ELECTRICAL FACTORS

Electrical design dictates the type, size, and number of bundle conductors per phase. Phase conductors are selected to have sufficient thermal capacity to meet continuous, emergency overload, and short-circuit current ratings. For EHV lines, the number of bundle conductors per phase is selected to control the voltage gradient at conductor surfaces, thereby reducing or eliminating corona.

P.177 ref 2

Mechanical design focuses on the strength of the conductors, insulator strings, and support structures. Conductors must be strong enough to support a specified thickness of ice and a specified wind in addition to their own weight. Suspension insulator strings must

P.177 ref 2

The dc resistance of a conductor at a specified temperature T is

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

DC

where ρ_T = conductor resistivity at temperature T
l = conductor length
A = conductor cross-sectional area

P.178 ref 2

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

or

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

Quantity	Symbol	SI Units	English Units
Resistivity	ρ	Ωm	Ω-cmil/ft
Length	ℓ	m	ft
Cross-sectional area	A	m^2	cmil
dc resistance	$R_{dc} = \frac{\rho\ell}{A}$	Ω	Ω

Tableau des résistivités à la page 179 ref 2

Conductor resistance depends on the following factors:

1. Spiraling
2. Temperature
3. Frequency ("skin effect")
4. Current magnitude—magnetic conductors

Resistivity of conductor metals varies linearly over normal operating temperatures according to

$$\rho_{T2} = \rho_{T1}\left(\frac{T_2 + T}{T_1 + T}\right) \tag{4.2.3}$$

where ρ_{T2} and ρ_{T1} are resistivities at temperatures T_2 and T_1°C, respectively. T is a temperature constant that depends on the conductor material and is listed in Table 4.3.

The ac resistance or *effective* resistance of a conductor is

$$R_{ac} = \frac{P_{loss}}{|I|^2} \quad \Omega \tag{4.2.4}$$

AC

P_{loss} = real power loss in watts

I = rms conductor current

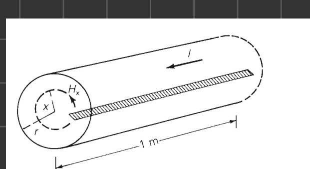
4.3

+ la fréquence monte + gros les pertes, la résistance AC augmente
↳ Souvent fait pour 50 - 60 Hz

Pertes à cause des pertes insulation sont beaucoup plus petite que les pertes I^2R P.181 ref 2
↳ pertes corona

4.4

$$(\mu = \mu_0 = 4\pi \times 10^{-7}\,\text{H/m})$$



$$H_x(2\pi x) = I_x \quad \text{for } x < r \tag{4.4.2}$$

where I_x is the portion of the total current enclosed by the contour. Solving (4.4.2),

P.182 ref 2

$$H_x = \frac{I_x}{2\pi x} \quad \text{A/m} \tag{4.4.3}$$

Now assume a uniform current distribution within the conductor, that is

$$I_x = \left(\frac{x}{r}\right)^2 I \quad \text{for } x < r \tag{4.4.4}$$

Using (4.4.4) in (4.4.3)

$$H_x = \frac{xI}{2\pi r^2} \quad \text{A/m} \tag{4.4.5}$$

For a nonmagnetic conductor, the magnetic flux density B_x is

$$B_x = \mu_0 H_x = \frac{\mu_0 x I}{2\pi r^2} \quad \text{Wb/m}^2 \tag{4.4.6}$$

The internal inductance L_{int} per-unit length of conductor due to this flux linkage is then

$$L_{int} = \frac{\lambda_{int}}{I} = \frac{\mu_0}{8\pi} = \frac{1}{2} \times 10^{-7} \quad \text{H/m} \tag{4.4.10}$$

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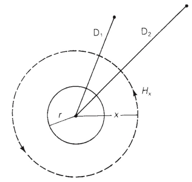
The external inductance L_{12} per-unit length due to the flux linkages between D_1 and D_2 is then

$$L_{12} = \frac{\lambda_{12}}{I} = 2 \times 10^{-7} \ln\left(\frac{D_2}{D_1}\right) \quad \text{H/m} \tag{4.4.17}$$

P.184

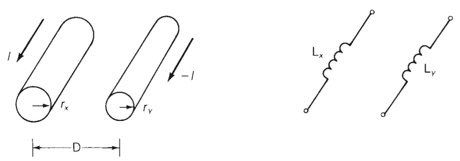
Integrating (4.4.15) between two external points at distances D_1 and D_2 from the conductor center gives the external flux linkage λ_{12} between D_1 and D_2:



$\boxed{4.5}$

P.187

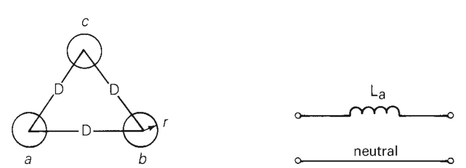
$$\begin{aligned}
\lambda_x &= 2 \times 10^{-7}\left(I_x \ln \frac{1}{D_{xx}} + I_y \ln \frac{1}{D_{xy}}\right) \\
&= 2 \times 10^{-7}\left(I \ln \frac{1}{r'_x} - I \ln \frac{1}{D}\right) \\
&= 2 \times 10^{-7} I \ln \frac{D}{r'_x} \quad \text{Wb-t/m}
\end{aligned}$$



(a) Geometry (b) Inductances

The inductance of conductor x is then

$$L_x = \frac{\lambda_x}{I_x} = \frac{\lambda_x}{I} = 2 \times 10^{-7} \ln \frac{D}{r'_x} \quad \text{H/m per conductor}$$



(a) Geometry (b) Phase inductance

To determine inductance, assume balanced positive-sequence currents I_a, I_b, I_c that satisfy $I_a + I_b + I_c = 0$. Then (4.4.30) is valid and the total flux linking the phase a conductor is

$$\begin{aligned}
\lambda_a &= 2 \times 10^{-7}\left(I_a \ln \frac{1}{r'} + I_b \ln \frac{1}{D} + I_c \ln \frac{1}{D}\right) \\
&= 2 \times 10^{-7}\left[I_a \ln \frac{1}{r'} + (I_b + I_c) \ln \frac{1}{D}\right]
\end{aligned} \tag{4.5.7}$$

Using $(I_b + I_c) = -I_a$,

$$\begin{aligned}
\lambda_a &= 2 \times 10^{-7}\left(I_a \ln \frac{1}{r'} - I_a \ln \frac{1}{D}\right) \\
&= 2 \times 10^{-7} I_a \ln \frac{D}{r'} \quad \text{Wb-t/m}
\end{aligned}$$

The inductance of phase a is then

$$L_a = \frac{\lambda_a}{I_a} = 2 \times 10^{-7} \ln \frac{D}{r'} \quad \text{H/m per phase}$$

Composite 4.6

and the inductance of conductor x, $L_x = \frac{\lambda_x}{I}$, can be written as

$$L_x = 2 \times 10^{-7} \ln \frac{D_{xy}}{D_{xx}} \quad \text{H/m per conductor}$$

where

$$D_{xy} = \sqrt[MN]{\prod_{k=1}^{N} \prod_{m=1'}^{M} D_{km}}$$

$$D_{xx} = \sqrt[N^2]{\prod_{k=1}^{N} \prod_{m=1}^{N} D_{km}}$$

D = distance
N = nombre de sous-conducteur dans conducteur x
M = nombre de sous-conducteur dans conducteur y

g $(I_b + I_c) = -I_a$ in (4.6.14),

$$\lambda_a = \frac{2 \times 10^{-7}}{3} \left[3I_a \ln \frac{1}{D_S} - I_a \ln \frac{1}{D_{12}D_{23}D_{31}} \right]$$

$$= 2 \times 10^{-7} I_a \ln \frac{\sqrt[3]{D_{12}D_{23}D_{31}}}{D_S} \quad \text{Wb-t/m}$$

Pour conducteur avec espacement à égal

$$L_a = \frac{\lambda_a}{I_a} = 2 \times 10^{-7} \ln \frac{\sqrt[3]{D_{12}D_{23}D_{31}}}{D_S} \quad \text{H/m per phase}$$

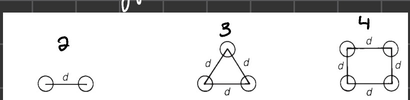
$$D_{eq} = \sqrt[3]{D_{12}D_{23}D_{31}}$$

results in

$$L_a = 2 \times 10^{-7} \ln \frac{D_{eq}}{D_S} \quad \text{H/m}$$

Resumé

Types de bundles



Two-conductor bundle:

$$D_{SL} = \sqrt[4]{(D_S \times d)^2} = \sqrt{D_S d}$$

Three-conductor bundle:

$$D_{SL} = \sqrt[9]{(D_S \times d \times d)^3} = \sqrt[3]{D_S d^2}$$

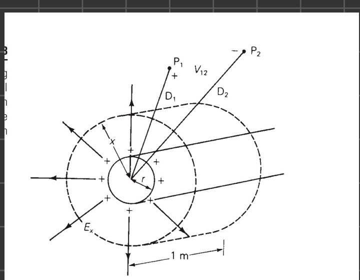
Four-conductor bundle:

$$D_{SL} = \sqrt[16]{(D_S \times d \times d \times d\sqrt{2})^4} = 1.091 \sqrt[4]{D_S d^3}$$

The inductance is then

$$L_a = 2 \times 10^{-7} \ln \frac{D_{eq}}{D_{SL}} \quad \text{H/m}$$

4.8



$$E_x = \frac{q}{2\pi\varepsilon x} \quad \text{V/m}$$

$$V_{12} = \int_{D_1}^{D_2} \frac{q}{2\pi\varepsilon x} dx = \frac{q}{2\pi\varepsilon} \ln \frac{D_2}{D_1} \quad \text{volts}$$

4.9

$$V_{xy} = \frac{1}{2\pi\varepsilon}\left[q \ln\frac{D_{yx}}{D_{xx}} - q \ln\frac{D_{yy}}{D_{xy}}\right]$$

$$= \frac{q}{2\pi\varepsilon}\ln\frac{D_{yx}D_{xy}}{D_{xx}D_{yy}}$$

Using $D_{xy} = D_{yx} = D$, $D_{xx} = r_x$, and $D_{yy} = r_y$, (4.9.1) becomes

$$V_{xy} = \frac{q}{\pi\varepsilon}\ln\frac{D}{\sqrt{r_x r_y}} \quad \text{volts}$$

For a 1-meter line length, the capacitance between conductors is

E LL

$$C_{xy} = \frac{q}{V_{xy}} = \frac{\pi\varepsilon}{\ln\left(\frac{D}{\sqrt{r_x r_y}}\right)} \quad \text{F/m line-to-line}$$

and if $r_x = r_y = r$,

$$C_{xy} = \frac{\pi\varepsilon}{\ln(D/r)} \quad \text{F/m line-to-line}$$

If the two-wire line is supplied by a transformer with a grounded center tap, then the voltage between each conductor and ground is one-half that given by (4.9.2). That is,

$$V_{xn} = V_{yn} = \frac{V_{xy}}{2} \tag{4.9.5}$$

$$C_n = C_{xn} = C_{yn} = \frac{q}{V_{xn}} = 2C_{xy}$$

E LN

$$= \frac{2\pi\varepsilon}{\ln(D/r)} \quad \text{F/m line-to-neutral}$$

$$C_{an} = \frac{2\pi\varepsilon}{\ln(D_{eq}/D_{SC})} \quad \text{F/m}$$

where

$$D_{SC} = \sqrt{rd} \quad \text{for a two-conductor bundle}$$

4.10

Similarly,

$$D_{SC} = \sqrt[3]{rd^2} \quad \text{for a three-conductor bundle}$$

$$D_{SC} = 1.091\sqrt[4]{rd^3} \quad \text{for a four-conductor bundle}$$

4.12

Wildi

46.1

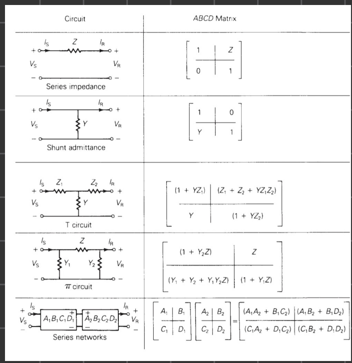
1. assurer la bonne puissance au client
2. fournir tension stable ±10 % de variation à comparer de la tension nominal
3. fréquence stable variation max de ±0,1 Hz
4. fournir énergie a prix abordable
5. Maintenir des normes de sécurité rigoureuse
6. Veiller à la protection de l'environnement

46.2

1. Basse tension (BT) 600V et −
2. moyenne tension (MT) 2,4 KV à 64 KV
3. haute tension (HT) 230 KV
4. tres haute tension (THT) 765 KV → 1000 Km

Power

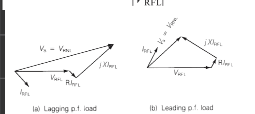
5.1



Circuit	ABCD Matrix
Series impedance	$\begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$
Shunt admittance	$\begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix}$
T circuit	$\begin{bmatrix} (1 + YZ_1) & (Z_1 + Z_2 + YZ_1Z_2) \\ Y & (1 + YZ_2) \end{bmatrix}$
π circuit	$\begin{bmatrix} (1 + Y_2Z) & Z \\ (Y_1 + Y_2 + Y_1Y_2Z) & (1 + Y_1Z) \end{bmatrix}$
Series networks	$\begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix}\begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} = \begin{bmatrix} (A_1A_2 + B_1C_2) & (A_1B_2 + B_1D_2) \\ (C_1A_2 + D_1C_2) & (C_1B_2 + D_1D_2) \end{bmatrix}$

$$\text{percent VR} = \frac{|V_{RNL}| - |V_{RFL}|}{|V_{RFL}|} \times 100$$

VR = Voltage regulation



4.2

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}\begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

Parameter	A = D	B	C
Units	per Unit	Ω	S
Short line (less than 25 km)	1	Z	0
Medium line—nominal π circuit (25 to 250 km)	$1 + \frac{YZ}{2}$	Z	$Y\left(1 + \frac{YZ}{4}\right)$
Long line—equivalent π circuit (more than 250 km)	$\cosh(\gamma l) = 1 + \frac{Y'Z'}{2}$	$Z_c \sinh(\gamma l) = Z'$	$(1/Z_c)\sinh(\gamma l) = Y'\left(1 + \frac{Y'Z'}{4}\right)$
Lossless line (R = G = 0)	$\cos(\beta l)$	$jZ_c \sin(\beta l)$	$\frac{j\sin(\beta l)}{Z_c}$

Wildi

42.12

P = puissance activé absorbé par charge

P_J = Puissance active dissipé par effet Joules RI^2

Q_L = Puissance réactivé absorbé par la ligne $X_L I^2$

Q_c = Puissance réactive généré par la ligne E^2/X_c

- Si une des puissance est négligeable à comparé de puissance transporté elle peut être négliger
  - ↳ Exemple : ligne 600V sont courtes donc X_c très élevé donc $\frac{E^2}{X_c}$ devient négligeable on peut donc enlever X_c
  - ↳ Exemple : ligne 735 KV (Sept-îles → Churchill Falls) pertes Joules sont négligeable on peut donc enlever R

42.13

Interessant voir direct P.1034

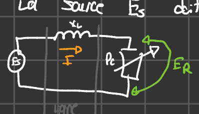
42.16 : ligne inductive

$$P_{Max} = \frac{E_s^2}{2X_L}$$

$$E_R = 0.707\ E_s$$

① ligne inductive offre meilleur régulation qu'une ligne résistive

② La source E_s doit fournir puissance consommé par charge + $P_{absorbé}$ par la ligne $X_L I^2$



42.17 : ligne inductive avec compensation

$$P_{max} = \frac{E_s^2}{X_L}$$

① En comparant avec 46.16 on voit que celle-ci peut transporter le double

46.18 : ligne inductive relant deux réseaux

$$P = \frac{E^2}{X_L} \sin(\theta)$$

E = tension Ligne - Neutre (V)
P = puissance active transporter par phase (W)
X_L = reactance inductive par phase (Ω)
θ = angle de déphasage entre les tension entre les deux extrémité de la ligne (°)

triphase

$$P_T = \frac{E_L^2}{X_L} \sin(\theta)$$

P_T = puissance active total transporté par une ligne triphase (MW)
E_L = tension Ligne - ligne (KV)
X_L = reactance inductive par phase (Ω)
θ = angle de déphasage entre les tension entre les deux extrémité de la ligne (°)

46.21 : Methode augmente puissance

Compensateur série

$$P_{max} = \frac{E_L^2}{(X_L - X_{CS})}$$