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ELECTRICAL AND ELCTRONICS ENGINEERING

II nd YEAR / IVth SEMESTER

EE8402 – Transmission and Distribution

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UNIT 01 – Transmission line Parameters

Learning is the only thing the mind never exhaust, never fears, and never regret.

—Leonardo Da Vinci

UNIT-1

- Structure of Power System
- Parameters of single and three phase transmission lines with single and double circuits
  - Symmetrical and Unsymmetrical spacing
- application of self and mutual GMD
- skin and proximity effects
- conductor types and electrical parameters of EHV lines.

Structure of Power System

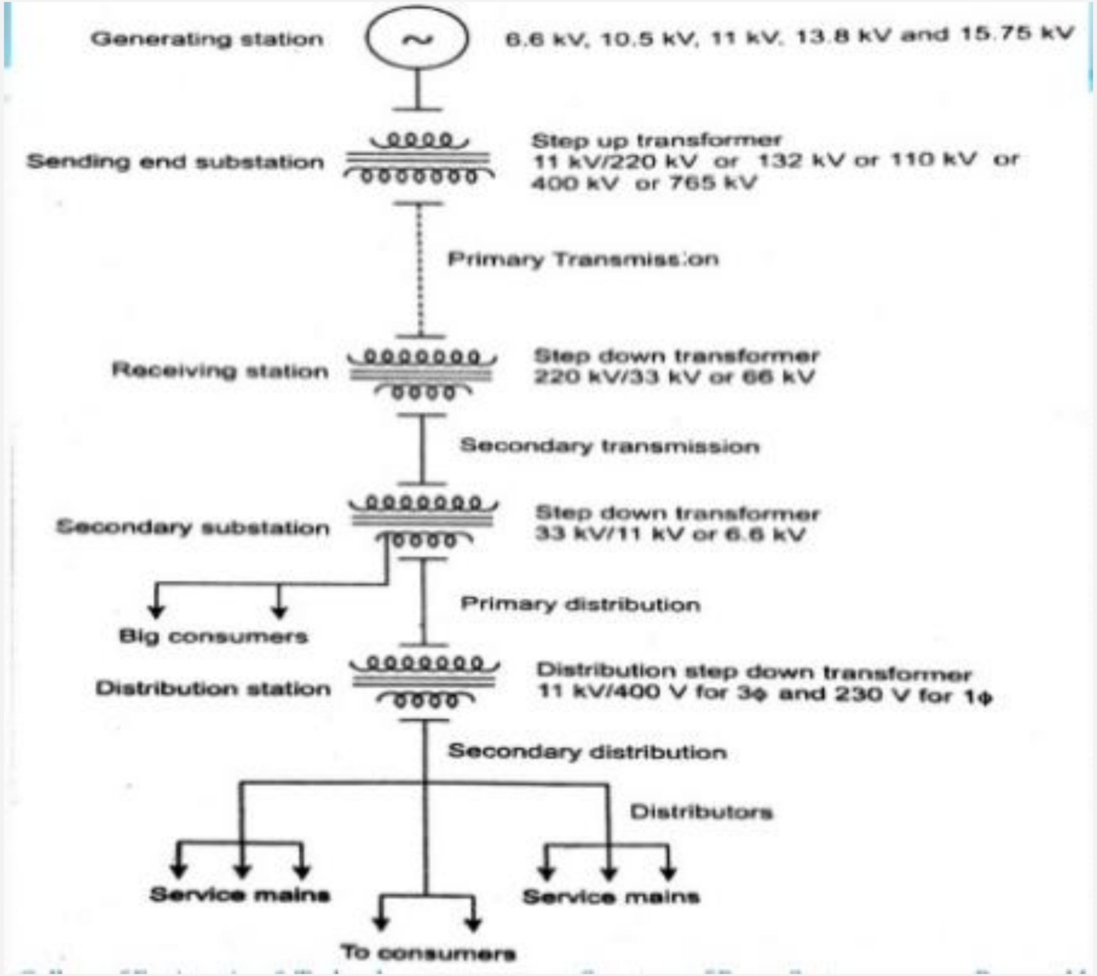
- An Electric supply system consists of three principal components
  - The Power Station
  - Transmission line
  - Distribution system

- The Electric supply system can be broadly Classified into
  - DC or AC system
  - Overhead or Underground system

Typical Ac Power Supply Scheme

- Generating System
- Primary Transmission
- Secondary Transmission
- Primary Distribution
- Secondary Distribution

Single line diagram



Generators:

- Generator is a device which converts mechanical energy into electrical energy. Generating voltages are normally 6.6KV, 10.5KV or 11KV

- This generating voltages can be step up to 110KV/132 KV/220KV at the generating to reduce transmission losses.

Primary Transmission:

- Primary Transmission voltages are 110KV,132KV or 220KV or 400KV or 760 KV with 3 phase 3 wire system

- The high voltage transmission lines transmit power from sending end substation to the receiving end substation.

Secondary Transmission:

- At the receiving end substation the voltage is steppes down to 66KV or 33KV or 22KV using step down transformers.

- The secondary transmission line forms the link between the receiving end substation to various substation with 3 phase 3 wire system.

Primary Distribution:

- At the secondary substations, the voltage is stepped down to 11KV or 6.6KV using step down transformers.

- The big consumers are generally supplied power at 11KV for further handling with their own substation.

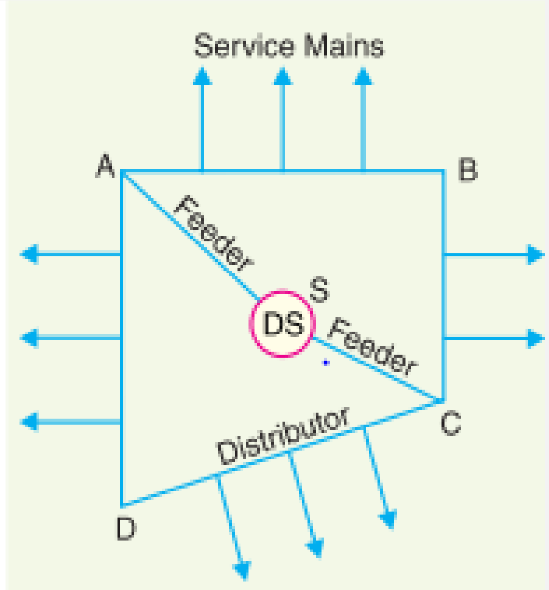
- The primary distributor forms a link between secondary substation and distribution substation with 3 phase 3 wire system.

Secondary Distribution:

- At the distribution substation the voltage is stepped down to 400V (for 3 phase) or 230V (for 1 phase) using step down transformers.

- The distribution lines are drawn along the roads and service connections to the consumers are tapped off from the distributors with 3 phase 4 wire system.

- It consists of feeders, distributors and service mains.



SC or SA-Feeders

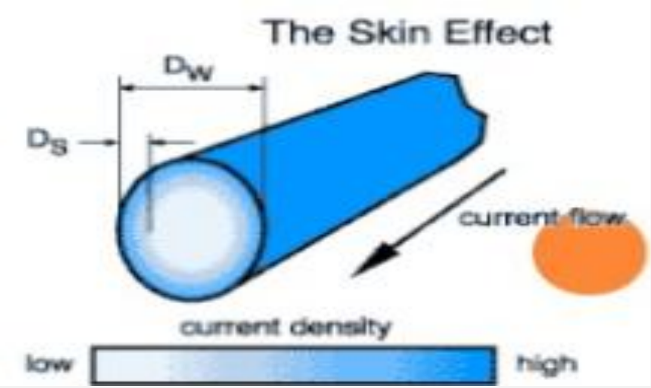
AB, BC,CD and AD-distributors

- A practical power system has a large number of auxiliary equipments (e.g., fuses, circuit breakers, voltage control devices etc.).

Skin Effect

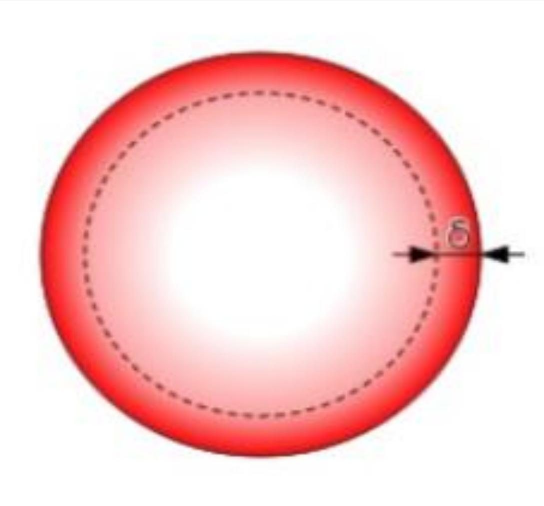
- Skin effect is the tendency of an alternating electric current to become distributed within a conductor such that the current density is largest near the surface of the conductor and decreases with greater depths in the conductor.

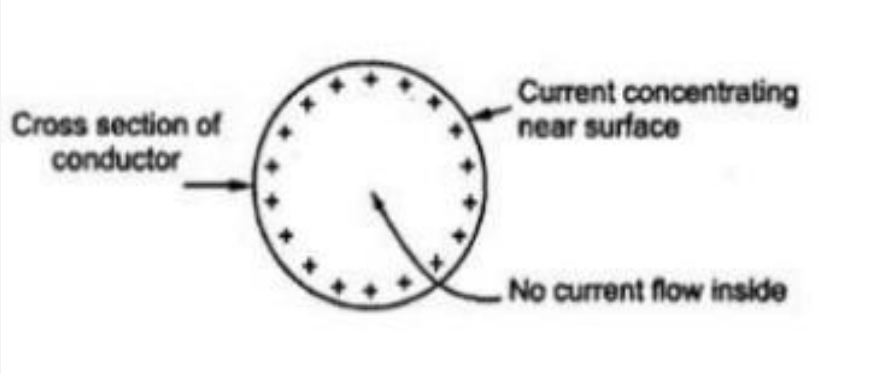
- It causes the effective resistance of the conductor to increase at higher frequencies where the skin depth is smaller, thus reducing the effective cross-section of the conductor.



Factors:

- ➢ Nature of material
- ➢ Diameter of wire
- ➢ Frequency
- ➢ Shape of wire





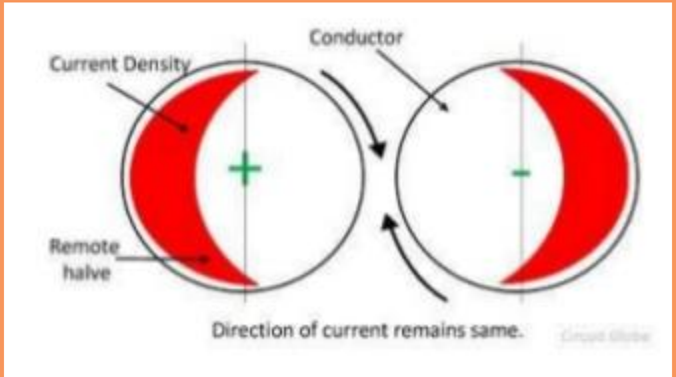
Proximity Effect

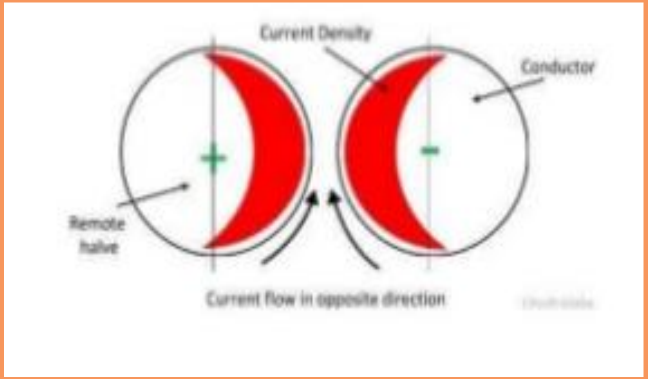
- The term proximity effect refers to the influence of alternating current in conductor on the current distribution in another nearby conductor.

- When two or more conductors are placed near to each other, then their magnetic fields interact with each other. Due to this interaction the current in each of them is redistributed.

- If DC flows, the current are uniformly distributed hence no proximity effect occurs in the surface of the conductor.

- **When the conductors carry the current in same direction magnetic fields cancelling each other and hence no current flow through it.**
- **When the conductors carry the current in opposite direction the close part of the conductor carries more current and the magnetic field of the far off half of the conductor cancel each other.**





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Factors affecting Proximity Effect

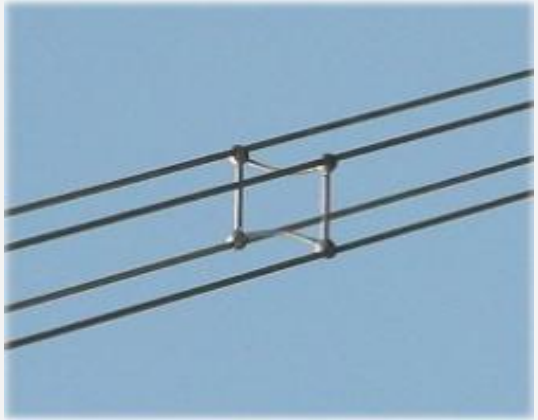
- ➢ Increase in frequency
- ➢ More the diameter of the conductor
- ➢ Material of conductor

<u>Ferranti Effect</u>

- The Ferranti effect is a phenomenon that describes the increase in voltage at the receiving end of a long transmission line relative to the voltage at the sending end when the lines are either lightly loaded or open circuit.

Bundled Conductor

- Bundled conductors are used in transmission lines where the voltage exceeds 230KV.
- At such high voltages ordinary conductors will result in excessive corona and noise which may affect communication lines.
- The conductors are separated from each other by means of spacers at regular intervals.

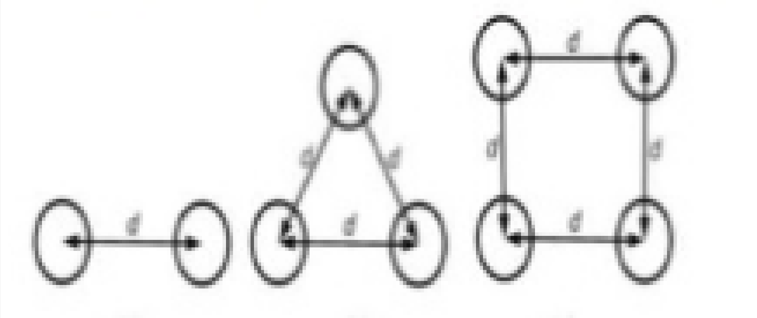


Advantages of Bundled Conductors

- To reduce the corona loss and radio interference

- To improvement in transmission efficiency

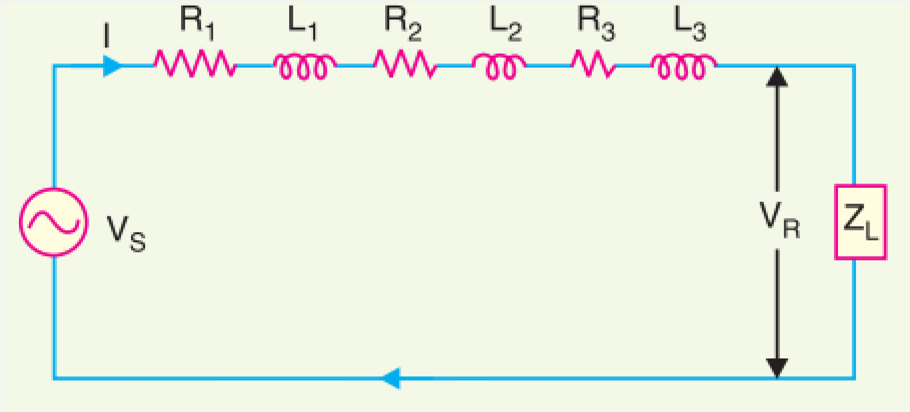
- Bundled conductor lines will have higher capacitance to neutral in comparison with single lines. Thus they will have higher charging current which helps in improving the power factor.

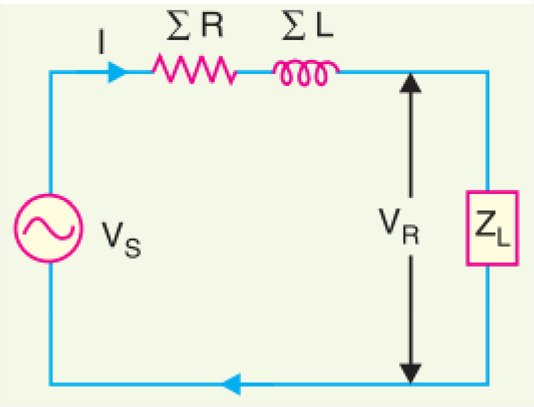


Constants of Transmission Lines

- Resistance
- Inductance
- Capacitance

-Uniformly distributed along the whole length of the line.





Resistance:

- It is the opposition of line conductors to current flow. The resistance is distributed uniformly along the whole length of the line.

Inductance:

- When an alternating current flows through a conductor, a changing flux is setup which links the conductor. Due to these flux linkages, the conductor possesses inductance.

Inductance, $L = \psi/I$ henry

Where, ψ = flux linkages in weber-turns
I = current in amperes

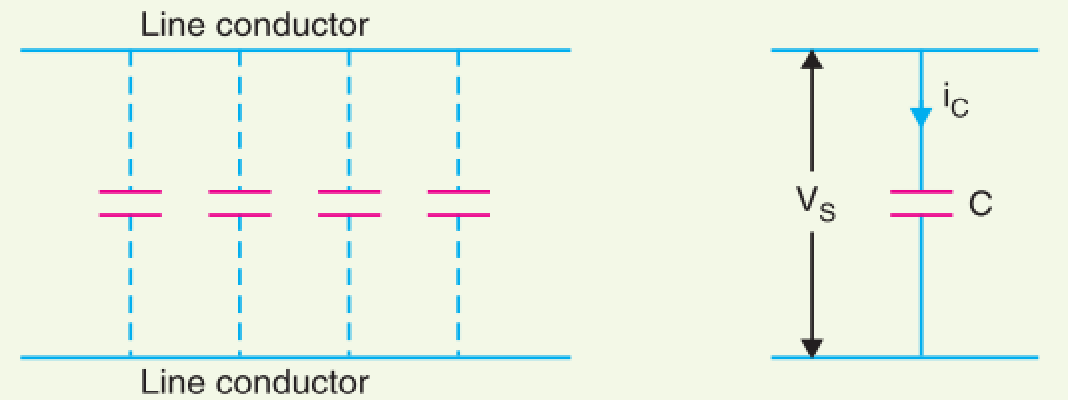
Capacitance:

- As any two conductors of an overhead transmission line are separated by air which acts as an insulation, therefore, capacitance exists between any two overhead line conductors.

Capacitance, $C = q/v$ farad

Where, q = charge on the line in coulomb

v = p.d. between the conductors in volts



Flux Linkages

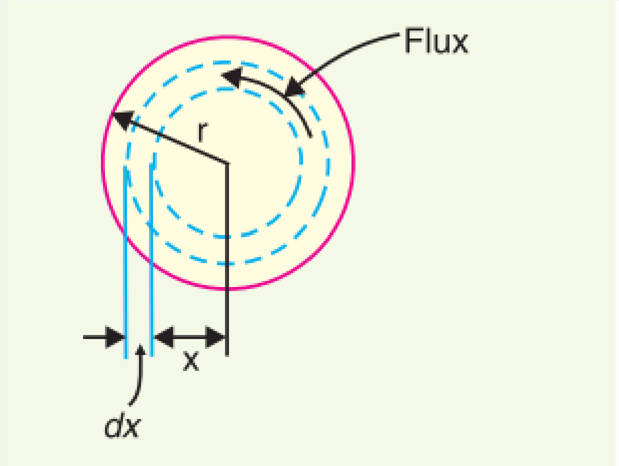
- The inductance of a circuit is defined as the flux linkages per unit current.
- To find the inductance of a circuit, the determination of flux linkages is of primary importance.

(i)Flux Linkages outside the conductor
(ii)Flux Linkages inside the conductor

- Both these fluxes will contribute to the inductance of the conductor

Flux linkages due to internal flux.

- Consider a long straight cylindrical conductor of radirus *r* metres and carrying a current *I* amperes.
  The magnetic field intensity at a point *x* metres from the centre



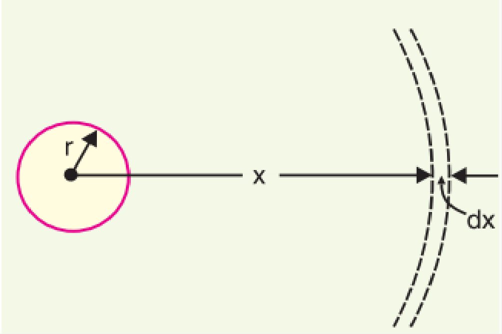
$$*H_x = \frac{I_x}{2\pi x}$$

- Total flux linkages from centre upto the conductor surface is

$$= \frac{\mu_0 I}{8\pi} \text{ weber-turns per metre length}$$

Flux linkages due to External flux.

- The external flux extends from the surface of the conductor to infinity. Referring the field intensity at a distance *x* metres (from centre) outside the conductor



$$\text{Flux density,} \qquad B_x = \mu_0 H_x = \frac{\mu_0 I}{2\pi x} \text{ wb/m}^2$$

- Total flux linkages of the conductor from surface to infinity,

$$\psi_{ext} = \int_r^\infty \frac{\mu_0 I}{2\pi x} dx \text{ weber-turns}$$

Overall flux linkages,

$$\psi = \psi_{int} + \psi_{ext}$$

$$\psi = \frac{\mu_0 I}{2\pi}\left[\frac{1}{4} + \int_r^\infty \frac{dx}{x}\right] \text{ wb-turns/m length}$$

Flux Linkages in Parallel Current Carrying Conductor

- Determine the flux linkages in a group of parallel current carrying conductors *A*,*B*, *C* etc., Let us consider the flux linkages with one conductor, say conductor *A*.

Flux linkages with conductor *A* due to its own current

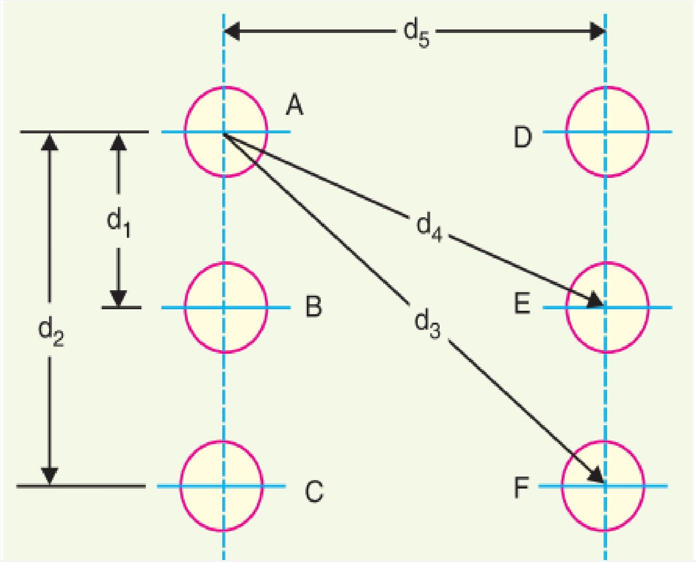
$$= \frac{\mu_0 I_A}{2\pi}\left[\frac{1}{4} + \int_r^{\infty} \frac{dx}{x}\right]$$

Flux linkages with conductor A due to current IB

$$= \frac{\mu_0 I_B}{2\pi}\int_{d_1}^{\infty} \frac{dx}{x}$$

Flux linkages with conductor A due to current IC

$$= \frac{\mu_0 I_C}{2\pi}\int_{d_2}^{\infty} \frac{dx}{x}$$

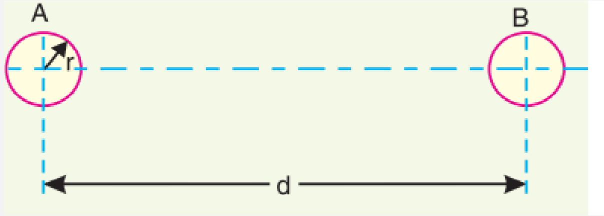


Total flux linkages with conductor *A*

$$= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4} + \int_r^{\infty} \frac{dx}{x}\right) + \frac{\mu_0 I_B}{2\pi}\int_{d_1}^{\infty} \frac{dx}{x} + \frac{\mu_0 I_C}{2\pi}\int_{d_2}^{\infty} \frac{dx}{x} + \ldots$$

Inductance of a Single Phase Two-wire Line

- Consider a single phase overhead line Consisting of two parallel conductors *A* and *B* spaced *d* metres apart,Conductors *A* and *B* carry the same amount of current (*i.e. IA* = *IB*),



- Flux linkages with conductor *A* due to its own current and IB

$$= \frac{\mu_0}{2\pi}\left[\frac{I_A}{4} - I_A \log_e r - I_B \log_e d\right] \quad (\because I_A + I_B = 0)$$

- The inductance of the two-wire line and is sometimes called loop inductance.

$$\text{Loop inductance} = 10^{-7}\left[1 + 4\log_e \frac{d}{r}\right] \text{H / m}$$

Problem

- ***A single phase line has two parallel conductors 2 metres apart. The diameter of each conductor is 1·2 cm. Calculate the loop inductance per km of the line.***

<u>Solution:</u>

Spacing of conductors, d = 2 m = 200 cm

Radius of conductor, r = 1·2/2 = 0·6 cm

Loop inductance per metre length of the line

$= 10^{-7} (1 + 4 \log_e d/r)$ H

$= 10^{-7} (1 + 4 \log_e 200/0{\cdot}6)$ H

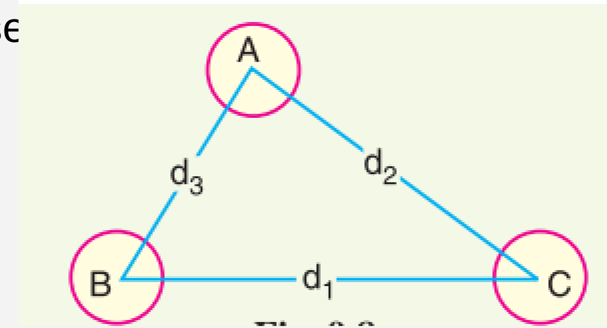
$= 24{\cdot}23 \times 10^{-7}$ H

Loop inductance per km of the line

$= 24{\cdot}23 \times 10^{-7} \times 1000 = 24{\cdot}23 \times 10^{-4}$ H = **<u>2·423 mH</u>**

Inductance of a 3-Phase Overhead Line

- Three conductors *A*, *B* and *C* of a 3-phase carrying currents *IA*, *IB* and *IC* respectively. Let *d*1, *d*2 and *d*3 be the spacing's between the conductors



- Let us further assume that the loads are balanced

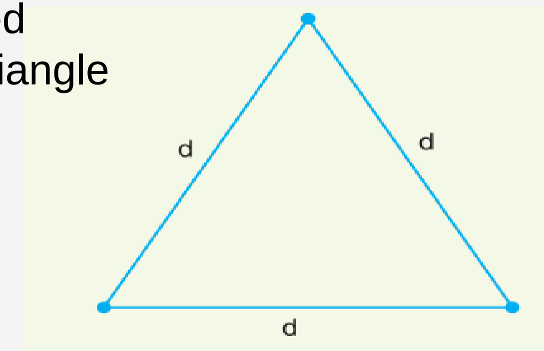
$$I_A + I_B + I_C = 0.$$

- Total flux linkages with conductor *A, due to own current, IB and IC*

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A - I_B \log_e d_3 - I_C \log_e d_2\right]$$

➢ Symmetrical Spacing

- If the three conductors *A, B* and *C* are placed symmetrically at the corners of an equilateral triangle of side *d,* then, *d*1 = *d*2 = *d*3 = *d.* Under such conditions, the flux linkages with conductor *A,*



$$= \frac{\mu_0 I_A}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{ werber-turns/m}$$

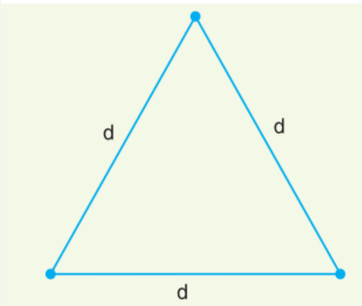
- Inductance of conductor *A,*

$$L_A = 10^{-7}\left[0 \cdot 5 + 2\log_e \frac{d}{r}\right] \text{ H/m}$$

- Derived in a similar way, the expressions for inductance are the same for conductors *B* and *C*.

Problem

- ***Find the inductance per km of a 3-phase transmission line using 1·24 cm diameter conductors when these are placed at the corners of an equilateral triangle of each side 2 m.***



Solution:

conductor spacing d = 2 m

conductor radius r = 1·24/2 = 0·62 cm.

Inductance/phase/m = 10^{-7} (0·5 + 2 $\log_e d/r$) H

= 10^{-7} (0·5 + 2 $\log_e$ 200/0·62) H

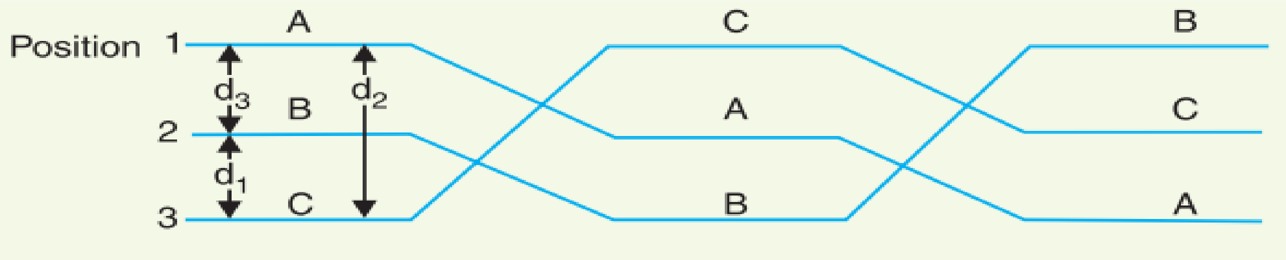
= 12 × 10^{-7} H

Inductance/phase/km = 12 × 10^{-7} × 1000

= 1·2 × 10^{-3} H = **1·2 mH**

➢ Unsymmetrical Spacing

- 3-phase transposed line having unsymmetrical spacing. Let us assume that each of the three sections is 1 m in length



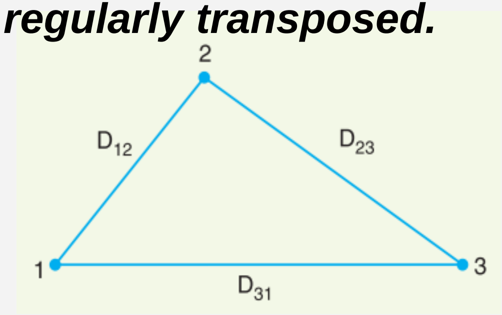
- Inducance of each line conductor

$$= \frac{1}{3}(L_A + L_B + L_C)$$

$$= \left[0 \cdot 5 + 2\log_e \frac{\sqrt[3]{d_1\, d_2\, d_3}}{r}\right] \times 10^{-7} \text{ H/m}$$

Problem

- ***The three conductors of a 3-phase line are arranged at the corners of a triangle of sides 2 m, 2·5 m and 4·5 m. Calculate the inductance per km of the line when the conductors are regularly transposed. The diameter of each conductor is 1·24 cm.***



Solution:

D12 = 2 m, *D23* = 2·5 m and *D31* = 4·5 m.

The conductor radius *r* = 1·24/2 = 0·62 cm.

$$\text{Equivalent equilateral spacing, } D_{eq} = \sqrt[3]{D_{12} \times D_{23} \times D_{31}} = \sqrt[3]{2 \times 2 \cdot 5 \times 4 \cdot 5} = 2 \cdot 82 \text{ m} = 282 \text{ cm}$$

$$\text{Inductance/phase/m} = 10^{-7}(0 \cdot 5 + 2 \log_e D_{eq}/r) \text{ H} = 10^{-7}(0 \cdot 5 + 2 \log_e 282/0 \cdot 62) \text{ H}$$

$$= 12 \cdot 74 \times 10^{-7} \text{ H}$$

$$\text{Inductance/phase/km} = 12 \cdot 74 \times 10^{-7} \times 1000 = 1 \cdot 274 \times 10^{-3} \text{ H} = \mathbf{1 \cdot 274 \text{ mH}}$$

➢ Self GMD

- The use of self geometrical mean distance and mutual geometrical mean distance simplifies the inductance calculations, particularly relating to multiconductor arrangements.

- For a solid round conductor of radius r,
  the self-GMD or GMR = 0·7788 r

- Inductance/conductor/m = $2 \times 10^{-7} \log_e d/D_s$*
  where D_s= GMR or self-GMD = 0·7788 r

➢ It depends
- **Size**
- **Shape of conductor**

➢ It not depends
- **Spacing between the conductors**

➢ Mutual GMD

- The mutual-GMD is the geometrical mean of the distances form one conductor to the other and, therefore, must be between the largest and smallest such distance

- Mutual-GMD between phases *A* and *B* is

$$D_{AB} = (D_{ab} \times D_{ab'} \times D_{a'b} \times D_{a'b'})^{1/4}$$

- Mutual-GMD between phases *B* and *C* is

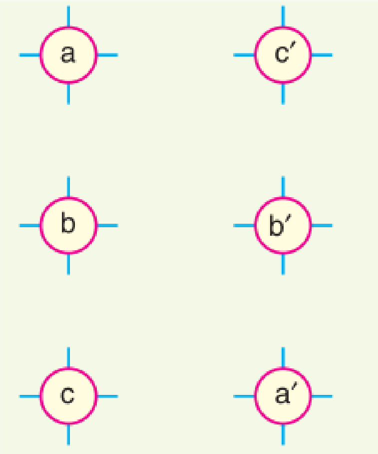
$$D_{BC} = (D_{bc} \times D_{bc'} \times D_{b'c} \times D_{b'c'})^{1/4}$$

- Mutual-GMD between phases *C* and *A* is

$$D_{CA} = (D_{ca} \times D_{ca'} \times D_{c'a} \times D_{c'a'})^{1/4}$$

- Equalent mutual GMD,

$$D_m = (D_{AB} \times D_{BC} \times D_{CA})^{1/3}$$



Problem

- ***Calculate the inductance of each conductor in a 3-phase, 3-wire system when the conductors are arranged in a horizontal plane with spacing such that D31 = 4 m ; D12 = D23 = 2m.The conductors are transposed and have a diameter of 2·5 cm.***

<u>Solution:</u>

The conductor radius r = 2·5/2 = 1·25 cm.

Equivalent equilateral spacing, $D_{eq} = \sqrt[3]{D_{12} \times D_{23} \times D_{31}} = \sqrt[3]{2 \times 2 \times 4} = 2 \cdot 52 \text{ m} = 252 \text{ cm}$

$$\text{Inductance/phase/m} = 10^{-7}\,(0{\cdot}5 + 2\log_e D_{eq}/r)\text{ H}$$

$$= 10^{-7}\,(0{\cdot}5 + 2\log_e 252/1{\cdot}25)\text{ H}$$

$$= 11{\cdot}1 \times 10^{-7}\text{H}$$

$$\text{Inductance/phase/km} = 11{\cdot}1 \times 10^{-7} \times 1000$$

$$= 1{\cdot}11 \times 10^{-3}\text{ H} = \mathbf{1{\cdot}11\ mH}$$

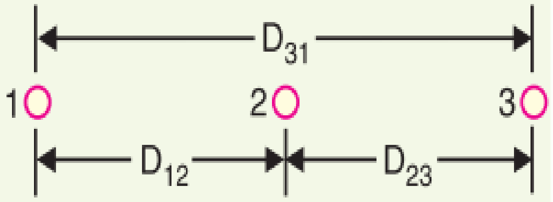
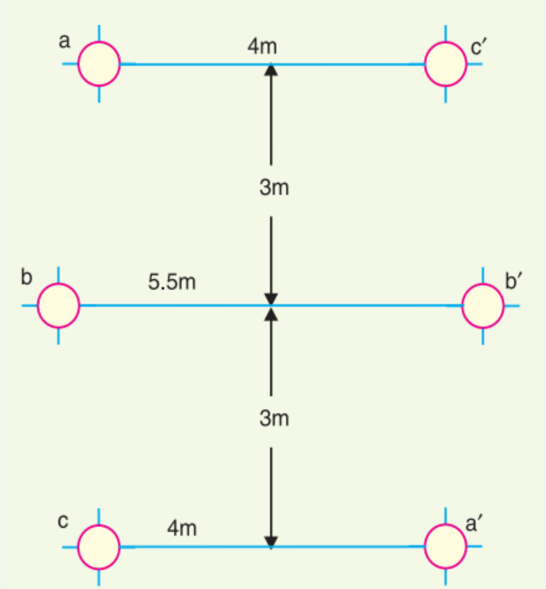


Fig. 9.13

Problem

- ***Find the inductance per phase per km of double circuit 3-phase line shown in Fig. The conductors are transposed and are of radius 0·75 cm each. The phase sequence is ABC.***



Solution:

G.M.R. of conductor = 0·75 × 0·7788 = 0·584 cm

Distance *a* to *b* = $\sqrt[3]{3^2 + 0.75^2}$ = 3·1 m

Distance *a* to *b′* = $\sqrt[3]{3^2 + 4.75^2}$ = 5·62 m

Distance *a* to *a′* = $\sqrt[3]{6^2 + 4^2}$ = 7·21 m

Equivalent self G.M.D. of one phase is

$$D_s = \sqrt[3]{D_{s1} \times D_{s2} \times D_{s3}}$$

where $$D_{s1} = \sqrt[4]{D_{aa} \times D_{aa'} \times D_{a'a'} \times D_{a'a}}$$

Contd..

$$= \sqrt[4]{\left(0\cdot 584\times 10^{-2}\right)\times(7\cdot 21)\times\left(0\cdot 584\times 10^{-2}\right)\times(7\cdot 21)} = 0{\cdot}205\text{ m} = D_{s3}$$

$$D_{s2} = \sqrt[4]{\left(D_{bb}\times D_{bb'}\times D_{b'b'}\times D_{b'b}\right)}$$

$$= \sqrt[4]{\left(0\cdot 584\times 10^{-2}\right)\times(5\cdot 5)\times\left(0\cdot 584\times 10^{-2}\right)\times 5\cdot 5} = 0\cdot 18\text{ m}$$

$$D_s = \sqrt[3]{0\cdot 205\times 0\cdot 18\times 0\cdot 205} = 0{\cdot}195\text{ m}$$

Equivalent mutual G.M.D. is

$$D_m = \sqrt[3]{D_{AB}\times D_{BC}\times D_{CA}}$$

where $$D_{AB} = \sqrt[4]{D_{ab}\times D_{ab'}\times D_{a'b}\times D_{a'b'}} = \sqrt[4]{3\cdot 1\times 5\cdot 62\times 5\cdot 62\times 3\cdot 1}$$

$$= 4{\cdot}17\text{ m} = D_{BC}$$

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Contd…

$$D_{CA} = \sqrt[4]{D_{ca} \times D_{ca'} \times D_{c'a} \times D_{c'a'}}$$

$$= \sqrt[4]{6 \times 4 \times 4 \times 6} = 4{\cdot}9 \text{ m}$$

$$D_m = \sqrt[3]{4{\cdot}17 \times 4{\cdot}17 \times 4{\cdot}9} = 4{\cdot}4 \text{ m}$$

Inductance/phase/m = 10−7 × 2 loge *Dm*/*Ds*

= 10−7 × 2 loge 4·4/0·195 H

= 6·23 × 10−7 H

= 0·623 × 10−3 mH

Inductance/phase/km = 0·623 × 10−3 × 1000

= **0·623 mH**

Thank you