Ch.4. Transmission Line Parameters

Note Title 3/1/2014

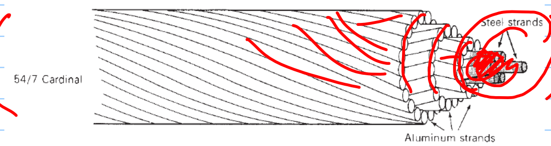
4.1. Transmission Line Design Considerations:

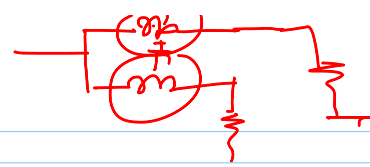
* Transmission lines consist of:

① Conductors:

Types:
- Aluminum conductor, steel re-inforced (ACSR)
- All - Aluminume conductor (AAC)
- All - Aluminume - alloy conductor (AAAC)
- Aluminum conductor, Alloy-reinforced (ACAR)
- Aluminum-clad steel conductor (Alumowed)

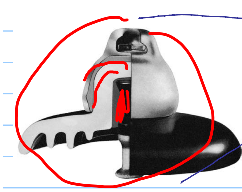
Bundle: more than one conductor per phase to control corona and reduce the electric field strength.

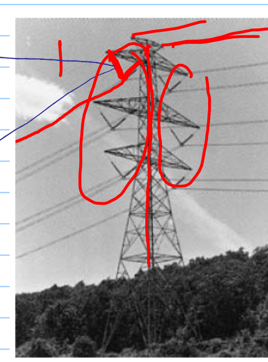




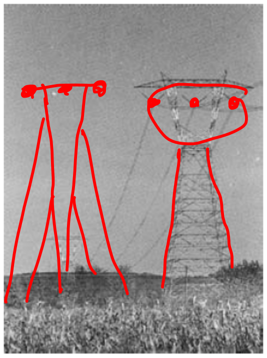
② Insulators:

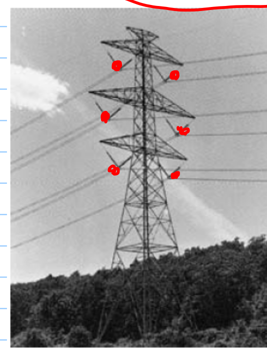
Nominal Voltage (kV)	Suspension Insulator String: Number of Strings per Phase	Number of Standard Insulator Discs per Suspension String	Shield Wires: Type	Number	Diameter (cm)
69	1	4 to 6	Steel	0, 1 or 2	
138	1	8 to 11	Steel	0, 1 or 2	
230	1	12 to 21	Steel or ACSR	1 or 2	1.1 to 1.5
345	1	18 to 21	Alumoweld	2	0.87 to 1.5
345	1 and 2	18 to 21	Alumoweld	2	0.87 to 1.5
500	2 and 4	24 to 27	Alumoweld	2	0.98 to 1.5
500	2 and 4	24 to 27	Alumoweld	2	0.98 to 1.5
765	2 and 4	30 to 35	Alumoweld	2	0.98

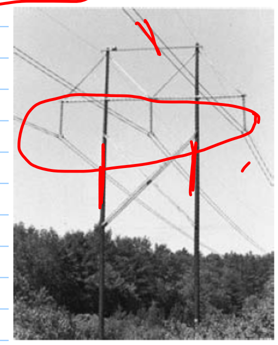




③ Support Structure: & ④ Shield Wires: O/H







Thereafter, transmission-line design is based on optimization of electrical, mechanical, environmental, and economic factors.

4.2 Resistance:

m^2

cmil

$$R_{dc,T} = \frac{\rho_T l}{A} \quad \Omega$$

where ρ_T = conductor resistivity at temperature T

l = conductor length

A = conductor cross-sectional area

D in $\xrightarrow{\times 1000}$ d mil , 1 cmil = $\frac{\pi}{4}$ sq mil

$$A = \left(\frac{\pi}{4} D^2 \text{ in.}^2\right)\left(1000 \frac{\text{mil}}{\text{in.}}\right)^2 = \frac{\pi}{4}(1000\ D)^2 = \frac{\pi}{4} d^2 \quad \text{sq mil}$$

or

$$A = \left(\frac{\pi}{4} d^2 \text{ sq mil}\right)\left(\frac{1 \text{ cmil}}{\pi/4 \text{ sq mil}}\right) = d^2 \quad \text{cmil}$$

Conductor resistance depends on the following factors: Read Ex 4.1

1. Spiraling → Stranded ⇒ + 1% ~ 2% longer
2. Temperature → $\rho_{T2} = \rho_{T1}\left(\frac{T_2 + T}{T_1 + T}\right)$
3. Frequency ("skin effect") → $R_{ac} = \frac{P_{loss}}{|I|^2}\ \Omega$
4. Current magnitude—magnetic conductors

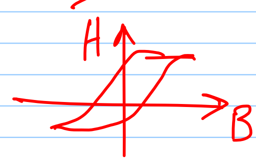
4.3 Conductance:

* Caused by insulator leakage current and corrona.
* Very small ⇒ neglegable.

4.4. Inductance: Solid Cylindrical Conductor:

The inductance of a magnetic circuit that has a constant permeability μ can be obtained by determining the following:

1. Magnetic field intensity H, from Ampere's law
2. Magnetic flux density B $(B = \mu H)$
3. Flux linkages λ
4. Inductance from flux linkages per ampere $(L = \lambda/I)$



① Internal inductance: $x < r$

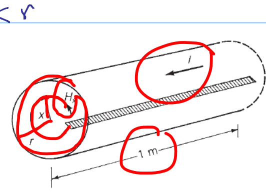
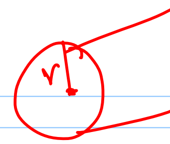


FIGURE 4.6
Internal magnetic field of a solid cylindrical conductor

$\frac{\pi x^2}{\pi r^2}$ $\left(\frac{x}{r}\right)^2$



$$\oint H_{\tan}\, dl = I_{\text{enclosed}}$$

$$H_x(2\pi x) = I_x \quad \text{for } x < r \longrightarrow H_x = \frac{I_x}{2\pi x} \quad \text{A/m}$$

$$I_x = \left(\frac{x}{r}\right)^2 I \quad \text{for } x < r \longrightarrow H_x = \frac{xI}{2\pi r^2} \quad \text{A/m}$$

$$B_x = \mu_0 H_x = \frac{\mu_0 x I}{2\pi r^2} \quad \text{Wb/m}^2$$

$$\Delta\Phi \quad d\Phi = B_x\, dx \quad \text{Wb/m} \quad , \quad d\lambda = \left(\frac{x}{r}\right)^2 d\Phi = \boxed{\frac{\mu_0 I}{2\pi r^4} x^3\, dx \quad \text{Wb-t/m}} = d\lambda$$

$$\lambda_{\text{int}} = \int_0^r d\lambda = \boxed{\frac{\mu_0 I}{2\pi r^4}\int_0^r x^3\, dx} = \frac{\mu_0 I}{8\pi} = \frac{1}{2} \times 10^{-7} I \quad \text{Wb-t/m} \longrightarrow \mathrm{L_{int}} = \frac{\lambda_{\text{int}}}{I} = \frac{\mu_0}{8\pi} = \frac{1}{2} \times 10^{-7} \quad \text{H/m}$$

② External inductance: $x > r$

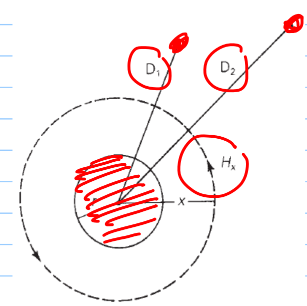
$$H_x(2\pi x) = I \longrightarrow H_x = \frac{I}{2\pi x} \quad \text{A/m} \quad x > r$$

Outside the conductor, $\mu = \mu_0$ and

$$B_x = \mu_0 H_x = (4\pi \times 10^{-7}) \frac{I}{2\pi x} = 2 \times 10^{-7} \frac{I}{x} \quad \text{Wb/m}^2$$

$$d\Phi = B_x\, dx = 2 \times 10^{-7} \frac{I}{x}\, dx \quad \text{Wb/m}$$

$\cancel{I_x}$ I



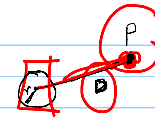
Since the entire current I is linked by the flux outside the conductor,

$$d\lambda = d\Phi = 2 \times 10^{-7} \frac{I}{x}\, dx \quad \text{Wb-t/m}$$

$$\lambda_{12} = \int_{\mathrm{D_1}}^{\mathrm{D_2}} d\lambda = 2 \times 10^{-7} I \int_{\mathrm{D_1}}^{\mathrm{D_2}} \frac{dx}{x}$$

$$= 2 \times 10^{-7} I \ln\left(\frac{\mathrm{D_2}}{\mathrm{D_1}}\right) \quad \text{Wb-t/m}$$

$$L_{12} = \frac{\lambda_{12}}{I} = 2\times 10^{-7}\ln\left(\frac{D_2}{D_1}\right)\quad \text{H/m}$$



If $D_1 = r$, $D_2 = D$: λ_P = internal flux + external flux.

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

$\left(\frac{1}{2} = 2\ln e^{\frac{1}{4}}\right)$ identity leads to:

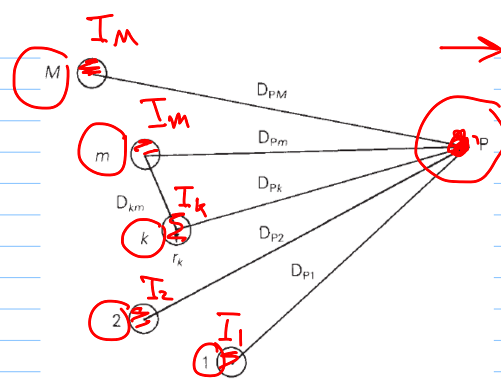
$$\lambda_P = 2\times 10^{-7} I\left(\ln e^{1/4} + \ln\frac{D}{r}\right)$$

$$= 2\times 10^{-7} I \ln\frac{D}{e^{-1/4} r}$$

$$= 2\times 10^{-7} I \ln\frac{D}{r'}\quad \text{Wb-t/m}\quad , \quad r' = e^{-\frac{1}{4}} r = 0.7788\, r$$

$$L_P = \frac{\lambda_P}{I} = 2\times 10^{-7}\ln\left(\frac{D}{r'}\right)\quad \text{H/m}$$

③ Array of Conductors:



$$\lambda_{kPk} = 2\times 10^{-7} I_k \ln\frac{D_{Pk}}{r'_k}$$

$$\lambda_{kPm} = 2\times 10^{-7} I_m \ln\frac{D_{Pm}}{D_{km}}$$

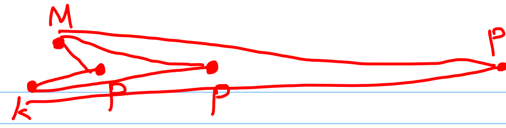
$$\lambda_{kP} = \lambda_{kP1} + \lambda_{kP2} + \cdots + \lambda_{kPM} = 2\times 10^{-7}\sum_{m=1}^{M} I_m \ln\frac{D_{Pm}}{D_{km}}$$

$$\lambda_{kP} = 2\times 10^{-7}\sum_{m=1}^{M} I_m \ln\frac{1}{D_{km}} + 2\times 10^{-7}\sum_{m=1}^{M} I_m \ln D_{Pm}$$

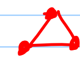
$$\lambda_{kP} = 2\times 10^{-7}\left[\sum_{m=1}^{M} I_m \ln\frac{1}{D_{km}} + \sum_{m=1}^{M-1} I_m \ln D_{Pm} + I_M \ln D_{PM}\right]$$

$$I_1 + I_2 + \cdots + I_M = \sum_{m=1}^{M} I_m = 0 \longrightarrow I_M = -(I_1 + I_2 + \cdots + I_{M-1}) = -\sum_{m=1}^{M-1} I_m$$

$$\lambda_{k\mathrm{P}} = 2 \times 10^{-7}\left[\sum_{m-1}^{M} I_m \ln \frac{1}{\mathrm{D}_{km}} + \sum_{m-1}^{M-1} I_m \ln \mathrm{D}_{\mathrm{P}m} - \sum_{m-1}^{M-1} I_m \ln \mathrm{D}_{\mathrm{P}M}\right]$$



$$\lambda_{k\mathrm{P}} = 2 \times 10^{-7}\left[\sum_{m-1}^{M} I_m \ln \frac{1}{\mathrm{D}_{km}} + \sum_{m-1}^{M-1} \cancel{I_m \ln \frac{\mathrm{D}_{\mathrm{P}m}}{\mathrm{D}_{\mathrm{P}M}}}\right]$$

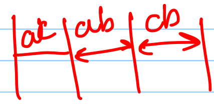


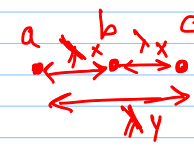
$\left(\frac{D_{MP}}{D_{kP}}\right)$

$dn\,l = 0$

Now, let λ_k equal the total flux linking conductor k out to infinity. That is, $\lambda_k = \lim_{\mathrm{P}\to\infty} \lambda_{k\mathrm{P}}$. As $\mathrm{P} \to \infty$, all the distances $\mathrm{D}_{\mathrm{P}m}$ become equal, the ratios $\mathrm{D}_{\mathrm{P}m}/\mathrm{D}_{\mathrm{P}M}$ become unity, and $\ln(\mathrm{D}_{\mathrm{P}m}/\mathrm{D}_{\mathrm{P}M}) \to 0$. Therefore, the second summation in (4.4.29) becomes zero as $\mathrm{P} \to \infty$, and

$$\lambda_k = 2 \times 10^{-7} \sum_{m-1}^{M} I_m \ln \frac{1}{\mathrm{D}_{km}} \quad \text{Wb-t/m}$$





X2 air