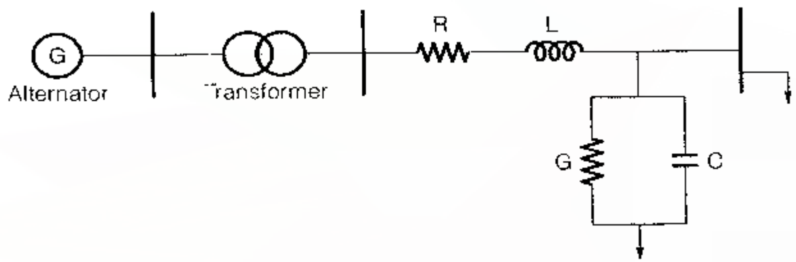
2

Line Parameters

Transmission line is a carrier on which bulk amount of power from a remote generating station to the operative areas is being carried out.



Transmission line is

(i) series combination of resistance (R) and inductance (L) and

(ii) Parallel combination of shunt conductance (G) and capacitance (C).

Note:

- The line parameter of transmission line is calculated in per unity or per km and are constant for entire line length.
- The shunt conductance is caused by leakage current.
- In transmission line if G = 0 means leakage current is assume to be zero.
- Power loss in the conductor in only due to series resistance.
- Power transmission capacity of the line is mainly governed by the series inductance.

❑ Resistance of a conductor

$$R_{eff} = \frac{\text{Power loss in conductor}}{I^2} \text{ ohms.}$$

where, R_{ef} = Effective resistance of the conductor

❑ D.C. Resistance of a Conductor

$$R_{dc} = \rho \frac{l}{A} \text{ ohms.}$$

where, ρ = Resistivity of conductor, Ω-m

l = Length of conductor, metre

A = Cross-sectional area, m^2

Note:

The effective resistance is equal to the dc resistance of the conductor only if the current is uniformly distributed through out the cross-sectional area of the conductor (i.e. for DC only).

Skin Effect

If DC is passed in a conductor, the current density is uniform over the cross-section of the conductor but when an alternating current flows through a conductor, the distribution tends to become non uniform. There is a tendency of the current to crowd near the surface of the conductor. This phenomenon is called "skin effect".

Remember:

Skin effect increases with increase in frequency, conductor diameter and permeability.

Proximity Effect

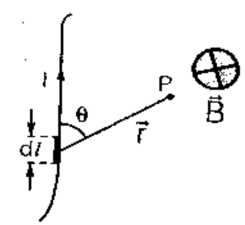
When two or more conductors are in proximity, their electromagnetic field interact with each other, with the result that the current in each of them is redistributed such that the greater current density is concentrated in that part of the strand most remote from the interfering conductor. In each case, a reduced current rating results from the apparent increase of resistance.

Magnetic Flux Density

Biot-savart's law

❑ Magnetic flux at any point produced by a current carrying element

$$dB = \frac{\mu}{4\pi} \frac{I d\vec{l} \times (\vec{r})}{r^3}$$



where, dB = Infinitesimal flux density at point P

I = Current in element

dl = Length of element

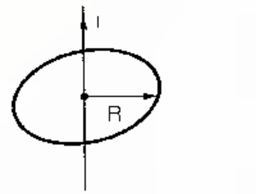
θ = Angle between current direction and radius vector to P

r = Radius vector

μ = Permeability of medium

- Magnetic flux density B at any point to an infinite conductor.

$$\boxed{B = \frac{\mu I}{2\pi R}}$$



where, R = Radial distance of the point from the conductor.

Note:

The direction of the flux density is normal to the plane containing the conductor and radius vector R.

Amperes's law

$$\boxed{\int H.dl = I_{enclosed}}$$

where, H = Magnetic field intensity

I = R.M.S. value of current enclosed by an amperian loop.

Relation Between Magnetic Flux Density and Magnetic Field Intensity

$$\boxed{B = \mu H}, \boxed{\mu = \mu_0 \mu_r}$$

where, $\mu_0 = 4\pi \times 10^{-7}$ H/m

= Permeability of free space and

μ_r = Relative permeability of the medium

μ_r = 1 (for non magnetic material)

Inductance

Inductance of an inductor is the ratio of its total magnetic flux linkages to the current I through the inductor.

$$\boxed{L = \frac{N\Psi_m}{I} = \frac{\lambda}{I}} \text{ Henry}$$

where, Ψ_m = Magnetic flux linkages through a single turn

N = Total number of turns.

λ = Total magnetic flux linkages

Above formulae is valid for a medium in which the permeability is constant.

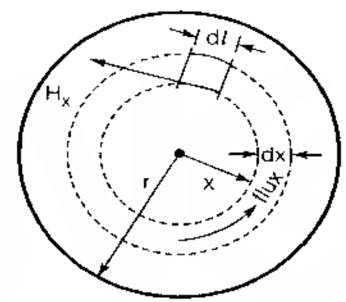
Remember:

The permeability of ferrous medium is not constant. For such cases the inductance is defined as the ratio of infinitesimal change in flux linkage to the infinitesimal change in current producing it

$$\boxed{L = \frac{d\lambda}{dI}} \text{ Henry}$$

- Flux linkages within the conductor

$$\boxed{\Psi_{int} = \frac{\mu I}{8\pi}} \text{ Wb-T/m}$$



where, Ψ_{int} = Total internal flux linkages

I = R.M.S. value of the current.

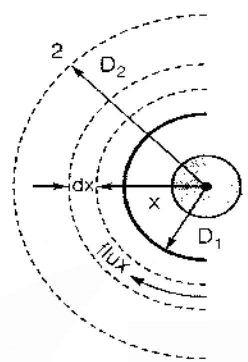
$$\boxed{\Psi_{int} = 0.5 I \times 10^{-7}} \text{ Wb-T/m}$$

- Inductance of the conductor, contributed by flux within the conductor:

$$\boxed{L_{int} = 0.5 \times 10^{-7}} \text{ H/m} \quad \text{as} \quad \boxed{L_{int} = \frac{\Psi_{int}}{I}}$$

- Flux linkages outside the conductor

$$\Psi_{12} = \frac{\mu I}{2\pi} ln\left(\frac{D_2}{D_1}\right) \text{ Wb-T/m}$$



for $\mu_r = 1$

$$\Psi_{12} = 2\times10^{-7} ln\left(\frac{D_2}{D_1}\right) \text{ Wb-T/m}$$

where Ψ_{12} = Total flux linkages between points 1 and 2

- Inductance of the conductor, contributed by flux between points 1 and 2:

$$L_{12} = 2\times10^{-7} ln\left(\frac{D_2}{D_1}\right) \text{ H/m}$$

- Inductance of a single phase two wire line:

$$L = 4\times10^{-7}\ ln\left(\frac{D}{r'}\right) \text{ H/m}$$

where, D = Distance between two solid conductors of same radii r

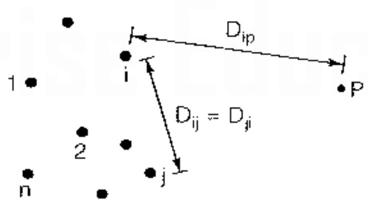
r' = Radius of fictitious conductor

= 0.7788 r

- Flux linkages of one conductor in an array:

Figure shows an array of n long round conductors suspended parallel to each other in space and carrying currents $I_1, I_2, \ldots, I_n$.

Such that: $I_1 + I_2 + I_3 + \ldots + I_n = 0$



$$\Psi_i = 2\times10^{-7}\left[I_1\, ln\frac{1}{D_{i1}} + I_2\, ln\frac{1}{D_{i2}} + \ldots + I_i\, ln\frac{1}{D_{ii}} + \ldots + I_n\, ln\frac{1}{D_{in}}\right] \text{ Wb-T/m}$$

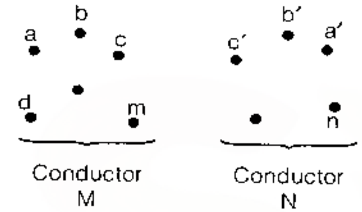
where, Ψ_i = Total flux linkages of conductor i

D_{ij} = Centre to centre distance between conductor i and j

D_{ii} = Distance of conductor i from itself and equals $0.7788\, r_i$

Inductance of Composite Conductor Lines

Conductor M consists of m similar parallel sub-conductors and conductor N consists of n similar parallel sub-conductors.



(Single phase line having composite conductors)

If line current is I, then each strand of conductor M carries a current I/m and each strand of conductor N carries a current of –I/n (the conductor N being the return conductor).

$$L_M = 2\times10^{-7}\times ln\frac{\left[(D_{aa'}D_{ab'}\ldots D_{an})(D_{ba'}D_{bb'}\ldots D_{bn})\ldots(D_{ma'}D_{mb'}\ldots D_{mn})\right]^{1/mn}}{\left[(D_{aa}D_{ab}\ldots D_{am})(D_{ba}D_{bb}\ldots D_{bm})\ldots(D_{ma}D_{mb}\ldots D_{mm})\right]^{1/m^2}} \text{ H/m}$$

where, L_M = inductance of conductor M

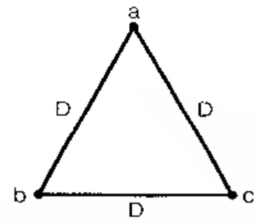
$$L = 2\times10^{-7}\ ln\left(\frac{GMD}{GMR}\right)$$

Remember:

- GMD = mnth root of the product of mn distances (known as the geometric mean distance between conductor M and conductor N and denoted by D_m).
- GMR = $(m^2)^{th}$ root of the product of m^2 distances these being the distances from each sub-conductor of conductor M to every other sub-conductor of conductor M (including $D_{aa}, D_{bb} \ldots D_{mm}$).
- GMR = Geometric mean radius (denoted by D_s).
- D_{aa} = 0.7788 times the radius of sub-conductor 'a'.

Inductance of 3-ϕ Line With Equivalent Spacing.

Assuming balanced currents i.e. ($I_a + I_b + I_c = 0$)



$$\boxed{L_a = 2 \times 10^{-7}\, ln\left(\frac{D}{r'}\right)} \text{ H/m}$$

where, L_a = Inductance of phase a

D = Distance between any two phases

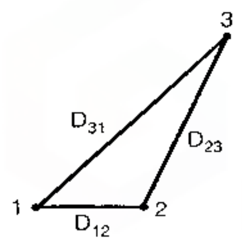
r' = 0.7788r = Radius of fictitious conductor

= 0.7788 times the radius of conductor

$L_a = L_b = L_c$ (Because of symmetry)

Inductance of 3-ϕ line with unsymmetrical spacing

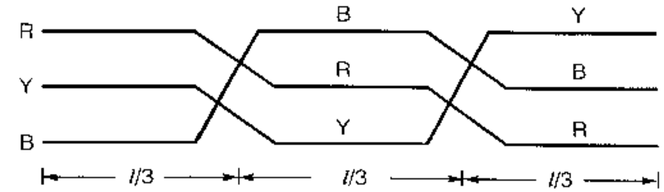
In this case the lines are transposed.



Transposition of transmission line

When ever 3ϕ unsymmetrical line running parallel and neighbour to the communication line it cause interference in the communication line. In order to eliminate the communication interference transposition of line is recommended.

Change the position of power conductor at regular interval with equidistance for a given line length, so that the position of power conductor is replaced by its successive phase conductor.



Advantages of Transposition

(i) Net resultant flux ϕ_r which link with communication line become zero.

(ii) GMD/phase equal.

(iii) L/phase equal.

(iv) I/phase equal.

(v) Flux per phase equal.

Note:

Transposition of transmission line is an old technique. The radio interference is eliminated by completely insulating any one of the phases.

Inductance of Phase-1

$$\boxed{L_1 = 2 \times 10^{-7}\, ln\left(\frac{D_{eq}}{r'}\right)} \text{ H/m}$$

where, L_1 = inductance of phase 1

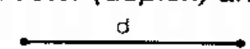
$D_{eq} = \sqrt[3]{D_{12}D_{23}D_{31}}$

= Equivalent spacing

= Geometric mean of the distance of the line.

Inductance of Bundled Conductor Lines

(a) For a two conductor (duplex) arrangement

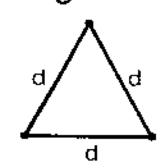


$$D_s^b = \sqrt[4]{(D_s.d)^2} = \sqrt{D_s \cdot d}$$

(b) For a three conductor (tripex) arrangement

$$D_s^b = \sqrt[9]{(D_s \cdot d \cdot d)^3}$$

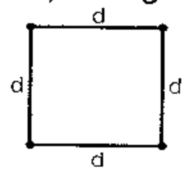
$$= \sqrt[3]{D_s \cdot d^2}$$



(b) For a four-conductor (quadruplex) arrangement

$$D_s^b = \sqrt[16]{(D_s \cdot d \cdot d \cdot d\sqrt{2})^4}$$

$$= 1.09 \times \sqrt[4]{D_s \cdot d^3}$$



where, D_s^b = Geometric mean radius of bundled conductor

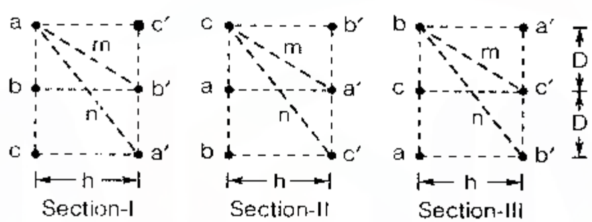
D_s = Geometric mean radius of each sub-conductor of bundle

d = Spacing between the sub-conductors of a bundle

Remember:

- GMD of a bundled conductor line can be found by taking the root of the product of distances from each conductor of a bundle to every other conductor of other bundles.
- Inductance of bundled conductor line is less than the inductance of the line with one conductor per phase.

Inductance of Double Circuit 3-ϕ Line



Inductance per phase per metre length

$$\boxed{L = 2 \times 10^{-7}\, ln\left[2^{1/6}\left(\frac{D}{r'}\right)^{1/6} \cdot \left(\frac{m}{n}\right)^{1/3}\right]} \text{ H/phase/m.}$$

Mutual Inductance

Mutual inductance is defined as the flux linkages of one circuit due to the current in the second circuit per-ampere of current in the second circuit. If the current I_2 produces λ_{12} flux linkages with circuit 1. The mutual inductance is

$$\boxed{M_{12} = \frac{\lambda_{12}}{I_2}} \text{ Henry}$$

Electrical Field and Potential Difference

- The lines of electric flux originate on the positive charges on one conductor and terminate on the negative charges on the other conductor.
- If a long straight cylindrical conductor has a uniform charge throughout its length and is isolated from other charges.

❑ **Electric field intensity E at any point**

$$\boxed{E = \frac{q}{2\pi \in x}} \text{ V/m}$$

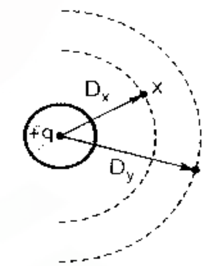
where, q = Charge on conductor per unit length

$\in$ = Permittivity of the medium

x = Distance from conductor to the point under consideration.

❑ **The potential difference between two points**

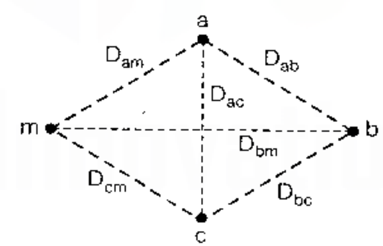
$$\boxed{V_{xy} = \frac{q}{2\pi \in}\, ln\left(\frac{D_y}{D_x}\right)} \text{ Volts.}$$



where, D_x, D_y = Distance of point x and y from charge q

q = Charge per unit length

❑ **The potential difference between two conductor of an array of parallel conductors**



(An array of m charged conductors)

$$\boxed{V_{ab} = \frac{1}{2\pi \in}\left[q_a\, ln\frac{D_{ab}}{r_a} + q_b\, ln\frac{r_b}{D_{ba}} + q_c\, ln\frac{D_{cb}}{D_{ca}} + \dots + q_m\, ln\frac{D_{mb}}{D_{ma}}\right]}$$

Capacitance

Capacitance of Two Wire Line

$$C_{ab} = \frac{0.01206}{\log\left(\frac{D}{r}\right)} \ \mu F/km$$

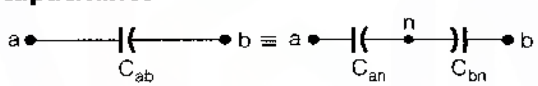
where, C_{ab} = Capacitance between the conductors per unit length
q = Charge per unit length
r = Radius of conductor a and b

If the conductor have different radii

$$C_{ab} = \frac{0.01206}{\log\left(\frac{D}{\sqrt{r_a r_b}}\right)} \ \mu F/km$$

where, r_a, r_b = Radius of conductor 'a' and conductor 'b' respectively.
C_{ab} = Line to line capacitance

Line to neutral capacitance



$$C_{an} = C_{bn} = 2C_{ab}$$

Charging Current

- The current caused by the alternate charging and discharging of the line due to alternating voltage is called **charging current** of the line.

Note: Charging current flows in a line even when the line is open circuited and affects the voltage drop, efficiency and power factor of the line.

Charging Current for 1-φ line

$$I_C = j\omega C_{ab} V_{ab} = j\,2\pi f\, C_{ab} V_{ab}$$

where, V_{ab} = Potential difference between conductor a and b
f = Frequency of alternating voltage

Capacitance of 3-φ line with equilateral spacing

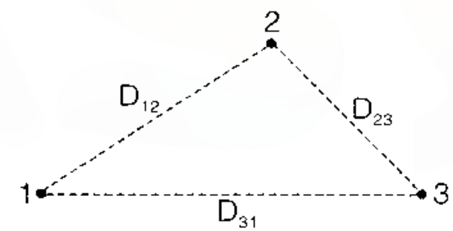
$$C_n = \frac{0.02412}{\log\left(\frac{D}{r}\right)} \ \mu F/km$$

where, C_n = Line to neutral capacitance
D = Spacing between conductors
r = Radius of each conductor

Charging current per phase

$$I_C = j\omega C_n V_{an}$$

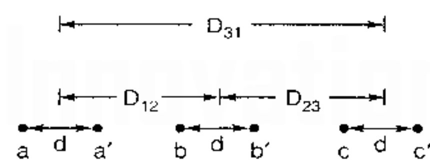
Capacitance of 3-φ line with asymmetrical spacing



$$C_n = \frac{0.02412}{\log\left(\frac{D_{eq}}{r}\right)} \ \mu F/km$$

where, $D_{eq} = \sqrt[3]{D_{12} D_{23} D_{31}}$

Capacitance of bundled conductor lines



$$C_n = \frac{0.02412}{\log\left(\frac{D_{eq}}{\sqrt{rd}}\right)} \ \mu F/km$$

The term $\sqrt{rd}$ is known as GMR or self GMD for a two bundle; denoted by D_{sc}^{b}

(a) For a two conductor bundle

$$D_{sc}^{b} = \sqrt{rd}$$

(b) For a three conductor bundle

$$D_{sc}^{b} = \sqrt[9]{(r \times d \times d)^3} = \sqrt[3]{rd^2}$$

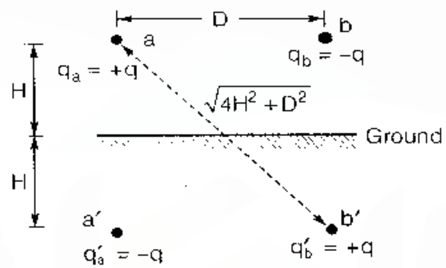
(c) For a four conductor bundle

$$D_{sc}^{b} = \sqrt[16]{(r \times d \times d \times \sqrt{2}d)^4} = 1.09\sqrt[4]{rd^3}$$

Effect of Ground on Line Capacitance (Method of Images)

The presence of ground alters the electric field of a line and hence affect the line capacitance.

(a) ***For 1-ϕ line***



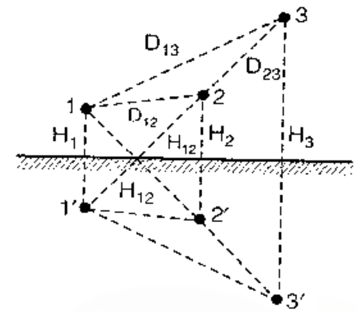
$$C_{ab} = \frac{0.01206}{\log\left(\dfrac{D}{r\left(1+\dfrac{D^2}{4H^2}\right)^{0.5}}\right)} \ \mu F/km$$

where, H = Height of conductor from ground

$$C_{an} = 2C_{ab} = \frac{0.02412}{\log\left(\dfrac{D}{r'}\right)} \ \mu F/km$$

$$r' = r\sqrt{1+\left(\frac{D}{2H}\right)^2}$$

(b) ***For 3-ϕ line***



Conductors of a 3-phase line with image charges

$$C_n = \frac{0.02412}{\log\left(\dfrac{D_{eq}}{r}\right) - \log\left[\dfrac{\sqrt[3]{H_{12}H_{23}H_{31}}}{\sqrt[3]{H_1H_2H_3}}\right]}$$

where, H_1, H_2, H_3, and H_{12}, H_{23}, H_{31} are shown in figure. C_n is in μF/km.

Remember:

Presence of ground increases the line capacitance by small amount.

■■■■