بسم الله الرحمن الرحيم

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Postgraduate (Pre-master) Course

Transmission and Distribution of Electrical Power

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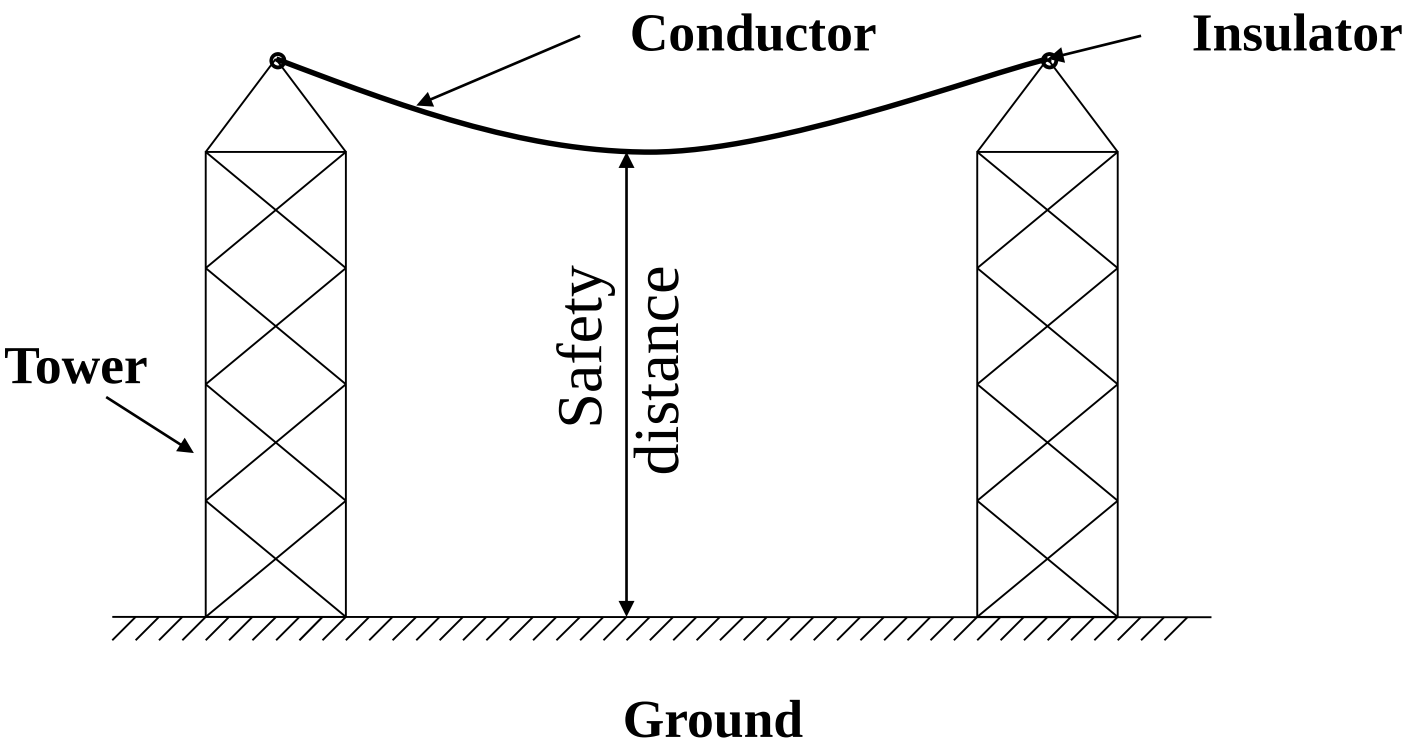
Contents

Chapter 1:
Transmission Line Constants

1. Main parts of over head T .L.



Types of conductors

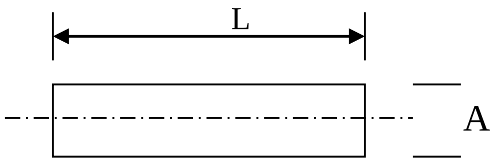
- Hard –drawn copper conductors .
- Aluminum- core steel–rein forced (ACSR).
- For rural electrification , all – aluminum conductors are used.
- Steel wires are used as earthing wires for over head T. L.

The main constants required are

- Resistance (R "ohm").
- Inductance (L "hennery") & corresponding X_L.
- Capacitance (C " farad ") & corresponding X_c.

Resistance of over head T . L .

- $R = \rho L/A \quad \Omega$
- Where :



R: resistance of T.L (Ω)

ρ : resistivity of T.L conductor (Ω .m)

L : length of T.L (m)

A : cross –section area (m^2)

- For hard –drawn conductors : $\rho = 1.724 * 10^{-8}$ Ω.m at 20 °C
- For all – aluminum conductors : $\rho = 2.860 * 10^{-8}$ Ω.m at 20 °C

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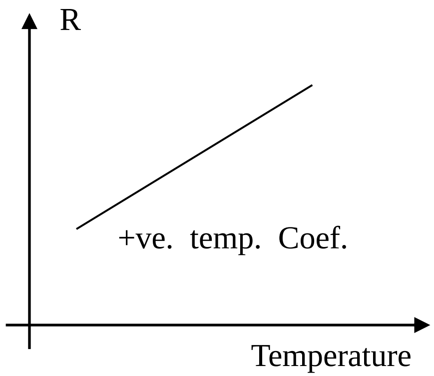
Effect of Temperature on Resistance

- The resistance of T.L increases with Temperature
- The rise in resistance depends on the Temperature coefficient of conductor material (α).

$$\frac{R_{t2}}{R_{t1}} = \frac{1/\alpha_0 + t_2}{1/\alpha_0 + t_1}$$



Where :

R_{t2}	: Resistance of T .L at t_2	(Ω)
R_{t1}	: Resistance of T .L at t_1	(Ω)
α_0	: Temperature coefficient at 0 °C	(1/°C)
T_1	: First temperature	(°C)
T_2	: Second temperature	(°C)

- For hard – drawn copper $\alpha_0 = 0.0041\ ^\circ/C$
  For aluminum $\alpha_0 = 0.0038\ ^\circ/C$

Skin Effect on Conductors

when alternating current is passing through conductors, there is an unequal distribution of current in any cross – section of the conductor, the current density at the surface being higher than the current density at the center of the conductor . this causes larger power loss for a given r.m.s alternating current than the loss when the same value of DC is flowing in the conductor.

- $R_{ac} > R_{dc}$

$$R_{ac} = \frac{\text{Average power losses}}{I^2_{rms}}$$

$$\text{Skin effect ratio} = \frac{R_{ac}}{R_{dc}}$$

Which depends on

- Permeability (Type of material).
- Area of cross section of the conductor.
- Frequency of the supply.

Inductance & Reactance of O.H.T.L

Inductance of overhead transmission line depends on:

- Size of conductor.
- Distance between conductors.
- Material of conductors.

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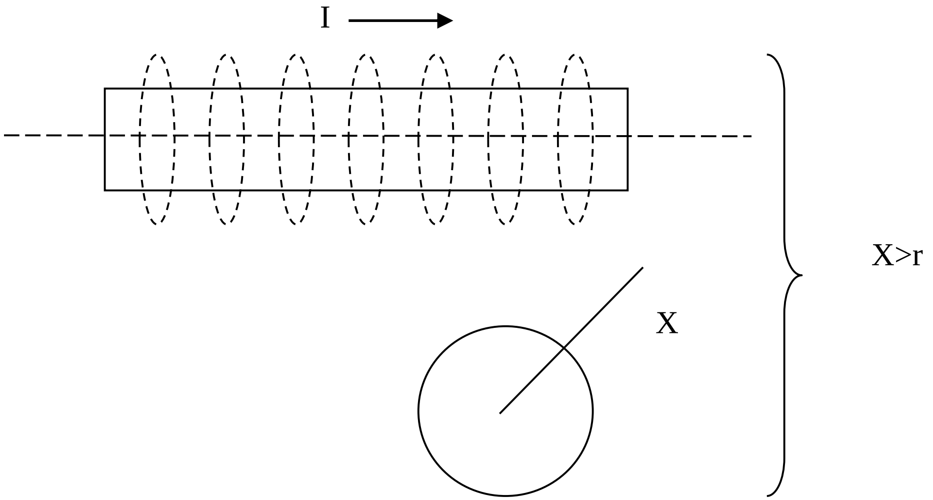
Inductance & Reactance of O.H.T.L

$$H = \frac{I}{2\pi x}$$ A.turn/m

H : electric field intensity.



$$B = \frac{2*10^{-7}}{x} I$$ wb/m²

$$H = \frac{Ix}{2\pi r^2}$$ A.turn/m

$$B = \frac{2*10^{-7}}{r^2} Ix$$ wb/m²

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Inductance of Two Conductor (Single Phase)

$$\lambda_{\text{total}} = \lambda_{\text{inside}} + \lambda_{\text{outside}}$$

$$\lambda_{\text{inside}} = \int_0^r \frac{2*10^{-7} xI}{r^2} * \frac{\pi x^2}{\pi r^2} dx$$

$$\lambda_{\text{inside}} = \int_0^r \frac{2*10^{-7} x^3}{r^4} dx = \frac{2*10^{-7} I}{r^4} \frac{1}{4} x^4 \Big|_0^r$$

$$= \frac{2*10^{-7} I}{4r^4} * r^4 = \frac{1}{2} * 10^{-7} I \qquad \text{linkages /m}$$

Continue

$$\lambda_{outside} = \int_r^D \frac{2*10^{-7} xI}{r^2} * \frac{\pi r^2}{\pi x^2} dx$$

$$= \int_r^D \frac{2*10^{-7} I}{X} dx = 2*10^{-7} I \ln \frac{D}{r}$$

$$\lambda_{outside} = 2*10^{-7} I \ln \frac{D}{r} \quad \text{linkages/m}$$

$$\lambda_{total} = \lambda_{inside} + \lambda_{outside}$$

$$= \frac{1}{2} * 10^{-7} I + 2*10^{-7} I \ln \frac{D}{r}$$

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$$L_1 = \frac{\lambda_1}{I} = 10^{-7}\left(2\ln\frac{D}{r} + \frac{1}{2}\right) \quad \text{H/m}$$

In case of non magnetic or hollow conductor

$L_t = L_1 + L_2 = 2L_1$ (Two identical conductors)

In Case of Magnetic Conductor

$$L = 10^{-7}\left(\ln\frac{D}{r} + \frac{1}{2}\frac{\mu}{\mu_o}\right)$$

μ : permeability

μ_r : relative permeability

$$X_t = 2\pi f L_t \quad \Omega$$

$$\lambda = 10^{-7} I\left(2\ln\frac{D}{r} + \frac{1}{2}\right) = 2 * 10^{-7} I\left(\ln\frac{D}{r} + \frac{1}{4}\right)$$

Continue

$$\lambda = 2 * 10^{-7} I \ln \frac{D}{re^{-0.25}}$$

Where:

r e $^{-.025}$: geometric mean radius (GMR)

or self – geometric mean distance.

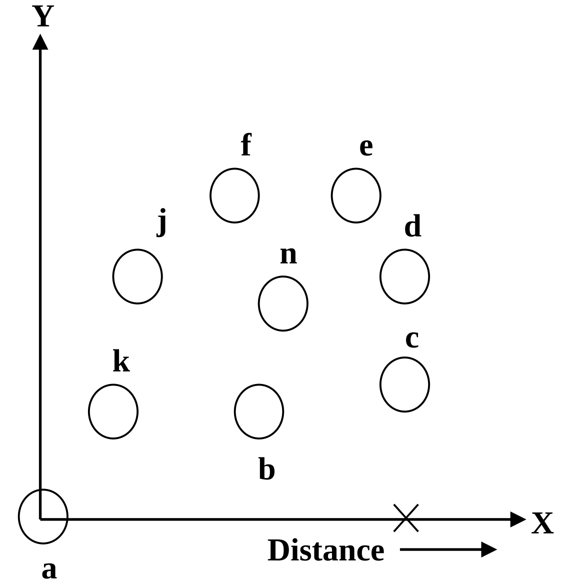
D : distance bet. Two conductors

or mutual distance between two conductors

General Expression for Inductance of a Group of Parallel Wires

$$\lambda_a = 10^{-7}\left(\frac{I_a}{2}\frac{\mu}{\mu_0} + 2I_a \ln\frac{D_{ax}}{r}\right)$$

$$\lambda_{total} = 10^{-7}\left(\frac{I_a}{2}\frac{\mu}{\mu_0} + 2I_a \ln\frac{D_{ax}}{r} + 2I_p \ln\frac{D_{bx}}{D_{ab}} + .. + 2In \ln\frac{D_{nx}}{D_{an}}\right)$$



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

" Closed loop"

$$I_n = -(I_a + I_b + I_c + \ldots\ldots\ldots + I_{n-1})$$

by substitution

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Continue

$$\lambda_a = 10^{-7}[\frac{I_a}{2}\frac{\mu}{\mu_0} + 2I_a(\ln\frac{D_{ax}}{r} - \ln\frac{D_{nx}}{D_{an}})$$

$$+ 2I_b(\ln\frac{D_{bx}}{D_{ab}} - \ln\frac{D_{nx}}{D_{ab}})$$

$$+ \ldots\ldots\ldots + 2I_{n-1}(\ln\frac{D_{nx}}{D_{an}})]$$

$$\text{since, } \ln A - \ln B = \ln\frac{A}{B}$$

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Continue

$$\lambda_a = 10^{-7}[\frac{I_a}{2}\frac{\mu}{\mu_0} + 2I_a(\ln\frac{D_{ax}}{r}.\frac{D_{an}}{D_{nx}}))$$

$$+ 2I_b(\ln(\frac{D_{bx}}{D_{ab}}.\frac{D_{an}}{D_{nx}}))$$

$$+ \ldots + 2I_{n-1}(\ln(\frac{D_{n-1x}}{D_{an-1}}.\frac{D_{an}}{D_{nx}}))]$$

Continue

$$\lambda_a = 10^{-7}[\frac{I_a}{2}\frac{\mu}{\mu_0} + 2I_a(\ln\frac{D_{ax}}{r}.\frac{D_{an}}{D_{nx}}))$$

$$+2I_b(\ln(\frac{D_{bx}}{D_{ab}}.\frac{D_{an}}{D_{nx}}))$$

$$+\ldots+2I_{n-1}(\ln(\frac{D_{n-1x}}{D_{an-1}}.\frac{D_{an}}{D_{nx}}))]$$

Continue

When X approaches infinity,

$$\frac{D_{ax}}{D_{nx}} = \frac{D_{bx}}{D_{nx}} = \dots\dots\dots = \frac{D_{n-1}}{D_{nx}} = 1$$

$$\lambda_a = 10^{-7}[\frac{I_a}{2}\frac{\mu}{\mu_0} + 2I_a \ln\frac{D_{an}}{r}$$

$$+ 2I_b \ln\frac{D_{an}}{D_{ab}}$$

$$+ \ldots + 2I_{n-1} \ln\frac{D_{an}}{D_{an-1}}]$$

Continue

$$\text{Since,} \quad -\ln A = \ln(A)^{-1} = \ln\frac{1}{A}$$

$$\lambda_a = 10^{-7}[\frac{I_a}{2}\frac{\mu}{\mu_0} + 2I_a \ln\frac{1}{r} + 2I_b \ln\frac{1}{D_{ab}}$$

$$+ \ldots + 2I_{n-1}\ln\frac{1}{D_{an-1}}$$

$$+ 2\ln D_{an}(I_a + I_b + \ldots + I_{n-1})]$$

Continue

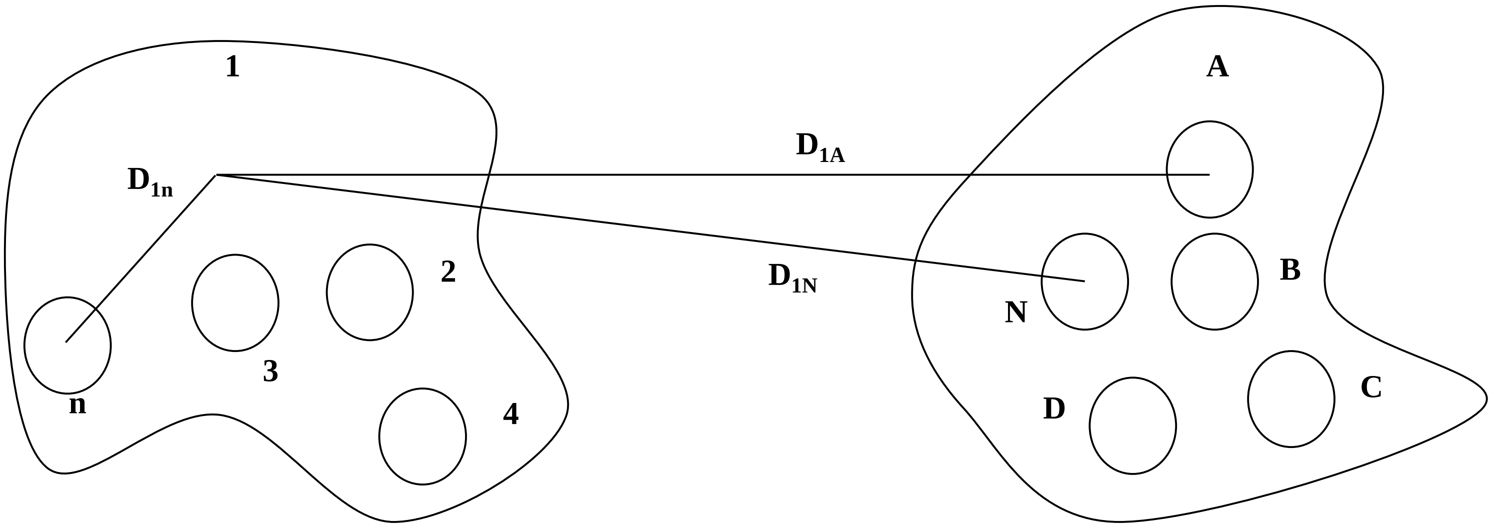
$$\lambda_a = 10^{-7}[\frac{I_a}{2}\frac{\mu}{\mu_0} + 2I_a \ln\frac{1}{r} + 2I_b \ln\frac{1}{D_{ab}}$$

$$+ \ldots + 2I_f \ln\frac{1}{D_{af}} + 2I_n \ln\frac{1}{D_{an}}]$$

$$L_a = \frac{\lambda_a}{I_a} \quad \text{m/H}$$

$$X_{La} = 2\pi f L_a \quad \Omega$$

General Expression for Inductance of Two Parallel Conductors of Irregular Cross-Section



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The linkages about the small element I can be obtained by,

$$\lambda_1 = 2*10^{-7} * (\frac{I}{n})(\frac{1}{4} + \ln\frac{1}{r_1} + \ln\frac{1}{D_{12}} + \ln\frac{1}{D_{13}} + \ldots + \ln\frac{1}{D_{1n}} - \ln\frac{1}{D_{1a}} - \ln\frac{1}{D_{1B}} \ldots - \ln\frac{1}{D_{1n}}) \quad \text{Linkage}/\text{m}$$

Similarly, $\lambda_2, \lambda_3, \ldots, \lambda_n$ can be obtained

$$\lambda_{total} = \lambda_1 + \lambda_2 + \lambda_3 + \ldots + \lambda_n$$

The linkages about the conductor are given by (λ_{total})

$$\lambda_{total} = \frac{2*10^{-7}}{n^2} I[\frac{1}{4} + \ln\frac{1}{r_1} + \ln\frac{1}{D_{12}} + \ldots + \ln\frac{1}{D_{1n}}$$

$$+\frac{1}{4} + \ln\frac{1}{r_2} + \ln\frac{1}{D_{21}} + \ldots + \ln\frac{1}{D_{2n}}$$

$$+\frac{1}{4} + \ln\frac{1}{r_n} + \ln\frac{1}{D_{n1}} + \ldots + \ln\frac{1}{D_{nn}}$$

$$-\ln\frac{1}{D_{1A}} - \ln\frac{1}{D_{1B}} - \ldots - \ln\frac{1}{D_{1n}}$$

$$-\ln\frac{1}{D_{2A}} - \ln\frac{1}{D_{2B}} - \ldots\ldots - \ln\frac{1}{D_{2n}}]$$

Continue

$$\text{since} \ln\frac{1}{D_1} - \ln\frac{1}{D_2} = \ln\frac{1/D_1}{1/D_2} = \ln\frac{D_2}{D_1}$$

$$\frac{1}{n^2}\ln X = \ln\sqrt[n^2]{X}$$

$$\lambda_{total} = 2*10^{-7} I[\frac{1}{4n} + \ln\frac{\sqrt[n^2]{D_{1A}D_{1B}.........D_{1n}D_{2A}D_{2B}..........D_{2n}}}{\sqrt[n^2]{r_1 D_{12}......D_{1n} r_2 D_{21}......D_{2n}.....r_n D_{n1}...}}]$$

Continue

If n is taken as infinity, the term $\frac{1}{4n}$ is negligible and approaches to zero, thus,

$$\lambda = 2*10^{-7} I \ln \frac{\sqrt[n^2]{D_{1A} D_{1B} \ldots\ldots D_{1n} D_{2A} D_{2B} \ldots\ldots D_{2n} \ldots\ldots}}{\sqrt[n^2]{r_1 D_{12} \ldots\ldots D_{1n} r_2 D_{21} \ldots\ldots\ldots\ldots\ldots D_{2n} r_n}}$$

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

Continue

$$L = \frac{\lambda}{I}$$

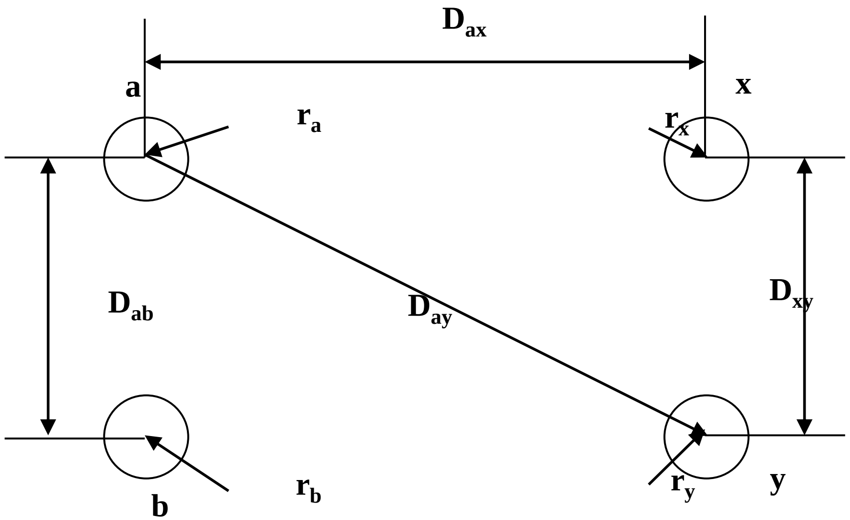
Definitions:

D_m : (Geometric mean distance) “GMD“ : is the distance between the one conductor in coil side and the other conductors in the other coil side.

Ds : (self – geo metric mean distance) “SGMD“ or (Geometric mean radius)”GMR” is the distance between the one conductor in coil side and the other conductors in the same coil side

Inductance of Two Parallel Wires with Single–Phase Circuit

Using general expression



$$D_m = D$$

$$D_s = re^{-0.25}$$

$$L = L_a + L_b$$ H/m (For both conductors)

Inductance of Single-Phase Line with Multi–Conductors

using general expression

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

For identical conductors, $r_a = r_b = r_x = r_y = r$

$$D_m = \sqrt[2*2]{D_{ax}.D_{ay}\ .D_{bx}.D_{by}}$$

Where;

$$D_{ay} = \sqrt{(D_{ax})^2 + (D_{xy})^2}$$

Continue

$$D_s = \sqrt[(2)^2]{r_a . D_{ab} . r_b . D_{ba}} = \sqrt[4]{r_a D_{ab} r_b D_{ba}}$$

$$r_a = r_b = r \qquad D_{ab} = D_{ba}$$

$$Note : r_a = re^{-0.25}$$

$$D_s = \sqrt{r D_{ab}}$$

If $D_{ab}=D_{xy}$, then D_s of the conductors on the left hand side as well as on the right hand side is equal.

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Transmission and Distribution of Electrical Power

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