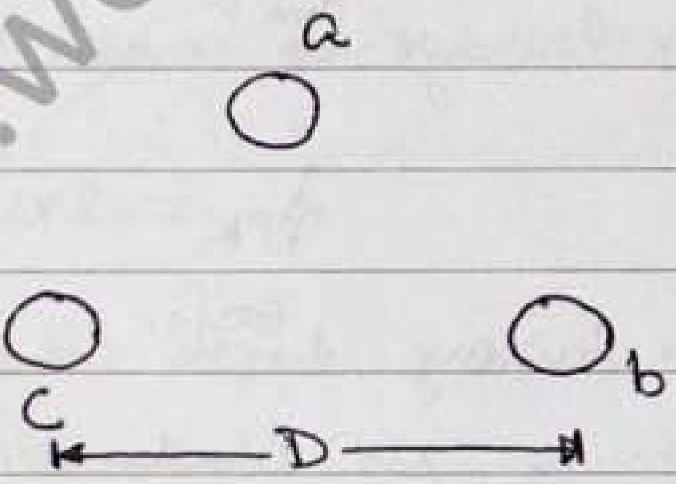
Lecture : 04

INDUCTANCE CALCULATIONS FOR 3φ LINE

⊛ Inductance Calculation for 3φ transmission line with:

a. Equilateral spacing
b. Transposition
c. Bundled conductor

a. EQUILATERAL SPACING:



Flux linkage of conductor 'a' due to its own current

$$\lambda_{aa} = 2\times10^{-7} I_a \ln \frac{1}{r'}$$

Flux linkage on conductor 'a' due to current flowing in 'b'

$$\lambda_{ab} = 2\times10^{-7} I_b \cancel{\ln \frac{D}{r}} \ln \frac{1}{D}$$

Similarly,

$$\lambda_{ac} = 2\times10^{-7} I_c \ln \frac{1}{D}$$

Total flux linkage on conductor 'a'

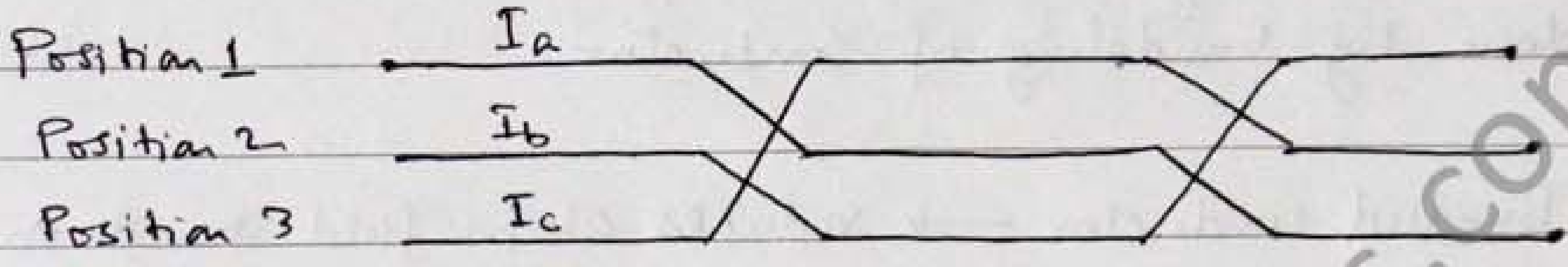
$$\lambda_a = 2\times10^{-7} \left(I_a \ln \frac{1}{r'} + I_b \ln \frac{1}{D} + I_c \ln \frac{1}{D} \right)$$

$$= 2\times10^{-7} \left(I_a \ln \frac{1}{r'} - I_a \ln \frac{1}{D} \right) \quad \left[\text{bcoz } I_a + I_b + I_c = 0, \; I_b + I_c = -I_a \right]$$

$$\boxed{\lambda_a = 2\times10^{-7} I_a \ln \frac{D}{r'}} \text{ wb-t/m.}$$

$$\boxed{L_a = 2\times10^{-7} \ln \frac{D}{r'}} \text{ H/m}$$

b. THREE PHASE TRANSPOSED LINE



→ Practically it is not possible to have all the conductor are in equilateral spacing. Therefore flux linkage will not be same on each conductor. So, Transposition is done.
In transposition, we change the position of conductor over $\frac{1}{3}$rd of the Length of transmission line. Each conductor had gone through all the three position and therefore total flux linkage on each of the conductor will be almost same. This makes the transmission line more balanced.

Now,
Flux linkage ~~of~~ on conductor 'a' First in $\frac{1}{3}$rd of transmission line = λ_{a1}

$$\lambda_{a1} = 2\times10^{-7}\left[I_a \ln\frac{1}{D_a} + I_b \ln\frac{1}{D_{12}} + I_c \ln\frac{1}{D_{13}}\right] \text{ wb-t/m.}$$

Similarly,
$$\lambda_{a2} = 2\times10^{-7}\left[I_a \ln\frac{1}{D_a} + I_b \ln\frac{1}{D_{23}} + I_c \ln\frac{1}{D_{12}}\right] \text{ wb-t/m.}$$

$$\lambda_{a3} = 2\times10^{-7}\left[I_a \ln\frac{1}{D_a} + I_b \ln\frac{1}{D_{31}} + I_c \ln\frac{1}{D_{23}}\right] \text{ wb-t/m.}$$

Total Flux linkage $= \lambda_{a1}\left(\frac{1}{3}\right) + \lambda_{a2}\left(\frac{1}{3}\right) + \lambda_{a3}\left(\frac{1}{3}\right) = \dfrac{\lambda_{a1}+\lambda_{a2}+\lambda_{a3}}{3}$.

$$\boxed{\therefore \lambda_a = 2\times10^{-7} I_a \ln\frac{(D_{12}D_{23}D_{31})^{1/3}}{D_a}}$$

$$\boxed{L_a = 2\times10^{-7} \ln\frac{(D_{12}D_{23}D_{31})^{1/3}}{D_a}} \qquad \boxed{D_a = r e^{1/4}}$$

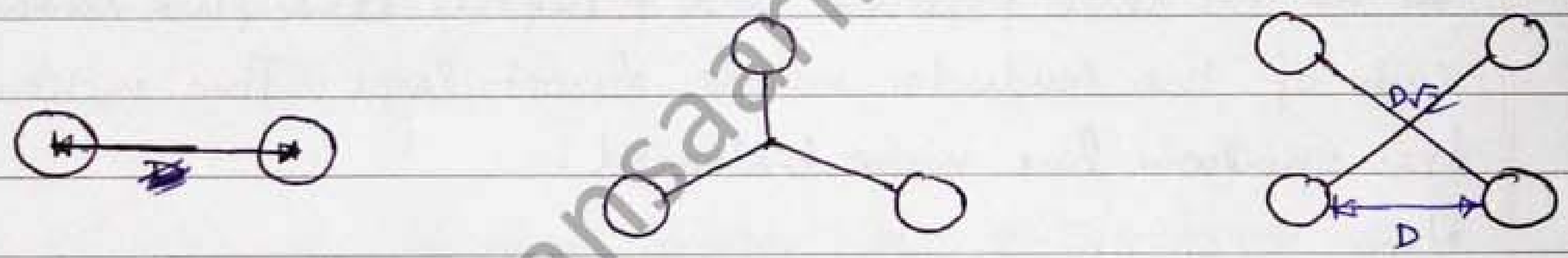
$$D_{eq} = (D_{12}D_{23}D_{31})^{1/3}.$$

→ We know, $L \propto \frac{1}{r'}$. So, we can reduce the inductance of conductor by increasing the effective radius. This can be done by bundeling of conductor.

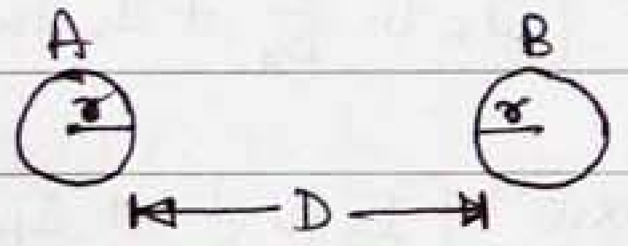
→ Bundled conductor → reduces electric field strength on conductor surface
→ Reduces corona loss
→ Increases effective radius (GMR)
→ Reduces inductance

C. BUNDLED CONDUCTOR LINE

In India, 2 cond & 4 conductor → 400kV line
2 conductor → 200kV line



How to calculate Effective Distance D_s?



Distance of conductor A with itself $= r'$
Distance of conductor A with B $= D$
Distance of conductor B with itself $= r'$
Distance of conductor B with A $= D$.
So, there are four distances involved. So, it will be fourth root of $(r' \times D)^2$.

$$\boxed{D_s = \sqrt[4]{(r' \times D)^2} = \sqrt[2]{r'd}}$$ (For two conductor)

$$\boxed{D_s = \sqrt[9]{(r \times d \times d)^3} = \sqrt[3]{r'd^2}}$$ → for three conductor.

$$\boxed{D_s = \sqrt[16]{(r' \times d \times d \times d\sqrt{2})} = 1.091\sqrt[4]{r'd^3}}$$ → for four conductor

→ For 3 conductor, we get 9 distance. ~~How? One for itself~~ How?

for conductor A → one for itself = r'

Distance from B = d

Distance from c = d.

Similarly for conductor B & C.

Total distance = 9.

→ for 4 conductor we get 16 distances. One for itself & 3 more for other 3 conductors i.e. Distance ~~from~~ of A to other 3 cond. B, C, D.

$$\therefore D_s = \sqrt[16]{(r' \times d \times d \times d\sqrt{2})^4} = 1.09\sqrt[4]{r' d^3}.$$

→ power 4 is taken bcoz r', d, d, $d\sqrt{2}$ is repeating four times.

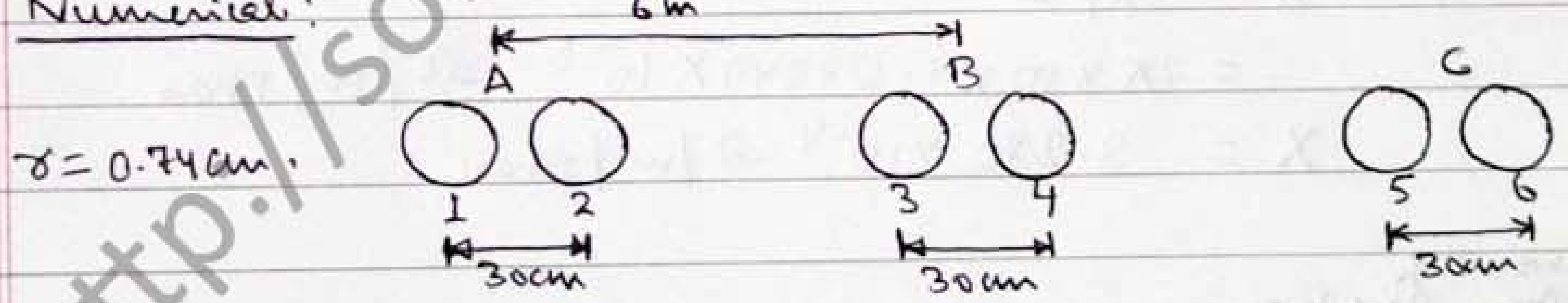
We know,

$$\boxed{L_a = 2\times10^{-7} \ln \frac{D_{eq}}{D_s}}$$

where D_s = GMR of Bundled cond.

So, Here $D_s \uparrow$ for bundled conductor. $\therefore L \downarrow$.

<u>Numerical:</u> 3φ transposed line.



The Phase A, B & C are horizontally spaced with bundeling of 2 conduct[ors]

(a) Determine L in mH/km and mH/m.

(b) Find the inductive line reactance/Phase in Ω/m at 50Hz

Mutual GMD b/w the different Phases

$$D_{ab} = (r_{13} r_{14} r_{23} r_{24})^{1/4} = (6\times6.3\times5.7\times6)^{1/4}$$

$$= 5.9962\text{ m}$$

Similarly D_{bc} ~~= D_{ca}~~ = 5.9962 m.

$$D_{ca} = (r_{15} r_{16} r_{25} r_{26})^{1/4} = (12\times12.3\times11.7\times12)^{1/4}$$

$$= 11.9981\text{ m}.$$

The equivalent equilateral spacing b/w the phases is given by

$$D_{eq} = (D_{ab} D_{bc} D_{ca})^{1/3} = (5.9962 \times 5.9962 \times 11.9981)^{1/3}$$

$$D_{eq} = 7.5559 \text{ m.}$$

Now, self GMD will be same bcoz all are bundled at 30cm & also have same radius.

$$\therefore D_s = (r' \times 30)^{1/2} = (e^{-1/4} \times r \times 30)^{1/2}$$

$$= 4.158 \text{ cm.}$$

$$\therefore \text{Inductance/phase} = 2 \times 10^{-7} \ln \frac{D_{eq}}{D_s}$$

$$L = 1.04049 \times 10^{-6} \text{ H/m/phase}$$

$$= 1.04049 \times 10^{-3} \text{ mH/m/phase}$$

$$= 1.04049 \text{ mH/km/phase.}$$

Now, (b) $X = 2\pi f L$

$$= 2\pi \times 50 \times 1.04049 \times 10^{-6} \ \Omega\text{/m/phase}$$

$$X = 3.270 \times 10^{-4} \ \Omega\text{/m/phase}$$

Answer the Questions:

1. Why Bundled conductor are used in EHV lines?
2. What is transposition?