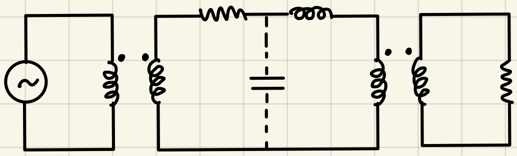
AC CH3 伝転線RLC



$R = \frac{l}{\mu A} = \frac{\rho l}{A}$

$L \propto N^2$. $L = \frac{\overset{\text{導磁}}{\mu} A}{l} N^2$

通电流的導体 ⟶ 產生磁場

安培定律 $\oint H \cdot dl = Ni$ ($N=1$ ⇒ 一根長導体)

① 無限長單一通电流導体

磁通鏈 $\lambda = \lambda_{外} + \lambda_{内} = \left(\frac{\mu_0 i}{2\pi}\right)\left(\frac{\mu_r}{4}^{\text{内}} + \ln^{\text{外}} \frac{R}{r}\right) = \left(\frac{\mu_0 i}{2\pi}\right)\left(\ln \frac{R}{r'}\right)$

② 無限長 多個通电流導体

三相平衡 $i_a + i_b + i_c = 0$, $\lambda_a = l_a i_a = \left(\frac{\mu_0 i_a}{2\pi}\right) \ln \frac{D}{r'}$

$\lambda_a = \frac{\mu_0 i_a}{2\pi}\left(\frac{\mu_r}{4} + \ln \frac{R}{r}\right) + \frac{\mu_0 i_b}{2\pi}\left(\ln \frac{R}{D}\right) + \frac{\mu_0 i_c}{2\pi}\left(\ln \frac{R}{D}\right)$

③ 捆束導体 (每相有多導体)

$\lambda_1 = \frac{\mu_0}{2\pi}\left(i_a \ln \frac{1}{R_{GMR}} + i_b \ln \frac{1}{D_{1b}} + i_c \ln \frac{1}{D_{1c}}\right)$

$\lambda_1 = \left(\frac{\mu_0 i_a}{2\pi}\right)\left(\ln \frac{D}{R_{GMR}}\right)$

④ 捆束平移

$\bar{l}_a = \bar{l}_b = \bar{l}_c = \left(\frac{\mu_0}{2\pi}\right) \ln \frac{D_m}{R_{GMR}}$

$\log AB = \log A + \log B$

$\log \frac{A}{B} = \log A - \log B$

$\frac{\mu_r}{4} = \log_{10} 10^{\frac{\mu_r}{4}}$

$= \ln e^{\frac{\mu_r}{4}} = \ln \frac{1}{e^{-\frac{\mu_r}{4}}}$

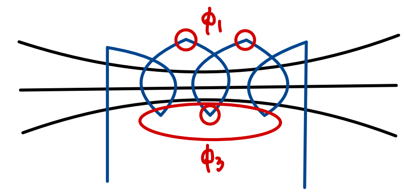
3.1磁學回顧(Review of Magnetics)

Ampere's Circuital Law: $\mathcal{F} = \oint \mathrm{H} \cdot d l = \mathrm{N}i$ 磁動勢

磁通密度. 非 constant

$\mathrm{B} = \mu \mathrm{H}$, $\mathrm{B} = \Phi/\mathrm{A}$, Φ: flux, B: flux density (webers/m^2), H: magnetic field intensity (A · turn/m)

磁通鏈Flux linkages: $\lambda = \mathrm{N}\Phi = \mathrm{L}i = \sum_{i=1}^{\mathrm{N}} \Phi_i$



Ex3.1 Calculate the inductance.

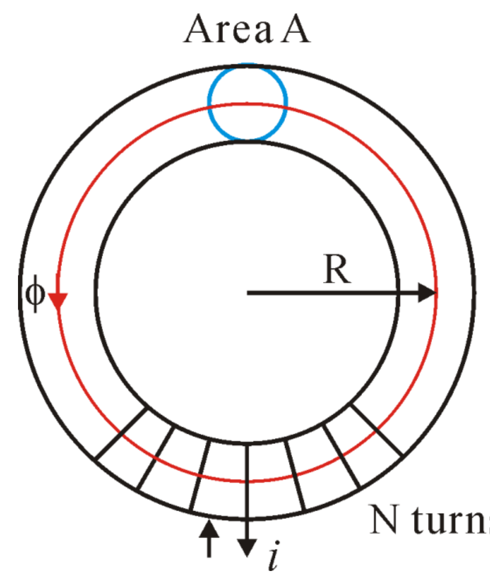
$\mathcal{F} = \mathrm{H}l = \mathrm{N}i$

$\mathrm{B} = \mu \mathrm{H} = \mu \mathrm{N}i/l,$

$\Phi = \mathrm{BA} = (\mu \mathrm{A}/l)\mathrm{N}i$,

$L = \lambda/i = \mathrm{N}\Phi/i = (\mu \mathrm{AN}^2/l) = \mu \mathrm{AN}^2/(2\pi \mathrm{R})$

inductance: relates flux linkage to current



$e_{ind} = L\frac{di}{dt} = N\frac{d\phi}{dt}$ $\phi = BA = \mu HA = \mu\frac{Ni}{l}A$

$\frac{Li}{t} = \frac{N\phi}{t} = N\mu\frac{Ni}{lt}A$

$L = \frac{N^2\mu A}{l}$

3.2無限長直電線的磁通鏈(Flux Linkages of Infinite Straight Wire)

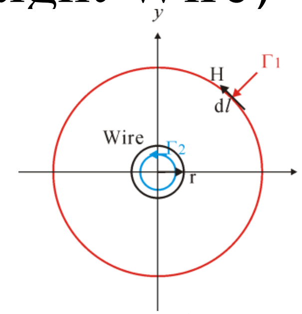


Figure 3.2: wire carrying current

外

Case 1 ($x > r$): $F = \oint H \cdot dl = \overset{N=1}{i} = H \cdot 2\pi x \Rightarrow H = i/(2\pi x)$

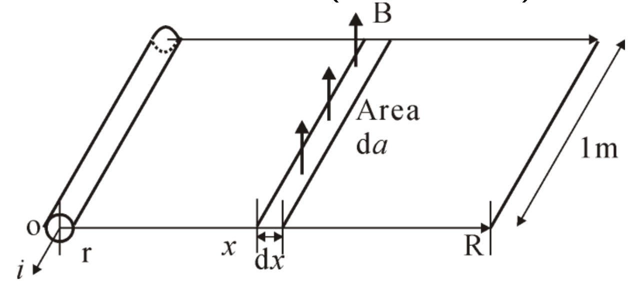
內

Case 2 ($x \le r$): $\oint H \cdot dl = i_e = (\pi x^2/\pi r^2) i = H \cdot 2\pi x \Rightarrow H = (x/2\pi r^2) i$

$B = \mu_r \mu_o H$, $\mu_o = 4\pi \times 10^{-7}$,

不導磁

μ_r of the air, copper, and aluminum is near 1.



線外 : $\mu_0 \int_r^R H\,dx = \mu_0 \int_r^R \frac{i}{2\pi x} dx = \frac{\mu_0 i}{2\pi} \int \frac{1}{x} dx = \frac{\mu_0 i}{2\pi} \ln\left(\frac{R}{r}\right)$

線內 : $\mu_r \mu_0 \int_0^r \frac{x}{2\pi r^2} \times \frac{\pi x^2}{\pi r^2} i\,dx = \frac{\mu_r \mu_0 i}{2\pi r^4} \int_0^r x^3 dx = \frac{\mu_r \mu_0 i}{2\pi r^4} \times \frac{r^4}{4} = \frac{\mu_r \mu_0 i}{8\pi}$

Figure 3.3: infinite wire of radius r, find flux crossing rectangle.

Case 1 ($x > r$, $N=1$): $\lambda_1 = \Phi_1 = \int_A B(x)dx = \mu_o \int_A H(x)dx = \mu_o \int_r^R i/(2\pi x)\,dx$

$= (\mu_o i/2\pi)\ln(R/r)$. (Caution: $R \to \infty$ 找不到)

Case 2 ($x \le r$, $\boxed{N = \pi x^2/\pi r^2} < 1$): $\lambda_2 = \mu_r \mu_o \int_0^r (x/2\pi r^2)(\pi x^2/\pi r^2) i\,dx = \mu_r \mu_o i/(8\pi)$

Total Flux Linkages per meter of one Infinite Straight Wire :

$\lambda = \lambda_2 + \lambda_1 = (\mu_o i/2\pi)[\mu_r/4 + \ln(R/r)]$

3.3 多導體情況下的磁通鏈(Flux Linkages of Multi-Conductors)

Total Flux Linkages per meter of one Infinite Straight Wire :

(自)內 (互)外

$$\lambda = \lambda_2 + \lambda_1 = (\mu_o\, i/2\pi)[\mu_r/4 + \ln(R/r)]$$

$\lambda_1 = \phi_1 = B_1A_1 = \mu_0 H_1 A_1$

$\lambda_2 = \phi_2 = B_2A_2 = \mu_r\mu_0 H_2 A_2$

$H_1A_1 = \int_A H(x)\,dx = \int_A \frac{i}{2\pi x}\,dx$

$H_2A_2 = \int_A H(x)\,dx = \int_A \frac{x}{2\pi r^2}\left(\frac{\pi x^2}{\pi r^2}\right) i\,dx$

Total Flux Linkages per meter of multi-Conductors for wire 1:

從 wire 1 的視角出發的自感 從 wire 1 的視角出發的外感

$$\lambda_1 = (\mu_o/2\pi)\{i_1[\mu_r/4 + \ln(R_1/r_1)] + i_2\ln(R_2/d_{12}) + \cdot\ \ \cdot + i_n\ln(R_n/d_{1n})\}$$

distance

$$= (\mu_o/2\pi)\{i_1[\mu_r/4 + \ln(1/r_1)] + i_2\ln(1/d_{12}) + \cdot\ \ \cdot + i_n\ln(1/d_{1n})\}$$

$$+(\mu_o/2\pi)[i_1(\ln(R_1) + i_2\ln(R_2) + \cdot\ \ \cdot + i_n\ln(R_n)]$$

Assuming $i_1+i_2+\cdot\ \ \cdot+i_n = 0$ and $R_1 = R_2 = \cdot\ \ \cdot = R_n = R$

$$\lambda_1 = (\mu_o/2\pi)\{i_1[\mu_r/4 + \ln(1/r_1)] + i_2\ln(1/d_{12}) + \cdot\ \ \cdot + i_n\ln(1/d_{1n})\}$$

$$= l_{11}i_1 + l_{12}i_2 + \cdot\ \ \cdot + l_{1n}i_n$$

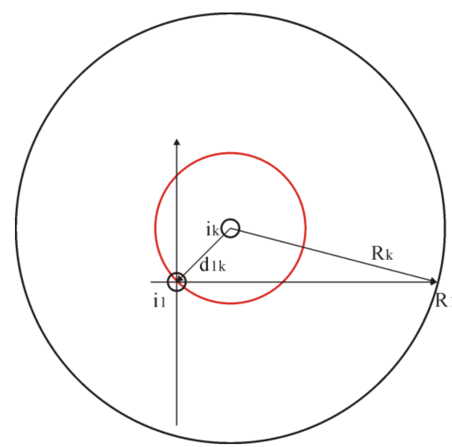
$i_1\ln(\frac{R}{r_1}) = i_1(\ln R - \ln r_1)$

$i_2\ln(\frac{R}{r_2}) = i_2(\ln R - \ln r_2) \Rightarrow i_n\ln(\frac{R}{r_n}) = i_n(\ln R - \ln r_n)$

$\vdots$

$$\lambda_k = (\mu_o/2\pi)\{i_1(\ln(1/d_{k1}) + i_2\ln(1/d_{k2}) + \cdot + i_k[\mu_r/4 + (\ln(1/r_k)] + \cdot + i_n\ln(1/d_{kn})]\}$$

$$= l_{k1}i_1 + l_{k2}i_2 + \cdot + l_{kk}i_k + \cdot + l_{kn}i_n$$



Ex3.2 Calculate the inductance per meter of each phase of a three-phase transmission line.

Assume that 1. Conductors equally spaced D and have equal radii r.

2. $i_a + i_b + i_c = 0$.

$$\lambda_a = (\mu_o/2\pi)\{i_a[\mu_r/4 + \ln(1/r)] + i_b\ln(1/D) + i_c\ln(1/D)\}$$

$$= (\mu_o/2\pi)\{i_a[\mu_r/4 + \ln(1/r)] - i_a\ln(1/D)\}$$

$$= (\mu_o/2\pi)[\mu_r/4 + \ln(1/r) - \ln(1/D)] \times i_a$$

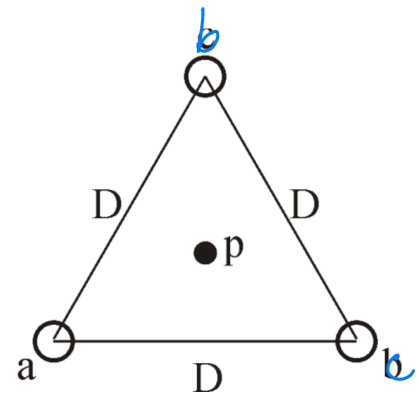
$$= (\mu_o/2\pi)[\ln e^{(\mu r/4)} + \ln(1/r) - \ln(1/D)] \times i_a$$

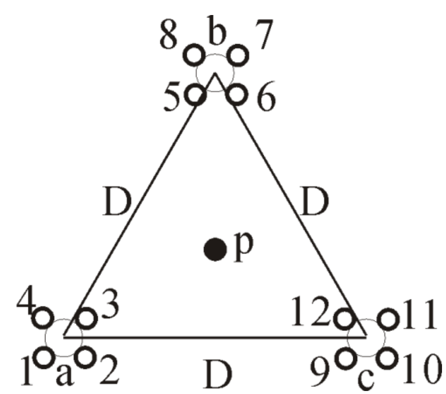
$$= (\mu_o/2\pi)[\ln(1/r\, e^{-(\mu r/4)}) - \ln(1/D)] \times i_a$$

$$= (\mu_o/2\pi)[\ln(1/r') - \ln(1/D)] \times i_a$$

$$= (\mu_o/2\pi)[\ln(D/r')] \times i_a$$

$$= l_a \times i_a$$





Assume that 1. $D = 1$m, $r = 0.01$m.

$\mu_r = 1$, $\mu_o = 4\pi \times 10^{-7}$,

$l_a = ?$

3.4捆束導體(Conductor Bundling)

$$\lambda_1 = (\mu_o/2\pi)\{ (i_a/4)[\mu_r/4 + \ln(1/r) + \ln(1/d_{12}) + \ln(1/d_{13}) + \ln(1/d_{14})]$$
$$+ (i_b/4)[\ln(1/d_{15}) + \ln(1/d_{16}) + \ln(1/d_{17}) + \ln(1/d_{18})]$$
$$+ (i_c/4)[\ln(1/d_{19}) + \ln(1/d_{1,10}) + \ln(1/d_{1,11}) + \ln(1/d_{1,12})] \}$$
$$= (\mu_o/2\pi)(i_a \ln 1/R_{GMR} + i_b \ln 1/D_{1b} + i_c \ln 1/D_{1c}$$

單相多導体

$r' = r\, e^{-(\mu r/4)}$, $R_{GMR} = (r' d_{12} d_{13} d_{14})^{1/4}$ (geometric mean radius)

$D_{1b} = (d_{15} d_{16} d_{17} d_{18})^{1/4}$, $D_{1c} = (d_{19} d_{1,10} d_{1,11} d_{1,12})^{1/4}$

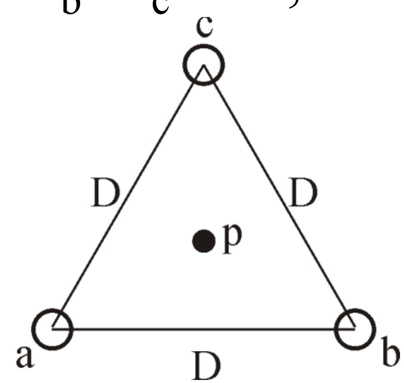
Assuming $D_{1b} = D_{1c} = D$ (geometric mean distance), $i_a + i_b + i_c = 0$,

$\lambda_1 = (\mu_o/2\pi)\, i_a \ln D/R_{GMR}$

Inductance $l_1 = \lambda_1/(i_a/4) = 4\,(\mu_o/2\pi) \ln D/R_{GMR}$

For phase a: $l_1 = l_2 = l_3 = l_4$, and four parallel lines,

$l_a = l_1/4 = (\mu_o/2\pi) \ln D/R_{GMR}$, and $l_a = l_b = l_c$



Ex3.3 Find the geometric mean radius (GMR) of three symmetrically spaced conductors. Assume that r = 2cm and $r' = r\, e^{-(\mu r/4)} = 2e^{-1/4} = 1.56$ cm ,

$d_{12} = d_{13} = d_{23} = 50$cm , $R_{GMR} = (r' d_{12} d_{13})^{1/3} = ?$,

3.5移位(Transposition)

It is usually more convenient to arrange the phases in a horizontal or vertical configuration, therefore the symmetry is lost. One way to regain the symmetry and restore balanced conditions is to use the method of transposition of lines.

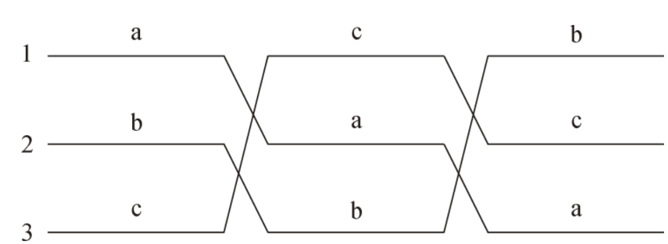
$\lambda_a \backslash = (\lambda_{a1} + \lambda_{a2} + \lambda_{a3})/3$, $D_m = (d_{12}\, d_{23}\, d_{13})^{1/3}$,

$$\lambda_a \backslash = (1/3)(\mu_o/2\pi)\{\, i_a \ln(1/r') + i_b \ln(1/d_{12}) + i_c \ln(1/d_{13})$$
$$+ i_a \ln(1/r') + i_b \ln(1/d_{23}) + i_c \ln(1/d_{12})$$
$$+ i_a \ln(1/r') + i_b \ln(1/d_{13}) + i_c \ln(1/d_{23}) \,\}$$

$$\lambda_a \backslash = (\mu_o/2\pi)\{\, i_a \ln(1/r') + i_b \ln(1/D_m) + i_c \ln(1/D_m) \,\}$$
$$= (\mu_o/2\pi)\{\, i_a \ln(1/r') - i_a \ln(1/D_m) \,\} = (\mu_o/2\pi)\, i_a \ln(D_m/r')$$

$l_a \backslash = l_b \backslash = l_c \backslash = (\mu_o/2\pi) \ln(D_m/r')$ for one line transposition

$l_a \backslash = l_b \backslash = l_c \backslash = (\mu_o/2\pi) \ln(D_m/R_{GMR})$ for conductor bundling transposition



Ex 3.5 Find the inductance per meter of the 3-phase line shown in figure E3.5. The conductors are aluminum ($\mu_r = 1$), with radius $r = \overset{1.27\,cm}{0.5}$ inch, $d_{12} = d_{23} = 20$ ft, $d_{13} = 40$ ft, each phase has two conductors and distance is 18 inch.

(a) $r' = r\,\overset{0.7788}{\boxed{e^{-(\mu r/4)}}} = 0.5 \times 0.78$, $R_{GMR} = (r' \times 18)^{1/2} = 2.65$ inch $= 0.22$ ft

(b) $Dm = (20\text{ ft} \times 20\text{ ft} \times 40\text{ ft})^{1/3} = 25.2$ ft

(c) $l_a \backslash = l_b \backslash = l_c \backslash = (\mu_o/2\pi)\ln(D_m/R_{GMR}) = 2 \times 10^{-7}\ln(25.2/0.22)$

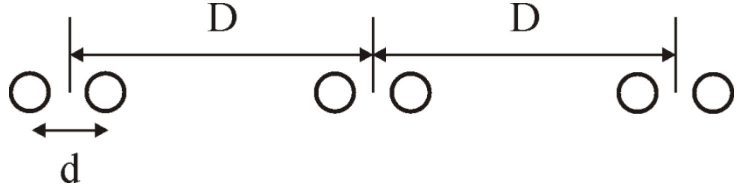
$= 9.47 \times 10^{-7}$ H/m

$\approx 10^{-6}\,H/m = 1\mu H/m = 1mH/km$ $\boxed{\text{很大}}$

$X = \omega L$

$= 377 \times 1mH/km$

$= 0.377\,H/km$



有电荷 → 有电容

有电荷 → 有电場

电荷移动 → 电流

3.6電場回顧(Review of Electric Fields)

电通密度向量

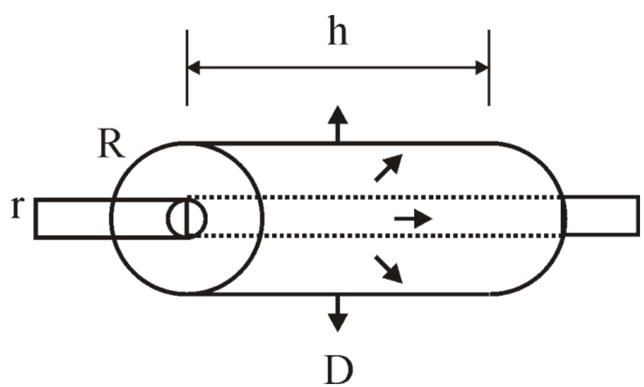
Gauss's law: $\int_A D \cdot da = q_e$,

D: electric flux density vector (coulombs/m^2 = C/m^2),電通密度向量

da : differential area with direction normal to the surface (m^2),方向垂直表面的微小面積

A: total closed surface area (m^2)總封閉表面積

q_e : algebraic sum of all charge enclosed by A (coulombs = C), A所包圍的電荷之代數和



Ex 3.6 Find the field of an infinite uniformly charfed straight round wire

Gauss's law: $\int_A D \cdot da = q_e$,

Draw a cylindrical Gaussian surface concentric with the wire and h meters long (the charge on the wire is q e/m of length). Considerations of symmetry indicate that D is radial and constant in magnitude over the curved portion of the cylinder (it is zero on the end caps).

$\int_A D \cdot da = D\,(2\,\pi\,Rh) = qh$

$D = q\,/\,(2\pi R)$, $R \geqq r$; $D = (a_r)\,q\,/\,(2\pi R)$, $R \geqq r$, (a_r) is a radially directed unit vector.

$D = \varepsilon E$, $\varepsilon = \varepsilon_r\,\varepsilon_o$,

Electric field: E (volts / meter) (E = force/q, force = $k\,q_1\,q_2\,/\,r^2$)

$\varepsilon_o = 8.854 \times 10^{-12} = (1/36\pi) \times 10^{-9}$ (F/m)(permittivity:介電係數)

ε_r relative permittivity 相對介電係數

Voltage difference

$v_{\beta\alpha} = v_{P\beta} - v_{P\alpha} = -\int_{P\alpha}^{P\beta} E \cdot dl$

电場×路徑積分

有2個电荷

$F = \frac{kq_1q_2}{r^2}$

有1個电荷

$E = \frac{F}{q} = \frac{kq_1}{r^2}$

3.7線路電容(Line Capacitance: relates charge to voltage)

Voltage difference

$$v_{\beta\alpha} = v_{P\beta} - v_{P\alpha} = -\int_{P\alpha}^{P\beta} E \cdot dl = -\int_{P\alpha}^{P\beta} D/\varepsilon \cdot dl$$

$$= -\int_{R\alpha}^{R\beta} q/(2\pi\varepsilon R)dR = (q/2\pi\varepsilon)\ln(R_\alpha/R_\beta)$$

$$v_{\beta\alpha} = v_{P\beta} - v_{P\alpha} = (1/2\pi\varepsilon)\Sigma^{n}_{i=1}(q_i)\ln(R_{\alpha i}/R_{\beta i})$$

距離夠遠 ⇒ $V_{P\alpha}=0$

Assuming $q_1 + q_2 + \cdot + q_n = 0$, $P\alpha \to \infty$, $R_{\alpha 1} = R_{\alpha 2} = \cdot = R_{\alpha n} = R$

$$v_\beta = (1/2\pi\varepsilon)\Sigma^{n}_{i=1}(q_i)\ln(1/R_{\beta i})$$

$v_1 = (1/2\pi\varepsilon)(q_1 \ln 1/R_{11} + q_2 \ln 1/R_{12} + \cdot + q_n \ln 1/R_{1n})$ for n lines

$$v_1 = (1/2\pi\varepsilon)(q_1 \ln 1/r_1 + q_2 \ln 1/d_{12} + \cdot + q_n \ln 1/d_{1n})$$

$$v_k = (1/2\pi\varepsilon)(q_1 \ln 1/d_{k1} + q_2 \ln 1/d_{k2} + \cdot + q_k \ln 1/r_k + \cdot + q_n \ln 1/d_{kn})$$

Matrix notation

不同电荷之間存在电容

$v = \underset{\text{a matrix}}{F} q$, $\underline{q = C v}$, $C = F^{-1}$

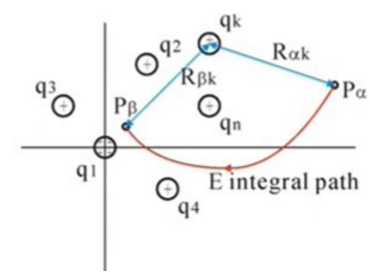
不同位置的电荷 相对应的 V

$I = \frac{Q}{t} = C\frac{dV}{dt} = C\frac{V}{t} \Rightarrow Q = CV$

① $D = \frac{q}{2\pi R}$

② $D = \varepsilon E$

$\Rightarrow -\int E\,dl = -\int \frac{D}{\varepsilon}\,dl = -\int \frac{q}{2\pi R\varepsilon}\,dl$



Ex 3.7 Calculate an expression for the capacitance per meter of a three-phase transmission line.

Assume that 1. conductors are equally spaced, D, and have equal radii r. 2. $q_a + q_b + q_c = 0$ ($c_a = c_b = c_c = c$, $v_a + v_b + v_c = 0$).

$v_a = (1/2\pi\varepsilon)(q_a \ln 1/r + q_b \ln 1/D + q_c \ln 1/D) = (1/2\pi\varepsilon)(q_a \ln 1/r - q_a \ln 1/D)$
$= (1/2\pi\varepsilon)(q_a \ln D/r)$

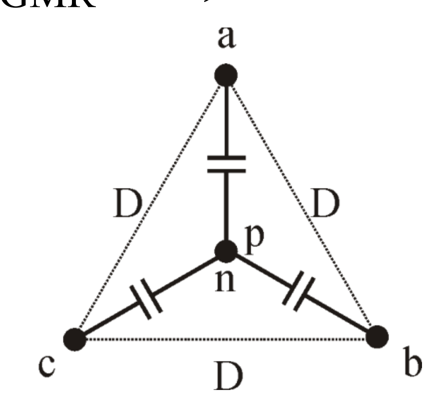
$C = q/v$, $c_a = c_b = c_c = c = (2\pi\varepsilon) / (\ln D/r)$ (F/m : 法拉/米) to neutral

$c_a \backslash = c_b \backslash = c_c \backslash = (2\pi\varepsilon) \ln(D_m/r)$ for one line transposition

$c_a \backslash = c_b \backslash = c_c \backslash = (2\pi\varepsilon) \ln(D_m/R_{GMR})$ for conductor bundling transposition

$D_m = (D_{12} D_{23} D_{13})^{1/3}$

$R^c{}_b = R_{GMR} = (r\, d_{12} d_{13} \cdot d_{1b})^{1/b}$, $b>1$; $R^c{}_b = R_{GMR} = r$, when $b=1$



Ex 3.8 Find phase-neutral capacitance and capacitive reactance per mile for a three-phase line with Dm=35.3 ft, conductor diameter = 1.25 in.

Solution: In air $\varepsilon = \varepsilon_r \varepsilon_o = 1 \times \varepsilon_o = 8.854 \times 10^{-12}$

$c\backslash = (2\pi\varepsilon) / (\ln Dm / r) = 2\pi \times 8.854 \times 10^{-12} / \ln[35.3 \times 12)/(1.25/2)]$

$= 8.53 \times 10^{-12}$ (F/m : 法拉/米)

$\omega\, c\backslash = 2\pi \times 60\text{Hz} \times 8.53 \times 10^{-12}$ mho/m $= 3.216 \times 10^{-9}$ mho/m

$= 3.216 \times 10^{-9} \times 1609.34$ mho/mile $= 5.175 \times 10^{-6}$ mho/mile 不大

Phase-neutral reactance

線&線之間有Capacitor 但阻抗过大，一般沒有current

$|Xc| = 1/(\omega\, c\backslash) = 1/(3.216 \times 10^{-9}) = 3.11 \times 10^{8}\ \Omega\text{-m}$

$= 1/(5.175 \times 10^{-6}) = 0.193$ MΩ-mile

$C = \frac{2\pi\varepsilon}{\ln\frac{D}{r}}$

$C = 10^{-6}F$

$i = C\frac{dv}{dt} = CsV$

$V = \frac{1}{Cs} i = \frac{1}{j\omega C} i$

It should be noted that we are neglecting the effect of the (conducting) earth under the transmission line. Charges are include in the earth, and these have some effect on the calculated values of capacitance. The effect is usually quite small for lines of reasonable height operating under normal non-fault conditions.

3.8典型參數值(Typical Parameter Values)

TW max next 69kV

Conductors per phase (18-in. spacing) :	1(138kV),	2(345kV),	4(765kV)
Number of strands aluminum/steel :	54/7,	45/7,	54/19
Diameter (in.) :	0.977,	1.165,	1.424
Conductor GMR (ft) :	0.0329,	0.0386,	0.0479
Current-carrying capacity per conductor(A):	770,	1010,	1250
Bundle GMR-R_{GMR} (ft) :	0.0329,	0.2406,	0.6916
Flat phase spacing (ft) :	17.5,	26.0,	45.0
GMD phase spacing (ft) :	22.05,	32.76,	56.70
Inductance (H/m $\times 10^{-7}$) :	13.02,	9.83,	8.81
X_L (Ω/mile) :	0.789,	0.596,	0.535
Capacitance (F/m $\times 10^{-12}$) :	8.84,	11.59,	12.78
$\|X_C\|$ (MΩ-mile to neutral) :	0.186,	0.142,	0.129
Resistance (Ω/mile), dc, 50°C :	0.1618,	0.0539,	0.0190
Resistance (Ω/mile), 60Hz, 50°C :	0.1688,	0.0564,	0.0201
Surge impedance loading (MVA) :	50,	415,	2268

Three phase line-to-line 138 kVrms / 60Hz

Conductors per phase (18-in. spacing) : 1 線數 (138kV) V_{LL}

Number of strands aluminum/steel : 54/7,

Diameter (in.) : Inch $0.977 \div 2 \div 12 = 0.0407$ ft, 半徑 feet

Conductor GMR (ft): $0.0329 = 0.0407 \times 0.8? = 0.0317 = 0.0407 \times e^{-\mu r/4} = 0.0407 \times 0.7788$ 根據Fe&Al的含量估算

Current-carrying capacity per conductor(A): 770, $1\,mm^2 \approx 7A$

Bundle GMR-R_{GMR} (ft) : $r' = 0.0329$, $r = 0.0407 = 0.977 \div 2 \div 12$

Flat phase spacing (ft) : 17.5,

GMD phase spacing (ft): $22.05 = (17.5 \times 17.5 \times 2 \times 17.5)^{1/3} = 17.5 \times 1.26$

Inductance (H/m $\times 10^{-7}$) : $13.02 = 2 \times 10^{-7} \times \ln(22.05 / 0.0329)$

X_L (Ω/mile) : $0.789 = 2\pi \times 60 \times 13.02 \times 10^{-7} \times 1609.34$ 1 mile = 1609.34m

Capacitance (F/m $\times 10^{-12}$): $8.84 = 2\pi \times \underbrace{8.854 \times 10^{-12}}_{\varepsilon_0} / \ln(22.05 / 0.407)$

$|X_C|$ (MΩ-mile to neutral) : $0.186 = 1/(2\pi \times 60 \times 8.84 \times 10^{-12} \times 1609.34)$

Resistance (Ω/mile), dc, 50°C: $0.1618 = \rho \times 1609.34/[\pi(0.977 \times 2.54 \times 10^{-2}/2)^2]$, $\rho = 4.863 \times 10^{-8}$

Resistance (Ω/mile), 60Hz, 50°C : $0.1688 = 0.1618 \times 1.0433$ skin effect：需校正

Surge impedance loading (MVA): 50 ?= $61.4 = 1 \times \sqrt{3} \times 138 \times 0.77 / 3$ (MVA)

一個相(線)

$$P(t) = V_a(t)\, i_a(t) + V_b(t)\, i_b(t) + V_c(t)\, i_c(t)$$

$$= 3 V_{\text{相}}\, i_{\text{相}} \cos\theta_{\text{功因角}}$$

$$= \sqrt{3}\, V_{L\text{-}L}\, \underbrace{i_{L\text{-}L}}_{\text{線-線}} \cos\theta_{\text{功因角}}$$

視在功率 $S = 3 V_{\text{相}}\, i_{\text{相}} = \sqrt{3}\, V_{L\text{-}L}\, i_{L\text{-}L}$

Three phase line-to-line 345 kVrms / 60Hz

Conductors per phase (18-in. spacing) : 2(345kV)

Number of strands aluminum/steel : 45/7,

Diameter (in.) : $1.165 \div 2 \div 12 = 0.0485$ ft,

Conductor GMR (ft):0.0386 $=0.0485\times0.8?= 0.0378 = 0.0485\times e^{-\mu r/4} = 0.0485\times0.7788$

Current-carrying capacity per conductor(A): 1010,

Bundle GMR-R_{GMR} (ft) : for L $0.2406 = [0.0386 \times (18/12)]^{1/2}$,

for C $0.2697 = [0.0485\times (18/12)]^{1/2}$

Flat phase spacing (ft) : 26.0,

GMD phase spacing (ft): $32.76 = (26.0\times26.0\times2\times26.0)^{1/3} = 26.0\times1.26$

Inductance (H/m $\times10^{-7}$) : $9.83 = 2\times 10^{-7} \times \ln (32.76 / 0.2406)$

X_L (Ω/mile) : $0.596 = 2\pi \times 60 \times 9.83\times 10^{-7} \times 1609.34$

r 沒有分內外

Capacitance (F/m $\times10^{-12}$): $11.59 = 2\pi\times 8.854 \times 10^{-12} / \ln (32.76 / 0.2697)$

$|X_C|$ (MΩ-mile to neutral) : $0.142 = 1/(2\pi \times 60 \times 11.59\times 10^{-12} \times 1609.34)$

Resistance (Ω/mile),dc,50°C: $0.0539=\rho\times1609.34/[2 \times \pi(1.165 \times 2.54\times10^{-2}/2)^2]$, $\rho=4.6066 \times 10^{-8}$

Resistance (Ω/mile), 60Hz, 50°C : $0.0564 = 0.0539 \times 1.0464$

Surge impedance loading (MVA):$415?=402.3=2\times\sqrt{3}\times345\times1.010/3$ (MVA)

Three phase line-to-line 765 kVrms / 60Hz

Conductors per phase (18-in. = 1.5-ft spacing) : 4(765kV)

Number of strands aluminum/steel : 54/19,

Diameter (in.) : $1.424 \div 2 \div 12 = 0.0593$ ft,

Conductor GMR (ft): $0.0479 = 0.0593 \times 0.8? = 0.0462 = 0.0593 \times e^{-\mu r/4} = 0.0593 \times 0.7788$

Current-carrying capacity per conductor(A): 1250,

Bundle GMR-R_{GMR} (ft) : for L $0.6916 = [0.0479 \times 1.5 \times 1.5 \times 1.5 \times \sqrt{2}]^{1/4}$,

for C $0.7294 = [0.0593 \times 1.5 \times 1.5 \times 1.5 \times \sqrt{2}]^{1/4}$,

Flat phase spacing (ft) : 45.0,

GMD phase spacing (ft): $56.7 = (45.0 \times 45.0 \times 2 \times 45.0)^{1/3} = 45.0 \times 1.26$

Inductance (H/m $\times 10^{-7}$) : $8.81 = 2 \times 10^{-7} \times \ln(56.7 / 0.6916)$

X_L (Ω/mile) : $0.535 = 2\pi \times 60 \times 8.81 \times 10^{-7} \times 1609.34$

Capacitance (F/m $\times 10^{-12}$): $12.78 = 2\pi \times 8.854 \times 10^{-12} / \ln(56.7 / 0.7294)$

$|X_C|$ (MΩ-mile to neutral) : $0.129 = 1/(2\pi \times 60 \times 12.78 \times 10^{-12} \times 1609.34)$

Resistance (Ω/mile),dc,50°C: $0.0190 = \rho \times 1609.34/[4 \times \pi(1.424 \times 2.54 \times 10^{-2}/2)^2]$, $\rho = 4.854 \times 10^{-8}$

Resistance (Ω/mile), 60Hz, 50°C : $0.0201 = 0.0190 \times 1.0579$

Surge impedance loading (MVA) : 2268 ?= $2208.3 = 4 \times \sqrt{3} \times 765 \times 1.250/3$ (MVA)

3.9結論與習題(Summary)

For a three-phase line with transposition and bundling, the average per phase inductance (H/m) is given by

$l\backslash = (\mu_o /2\pi) \ln(D_m/R_{GMR})$ for conductor bundling transposition

$D_m = (D_{12} D_{23} D_{13})^{1/3}$

$r' = re^{-(\mu r/4)}$, $R_b = R_{GMR} = (r' d_{12} d_{13} \cdot d_{1b})^{1/b}$, $b>1$; $R_b = R_{GMR} = r'$, when $b=1$

The formula for average capacitance (F/m) to neutral is

$c\backslash = (2\pi\varepsilon) \ln(D_m/R_{GMR})$ for conductor bundling transposition

$D_m = (D_{12} D_{23} D_{13})^{1/3}$

$R^c{}_b = R_{GMR} = (r\, d_{12} d_{13} \cdot d_{1b})^{1/b}$, $b>1$; $R^c{}_b = R_{GMR} = r$, when $b=1$