Transmission and Distribution of Electrical Power

By

Associate Prof. / Mohamed Ahmed Ebrahim Mohamed

E-mail: mohamedahmed_en@yahoo.com

mohamed.mohamed@feng.bu.edu.eg

Web site: http://bu.edu.eg/staff/mohamedmohamed033

Lecture (2)

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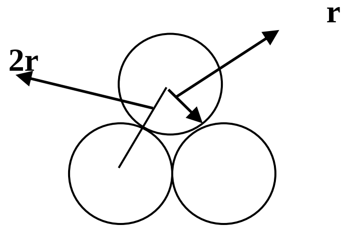
Inductance of stranded conductors

Case 1: 3-strand cable



$$L = 2*10^{-7} \ln \frac{D_m}{D_s} \qquad \text{H/m}$$

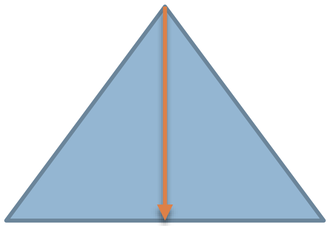
$$D_s = \sqrt[(3)^2]{r.2r.2r.2r.r.2r.2r.r.2r.2r} = \sqrt{(2r)^6.(r)^3}$$

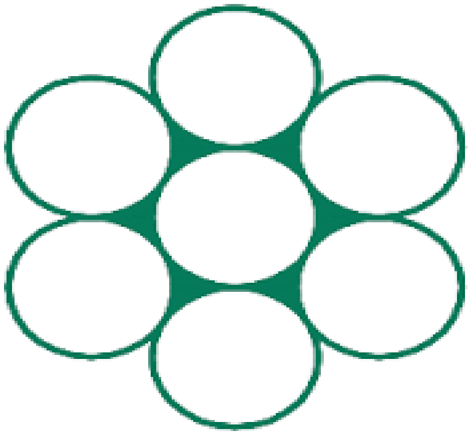
$$D_s = \sqrt[9]{(2r)^6.(re^{-0.25})^3} \quad \text{where,} \quad \mathrm{r} = \mathrm{re}^{-0.25}$$

$$D_m = \sqrt[3]{2r.2r.2r} = 2r$$

Case 2: 7-strand cable

$$L = 2*10^{-7}\ln\frac{D_m}{D_s}$$ H/m





To get D_s we have 24 terms of 2r, 12 terms of $2\sqrt{3}r$
6 terms of 4r, and 7 terms of r.

$$D_s = \sqrt[(7)^2]{(re^{-0.25})^7 (2r)^{24} (2/\sqrt{3}r)^{12} (4r)^6}$$

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Self–GMD of Composite Stranded Conductors

Two-stranded Composite conductor

$$D_s = \sqrt[(1+c)^2]{(2r)^{2c}(re^{-0.25})^{1+c^2}}$$

Seven-stranded Composite conductor

$$D_s = \sqrt[(6+c)^2]{(2r*6^{1/5})^{30}*(2r)^{12c}*(re^{-0.25})^{(6+c^2)}}$$

Inductance of a Three–Phase Line:

(a) balanced Three–Phase Line:

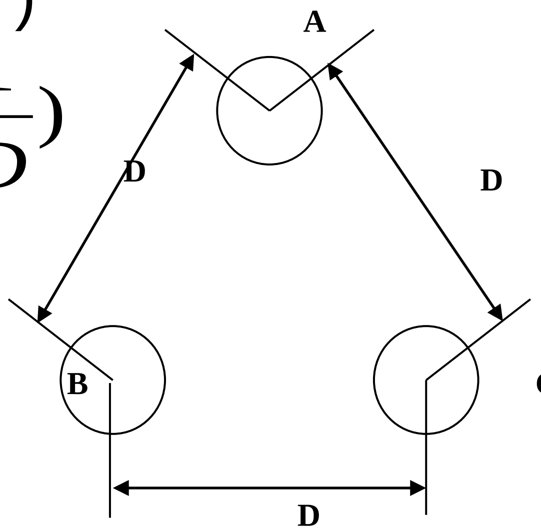
$$\lambda_a = 2*10^{-7}(I_a \ln\frac{1}{D_s} + I_b \ln\frac{1}{D} + I_c \ln\frac{1}{D}$$

$$I_a + I_b + I_c = 0 \qquad \text{(balanced)}$$

$$\lambda_a = 2*10^{-7}(I_a \ln\frac{1}{D_s} - I_a \ln\frac{1}{D})$$

$$= 2*10^{-7} I_a \ln\frac{D}{D_s}$$

$$L_a = \frac{\lambda_a}{I_a} = 2*10^{-7} \ln\frac{D}{D_s} \qquad \text{H/m}$$



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$$L_t = L_a + L_b + L_c = 3L_a$$ (balanced and identical)

$$X_{lt} = 2\pi f L_t \qquad \Omega$$

(b) Unbalanced Three–Phase Line

If the spacing of the transmission line conductors is not symmetrical , the linkages for different conductors would be different and unbalanced voltages would be produced under loading conditions.

Continue

The unbalanced condition causes unequal reactances Which cause inductive interference with parallel communication circuits and also result in unbalanced–phase charging currents .

T_0 reduce these effects , the three–phase line with unequal spacing are transposed .

$$\lambda_a = 2*10^{-7} I_a \ln \frac{\sqrt[3]{D_{ab} D_{bc} D_{ca}}}{D_s} \quad \text{Linkages / m}$$

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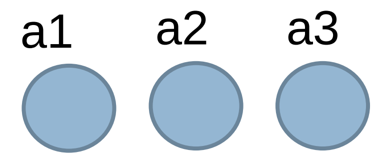
$$L_a = 2*10^{-7} \ln \frac{\sqrt{D_{ab} D_{bc} D_{ca}}}{D_s}$$ H/m



$$L_a = 2*10^{-7} \ln \frac{D_m}{D_s}$$ H/ m

Arrangement of three–phase line with 3 parallel conductors in each phase,

$$D_s \; of \; A = \sqrt[(3)^2]{r_{a1}.D_{a1a2}.D_{a1a3}.r_{a2}.D_{a2a1}.D_{a2a3}.r_{a3}.D_{a3a1}.D_{a3a2}}$$

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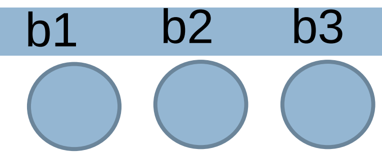
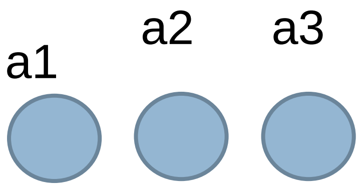


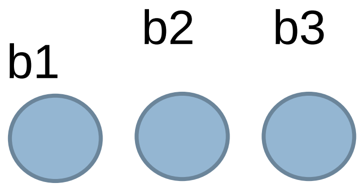
$$D_s of\ B = \sqrt[(3*3)]{r_{b1}.D_{b1b2}.D_{b1b3} r_b .D_{b2b1} D_{b2b3} r_{b3}.D_{b3b1}.D_{b3b2}}$$

Using the same procedure to obtain D_S of C.

$$D_{AB} = \sqrt[(3*3)]{D_{a1b1}.D_{a1b2}.D_{a1b3}.D_{a2b1}.D_{a2b2}.D_{a2b3}.D_{a3b1}.D_{a3b2}.D_{a3b3}}$$

$$D_{BC} = \sqrt[(3*3)]{D_{b1c1}.D_{b1c2}.D_{b1c3}.D_{b2c1}.D_{b2c2}.D_{b2c3}.D_{b3c1}.D_{b3c2}.D_{b3c3}}$$





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Using the same procedure to obtain D_{ca}

$$D_m = \sqrt[3]{D_{ab} D_{bc} D_{ca}}$$

If the system is fully transposed,

$$D_m = \sqrt[3]{D_{ab} D_{bc} D_{ca}}$$

$$X = 2\pi f L \qquad \Omega \text{ / phase}$$

Capacitance of O.H.T.L

If the conductor has change q C/ m , then, the dielectric flux density D at a distance X m is,

$$D = \frac{q}{2\pi X} \qquad C/m^2$$

- Area which total flux passes being $2\pi X \quad m^2$

- Unit change situated in a field of unit electric flux Density in air its force is ,

$$36\pi * 10^9 \qquad V/m$$

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The voltage gradient is given by,

$$\frac{dE}{dX} = 36\pi * 10^3 \; D = 36\pi * 12^3 * \frac{q}{2\pi X} = 18 * 10^3 \frac{q}{X}$$ V/m

Then ,

$$V_{AB} = \int \frac{dE}{dX} = \int_A^B 18 * 10^9 \frac{q}{X} dX = 18 * 12^9 q \ln \int_A^B = 18 * 10^9 q \ln \frac{B}{A}$$

$$E_{an} = 18 * 10^9 \sum_{k=a}^{n} q_k \ln \frac{D_{kn}}{D_{ka}}$$

$$C = \frac{q}{E}$$ farad

Capacitance of Two Parallel Conductors

$$E_{AB} = 18*10^{9}(q_A \ln\frac{D}{r} - q_B \ln\frac{D}{r})$$

$$= 18*10^{9}(q_A \ln\frac{D}{r} + q_B \ln\frac{D}{r})$$

$$= 18*10^{9}(2q_A \ln\frac{D}{r})$$

$$E_{AB} = 36*10^{9} q_A \ln\frac{D}{r}$$

Continue

$$C_{AB} = \frac{q_A}{E_{AB}} = \frac{q_A}{36*10^9 q_A \ln \frac{D}{r}}$$

$$C_{AB} = \frac{1}{36*10^9 Ln \frac{D}{r}}$$

F/m

$$C_{AN} = \frac{q_A}{E_{AB}/2} = \frac{1}{18*10^9 \ln \frac{D}{r}}$$

Capacitance of Three–Phase Line

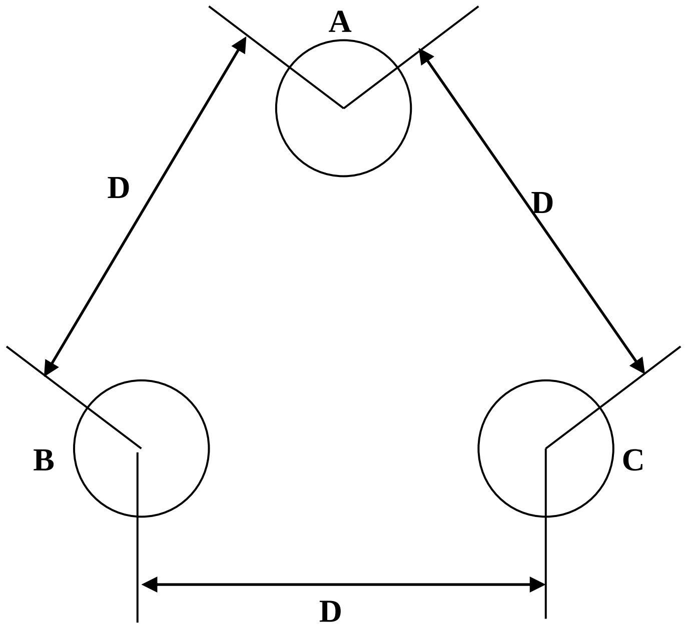
(a) Balanced Three–Phase Line

$$E_{AN} = E_{BN} = E_{CN}$$

$$q_A + q_B + q_c = 0$$

$$C_{AN} = C_{BN} = C_{CN}$$

$$C_{AN} = \frac{1}{18*10^9 \ln \frac{D}{r}}$$



(b) Unbalanced Three–Phase Line

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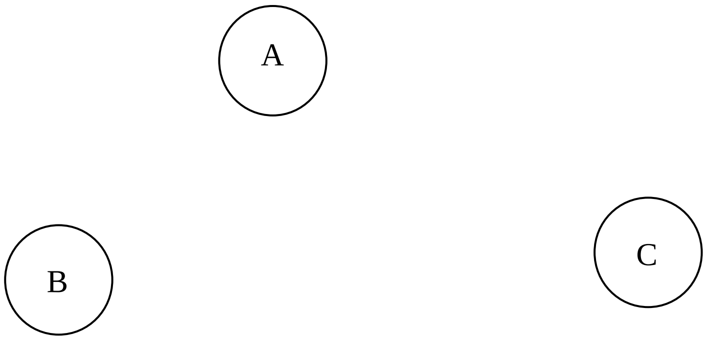
D_s

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



Capacitance of a Single–Phase Line with Earth Return

$$C_{AN} = \frac{1}{18*10^9 \ln \frac{2h}{r}}$$ F/m

Capacitance of Multi–Circuit Three–Phase Line

Ph (1)……aa'

Ph (2)……bb'

Ph (3)……cc'

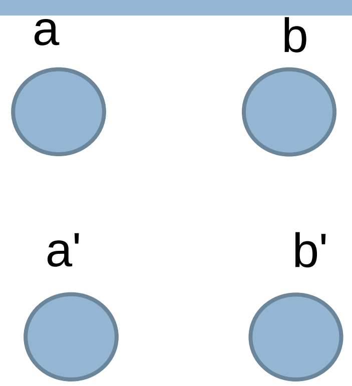
$$C_{AN} = \frac{1}{18*10^9 Ln\frac{D_m}{D_s}}$$ F/ m/ ph

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

Continue

$$D_{AB} = \sqrt[2*2]{D_{ab}D_{ab'}D_{a'b}D_{a'b'}}$$

$$= \sqrt[4]{D.\sqrt{3}D.\sqrt{3}D.D} = (3)^{1/4} D$$



$$D_{BC} = \sqrt[2*2]{D_{bc}.D_{bc'}D_{b'c}D_{b'c'}}$$

$$= \sqrt[4]{\sqrt{3}D.D.D.\sqrt{3}D} = (3)^{1/4} D$$

Using the same procedure to obtain D_{CA}

Continue

$$D_s \text{ of } A = \sqrt[(2)^2]{r_a D_{AA'} . r_{a'} D_{A'A}}$$

$$= \sqrt[4]{r^2 (2D)(2D)} = \sqrt{(2D) r}$$

Using the same procedure to obtain SGMD of circuit B, and C.

Comparison of Relations for Inductance and Capacitance

The term $\frac{D_m}{D_s}$ appears in inductance and capacitance

Such that, for inductance, $r = re^{-0.25}$

for capacitance, $r = r$ (conductor radius)

$$L * C = \frac{1}{9*10_{16}} = \frac{1}{V^2}$$

Where, V : velocity of light

$$\because \text{Capacitive reactonce}\, X_c = \frac{1}{2\pi fC} \quad \Omega$$

$$\text{the charging current / phase} = \frac{V}{X_c} = V*2\pi fc \quad A$$

With Our Best Wishes

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Associate Prof. Dr . Mohamed Ahmed Ebrahim