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.

Some of the empirical formulae are

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

$$S = \sqrt{d} + 0{\cdot}012V$$

$$S = 0{\cdot}75\sqrt{d} + \frac{V}{150}$$

$$S = 0{\cdot}75\sqrt{d} + \frac{V^2}{20000}$$

$$S = 0{\cdot}7\sqrt{d} + \frac{V}{100} + 0{\cdot}25$$

$$S = 0{\cdot}65\sqrt{d} + 0{\cdot}007$$

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

$$S = 0{\cdot}8\sqrt{d+l} + \frac{V}{150}$$

$$S = 0{\cdot}75\sqrt{(d+l)\sin\theta} + \frac{V}{125}$$

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.

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 : 132kV line

$$132\,kV = 33 + \frac{(132-33)}{33} \times 33 = 33 + 3 \times 33\,kV$$

$\therefore$ Ground clearance $= 5.18 + 3 \times 0.3048 = 6.0944\,m$

Example : 400kV line

$$400\,kV = 33 + \frac{(400-33)}{33} \times 33 = 33 + 11.1212 \times 33\,kV$$

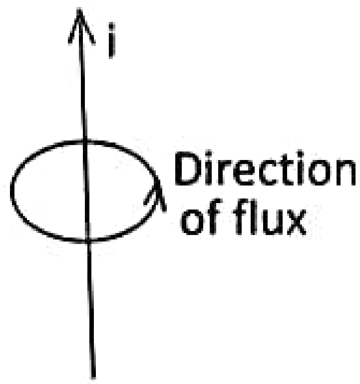
$\therefore$ Ground clearance $= 5.18 + 11.1212 \times 0.3048 = 8.5697\,m$

Line Parameters

- Any electric transmission line has four parameters, namely- resistance, inductance, capacitance & shunt conductance.
- Design & performance of lines depend on these parameters.
- These are uniformly distributed along the whole line.
- So, theses 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.

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.,



$$|e| = \frac{d}{dt}(N\Phi) = N.\frac{d\Phi}{dt} \text{ Volt ..... (1)}$$

- 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.

$$|e| \propto \frac{di}{dt} \text{ or, } |e| = L.\frac{di}{dt} \text{ Volt ..... (2)}$$

where, L is the constant of proportionality & is known as self inductance of the circuit.

Equating eqns. (1) & (2),

$$L.\frac{di}{dt} = N.\frac{d\Phi}{dt}$$

$$\text{or, } L = N.\frac{d\Phi}{di} \text{ ..... (3)}$$

- If permeability of the magnetic circuit is assumed to be constant, then, $\frac{d\Phi}{di} = \frac{\Phi}{i}$.
- Therefore, from eqn. (3),

$$L = N.\frac{\Phi}{i} \text{ Henry ..... (4)}$$

- For a single conductor,

$$L = \frac{\Phi}{i} \text{ Henry ..... (5)}$$

Inductance of a Conductor

- Consider, a solid, round, infinitely long conductor, situate in air - of radius 'r' & carrying a current of 'i.'
- Flux linking with conductor has of 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 conds. in the vicinity.
- External flux links with the whole cond.

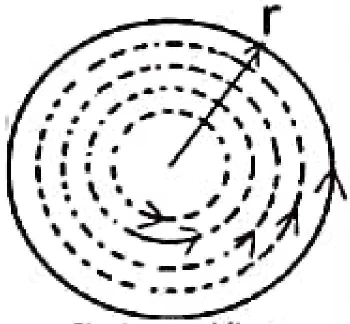


Fig. Internal flux

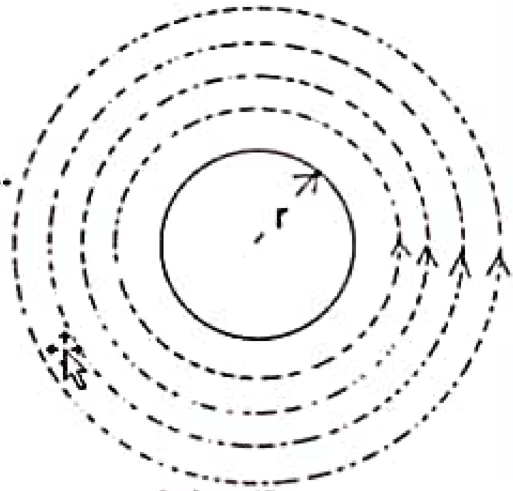


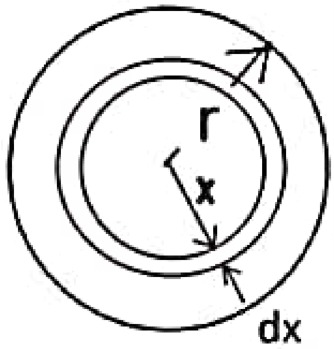
Fig. External flux

•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 cond.

- Consider, a distance 'x' & an elemental distance 'dx' there.
- Magnetic field intensity at distance 'x' be 'H_x.'

Applying Ampere's law,

$$2.\pi.x.\ H_x = i_x \quad ..... (1)$$

where i_x is current enclosed by the path.

Or, $H_x = \frac{i_x}{2.\pi.x}$ AT/m .... (2)

Now, current density $= \frac{i}{\pi.r^2}$ .... (3)

Therefore, $i_x = \pi.x^2$. current density $= \pi.x^2.\frac{i}{\pi.r^2} = \frac{x^2}{r^2}.i$ A ..... (4)

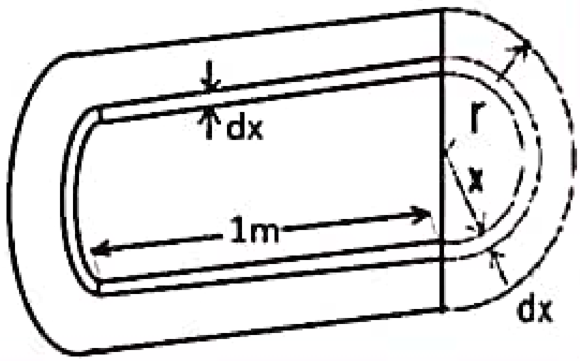
So, $H_x = \frac{x^2}{r^2}.i.\frac{1}{2.\pi.x} = i.\frac{x}{2.\pi.r^2}$ AT/m.................................... (5)

Now, flux density $= B_x = \mu.H_x = \mu.i.\frac{x}{2.\pi.r^2}$ wb/m^2 .... (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 $= d\Phi_x = B_x.(dx.1) = \mu.i.\frac{x}{2.\pi.r^2}.dx$ wb......... (7)

Again, flux linkage = flux . (no. of turns)

Here, $d\Phi_x$ links with $\frac{x^2}{r^2}$ fraction of cond.



So, flux linkage up to 'x' $= d\lambda_x = d\Phi_x . \frac{x^2}{r^2} = \mu . i . \frac{X}{2.\pi.r^2} . dx . \frac{x^2}{r^2}$

$$= \mu . i . \frac{x^3}{2.\pi.r^4} . dx \text{ wbT/m} \quad \ldots\ldots\ldots\ldots\ldots (8)$$

Total internal flux linkage $= \int_0^r d\lambda_x = \int_0^r \mu . i . \frac{x^3}{2.\pi.r^4} . dx$

$$= \frac{\mu . i}{2.\pi.r^4} . \frac{r^4}{4} = \frac{\mu . i}{8\pi} \text{ wbT/m} \quad \ldots\ldots\ldots\ldots\ldots (9)$$

Internal inductance $L_{in} = \frac{\text{Total internal flux linkage}}{\text{Current}}$

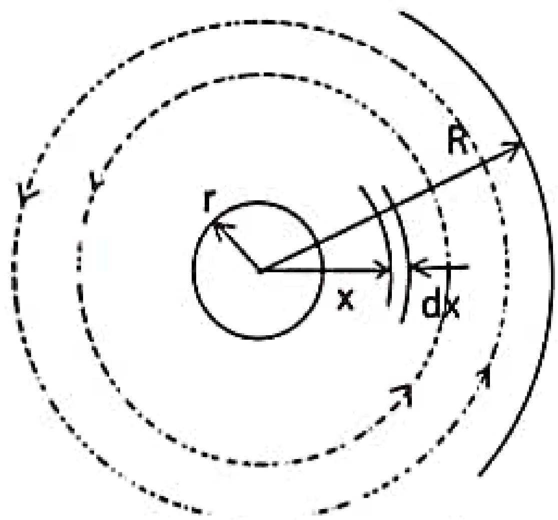
$$= \frac{\frac{\mu . i}{8\pi}}{i} = \frac{\mu}{8\pi} = \frac{\mu_0 . \mu_r}{8\pi} \text{ H/m} \quad \ldots\ldots\ldots\ldots\ldots (10)$$

If the conductor is suspended in air & cond. material is non-magnetic, then $\mu_r = 1$.

Then, $L_{in} = \frac{\mu_0}{8\pi}$ H/m $= \frac{4.\pi.10^{-7}}{8\pi} = \frac{1}{2}.10^{-7}$H/m .... (11)

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

'x' $= H_x = \frac{i}{2.\pi.x}$ AT/m .... (12)

Flux density $= B_x = \mu_0. H_x = \frac{\mu_0.i}{2.\pi.x}$ wb/m^2

Flux through the cylindrical shell of thickness 'dx' & length of

1m $= d\Phi_x = B_x. (dx.1) = \frac{\mu_0.i}{2.\pi.x}\, .\, dx$ .... (13)

This flux links with the whole conductor. So, flux linkage up to any distance 'x' = $d\lambda_x = d\Phi_x$ wbT/m ..... (14)

Therefore, total external flux linkage up to any very large but finite distance 'R' = $\int_0^R d\lambda_x = \int_0^R \frac{\mu_0 . i}{2.\pi.x} . dx = \frac{\mu_0 . i}{2.\pi} . \ln\frac{R}{r}$ wbT/m ..... (15)

Then, External inductance $L_{ex} = \frac{\text{Total external flux linkage}}{\text{Current}}$

$$= \frac{\mu_0}{2\pi} . \ln\frac{R}{r}\ \text{H/m} = \frac{4.\pi.10^{-7}}{2\pi} = 2.10^{-7} . \ln\frac{R}{r}\ \text{H/m} \quad ..... (16)$$

So, total inductance of the cond. per metre = $L = L_{in} + L_{ex}$

$$= \frac{1}{2} . 10^{-7} + 2.10^{-7} . \ln\frac{R}{r}\ \text{H/m} \quad ..... (17)$$

Simplifying, $L = 2.10^{-7} . \ln\frac{R}{r'}$ H/m .... (18)

where $r' = r.\, e^{-\frac{1}{4}} = 0.7788.\, r$ = equivalent radius of cond.

Flux Linkage in a Group of Conductors

- Consider, a group of 'n' long, parallel round conductors.
- Carrying currents $I_a, I_b, \dots I_n$.
- Forming a circuit, i.e.

$$I_a + I_b + I_c + \cdots + I_n = 0$$

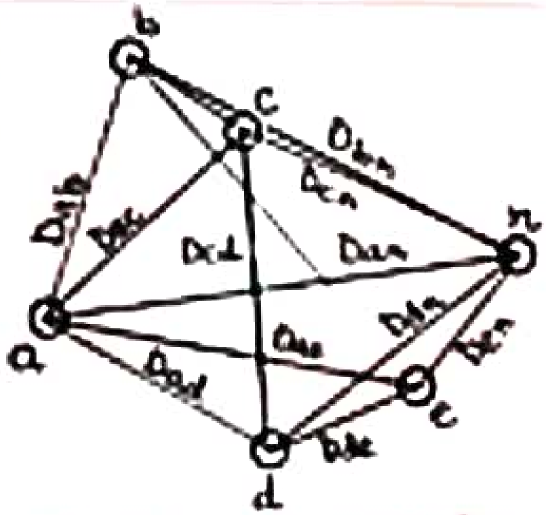


Fig. n-parallel conductors

- Distances $D_{ab}, D_{bc}, D_{ca}, \dots D_{an}$ etc.

are large compared to the radii $r_a, r_b, \dots r_n$ etc.

- Current distribution is uniform over the cross sectional area.
- The system is unaffected by external fields.

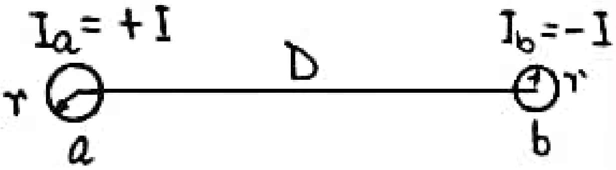
Flux linkage of any conductor 'a' is λ_a

$$=2.10^{-7}\left[I_a \ln\frac{1}{D_{aa}}+I_b.\ln\frac{1}{D_{ab}}+I_c.\ln\frac{1}{D_{ac}}+\cdots+I_n\ln\frac{1}{D_{an}}\right] \text{wbT/m}$$

$$=2.10^{-7}\sum_{x=a}^{n} I_x \ln\frac{1}{D_{ax}} \text{ wbT/m}$$

$\therefore$ Inductance of conductor 'a' $= L_a = \dfrac{\lambda_a}{I_a}$ H/m

Inductance of 1Φ Line



Flux linkage of conductor 'a' $=\lambda_a$

$$=2.10^{-7}\sum_{x=a}^{b} I_x.\ln\frac{1}{D_{ax}}=2.10^{-7}\left[I_a\ln\frac{1}{D_{aa}}+I_b.\ln\frac{1}{D_{ab}}\right]$$

$$=2.10^{-7}\left[I.\ln\frac{1}{r'}-I.\ln\frac{1}{D}\right]=2.10^{-7}\, I\ln\frac{D}{r'} \text{ wbT/m}$$

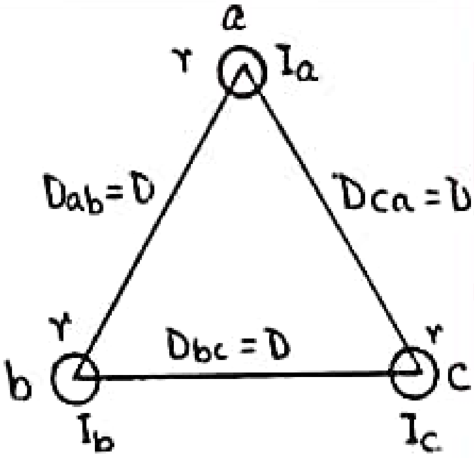
Inductance of conductor 'a' $= L_a = \dfrac{\lambda_a}{I_a} = 2.10^{-7}\ln\dfrac{D}{r'}$ H/m

Similarly, inductance of conductor 'b'

$$= L_b = 2.10^{-7} \ln \frac{D}{r'} \text{ H/m}$$

So, total inductance $= L_{ab}$

$$= L_a + L_b = 4 \cdot 10^{-7} \cdot \ln \frac{D}{r'} \text{ H/m}$$



Here, $I_a + I_b + I_c = 0$

$r' = 0.7788 r$

Inductance of Symmetrical 3Φ Line

- Symmetrical 3ϕ line: Conductors placed at corners of an equilateral triangle.
- Arrangement is also known as equilateral spacing

Flux linkage of conductor 'a' $= \lambda_a$

$$= 2.10^{-7} \sum_{x=a}^{c} I_x \ln \frac{1}{D_{ax}} \text{ wbT/m}$$

$$= 2.10^{-7} \left[I_a \ln \frac{1}{D_{aa}} + I_b \ln \frac{1}{D_{ab}} + I_c \ln \frac{1}{D_{ac}} \right] \text{ wbT/m}$$

$$= 2.10^{-7}\left[I_a \ln\frac{1}{r'} + I_b \ln\frac{1}{D} + I_c \ln\frac{1}{D}\right] \text{wbT/m}$$

$$= 2.10^{-7}\left[I_a \ln\frac{1}{r'} + (I_b + I_c) \ln\frac{1}{D}\right]$$

$$= 2.10^{-7}\left[I_a \ln\frac{1}{r'} - I_a \ln\frac{1}{D}\right] \text{(as, } I_b + I_c = -I_a\text{)}$$

$$= 2.10^{-7} . I_a . \ln\frac{D}{r'} \quad \text{wbT/m}$$

So, inductance of conductor 'a' $= L_a = \dfrac{\lambda_a}{I_a}$

$$= 2.10^{-7} \ln\frac{D}{r'} \quad \text{H/m}$$

Again, flux linkage of conductor 'b' $= \lambda_b$

$$= 2.10^{-7} \sum_{x=b}^{c} I_x . \ln\frac{1}{D_{bx}} \quad \text{wbT/m}$$

$$= 2.10^{-7}\left[I_b \ln\frac{1}{D_{bb}} + I_a \ln\frac{1}{D_{ba}} + I_c \ln\frac{1}{D_{bc}}\right]$$

$$= 2.10^{-7}\left[I_b \ln\frac{1}{r'} + (I_a + I_c)\ln\frac{1}{D}\right]$$

$$= 2.10^{-7}\left[I_b \ln\frac{1}{r'} - I_b \cdot \ln\frac{1}{D}\right]$$

$$= 2.10^{-7}\, I_b \cdot \ln\frac{D}{r'}, \text{ WbT/m}$$

So, inductance of conductor 'b' $= L_b = \dfrac{\lambda_b}{I_b}$

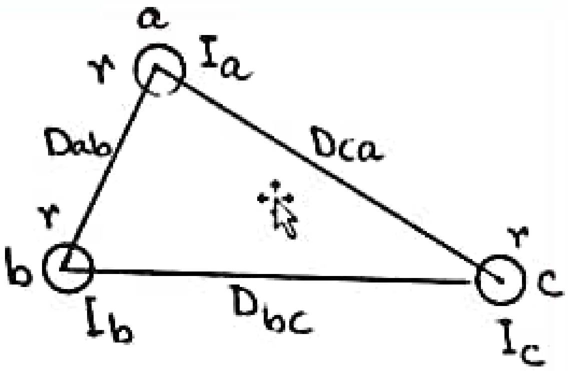
$$= 2.10^{-7} \ln\frac{D}{r'} \text{ H/m}$$

Similarly, inductance of conductor 'c' $= L_c$

$$= 2.10^{-7} \ln\frac{D}{r'} \text{ H/m}$$

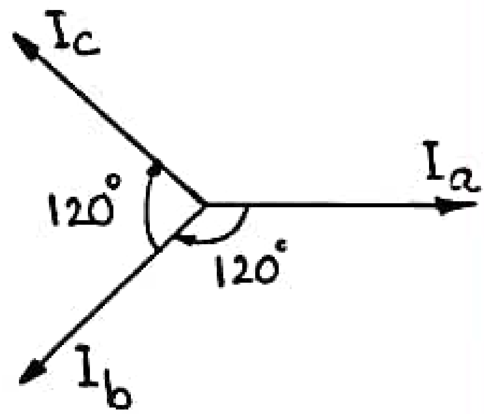
Hence, for same conductor and line geometry inductance per conductor of 3ϕ symmetrical line and 1ϕ line are equal.

Inductance of unsymmetrical 3Φ Line



- Take phase sequence as a-b-c.
- Take I_a as reference phasor.

$$I_a = I(1 + j0)$$
$$I_b = I\left(-\tfrac{1}{2} - j\sqrt{3}/2\right)$$
$$I_c = I\left(-\tfrac{1}{2} + j\sqrt{3}/2\right)$$



Flux linkage of conductor 'a' $= \lambda_a$

$$= 2.10^{-7} \sum_{x=a}^{c} I_x \ln \frac{1}{D_{ax}} \text{ WbT/m}$$

$$= 2.10^{-7}\left[I_a \ln \frac{1}{D_{aa}} + I_b \ln \frac{1}{D_{ab}} + I_c \ln \frac{1}{D_{ac}}\right]$$

$$= 2.10^{-7}\left[I(1+j0).\ln \frac{1}{r'} + I\left(-\tfrac{1}{2} - j\sqrt{3}/2\right).\ln \frac{1}{D_{ab}} + I\left(-\tfrac{1}{2} + j\sqrt{3}/2\right) \ln \frac{1}{D_{ac}}\right]$$

$$= 2.10^{-7}.I\left[\ln \frac{1}{r'} - \frac{1}{2}\ln \frac{1}{D_{ab}} - \frac{1}{2}\ln \frac{1}{D_{ac}} + j\sqrt{3}/2.\ln \frac{1}{D_{ac}} - j\sqrt{3}/2 \ln \frac{1}{D_{ab}}\right]$$

$$= 2.10^{-7}\, I\left[\ln\frac{1}{r'} - \frac{1}{2}\ln\frac{1}{D_{ab}.D_{ac}} + j\sqrt{3}/2\ln\frac{D_{ab}}{D_{ac}}\right]$$

$$= 2.10^{-7}.\, I\left[\ln\frac{\sqrt{D_{ab}.D_{ac}}}{r'} + j\sqrt{3}/2.\ln\frac{D_{ab}}{D_{ac}}\right] WbT/m$$

So, inductance of conductor 'a' $= L_a = \frac{\lambda_a}{I_a}$

$$= 2.10^{-7}\left[\ln\frac{\sqrt{D_{ab}D_{ac}}}{r'} + j\sqrt{3}/2\ln\frac{D_{ab}}{D_{ac}}\right] H/m$$

Similarly,

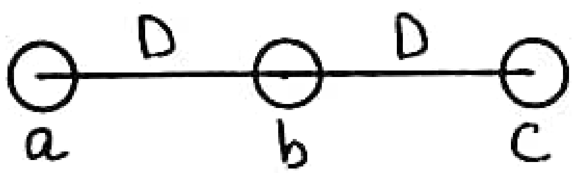
Inductance of conductor 'b' $= L_b$

$$= 2.10^{-7}\left[\ln\frac{\sqrt{D_{bc}D_{ba}}}{r'} + j\sqrt{3}/2\ln\frac{D_{bc}}{D_{ba}}\right] H/m$$

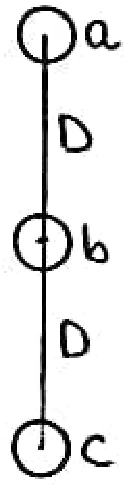
Inductance of conductor 'c' $= L_c$

$$= 2.10^{-7}\left[\ln\frac{\sqrt{D_{ca}D_{cb}}}{r'} + j.\sqrt{3}/2\ln\frac{D_{cb}}{D_{ca}}\right] H/m$$

- Inductances of the three phases are unequal.
- Although, currents are balanced, inductances are unbalanced.
- Inductive voltage drops are unequal.
- Inductances are complex as λ_a, λ_b & λ_c are not in phase with I_a, I_b & I_c respectively.
- Due to the imaginary part power transfer takes place between the phases by mutual induction.
- However, total power transfer in any case is zero.



Flat horizontal spacing



Flat vertical spacing

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 $= V_L$

$= I.\ j\omega L = j\omega.\ I\ (a + jb - jc)$

Therefore, apparent power $= V_L.\ I = j\omega.\ I^2(a + jb - jc)$

$= j\omega\ I^2a - \omega.\ I^2b + \omega.\ I^2c$ ..... (1)

In eqn (1):

$j\omega\ I^2a$ = reactive power.

$- \omega.\ I^2b$ = negative active power = power received from other phases by mutual induction.

$+ \omega.\ I^2c$ = positive active power = power supplied to other phases by mutual induction.

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

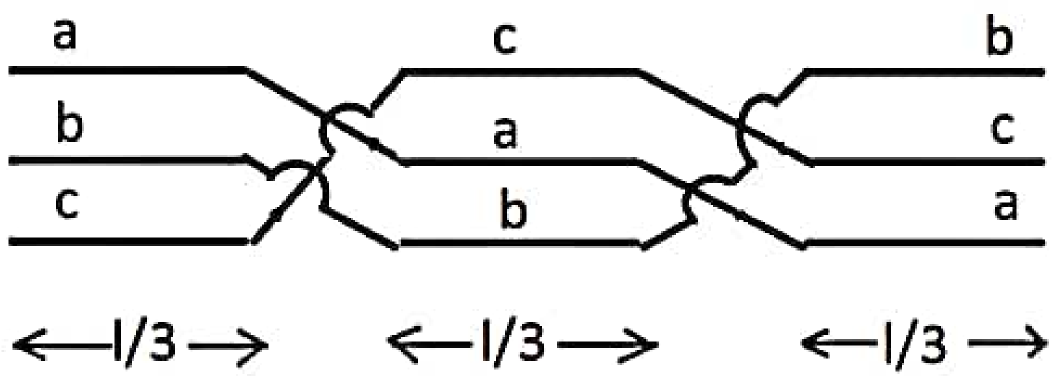
(i) Unequal inductances, hence unequal inductive reactances of the three phases.

(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.

- These problems can be avoided/ reduced by transposition of transmission line conductors.
- In transposed 3Φ transmission lines all phase conductors occupy positions of other phase conductors for almost same length.



Inductance of conductor 'a' is L_a

$= \frac{1}{3}$[Inductance for 1st 1/3 rd length + inductance for 2nd 1/3 rd length + inductance for 3rd 1/3 rd length]

$$= \frac{2.10^{-7}}{3}\left[\ln\frac{\sqrt{D_{ab}.D_{ac}}}{r'} + j\frac{\sqrt{3}}{2}\ln\frac{D_{ab}}{D_{ac}} + \ln\frac{\sqrt{D_{bc}D_{ba}}}{r'} + j\frac{\sqrt{3}}{2}\ln\frac{D_{bc}}{D_{ba}} + \ln\frac{\sqrt{D_{ca}D_{cb}}}{r'} + j\frac{\sqrt{3}}{2}\ln\frac{D_{ca}}{D_{cb}}\right] H/m$$

$$= \frac{2.10^{-7}}{3}\left[\ln\frac{\sqrt{D_{ab}^2 D_{bc}^2 D_{ca}^2}}{(r')^3} + j\frac{\sqrt{3}}{2}\ln\frac{D_{ab}.D_{bc}.D_{ca}}{D_{ab}.D_{bc}.D_{ca}}\right]$$

$$= \frac{2.10^{-7}}{3}.3.\ln\frac{\sqrt[3]{D_{ab}.D_{bc}.D_{ca}}}{r'} + j.0$$

So, $L_a = 2.10^{-7}\ln\frac{\sqrt[3]{D_{ab}.D_{bc}.D_{ca}}}{r'}$ H/m

Similarly, $L_b = L_c = 2.10^{-7}. \ln \frac{\sqrt[3]{D_{ab}.D_{bc}.D_{ca}}}{r'}$ H/m

$$= 2.10^{-7} \ln \frac{D_{eq}.}{r'} \text{ H/m}$$

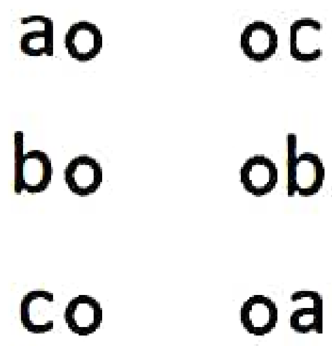
Where, $D_{eq} = \sqrt[3]{D_{ab}.D_{bc}D_{ca}}$

= Geometric mean of D_{ab}, D_{bc} & D_{ca}

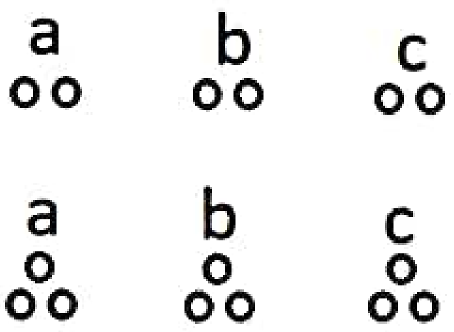
= Equivalent delta spacing/

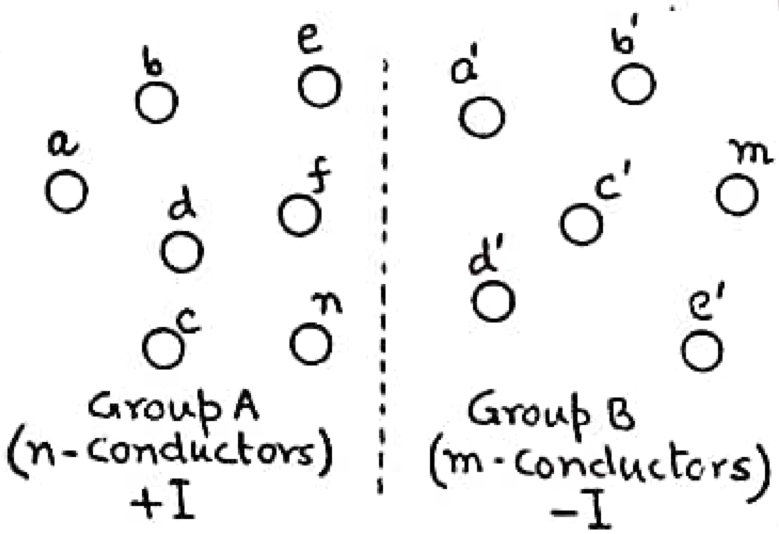
Equivalent equilateral spacing

Method of Geometric Mean Distance (GMD)



- This method is very convenient & useful to calculate inductance of a line, having several conductors connected in parallel for each phase.
- It is applicable to all cases of multi-strand or bundled conductor lines.





- Consider a 1ϕ line with two groups of conductors 'A' & 'B'
- Group A consists of 'n' parallel, round & very long conductors, connected in parallel.
- Total current carried by group A is $+I$.
- Each conductor of group A carries a current of $+I/n$.
- Similarly, each conductor of group B carries a current of $-I/m$.

Then,

Inductance of group A, consisting of 'n' conductors $= L_A$

$$= 2.10^{-7} \ln \frac{\left[(D_{aa'}.D_{ab'}\cdots D_{am}).(D_{ba'}.D_{bb'}\cdots D_{bm})\cdots\cdots(D_{na'}D_{nb'}\cdots D_{nm})\right]^{\frac{1}{m.n}}}{\left[(D_{aa}.D_{ab}\cdots D_{an}).(D_{ba}.D_{bb}\cdots D_{bn})\cdots\cdots(D_{na}.D_{nb}\cdots D_{nn})\right]^{\frac{1}{n^2}}} \text{ H/m}$$

$$= 2.10^{-7} \ln \frac{D_m}{D_S} \text{ H/m}$$

where,

- $D_m = [(D_{aa'}.D_{ab'}\dots D_{am}).(D_{ba'}.D_{bb'}\dots D_{bm})\dots\dots(D_{na'}D_{nb'}\dots D_{nm})]^{\frac{1}{m.n}}$

  = All possible distances $(m\times n)$ between conductors of groups A & B for which $(m\times n)^{th}$ root is taken.

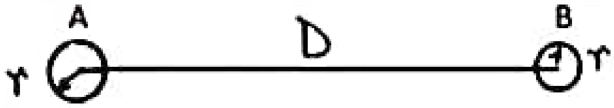
- This geometric mean is called mutual geometric mean distance (Mutual GMD) between conductors of groups A & B.

- $D_s = [(D_{aa}.D_{ab}\dots D_{an}).(D_{ba}.D_{bb}\dots D_{bn})\dots\dots(D_{na}.D_{nb}\dots D_{nn})]^{\frac{1}{n^2}}$

  = All possible distances $(n\times n)$ between conductors of group A for which $(n\times n = n^2)^{th}$ root is taken.

- This geometric mean is called self geometric mean distance (Self GMD).

A.C. Single Phase Circuit



Here, $n = m = 1$

$D_m = D$

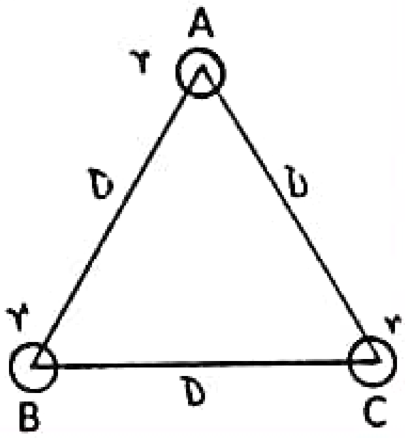
$D_s = D_{aa} = 0.7788\, r = r'$

$\therefore L_A = 2.10^{-7} \ln \frac{D_m}{D_s} = 2.10^{-7} \ln \frac{D}{r'}$ H/m

Similarly, $L_B = 2.10^{-7} \ln \frac{D}{r'}$ H/m

Total inductance $= L = L_A + L_B = 4.10^{-7} \ln \frac{D}{r'}$ H/m

A.C. Symmetrical Three Phase Line



Here, $n = 1$, $m = 2$

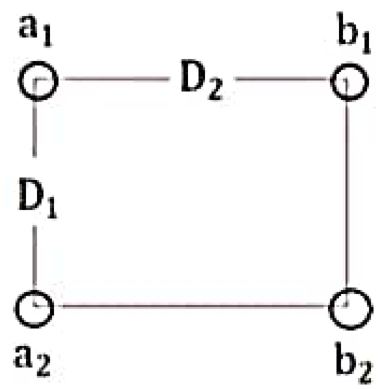
Inductance of conductor A is found first.

$D_m = (D.D)^{\frac{1}{2.1}} = D$, $D_s = D_{aa} = r'$

$\therefore L_A = 2.10^{-7} \ln \frac{D_m}{D_s} = 2.10^{-7} \ln \frac{D}{r'}$ H/m $= L_B = L_C$

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.



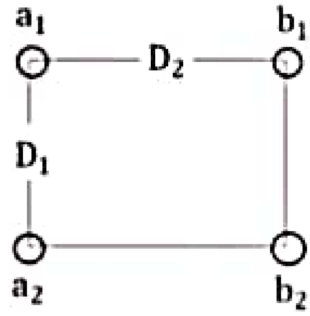
Here, $m = n = 2$

$$\therefore D_S = \left[(D_{a_1a_1}.D_{a_1a_2})(D_{a_2a_1}.D_{a_2a_2})\right]^{1/4} = \left[(r'.D_1)(D_1.r')\right]^{1/4} = (r'.D_1)^{1/2}$$

$$D_m = \left[(D_{a_1b_1}.D_{a_1b_2}).(D_{a_2b_1}.D_{a_2b_2})\right]^{1/4}$$

$$= \left[\left(D_2.\sqrt{D_1^2+D_2^2}\right).\left(\sqrt{D_1^2+D_2^2}.D_2\right)\right]^{1/4}$$

$$= \left(D_2.\sqrt{D_1^2+D_2^2}\right)^{1/2}$$



Inductance of conductor A $= L_A = 2.10^{-7} \ln \frac{D_m}{D_s}$ H/m

$$= 2.10^{-7} \ln \frac{\left(D_2.\sqrt{D_1^2+D_2^2}\right)^{1/2}}{(r'.D_1)^{1/2}} \text{ H/m}$$

$$= 10^{-7} \ln \left(\frac{D_2.\sqrt{D_1^2+D_2^2}}{(r'.D_1)}\right) \text{H/m} = L_B$$

Total inductance of the system $= L = L_A + L_B = 2.10^{-7} \ln \frac{\left(D_2.\sqrt{D_1^2+D_2^2}\right)}{(r'.D_1)}$ H/m