TRANSMISSION LINE PARAMETERS

- Parameters in the transmission line
  - resistance r, inductance L, capacitance C
  - L and C are due to the effects of magnetic and electric fields around the conductor
- Overhead transmission line
  - ANSI voltage standard: 69kV, 115kV, 138kV, 161kV, 230kV, 345kV, 500kV, 765kV line-to-line
  - extra-high-voltage (EHV): >230kV, ultra-high-voltage (UHV): ≥765kV
  - bundling: use more than one conductor per phase, usually used at voltage > 230kV
  - advantage of bundling: increase effective radius of line conductor, reduce electric field strength and reduces corona power loss, audio loss and radio interference, and reduces line reactance

LINE RESISTANCE

- Transmission line resistance
  - dc flow: resistance of solid round conductor is given by $R_{dc}=\rho l/A$
  - ac flow: the current distribution is not uniform, the current density is greatest at surface of the conductor, this is called skin effect, therefore, $R_{ac} > R_{dc}$
  - temperature: resistance increases when temperature increases
- Transmission line inductance
  - definition of inductance L: $L=\lambda/I$, λ is flux linkage
  - magnetic field density: $H_x=I_x/2\pi x$, x is the radius of circle, I_x induces magnetic field density H_x

INTERNAL INDUCTANCE

- Derivation of internal inductance L_{int}
  - consider the flux linked by the portion $x \le r$ of current I_a flowing inside a cylinder of radius x, the magnetic intensity:

$$\int H dl = I_{enclosed}$$

  - Since $I_a = \frac{\pi x^2}{\pi r^2} I, \quad \text{therefore } 2\pi x H_x = \frac{\pi x^2}{\pi r^2} I$
  - magnetic flux density B_x:
    $B_x = \mu_o H_x = \mu_o x I / 2\pi r^2$
  - μ_o is the permeability of free space: $4\pi \times 10^{-7}$ H/m
  - since current flowing into the circuit of x is only a fraction of I_a, the effective turn is equivalent to the fraction $N = \pi x^2/\pi r^2$

INTERNAL INDUCTANCE

- Derivation of internal inductance L_{int}
  - $\pi x^2/\pi r^2$ turns of the current I_a linked by flux:
  - $d\lambda_x = (\pi x^2/\pi r^2)\ d\phi_x = (\pi x^2/\pi r^2)\ (B_x \times 1dx)$
    $= (\pi x^2/\pi r^2)\ (\mu_o x I/2\pi r^2) \times 1dx = (\mu_o I)\ x^3/(2\pi r^4)\ dx$
  - total flux linkage in the inductor:

$$\lambda_{\text{int}} = \frac{\mu_o I}{2\pi r^4}\int_0^r x^3 dx = \frac{\mu_o I}{8\pi}$$

  - inductor due to the internal flux:

    $L_{int} = \mu_o/8\pi = (1/2)\times 10^{-7}$ H/m
  - inductor L_{int} is independent of the conductor radius r

EXTERNAL INDUCTANCE

- Derivation of external inductance L_{ext}
  - consider H_x external to conductor at x>r, since the circle at radius x enclose entire current, I_x=I (*see Fig.4.4*): $B_x=\mu_o H_x=\mu_o I/2\pi x$
  - the entire current I is linked by the flux outside the conductor, $d\lambda_x=d\phi_x$ = $B_x dx*1=\mu_o I/(2\pi x)*dx$
  - external flux linkage between D_1 and D_2 :

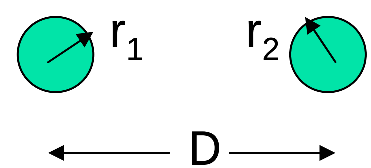
$$\lambda_{ext}=\frac{\mu_o I}{2\pi}\int_{D_1}^{D_2}\frac{1}{x}dx=2\times10^{-7} I \ln\frac{D_2}{D_1} \quad \text{Wb/m}$$

  - inductance between two points D_1 and D_2 due to the external flux:

$$\mathrm{L}_{ext}=2\times10^{-7}\ln\frac{D_2}{D_1} \quad \text{H/m}$$

INDUCTANCE OF A SINGLE-PHASE LINE

- Single-phase line inductance in conductor 1 (L_1)
  - consider one meter length of two solid round conductors, radius r_1 and r_2 in the figure below:



  - internal inductance: $L_{1(int)} = (1/2)\times10^{-7}$
  - inductance beyond D links a net current of zero and doesn't contribute to net magnetic flux linkage, thus the external inductance $L_{1(ext)} = 2\times10^{-7}*\ln(D/r_1)$
  - total inductance of conductor 1:

$$L_1 = L_{1(\text{int})} + L_{1(ext)} = \frac{1}{2}\times10^{-7} + 2\times10^{-7}\ln\frac{D}{r_1} = 2\times10^{-7}\ln\frac{1}{r_1'} + 2\times10^{-7}\ln\frac{D}{1}$$

$$\text{where } r_1' = r_1 e^{-\frac{1}{4}}$$

INDUCTANCE OF A SINGLE-PHASE LINE

- Single-phase line inductance
  - total inductance of conductor 2:

$$L_2 = 2\times10^{-7}\ln\frac{1}{r_2^{'}} + 2\times10^{-7}\ln\frac{D}{1} \quad \text{H/m}$$

  - if $r_1=r_2=r$, inductance per phase per meter length of the line:

$$L = 2\times10^{-7}\ln\frac{1}{r^{'}} + 2\times10^{-7}\ln\frac{D}{1} \quad \text{H/m}$$

  - the first term is only the fraction of conductor radius
  - the second term is dependent only on conductor spacing
  - the term $r' = re^{-1/4}$ is called self-geometric mean distance of a circle with radius r by GMR
  - GMR is called geometric mean radius

FLUX LINKAGE IN TERMS OF SELF AND MUTUAL INDUCTANCES

- Flux linkage in a single-phase two-wire line
  - flux linkage: $\lambda_1 = (L_{11} - L_{12})I_1 \qquad \lambda_2 = (-L_{21} + L_{22})I_2$
  - self and mutual inductance:

$$L_{11} = 2\times10^{-7}\ln\frac{1}{r_1^{'}}, \quad L_{22} = 2\times10^{-7}\ln\frac{1}{r_2^{'}}, \quad L_{12} = 2\times10^{-7}\ln\frac{1}{D}$$

  - for a group of n conductors: $I_1+I_2+\ldots+I_n=0$
  - the flux linkage of conductor *i* :

$$\lambda_i = L_{ii}I_i + \sum_{j=1}^{n} L_{ij}I_j \qquad \mathrm{j} \neq \mathrm{i}$$

$$\lambda_i = 2\times10^{-7}\left(I_i \ln\frac{1}{r_i^{'}} + \sum_{j=1}^{n} I_j \ln\frac{1}{D_{ij}} \right) \qquad \mathrm{j} \neq \mathrm{i}$$

INDUCTANCE OF THREE-PHASE TRANSMISSION LINES

- 3-phase line with three symmetrical spacing conductors, the single-phase inductance L
  - balanced three-phase currents: $I_a+I_b+I_c=0$
  - total flux linkage of phase a (*see fig.4.7*):

$$\lambda_a = 2\times 10^{-7}\left(I_a \ln\frac{1}{r'} + I_b \ln\frac{1}{D} + I_c \ln\frac{1}{D}\right)$$

  - substituting for $I_b+I_c=-I_a$, flux linkage of phase a:

$$\lambda_a = 2\times 10^{-7}\left(I_a \ln\frac{1}{r'} - I_a \ln\frac{1}{D}\right) = 2\times 10^{-7} I_a \ln\frac{D}{r'}$$

  - per-phase per kilo-meter length L:

$$L = 0.2\ln\frac{D}{r'} = 0.2\ln\frac{D}{re^{-\frac{1}{4}}} \quad \text{mH/km}$$

  - inductance per-phase of a three-phase circuit with equal spacing is the same as one conductor of a single-phase circuit

INDUCTANCE OF THREE-PHASE TRANSMISSION LINES

- 3-phase line with three asymmetrical spacing conductors
  - even in balanced three-phase currents, the voltage drop due to different line inductance will be unbalanced
  - the phase a, b and c flux linkages:

$$\lambda_a = 2\times10^{-7}\left(I_a \ln\frac{1}{r'} + I_b \ln\frac{1}{D_{12}} + I_c \ln\frac{1}{D_{13}}\right)$$

$$\lambda_b = 2\times10^{-7}\left(I_a \ln\frac{1}{D_{12}} + I_b \ln\frac{1}{r'} + I_c \ln\frac{1}{D_{23}}\right)$$

$$\lambda_c = 2\times10^{-7}\left(I_a \ln\frac{1}{D_{13}} + I_b \ln\frac{1}{D_{23}} + I_c \ln\frac{1}{r'}\right)$$

  - use $\lambda = LI$
  - the phase a, b, and c inductances:

$$L_a = \frac{\lambda_a}{I_a} = 2\times10^{-7}\left(\ln\frac{1}{r'} + a^2 \ln\frac{1}{D_{12}} + a \ln\frac{1}{D_{13}}\right)$$

$$L_b = \frac{\lambda_b}{I_b} = 2\times10^{-7}\left(a \ln\frac{1}{D_{12}} + \ln\frac{1}{r'} + a^2 \ln\frac{1}{D_{23}}\right)$$

$$L_c = \frac{\lambda_c}{I_c} = 2\times10^{-7}\left(a^2 \ln\frac{1}{D_{13}} + a \ln\frac{1}{D_{23}} + \ln\frac{1}{r'}\right)$$

  - where, $a=1\angle120^{o}$, the phase inductance contain imaginary term

INDUCTANCE OF THREE-PHASE TRANSMISSION LINES

- Transpose line
  - practical transmission lines cannot maintain symmetrical spacing due to the construction considerations
  - one way to regain symmetry and to obtain a per-phase model is to consider transposition
  - transposition arrangement: interchange phase every one-third the length (*see Fig.4.9*)
  - for complete transposed lines, the inductance is the average value of $L=(L_a+L_b+L_c)/3$
  - note $a+a^2=1\angle 120^o+1\angle 240^o=-1$

$$L=\frac{2\times 10^{-7}}{3}\left(3\ln\frac{1}{r'}-\ln\frac{1}{D_{12}}-\ln\frac{1}{D_{23}}-\ln\frac{1}{D_{13}}\right)\quad \text{H/m}$$

  - rearrange equation L and we obtain (*pp.114-115*):

$$L=2\times 10^{-7}\ln\frac{\sqrt[3]{D_{12}D_{23}D_{13}}}{r'}=2\times 10^{-7}\ln\frac{GMD}{GMR}\quad \text{H/m}$$

  - GMD is geometric mean distance (equivalent conductor spacing)
  - GMR is geometric mean radius (equivalent conductor radius)

INDUCTANCE OF COMPOSITE CONDUCTORS

- In practical transmission line, stranded conductors and bundled conductors are used.
- The inductance of the composite conductors are analyzed with GMR and GMD
- A bundled case of single phase line with n strands in x conductor and m strands in y conductor
  - current is assumed equally divided among strands (sub-conductor), current per strand in x is I/n, current per strand in y is I/m
  - flux linkage about strand a: (*from Eq. 4.43 pp.116*)

$$\lambda_a = 2\times10^{-7} I \ln \frac{\sqrt[m]{D_{aa'}D_{ab'}\cdots D_{am}}}{\sqrt{r_x^{'}D_{ab}D_{ac}\cdots D_{an}}}$$

  - inductance of strand a:

$$L_a = \frac{\lambda_a}{I/n} = 2n\times10^{-7} \ln \frac{\sqrt[m]{D_{aa'}D_{ab'}\cdots D_{am}}}{\sqrt[n]{r_x^{'}D_{ab}D_{ac}\cdots D_{an}}}$$

  -

INDUCTANCE OF COMPOSITE CONDUCTORS

- inductance of strand n:

$$L_n = \frac{\lambda_n}{I/n} = 2n \times 10^{-7} \ln \frac{\sqrt[m]{D_{na'}D_{nb'}\cdots D_{nm}}}{\sqrt[n]{r_x^{'}D_{na}D_{nb}\cdots D_{nc}}}$$

- average of the inductance in any strand in x

$$L_{av} = \frac{L_a + L_b + L_c + \cdots + L_n}{n}$$

- the equivalent inductance of conductor x in n strands

$$L_x = \frac{L_{av}}{n} = \frac{L_a + L_b + L_c + \cdots + L_n}{n^2} = 2 \times 10^{-7} \ln \frac{GMD}{GMR_X} \quad \mathrm{H/m}$$

- where GMD and GMR_X are as follow:

$$GMD = \sqrt[mn]{(D_{aa'}D_{ab'}\cdots D_{am})\cdots(D_{na'}D_{nb'}\cdots D_{nm})}$$

$$GMR_X = \sqrt[n^2]{(D_{aa}D_{ab}\cdots D_{an})\cdots(D_{na}D_{nb}\cdots D_{nn})}$$

GMD AND GMR OF COMPOSITE CONDUCTORS

- Definition of GMD:
  - *mn* th root of D's product about any strand in x to strands in y
- Definition of GMR_X:
  - *nn* th root of r_x' product about any strand in x to the other strands in x
- GMR of the seven identical strands in a conductor
  - *see example 4.1*
  - a large number of strands in GMR calculation would be tedious, usually GMRs are available in manufacturer's data

GMR OF BUNDLED CONDUCTORS

- Extra high voltage transmission lines are constructed with bundled conductors
- Advantages of the bundling:
  - reduce line reactance
  - increase power capability
  - reduce voltage surface gradient and corona loss
  - reduce surge impedance
- Common conductor bundling arrangement
  - two sub-conductor bundling GMR: $D_s^b = \sqrt{D_s \times d}$
  - three sub-conductor bundling GMR: $D_s^b = \sqrt[9]{(D_s \times d \times d)^3}$
  - four sub-conductor bundling GMR: $D_s^b = \sqrt[16]{(D_s \times d \times d \times d \times 2^{\frac{1}{2}})^4}$

INDUCTANCE OF THREE-PHASE DOUBLE CIRCUIT

- A three phase double circuit line consists of two identical three-phase circuits
- The circuits are operated with a_1-a_2, b_1-b_2, c_1-c_2 in parallel as *figure 4.13*
- Geometric arrangement of three-phase double circuit
  - unbalanced with different spacing, cause unbalanced voltage drop
  - to achieve balance, use transpose arrangement
- To obtain inductance of three-phase double circuit line, we must
  - consider transpose effect of L
  - consider bundle effect of L
  - combine transpose and bundle effects together

INDUCTANCE OF THREE-PHASE DOUBLE CIRCUIT

- Calculation of the GMD:
  - starting from the calculation of per-phase GMD: group identical phase together
  - find GMD between each phase group
  - $$D_{AB} = \sqrt[4]{D_{a1b1}D_{a1b2}D_{a2b1}D_{a2b2}}$$
    $$D_{BC} = \sqrt[4]{D_{b1c1}D_{b1c2}D_{b2c1}D_{b2c2}}$$
    $$D_{AC} = \sqrt[4]{D_{a1c1}D_{a1c2}D_{a2c1}D_{a2c2}}$$
  - equivalent GMD per phase is
  - $$GMD = \sqrt[3]{D_{AB}D_{BC}D_{AC}}$$

INDUCTANCE OF THREE-PHASE DOUBLE CIRCUIT

- Calculation of the GMR:
  - starting from the calculation of per-phase GMR: group identical phase together
  - find GMR between each phase group
  - $$D_{SA} = \sqrt[4]{(D_s^b D_{a1a2})^2} = \sqrt{D_s^b D_{a1a2}}$$
    $$D_{SB} = \sqrt[4]{(D_s^b D_{b1b2})^2} = \sqrt{D_s^b D_{b1b2}}$$
    $$D_{SC} = \sqrt[4]{(D_s^b D_{c1c2})^2} = \sqrt{D_s^b D_{c1c2}}$$
  - where D_s^b is the two-subconductor bundled distance
  - equivalent GMR per phase is $GMR_L = \sqrt[3]{D_{SA} D_{SB} D_{SC}}$

INDUCTANCE OF THREE-PHASE DOUBLE CIRCUIT

- The per-phase inductance of the transpose line
  - $$L = 2\times10^{-7}\ln\frac{\sqrt[3]{D_{12}D_{23}D_{13}}}{r'} = 2\times10^{-7}\ln\frac{GMD}{GMR_L} \quad \text{H/m}$$
  - where GMD: $GMD = \sqrt[3]{D_{AB}D_{BC}D_{AC}}$
  - where GMR: $GMR_L = \sqrt[3]{D_{SA}D_{SB}D_{SC}}$
  - for the inductance per-phase in mH/km
  - $$L = 0.2\ln\frac{GMD}{GMR_L} \quad \text{mH/km}$$

REVIEW OF LINE INDUCTANCE

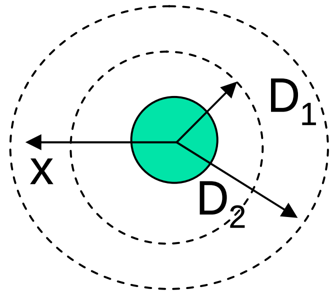
- Internal inductance
  - $L_{int}=\mu_o/8\pi=(1/2)\times10^{-7}$ H/m
- External inductance
  - $L_{ext} = 2\times10^{-7}\ln\frac{D_2}{D_1}$ H/m
- Single-phase line inductance
  - $L = 2\times10^{-7}\ln\frac{D}{r'}$ H/m
- Three-phase line inductance (symmetrical spacing
  - $L = 2\times10^{-7}\ln\frac{D}{r'}$ H/m

REVIEW OF LINE INDUCTANCE

- Three-phase line inductance (transpose line)
  - $$\mathrm{L} = 2\times10^{-7}\ln\frac{\sqrt[3]{D_{12}D_{23}D_{13}}}{r^{'}} = 2\times10^{-7}\ln\frac{GMD}{GMR} \quad \mathrm{H/m}$$
- Inductance of composite conductors in x group (n conductor in x, m conductor in y)
  - $$\mathrm{L}_{av} = 2\times10^{-7}\ln\frac{GMD}{GMR_X} \quad \mathrm{H/m}$$
  - where $GMD = \sqrt[mn]{(D_{aa'}D_{ab'}\cdots D_{am})\cdots(D_{na'}D_{nb'}\cdots D_{nm})}$
  - where $GMR_X = \sqrt[n^2]{(D_{aa}D_{ab}\cdots D_{an})\cdots(D_{na}D_{nb}\cdots D_{nn})}$
- Inductance of three-phase double-circuit line (per-phase)
  - $$\mathrm{L} = 2\times10^{-7}\ln\frac{\sqrt[3]{D_{AB}D_{BC}D_{CA}}}{\sqrt[3]{D_{SA}D_{SB}D_{SC}}} = 2\times10^{-7}\ln\frac{GMD}{GMR_L} \quad \mathrm{H/m}$$

LINE CAPACITANCE

- Derivation of the line capacitance
  - consider a long round conductor with radius r , carrying a charge of q coulombs per meter length:

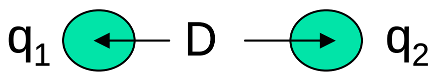


  - electric flux density at a cylinder of radius x:

    $D = q/A = q/(2\pi x)$
  - electric field intensity
  - $E = D/\varepsilon_0 = q/(2\pi\varepsilon_0 x)$
  - ε_o is the permitivity of free space: 8.85×10^{-12} F/m
  - potential difference between cylinders from D_1 to D_2
  - $$V_{12} = \int_{D_1}^{D_2} E dx = \int_{D_1}^{D_2} \frac{q}{2\pi\varepsilon_0 x} dx = \frac{q}{2\pi\varepsilon_0} \ln \frac{D_2}{D_1}$$

CAPACITANCE OF SINGLE-PHASE LINE

- Derivation of the line capacitance
  - consider two conductors with radius r , carrying a charge of q_1 coulombs/meter in conductor 1 and q_2 in conductor 2



  - voltage between conductor 1 and 2 by q_1 or q_2

$$V_{12(q_1)} = \frac{q_1}{2\pi\varepsilon_0}\ln\frac{D}{r} \qquad V_{21(q_2)} = \frac{q_2}{2\pi\varepsilon_0}\ln\frac{D}{r}$$

  - potential difference due to q_1 and q_2 (q_1=-q_2)

$$V_{12} = V_{12(q_1)} + V_{12(q_2)} = \frac{q_1}{2\pi\varepsilon_0}\ln\frac{D}{r} + \frac{q_2}{2\pi\varepsilon_0}\ln\frac{r}{D} = \frac{q}{\pi\varepsilon_0}\ln\frac{r}{D}$$

  - capacitance between conductors

$$C_{12} = \frac{\pi\varepsilon_0}{\ln\frac{D}{r}} \quad \text{F/m}$$

or

$$C = \frac{2\pi\varepsilon_0}{\ln\frac{D}{r}} \quad \text{F/m}$$

CAPACITANCE OF THREE-PHASE LINES

- Derivation of the line capacitance
  - consider one meter length of a three-phase line with three long conductors with radius r , transposed spacing shown in *figure 4.18*
  - a balanced three-phase system: $q_a + q_b + q_c = 0$
  - voltage between phase a and b in section I

$$V_{ab(I)} = \frac{1}{2\pi\varepsilon_0}\left(q_a \ln\frac{D_{12}}{r} + q_b \ln\frac{r}{D_{12}} + q_c \ln\frac{D_{23}}{D_{13}} \right)$$

  - voltage between phase a and b in section II

$$V_{ab(II)} = \frac{1}{2\pi\varepsilon_0}\left(q_a \ln\frac{D_{23}}{r} + q_b \ln\frac{r}{D_{23}} + q_c \ln\frac{D_{13}}{D_{12}} \right)$$

  - voltage between phase a and b in section III

$$V_{ab(III)} = \frac{1}{2\pi\varepsilon_0}\left(q_a \ln\frac{D_{13}}{r} + q_b \ln\frac{r}{D_{13}} + q_c \ln\frac{D_{12}}{D_{23}} \right)$$

CAPACITANCE OF THREE-PHASE LINES

- Derivation of the line capacitance (continue)
  - average value of V_{ab} :

$$V_{ab} = \frac{1}{3}\left(V_{ab(I)} + V_{ab(II)} + V_{ab(III)}\right) = \frac{1}{2\pi\varepsilon_0}\left(q_a \ln\frac{GMD}{r} + q_b \ln\frac{r}{GMD}\right)$$

  - similarly, V_{ac} :

$$V_{ac} = \frac{1}{3}\left(V_{ac(I)} + V_{ac(II)} + V_{ac(III)}\right) = \frac{1}{2\pi\varepsilon_0}\left(q_a \ln\frac{GMD}{r} + q_c \ln\frac{r}{GMD}\right)$$

  - for $q_b + q_c = - q_a$, $V_{ab} + V_{ac}$:

$$V_{ab} + V_{ac} = \frac{1}{2\pi\varepsilon}\left(2q_a \ln\frac{GMD}{r} - q_a \ln\frac{r}{GMD}\right) = \frac{3q_a}{2\pi\varepsilon_0}\ln\frac{GMD}{r}$$

  - for balanced three-phase voltages
    - $V_{ab} + V_{ac} = 3V_{an}$ from Eq.4.83
  - the capacitance per-phase to neutral

$$C = \frac{q_a}{V_{an}} = \frac{2\pi\varepsilon_0}{\ln\frac{GMD}{r}} \quad \text{F/m}$$

EFFECT OF BUNDLING

- Derivation of the line capacitance (bundling)
  - the effective radius of bundled conductor is r^b
  - the capacitor per phase for bundled conductor

$$C = \frac{2\pi\varepsilon_0}{\ln \frac{GMD}{r^b}} \quad \text{F/m, where } \mathrm{r}^{\mathrm{b}} = \textit{effective bundle spacing}$$

  - for two-subconductor bundle :

$$r^b = \sqrt{r \times d}$$

  - for three-subconductor bundle :

$$r^b = \sqrt[3]{r \times d^2}$$

  - for four-subconductor bundle :

$$r^b = 1.09\sqrt[4]{r \times d^3}$$

- Derivation of the line capacitance (three-phase)
  - the effective radius of bundled conductor is GMR_c
  - the equivalent per-phase capacitance to neutral

$$C = \frac{2\pi\varepsilon_0}{\ln \frac{GMD}{GMR_c}} \quad \text{F/m, where } \mathrm{GMR_c} \text{ is } \textit{for phase group}$$

  - GMR_c per-phase to neutral :

$$GMR_c = \sqrt[3]{r_A r_B r_C}$$

  - effective radius for phase A, B, and C :

$$r_A = \sqrt{r^b D_{a1a2}}$$

$$r_B = \sqrt{r^b D_{b1b2}}$$

$$r_C = \sqrt{r^b D_{c1c2}}$$

EFFECT OF EARTH ON THE CAPACITANCE

- The electric flux lines for an isolated charged conductor are radial and are orthogonal to cylindrical equipotential surfaces
- Earth level is like equipotential surface
- To simulate effect of equipotential surface, the earth level is replaced by a fictitious charged conductor
  - with charge equal and opposite to the charge on actual conductor
  - at a depth below the surface of the earth the same as the height of the actual conductor above earth
- The effect of the earth can increase capacitance
  - normally due to the height >> distance between conductors, therefore, effect of earth is negligible
  - for balanced steady-state analysis, effect of earth is neglected
  - for unbalanced faults, earth's effect is considered

INDUCTION

- Magnetic field induction
  - transmission line magnetic fields affect objects close to the line
  - reason: line current produce magnetic field, magnetic field induces voltage in objects that have a long length parallel to line
- Magnetic field have been reported to affect (long term harm)
  - human blood
  - growth, behavior
  - immune systems
  - neural functions
- Electrostatic induction
  - transmission line electric fields affect objects close to the line
  - reason: high voltage produce electric field, electric field induces currents in objects in the area of the electric field
- Concern of the Electrostatic induction (instant harm)
  - human body may be exposed to steady current or spark discharge from charged objects

CORONA

- Corona
  - the partial ionization surrounding the conductor surface
  - reason: when surface potential gradient of a conductor exceeds the dielectric strength of the surrounding air, ionization occurs
- Corona effect
  - produce power loss
  - produce audible noise
  - radio interference in the AM band
- Corona is affected by
  - conductor diameter, bundling
  - type of conductor
  - condition of surface: air dust, humidity, wind
- Corona can be reduced by
  - increasing the conductor size
  - conductor bundling