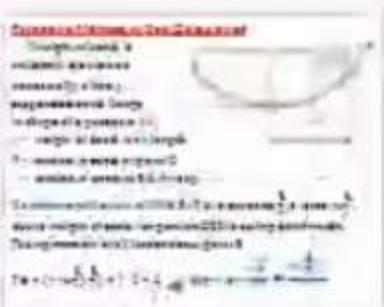
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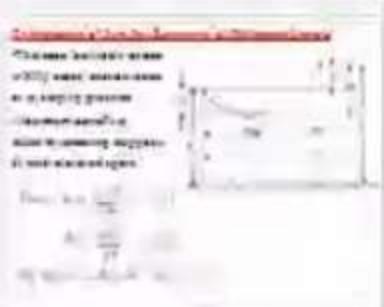
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I Sag & Tension

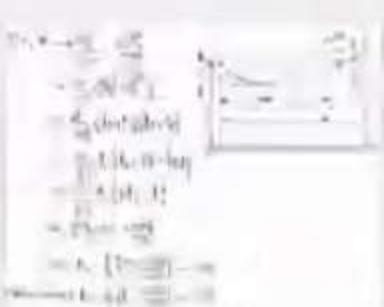
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79



80



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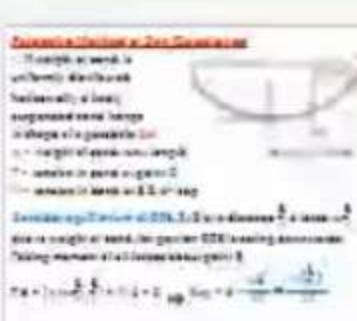
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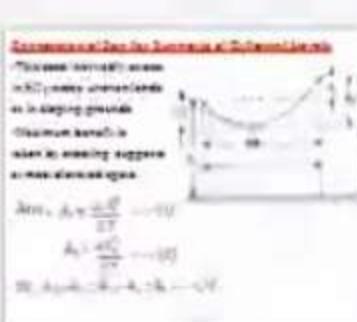
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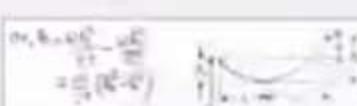
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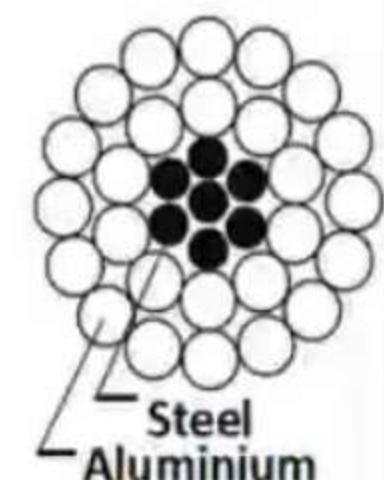
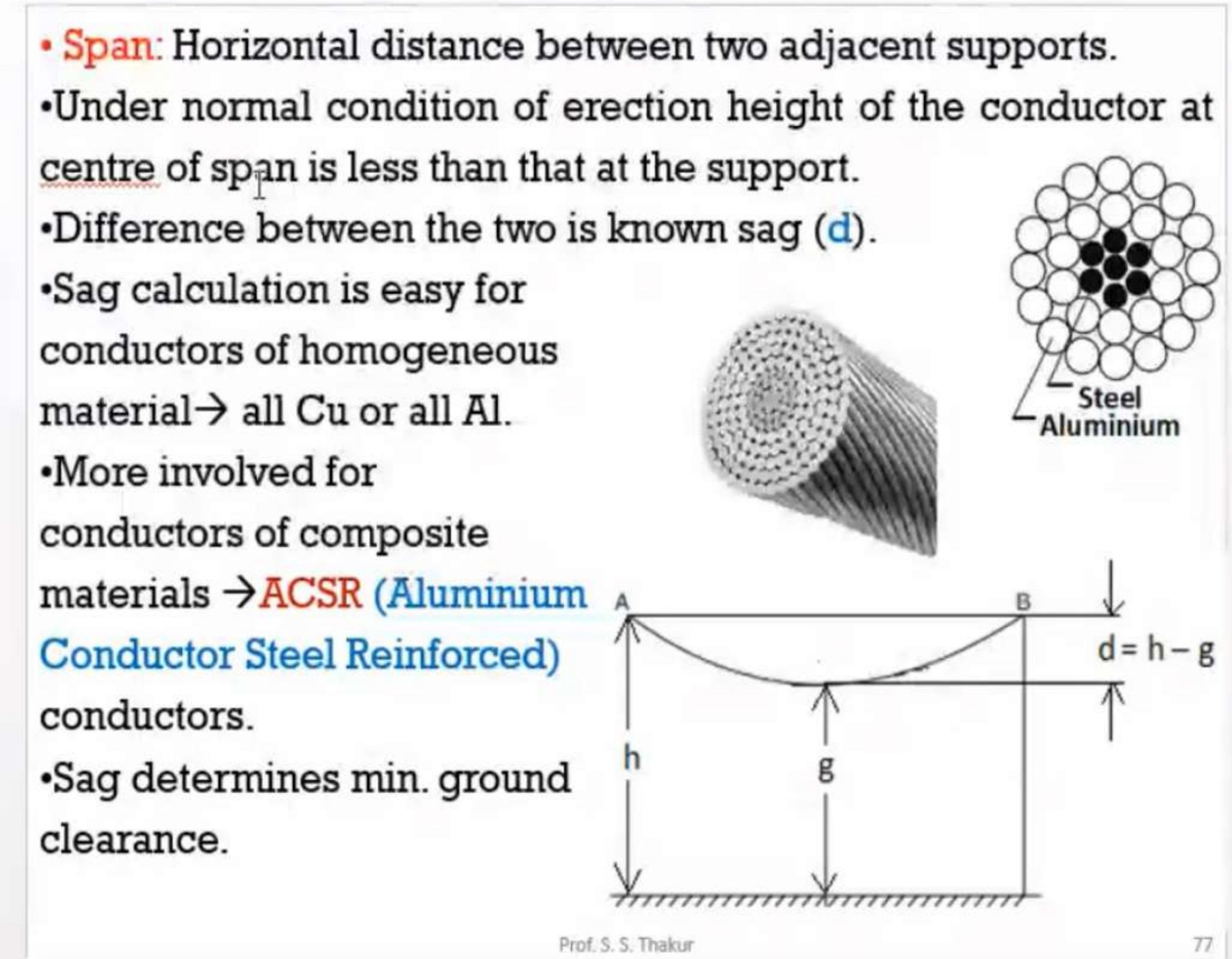
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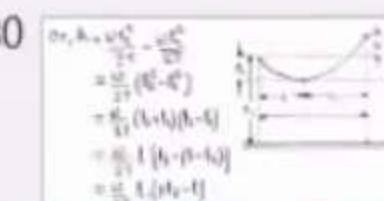
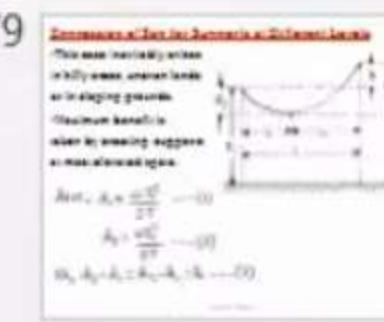
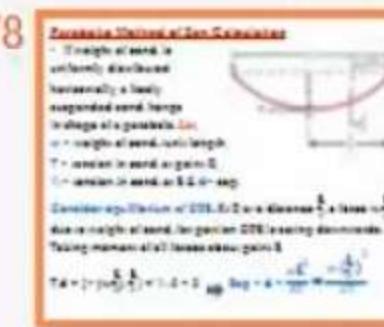
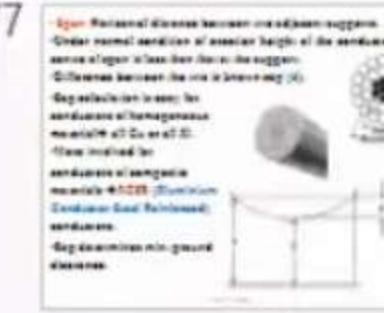
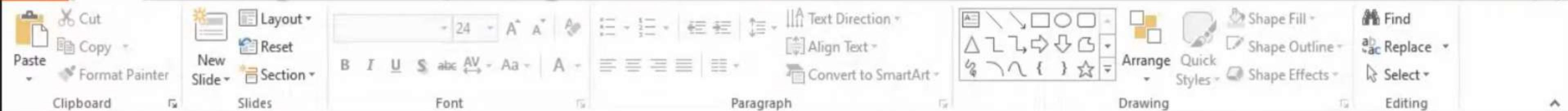


- **Span:** Horizontal distance between two adjacent supports.
- Under normal condition of erection height of the conductor at centre of span is less than that at the support.
- Difference between the two is known sag (**d**).
- Sag calculation is easy for conductors of homogeneous material → all Cu or all Al.
- More involved for conductors of composite materials → **ACSR (Aluminium Conductor Steel Reinforced)** conductors.
- Sag determines min. ground clearance.



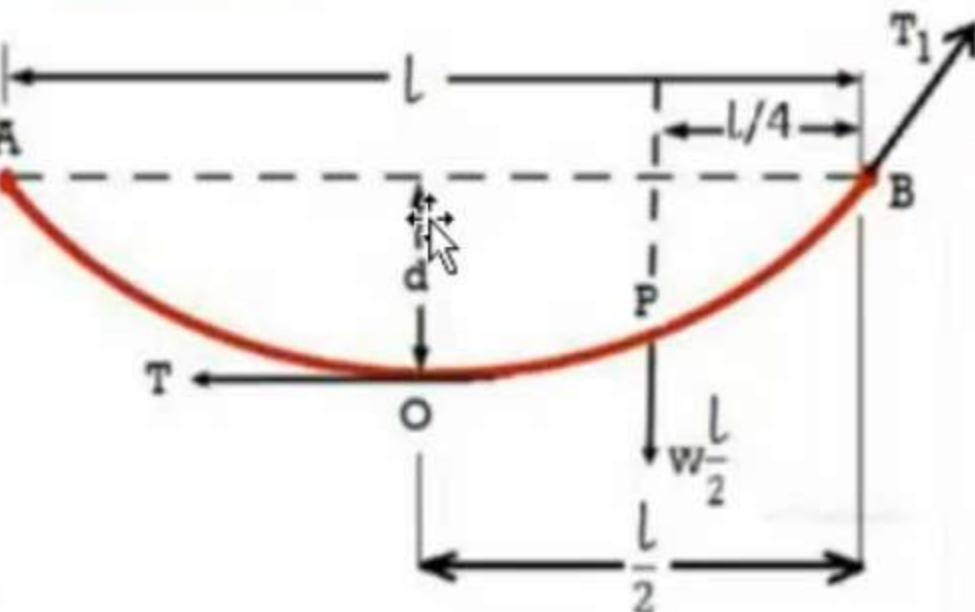
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Parabolic Method of Sag Calculation

- If weight of cond. is uniformly distributed horizontally, a freely suspended cond. hangs in shape of a parabola. Let, w = weight of cond./unit length, T = tension in cond. at point O, T_1 = tension in cond. at B & d = sag.

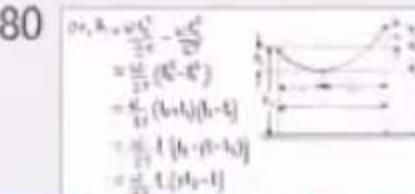
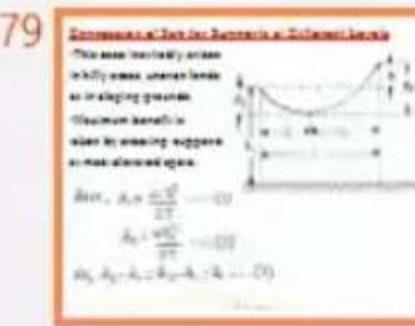
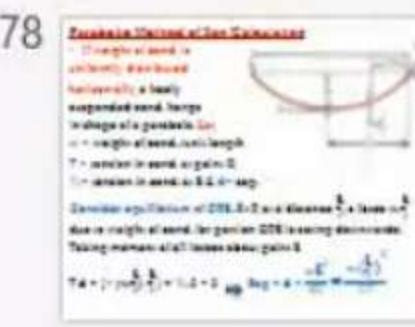
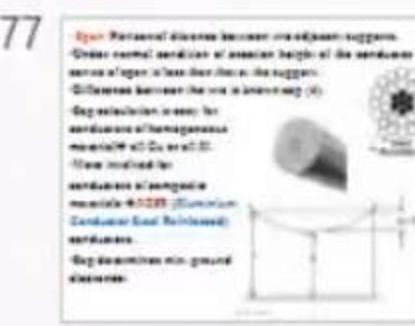


Consider equilibrium of OPB. At P, at a distance $\frac{l}{4}$, a force $w \cdot \frac{l}{2}$ due to weight of cond. for portion OPB is acting downwards. Taking moment of all forces about point B,

$$T.d + \left\{ -\left(w \cdot \frac{l}{2}\right) \cdot \frac{l}{4} \right\} + T_1 \cdot 0 = 0 \rightarrow \text{Sag } d = \frac{wl^2}{8T} = \frac{w \left(\frac{l}{2}\right)^2}{2T}$$

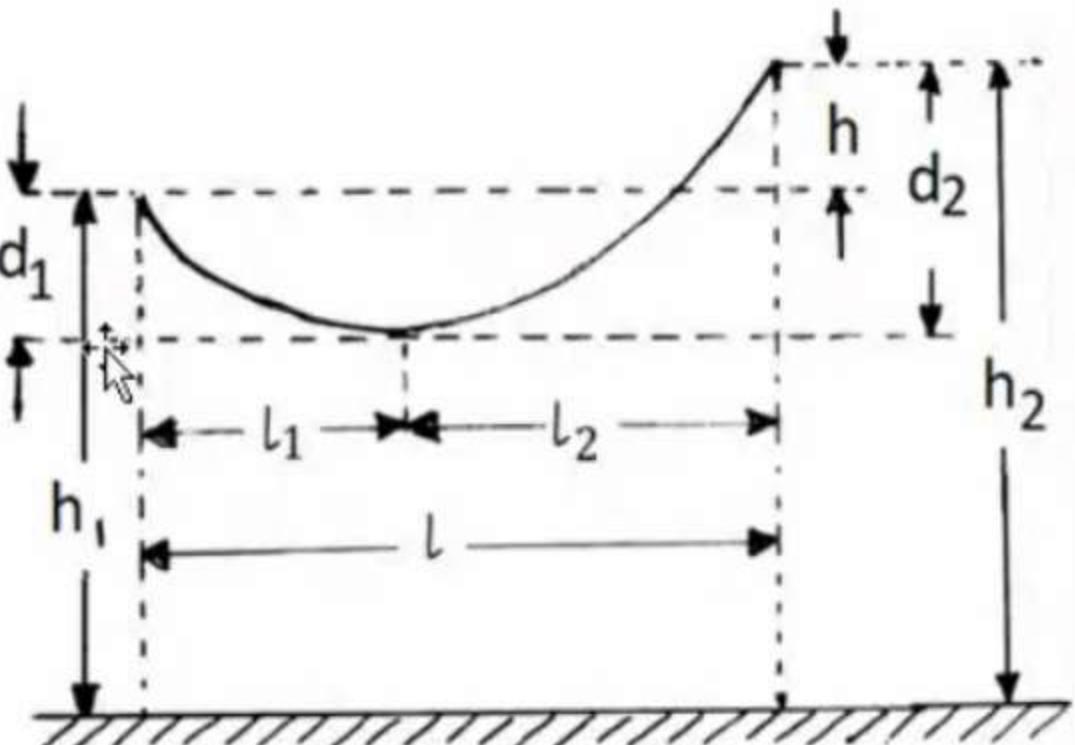
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Expression of Sag for Supports at Different Levels

- This case inevitably arises in hilly areas, uneven lands or in sloping grounds.
- Maximum benefit is taken by erecting supports at most elevated spots.



$$\text{Here, } d_1 = \frac{\omega \cdot l^2}{2T} \quad \dots (1)$$

$$d_2 = \frac{\omega l_2^2}{2T} \quad \dots (2)$$

$$\text{So, } d_2 - d_1 = h_2 - h_1 = h \quad \dots (3)$$

Prof. S. S. Thakur

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Backward 5 sec -[00:22:01 / 54%]

EEC 401 - PPT 05.03.2021 USE IT - PowerPoint (Product Activation)

The image shows the 'Clipboard' tab selected in the Microsoft Word ribbon. The tab has a blue background and white text. To its left is a small icon of a clipboard with a document. Below the tab, there are four items: 'Paste' with a dropdown arrow, 'Format Painter' with a paintbrush icon, and two other items partially visible.

A yellow sun-like icon with a white outline, positioned next to the 'New' button.

The image shows the Microsoft Word ribbon with the 'Home' tab selected. The ribbon includes sections for Font (size 24, bold, italic, underline, etc.), Paragraph (align, spacing, etc.), and other document settings like Text Direction, Align Text, and Convert to SmartArt.

77

- Open -Residual distance between two adjacent surfaces.
- Outer normal -Orientation of a vertical height of the surface at a point of origin in base direction to the surface.
- Glossiness increases the more it becomes (0).
- Ray reflection is easy for surfaces of homogeneous materials (e.g. Cu or Al).
- Glass involved for surfaces of homogeneous materials (e.g. glass).
- Glossiness \rightarrow **Gloss** (illumination conditions: Direct Light, Reflected Light).
- Glossiness increases ground glossiness.



Successive Offer for Business at Different Prices

This graph illustrates the concept of consumer surplus. It shows a downward-sloping demand curve (D) and three horizontal price levels (P1, P2, P3). The intersection of the demand curve and P1 is point A1, and the intersection with P2 is point A2. The area under the demand curve between A1 and A2 is shaded blue, representing consumer surplus.

80 

$$\begin{aligned}
 & \text{Area}_1 = \frac{1}{2} t_1^2 - \frac{1}{2} t_0^2 \\
 & = \frac{t_1^2 - t_0^2}{2} \\
 & = \frac{t_1 + t_0}{2} \cdot (t_1 - t_0) \\
 & = \frac{t_1 + t_0}{2} \cdot \Delta t \\
 & = \frac{t_1 + t_0}{2} \cdot (t_2 - t_1) \\
 & = \frac{t_1 + t_0}{2} \cdot t_2 - \frac{t_1 + t_0}{2} \cdot t_1 \\
 & = \frac{t_1 + t_0}{2} \cdot t_2 - \frac{t_1 + t_0}{2} \cdot t_1 \\
 & = \frac{t_1 + t_0}{2} \cdot (t_2 - t_1) \\
 & = \frac{t_1 + t_0}{2} \cdot \Delta t
 \end{aligned}$$

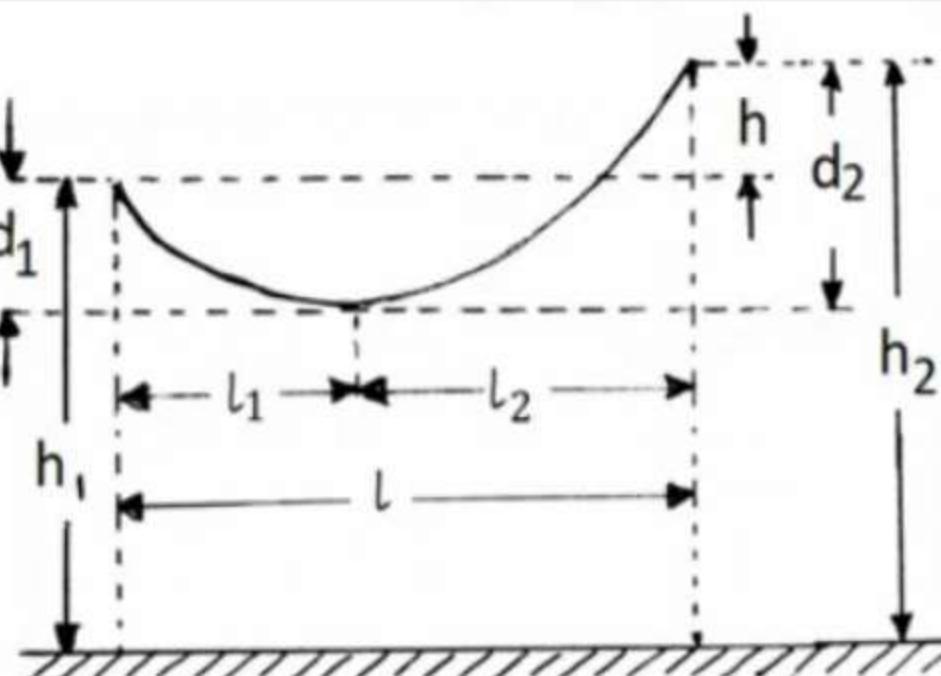
Fig 2, 2.5, are estimated from ages (2-4.5), and d. 2.6, are estimated from ages (3-4.6).

$$\begin{aligned}
 \text{Or, } h &= \frac{\omega l_2^2}{2T} - \frac{\omega l_1^2}{2T} \\
 &= \frac{\omega}{2T} (l_2^2 - l_1^2) \\
 &= \frac{\omega}{2T} (l_2 + l_1)(l_2 - l_1) \\
 &= \frac{\omega}{2T} \cdot l \cdot \{l_2 - (l - l_2)\} \\
 &= \frac{\omega}{2T} \cdot l \cdot (2l_2 - l)
 \end{aligned}$$

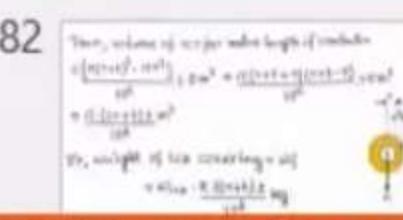
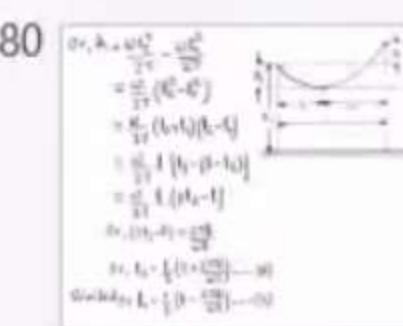
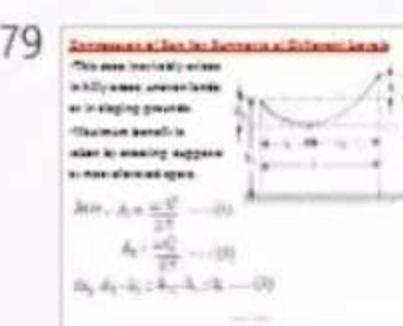
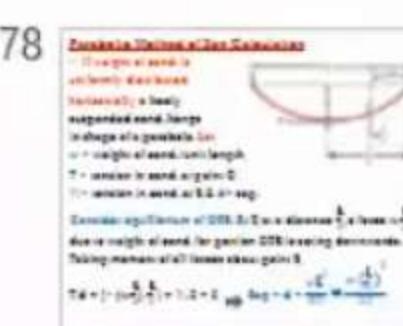
$$\text{Or, } (2l_2 - l) = \frac{2Th}{(2)}$$

$$\text{Or, } l_2 = \frac{1}{2} \left(l + \frac{2Th}{\omega l} \right) \dots$$

$$\text{Similarly, } L_1 = \frac{1}{2} \left(l - \frac{2Th}{\omega t} \right) \dots (5)$$



Forward 5 sec - [00:22:11 / 54%]



First l_1 & l_2 are calculated from eqns. (5) & (4), then d_1 & d_2 are calculated from eqns. (1) & (2).

Effects of Wind & Ice Covering

During service conductor is subjected to forces due to:

- (i) Its own weight (w), acting vertically downwards,
- (ii) Wind load (w_w) of various strength, acting horizontally &
- (iii) Weight of ice covering (w_i), acting vertically downwards.

Let,

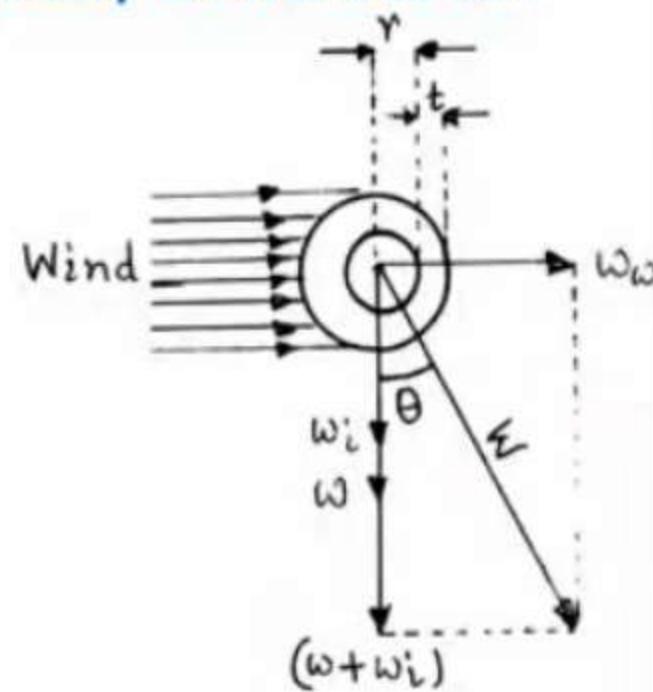
r = radius of conductor in mm.

t = thickness of ice covering in mm.

w = weight of conductor/m in kg,

P = wind pressure in kg/m²,

w_{ice} = weight/unit volume of ice in kg/m³



Forward 5 sec - [00:26:51 / 65%]

79

Accessories & Devices Required at Distribution

This area includes
• Insulators, insulator loads
• In insulating grounds
• Maximum sag
• Allow for snow, sleet, rain
• Minimum clearance

$$\Delta H_1 = \Delta_1 + \frac{\pi r^2}{10^6} \quad \dots(1)$$

$$\Delta_1 = \frac{\pi r^2}{10^6} \quad \dots(2)$$

$$\Delta_1, \Delta_2, \Delta_3 = \Delta_1, \Delta_2, \Delta_3 \dots(3)$$

80

$$\sigma_r, k = \frac{r_1^2 - r_2^2}{2\pi} = \frac{\pi(r_1^2 - r_2^2)}{2\pi} = \frac{\pi(r_1^2 - r_2^2)(k_1 - k_2)}{2\pi} = \frac{1}{2} \left[k_1 - k_2 \right] (r_1^2 - r_2^2) = \frac{1}{2} (k_1 - k_2) t^2$$

$$t = \frac{1}{2} \left[\left(k_1 - k_2 \right) \frac{r_1^2 - r_2^2}{t^2} \right] = \frac{1}{2} \left[\left(k_1 - k_2 \right) \frac{r_1^2 - r_2^2}{t^2} \right] = \frac{1}{2} \left[\left(k_1 - k_2 \right) \frac{r_1^2 - r_2^2}{t^2} \right]$$

81

Types of ice load

There are two types of ice load:
1. Weight of ice load
2. Wind load due to ice load

Weight of ice load

When ice load is suspended in form due to:
 (i) Wind load (ii) Weight of ice load (iii) Weight of snow covering (iv) Weight of snow load

Wind load due to ice load

When ice load is suspended in form due to:
 (i) Weight of ice load (ii) Weight of snow covering (iii) Weight of snow load

82

Weight of ice load per unit length of conductor

$$W_i = \frac{\rho_i g (r_1^2 - r_2^2)}{10^6} = \frac{\rho_i g \pi t^2}{10^6}$$

$$W_i = \frac{\rho_i g \pi t^2}{10^6} = \frac{0.2 \times 10^3 \times 10 \times \pi \times 10^{-6}}{10^6} = 0.002 \text{ kg/m}$$

Without ice covering wind load w_w

$$= P \cdot \frac{2r}{10^3} \cdot 1.0 \text{ kg.}$$

83

Vertical wind load

$$W_i = \frac{\rho_i g (r_1^2 - r_2^2)}{10^6} = \frac{\rho_i g \pi t^2}{10^6}$$

$$W_i = \frac{\rho_i g \pi t^2}{10^6} = \frac{0.2 \times 10^3 \times 10 \times \pi \times 10^{-6}}{10^6} = 0.002 \text{ kg/m}$$

Then, volume of ice per metre length of conductor

$$= \frac{\pi(r+t)^2 - \pi r^2}{10^6} \cdot 1.0 \text{ m}^3 = \frac{\pi(r+t+r)(r+t-r)}{10^6} \cdot 1.0 \text{ m}^3$$

$$= \frac{\pi \cdot (2r+t) \cdot t}{10^6} \text{ m}^3$$

So, weight of ice covering $= w_i$

$$= w_{ice} \cdot \frac{\pi \cdot (2r+t) \cdot t}{10^6} \text{ kg.}$$

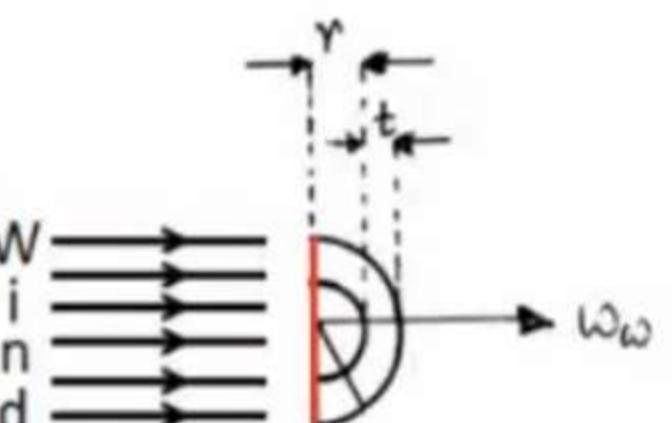


Without ice covering wind load w_w

$$= P \cdot \frac{2r}{10^3} \cdot 1.0 \text{ kg.}$$

With ice covering wind load w_w

$$= P \cdot \frac{2(r+t)}{10^3} \cdot 1.0 \text{ kg.}$$



Forward 5 sec - [00:31:11 / 76%]

80

$$\begin{aligned} \sigma_x &= \frac{\omega^2}{2T} \left(\frac{\omega_0^2}{\omega^2} - \frac{\omega_i^2}{\omega^2} \right) \\ &= \frac{\omega^2}{2T} (\theta_0^2 - \theta_i^2) \\ &= \frac{\theta_0^2}{2T} (b_1 t_1) (b_2 t_2) \\ &= \frac{\theta_0^2}{2T} \left[b_1 \cdot (b_2 - b_1) \right] \\ &= \frac{\theta_0^2}{2T} t_1 (t_2 - t_1) \\ &= \frac{\theta_0^2}{2T} (t_2 - t_1) \\ &= \frac{\theta_0^2}{2T} \left(t_2 + \frac{t_1}{2} - \frac{3t_1}{2} \right) \\ &= \frac{\theta_0^2}{2T} \left(t_2 - \frac{t_1}{2} \right) \end{aligned}$$

81

From Q. 80, we calculated from eqns (8) & (1), that θ_0^2, θ_i^2 , are calculated from eqns (7) & (6).

Notes on Wind Loading:

- (i) Wind load (w_w) increases linearly along horizontally &
- (ii) Weight of ice covering (w_i) varies vertically downwards.

Let,

- θ = angle of inclination in rad.
- t = thickness of ice covering in mm.
- w = weight of ice covering in kg.
- P = wind pressure in kg/m².
- w_w = weight of air in kg/m³.

82

Then, volume of ice = for total length of conductor

$$= \frac{\pi (b_1 t_1)^2 + \pi (b_2 t_2)^2}{2T} = \frac{\pi (b_1^2 t_1^2 + b_2^2 t_2^2)}{2T} \text{ m}^3$$

Weight of ice covering = w_i

$$= \rho_{ice} \cdot \frac{\pi (b_1 t_1)^2 + \pi (b_2 t_2)^2}{2T} \text{ kg}$$

Without ice covering, weight of conductor

$$= \rho_{air} \cdot \frac{\pi (b_1 t_1)^2 + \pi (b_2 t_2)^2}{2T} \text{ kg}$$

With ice covering, weight of conductor

$$= \rho_{air} \cdot \frac{\pi (b_1 t_1)^2 + \pi (b_2 t_2)^2}{2T} + w_i \cdot \frac{\pi (b_1 t_1)^2 + \pi (b_2 t_2)^2}{2T} \text{ kg}$$

83

Explanatory note:

$$w_w = \frac{1}{2} \rho_{air} V^2 \text{ kg/m}^2$$

and $w_i = \frac{1}{2} \rho_{ice} V^2 \text{ kg/m}^2$

Hence, weight $w = \frac{1}{2} \rho_{air} V^2$

Vertical sag = $d = \frac{w l^2}{8 T}$

To calculate V , we have to find V from the formula,

$$V = 0.006 V^2 \text{ kg/m}^2$$

Loading factor is defined as $q = \frac{W}{w}$

84

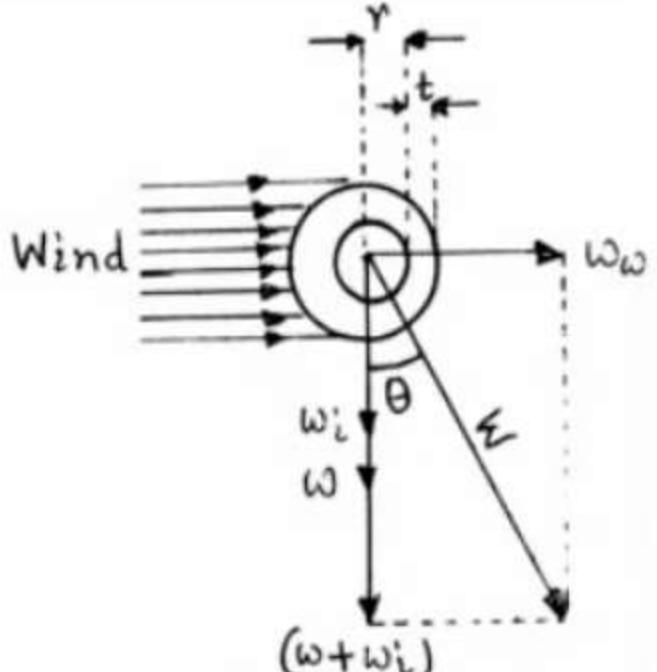
Statement: A single span of a transmission line is 200m long. The conductors have a cross section of 1.8 cm^2 . Heat losses suggest that the sag should not be allowed to exceed 17 metres in case of a snow load of the above weight of 100 kg/m^2 (a) in still air & (b) with a wind pressure of 100 kg/m^2 & a 1.0 km increasing to the lower ends also find the required sag. Take specific gravity of ice as 1.05.

So, resultant load W

$$= \sqrt{(w + w_i)^2 + w_w^2} \text{ kg}$$

and $\tan \theta = \frac{w_w}{(w + w_i)}$

Hence, sag $d = \frac{w l^2}{8 T}$



Vertical sag = $d = \frac{w l^2}{8 T}$

If wind velocity is given, then wind pressure is found from the formula,

$$P = 0.006 V^2 \text{ kg/m}^2$$

Loading factor is defined as $q = \frac{W}{w}$

Forward 5 sec - [00:33:11 / 81%]

Microsoft account

82
Total weight of ice for unit length of conductor
 $T = \frac{W}{2} l = \frac{\rho g A t}{2} l$
 $\therefore T = \frac{\rho g A t}{2} l$

Weight of ice coating on sag
 $w = \rho g t$

Weight of ice per unit length
 $w = \rho g t l$

Total weight of conductor and ice coating
 $T = w + T_0$

83
Stressed load T_0
 $T_0 = \frac{W}{2} l = \frac{\rho g A t}{2} l$
and $T_0 = \frac{w}{2} l$
Hence, sag $s = \frac{T_0}{w}$
If sag is allowed to exceed permissible limit then formula
 $s = \frac{4 T_0^2}{w l^2}$
Loading factor is calculated as $\frac{w}{T_0}$

84
Statement: A single span of a transmission line is 150m long, the supporting structures being level. The conductors have a cross section of 2.5 cm^2 hard drawn copper. Find the sag which must be allowed if tension is not to exceed one-fifth of the ultimate strength ($40,000 \text{ N per cm}^2$), (a) in still air & (b) with a wind pressure of 13 N per metre^2 & a 1.25 cm ice-coating. In the later case also find the vertical sag. Take specific gravity of copper as 8.9 gm/cc & density of ice as 920 kg/m^3 .
I

85
Maximum stress $T = \frac{1}{2} \times 40,000 \text{ N/cm}^2$
 $= \frac{1}{2} \times 40,000 \times \frac{1}{8.9} \text{ kg/cm}^2$
 $= 4,494 \text{ kg/cm}^2$
 $\therefore r = \sqrt{\frac{A}{\pi}}$
Weight of conductor $w = \rho g A t$
Weight of conductor $w = \rho g A t$
 $w = 2.128 \text{ kg/cm}^2$
Weight of ice coating $w = \frac{1}{2} \times 920 \text{ kg/m}^3 \times 1.25 \text{ cm}$
 $w = 5.900 \text{ kg/m}^2$

86
Weight of ice coating $w = \frac{1}{2} \times 920 \text{ kg/m}^3 \times 1.25 \text{ cm}$
 $w = 5.900 \text{ kg/m}^2$
Weight of conductor $w = \frac{1}{2} \times 920 \text{ kg/m}^3 \times 1.25 \text{ cm}$
 $w = 5.900 \text{ kg/m}^2$

Problem: A single span of a transmission line is 150m long, the supporting structures being level. The conductors have a cross section of 2.5 cm^2 hard drawn copper. Find the sag which must be allowed if tension is not to exceed one-fifth of the ultimate strength ($40,000 \text{ N per cm}^2$), (a) in still air & (b) with a wind pressure of 13 N per metre^2 & a 1.25 cm ice-coating. In the later case also find the vertical sag. Take specific gravity of copper as 8.9 gm/cc & density of ice as 920 kg/m^3 .

Solution: Given data: Span $l = 150 \text{ m}$

$$\text{Cross section } \pi r^2 = 2.5 \text{ cm}^2 \quad (r = \text{radius})$$

$$\text{Or, } r = 0.892 \text{ cm} = 8.92 \text{ mm}$$

$$\text{Ice coating} = t = 1.25 \text{ cm} = 12.5 \text{ mm}$$

Forward 5 sec - [00:36:41 / 90%]

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82
 Total volume of ice for total length of conductor
 $\pi \left(\frac{D^2}{4} \right) L = \pi \left(\frac{\pi^2}{4} \right) L = \frac{\pi^2 D^2 L}{16}$
 $\approx 0.000112 m^3$
 Weight of ice covering = m_i
 $= 0.000112 \times 8.9 \text{ gm/cm}^3$
 Weight ice covering conductors = $\approx 0.001 \text{ kg/m}$
 Weight ice covering conductors = $\approx 0.001 \text{ kg/m}$

83
 Weight of conductor = $2.5 \times 1 \times 8.9 \text{ gm}$
 Weight of conductor = $2.5 \times 1 \times 8.9 \times 10^{-3} \text{ kg}$
 Weight of conductor = $2.5 \times 10^{-3} \text{ kg}$
 Weight of conductor = 2.5 g/cm^3
 Weight of conductor = 2.5 g/cm^3
 Weight of conductor = 2.5 g/cm^3
 Weight of conductor = 2.5 g/cm^3

84
 Problem: A single span of a transmission line is 150m long. The sagging clearance being 10m. The conductor has a mass density of 2.5 gm/cm^3 . Find the sag which must be achieved if tension is not to exceed weight of the conductor (12.225 kg per m). (a) in still air & (b) with a wind pressure of 120 kg/m² over & 1.00m increasing to the base. Also find the revised sag. Take specific gravity of copper as 8.9 and density of ice as 900 kg/m³.
 Solution: Given data: Span = 150m
 Density = 2.5 gm/cm^3 ($\rho = \text{constant}$)
 $D = 1.00 \text{ m} \times 0.02 \text{ m}$
 Sagging = $10 \text{ m} \times 0.02 \text{ m}$

85
 Working tension $T = \frac{1}{5} \times 40,000 \text{ N/cm}^2$
 $\approx 0.0001 \times \frac{1}{5} \times 40,000 \text{ kg/cm}^2$
 $\approx 0.0001 \times 8 \text{ kg/cm}^2$
 $\approx 0.0001 \times 8 \times 10^6 \text{ kg/m}^2$
 Weight of conductor = $2.5 \times 1 \times 8.9 \text{ gm}$
 $\approx 2.5 \times 1 \times 8.9 \times 10^{-3} \text{ kg}$
 $\approx 2.5 \times 10^{-3} \text{ kg}$
 (a) Sag in still air $d = \frac{\omega l^2}{8T} = \frac{2.5 \times 10^{-3} \times (150)^2}{8 \times 0.0001 \times 8 \times 10^6}$
 $= 3.0695 \text{ m}$

86
 (a) Weight of conductor = $2.5 \times 1 \times 8.9 \text{ gm} = 2.5 \times 1 \times 8.9 \times 10^{-3} \text{ kg}$
 $\approx 0.0001 \times 2.5 \times 8.9 \times 10^6 \text{ kg}$
 $\approx 0.0001 \times 2.5 \times 8.9 \times 10^6 \text{ kg}$
 Weight of conductor = $\sqrt{2(T + \omega l^2)}$
 $\approx \sqrt{2(0.0001 \times 8 \times 10^6 + 2.5 \times 10^{-3} \times 150^2)}$
 $\approx 0.0001 \times 8 \times 10^6 \text{ kg}$

$$\text{Working tension } T = \frac{1}{5} \times 40,000 \text{ N/cm}^2$$

$$= \frac{1}{5} \times 40,000 \times \frac{1}{9.81} \text{ Kg/cm}^2$$

$$= 815.494 \times 2.5 \text{ Kg}$$

$$= 2038.735 \text{ Kg.}$$

$$\text{Weight of conductor/cm} = 2.5 \times 1 \times 8.9 \text{ gm}$$

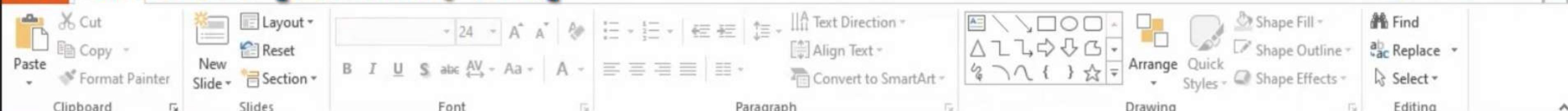
$$\text{So, weight of conductor/m} = \frac{2.5 \times 8.9}{1000} \times 100$$

$$= 2.225 \text{ Kg} (= \omega \text{ say})$$

$$(a) \text{ Sag in still air } d = \frac{\omega l^2}{8T} = \frac{2.225 \times (150)^2}{8 \times 2038.735}$$

$$= 3.0695 \text{ m}$$

Forward 5 sec-[00:39:51 / 97%]



$$(b) \text{Weight of ice/m} = \frac{\omega_{ice} \times \pi \cdot (2r+t) \cdot t}{10^6} \text{ kg} \quad (= \omega_i \text{ say})$$

$$= \frac{920 \times \pi \times (2 \times 8.92 + 12.5) 12.5}{10^6} \text{ kg} = 1.0961 \text{ kg}$$

$$\text{Wind load } w_w = 13 \text{ N} = \frac{13}{9.81} \text{ kg} = 1.3252 \text{ kg}$$

So, resultant load $W = \sqrt{(w + w_i)^2 + w_w^2}$

$$= \sqrt{(2.225 + 1.0961)^2 + (1.3252)^2}$$

$$= 3.5756 \text{ kg}$$

$$\text{Hence, sag } d = \frac{Wl^2}{8T} = \frac{3.5756 \times (150)^2}{8 \times 2038.735} = 4.9727 \text{ m}$$

Forward 5 sec - [00:40:31 / 99%]

Cut, Copy, Paste, Format Painter, New Slide, Section, Clipboard, Slides, Font, Paragraph, Drawing, Editing.

84

Statement: A single span air's suspension line is 100m long. The sagging distance being level. The maximum force a mass of 1.5 kg. Total droop sagger. Find the sag which must be allowed if tension is to be assumed constant at the ultimate strength (10,000N per mm²). (g) to pull air & (b) with a total pressure of 1.07 kg per square m & 1.00m difference. In the later case also find the required sag. Take specific gravity of air pressure & density of air as 1.20kg/m³.

Solution: Given data: Span = 100m
Given tension $T = 1.5 \text{ kg}$
 $T = 1.5 \times 9.81 \text{ N}$
Given droop $\delta = 1.00 \text{ m}$
 $\delta = 1.00 \text{ m} = 1.00 \text{ m}$
Given sag = $1.00 \text{ m} + 1.00 \text{ m}$

85

Working: Given $T = \frac{1}{2} \times 1.5 \times 9.81 \text{ N/m}^2$
 $= \frac{1}{2} \times 1.5 \times 9.81 \times \frac{1}{1000} \text{ kg/m}^2$
 $= 0.073575 \text{ kg/m}^2$
 $\approx 7.3575 \text{ kg/m}^2$
Weight of conductor: $w = 3.14 \times 10^{-3} \text{ kg/m}$
 $\text{Total weight of conductor} = 3.14 \times 10^{-3} \times 100$
 $= 3.14 \times 10^{-2} \text{ kg}$
 $\text{Working load} = \frac{w}{T} = \frac{3.14 \times 10^{-2}}{7.3575} \text{ m}$
 $\approx 0.0042 \text{ m}$

86

Working: Given weight of sagging = $3.14 \times 10^{-2} \times 9.81 \times 100 \text{ kg}$
 $= \frac{3.14 \times 10^{-2} \times 9.81 \times 100}{7.3575} \text{ kg}$
 $\approx 0.0042 \text{ m}$
 $\text{Minimum sag} = \frac{1}{2} \times 10 = 5 \text{ m}$
 $\delta_1 = \text{minimum height} = \sqrt{100^2 + 5^2} \text{ m}$
 $= \sqrt{10000 + 25} \text{ m}$
 $\approx 10.00 \text{ m}$
 $\text{Hence, sag } \delta = \frac{10^2 - 5^2}{10^2} = \frac{75}{100} = 0.75 \text{ m}$
 $\approx 0.75 \text{ m}$

87

Working: Given sag $\delta = 1.00 \text{ m}$
 $\delta = \frac{1}{2} \times 10 = 5 \text{ m}$
 $\delta = \sqrt{100^2 + 5^2} \text{ m}$
 $\approx 10.00 \text{ m}$

88

Statement: An enclosed box suspended at certain height above the ground having an ultimate strength of 10,000N per mm². A area of 1.5 m². When suspended between supports 100m apart & having a 1.0m difference in level. Find the required sag which must be allowed so that tension of air shell is 8 with minimum tension with 1kg of air per square m & a total pressure of 1.07 kg per square m. The conductor weighs 1.20kg per meter.

Solution: Given data: Area = 1.5 m^2
 $A = 1.5 \times 1000 \text{ mm}^2$
 $T = 1.20 \text{ kg/m}$

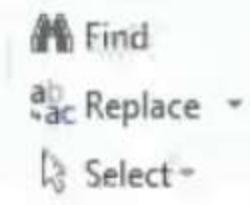
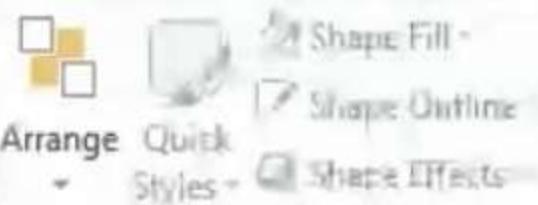
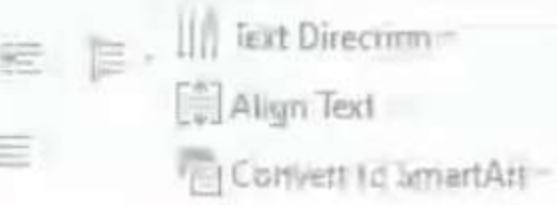
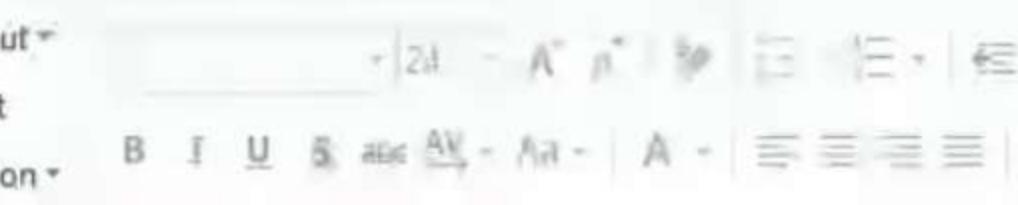
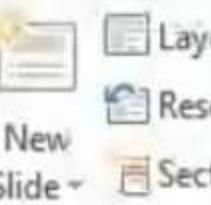
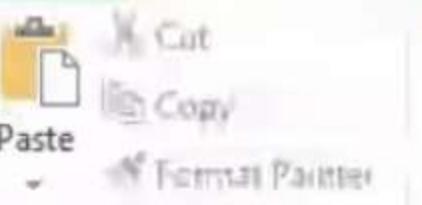
$$\text{Vertical sag} = d \cos \theta$$

$$= d \cdot \cos [\tan^{-1} \left(\frac{w_w}{w + w_i} \right)]$$

$$= 4.9327 \times \cos \left[\tan^{-1} \left(\frac{1.3252}{2.225 + 1.0961} \right) \right]$$

$$= 4.58145 \text{ m}$$





- Problem: An overhead line conductor consists of seven strands silicon-bronze, having an ultimate strength of 78500N per cm^2 & an area of 2.2 cm^2 . When erected between supports 600m apart & having a 15m difference in level, find the vertical sag which must be allowed so that factor of safety shall be 5 with conductor loaded with 1kg of ice per metre & a wind pressure of 17.15N per metre. The conductor weighs 2.03kg per metre.

Sol

Given data

Span $l = 600\text{m}$; difference of height of supports $= h = 15\text{m}$;
 weight of conductor/m $= \omega = 2.03\text{ kg}$; ice loading/m $= \omega_i = 1\text{ kg}$;

$$\text{Wind load} = \omega_w = 17.15 N = \frac{17.15}{9.81} kg = 1.7482 kg.$$

$$\text{Working tension } T = \frac{78500}{F} \text{ N/cm}^2$$

$$= \frac{78500}{5 \times 9.81} \times 2.2 \text{ kg} = 3520.8970 \text{ kg}$$

$$\text{Cross sectional area} = 2.2 \text{ cm}^2$$

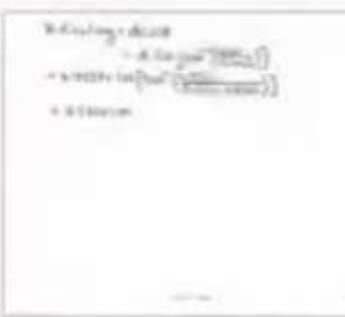
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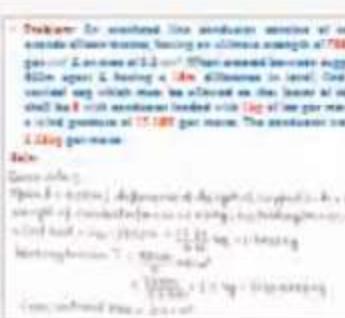
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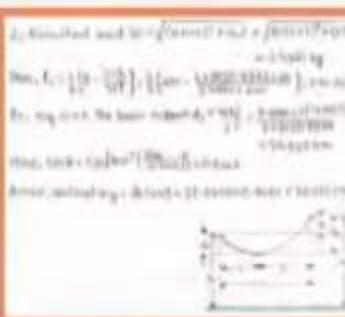
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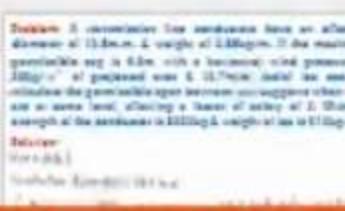
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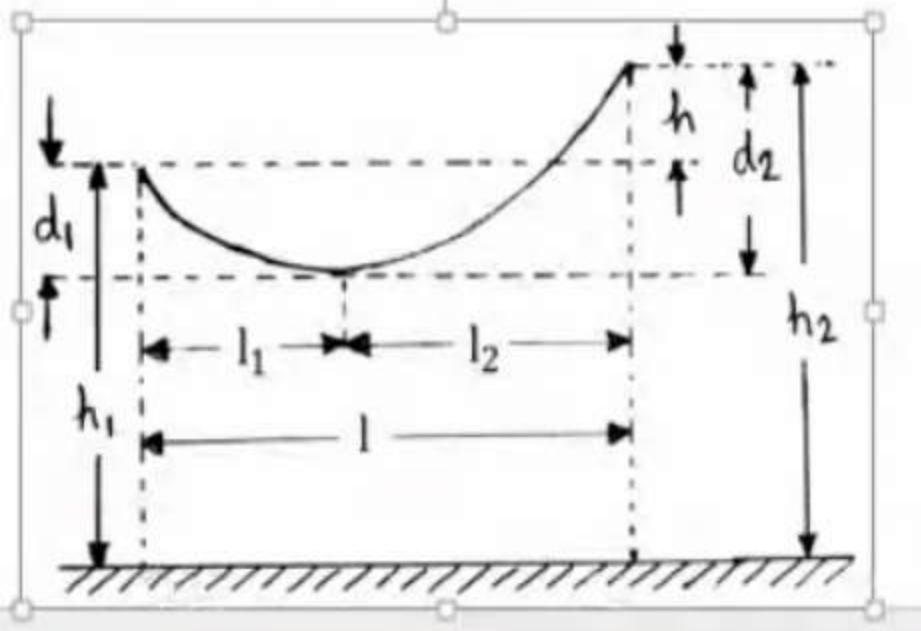
$$\text{Resultant load } W = \sqrt{(\omega + \omega_i)^2 + \omega_w^2} = \sqrt{(2.03 + 1)^2 + (1.7482)^2} \\ = 3.4981 \text{ kg.}$$

$$\text{Here, } l_1 = \frac{1}{2} \left[l - \frac{2Th}{Wl} \right] = \frac{1}{2} \left[600 - \frac{2 \times 3520.8970 \times 15}{3.4981 \times 600} \right] = 274.8375 \text{ m}$$

$$\text{So, sag w.r.t. the lower support } d_1 = \frac{Wl_1^2}{2T} = \frac{3.4981 \times (274.8375)^2}{2 \times 3520.8970} \\ = 37.5259 \text{ m}$$

$$\text{Now, } \cos \theta = \cos \left[\tan^{-1} \left(\frac{\omega_w}{\omega + \omega_i} \right) \right] = 0.8662$$

$$\text{Hence, vertical sag} = d_1 \cos \theta = 37.5259 \times 0.8662 = 32.5021 \text{ m}$$



Problem: A transmission line conductors have an effective diameter of 19.5m.m. & weight of 0.85kg/m. If the maximum permissible sag is 6.3m, with a horizontal wind pressure of 39kg/ m² of projected area & 12.7m.m. radial ice coating, calculate the permissible span between two supports when they are at same level, allowing a factor of safety of 2. Ultimate strength of the conductor is 8000kg & weight of ice is 910kg/m³.

Solution

Given data

Conductor diameter = 19.5 m.m.

∴ Radius = $r = \frac{19.5}{2} = 9.75$ m.m; weight of conductor/m = $w = 0.85$ kg;

maxm. permissible sag = $d = 6.3 \text{ m}$; Wind pressure $P = 39 \text{ Kg/m}^2$;

ice coating = $t = 12.7 \text{ m.m.}$; ultimate strength = 8000 kg.

factor of safety = 2 ; weight of ice/unit volume = $w_{ice} = 910 \text{ kg/m}^3$

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88

Details: An overhead line conductor tension of seven strands of diameter 12.5 mm having an ultimate strength of 17,700 kg per strand & a sag of 1.2 m. Then consider because suggestion of standard says that when the conductor is at the lowest point it should be 2 times conductor tension with 10% safety factor. The conductor weight is 1.169 kg/m.

Solution: Given: T = 17700 kg, sag = 1.2 m, safety factor = 2, weight = 1.169 kg/m, ultimate strength = 17700 kg/m.

Conductor weight = $\frac{\pi D^2}{4} \times \rho \times 1000$

Conductor weight = $\frac{\pi \times (12.5)^2}{4} \times 7.85 \times 1000 = 1.169 \text{ kg/m}$

89

Details: A conductor has a sag of 1.2 m & a span of 30 m. If the maximum permissible sag is 0.8 m, with a horizontal wind pressure of 1.5 kg/m², if permissible stress & 10% more, what will be sag? Assume the permissible stress because suggestion of standard says that when the conductor is at the lowest point it should be 2 times conductor tension with 10% safety factor. The conductor weight is 1.169 kg/m.

Solution: Given: S = 1.5 kg/m², L = 30 m, sag = 1.2 m, safety factor = 2, weight = 1.169 kg/m.

Conductor weight = $\frac{\pi D^2}{4} \times \rho \times 1000$

Conductor weight = $\frac{\pi \times (12.5)^2}{4} \times 7.85 \times 1000 = 1.169 \text{ kg/m}$

90

Details: It represents the conductor force on effective diameter of 12.5 mm & weight of 1.169 kg/m. If the maximum permissible sag is 0.8 m, with a horizontal wind pressure of 1.5 kg/m², if permissible stress & 10% more, what will be sag? Assume the permissible stress because suggestion of standard says that when the conductor is at the lowest point it should be 2 times conductor tension with 10% safety factor. The conductor weight is 1.169 kg/m.

Solution: Given: S = 1.5 kg/m², L = 30 m, sag = 1.2 m, safety factor = 2, weight = 1.169 kg/m.

Conductor weight = $\frac{\pi D^2}{4} \times \rho \times 1000$

Conductor weight = $\frac{\pi \times (12.5)^2}{4} \times 7.85 \times 1000 = 1.169 \text{ kg/m}$

91

Details: Weight of ice covering = 1.169 kg/m². If the maximum permissible sag is 0.8 m, with a horizontal wind pressure of 1.5 kg/m², if permissible stress & 10% more, what will be sag? Assume the permissible stress because suggestion of standard says that when the conductor is at the lowest point it should be 2 times conductor tension with 10% safety factor. The conductor weight is 1.169 kg/m.

Solution: Given: S = 1.5 kg/m², L = 30 m, sag = 1.2 m, safety factor = 2, weight = 1.169 kg/m.

Conductor weight = $\frac{\pi D^2}{4} \times \rho \times 1000$

Conductor weight = $\frac{\pi \times (12.5)^2}{4} \times 7.85 \times 1000 = 1.169 \text{ kg/m}$

92

Details: An overhead line is a 100 m spanning a suspended span with a weight of 12.5 kg/m. If the maximum permissible sag is 0.8 m, with a horizontal wind pressure of 1.5 kg/m², if permissible stress & 10% more, what will be sag? Assume the permissible stress because suggestion of standard says that when the conductor is at the lowest point it should be 2 times conductor tension with 10% safety factor. The conductor weight is 1.169 kg/m.

Solution: Given: S = 1.5 kg/m², L = 100 m, sag = 1.2 m, safety factor = 2, weight = 1.169 kg/m.

Here, weight of ice covering = $w_i = \frac{\omega_{ice} \cdot \pi (2r+t) \cdot t}{10^6} \text{ kg}$

$$= \frac{910 \times \pi \times (2 \times 9.75 + 12.7) \times 12.7}{10^6} \text{ kg} = 1.169 \text{ kg}$$

Wind load = $\frac{P \cdot 2 \cdot (r+t)}{10^3} \text{ kg} = \frac{39 \times 2 \times (9.75 + 12.7)}{10^3} = 1.7511 \text{ kg} = w_w$

So, resultant load = $W = \sqrt{(w + w_i)^2 + w_w^2} = \sqrt{(0.85 + 1.169)^2 + (1.7511)^2} = 2.6727 \text{ kg}$

Now, working tension = $T = \frac{8000}{2} = 4000 \text{ kg}$

As, sag $d = \frac{Wl^2}{8T}$, span = $l = \sqrt{\frac{8Td}{W}} = \sqrt{\frac{8 \times 4000 \times 6.3}{2.6727}} \text{ m} = 274.646 \text{ m}$

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Problem: An overhead line at a river crossing is supported from two towers of heights 30.5m & 91.5m above the water level with a span of 305m. If the required clearance between the conductor & water level midway between the towers is 53.4m and if both the towers are on the same side of maximum sag point of the parabolic configuration, calculate the strike tension on the conductor. Weight of conductor is 0.88kg/m. Also calculate the distances of the two towers from the point of maximum sag.

Solution:

The diagram illustrates a parabolic conductor sag between two towers. The horizontal distance between the towers is labeled $l_1 = 305\text{m}$. The left tower is at a height of $h_1 = 30.5\text{m}$ above the water level. The right tower is at a height of $h_2 = 91.5\text{m}$ above the water level. The minimum height of the conductor above the water level, known as the sag, is labeled $h_3 = 53.4\text{m}$. The vertical distance from the water level to the towers is d_1 and d_2 respectively. The horizontal distance from the base of each tower to the point of maximum sag is labeled l_2 .

92

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90

Given: Two transmission towers of height $h_1 = 30.5\text{m}$ & $h_2 = 91.5\text{m}$ with a horizontal span of $l = 305\text{m}$. The conductor hangs in a parabolic shape with a clearance of $h_3 = 53.4\text{m}$ at the middle of the span. Find the tension in the conductor.

91

Solution: Weight of conductor per unit length $= \omega = 0.88\text{ kg/m}$

$$\text{Total weight} = \omega \times \text{length} = 0.88 \times 305 = 267.2\text{ kg}$$

$$T = \frac{\omega}{2} (l_1^2 + l_2^2) = \frac{267.2}{2} (305^2 + 240^2) = 115571\text{ N}$$

$$\text{Ans. according to question, } T = \frac{\omega}{2} (l_1^2 + l_2^2)$$

$$T = \frac{0.88}{2} (305^2 + 240^2) = \frac{0.88}{2} (93025 + 57600) = 40500\text{ N}$$

92

Given: Two transmission towers of height $h_1 = 30.5\text{m}$ & $h_2 = 91.5\text{m}$ with a horizontal span of $l = 305\text{m}$. The conductor hangs in a parabolic shape with a clearance of $h_3 = 53.4\text{m}$ at the middle of the span. Find the tension in the conductor.

93

Given: Two transmission towers of height $h_1 = 30.5\text{m}$ & $h_2 = 91.5\text{m}$ with a horizontal span of $l = 305\text{m}$. The conductor hangs in a parabolic shape with a clearance of $h_3 = 53.4\text{m}$ at the middle of the span. Find the tension in the conductor.

94

Solution: Weight of conductor per unit length $= \omega = 0.88\text{ kg/m}$

$$T = \frac{\omega}{2} (l_1^2 + l_2^2)$$

$$T = \frac{0.88}{2} (305^2 + 240^2) = 40500\text{ N}$$

Given data:

Height of towers $h_1 = 30.5\text{m}$ and $h_2 = 91.5\text{m}$; Span $= l = 305\text{m}$;

Clearance of conductor at middle of span $= h_3 = 53.4\text{m}$;

Weight of conductor/m $= \omega = 0.88\text{ kg/m}$.

$$\text{Here, } d_2 - d_1 = h_2 - h_1 = \frac{\omega}{2T} (l_2^2 - l_1^2)$$

$$\text{Or, } 91.5 - 30.5 = \frac{0.88}{2T} (l_2 + l_1)(l_2 - l_1)$$

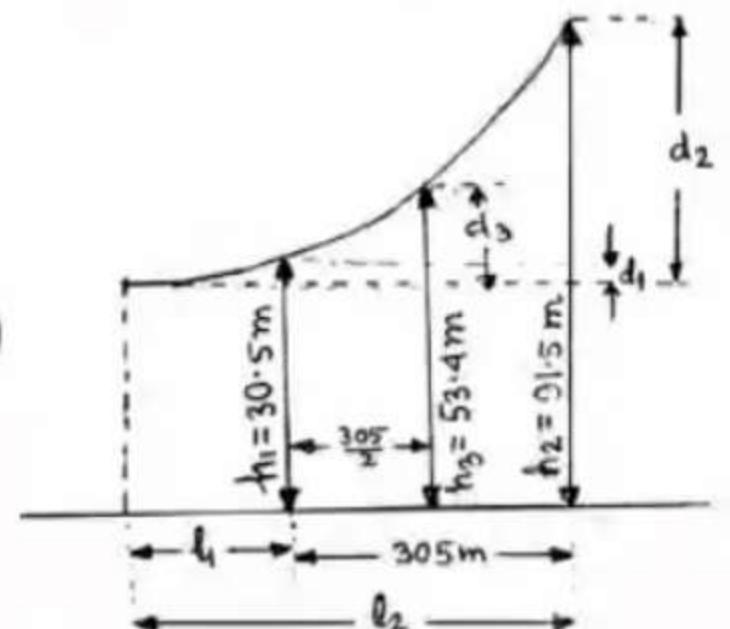
$$= \frac{0.88}{2T} (305 + 240) \times 305$$

$$\text{Or, } T = 2.2(305 + 240) \dots (1)$$

$$\text{Again, } d_3 - d_1 = h_3 - h_1 = \frac{\omega}{2T} \left\{ \left(l_1 + \frac{305}{2} \right)^2 - l_1^2 \right\}$$

$$\text{Or, } 53.4 - 30.5 = \frac{0.88}{2T} \left(l_1 + \frac{305}{2} + l_1 \right) \left(l_1 + \frac{305}{2} - l_1 \right)$$

$$\text{Or, } T = 2.930 \left(240 + \frac{305}{2} \right) \dots (2)$$



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91

Equation of the string: $T = \frac{W}{2L} \sqrt{4L^2 + \left(\frac{V}{L}\right)^2}$

Given: $W = 2.2 \text{ kN}$, $L = 305 \text{ m}$, $V = 20 \text{ m/s}$

$T = \frac{2.2 \times 10^3}{2 \times 305} \sqrt{4 \times 305^2 + \left(\frac{20}{305}\right)^2} = 153.5032 \text{ N}$

92

Deflection: An additional diagram shows the deflection curve. The maximum deflection is given as 15.5 m . This value is converted into a height of 15.5 m . It is required to determine the maximum deflection at lower levels. Therefore, the deflection is 15.5 m and it is assumed that the deflection is zero at the corner of the maximum sag point of the parabolic deflection curve. Maximum deflection occurs at the midpoint. Height of maximum deflection is 15.5 m . The distance from the corner to the point of maximum deflection is 15.5 m .

93

Equation of the string: $T = \frac{W}{2L} \sqrt{4L^2 + \left(\frac{V}{L}\right)^2}$

Given: $W = 2.2 \text{ kN}$, $L_1 = 153.5032 \text{ m}$, $V = 20 \text{ m/s}$

$T = \frac{2.2 \times 10^3}{2 \times 153.5032} \sqrt{4 \times 153.5032^2 + \left(\frac{20}{153.5032}\right)^2} = 2.2 \text{ kN}$

94

Equation of the string: $T = \frac{W}{2L} \sqrt{4L^2 + \left(\frac{V}{L}\right)^2}$

Given: $W = 2.2 \text{ kN}$, $L_1 = 153.5032 \text{ m}$, $V = 20 \text{ m/s}$

$T = \frac{2.2 \times 10^3}{2 \times 153.5032} \sqrt{4 \times 153.5032^2 + \left(\frac{20}{153.5032}\right)^2} = 2.2 \text{ kN}$

95

Diagram showing the relationship between Temperature and Deflection.

- Deflection is zero at zero temperature.
- At temperature T_0 , deflection is zero.
- Deflection & minimum at the temperature T_0 .
- From previous point, deflection is zero at zero temperature.
- As temperature T increases, deflection increases in the range of T_0 .
- Curves of deflection vs. temperature are shown as follows:

Equating (1) and (2),

$$2.930\left(2l_1 + \frac{305}{2}\right) = 2.2(305 + 2l_1)$$

Solving, $l_1 = 153.5032 \text{ m}$

$$l_2 = l_1 + 305 = 458.5032 \text{ m}$$

$$\therefore \text{Tension } T = 2.2(305 + 2l_1) = 1346.4145 \text{ kg}$$

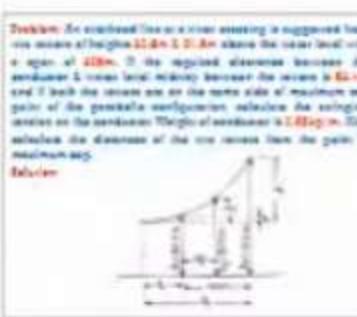
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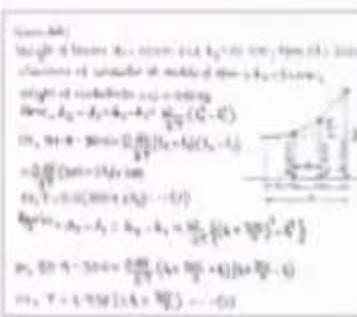
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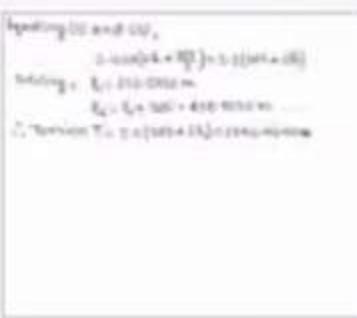
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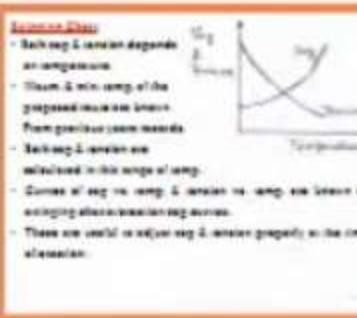
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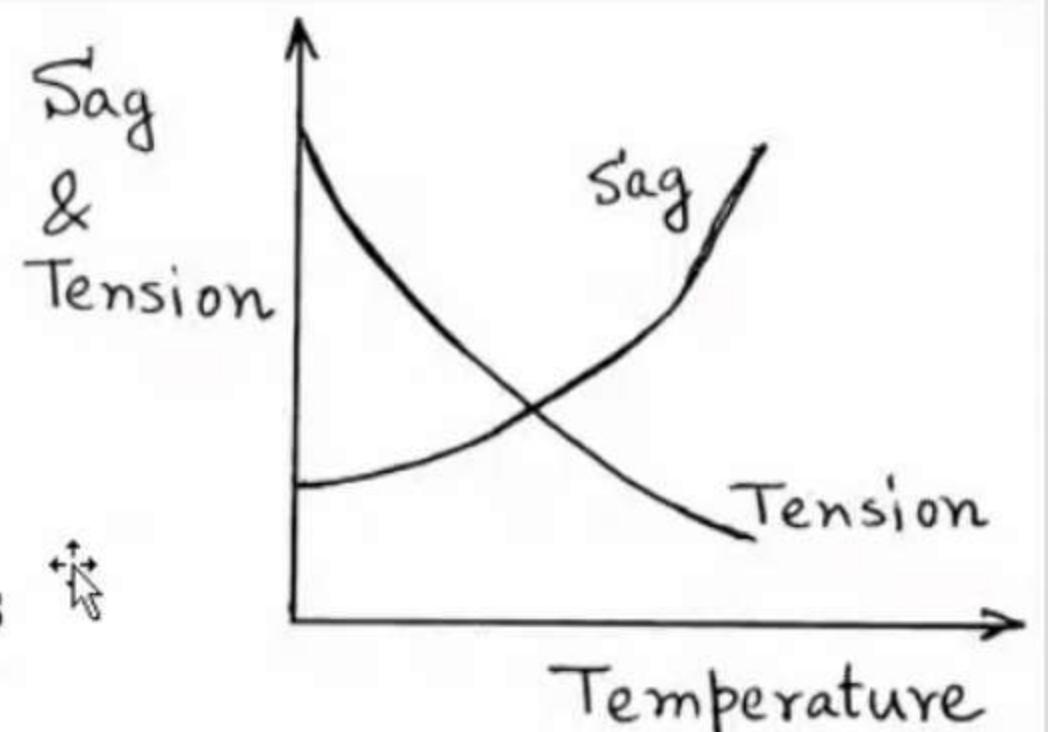


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Stringing Chart

- Both sag & tension depends on temperature.
- Maxm. & min. temp. of the proposed route are known from previous years records
- Both sag & tension are calculated in this range of temp.
- Curves of sag vs. temp. & tension vs. temp. are known as stringing charts/erection sag curves.
- These are useful to adjust sag & tension properly at the time of erection.



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Sag Template

- Essential to allocate position & height of supports correctly on profile.
- Made of transparent celluloid, perspex or sometimes cardboard.
- Following curves are marked on it.
 - Hot temperature curve:** Obtained by plotting sag at maxm. temp. vs. span length (AJBKC).
 - Ground clearance curve:** Situated below the hot curve & is at a distance from it, equal to the ground clearance as prescribed by the regulations for the given line (DQEFGH).
 - Support foot curve:** It gives location of the footing of towers. It is situated below the hot curve at a distance – height of a standard tower from the lowest point of attachment to the ground level (GHI).

The diagram illustrates a sag template used for overhead power lines. It features three nested, U-shaped curves representing different levels of sag. The top curve is labeled A, J, B, K, C. The middle curve is labeled D, Q, E. The bottom curve is labeled G, H, I. Vertical dashed lines connect points A, D, and G to a horizontal base line at the bottom, and points C, F, and I to the same base line. Points J, E, and H are also marked on the base line. The regions between the curves are shaded with different patterns: the top region is hatched, the middle region has diagonal lines, and the bottom region has horizontal lines.

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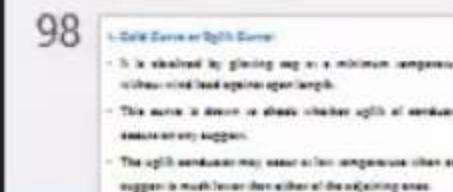
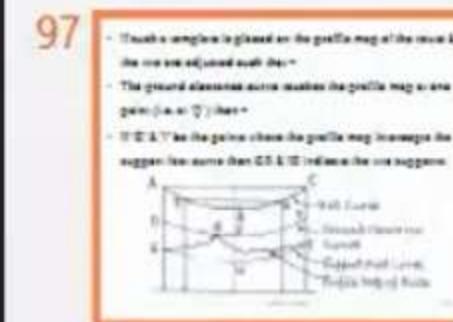
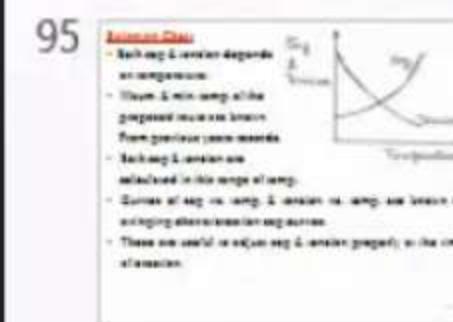
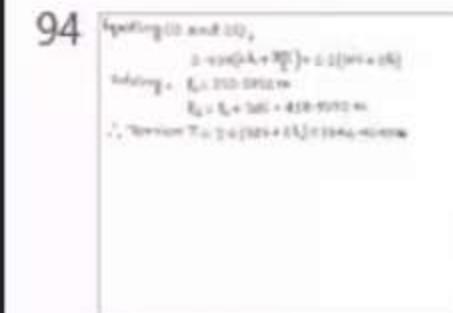
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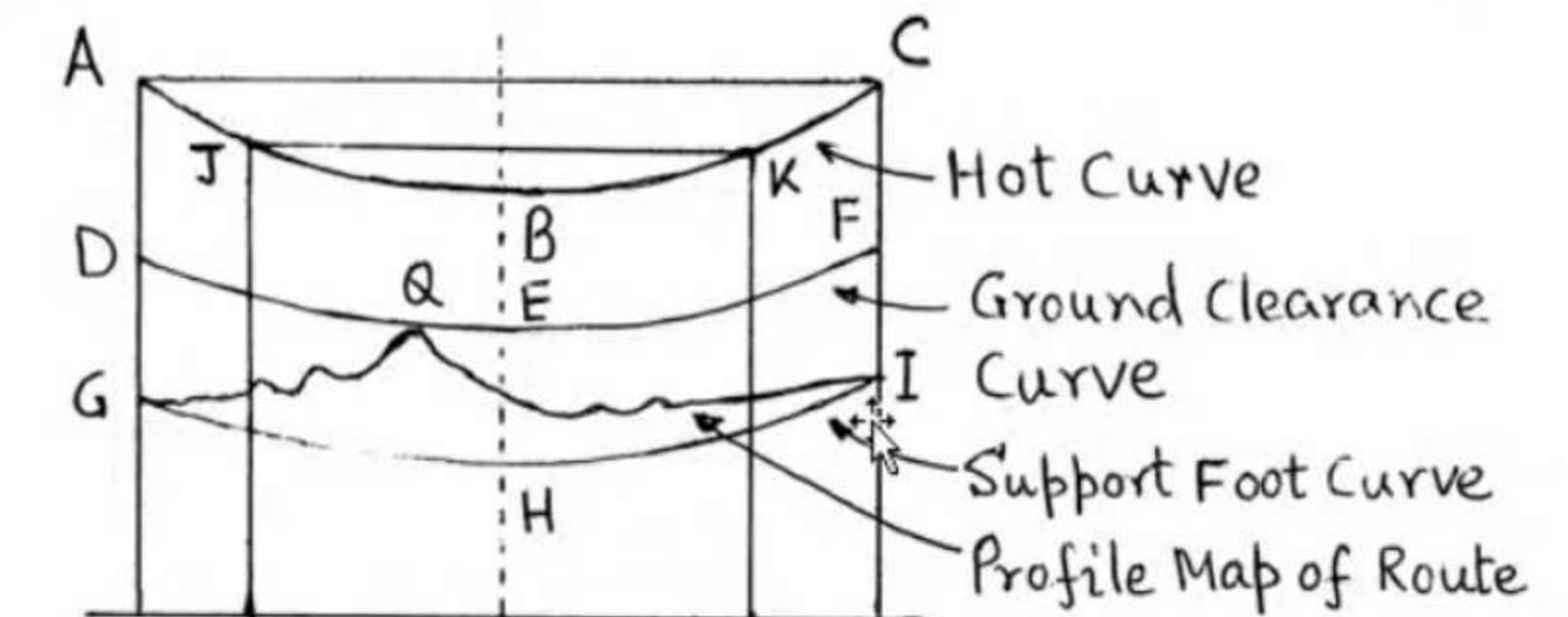
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- If such a template is placed on the profile map of the route & the two are adjusted such that -
- The ground clearance curve touches the profile map at one point (i.e. at 'Q') then -
- If 'G' & 'I' be the points where the profile map intercepts the support foot curve then GA & IC indicate the two supports.

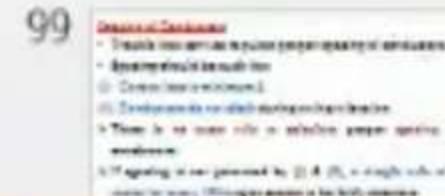
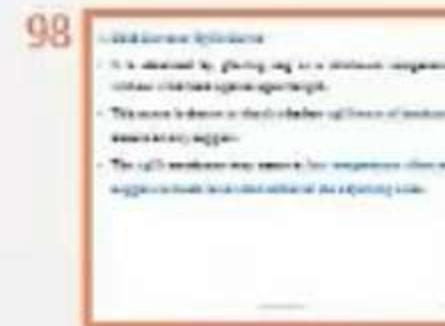
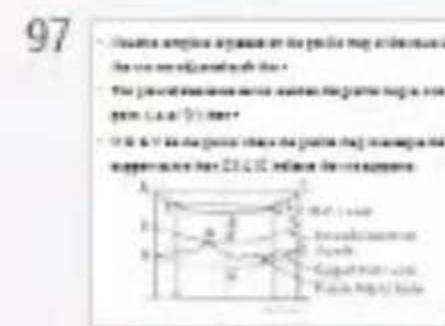
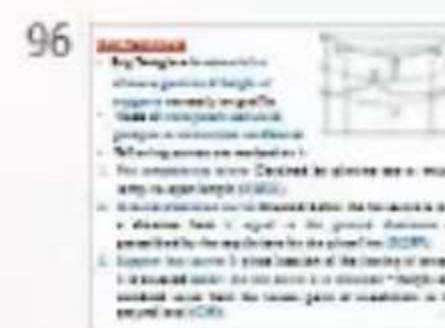
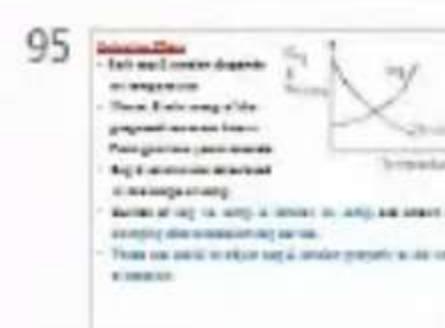


Prof. S. S. Thakur

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4. Cold Curve or Uplift Curve:

- It is obtained by plotting sag at a minimum temperature without wind load against span length.
- This curve is drawn to check whether upliftment of conductor occurs on any support.
- The uplift conductor may occur at low temperature when one support is much lower than either of the adjoining ones.

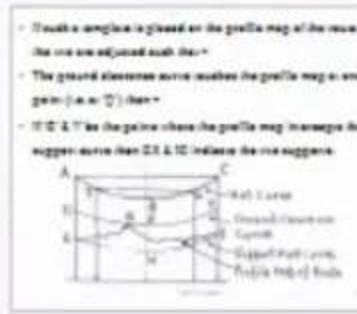
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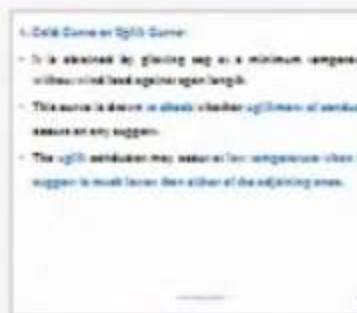
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Spacing of Conductors

- Trouble free service requires proper spacing of conductors.
- Spacing should be such that
 - (i) Corona loss is minimum &
 - (ii) Conductors do not clash during swing/vibration.
- There is no exact rule to calculate proper spacing of conductors.
- If spacing is not governed by (i) & (ii), a simple rule of 1 metre for every 100m span seems to be fairly accurate.
- Different countries use various empirical formulae → that give different spacing for same span & conductor size.
- deduced from experience of conductor loading, conditions of temperature, wind, ice etc.

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- Insulator sag is placed on the profile map of the route.
- The ground clearance serve reduces the profile map to one point (i.e. 0').
- If 'D & T' is the profile where the profile map measures the height more than D & T, then the deflection angle.

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- Total Sag or Spill Sag.
- It is obtained by placing sag at a maximum temperature without load against sag length.
- This formula is used to check whether sag limit of conductor is met or not.
- The sag value may increase in low temperature than and decrease in high temperature due to variation of ambient air.

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- Factors of Conductor sag
- These factors affect sag greater regarding of conductor.
- Sagging should be such that
- (i) Current loss is minimum &
- (ii) Conductors do not touch during icing condition.
- (iii) There is no severe risk of excessive sagging of conductors.
- (iv) Sagging is not governed by (i) & (ii), a single rule of thumb is every 100m sag distance is to be fixed.
- (v) Different association has different empirical formulae. It has given 4 different sagging formulae open C conductor sag.
- (vi) Induced current experience of conductor heating, conductor sag temperature & wind force.

100

- Some of the empirical formulae
- $S = \frac{V}{150} \sqrt{d}$
- $S = \frac{V}{150} \sqrt{d+2l}$
- $S = \frac{V}{150} \sqrt{d+2l + \frac{d}{l}}$
- $S = \frac{V}{150} \sqrt{d + \frac{d^2}{l^2}}$
- $S = \frac{V}{150} \sqrt{d + \frac{d^2}{l^2} + \frac{d}{l}}$
- $S = \frac{V}{150} \sqrt{d + \frac{d^2}{l^2} + \frac{d}{l} + \frac{d}{l^2}}$
- $S = \frac{V}{150} \sqrt{d + \frac{d^2}{l^2} + \frac{d}{l} + \frac{d}{l^2} + \frac{d}{l^3}}$
- These formulae are quite difficult to choose depends on local conditions of temperature, ice & wind.

101

- The entire network voltage tolerance of conductor above ground must be maintained under all loading conditions.
- It depends on system voltage.
- Indian Electricity Directive a tolerance of 10% of 1.1 times or 1.1 times or 1.22 times or 1.22 times additional 1.1 times or 1.22 times tolerance should be provided.
- Example: 7.13 kV line

Some of the empirical formulae are

$$S = \sqrt{d} + \frac{V}{150}$$

$$S = \sqrt{d} + 0.012V$$

$$S = 0.75\sqrt{d} + \frac{V}{150}$$

$$S = 0.75\sqrt{d} + \frac{V^2}{20000}$$

$$S = 0.7\sqrt{d} + \frac{V}{100} + 0.25$$

$$S = 0.65\sqrt{d} + 0.007$$

$$S = 2d \sin \theta$$

$$S = 0.8\sqrt{d+l} + \frac{V}{150}$$

$$S = 0.75\sqrt{(d+l)} \sin \theta + \frac{V}{125}$$

where,
 d = sag in metre,
 V = voltage(kV) betn. conductors,
 l = insulator string length (m) &
 θ = deflection of insulator string.

❖ These formulae serve as guide, final choice depends on local conditions of temperature, ice & wind. I

100

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98

• It is measured by giving sag or minimum clearance between conductor and ground at maximum temperature.

• This value is chosen to check whether sag of conductor comes in any support.

• The sag of conductor may increase at low temperature when sag supports are made from less elastic material of supporting poles.

99

• These lines serve as regular supply to consumers.

• Operating voltage is 33kV.

• Conductor diameter is minimum 25mm².

• There is no upper limit to minimum sag of conductors.

• If operating voltage is generated by 33 kV, a single pole of 1.5m for every 100m span is to be fixed.

• If three conductors are used, sag should be 1.5m for every 100m span.

• Minimum clearances of conductors under all conditions of temperature and wind speeds.

100

Some of the formulae for clearance:

$$d = \frac{D}{2} + \frac{s}{2}$$
$$d = \frac{D}{2} + 0.3048$$
$$d = 0.3333D + 0.3048$$
$$s = 1.5033D + \frac{0.3048}{2}$$
$$s = 1.5033D + 0.1524$$
$$s = 1.5033D + 0.1524$$
$$s = 1.5033D + 0.1524$$

• These formulae are not applicable for lines depending on load variations of conductors, i.e., wind speeds.

101

• For safety reasons, adequate clearance of conductors above ground must be maintained under all loading conditions.

• It depends on system voltage.

• Indian Electricity Act says a clearance of 17feet/ 5.18m is to be provided for 33kV line & for every additional 33kV or part thereof, additional 1 foot/ 0.3048m clearance should be provided.

Example : 132 kV line

$$132 \text{ kV} = 33 + \frac{(132-33) \times 33}{33} = 33 + 3 \times 33 \text{ kV}$$

∴ Ground clearance = $5.18 + 3 \times 0.3048 = 6.0944 \text{ m}$

102

Ground Clearance

- For safety reasons, adequate clearance of conductor above ground must be maintained under all loading conditions.
- It depends on system voltage.
- Indian Electricity Act says a clearance of 17feet/ 5.18m is to be provided for 33kV line & for every additional 33kV or part thereof, additional 1 foot/ 0.3048m clearance should be provided.

Example : 132 kV line

$$132 \text{ kV} = 33 + \frac{(132-33) \times 33}{33} = 33 + 3 \times 33 \text{ kV}$$

$$\therefore \text{Ground clearance} = 5.18 + 3 \times 0.3048 = 6.0944 \text{ m}$$

Example : 400 kV line

$$400 \text{ kV} = 33 + \frac{(400-33) \times 33}{33} = 33 + 11.1212 \times 33 \text{ kV}$$

$$\therefore \text{Ground clearance} = 5.18 + 11.1212 \times 0.3048 = 8.5697 \text{ m}$$

101

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99

Answers

- Troublesome question regarding self-inductance.
- Coupling coefficient much less than 1.
- Currents do not decay during coupling inductance.
- > There is no reason why there is no coupling between primary & secondary.
- > Coupling is not generated by (1) & (2), a simple rule of thumb for every 100m of copper wire is 1.2 nH/m.
- > Different materials can reduce magnetic coupling & give different coupling for same given L & conductor size.
- > Reduced skin effect of conductor leading, ventilation of components, winding distance.

100

Some of the simplified formulas are

$$L = \mu_0 \cdot \frac{N}{l}$$

$$L = \mu_0 \cdot \frac{N^2}{l}$$

$$L = \mu_0 \cdot \frac{N^2 \cdot \pi d^2}{l}$$

$$L = \mu_0 \cdot \frac{N^2 \cdot \pi d^2}{l} \cdot \frac{l}{l + 2d}$$

$$L = \mu_0 \cdot \frac{N^2 \cdot \pi d^2}{l} \cdot \frac{l}{l + 2d}$$

$$L = \mu_0 \cdot \frac{N^2 \cdot \pi d^2}{l} \cdot \frac{l}{l + 2d}$$

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$$L = \mu_0 \cdot \frac{N^2 \cdot \pi d^2}{l} \cdot \frac{l}{l + 2d}$$

$$L = \mu_0 \cdot \frac{N^2 \cdot \pi d^2}{l} \cdot \frac{l}{l + 2d}$$

where

μ_0 = mag. permeability

N = number of turns per unit length

d = insulation thickness per turn

l = distance of insulation from center

In These formulas some variables, like μ_0 depends on frequency of component, see E & C.

101

Answers

- For safety reasons, adequate clearance of conductor above ground must be maintained under all loading conditions.
- Inductance of system voltage.
- Inductance of system current.
- Inductance of system voltage & for every additional 100m of power cable, additional 1 turn of 100m of clearance should be provided.

Example 1: 100V Bus

$$100\text{V} \times 10 \times \frac{\mu_0 \cdot \pi d^2}{l} \times 23 = 23 \times 3 \times 100\text{A}$$

$$\therefore \text{Required clearance} = 0.08 \times 3 \times 100 = 0.0048\text{m}$$

Example 1: 400V Bus

$$400\text{V} \times 10 \times \frac{\mu_0 \cdot \pi d^2}{l} \times 23 = 23 \times 3 \times 100 = 0.0096\text{m}$$

$$\therefore \text{Required clearance} = 0.04 \times 10 \times 23 = 0.0096\text{m}$$

102

Line Inductance

103

Answers

- By classic formulation line has four parameters: resistance (R), inductance (L), capacitance (C) & admittance (G).
- Design & performance of lines depend on these parameters.
- These are uniformly distributed along the entire line.
- So, measures are given as distributed parameters.
- Their values are given for unit length of the line.
- These are denoted with \perp , \parallel & \square .
- Their values depend on conductor geometry. See geometry.

Line Inductance

Prof. S. S. Thakur

102

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Line Parameters

- Any electric transmission line has four parameters- resistance (R), inductance (L), capacitance (C)& shunt conductance (G).
- Design & performance of lines depend on these parameters.
- These are uniformly distributed along the whole line.
- So, these are known as distributed parameters.
- Their values are given for unit length of the line.
- These are denoted as R, L, C & G.
- Their values depend on conductor geometry, line geometry & conductor material.
- R & L form the series impedance; C & G form the shunt admittance of the line.

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101 **Answer**

- No other losses, voltage across inductor will be given under all leading conditions.
- Inductance of a coil of 100 turns is given by $L = \mu_0 N^2 A / l$ for every additional 100 turns per meter additional 1 henry is added.
- Example 1: 100 turns, $\mu_0 = 4\pi \times 10^{-7} \text{ N/A}^2$, $A = 0.01 \text{ m}^2$, $l = 0.1 \text{ m}$
- Current through coil is $i = 10 \text{ A}$
- Induced emf is $e = -N \frac{di}{dt}$
- Induced emf is $e = -100 \times 10 \times 0.1 = -100 \text{ V}$

102 **Line Inductance**

103 **Ans**

- Only class 1 inductor has linear magnetization (B), inductance (L), magnetomotive force (MM).
- Design & performance of coils depend on these parameters.
- These are uniformly distributed along the entire coil.
- No change in flux density in air gap.
- Their values are given for unit length of the coil.
- These are derived on L.C.L.
- Their values depend on conductor geometry, core geometry & magnetic material.
- R.L.L. gives the series impedance, Q & C give the shunt admittance of the coil.

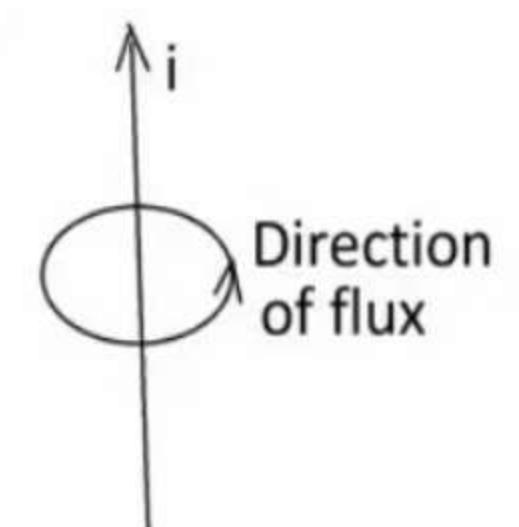
104 **Ans**

- Current carrying conductor produces flux surrounding it.
- With variation of current flux linkage of the conductor changes & an emf is induced in it (Faraday's law), i.e.,

$$|e| = \frac{d}{dt}(N\Phi) = N \cdot \frac{d\Phi}{dt} \text{ Volt} \dots\dots (1)$$

Line Inductance

- A current carrying conductor produces flux surrounding it.
- With variation of current flux linkage of the conductor changes & an emf is induced in it (Faraday's law), i.e.,



$$|e| = \frac{d}{dt}(N\Phi) = N \cdot \frac{d\Phi}{dt} \text{ Volt} \dots\dots (1)$$

- Here, $N\Phi$ is the flux linkage of the conductor in weber-turns.
- Again, **self induced emf** is proportional to rate of change of current, $\frac{di}{dt}$, i.e.

$$|e| \propto \frac{di}{dt} \text{ or, } |e| = L \cdot \frac{di}{dt} \text{ Volt} \dots\dots (2)$$

where, L is the constant of proportionality & is known as **self inductance** of the circuit.

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102

Line Inductance

103

QUESTION

- Any electric conductor has four parameters resistive (R), inductive (L), capacitive (C) & dielectric loss (D).
- Design & performance of lines depend on these parameters.
- These are uniformly distributed along the whole line.
- No losses are known as dielectric parameter.
- Their values are given for unit length of the line.
- These are denoted as R , L , C & D .
- Their values depend on conductor geometry, the geometry & insulation material.
- R , L & C have the same dimension; D & C have the same dimension of the line.

104

QUESTION

- A current carrying conductor produces flux linking it.
- This variation of flux due to change in the conductor changes & current is induced in it (Faraday's law).
- $\frac{d\Phi}{dt} = B \frac{dA}{dt} = B \frac{dI}{dt} \cdot A$ (1)
- Here, A is the free area of the conductor in cross-section.
- Since, self induced emf is proportional to rate of change of current.
- $\text{emf} = N \frac{d\Phi}{dt} = N \frac{dI}{dt} \cdot A$ (2)
- where, N is the number of protons per A is known as self inductance of the loop.

105

Solving eqns. (1) & (2)

$$N \frac{dI}{dt} = N \frac{d\Phi}{dt}$$

If permeability of the magnetic circuit is assumed to be constant, then, $\frac{d\Phi}{di} = \frac{\Phi}{i}$.

or, $N \frac{dI}{dt} = N \frac{\Phi}{i}$ (3)

Therefore, from eqn. (3),

$$L = N \cdot \frac{\Phi}{i} \text{ Henry} \quad \dots \dots \dots (4)$$

106

QUESTION

- Consider a solid round, infinitely long conductor placed in air at radius 'r'. Carrying a current of I .
- Flux linking with conductor has one path.
- If the current flow is I , the current density is J .
- Current I is given by $I = J \cdot \pi r^2$.
- Area of cross-section $A = \pi r^2$.
- Total current $I = J \cdot \pi r^2$.

Equating eqns. (1) & (2),

$$L \cdot \frac{di}{dt} = N \cdot \frac{d\Phi}{dt}$$

$$\text{or, } L = N \cdot \frac{d\Phi}{di} \quad \dots \dots \dots (3)$$

- If **permeability** of the magnetic circuit is assumed to be

$$\text{constant, then, } \frac{d\Phi}{di} = \frac{\Phi}{i}.$$

- Therefore, from eqn. (3),

$$L = N \cdot \frac{\Phi}{i} \text{ Henry} \quad \dots \dots \dots (4)$$

- For a single conductor,

$$L = \frac{\Phi}{i} \text{ Henry} \quad \dots \dots \dots (5)$$

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103

Inductance

- Any closed conductor carries four parameters resistance (R), inductance (L), capacitance (C) & self mutual inductance (M).
- Design & performance all these depend on these parameters.
- These are uniformly distributed along the whole line.
- So, these are known as distributed parameters.
- Their values are given by unit length of the line.
- These are denoted as L , C & M .
- Their values depend on conductor geometry, the geometry & conductor material.
- R , C & M have the same dimensions; L & M have the same dimensions as the inductance of the line.

104

Inductance

- A current carrying conductor produces flux around it.
- This induction of current due to change of the conductor always & air core is induced in it (Faraday's Law).
- $\text{d}B/dt = \mu_0 (Id/l) \text{A/m}$ (1)
- Here, I is the total current of the conductor in Amperes.
- Flux, Φ induced and is proportional to rate of change of current.
- $\Phi = \mu_0 (Id/l) \text{Wb}$ (2)
- where, I is the amount of magnetization & is known as self inductance of the conductor.

105

Spooling area (A) (S)

$$L = \frac{\mu_0 \cdot \pi r^2}{l} \cdot S$$

If permeability of the magnetic circuit is assumed to be constant, then $S = \frac{l}{\mu_0} \text{Wb/V}$ (3)

Thus, $S = \frac{l}{\mu_0} \text{Wb/V}$ (4)

For a single conductor:

$$L = \frac{\mu_0 \cdot \pi r^2}{l} \cdot \frac{l}{\mu_0} \text{Wb/V}$$

106

Inductance of Conductor

- Consider a solid round, infinitely long conductor situated in air - of radius ' r ' & carrying a current of ' i '.
- Flux linking with conductor has two parts –
 - (i) the internal flux & (ii) the external flux.

107

Inductance due to internal flux = Internal Inductance (L_i , Wb/A)

Inductance due to external flux = External Inductance (L_e , Wb/A)

Total inductance (L) = $L_i + L_e$ Wb/A

Inductance of a Conductor

- Consider, a solid, round, infinitely long conductor, situated in air - of radius ' r ' & carrying a current of ' i '.
- Flux linking with conductor has two parts –
 - (i) the internal flux & (ii) the external flux.
- Internal flux is present inside conductor, due to its own current – does not link with whole conductor but only a fraction of it.
- External flux is present around the cond. -due to its own current & currents in other conductors in the vicinity.
- External flux links with the whole cond.

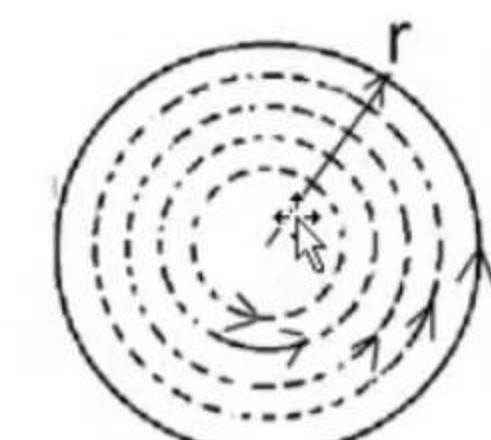


Fig. Internal flux

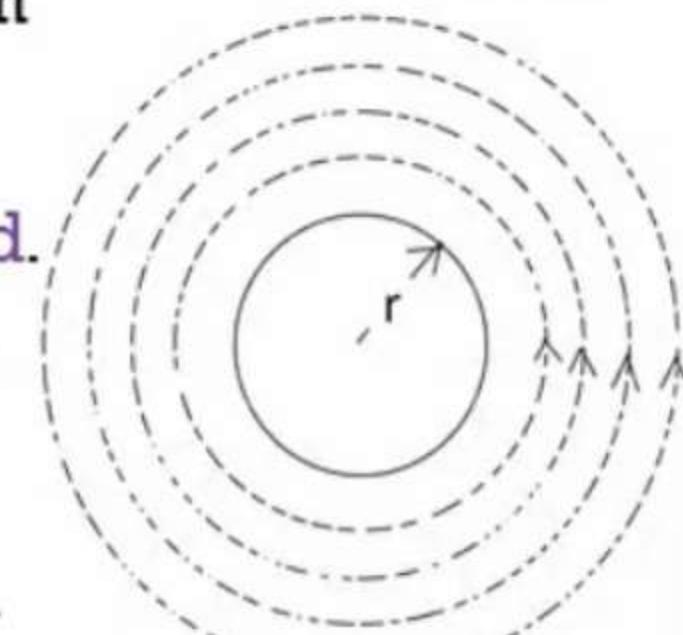


Fig. External flux

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104
QUESTION

- Current carrying conductor produces flux surrounding it.
- With increase of current flux linkage of the conductor changes & so does the induced emf in it (Faraday's Law).
- Now, $\frac{d\Phi}{dt}$ is the rate of change of the linkages in the conductor.
- Induced emf is proportional to rate of change of linkages.
- $\text{emf} = \frac{d\Phi}{dt} \cdot N$ (1)

where, N is the number of turns enclosed by the loop or the coil.

105
Equation (1) is (2)

$$\frac{d\Phi}{dt} = \mu_0 \frac{dB}{dx} \cdot A$$

$$\Rightarrow \text{emf} = \mu_0 \frac{d}{dx} \left(B \cdot A \right) \cdot N$$

- If permeability of the magnetic core is assumed to be constant, then $\frac{d\Phi}{dt} = \frac{d\Phi}{dt}$.
- Therefore, $\text{emf} = \frac{d\Phi}{dt}$.
- For a single conductor, $\text{emf} = \frac{d\Phi}{dt}$ Henry(2)

106
QUESTION

- Consider a solid, round, infinitely long conductor situated in air (vacuum). It carrying a current of I .
- Flux linking with conductor has one path.
- The internal flux Φ_i is the enclosed flux.
- External flux Φ_e is present outside the conductor.
- Due to law of conservation of flux, $\Phi_i + \Phi_e = \text{constant}$.
- External flux is zero because there is no free space in the vicinity.
- External flux links with the whole coil.

107
QUESTION

- Induction due to internal flux = Internal inductance (L_{in}) Henry.
- Induction due to external flux = External inductance (L_{ex}) Henry.
- Total inductance (per unit length) = $(L_{in} + L_{ex})$ Henry.

ANSWER

Let choose path of the current in the coil, so far away that its magnetic field is not affected.

- Current distribution is uniform over the cross section of the conductor.
- Consider, a distance ' x ' & an elemental distance ' dx ' there.
- Magnetic field intensity at distance ' x ' be ' H_x '.

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On $I_x = \mu_0 H_x$ (1)

Permeability density = μ_0 (2)

Therefore, $I_x = \mu_0 H_x$ (3)

Current density = $I_x / A = \mu_0 H_x / A$ (4)

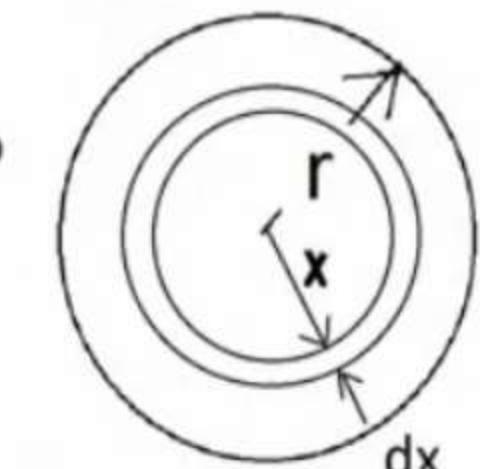
Permeability density = $\mu_0 = 4\pi \times 10^{-7} \text{ Vs/Ampere}$ (5)

where, A is area enclosed by the path.

- Inductance due to internal flux – internal inductance (L_{in} H/m).
- Inductance due to external flux – external inductance (L_{ex} H/m).
- So, total inductance (per metre length) = $[L_{in} + L_{ex}]$ H/m.

Internal Inductance

- Let, return path of the current in the cond. be so far away that its magnetic field is not affected.



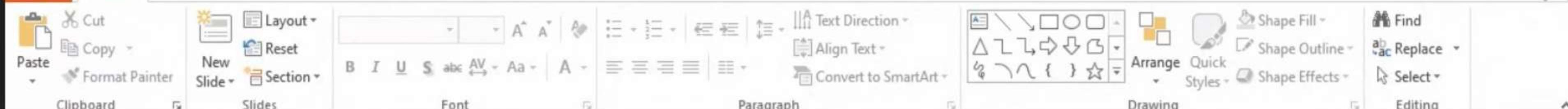
- Current distribution is uniform over the cross section of the conductor.

- Consider, a distance ' x ' & an elemental distance ' dx ' there.
- Magnetic field intensity at distance ' x ' be ' H_x '.

Applying Ampere's law,

$$2\pi x \cdot H_x = i_x \dots (1)$$

where i_x is current enclosed by the path.



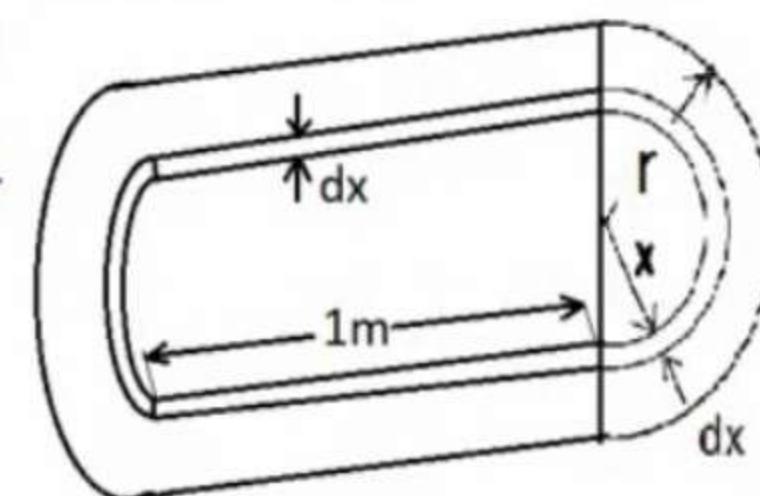
Therefore, $i_x = \pi \cdot x^2 \cdot \text{current density} = \pi \cdot x^2 \cdot \frac{i}{\pi r^2} = \frac{x^2}{r^2} \cdot i \text{ A} \dots (4)$

Now, flux density = $B_x \equiv \mu \cdot H_x = \mu \cdot i \cdot \frac{x}{2\pi r^2}$ wb/m² (6)

where μ is permeability of cond. material. Now, flux through a cylindrical shell at a distance 'x' from the centre with thickness 'dx' & 1m length = $d\Phi_x = B_x \cdot (dx \cdot 1) = \mu \cdot i \cdot \frac{x}{2\pi r^2} \cdot dx$ wb..... (7)

Again, flux linkage = flux . (no. of turns)

Here, $d\Phi_x$ links with $\frac{x^2}{r^2}$ fraction of cond.



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Inductance due to Toroid:

- Consider a toroidal core, initially long conductor inserted in air at radius 'r' & carrying a current 'i'.
- Flux linking with conductor has one path.
- The current has $\oint \text{d}l = i$ in the core.
- Current has a presence inside conductor.
- Due to iron core, there is no link with outside conductor but only a leakage flux.
- 漏磁 flux is present around the core.
- Due to iron core, there is more in other conductors in the circuit.
- 漏磁 flux links with the whole core.

107

Inductance due to Internal flux - Internal Inductance (L_{in}):

Inductance due to internal flux measured Inductance (L_{in}):

- The total inductance (per unit length) = $L_{in} = L_{ext}/2$.
- Assumptions:**

 - Let, current path of the source in the core, be axially symmetrical magnetic field is non-uniform.
 - Current distribution is uniform over the area cross-section of the core.
 - Consider a current 'i' in an elemental diameter 'dr' there.
 - Magnetic field intensity at distance 'r' is B_r .

Applying Faraday's law:

$$\text{Rate } \frac{d\Phi}{dt} = \frac{d}{dt} \int_B B_r dA = B_r \frac{d}{dt} \int_A dA = B_r \cdot 2\pi r \cdot dr$$

Where B_r is measured by the graph.

108

Calculation:

Given $I = 100 \text{ A}$

Then current density = $\frac{I}{A} = \frac{100}{\pi r^2} \text{ A/m}^2$

Therefore, $I_r = r \cdot I \cdot \text{current density} = r^2 \cdot \frac{100}{\pi r^2} = \frac{100}{\pi} \text{ A}$

Now, $B_r = \frac{\mu_0 \cdot I_r}{2\pi r} = \frac{\mu_0 \cdot 100}{2\pi r} \text{ T/m}$

Now, flux density = $B_r \cdot \pi r^2 = \frac{\mu_0 \cdot 100 \cdot \pi r^2}{2\pi r} = \frac{\mu_0 \cdot 50 \pi r}{2} \text{ Wb/m}^2$

Where r is permeability of core material. Flux through a cylindrical shell of radius 'r' from the source with thickness dr & the length = $2\pi r$, $d\Phi = B_r \cdot 2\pi r \cdot dr$

Again, flux linkage = $\text{Rate } \frac{d\Phi}{dt} = \frac{d}{dt} \int_B B_r dA = B_r \frac{d}{dt} \int_A dA = B_r \cdot 2\pi r \cdot dr$

Here, $A = \pi r^2$

109

Calculation:

Given $I = 100 \text{ A}$

Then $I_r = \frac{I}{A} = \frac{100}{\pi r^2} \text{ A/m}^2$

Then internal flux linkage = $\int_B B_r dA = \int_B B_r \cdot 2\pi r \cdot dr = \frac{\mu_0 \cdot 50 \pi r}{2} \cdot 2\pi r \cdot dr$

Internal Inductance $L_{in} = \frac{\text{Rate } \frac{d\Phi}{dt}}{\text{Current } I} = \frac{\frac{d}{dt} \int_B B_r dA}{I} = \frac{\frac{d}{dt} \int_B B_r dA}{I}$

If the conductor is suspended in air & conductor material is non-magnetic, then $\mu_r = 1$.

110

Given $I = 100 \text{ A}$

Then $I_r = \frac{I}{A} = \frac{100}{\pi r^2} \text{ A/m}^2$

Because internal inductance of any conductor is independent of wind geometry (axial).

Assumptions:

- Flux lines surrounding the source are in the form of concentric circles.
- Magnetic field intensity at any distance r is $B_r = \frac{\mu_0 \cdot I_r}{2\pi r}$.

The total flux linkage = $\int_B B_r dA = \int_B B_r \cdot 2\pi r \cdot dr = \frac{\mu_0 \cdot 50 \pi r}{2} \cdot 2\pi r \cdot dr$

So, flux linkage up to 'x' = $d\lambda_x = d\Phi_x \cdot \frac{x^2}{r^2} = \mu \cdot i \cdot \frac{x}{2\pi r^2} \cdot dx \cdot \frac{x^2}{r^2}$

$$= \mu \cdot i \cdot \frac{x^3}{2\pi r^4} \cdot dx \text{ wbT/m} \dots\dots\dots (8)$$

Total internal flux linkage = $\int_0^r d\lambda_x = \int_0^r \mu \cdot i \cdot \frac{x^3}{2\pi r^4} \cdot dx$

$$= \frac{\mu \cdot i}{2\pi r^4} \cdot \frac{r^4}{4} = \frac{\mu \cdot i}{8\pi} \text{ wbT/m} \dots\dots\dots (9)$$

Internal inductance $L_{in} = \frac{\text{Total internal flux linkage}}{\text{Current}}$

$$= \frac{\mu \cdot i}{8\pi} = \frac{\mu}{8\pi} = \frac{\mu_0 \cdot \mu_r}{8\pi} \text{ H/m} \dots\dots\dots (10)$$

If the conductor is suspended in air & conductor material is non-magnetic, then $\mu_r = 1$.

Hence, internal inductance of any conductor is independent of cond. geometry (radius).

External Inductance

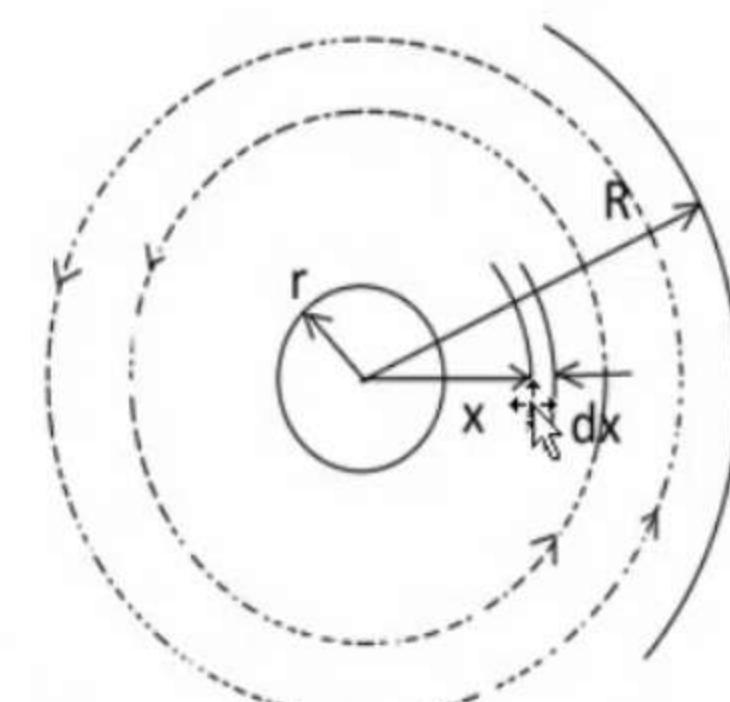
- Flux lines surrounding the cond. are in the form of concentric circles

Magnetic field intensity at any distance

$$\text{Flux density } B_x = \mu_0 \cdot H_x = \frac{\mu_0 \cdot i}{2\pi x} \text{ wb/m}^2$$

Flux through the cylindrical shell of thickness 'dx' & length of

$$l_m = d\Phi_x = B_x \cdot (dx \cdot l) = \frac{\mu_0 \cdot i}{2\pi x} \cdot dx \quad \dots \dots \dots \quad (13)$$



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This flux links with the whole conductor. So, flux linkage

$$d\lambda_x = d\Phi_x \cdot l = d\Phi_x = \frac{\mu_0 \cdot i}{2\pi x} \cdot dx \text{ wbT/m} \dots (14)$$

Therefore, total external flux linkage up to any very large but finite distance 'R' = $\int_r^R d\lambda_x = \int_r^R \frac{\mu_0 \cdot i}{2\pi x} \cdot dx = \frac{\mu_0 \cdot i}{2\pi} \cdot \ln \frac{R}{r} \text{ wbT/m} \dots (15)$

Then, external inductance $L_{ex} = \frac{\text{Total external flux linkage}}{\text{Current}}$

$$= \frac{\mu_0}{2\pi} \cdot \ln \frac{R}{r} \text{ H/m} = \frac{4\pi \cdot 10^{-7}}{2\pi} = 2 \cdot 10^{-7} \cdot \ln \frac{R}{r} \text{ H/m} \dots (16)$$

So, total inductance of the cond. per metre = $L = L_{in} + L_{ex}$

$$= \frac{1}{2} \cdot 10^{-7} + 2 \cdot 10^{-7} \cdot \ln \frac{R}{r} \text{ H/m} \dots (17)$$

Simplifying, $L = 2 \cdot 10^{-7} \cdot \ln \frac{R}{r'} \text{ H/m} \dots (18)$

where $r' = r \cdot e^{-\frac{1}{4}} = 0.7788 \cdot r$ = equivalent radius of cond.

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Flux Linkage in a Group of Conductors

- Consider a group of 'n' long, parallel & round conductors a, b, c,n.
- Carrying currents $I_a, I_b, I_c, \dots, I_n$.
- Forming a circuit, i.e.
 $I_a + I_b + I_c + \dots + I_n = 0$
- Distances $D_{ab}, D_{bc}, D_{ca}, \dots, D_{an}$ etc. are large compared to the radii of the conductors $r_a, r_b, r_c, \dots, r_n$ etc.
- Current distribution is uniform over the cross sectional area.
- The system is unaffected by external fields.

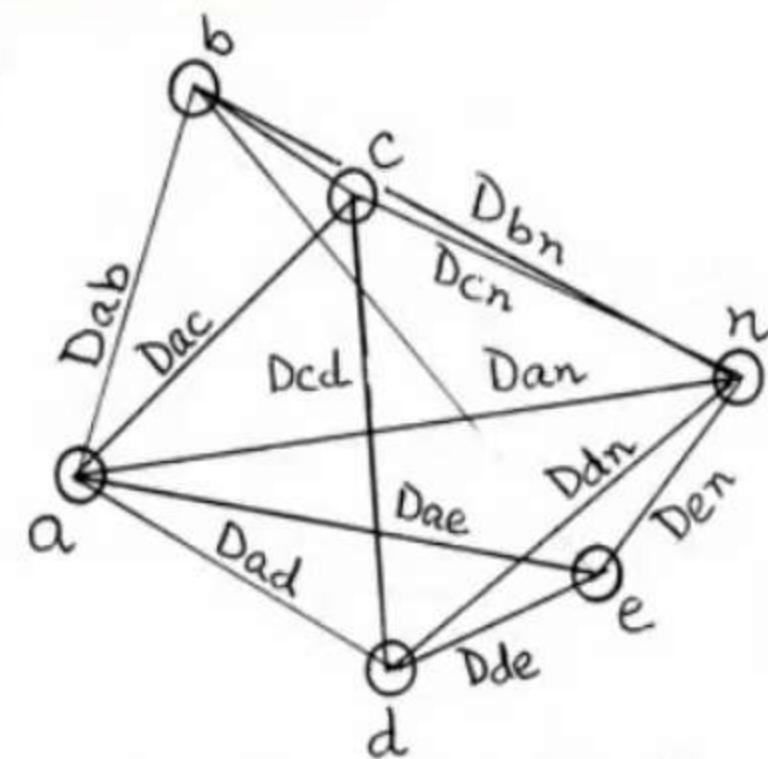


Fig. n-parallel conductors

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111

The two lines with the width a and b have length D .
 $\therefore I_a = I_b = I \Rightarrow I_a = I_b = \frac{1}{2} I$
 Therefore, total current linkage up to any very large distance D is $I_a + I_b = I$
 Total inductance $L = \frac{I^2}{2\pi \mu_0 D}$
 Then mutual inductance $M = \frac{I_a I_b}{2\pi \mu_0 D}$
 $\therefore M = \frac{I^2}{2\pi \mu_0 D}$
 Mutual inductance of the two conductors $= L_a + L_b + M$
 $\therefore L_{ab} = 2L_a + 2M = 2L_a + 2L_b$
 Length of each conductor $= D$

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Inductance in a Group of Conductors

- Consider a group of n long parallel conductors.
- Current contribution in x direction
- Carrying conductor x : I_x
- Neighboring conductors $x+1, x+2, \dots, n$
- Distance between x and $x+1$ is D_{ax}
- Distance between x and $x+2$ is D_{ax+1}
- Distance between x and n is D_{an}
- Flux linkage due to x in $x+1, x+2, \dots, n$ is $\lambda_{x+1}, \lambda_{x+2}, \dots, \lambda_n$ respectively.
- Sum of flux linkages in $x+1, x+2, \dots, n$ is $\sum_{x+1}^n \lambda_x$.
- Current distribution is uniform over the areas enclosed by the conductors.
- The system is confined by external fields.

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The voltage v_a across conductor 'a' may be given as
 $v_a = \int_{a'}^{a''} B_x dx = \int_{a'}^{a''} \frac{\mu_0 I}{2\pi x} dx = \frac{\mu_0 I}{2\pi} \ln \frac{x''}{x'}$
 Inductance of conductor 'a' $= v_a / I_a$
 Similarly, the voltage v_b across conductor 'b' may be given as
 $v_b = \int_{b'}^{b''} B_x dx = \int_{b'}^{b''} \frac{\mu_0 I}{2\pi x} dx = \frac{\mu_0 I}{2\pi} \ln \frac{x''}{x'}$
 Inductance of conductor 'b' $= v_b / I_b$
 Here, $x_{a'}, x_{a''}, x_{b'}, x_{b''}$ are $r_a, r_a + D, r_b, r_b + D$ respectively.

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Inductance of 1Φ Line

The inductance of conductor 'a' is $L_a = \frac{1}{2} \mu_0 I_a^2 / D$
 $\therefore L_a = \frac{1}{2} \mu_0 I_a^2 / (2\pi r_a) = \frac{\mu_0 I_a^2}{4\pi r_a}$
 Inductance of conductor 'b' is $L_b = \frac{1}{2} \mu_0 I_b^2 / D$
 $\therefore L_b = \frac{1}{2} \mu_0 I_b^2 / (2\pi r_b) = \frac{\mu_0 I_b^2}{4\pi r_b}$
 \therefore Total inductance $L_{ab} = L_a + L_b = \frac{1}{2} \mu_0 (I_a^2 + I_b^2) / D$

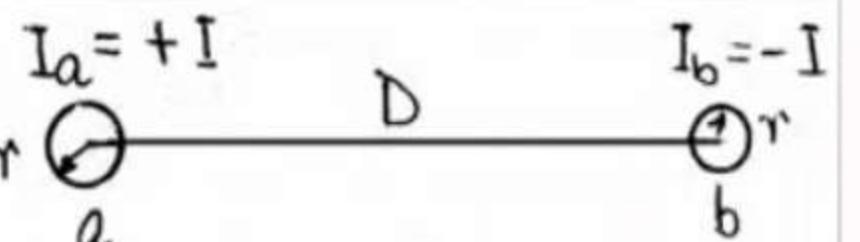
115

Inductance of 2Φ Line

Opposite sides of the triangle carry same current in the same direction.
 Opposite sides of the triangle carry same current in the opposite direction.
 Flux linkage of conductor 'a' is $v_a = \int_{a'}^{a''} B_x dx = \int_{a'}^{a''} \frac{\mu_0 I}{2\pi x} dx = \frac{\mu_0 I}{2\pi} \ln \frac{x''}{x'}$

Inductance of 1Φ Line

Flux linkage of conductor 'a' = λ_a



$$= 2 \cdot 10^{-7} \sum_{x=a}^b I_x \cdot \ln \frac{1}{D_{ax}} = 2 \cdot 10^{-7} \left[I_a \ln \frac{1}{D_{aa}} + I_b \ln \frac{1}{D_{ab}} \right]$$

$$= 2 \cdot 10^{-7} \left[I_a \ln \frac{1}{r_a} - I_b \ln \frac{1}{D} \right] = 2 \cdot 10^{-7} I_a \ln \frac{D}{r_a} \text{ wbT/m}$$

$$\text{Inductance of conductor 'a'} = L_a = \frac{\lambda_a}{I_a} = \frac{2 \cdot 10^{-7} I_a \ln \frac{D}{r_a}}{I_a} \text{ H/m}$$

Similarly, inductance of conductor 'b'

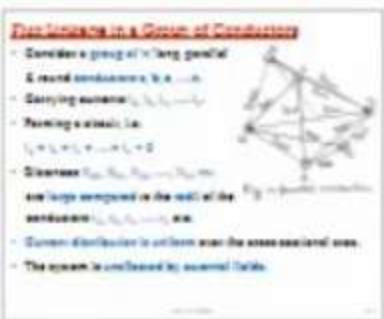
$$= L_b = 2 \cdot 10^{-7} I_b \ln \frac{D}{r_b} \text{ H/m}$$

So, total inductance = L_{ab}

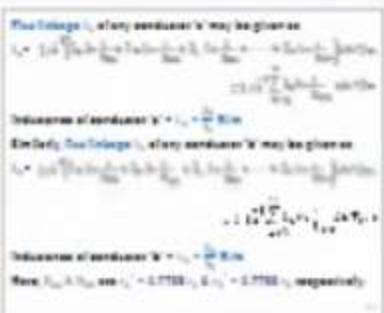
$$= L_a + L_b = 4 \cdot 10^{-7} \cdot \ln \frac{D}{r_a} \text{ H/m}$$

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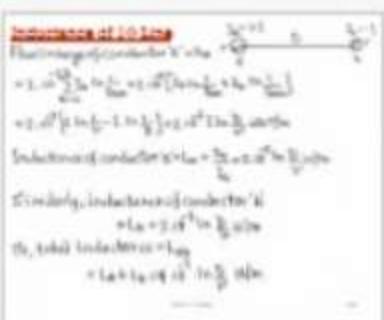
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113



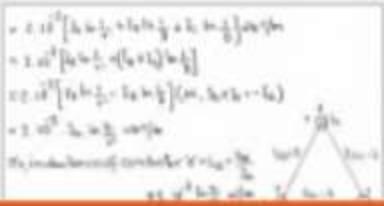
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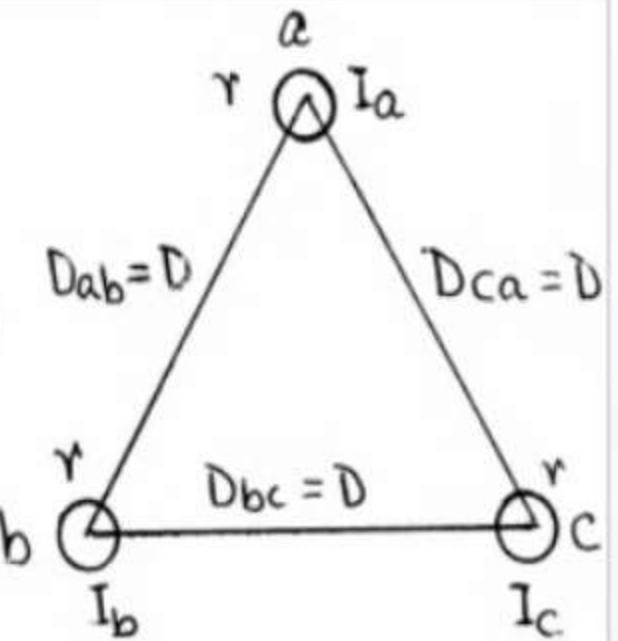


116



Inductance of Symmetrical 3Φ Line

- Symmetrical 3φ line: Conductors placed at corners of an equilateral triangle.
- Arrangement is also known as equilateral spacing.



$$\text{Here, } I_a + I_b + I_c = 0$$

$$r' = 0.7788r$$

Flux linkage of conductor 'a' = λ_a

$$= 2 \cdot 10^{-7} \sum_{x=a}^f I_x \ln \frac{1}{D_{ax}} \text{ wbT/m}$$

$$= 2 \cdot 10^{-7} \left[I_a \ln \frac{1}{D_{aa}} + I_b \ln \frac{1}{D_{ab}} + I_c \ln \frac{1}{D_{ac}} \right] \text{ wbT/m}$$

Forward 5 sec - [00:13:35 / 33%]

113
Flux linkage of every conductor 'a' may be given as
 $\lambda_a = \frac{2\pi r^2}{D} I_a \ln \frac{r}{r'} + \frac{2\pi r^2}{D} I_b \ln \frac{r}{D} + \frac{2\pi r^2}{D} I_c \ln \frac{r}{D}$
Similarly, flux linkage of every conductor 'b' may be given as
 $\lambda_b = \frac{2\pi r^2}{D} I_a \ln \frac{r}{r'} + \frac{2\pi r^2}{D} I_b \ln \frac{r}{D} + \frac{2\pi r^2}{D} I_c \ln \frac{r}{D}$
Inductance of conductor 'a' = $\frac{\lambda_a}{I_a}$
Here, $I_a = I_b = I_c = 0.7788 A$, $r = 0.7788 r'$, respectively.

114
Inductance of conductor 'a'
Flux linkage of conductor 'a' = $\lambda_a = \frac{2\pi r^2}{D} I_a \ln \frac{r}{r'} + \frac{2\pi r^2}{D} I_b \ln \frac{r}{D} + \frac{2\pi r^2}{D} I_c \ln \frac{r}{D}$
 $= 2 \cdot 10^{-7} \left[I_a \ln \frac{1}{r'} + (I_b + I_c) \ln \frac{1}{D} \right]$
Inductance of conductor 'b'
 $\lambda_b = \frac{2\pi r^2}{D} I_a \ln \frac{r}{r'} + \frac{2\pi r^2}{D} I_b \ln \frac{r}{D} + \frac{2\pi r^2}{D} I_c \ln \frac{r}{D}$
Similarly, inductance of conductor 'b'
 $\lambda_b = 2 \cdot 10^{-7} \left[I_a \ln \frac{1}{r'} + (I_b + I_c) \ln \frac{1}{D} \right]$
Total inductance = $L_a + L_b = 2 \cdot 10^{-7} \left[2I_a \ln \frac{1}{r'} + 2(I_b + I_c) \ln \frac{1}{D} \right]$

115
Inductance of conductor 'a'
Flux linkage of conductor 'a' = $\lambda_a = \frac{2\pi r^2}{D} I_a \ln \frac{r}{r'} + \frac{2\pi r^2}{D} I_b \ln \frac{r}{D} + \frac{2\pi r^2}{D} I_c \ln \frac{r}{D}$
 $= 2 \cdot 10^{-7} \left[I_a \ln \frac{1}{r'} + (I_b + I_c) \ln \frac{1}{D} \right]$
Inductance of conductor 'b'
 $\lambda_b = \frac{2\pi r^2}{D} I_a \ln \frac{r}{r'} + \frac{2\pi r^2}{D} I_b \ln \frac{r}{D} + \frac{2\pi r^2}{D} I_c \ln \frac{r}{D}$
 $= 2 \cdot 10^{-7} \left[(I_a + I_b) \ln \frac{1}{r'} + I_c \ln \frac{1}{D} \right]$

116
Flux linkage of conductor 'c'
 $\lambda_c = \frac{2\pi r^2}{D} I_c \ln \frac{r}{r'} + \frac{2\pi r^2}{D} I_a \ln \frac{r}{D} + \frac{2\pi r^2}{D} I_b \ln \frac{r}{D}$
 $= 2 \cdot 10^{-7} \left[I_c \ln \frac{1}{r'} + (I_a + I_b) \ln \frac{1}{D} \right]$

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Inductance of conductor 'a'
 $L_a = \frac{\lambda_a}{I_a} = \frac{2 \cdot 10^{-7} \left[I_a \ln \frac{1}{r'} + (I_b + I_c) \ln \frac{1}{D} \right]}{I_a} = 2 \cdot 10^{-7} \left[\ln \frac{1}{r'} + \frac{(I_b + I_c)}{I_a} \ln \frac{1}{D} \right]$
Inductance of conductor 'b'
 $L_b = \frac{\lambda_b}{I_b} = \frac{2 \cdot 10^{-7} \left[(I_a + I_b) \ln \frac{1}{r'} + I_c \ln \frac{1}{D} \right]}{I_b} = 2 \cdot 10^{-7} \left[\frac{(I_a + I_b)}{I_b} \ln \frac{1}{r'} + \ln \frac{1}{D} \right]$

$$\begin{aligned} &= 2 \cdot 10^{-7} \left[I_a \ln \frac{1}{r'} + I_b \ln \frac{1}{D} + I_c \ln \frac{1}{D} \right] \text{ wbT/m} \\ &= 2 \cdot 10^{-7} \left[I_a \ln \frac{1}{r'} + (I_b + I_c) \ln \frac{1}{D} \right] \\ &= 2 \cdot 10^{-7} \left[I_a \ln \frac{1}{r'} - I_a \ln \frac{1}{D} \right] \quad (\text{as, } I_b + I_c = -I_a) \\ &= 2 \cdot 10^{-7} \cdot I_a \cdot \ln \frac{D}{r'} \text{ wbT/m} \end{aligned}$$

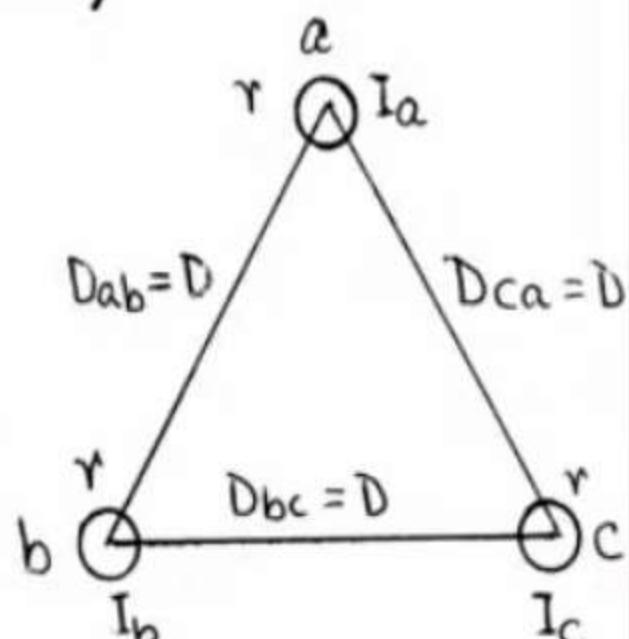
So, inductance of conductor 'a' = $L_a = \frac{\lambda_a}{I_a}$

$$= 2 \cdot 10^{-7} \ln \frac{D}{r'} \text{ H/m}$$

Again, flux linkage of conductor 'b' = λ_b

$$= 2 \cdot 10^{-7} \sum_{x=b}^c I_x \cdot \ln \frac{1}{D_{bx}} \text{ wbT/m}$$

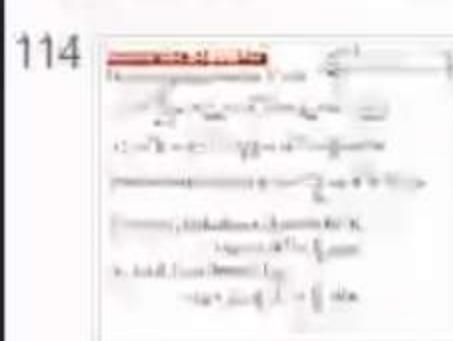
$$= 2 \cdot 10^{-7} \left[I_b \ln \frac{1}{D_{bb}} + I_a \ln \frac{1}{D_{ba}} + I_c \ln \frac{1}{D_{bc}} \right]$$



Here, $I_a + I_b + I_c = 0$

$$r' = 0.7788 r$$

Forward 5 sec - [00:15:35 / 38%]



$$= 2 \cdot 10^{-7} \left[I_b \ln \frac{1}{r_1} + (I_a + I_c) \ln \frac{1}{D} \right]$$

$$= 2 \cdot 10^{-7} \left[I_b \ln \frac{1}{r_1} - I_{\frac{a+c}{2}} \ln \frac{1}{D} \right]$$

$$= 2 \cdot 10^{-7} I_b \cdot \ln \frac{D}{r_1} \text{ WbT/m}$$

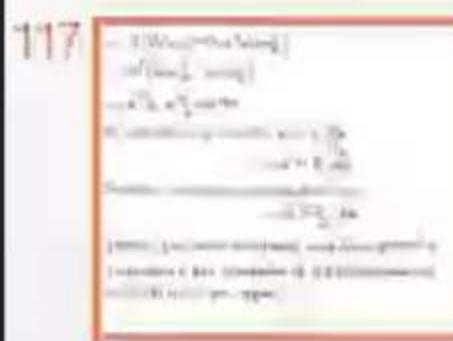
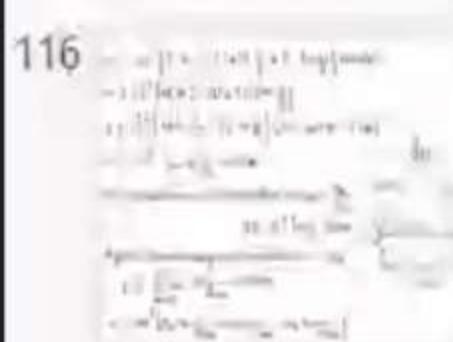
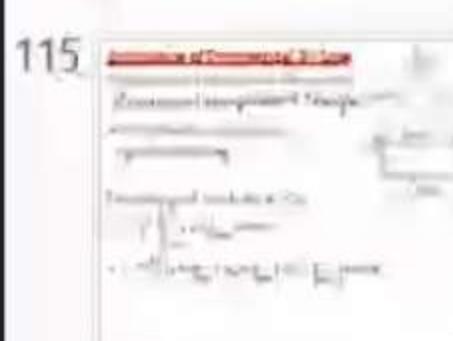
So, inductance of conductor 'b' = $L_b = \frac{\lambda_b}{I_b}$

$$= 2 \cdot 10^{-7} \ln \frac{D}{r_1} \text{ H/m}$$

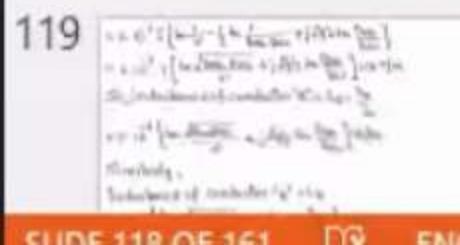
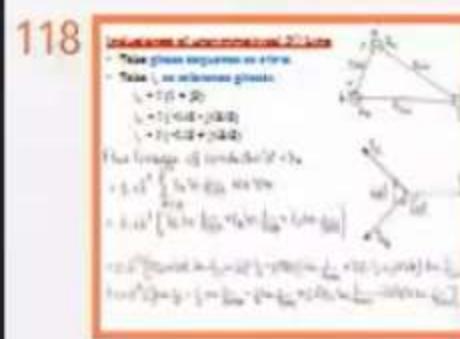
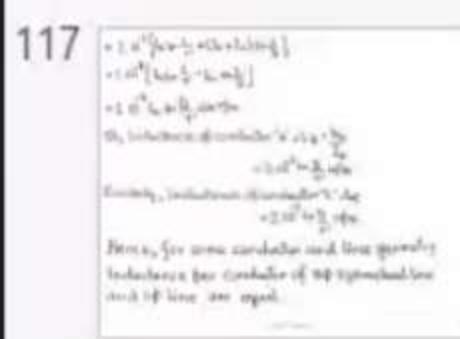
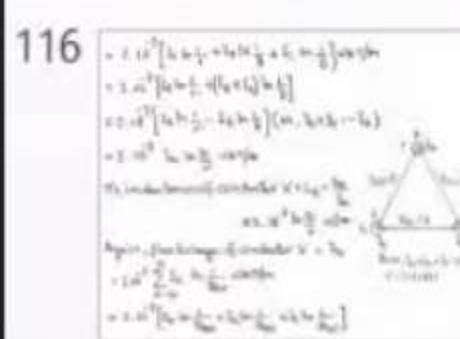
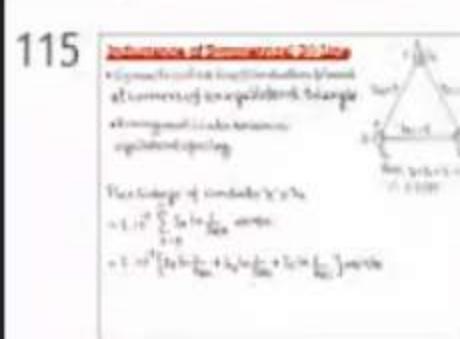
Similarly, inductance of conductor 'c' = L_c

$$= 2 \cdot 10^{-7} \ln \frac{D}{r_1} \text{ H/m}$$

Hence, for same conductor and line geometry
inductance per conductor of 3φ symmetrical line
and 1φ line are equal.



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Inductance of unsymmetrical 3Φ Line

- Take phase sequence as a-b-c.
- Take I_a as reference phasor.

$$I_a = I(1 + j0)$$

$$I_b = I(-\frac{1}{2} - j\frac{\sqrt{3}}{2})$$

$$I_c = I(-\frac{1}{2} + j\frac{\sqrt{3}}{2})$$

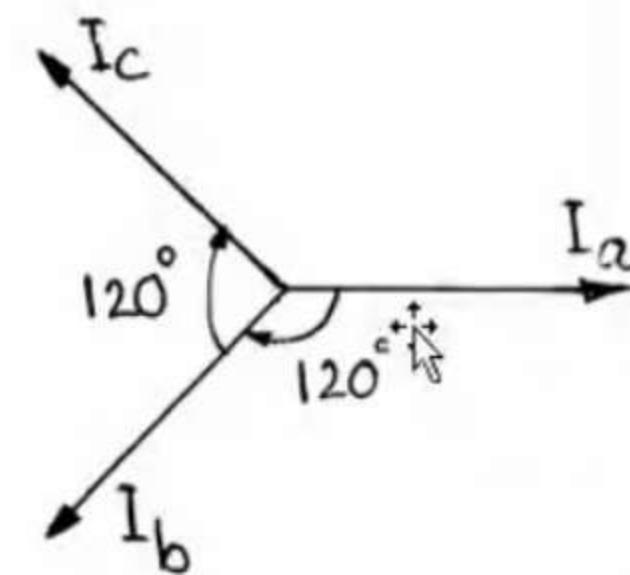
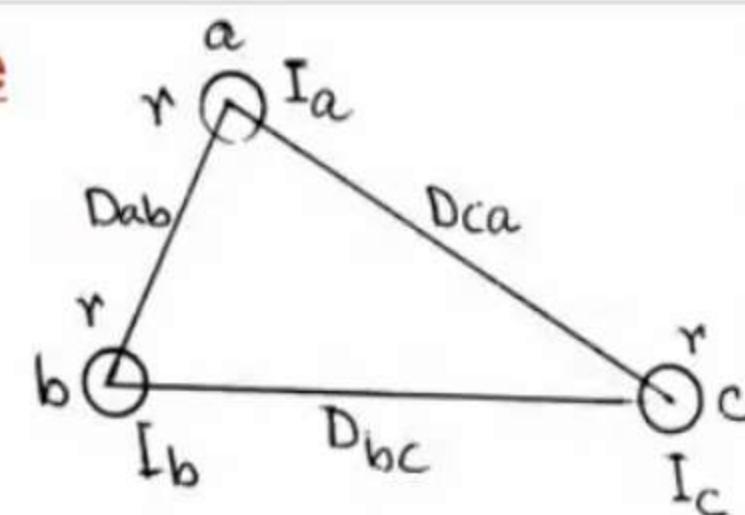
Flux linkage of conductor 'a' = λ_a

$$= 2 \cdot 10^{-7} \sum_{x=a}^c I_x \ln \frac{1}{D_{ax}} \text{ Wb T/m}$$

$$= 2 \cdot 10^{-7} \left[I_a \ln \frac{1}{D_{aa}} + I_b \ln \frac{1}{D_{ab}} + I_c \ln \frac{1}{D_{ac}} \right]$$

$$= 2 \cdot 10^{-7} \left[I(1+j0) \ln \frac{1}{r}, + I(-\frac{1}{2} - j\frac{\sqrt{3}}{2}) \ln \frac{1}{D_{ab}}, + I(-\frac{1}{2} + j\frac{\sqrt{3}}{2}) \ln \frac{1}{D_{ac}} \right]$$

$$= 2 \cdot 10^{-7} \cdot I \left[\ln \frac{1}{r}, - \frac{1}{2} \ln \frac{1}{D_{ab}} - \frac{1}{2} \ln \frac{1}{D_{ac}} + j\frac{\sqrt{3}}{2} \ln \frac{1}{D_{ac}} - j\frac{\sqrt{3}}{2} \ln \frac{1}{D_{ab}} \right]$$



Forward 5 sec - [00:21:55 / 53%]

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$\Rightarrow I_a^2 \left[\ln \frac{1}{r'} + \ln \frac{1}{D_{ab}} + \ln \frac{1}{D_{ac}} + j\sqrt{3}/2 \ln \frac{D_{ab}}{D_{ac}} \right]$

$\Rightarrow I_a^2 \left[\ln \frac{1}{r'} + \ln \frac{1}{D_{ab}} + \ln \frac{1}{D_{ac}} \right] + j\sqrt{3}/2 \ln \frac{D_{ab}}{D_{ac}}$

$\Rightarrow I_a^2 \left[\ln \frac{1}{r'} + \ln \frac{\sqrt{D_{ab} D_{ac}}}{r'} + j\sqrt{3}/2 \ln \frac{D_{ab}}{D_{ac}} \right]$

Applying formula of conductor 'a' $\Rightarrow I_a = \frac{\lambda_a}{L_a}$

$\Rightarrow I_a^2 \left[\ln \frac{\sqrt{D_{ab} D_{ac}}}{r'} + j\sqrt{3}/2 \ln \frac{D_{ab}}{D_{ac}} \right] = \frac{\lambda_a^2}{L_a^2}$

$\Rightarrow I_a^2 \left[\ln \frac{\sqrt{D_{ab} D_{ac}}}{r'} + j\sqrt{3}/2 \ln \frac{D_{ab}}{D_{ac}} \right] = \frac{\lambda_a^2}{I_a^2}$

$$= 2 \cdot 10^{-7} I \left[\ln \frac{1}{r'} - \frac{1}{2} \ln \frac{1}{D_{ab} \cdot D_{ac}} + j\sqrt{3}/2 \ln \frac{D_{ab}}{D_{ac}} \right]$$

$$= 2 \cdot 10^{-7} \cdot I \left[\ln \frac{\sqrt{D_{ab} \cdot D_{ac}}}{r'} + j\sqrt{3}/2 \ln \frac{D_{ab}}{D_{ac}} \right] \text{wbT/m}$$

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\Rightarrow So, inductance of conductor 'a' $= L_a = \frac{\lambda_a}{I_a}$

Bence, for same conductor and line geometry
Inductance per conductor of 3Ø symmetrical
and 1Ø line are equal.

$$\Rightarrow$$
 So, inductance of conductor 'a' $= L_a = \frac{\lambda_a}{I_a}$

$$= 2 \cdot 10^{-7} \left[\ln \frac{\sqrt{D_{ab} D_{ac}}}{r'} + j\sqrt{3}/2 \ln \frac{D_{ab}}{D_{ac}} \right] \text{H/m}$$

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\Rightarrow Similarly,

Inductance of conductor 'b' $= L_b$

$\Rightarrow L_b = 2 \cdot 10^{-7} \left[\ln \frac{\sqrt{D_{bc} D_{ba}}}{r'} + j\sqrt{3}/2 \ln \frac{D_{bc}}{D_{ba}} \right] \text{H/m}$

$$\Rightarrow$$
 Similarly,
Inductance of conductor 'b' $= L_b$

$$= 2 \cdot 10^{-7} \left[\ln \frac{\sqrt{D_{bc} D_{ba}}}{r'} + j\sqrt{3}/2 \ln \frac{D_{bc}}{D_{ba}} \right] \text{H/m}$$

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\Rightarrow Inductance of conductor 'c' $= L_c$

$\Rightarrow L_c = 2 \cdot 10^{-7} \left[\ln \frac{\sqrt{D_{ca} D_{cb}}}{r'} + j\sqrt{3}/2 \ln \frac{D_{cb}}{D_{ca}} \right] \text{H/m}$

$$\Rightarrow$$
 Inductance of conductor 'c' $= L_c$

$$= 2 \cdot 10^{-7} \left[\ln \frac{\sqrt{D_{ca} D_{cb}}}{r'} + j\sqrt{3}/2 \ln \frac{D_{cb}}{D_{ca}} \right] \text{H/m}$$

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\Rightarrow Summary:
- Inductances of the three phases are unequal.
- Although asymmetries between inductances are unimportant.
- Inductance voltage diagram is unequal.
- Inductances are unequal as $I_a > I_b > I_c$ and not in phase with I_a, I_b, I_c respectively.
- Due to the inhomogeneity per phase consider skin effect per phase.

Forward 5 sec - [00:26:15 / 64%]

117

118

119

120

- Inductances of the three phases are unequal.
- Although currents are balanced, inductances are unbalanced.
- Inductive voltage drops are unequal.
- Inductances are complex as $\lambda_a, \lambda_b & \lambda_c$ are not in phase with $I_a, I_b & I_c$ respectively.
- Due to the imaginary part power transfer takes amongst the phases by mutual induction.
- However, total power transfer in any case is zero.

121

❖ Points to note -

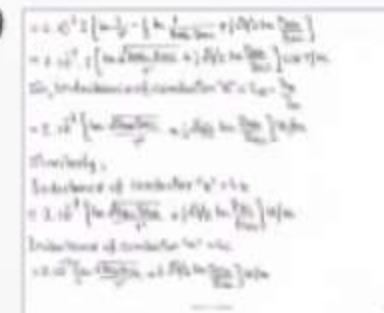
- Inductances of the three phases are **unequal**.
- Although **currents** are **balanced**, **inductances** are **unbalanced**.
- **Inductive voltage drops** are **unequal**.
- Inductances are complex as $\lambda_a, \lambda_b & \lambda_c$ are not in phase with $I_a, I_b & I_c$ respectively.
- Due to the **imaginary part power transfer** takes amongst the phases **by mutual induction**.
- However, **total power transfer in any case is zero**.

Backward 5 sec-[00:28:35 / 69%]

118



119



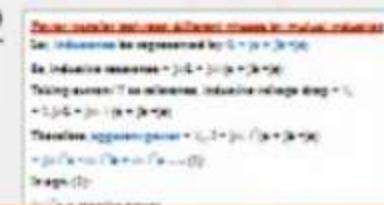
120



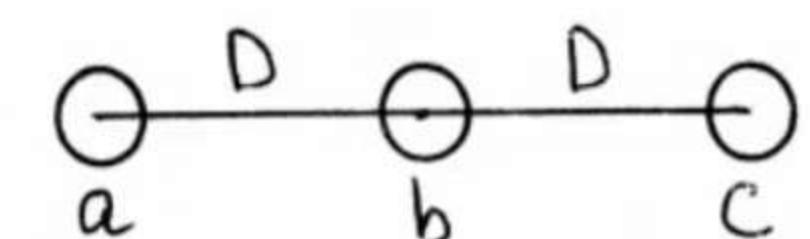
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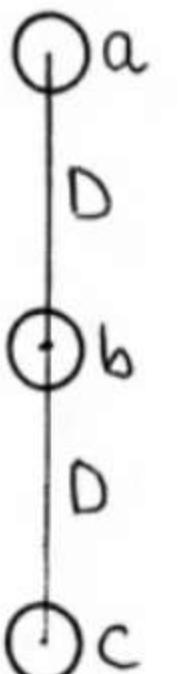
122



Determine Inductances of the following 3φ systems.



Horizontal spacing



I

Vertical spacing

Forward 5 sec - [00:28:45 / 70%]

119

Inductance of three phases are unequal.
Although currents are balanced, inductances are unbalanced.
Inductive voltage drops are unequal.
Inductances are negligible (L_1, L_2, L_3) are not in phase with
 I_1, I_2, I_3 respectively.
Due to the inductive power received from other phases by mutual induction.
Increase real power received by any phase to zero.

120

Balance current

- Inductances of the three phases are unequal.
- Although currents are balanced, inductances are unbalanced.
- Inductive voltage drops are unequal.
- Inductances are negligible (L_1, L_2, L_3) are not in phase with I_1, I_2, I_3 respectively.
- Due to the inductive power received from other phases by mutual induction.
- Increase real power received by any phase to zero.

121

Determine inductances of the following 3-phase systems.

122

Power received from other phases by mutual induction

Inductance is represented by $L = (a + jb - jc)$

Inductive reactance = $j\omega L = j\omega (a + jb - jc)$

Inductive voltage drop = $\frac{V_L}{I} = j\omega L \cdot I = j\omega (a + jb - jc) \cdot I$

Therefore, apparent power = $V_L \cdot I = j\omega \cdot I^2 (a + jb - jc)$

= $j\omega I^2 a - \omega I^2 b + \omega I^2 c$ (1)

123

Decomposition of the transmission losses

- Unsymmetrical coupling of the conductors is more common.
- Inductance is unbalance & unbalance at design & energization.
- Increases unbalanced coupling of conductive lines.
- Unbalanced inductances have unequal inductive reactances of the three phases.
- If the inductive voltage drops are unequal in the three phases, the balance current is zero.

Power transfer between different phases by mutual induction

Let, inductance be represented by: $L = (a + jb - jc)$

So, inductive reactance = $j\omega L = j\omega (a + jb - jc)$

Taking current 'I' as reference, inductive voltage drop = V_L

$$= I \cdot j\omega L = j\omega \cdot I (a + jb - jc)$$

Therefore, apparent power = $V_L \cdot I = j\omega \cdot I^2 (a + jb - jc)$

$$= j\omega I^2 a - \omega I^2 b + \omega I^2 c \quad \dots \dots (1)$$

In eqn. (1):

$j\omega I^2 a$ = reactive power.

$-\omega I^2 b$ = negative active power = power received from other phases by mutual induction.

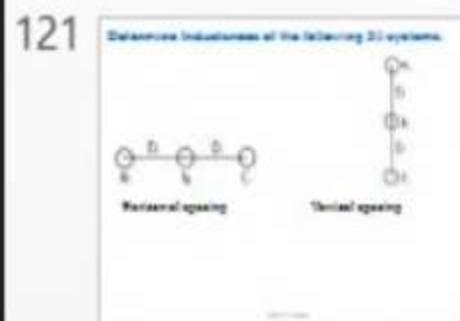
$+\omega I^2 c$ = positive active power = power supplied to other phases by mutual induction.

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Transposition of Transmission Lines

- Unsymmetrical spacing of line conductors is more common.
- It is due to cheapness & convenience of design & construction.
- However, unsymmetrical spacing of conductors makes -
 - (i) **Unequal inductances**, hence unequal inductive reactances of the three phases.
 - (ii) So, **inductive voltage drops** are **unequal** in the three phases for balance currents.
 - (iii) So, although the sending end voltages are balance, **receiving end voltages are unbalanced**.
 - (iv) Further, **disturbance/interference** takes place **with** the near by communication lines.



122

Given three-phase transmission line system
Line inductance per phase $= j(0.1 + j0.05)$
Per phase inductance $= j(0.1 + j0.05)$
Total inductance $= j(0.1 + j0.05) + j(0.1 + j0.05) + j(0.1 + j0.05)$
Total inductance $= j(0.3 + j0.15)$
Reactance $= j0.15$
 $j0.15$ = negative active power = power received from other phases by mutual induction.
 $+j0.15$ = positive active power = power supplied to other phases by mutual induction.

123

Transposition of Transmission Lines

- Unsymmetrical spacing of line conductors is more common.
- It is due to cheapness & convenience of design & construction.
- However, unsymmetrical spacing of conductors makes -
 - (i) **Unequal inductances**, hence unequal inductive reactances of the three phases.
 - (ii) **Inductive voltage drops are unequal** in the three phases for balance currents.
 - (iii) So, although the sending end voltages are balance, **receiving end voltages are unbalanced**.
 - (iv) Further, **disturbance/interference** takes place **with** the near by communication lines.

124

- These problems can be avoided by interchange of transmission line conductors.
- In unsymmetrical 3-phase lines all three conductors occupy positions of other phase conductors for three-seventh depth.

Backward 5 sec-[00:37:15 / 90%]

121 Determination of induced currents in three phases.

122 Determination of induced currents in three phases.

Induced currents in three phases due to mutual induction:

$$\text{Induced current in phase } A = \mu_0 \cdot I_A \cdot \frac{1}{2} \cdot \left(\frac{1}{R_1} + \frac{1}{R_2} \right) \cdot \left(\frac{1}{2\pi R_1} + \frac{1}{2\pi R_2} \right)$$

$$\text{Induced current in phase } B = \mu_0 \cdot I_B \cdot \frac{1}{2} \cdot \left(\frac{1}{R_1} + \frac{1}{R_2} \right) \cdot \left(\frac{1}{2\pi R_1} + \frac{1}{2\pi R_2} \right)$$

$$\text{Induced current in phase } C = \mu_0 \cdot I_C \cdot \frac{1}{2} \cdot \left(\frac{1}{R_1} + \frac{1}{R_2} \right) \cdot \left(\frac{1}{2\pi R_1} + \frac{1}{2\pi R_2} \right)$$

Definitions:

- μ_0 = magnetic permeability of free space
- I_A, I_B, I_C = currents in three phases
- R_1, R_2 = radii of conductors
- π = ratio of circumference to diameter

123 Decomposition of Transmission Lines

- Shaded mutual coupling of three conductors is same.
- Due to shuntless 2 resistances at design & determination.
- Because symmetrical coupling of conductors makes:

 - Shunt inductances same except inductive reactance of the three phases.
 - The induced voltage drops are equal in the three phases for balanced currents.
 - Although the sending and receiving end voltages are balanced, receiving end voltage is unbalanced.
 - Fluxes also do not have same phase with the same by commutation time.

124 These problems can be avoided/reduced by transposition of transmission line conductors.

In transposed 3 Φ transmission lines all phase conductors occupy positions of other phase conductors for almost same length.

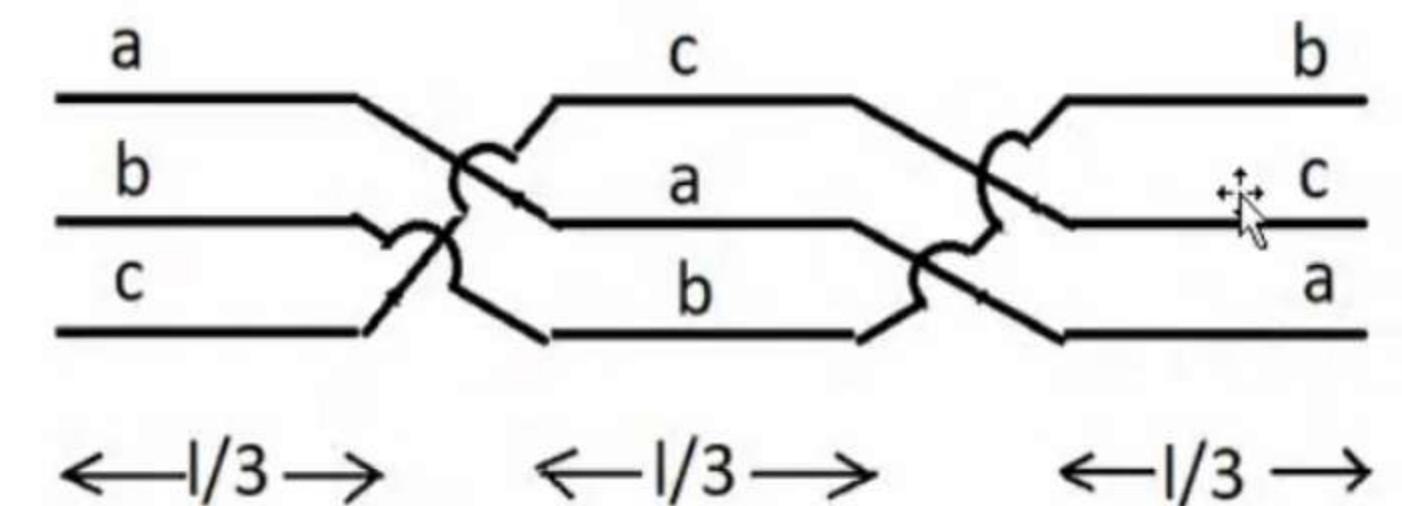
125 Induction of currents in three phases due to mutual induction:

$$\text{Induced current in phase } A = \mu_0 \cdot I_A \cdot \frac{1}{2} \cdot \left(\frac{1}{R_1} + \frac{1}{R_2} \right) \cdot \left(\frac{1}{2\pi R_1} + \frac{1}{2\pi R_2} \right)$$

$$\text{Induced current in phase } B = \mu_0 \cdot I_B \cdot \frac{1}{2} \cdot \left(\frac{1}{R_1} + \frac{1}{R_2} \right) \cdot \left(\frac{1}{2\pi R_1} + \frac{1}{2\pi R_2} \right)$$

$$\text{Induced current in phase } C = \mu_0 \cdot I_C \cdot \frac{1}{2} \cdot \left(\frac{1}{R_1} + \frac{1}{R_2} \right) \cdot \left(\frac{1}{2\pi R_1} + \frac{1}{2\pi R_2} \right)$$

- These problems can be avoided/reduced by transposition of transmission line conductors.
- In transposed 3 Φ transmission lines all phase conductors occupy positions of other phase conductors for almost same length.



Forward 5 sec - [00:37:25 / 91%]

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Inductance of conductor 'a' = L_a

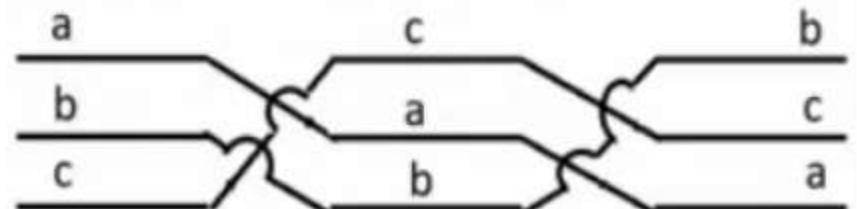
$$= \frac{1}{3} [\text{Inductance for first } \frac{1}{3} \text{rd length} + \text{Inductance for second } \frac{1}{3} \text{rd length} + \text{Inductance for third } \frac{1}{3} \text{rd length}]$$

$$= \frac{2 \cdot 10^{-7}}{3} \left[\ln \frac{\sqrt{D_{ab} \cdot D_{ac}}}{r'} + j \frac{\sqrt{3}}{2} \ln \frac{D_{ab}}{D_{ac}} + \ln \frac{\sqrt{D_{bc} \cdot D_{ba}}}{r'} + j \frac{\sqrt{3}}{2} \ln \frac{D_{bc}}{D_{ba}} + \right. \\ \left. + \ln \frac{\sqrt{D_{ca} \cdot D_{cb}}}{r'} + j \frac{\sqrt{3}}{2} \ln \frac{D_{ca}}{D_{cb}} \right] \text{H/m}$$

$$= \frac{2 \cdot 10^{-7}}{3} \left[\ln \frac{\sqrt{D_{ab}^2 \cdot D_{bc}^2 \cdot D_{ca}^2}}{(r')^3} + j \frac{\sqrt{3}}{2} \ln \frac{D_{ab} \cdot D_{bc} \cdot D_{ca}}{D_{ab} \cdot D_{bc} \cdot D_{ca}} \right]$$

$$= \frac{2 \cdot 10^{-7}}{3} \cdot 3 \cdot \ln \frac{\sqrt{3} \cdot D_{ab} \cdot D_{bc} \cdot D_{ca}}{r'} + j \cdot 0$$

$$\therefore L_a = \frac{2 \cdot 10^{-7} \ln \sqrt{3} \cdot D_{ab} \cdot D_{bc} \cdot D_{ca}}{r'} \text{ H/m} \quad \longleftrightarrow \frac{1}{3} \rightarrow \quad \longleftrightarrow \frac{1}{3} \rightarrow \quad \longleftrightarrow \frac{1}{3} \rightarrow$$



Forward 5 sec - [00:40:05 / 97%]

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123

Decomposition of Transmission Lines

- Dispersed spacing of the conductors in three phases.
- It is due to differences in conductances of the three phases.
- Reverse interconnected spacing of conductors in three phases.
- Due to differences, hence unequal resistive resources of the three phases.
- (i) If inductive voltage drops are equal in the three phases, then losses are minimum.
- (ii) Although the sending end voltages are balanced, receiving end voltages are unbalanced.
- (iii) Further, differences in conductances when placed with the same length of communication lines.

124

These problems can be avoided by reorganization of transmission line conductors.

In organized 3D transmission lines all three conductors occupy positions at which phase conductors form almost same length.

125

Indication of conductors 'N' = 1.

\Rightarrow Indication for first length = Indication for second length = Indication for third length

$$\sqrt[3]{D_{ab} \cdot D_{bc} \cdot D_{ca}} = \sqrt[3]{\frac{D_{ab}}{L_{ab}} \cdot \frac{D_{bc}}{L_{bc}} \cdot \frac{D_{ca}}{L_{ca}}} = \sqrt[3]{\frac{1}{L_{ab}} \cdot \frac{1}{L_{bc}} \cdot \frac{1}{L_{ca}}} = \sqrt[3]{\frac{1}{L_{ab} + L_{bc} + L_{ca}}} = \sqrt[3]{\frac{1}{3L}}$$

126

From above, $N = \sqrt[3]{D_{ab} \cdot D_{bc} \cdot D_{ca}}$

Where, $D_{eq} = \sqrt[3]{D_{ab} \cdot D_{bc} \cdot D_{ca}}$

- = Geometric mean of D_{ab} , D_{bc} & D_{ca}
- = Equivalent delta spacing
- = Equivalent equilateral spacing

127

Indication of transmission lines (3D).

- This method is very convenient & useful in calculating influences of lines having several conductors.
- Influences measured in general for each phase.
- It is applicable to all types of transmission lines.
- Bunched conductor lines.

Similarly, $L_b = L_c = 2 \cdot 10^7 \ln \frac{\sqrt[3]{D_{ab} \cdot D_{bc} \cdot D_{ca}}}{r'} H/m$

$$= 2 \cdot 10^7 \ln \frac{D_{eq}}{r'} H/m$$

Where, $D_{eq} = \sqrt[3]{D_{ab} \cdot D_{bc} \cdot D_{ca}}$

- = Geometric mean of D_{ab} , D_{bc} & D_{ca}
- = Equivalent delta spacing
- = Equivalent equilateral spacing

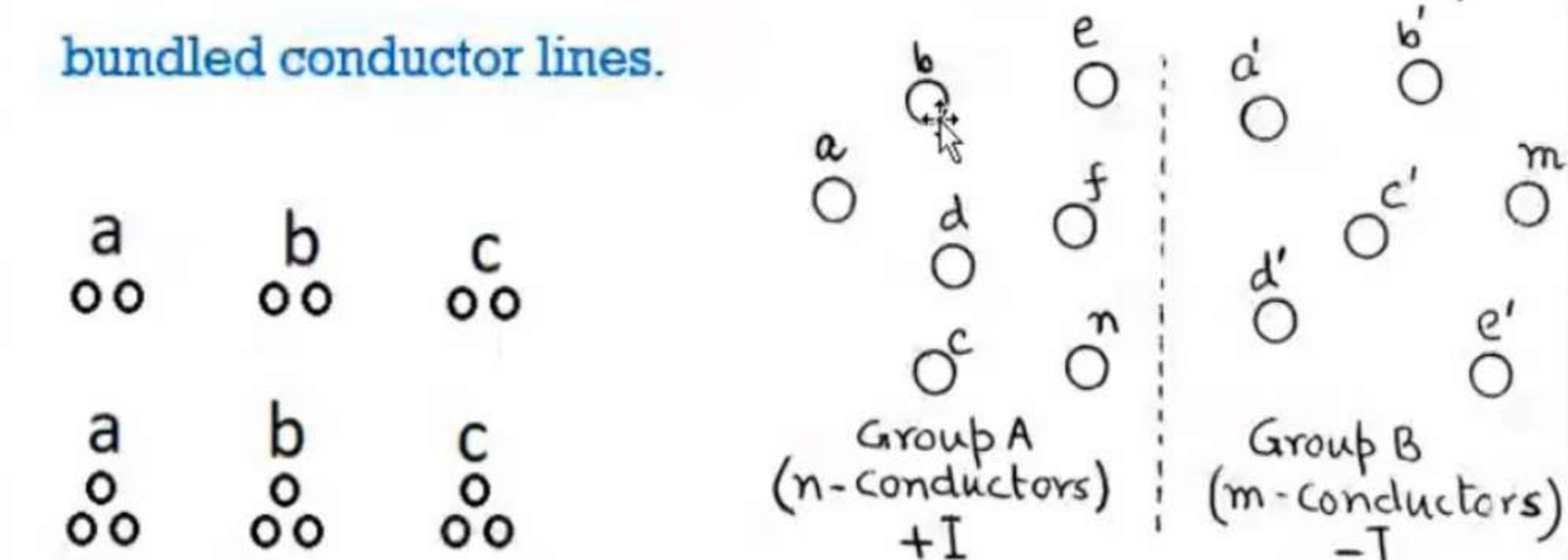
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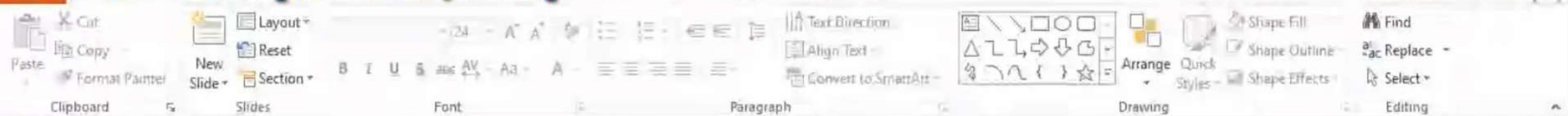
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Method of Geometric Mean Distance (GMD)

- This method is very convenient & useful to calculate inductance of lines, having several conductors connected in parallel for each phase.
- It is applicable to all cases of multi-strand or bundled conductor lines.



Forward 5 sec - [00:16:30 / 47%]



- Consider, a 1φ line with two groups of conductors 'A' & 'B.'
- Group 'A' consists of 'n' straight, round & very long conductors, connected in parallel.
- Total current carried by group 'A' is $+ I$.
- Each conductor in group 'A' carries a current of $+ I/n$.
- Group 'B' consists of 'm' straight, round & very long conductors, connected in parallel.
- Each conductor in group 'B' carries a current of $-I/m$. Then,

Inductance of group A, consisting of 'n' conductors = L_A

$$= 2 \cdot 10^{-7} \ln \frac{[(D_{aa}, D_{ab}, \dots, D_{an}), (D_{ba}, D_{bb}, \dots, D_{bm}), \dots, (D_{na}, D_{nb}, \dots, D_{nm})]}{[(D_{aa}, D_{ab}, \dots, D_{an}), (D_{ba}, D_{bb}, \dots, D_{bn}), \dots, (D_{na}, D_{nb}, \dots, D_{nn})]} \frac{1}{n^2} H/m$$

$$= 2 \cdot 10^{-7} \ln \frac{D_m}{D_s} H/m$$

- Here, $D_{aa}, D_{bb}, \dots, D_{nn}$ → equivalent radius of conductors.

Forward 5 sec - [00:24:11 / 69%]

126

Where,

- $D_m = [(D_{aa}, D_{ab}, \dots, D_{an}), (D_{ba}, D_{bb}, \dots, D_{bn}), \dots, (D_{na}, D_{nb}, \dots, D_{nn})]^{\frac{1}{m \cdot n}}$
= All possible distances ($m \times n$) between conductors of groups A & B for which $(m \times n)^{\text{th}}$ root is taken.
- This geometric mean is called mutual geometric mean distance (Mutual GMD) between conductors of groups A & B.

127

128

- $D_s = [(D_{aa}, D_{ab}, \dots, D_{an}), (D_{ba}, D_{bb}, \dots, D_{bn}), \dots, (D_{na}, D_{nb}, \dots, D_{nn})]^{\frac{1}{n^2}}$
= All possible distances ($n \times n$) between conductors of group A for which $(n \times n = n^2)^{\text{th}}$ root is taken.
- This geometric mean is called self geometric mean distance (Self GMD).

129

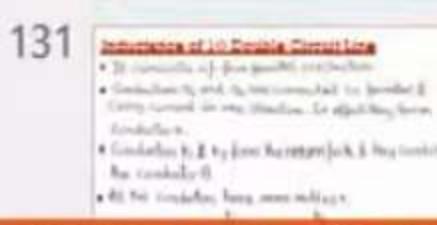
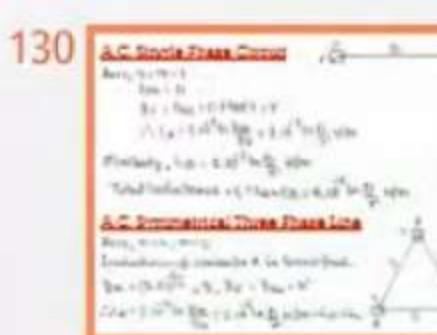
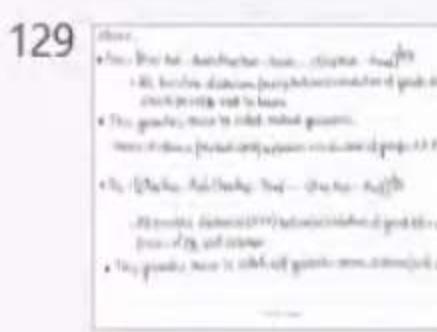
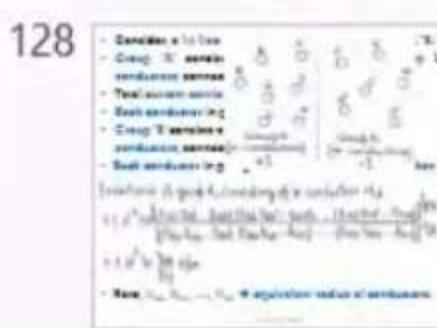
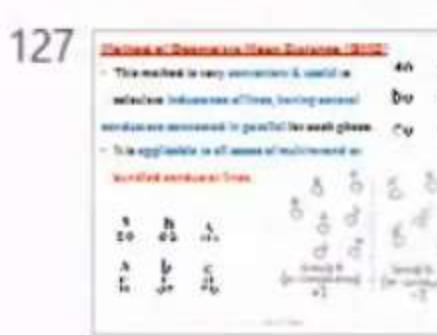
130

Prof. S. S. Thakur

129

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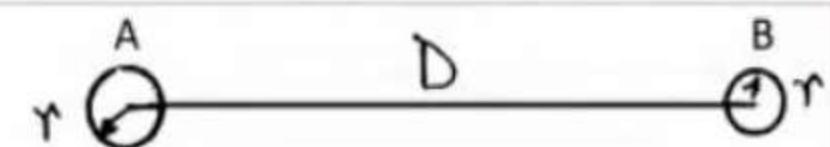
A.C. Single Phase Circuit

Here, $n = m = 1$

$$D_m = D$$

$$D_s = D_{aa} = 0.7788 \gamma = \gamma'$$

$$\therefore L_A = 2 \cdot 10^{-7} \ln \frac{D_m}{D_s} = 2 \cdot 10^{-7} \ln \frac{D}{\gamma'}, \text{ H/m}$$



$$\text{Similarly, } L_B = 2 \cdot 10^{-7} \ln \frac{D}{\gamma'}, \text{ H/m}$$

$$\text{Total inductance } L = L_A + L_B = 4 \cdot 10^{-7} \ln \frac{D}{\gamma'}, \text{ H/m}$$

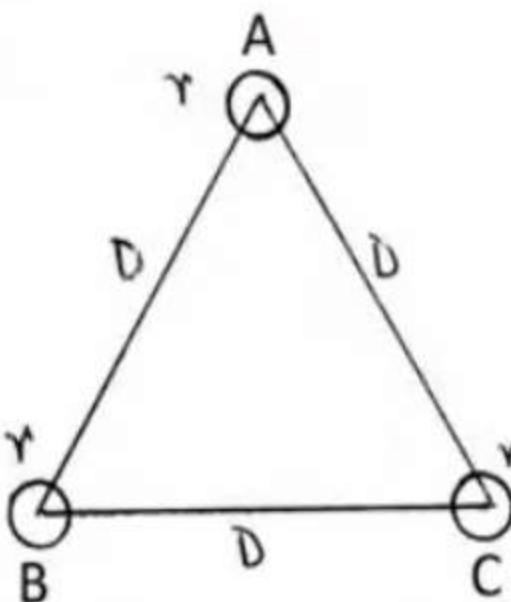
A.C. Symmetrical Three Phase Line

Here, $n = 1, m = 2$

Inductance of conductor A is found first.

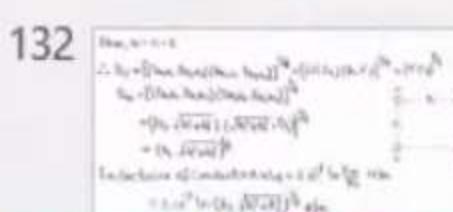
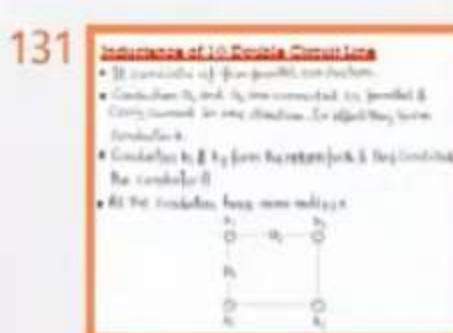
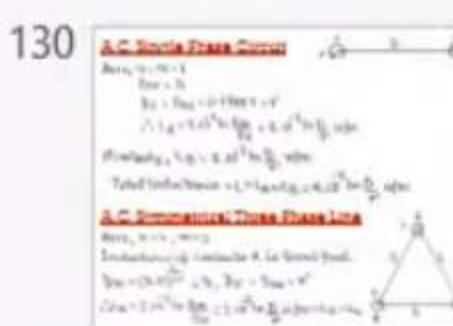
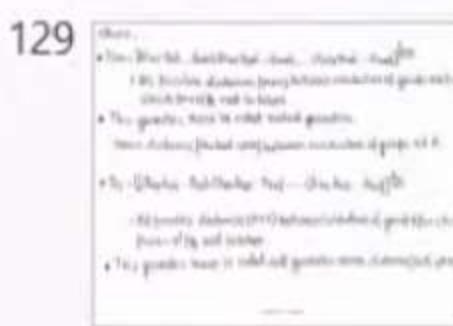
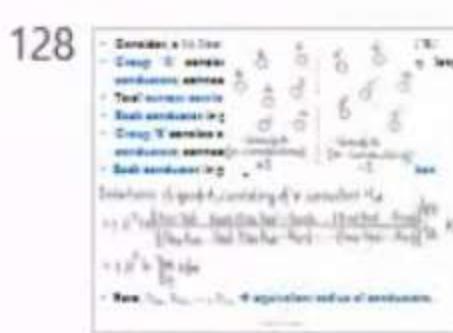
$$D_m = (D \cdot D)^{\frac{1}{2 \cdot 1}} = D, D_s = D_{aa} = \gamma'$$

$$\therefore L_A = 2 \cdot 10^{-7} \ln \frac{D_m}{D_s} = 2 \cdot 10^{-7} \ln \frac{D}{\gamma'} \text{ H/m} = L_B = L_C$$



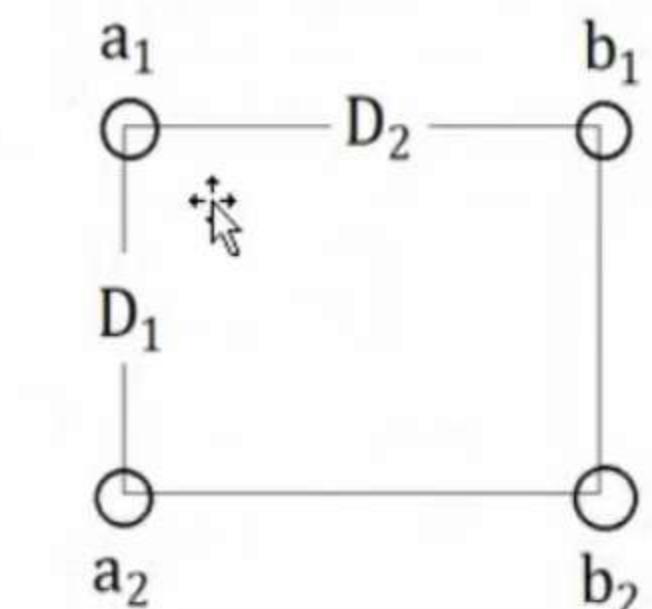
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Inductance of 1Φ Double Circuit Line

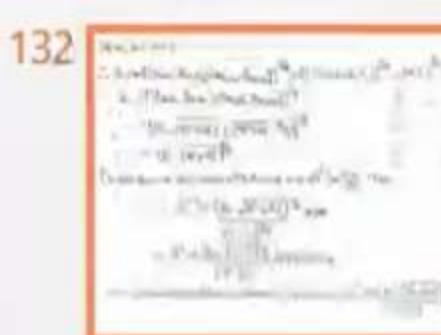
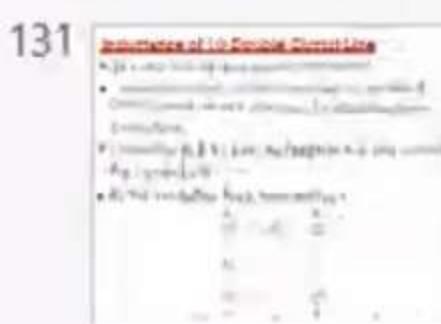
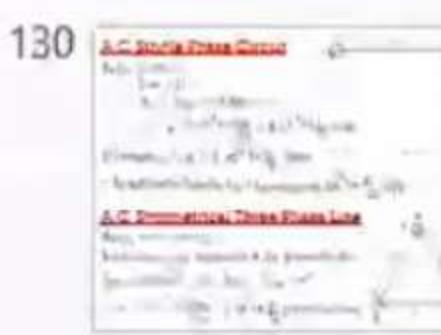
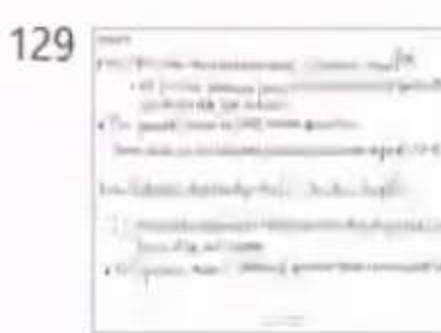
- It consists of four parallel conductors.
- Conductors a_1 and a_2 are connected in parallel & carry current in one direction. In effect they form Conductor A.
- Conductors b_1 & b_2 form the return path & they constitute the conductor B.
- All the conductors have same radius r .



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Forward 5 sec - [00:29:01 / 83%]

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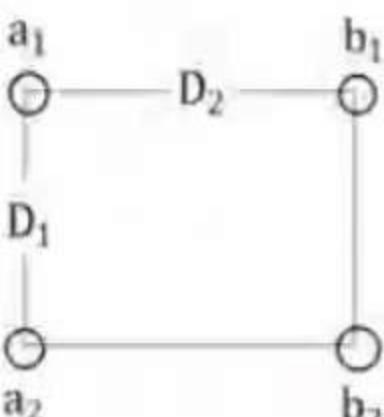
Here, $m = n = 2$

$$\therefore D_s' = [(D_{a_1 a_1}, D_{a_1 a_2})(D_{a_2 a_1}, D_{a_2 a_2})]^{1/4} = [(r' \cdot D_1)(D_1 \cdot r')]^{1/4} = (r' \cdot D_1)^{1/2}$$

$$D_m = [(D_{a_1 b_1}, D_{a_1 b_2})(D_{a_2 b_1}, D_{a_2 b_2})]^{1/4}$$

$$= [(D_2 \cdot \sqrt{D_1^2 + D_2^2}), (\sqrt{D_1^2 + D_2^2} \cdot D_2)]^{1/4}$$

$$= (D_2 \cdot \sqrt{D_1^2 + D_2^2})^{1/2}$$



Inductance of conductor A = $L_A = 2 \cdot 10^{-7} \ln \frac{D_m}{D_s} \text{ H/m}$

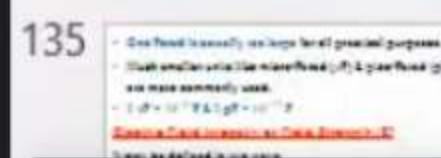
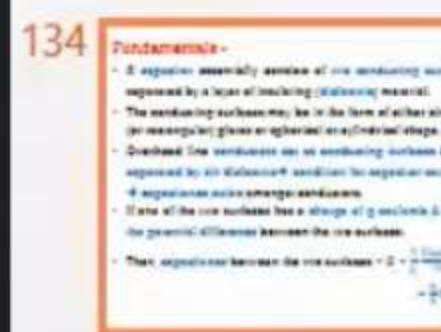
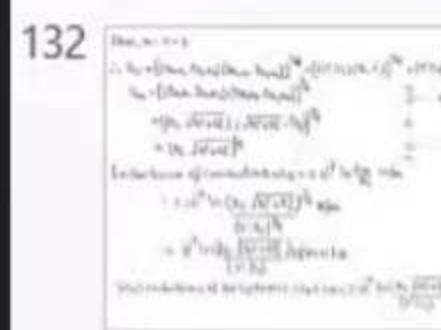
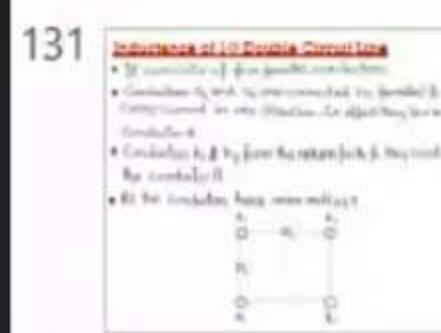
$$= 2 \cdot 10^{-7} \ln \frac{(D_2 \cdot \sqrt{D_1^2 + D_2^2})^{1/2}}{(r' \cdot D_1)^{1/2}} \text{ H/m}$$

$$= 10^{-7} \ln \frac{(D_2 \cdot \sqrt{D_1^2 + D_2^2})}{(r' \cdot D_1)} \text{ H/m} = L_B$$

Total inductance of the system = $L = L_A + L_B = 2 \cdot 10^{-7} \ln \frac{(D_2 \cdot \sqrt{D_1^2 + D_2^2})}{(r' \cdot D_1)} \text{ H/m}$

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Fundamentals -

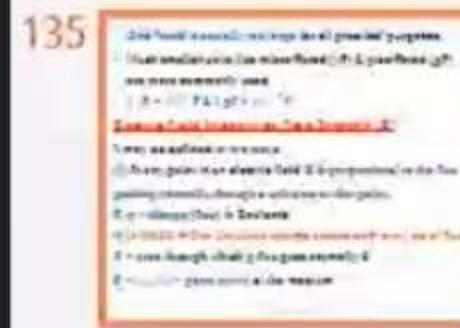
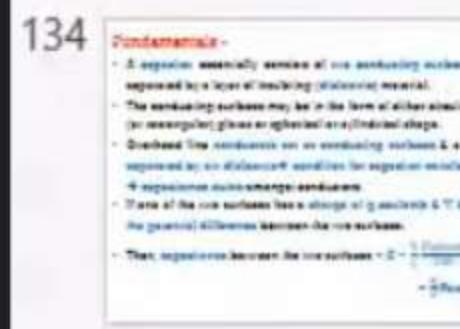
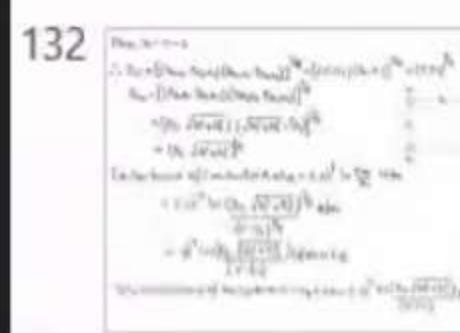
- A **capacitor** essentially consists of **two conducting surfaces** separated by a layer of insulating (**dielectric**) material.
- The conducting surfaces may be in the form of either circular (or rectangular) plates or spherical or cylindrical shape.
- Overhead line **conductors** act as **conducting surfaces** & are separated by air **dielectric** \rightarrow condition for capacitor satisfied \rightarrow **capacitance exists amongst conductors.** I
- If one of the two surfaces has a **charge of q coulomb** & V be the **potential difference** between the two surfaces.
- Then, **capacitance** between the two surfaces $= C = \frac{q}{V}$ **Coulomb**

$$= \frac{q}{V} \text{ Farad}$$

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- One Farad is actually too large for all practical purposes.
- Much smaller units like micro-Farad (μF) & pico-Farad (pF) are more commonly used.
- $1 \mu\text{F} = 10^{-6} \text{ F}$ & $1 \text{ pF} = 10^{-12} \text{ F}$

Electric Field Intensity or Field Strength (E)

It may be defined in two ways:

- (i) At any point in an electric field, E is proportional to the flux passing normally through a unit area at that point.

If, q = charge (flux) in Coulomb,

❖ In MKSA \rightarrow One Coulomb charge emanates \rightarrow one line of flux.

A = area through which q flux pass normally &

$K = K_0 \cdot K_r$ = permittivity of the medium

The image shows the 'Clipboard' tab selected from the ribbon menu.

A button labeled "New Slide" with a small icon of a document and a plus sign.

The screenshot shows the Microsoft Word ribbon with the 'Home' tab selected. The ribbon bar includes the 'File' tab, 'Home' tab, 'Insert', 'Page Layout', 'Design', 'Transitions', 'Animations', 'Review', and 'Help' tabs. Below the ribbon, there are two main sections: 'Font' and 'Paragraph'. The 'Font' section contains buttons for font style (B, I, U, S), font size (abc), and orientation (AV). The 'Paragraph' section contains buttons for alignment (Aa), spacing (A), and a 'Text Direction' button.

The screenshot shows the Microsoft Word ribbon with the 'Drawing' tab selected. On the far left is a toolbar with various drawing tools: a text box icon, a line icon, a square icon, a circle icon, a rounded rectangle icon, a triangle icon, a zigzag icon, a wavy line icon, a right-pointing arrow icon, a downward-pointing arrow icon, a left-pointing arrow icon, a curly brace icon, a left curly brace icon, a right curly brace icon, a left brace icon, a right brace icon, and a star icon. To the right of this toolbar are three icons: a stack of four squares with one yellow square in the middle, a paintbrush inside a rounded rectangle, and a shape with a brush stroke. Below these icons are the words 'Arrange', 'Quick Styles', and a dropdown arrow. To the right of these are three dropdown menus: 'Shape Fill', 'Shape Outline', and 'Shape Effects', each preceded by a small icon.

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when

$$K_0 = \text{permittivity of air} = \frac{1}{36 \cdot \pi \cdot 10^{-9}} \text{ F/m} = 8.84194 \cdot 10^{-12} \text{ F/m}$$

K_r = relative permittivity

Again, flux density $D = \frac{q}{A}$ (2)

Hence, D & E both are vectors

(ii) Electric field intensity at any point in an electric field is also defined as the force experienced by a unit +ve charge placed at that point.

Forward 5 sec - [00:15:42 / 47%]

The screenshot shows the Microsoft Word ribbon with the 'Home' tab selected. The ribbon includes tabs for File, Home, Insert, Page Layout, References, Mailings, and Review. The 'Home' tab has sections for Clipboard, Slides, Font, Paragraph, Drawing, and Editing. Each section contains various tools and dropdown menus for text and document manipulation.

Potential difference $V_{D_1 D_2} = \frac{q}{2\pi K} \cdot \int_{D_1}^{D_2} \frac{dx}{x} = \frac{q}{2\pi K} \cdot \ln \frac{D_2}{D_1}$

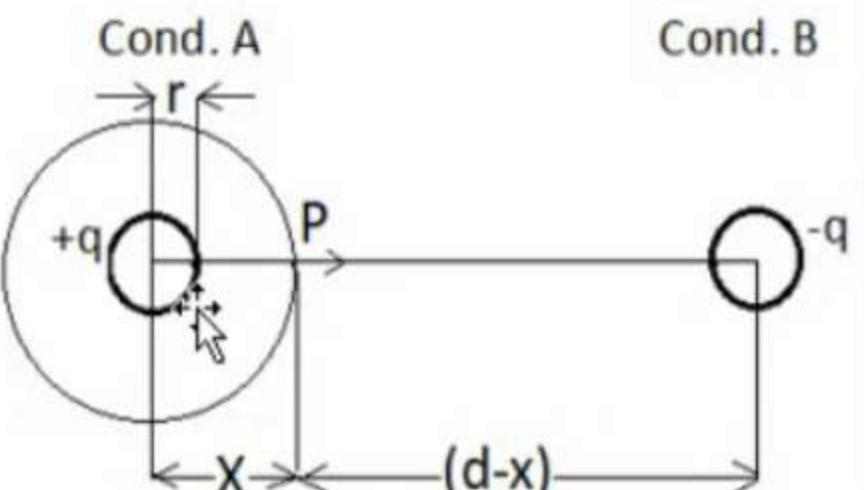
Capacitance between these equipotential surfaces = $\frac{q}{V_{D_1 D_2}}$

$$= \frac{2\pi K}{\ln \frac{D_2}{D_1}} F/m$$

Capacitance of a single phase line

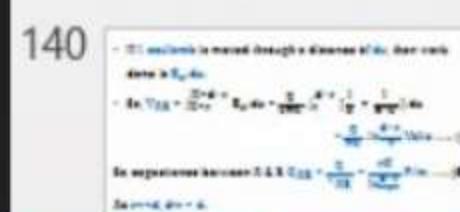
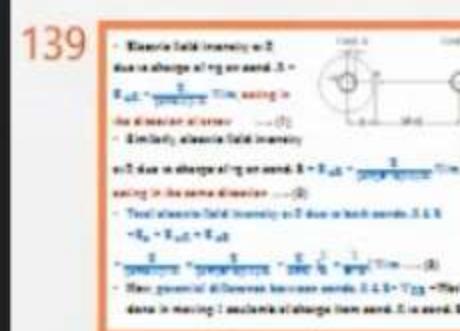
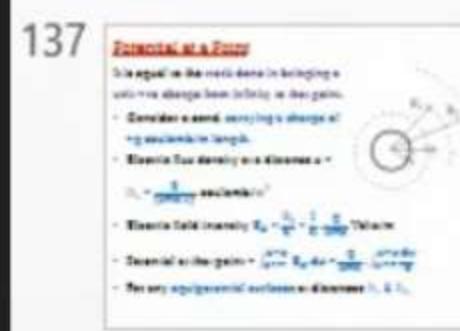
- Spacing of the conductors be d .
 - Charge on conductor 'A' is $+q$ Coulomb/m & charge on conductor 'B' is $-q$ Coulomb/m.
 - Radius of both conductors be r .
 - P be any point at a distance x from conductor 'A'.

The diagram shows two concentric circular conductors, A and B, centered at the origin of a Cartesian coordinate system. The inner conductor, A, has a radius labeled r and contains a positive charge $+q$. The outer conductor, B, also has a radius r and contains a negative charge $-q$. A horizontal line extends from the center to the right, representing the axis of symmetry. A point labeled 'P' is marked on this axis at a distance x from the center. A small arrow points towards point P from the text 'P be any point at a distance x from conductor 'A''. The label '(a)' is positioned at the bottom right of the diagram.



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- Electric field intensity at P, due to charge of $+q$ on cond. A =

$$E_{xA} = \frac{q}{(2\pi x) \cdot 1} \cdot K \text{ V/m, acting in the direction of arrow} \quad \dots \dots (1)$$

- Similarly, electric field intensity

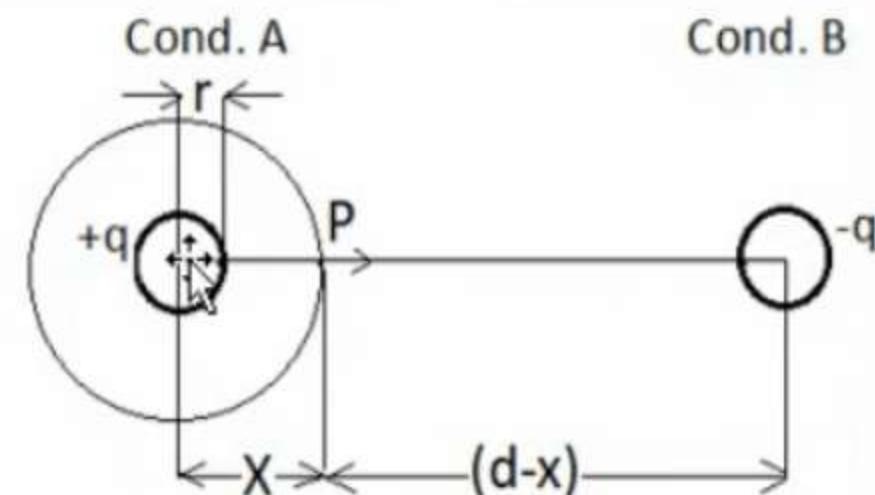
at P, due to charge of $-q$ on cond. B = $E_{xB} = \frac{q}{(2\pi(d-x)) \cdot 1} \cdot K \text{ V/m, acting in the same direction} \quad \dots \dots (2)$

- Total electric field intensity at P due to both cond. A & B

$$= E_x = E_{xA} + E_{xB}$$

$$= \frac{q}{(2\pi x) \cdot 1} \cdot K + \frac{q}{(2\pi(d-x)) \cdot 1} \cdot K = \frac{q}{2\pi K} \left[\frac{1}{x} + \frac{1}{d-x} \right] \text{ V/m} \quad \dots \dots (3)$$

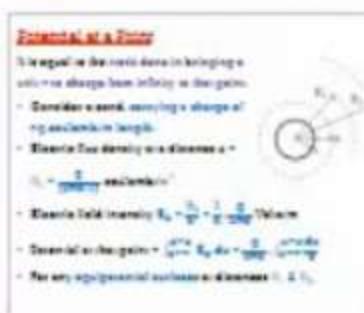
- Now, potential difference between cond. A & B = $V_{AB} = \text{Work done in moving 1 coulomb of charge from cond. A to cond. B.}$



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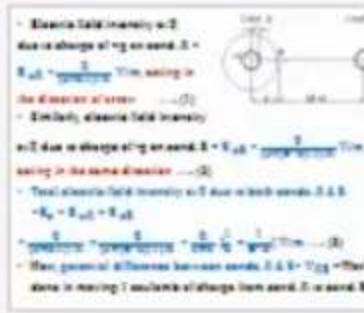
137



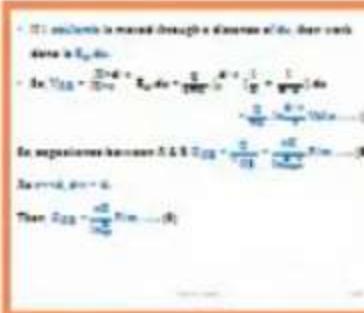
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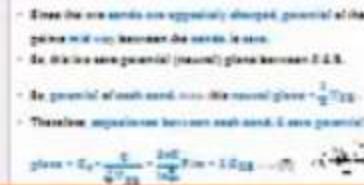
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- If 1 coulomb is moved through a distance of dx , then work done is $E_x \cdot dx$.

$$\begin{aligned} \text{So, } V_{AB} &= \int_{X=r}^{X=d-r} E_x \cdot dx = \frac{q}{2\pi K} \cdot \int_r^{d-r} \left[\frac{1}{x} + \frac{1}{d-x} \right] \cdot dx \\ &= \frac{q}{\pi K} \cdot \ln \frac{d-r}{r} \text{ Volts} \dots (4) \end{aligned}$$

$$\text{So, capacitance between A \& B } C_{AB} = \frac{q}{V_{AB}} = \frac{\pi K}{\ln \frac{d-r}{r}} \text{ F/m} \dots (5)$$

As $r \ll d$, $d-r \approx d$.

$$\text{Then, } C_{AB} = \frac{\pi K}{\ln \frac{d}{r}} \text{ F/m} \dots (6)$$

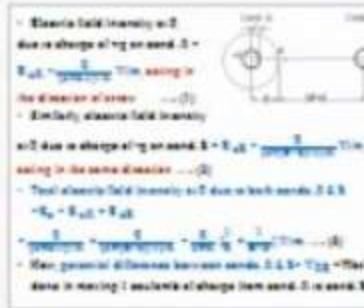
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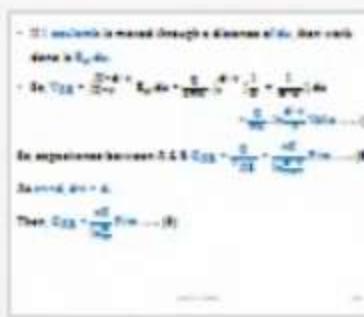
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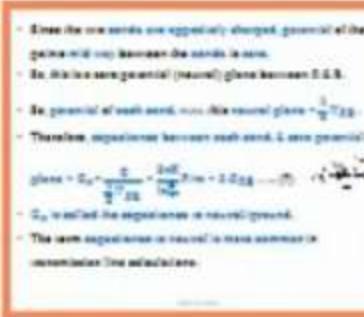
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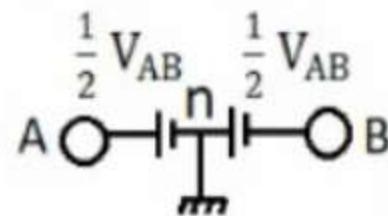


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- Since the two **conds.** are oppositely charged, potential of the points **mid way** between the **conds.** is zero.
- So, this is a zero potential (neutral) plane between A & B.
- So, potential of each cond. w.r.t. this neutral plane = $\frac{1}{2}V_{AB}$
- Therefore, **capacitance between each cond. & zero potential**

$$\text{plane} = C_n = \frac{q}{\frac{1}{2}V_{AB}} = \frac{2\pi K}{\ln \frac{d}{r}} F/m = 2.C_{AB} \quad \dots\dots (7)$$



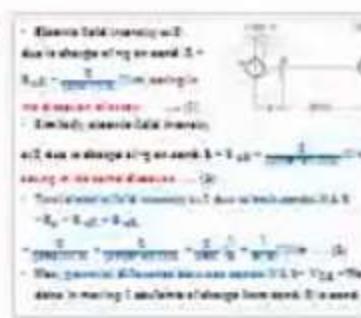
- C_n** is called the capacitance to neutral/ground.
- The term **capacitance to neutral** is more common in transmission line calculations.

Backward 5 sec-[00:25:53 / 78%]

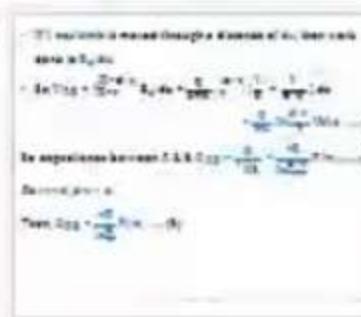
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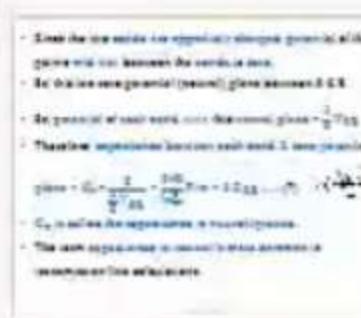
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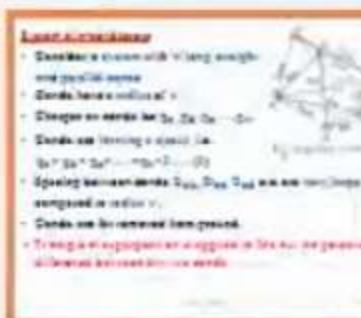
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System of n-conductors

- Consider, a **system** with '**n**' long, straight and parallel conds.
 - Conds. have a **radius** of '**r**'.
 - Charges on conds. be $q_a, q_b, q_c, \dots, q_n$.
 - Conds. are **forming a circuit**, i.e.

$$q_a + q_b + q_c + \dots + q_n = 0 \dots (1)$$
 - Spacing between conds. D_{ab}, D_{bc}, D_{cd} etc. are **very large** compared to **radius** '**r**'.
 - Conds. are far removed from ground.
- **Principle of superposition is applied to find out the potential difference between any two conds.**

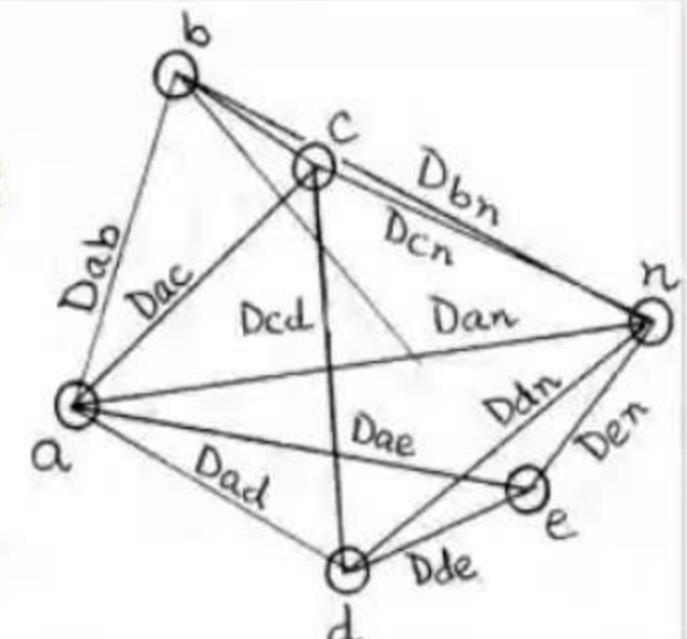


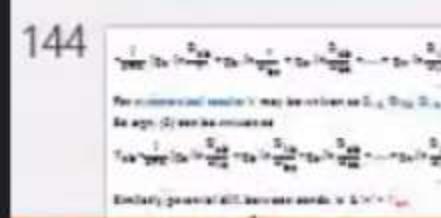
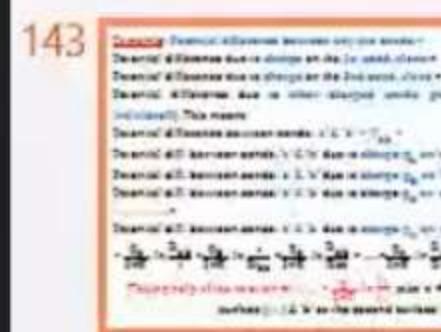
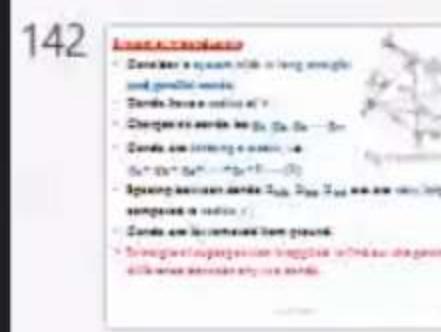
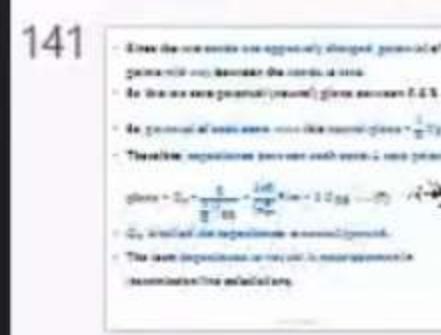
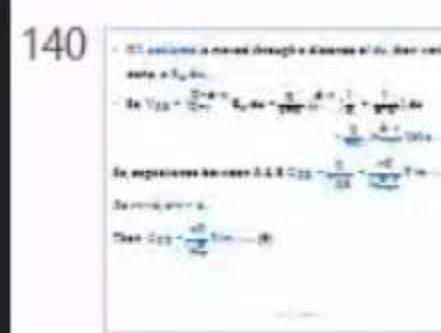
Fig. n-parallel conductors

Prof. S. S. Thakur

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Principle: Potential difference between any two cond. =

Potential difference due to charge on the 1st cond. alone +

Potential difference due to charge on the 2nd cond. alone +

Potential difference due to other charged cond. present individually. This means

Potential difference between cond. 'a' & 'b' = V_{ab} =

Potential diff. between cond. 'a' & 'b' due to charge q_a on 'a' +

Potential diff. between cond. 'a' & 'b' due to charge q_b on 'b' +

Potential diff. between cond. 'a' & 'b' due to charge q_c on 'c' +

..... +

Potential diff. between cond. 'a' & 'b' due to charge q_n on 'n'

$$= \frac{q_a}{2\pi K} \cdot \ln \frac{D_{ab}}{r} + \frac{q_b}{2\pi K} \cdot \ln \frac{r}{D_{ba}} + \frac{q_c}{2\pi K} \cdot \ln \frac{D_{cb}}{D_{ca}} + \dots + \frac{q_n}{2\pi K} \cdot \ln \frac{D_{nb}}{D_{na}} V$$

[Taking help of the relation $\rightarrow V_{D_1 D_2} = \frac{q}{2\pi K} \cdot \ln \frac{D_2}{D_1}$, take 'a' \rightarrow first surface (D_1) & 'b' as the second surface (D_2).]

Forward 5 sec - [00:29:13 / 89%]

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- Since the two surfaces are oppositely charged, potential at the point mid way between the surfaces is zero.
- At the two general (nearest) plane between D_{ab} .
- The potential at each surface, since the nearest plane = $\frac{1}{2} D_{ab}$.
- Therefore, separation between each surface & zero potential plane = $D_{ab} - \frac{1}{2} D_{ab} = \frac{1}{2} D_{ab}$ (2)
- D_{ab} is called the separation or mean distance.
- The same separation is used in most books to minimize the calculations.

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- Assumptions**
- Consider a system with 'n' long straight and parallel wires.
 - Consider there is no dielectric.
 - Charges on wires are $q_a, q_b, q_c, \dots, q_n$
 - Consider all having same length, i.e., $L = D_{ab} = D_{bc} = \dots = D_{an}$
 - Separation between wires $D_{ab}, D_{bc}, D_{ca}, \dots, D_{an}$ are very large compared to radius 'r'.
 - Consider wires to remain from ground.
 - Principle of superposition is applied to find out the potential difference between any two wires.

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- Assumptions**
- Potential difference between any two nodes = V_{ab}
 - Potential difference due to charges on the 1st node is V_{ab}
 - Potential difference due to charges on the 2nd node is V_{bc}
 - Potential difference due to other charged nodes present individually. This means
 - Potential difference between nodes a & b = V_{ab}
 - Potential difference between nodes b & c due to charges q_a & q_c
 - Potential difference between nodes c & a due to charges q_b & q_a
 -
 - Potential difference between nodes a & n due to charges q_a & q_n
 - $V_{ab} = V_{ba} = V_{bc} = V_{cb} = V_{ca} = V_{ac} = V_{an} = V_{na}$
 - V_{ab} is the sum of the voltages V_{ab} , V_{bc} , V_{ca} & V_{an}

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- Assumptions**
- Potential difference V may be written as V_{ab}, V_{bc}, V_{ca} & V_{an} as per eqn (2).
 - Equally potential diff. between nodes is $V_{ab} = V_{bc} = V_{ca}$
 - $V_{ab} = V_{ba} = V_{bc} = V_{cb} = V_{ca} = V_{ac} = V_{an} = V_{na}$

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- Assumptions**
- Same voltage is applied.
 - Charge on the conductors are $q_a, q_b, q_c, \dots, q_n$
 - $q_a = q_b = q_c = \dots = q_n$
 - Separation between nodes a & b is D_{ab}
 - Separation between nodes b & c is D_{bc}
 - Separation between nodes c & a is D_{ca}
 - Separation between nodes a & n is D_{an}

$$= \frac{1}{2\pi K} [q_a \cdot \ln \frac{D_{ab}}{r} + q_b \cdot \ln \frac{r}{D_{ba}} + q_c \cdot \ln \frac{D_{cb}}{D_{ca}} + \dots + q_n \cdot \ln \frac{D_{nb}}{D_{na}}] V \quad \dots \text{ (2)}$$

For **symmetrical results 'r'** may be written as D_{aa}, D_{bb}, D_{cc} etc.
So, eqn. (2) can be written as

$$V_{ab} = \frac{1}{2\pi K} [q_a \cdot \ln \frac{D_{ab}}{D_{aa}} + q_b \cdot \ln \frac{D_{bb}}{D_{ba}} + q_c \cdot \ln \frac{D_{cb}}{D_{ca}} + \dots + q_n \cdot \ln \frac{D_{nb}}{D_{na}}] V \quad \dots \text{ (3)}$$

Similarly, potential diff. between condns. 'a' & 'n' = V_{an}

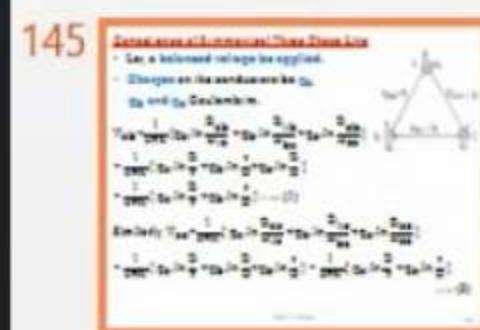
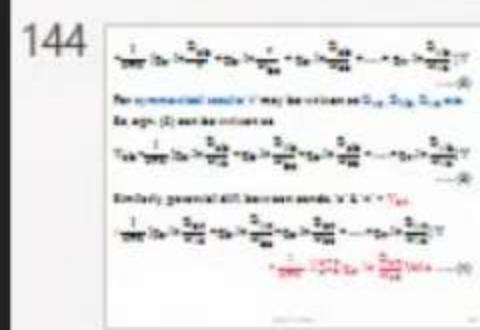
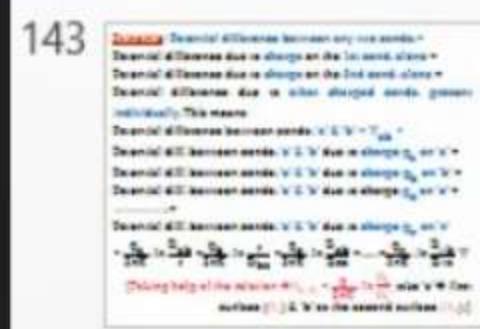
$$= \frac{1}{2\pi K} [q_a \cdot \ln \frac{D_{an}}{D_{aa}} + q_b \cdot \ln \frac{D_{bn}}{D_{ba}} + q_c \cdot \ln \frac{D_{cn}}{D_{ca}} + \dots + q_n \cdot \ln \frac{D_{nn}}{D_{na}}] V$$

$$= \frac{1}{2\pi K} \cdot \sum_{x=a}^{x=n} q_x \cdot \ln \frac{D_{xn}}{D_{xa}} \text{ Volts} \quad \dots \text{ (4)}$$

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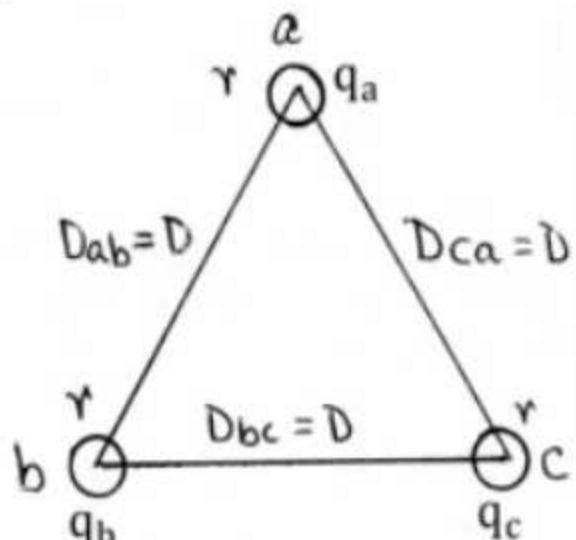
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Capacitance of Symmetrical Three Phase Line

- Let, a balanced voltage be applied.
- Charges on the conductors be q_a , q_b and q_c Coulomb/m.

$$\begin{aligned} V_{ab} &= \frac{1}{2\pi K} [q_a \cdot \ln \frac{D_{ab}}{D_{aa}} + q_b \cdot \ln \frac{D_{bb}}{D_{ba}} + q_c \cdot \ln \frac{D_{cb}}{D_{ca}}] \\ &= \frac{1}{2\pi K} [q_a \cdot \ln \frac{D}{r} + q_b \cdot \ln \frac{r}{D} + q_c \cdot \ln \frac{D}{r}] \\ &= \frac{1}{2\pi K} [q_a \cdot \ln \frac{D}{r} + q_b \cdot \ln \frac{r}{D}] \dots\dots (1) \end{aligned}$$



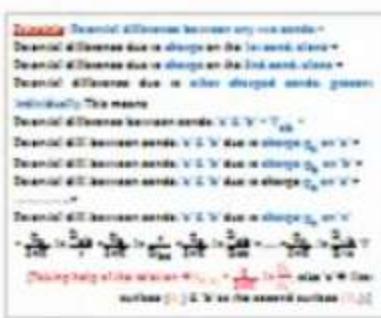
$$\text{Similarly, } V_{ac} = \frac{1}{2\pi K} [q_a \cdot \ln \frac{D_{ac}}{D_{aa}} + q_b \cdot \ln \frac{D_{bc}}{D_{ba}} + q_c \cdot \ln \frac{D_{cc}}{D_{ca}}]$$

$$= \frac{1}{2\pi K} [q_a \cdot \ln \frac{D}{r} + q_b \cdot \ln \frac{r}{D} + q_c \cdot \ln \frac{r}{D}] = \frac{1}{2\pi K} [q_a \cdot \ln \frac{D}{r} + q_c \cdot \ln \frac{r}{D}] \dots\dots (2)$$

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$$V_{ab} + V_{ac} = \frac{1}{2\pi K} [2q_a \cdot \ln \frac{D}{r} + (q_b + q_c) \cdot \ln \frac{r}{D}] \dots (3)$$

For a balanced system $q_a + q_b + q_c = 0$ Or, $q_b + q_c = -q_a$

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$$\text{So, } V_{ab} + V_{ac} = \frac{1}{2\pi K} [2q_a \cdot \ln \frac{D}{r} - q_a \cdot \ln \frac{r}{D}] = \frac{3q_a}{2\pi K} \cdot \ln \frac{D}{r} \dots (4)$$

Here, $V_{ab} = |V_{ab}| \angle 30^\circ$

$$= \sqrt{3} \cdot V_{an} \angle 30^\circ = \sqrt{3} \cdot V_{an} \left(\frac{\sqrt{3}}{2} + j \cdot \frac{1}{2} \right)$$

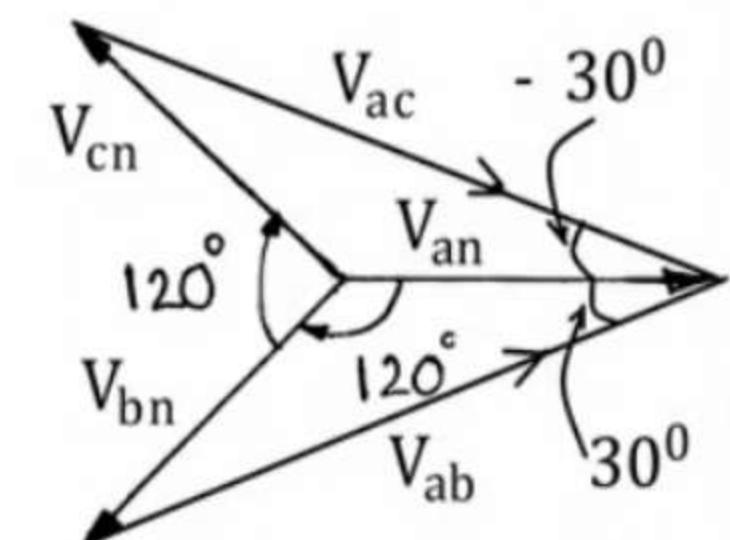
Also, $V_{ac} = |V_{ac}| \angle -30^\circ$

$$= \sqrt{3} \cdot V_{an} \left(\frac{\sqrt{3}}{2} - j \cdot \frac{1}{2} \right)$$

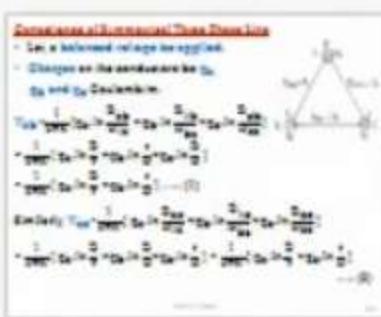
Therefore, $V_{ab} + V_{ac} = 3 \cdot V_{an} \dots (5)$

From eqns. (4) & (5)

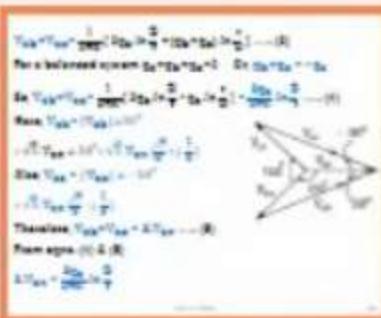
$$3 \cdot V_{an} = \frac{3q_a}{2\pi K} \cdot \ln \frac{D}{r}$$



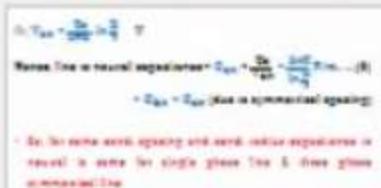
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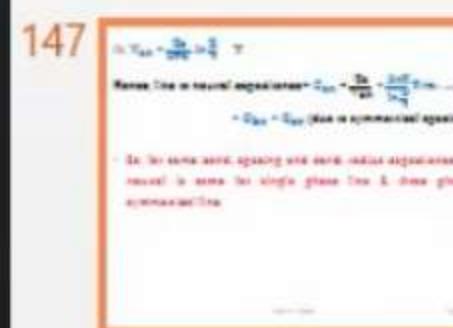
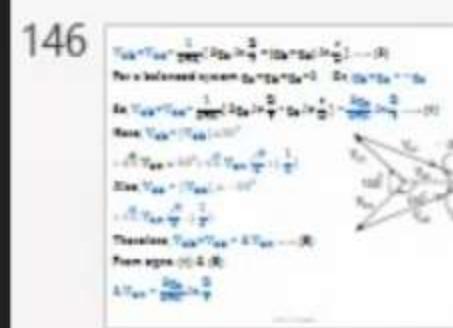
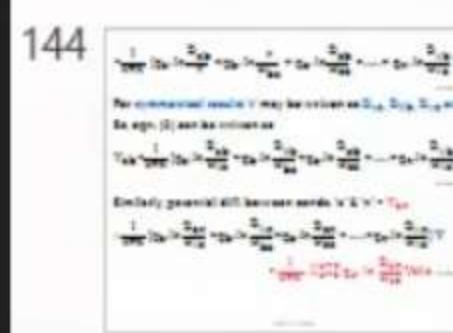
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$$\text{Or, } V_{an} = \frac{q_a}{2\pi K} \cdot \ln \frac{D}{r} \quad V$$

Hence, line to neutral capacitance = $C_{an} = \frac{q_a}{V_{an}} = \frac{2\pi K}{\ln \frac{D}{r}} F/m \dots\dots(6)$

$= C_{bn} = C_{cn}$ (due to symmetrical spacing)

I

- So, for same cond. spacing and cond. radius capacitance to neutral is same for single phase line & three phase symmetrical line.

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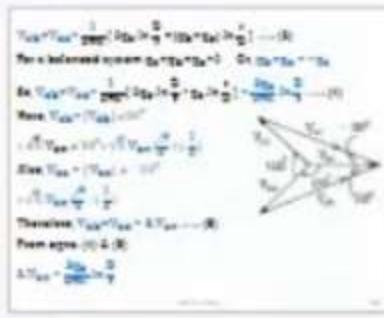
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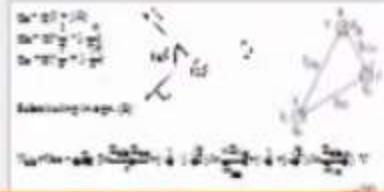
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Capacitance of Unsymmetrical Three Phase Line

$$V_{ab} = \frac{1}{2\pi K} [q_a \cdot \ln \frac{D_{ab}}{D_{aa}} + q_b \cdot \ln \frac{D_{bb}}{D_{ba}} + q_c \cdot \ln \frac{D_{cb}}{D_{ca}}]$$

$$= \frac{1}{2\pi K} [q_a \cdot \ln \frac{D_{ab}}{r} + q_b \cdot \ln \frac{r}{D_{ba}} + q_c \cdot \ln \frac{D_{cb}}{D_{ca}}] \text{ Volts} \dots\dots (1)$$

$$V_{ac} = \frac{1}{2\pi K} [q_a \cdot \ln \frac{D_{ac}}{D_{aa}} + q_b \cdot \ln \frac{D_{bc}}{D_{ba}} + q_c \cdot \ln \frac{D_{cc}}{D_{ca}}]$$

$$= \frac{1}{2\pi K} [q_a \cdot \ln \frac{D_{ac}}{r} + q_b \cdot \ln \frac{D_{bc}}{D_{ba}} + q_c \cdot \ln \frac{r}{D_{ca}}] \text{ Volts} \dots\dots (2)$$

$$V_{ab} + V_{ac} = \frac{1}{2\pi K} [q_a \cdot \ln \frac{D_{ab} D_{ac}}{r^2} + q_b \cdot \ln \frac{r D_{bc}}{D_{ba}} + q_c \cdot \ln \frac{D_{cb} r}{D_{ca}}] \text{ V} \dots\dots (3)$$

For a complete circuit $q_a + q_b + q_c = 0$.

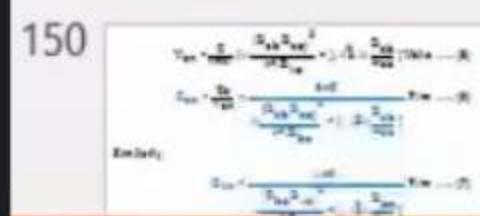
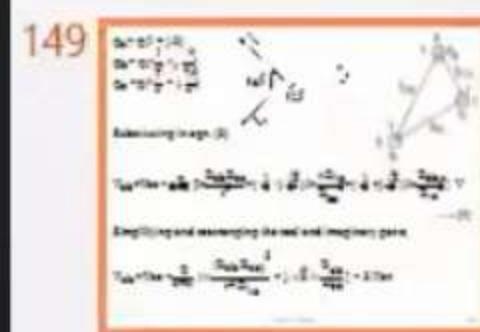
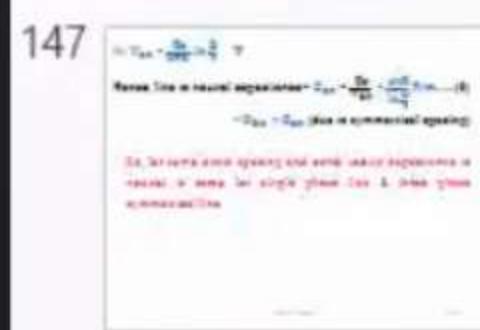
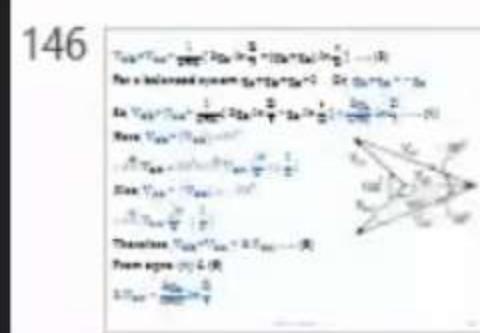
Taking phase sequence as a-b-c

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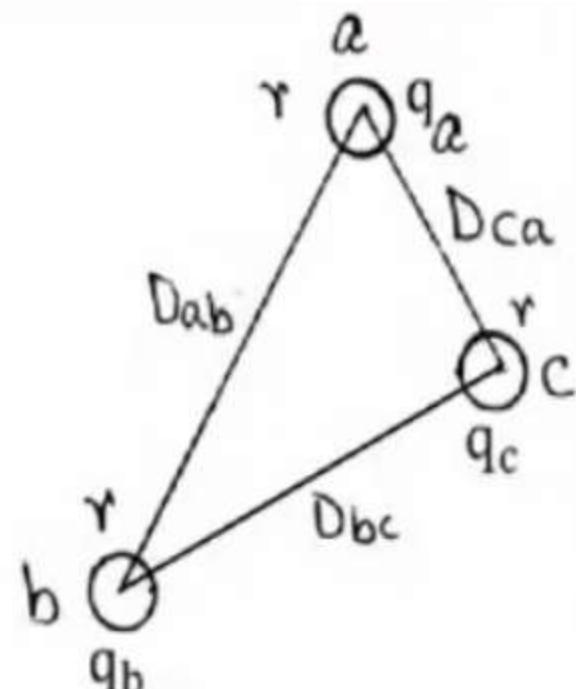
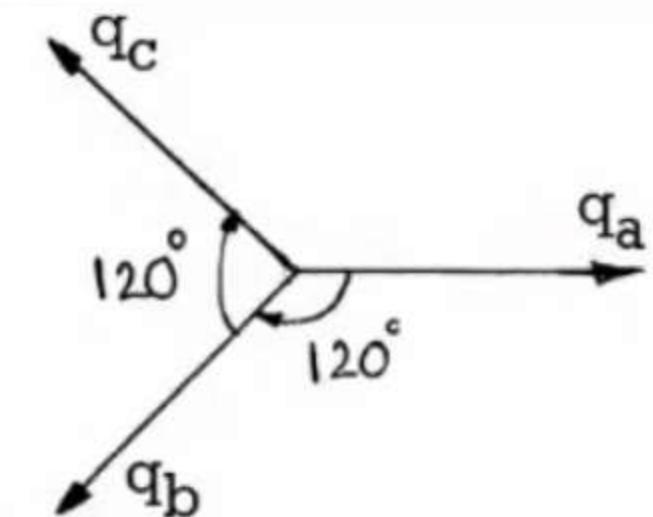


$$q_a = q(1 + j.0)$$

$$q_b = q\left(-\frac{1}{2} - j.\frac{\sqrt{3}}{2}\right)$$

$$q_c = q\left(-\frac{1}{2} + j.\frac{\sqrt{3}}{2}\right)$$

Substituting in eqn. (3)



$$V_{ab} + V_{ac} = \frac{q}{2\pi K} \left[\ln \frac{D_{ab} D_{ac}}{r^2} + \left(-\frac{1}{2} - j.\frac{\sqrt{3}}{2} \right) \cdot \ln \frac{r \cdot D_{bc}}{2} + \left(-\frac{1}{2} + j.\frac{\sqrt{3}}{2} \right) \cdot \ln \frac{D_{cb} \cdot r}{D_{ca}} \right] V \quad \dots\dots (4)$$

Simplifying and rearranging the real and imaginary parts,

$$V_{ab} + V_{ac} = \frac{q}{2\pi K} \left[\ln \frac{(D_{ab} D_{ac})^2}{r^3 \cdot D_{bc}} + j. \sqrt{3} \cdot \ln \frac{D_{ab}}{D_{ac}} \right] = 3 \cdot V_{an}$$

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Notes: Line to neutral separation = $d_{ab} + \frac{d_{bc}}{\sqrt{3}}$ (R)
 $\Rightarrow d_{bc} = d_{ab}$ (Line is symmetrical spacing)

- For some weak spacing and weak radial separation is required in case of single phase line & three phase symmetrical.

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Notes: Area of Three-phase Three-wire
 $T_{ab} = \frac{1}{2} \pi r^2 d_{ab}$
 $T_{bc} = \frac{1}{2} \pi r^2 d_{bc}$
 $T_{ca} = \frac{1}{2} \pi r^2 d_{ca}$
 $T_{ab} = \frac{1}{2} \pi r^2 d_{ab}$
 $T_{bc} = \frac{1}{2} \pi r^2 d_{bc}$
 $T_{ca} = \frac{1}{2} \pi r^2 d_{ca}$

Per a single phase $T_{ab} = T_{bc} = T_{ca}$
 Taking phase sequence as abc

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Notes: Calculating Impedance
 $Z_{ab} = \frac{V_{ab}}{I_{ab}}$
 $Z_{bc} = \frac{V_{bc}}{I_{bc}}$
 $Z_{ca} = \frac{V_{ca}}{I_{ca}}$
 Keeping and rearranging the real and imaginary part.
 $V_{ab} = \frac{Z_{ab}}{Z_{bc} + Z_{ca}} I_{bc}$

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Notes: $V_{ab} = \frac{Z_{ab}}{Z_{bc} + Z_{ca}} I_{bc}$
 $\Rightarrow V_{ab} = \frac{Z_{ab}}{Z_{bc} + Z_{ca}} \cdot \frac{V_{bc}}{Z_{bc}}$
 $\Rightarrow V_{ab} = \frac{Z_{ab}}{Z_{bc} + Z_{ca}} \cdot \frac{Z_{bc}}{Z_{bc}}$
 $\Rightarrow V_{ab} = \frac{Z_{ab}}{Z_{bc} + Z_{ca}} \cdot \frac{Z_{bc}}{Z_{bc}}$

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Notes: Dependence of different phases are different.
 - It is due to unbalanced spacing of conductors.
 - If different spacing occurs for different phases.
 - This causes unbalance resulting in voltage although sending end voltages are balanced.
 - Dependence can example numbers as $d_{ab} \neq d_{bc} \neq d_{ca}$
 Please note V_{ab}, V_{bc}, V_{ca} are not necessarily

$$V_{an} = \frac{q}{6\pi K} \left[\ln \frac{(D_{ab} D_{ac})^2}{r^3 \cdot D_{bc}} + j \cdot \sqrt{3} \cdot \ln \frac{D_{ab}}{D_{ac}} \right] \text{ Volts} \dots\dots (5)$$

$$C_{an} = \frac{q_a}{V_{an}} = \frac{6\pi K}{\left[\ln \frac{(D_{ab} D_{ac})^2}{r^3 \cdot D_{bc}} + j \cdot \sqrt{3} \cdot \ln \frac{D_{ab}}{D_{ac}} \right]} \text{ F/m} \dots\dots (6)$$

Similarly,

$$C_{bn} = \frac{6\pi K}{\left[\ln \frac{(D_{bc} D_{ba})^2}{r^3 \cdot D_{ac}} + j \cdot \sqrt{3} \cdot \ln \frac{D_{bc}}{D_{ba}} \right]} \text{ F/m} \dots\dots (7)$$

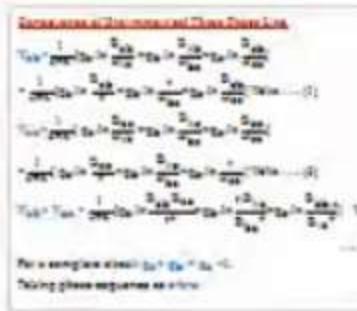
$$C_{bn} = \frac{6\pi K}{\left[\ln \frac{(D_{ca} D_{cb})^2}{r^3 \cdot D_{ab}} + j \cdot \sqrt{3} \cdot \ln \frac{D_{ca}}{D_{cb}} \right]} \text{ F/m} \dots\dots (8)$$

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$$\begin{aligned} Z_{ab} &= \frac{V_{ab}}{I_{ab}} = \frac{V_a - V_b}{I_{ab}} \\ Z_{bc} &= \frac{V_{bc}}{I_{bc}} = \frac{V_b - V_c}{I_{bc}} \\ Z_{ca} &= \frac{V_{ca}}{I_{ca}} = \frac{V_c - V_a}{I_{ca}} \end{aligned}$$

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- Capacitances are different.
- Due to unsymmetrical spacing of conductors.
- Due to different charging currents in different phases.
- This causes unbalanced receiving end voltages although sending end voltages are balanced.
- Capacitances are complex numbers as q_a, q_b & q_c are not in phase with V_{an}, V_{bn} & V_{cn} respectively.
- Due to presence of the imaginary part power transfer takes place between various phases, although at any instant of time total power transfer is zero.

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$$\begin{aligned} \text{For the } 1^{\text{st}} \text{ phase:} \quad & I_{1a} = \frac{V_a - V_{1a}}{Z_{1a}} = \frac{V_a - V_a}{Z_{1a}} = 0 \\ \text{For the } 2^{\text{nd}} \text{ phase:} \quad & I_{2a} = \frac{V_a - V_{2a}}{Z_{2a}} = \frac{V_a - V_a}{Z_{2a}} = 0 \\ \text{For the } 3^{\text{rd}} \text{ phase:} \quad & I_{3a} = \frac{V_a - V_{3a}}{Z_{3a}} = \frac{V_a - V_a}{Z_{3a}} = 0 \end{aligned}$$

- Capacitance of different phases are different.
- It is due to unsymmetrical spacing of conductors.
- So, different charging currents for different phases.
- This causes unbalanced receiving end voltages although sending end voltages are balanced.
- Capacitances are complex numbers as q_a, q_b & q_c are not in phase with V_{an}, V_{bn} & V_{cn} respectively.
- Due to presence of the imaginary part power transfer takes place between various phases, although at any instant of time total power transfer is zero.

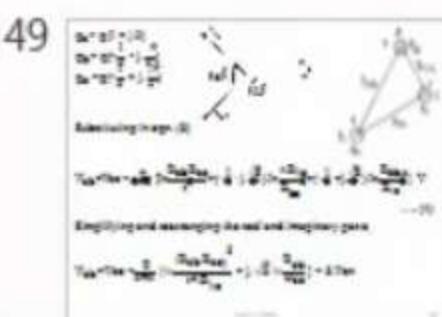
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$$\begin{aligned} V_{ab} &= \frac{Z_{ab}}{Z_{ab} + Z_{ac} + Z_{bc}} \cdot V_{\text{line}} \\ V_{ac} &= \frac{Z_{ac}}{Z_{ab} + Z_{ac} + Z_{bc}} \cdot V_{\text{line}} \\ V_{bc} &= \frac{Z_{bc}}{Z_{ab} + Z_{ac} + Z_{bc}} \cdot V_{\text{line}} \end{aligned}$$

- Dependence of different phases are different.
- It is due to asymmetric spacing of conductors.
- It is different depending on the different phases.
- This causes unbalance in sending and receiving although sending and receiving are balanced.
- Capacitances are complex numbers for the 3 phases with V_{ab}, V_{bc}, V_{ca} respectively.
- Due to presence of the imaginary part power factor values of three phases will also change, although at any instant of time real power remains same.

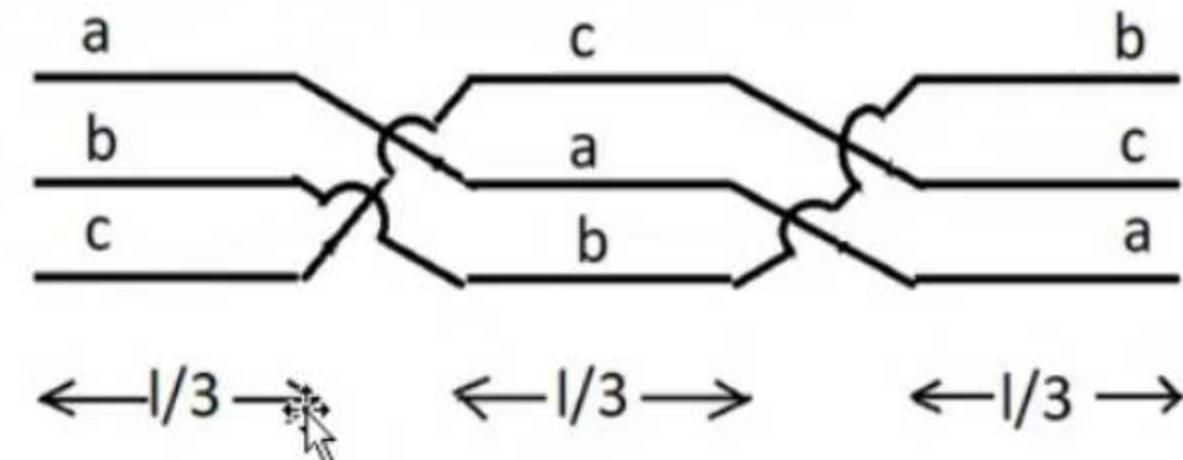
$$\begin{aligned} \text{Average capacitance of } 3\Phi \text{ unsymmetrical line} \\ \text{For the } 1^{\text{st }} \text{ 1/3 distance:} \\ \text{For the } 2^{\text{nd }} \text{ 1/3 distance:} \\ \text{For the } 3^{\text{rd }} \text{ 1/3 distance:} \end{aligned}$$

$$\begin{aligned} V_{ab} &= \frac{V_{\text{line}}}{3} (1 + \frac{2}{\pi} \tan^{-1} \frac{D_{ab}}{r}) \\ V_{ac} &= \frac{V_{\text{line}}}{3} (1 + \frac{2}{\pi} \tan^{-1} \frac{D_{ac}}{r}) \\ V_{bc} &= \frac{V_{\text{line}}}{3} (1 + \frac{2}{\pi} \tan^{-1} \frac{D_{bc}}{r}) \end{aligned}$$

Capacitance of a Transposed 3Φ Unsymmetrical Line

- Here, average capacitance of 3Φ are equal.

For the 1st 1/3 distance,



$$(V_{ab} + V_{ac})_1 = \frac{q}{2\pi K} \left[\ln \frac{(D_{ab} \cdot D_{ac})^2}{r^3 \cdot D_{bc}} + j \cdot \sqrt{3} \cdot \ln \frac{D_{ab}}{D_{ac}} \right] V$$

For the 2nd 1/3 distance,

$$(V_{ab} + V_{ac})_2 = \frac{q}{2\pi K} \left[\ln \frac{(D_{bc} \cdot D_{ba})^2}{r^3 \cdot D_{ac}} + j \cdot \sqrt{3} \cdot \ln \frac{D_{bc}}{D_{ba}} \right] V$$

For the 3rd 1/3 distance,

$$(V_{ab} + V_{ac})_3 = \frac{q}{2\pi K} \left[\ln \frac{(D_{ca} \cdot D_{cb})^2}{r^3 \cdot D_{ab}} + j \cdot \sqrt{3} \cdot \ln \frac{D_{ca}}{D_{cb}} \right] V$$

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Dependence of linear polarization on distance.

- Due to increase in separation of electrodes.
- Due to decrease in strength of electrodes.
- This causes increase in energy and energy although bending and stretching are involved.
- Dependence on complex numbers as $V_{ab} = V_{ca} = V_{bc}$ are in phase with $V_{ab} = V_{ca} = V_{bc}$, respectively.
- Due to presence of the charges due to polarisation.
- Due to increase in energy, although in any system of charge real part remains same.

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Dependence of T depend on the distance.

- For the average separation of 30 nm, $V_{ab} = V_{ca} = V_{bc}$
- For the 10 nm distance, $V_{ab} = V_{ca} = V_{bc}$
- For the 20 nm distance, $V_{ab} = V_{ca} = \frac{V_{ab}}{\sqrt{2}}$
- For the 30 nm distance, $V_{ab} = V_{ca} = \frac{V_{ab}}{\sqrt{3}}$
- For the 40 nm distance, $V_{ab} = V_{ca} = \frac{V_{ab}}{\sqrt{4}}$

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$V_{ab} = V_{ca} = V_{bc}$

$$\begin{aligned} & V_{ab} + V_{ac} = 3(V_{ab} + V_{ac})_1 + (V_{ab} + V_{ac})_2 + (V_{ab} + V_{ac})_3 \\ & \frac{1}{3} (V_{ab} + V_{ac})_1 + j \cdot \sqrt{3} \cdot \ln \left\{ \frac{(D_{ab} \cdot D_{bc} \cdot D_{ca})^4}{(r^9 D_{ab} \cdot D_{bc} \cdot D_{ca})} \right\} \\ & = \frac{q}{6\pi K} \cdot \ln \left\{ \frac{(D_{ab} \cdot D_{bc} \cdot D_{ca})^3}{r^9} \right\} \end{aligned}$$

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$V_{ab} = V_{ca} = V_{bc}$

$$\begin{aligned} & V_{ab} + V_{ac} = 3(V_{ab} + V_{ac})_1 + (V_{ab} + V_{ac})_2 + (V_{ab} + V_{ac})_3 \\ & \frac{1}{3} (V_{ab} + V_{ac})_1 + j \cdot \sqrt{3} \cdot \ln \left\{ \frac{(D_{ab} \cdot D_{bc} \cdot D_{ca})^4}{(r^9 D_{ab} \cdot D_{bc} \cdot D_{ca})} \right\} \\ & = \frac{9q}{6\pi K} \cdot \ln \left\{ \frac{\sqrt[3]{D_{ab} \cdot D_{bc} \cdot D_{ca}}}{r} \right\} \quad V \dots (1) \end{aligned}$$

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Thank you.

$$(V_{ab} + V_{ac}) = \frac{1}{3} \cdot [(V_{ab} + V_{ac})_1 + (V_{ab} + V_{ac})_2 + (V_{ab} + V_{ac})_3]$$

$$= \frac{q}{6\pi K} \left[\ln \left\{ \frac{(D_{ab} \cdot D_{bc} \cdot D_{ca})^4}{(r^9 D_{ab} \cdot D_{bc} \cdot D_{ca})} \right\} + j \cdot \sqrt{3} \cdot \ln \left\{ \frac{(D_{ab} \cdot D_{bc} \cdot D_{ca})^4}{(D_{ab} \cdot D_{bc} \cdot D_{ca})} \right\} \right]$$

$$= \frac{q}{6\pi K} \cdot \ln \left\{ \frac{(D_{ab} \cdot D_{bc} \cdot D_{ca})^3}{r^9} \right\}$$

$$= \frac{9q}{6\pi K} \cdot \ln \left\{ \frac{\sqrt[3]{D_{ab} \cdot D_{bc} \cdot D_{ca}}}{r} \right\} \quad V \dots (1)$$

$$\text{Again, } V_{ab} + V_{ac} = 3 \cdot V_{an} \quad V \dots (2)$$

So, from eqns. (1) & (2),

$$3 \cdot V_{an} = \frac{9q}{6\pi K} \cdot \ln \left\{ \frac{\sqrt[3]{D_{ab} \cdot D_{bc} \cdot D_{ca}}}{r} \right\} \dots (3)$$

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 - Dependence of different phases on distance.
 - Due to asymmetric spacing of electrodes.
 - Due to different charging sequence for different phases.
 - This causes unbalance in reading and voltage although sending and receiving are balanced.
 - Dependence on sequence numbers of D_{ab} , D_{bc} & D_{ca} are due to phase with V_{ba} , V_{cb} & V_{ac} respectively.
 - Due to presence of the impurities, gas given smaller value to less between various phases, although at any instant of time total capacitance remains same.

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 Dependence of transmission on Distance relation
 - New arrangement
 - separation of 20 cm
 - new equation
 For the 1+1+2 distance

$$\frac{V_{ab} + V_{bc} + V_{ca}}{3} = \frac{Q_{ab}}{D_{ab}} + \frac{Q_{bc}}{D_{bc}} + \frac{Q_{ca}}{D_{ca}}$$

$$(V_{ab} + V_{bc} + V_{ca})^2 = \left(\frac{Q_{ab}}{D_{ab}} + \frac{Q_{bc}}{D_{bc}} + \frac{Q_{ca}}{D_{ca}}\right)^2$$

 For the 2+1+1 distance

$$(V_{ab} + V_{bc} + V_{ca})^2 = \left(\frac{2Q_{ab}}{D_{ab}} + \frac{Q_{bc}}{D_{bc}} + \frac{Q_{ca}}{D_{ca}}\right)^2$$

 For the 2+1+2 distance

$$(V_{ab} + V_{bc} + V_{ca})^2 = \left(\frac{2Q_{ab}}{D_{ab}} + \frac{Q_{bc}}{D_{bc}} + \frac{2Q_{ca}}{D_{ca}}\right)^2$$

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$$\begin{aligned} Q_{ab} + Q_{bc} + Q_{ca} &= V_{ab} + V_{bc} + V_{ca} \\ \frac{Q_{ab}}{D_{ab}} + \frac{Q_{bc}}{D_{bc}} + \frac{Q_{ca}}{D_{ca}} &= \frac{V_{ab}}{D_{ab}} + \frac{V_{bc}}{D_{bc}} + \frac{V_{ca}}{D_{ca}} \\ \frac{Q_{ab}}{D_{ab}} + \frac{Q_{bc}}{D_{bc}} + \frac{Q_{ca}}{D_{ca}} &= \frac{V_{ab}}{D_{ab}} + \frac{V_{bc}}{D_{bc}} + \frac{V_{ca}}{D_{ca}} \end{aligned}$$

 Again, $V_{ab} = 2(V_{ba} - V)$ (2)
 In last equation (1) & (2),

$$2(V_{ba} - V) + \frac{Q_{bc}}{D_{bc}} + \frac{Q_{ca}}{D_{ca}} = \frac{V_{ab}}{D_{ab}} + \frac{V_{bc}}{D_{bc}} + \frac{V_{ca}}{D_{ca}}$$

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$$\begin{aligned} Q_{ba} &= \frac{V_{ab}}{D_{ab}} = \frac{2(V_{ba} - V)}{D_{ab}} \quad (\text{from } (1)) \\ \text{Hence, line to neutral capacitance } C_{bn} &= \frac{Q_{ba}}{V_{ba}} \\ &= \frac{2(V_{ba} - V)}{D_{ab}} = \frac{2(V_{ba} - V)}{D_{eq}} \quad (\text{from } (2)) \\ \text{Hence, } C_{bn} &= \frac{2(V_{ba} - V)}{D_{eq}} \end{aligned}$$

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 Thank you.

Or,
$$V_{an} = \frac{q}{2\pi K} \cdot \ln \left\{ \frac{\sqrt[3]{D_{ab} \cdot D_{bc} \cdot D_{ca}}}{r} \right\} \text{ Volts} \dots\dots (4)$$

Hence, line to neutral capacitance = $C_{an} = \frac{q}{V_{an}}$

$$= \frac{2\pi K}{\ln \left\{ \frac{\sqrt[3]{D_{ab} \cdot D_{bc} \cdot D_{ca}}}{r} \right\}} = \frac{2\pi K}{\ln \frac{D_{eq}}{r}} = C_{bn} = C_{cn} \text{ F/m} \dots\dots (5)$$

Where, $D_{eq} = \sqrt[3]{D_{ab} \cdot D_{bc} \cdot D_{ca}}$

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Diagram of a Dimeric DNA Polymerase

- New enzyme
- Segmentation of 2D
- New signal
- For the 1st 1/2 dimer
- For the 2nd 1/2 dimer
- For the 3rd 1/2 dimer
- For the 4th 1/2 dimer

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$T_{AA} = T_{AA} + \frac{1}{2}(T_{AA} + T_{AC}) + (T_{AC} + T_{AA}) + (T_{AC} + T_{AC})$

 $\rightarrow \frac{1}{2}T_{AA} + \frac{1}{2}T_{AC} + \frac{1}{2}T_{AC} + \frac{1}{2}T_{AA}$
 $\rightarrow \frac{1}{2}T_{AA} + \frac{1}{2}T_{AC}$
 $\rightarrow \frac{1}{2}T_{AA} + \frac{1}{2}T_{AC} \rightarrow T_{AA}$

Span: $T_{AA} = T_{AA} + 2(T_{AC}) \rightarrow (2)$

Re-ligation: (1) & (2)

$\Delta T_{AA} = \frac{1}{2}T_{AA} + \frac{1}{2}T_{AC} \rightarrow (2)$

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Q: $T_{AA} = \frac{1}{2}T_{AA} + \frac{1}{2}T_{AC}$ $\rightarrow (2)$

Ans: This is a neutral re-ligation = $T_{AA} = \frac{1}{2}T_{AA}$

 $\rightarrow \frac{1}{2}T_{AA} = \frac{1}{2}T_{AA} + \frac{1}{2}T_{AC} \rightarrow T_{AA} = T_{AC} \rightarrow (2)$

Thus: $T_{AC} = \frac{1}{2}T_{AA} + \frac{1}{2}T_{AC}$

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Thank you.

Thank you.