Module 2
Transmission line parameters

Part I

Dr. Suman Bhullar
AP,EIED
TIET,Patiala

Topics to be covered

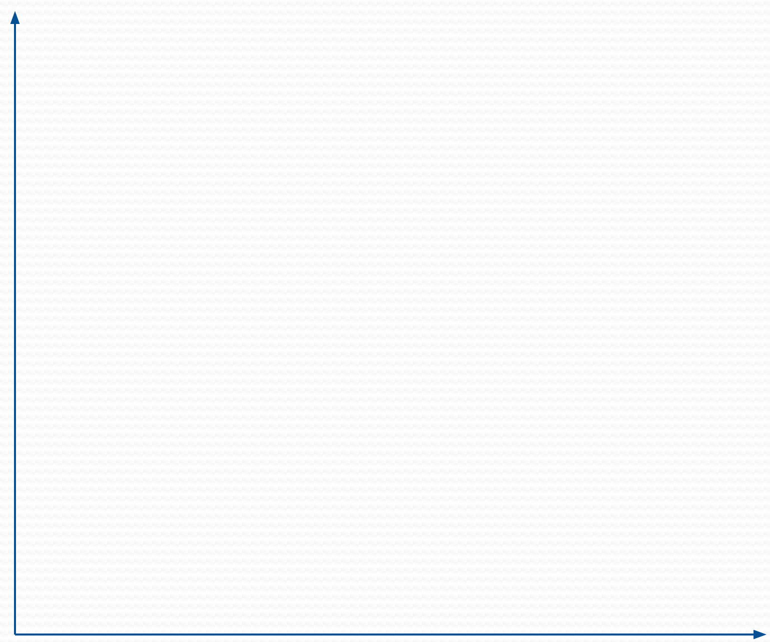
- Choice of voltage and frequency
- Skin effect and proximity effect
- Types of conductors

Choice of voltage and frequency

- If voltage level of transmission voltage is increased, there is reduction in the volume of conductor material required

Contd.

- A limit is decided when the saving due to cost of conductor material is offset by the increased cost of insulation, protection equipment, transformers etc.
- This limit is called economical transmission voltage.



Skin effect

- Uniform current distribution of over the conductor cross-section for DC only and non-uniform in case of AC.
- The degree of non-uniform distribution of current over conductor cross-section area increases with increase in frequency. This effect is known as skin effect.
- Skin effect is due to magnetic flux set up by alternating current inside the conductor.
- Even at 50 Hz, skin effect is significant and causes the AC resistance of a conductor to be greater than DC resistance as conductor cross-sectional area and frequency increases.

Proximity effect

- The current distribution in a conductor is also affected by the presence of other conductors in its vicinity, which is known as proximity effect.
- This effect can be neglected in case of overhead lines but causes an appreciable rise in the resistance of underground cables.

Conductors

- Electric Power can be transmitted by means of overhead lines or underground cables (preferably by overhead lines due to economic reasons).
- Major components of overhead transmission lines are- conductors, insulators, supports, cross arms, protection equipment etc.
- Conductors carry electric power from sending end to receiving end of power system.
- Basically a wire or combination of wires not insulated from each other, is called a conductor

Types of conductors

- Solid-smaller cross sectional area due to heavy weight and chances of breakage due to wind pressure in long spans
- Hollow-bigger diameter as compared to solid conductor for same current carrying capacity, reduced corona and skin effect

Stranded conductor

- composed of group of wires usually twisted together
- One central wire and one or more layers of conductors over the central wire and each layer is twisted in the sense opposite to that of the layer below
- Increased mechanical strength
- Overall diameter of stranded conductor=(2n+1)diameter of each strand where n= number of layers outside the central strand

Bundled conductor

- Two or more conductors per phase spaced by equal distances
- Used for transmitting power for long distances using EHV AC.
- Low corona loss due to large cross-sectional area
- Low inductance per phase
- Lower voltage regulation
- Increased power transfer capacity of transmission lines
- Reduced interference and improved stability

Module 2
Transmission line parameters

Part II

Dr. Suman Bhullar
AP,EIED
TIET,Patiala

Topics to be covered

- Types of conductor materials
- Size of conductor

Conductor materials

The conducting material should fulfil the following considerations:

- High electrical conductivity
- High tensile strength
- Low specific gravity
- Economical

No one material is ideally suitable for conductor. So, a compromise is made between the cost and required properties(electrical & mechanical).

Commonly used conductors

- Copper
- Aluminium
- Steel cored aluminium
- Galvanized steel
- Cadmium copper

Copper

Hard drawn copper is used for transmission and distribution of power. Although hard drawing reduces the electrical conductivity yet it improves the tensile strength.

- Ideal conducting material
- Physical properties
- Chemical properties
- Less Availability and high cost
- Q: what are the advantages of high current density?

Aluminium

- Pocket friendly
- light in weight
- particularly used in case of heavy current transmission where conductor size is prime consideration .
- A compromise is made between cost and properties while selecting aluminium as conducting material.
- Q: Why supporting towers are designed for greater transverse strength in case of aluminium conductors?

Comparison of copper and aluminium

- Specific gravity of aluminium is low as compared to copper.
- Aluminium has low conductivity(almost 60% of copper)
- Diameter of aluminium conductor=1.26 times diameter of copper conductor
- Lower tensile strength and high coefficient of linear expansion in case of Aluminium

Steel cored aluminium

- In order to improve the tensile strength, aluminium conductor is reinforced with a core of galvanized steel wire which is commonly known as ACSR conductors.
- ACSR(aluminium cored steel reinforced) conductor consists of galvanized steel core at the centre surrounded by aluminium strands
- In this composite conductor, steel core takes greater proportion of mechanical strength whereas aluminium strands carry bulk of current

Contd.

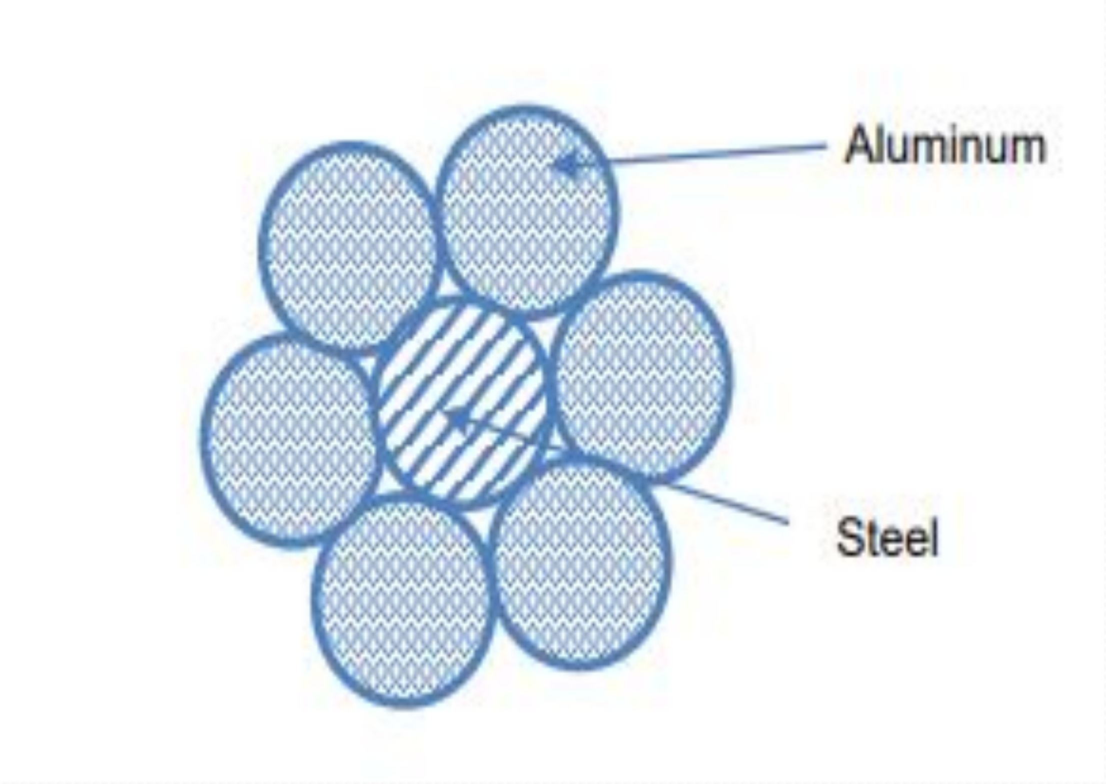


Figure 2.2: ACSR conductor

Galvanized steel

- Suitable for transferring small amount of power over small distances
- Favourable option for rural areas
- Due to higher tensile strength, galvanized steel can be used for extremely long spans or for short line sections exposed to adverse climatic conditions

Cadmium copper

- Addition of 1 to 2% of cadmium to copper, increases tensile strength by 50% reduced conductivity by 15%
- Can be used for exceptionally long spans due to high tensile strength
- As cadmium is costlier, it would be economically suitable for lines with small cross section

Conductor size

- Economic area of conductor is calculated using Kelvin's law
- Most economical area is that for which annual cost of transmission is minimum.

Annual charge on capital outlay

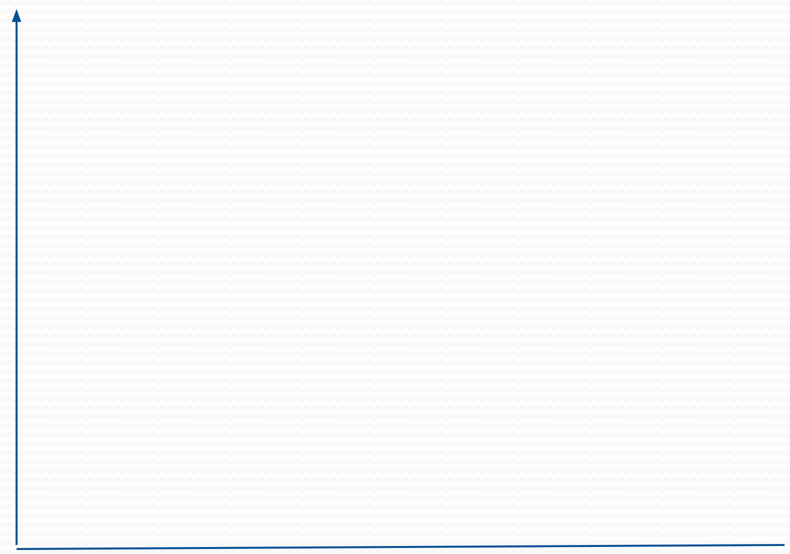
- Annual charge $=C1+C2\ A$

Where C1 and C2 are constants and A is area of cross section

Annual cost of energy wasted

- Annual cost of energy wasted$=C3/A$
- Where C3 is constant

- Variable part of annual outlay=annual cost of energy wasted



Module 2
Transmission line parameters

Part III

Dr. Suman Bhullar
AP,EIED
TIET,Patiala

Transmission line parameters

Transmission line has four main parameters-

- Series resistance
- Series inductance
- Shunt capacitance
- Shunt conductance

- Series resistance and shunt conductance are important when transmission efficiency and economics are to be evaluated as real transmission losses depend upon resistance of line
- Least significant in evaluating transmission capacity as do not affect the total equivalent impedance of the line.
- Three types of losses(i) ohmic losses (ii) corona loss(iii)leakage current
- Under normal operating conditions, corona loss and leakage current are considered to be negligible, hence conductance is assumed to be zero.

Line resistance

- The dc resistance of conductor is given by $R_{DC} = \rho\frac{l}{a}$

Where ρ=resistivity of conductor ,Ω-m

l=length in m

a=area of conductor cross-section,m^2

- $R_t = R_0 (1+\alpha_0 t)$
- Stranding of the conductors increases the length and hence resistance is increased

Inductance

- The induced emf is given by

$$e = \frac{d\lambda}{dt} = \frac{d\lambda}{di} \times \frac{di}{dt} = L\frac{di}{dt}$$

- $\frac{d\lambda}{di}$ is inductance of conductor in henrys. For linear flux linkages variations, $L = \frac{\lambda}{i}$,H
- For sinusoidal current, where we deal with r.m.s. values, $L = \frac{\psi}{I}$,H
- According to Ampere's law $\oint Hdl = I_{enclosed}$
- Also B=μH

Inductance of a single phase two wire line

Module 2
Transmission line parameters

Part IIIA

Dr. Suman Bhullar
AP,EIED
TIET,Patiala

Flux linkages of one conductor in an array

Assumptions:

- Distance between the conductors are large as compared to their radii.
- The current in each conductor may be credited with setting up a certain flux on its own.
- Total flux linkages of any one conductor is the sum of its linkages with all the individual fluxes set by the conductors of the system.

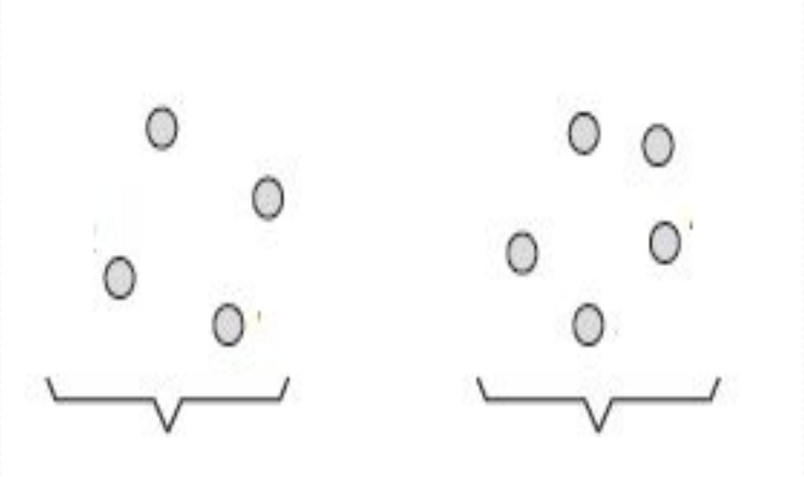
Inductance of composite conductor lines

- The composite conductor consists of two groups of conductors each having m and n number of strands or sub conductors

Assumption:

- All strands or sub conductors of the conductor to be identical so that they share equal current
- If line current is I, each strand or sub conductor of group one , carries a current of I/m and of group 2, carries a current of -I/n

(Reason being the group 2 conductors act as return conductors)

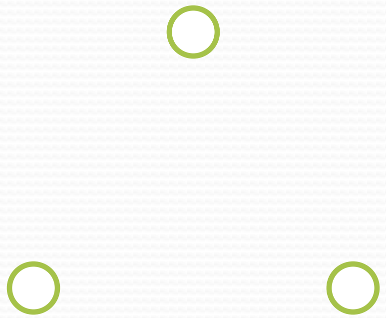


Module 2
Transmission line parameters

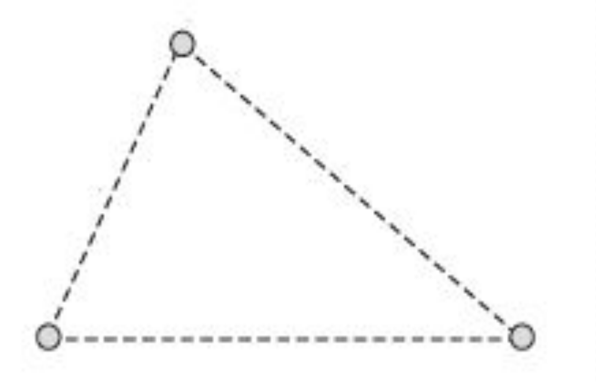
Part IIIB

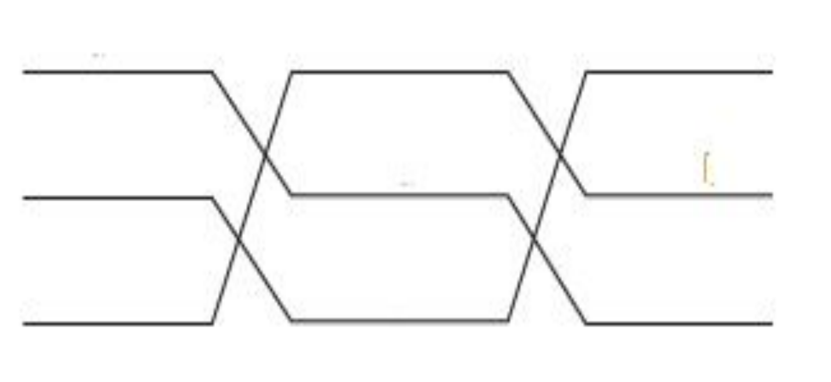
Dr. Suman Bhullar
AP,EIED
TIET,Patiala

Inductance of three phase line with equilateral spacing

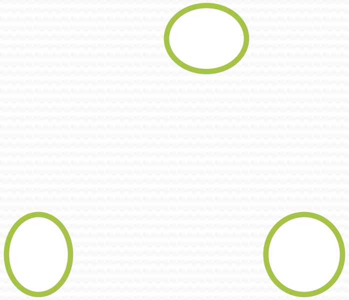


Inductance of three phase line with unsymmetrical spacing





Inductance of bundled conductor lines



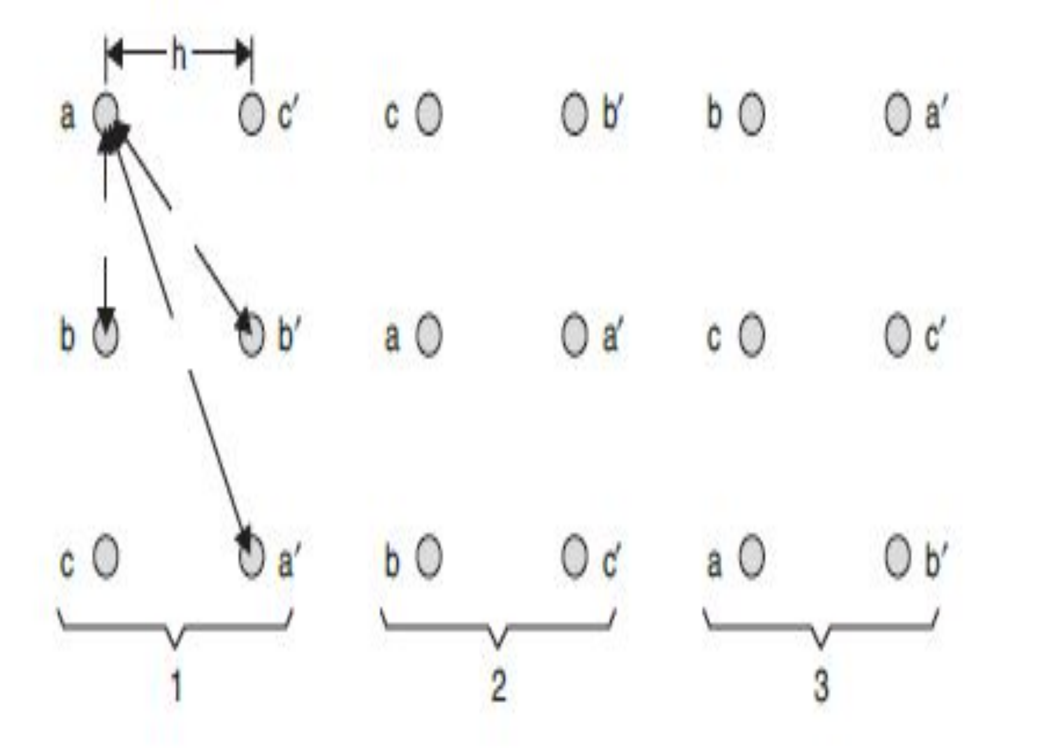
Inductance of double circuit three phase line

Double circuit three phase line means a three phase has two parallel conductors for each phase.

- Greater reliability
- High transmission capacity

It is desirable to have such configuration which results in low GMD and high GMR.

- Individual conductors of a phase widely separated in order to give high GMR
- Minimum distance between the phases to give low GMD


h
a
c′
c
b′
b
a′
b
b′
a
a′
c
c′
c
a′
b
c′
a
b′
1
2
3

Module 2
Transmission line parameters

Part IV

Dr. Suman Bhullar
AP,EIED
TIET,Patiala

Electric field and potential difference

- Consider a long straight cylindrical conductor lying in a uniform field with uniformly distributed charge throughout its length and isolated from other charges
- The charge on the conductor remains uniformly distributed around its periphery and flux is radial
- All points equidistant from such a conductor are points of equi-potential and have same flux density
- Consider an imaginary cylindrical surface concentric with the conductor at distance x units from conductor surface

Electric field and potential difference

Capacitance of two wire line

$$V_{ab} = \frac{1}{2\pi\epsilon}\left[q_a \ln\left(\frac{D}{r}\right) + q_b \ln\left(\frac{\quad}{\quad}\right) + q_c \ln\left(\frac{D}{\quad}\right)\right] \text{ — } (2.67)$$

Similarly,

$$V_{ac} = \frac{1}{2\pi\epsilon}\left[q_a \ln\left(\frac{D}{r}\right) + q_b \ln\left(\frac{D}{\quad}\right) + q_c \ln\left(\frac{\quad}{\quad}\right)\right] \text{ — } (2.68)$$

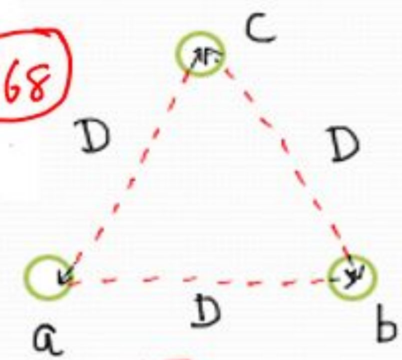


Figure 2.9: Three phase line with equilateral spacing

Addition of eq. (2.67) and (2.68)

$$V_{ab} + V_{ac} = \frac{1}{2\pi\epsilon}\left[2q_a \ln\left(\frac{D}{r}\right) + (q_b + q_c)\ln\left(\frac{\quad}{\quad}\right)\right] \rightarrow (2.69)$$

If there are no other charges in the vicinity, $q_a + q_b + q_c = 0$

Therefore, $V_{ab} + V_{ac} =$

Capacitance of three phase line with asymmetrical spacing

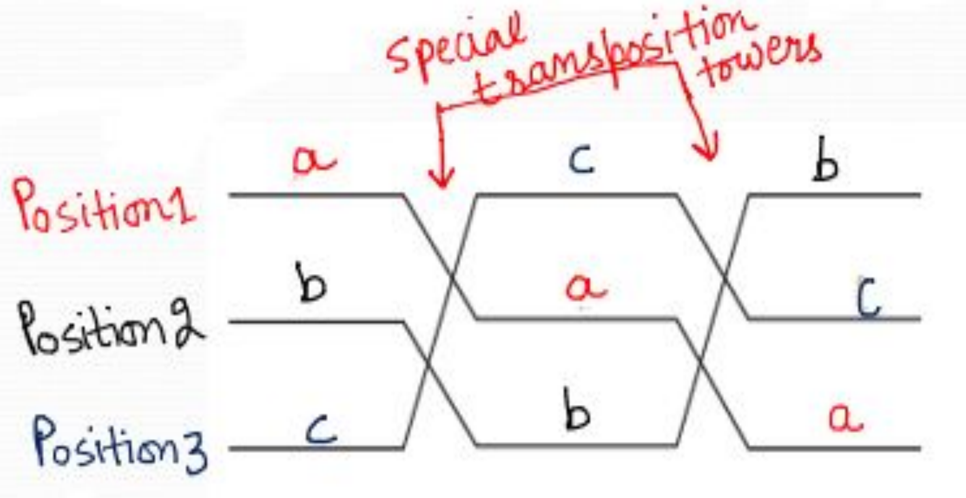


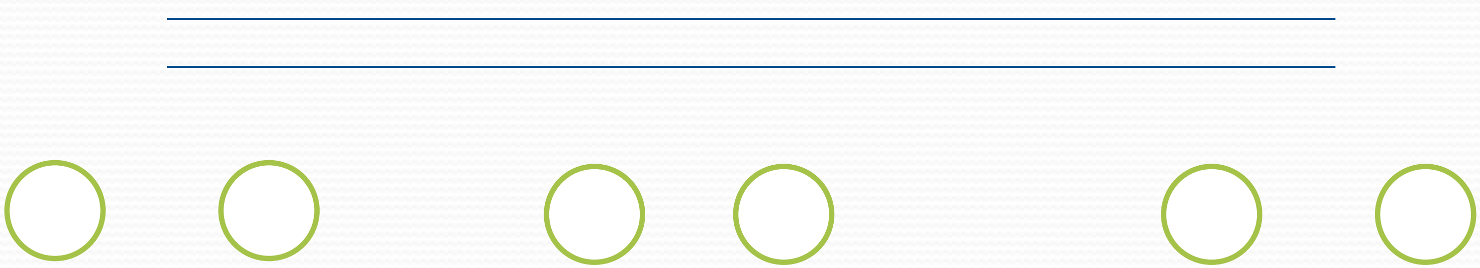
Figure 2.11: Transposition of T/M line

Capacitance of bundled conductor lines

- Consider 3-phase bundled conductor line with two conductors per phase

Assumption

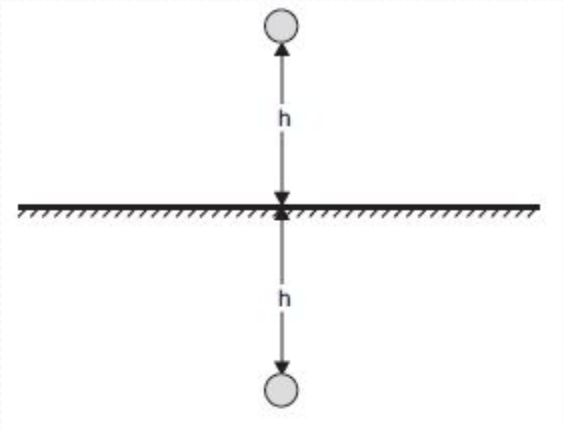
- Two sub conductors of each phase are in parallel, therefore the charge per bundle can be equally divided between the sub conductors of a bundle.



- Distance D12 is greater than d, D12 can be used in place of (D12-d) and (D12+d)

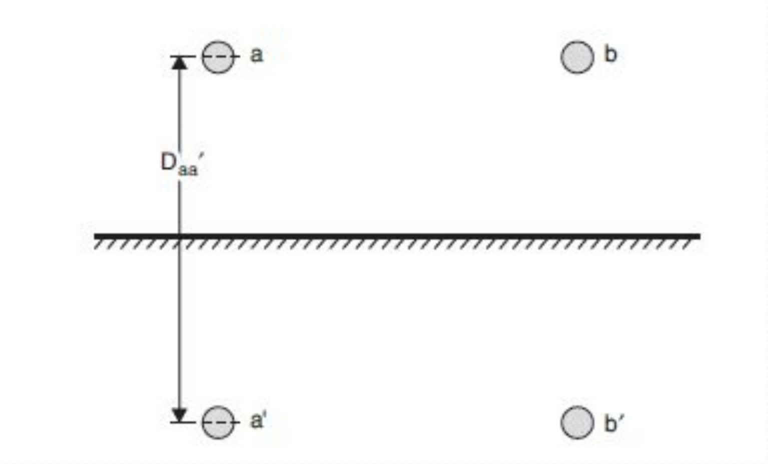
Effect of ground on line capacitance

- The presence of ground affects the line capacitance as it alters the electric field of a transmission line
- The effect of ground on line capacitance can be modelled using ,method of images
- Any one conductor and its image conductor are located at equal distances, but in opposite directions from the ground surface as shown in figure 2.13.



Effect of earth on capacitance of single phase line

- The conductors of a single phase line along with its image conductors are shown in figure 2.14.
- Assumption:
- $D_{aa}=D_{bb}$ and $D_{ab}=D_{ba}$



Effect of earth on capacitance of three phase line

- Capacitance calculation is done considering effect of transposition
- Assuming point P situated far away from the system,

potential of conductor a will be calculated considering transposition(at position 1,2 and 3 respectively)