wire, charge \( Q_{\text{total}} = Q_L \)

\[
\int \vec{D} \cdot d\vec{S} = \oint 2\pi r L = Q_L \]

\[
D = \frac{Q_L}{2\pi r} \quad \text{or} \quad \frac{\rho}{2} = \frac{Q_L}{2\pi r K}
\]

\[
E = \frac{D}{K} = \frac{Q_L}{2\pi r K}
\]

\[
V_{12} = \int_{D_1}^{D_2} \frac{Q_L}{2\pi K r} \, dr
\]

\[
V_{12} = \frac{Q_L}{2\pi K r} \ln \frac{D_2}{D_1}
\]

\[C_{ab} = \frac{Q_a Q_b}{V_{ab}} = \frac{2\pi K}{\ln \frac{D}{D_{ab}}} \]

\[C_{ab} = \frac{2\pi K}{\ln \frac{D}{D_{ab}}} \]

\[C = \frac{Q}{V} \]

\[\text{Correct solution:} \quad \frac{C}{\epsilon} = ME \text{cap} (D_p) \]

\[\epsilon = \frac{\pi K}{\ln \frac{D}{D_{ab}}} \]

if \( r_a = r_b \text{ or } r_a \neq r_b \)
\[ C_{ab} = \frac{\pi (8.85 \times 10^{-12} \text{ F/m})}{\ln \frac{D}{r}} \]

\[ C_{ab} = \frac{0.0388}{\log_{10} \frac{D^2}{r_a r_b}} \quad \text{mF/m} \]

\[ 2C_{ab} = C_{ax} = C_{bn} = \frac{0.0388}{\log_{10} \frac{D}{r}} \quad \text{mF/m} \]

\[ D_{sc} = r = \text{outside radius of conductor} - \text{not same for solid or stranded} \]

\[ X_c = \frac{1}{2\pi f C} = \frac{4.1 \times 10^6}{f} \frac{\log \frac{D}{r}}{52 \cdot \text{mi}} \text{ (TO NEW)} \]

\[ X_c = \frac{4.1 \times 10^6}{f} \log \frac{1}{r} + \frac{4.1 \times 10^6}{f} \log D \quad \text{2-mi} \text{ (TO NEW)} \]

\[ X'_a \quad \text{Table A.3} \]

\[ X'_d \quad \text{Table A.5} \]

Spacing factor
3.6 LINE EQUIL SPACING


can think of neutral point having a zero changes potential.

\[ V_{ab} = \frac{1}{2\pi K} \left( g_a \ln \frac{D}{r} + g_b \ln \frac{D}{r} + g_c \ln \frac{D}{r} \right) \]

\[ V_{ac} = \frac{1}{2\pi K} \left( g_a \ln D + g_b \ln D + g_c \ln D \right) \]

\[ V_{ab} + V_{ac} = \frac{1}{2\pi K} \left( 2g_a \ln D + (g_b + g_c) \ln \frac{r}{D} \right) \]

since \( g_a + g_b + g_c = 0 \) \( (g_b + g_c = -g_a) \)

\[ V_{ab} + V_{ac} = \frac{1}{2\pi K} \left( 3g_a \ln \frac{D}{r} \right) \]

Knowing that

\[ V_{ab} = \sqrt{3} V_{an} \quad (135^\circ) \]

\[ V_{ac} = \sqrt{3} V_{an} \quad (150^\circ) \]

\[ V_{ac} = -V_{ca} = \sqrt{3} V_{an} \quad (1-30^\circ) \]

\[ V_{ab} + V_{ac} = 2\sqrt{3} V_{an} \quad (866) = 3V_{an} = \frac{3g_a}{2\pi K} \ln \frac{D}{r} \]

\[ V_{an} = \frac{g_a}{2\pi K} \ln \frac{D}{r} \]

\[ C_n = \frac{g_a}{V_{an}} = \frac{2\pi K}{\ln \frac{D}{r}} = \frac{0.0388}{\log \frac{D}{r}} \text{ mF/mi} \]

Same as single phase - GND

\[ I_{cu4} = jw C_n V_{an} \quad \text{Amps/mile} \]
**EXAMPLE:** ACSR Ostrich - 20 mile line

\[ C_n = \frac{0.388}{\log \frac{D}{r}} = \frac{0.388}{\log \frac{10'}{10'}} = \frac{0.388}{(4.82)} \]

\[ C_n = 0.015222 \text{ mF/mi} \]

For 20 miles, \( C_n = 0.304588 \text{ mF} \)

\[ X_c = \frac{1}{377 \angle 0} = 8.70875 \Omega \]

\[ Z = -jX_c = -j8.71 \Omega \]

Normally, \( \frac{1}{2} \) of capacitance is put at each end of capacitance is put at

---

**PI Section**

With the tables,

\[ X_c = X_a + X_d \]

\[ X_c = \frac{0.1057 \times 10^6 \Omega \text{ m}}{20 \text{ miles}} + \frac{.0683 \times 10^6 \Omega \text{ m}}{20 \text{ miles}} = \frac{.1740 \times 10^6 \Omega \text{ m}}{20 \text{ miles}} = 87005 \Omega \]
Charging Current: \( i_c \times X_c \)

**EX** 69 KV OSTRICH 10 ft. spacing

\[
\begin{align*}
\Phi_A & \rightarrow I_{ch} \rightarrow \text{open} \\
\frac{69,000}{\sqrt{3}} \text{ source} & \rightarrow j 8708.52 \\
\rightarrow 0 & \Rightarrow \\
\text{N} \rightarrow I_{ch} = \frac{69\,\text{KV}}{\sqrt{3} \cdot (j 8708)} = j 4.57 \text{ Amps}
\end{align*}
\]

- Disconnect Sw.
- Circuit Bks.
- Must be able to disconnect.

**UNSYMMETRICAL SPACING**

- Average cap/phase
- Assuming transposition

**EX** OSTRICH - 10 miles

\[
\begin{align*}
\text{a} & \rightarrow 10' \rightarrow \text{b} \rightarrow 10' \rightarrow \text{c} \\
\text{Deg} & = \sqrt[3]{(10)^2 + 20} = 12.6 \text{ ft} \\
X_c & = .1057 + .075 = .181 \text{ M}\Omega \cdot \text{mi} \\
X_c & = \frac{.181}{10} = 18.1 \text{ K}\Omega \\
X_c & = \frac{1}{2 \pi f c} = \frac{\log \frac{12.6\,\text{K}}{134}}{27 \times (60) \times (0.0333) \times 10^{-6} \times (10 \text{ mi})} = 18.1 \text{ K}\Omega
\end{align*}
\]

\[\text{Assumes "continuous transposition"} \]

\[
\begin{align*}
\text{C}_{ab} = \text{C}_{ca} \quad D = 10' & \quad [C_{cb} = C_{ec}] \\
\text{C}_{bc} = \text{C}_{cb} \quad D = 10' & \quad (C_{ac} \text{ is larger}) \\
\text{C}_{ac} = \text{C}_{ea} \quad D = 20'
\end{align*}
\]
Bundled Conductors: \( r \) is replaced by \( D_{sc} \)

1. \( D_{sc} = \sqrt{rd} \)
2. \( D_{sc} = \sqrt[3]{rd^2} \)
3. \( D_{sc} = \sqrt[4]{rd^3\sqrt{2}} \)

Effect of earth on capacitance:

Remove earth and replace with imaginary IMAGE

CONDUCTORS \( \rightarrow \) same E field above ground line
\[
V_{ab} = \frac{1}{2\pi k} \left[ g_a \left( \ln \frac{D_{za}}{r} - \ln \frac{H_{12}}{H_1} \right) + g_b \left( \ln \frac{D_{12}}{D_{2z}} - \ln \frac{H_2}{H_{12}} \right) 
+ g_c \left( \ln \frac{D_{31}}{D_{13}} - \ln \frac{H_{23}}{H_{31}} \right) \right]
\]

Proceeding with similar derivation as before, \((\text{Vac}, \text{etc})\)

\[
C_{uv} = \frac{0.0388}{\log \frac{D_{yz}}{r} - \log \left( \frac{\sqrt{H_{12} H_{23} H_{31}}}{\sqrt{H_1 H_2 H_3}} \right)} \text{ uF/mi to neu}
\]

This term is subtracted from denominator.

So:

If conductors are very high above ground,

- \(H_1 \approx H_{12}\)
- \(H_2 \approx H_{23}\)
- \(H_3 \approx H_{31}\)

and correction is very small. We can usually ignore.

If conductors are close to the ground

- \(H_{12} \approx H_1\)
- \(H_{23} \approx H_2\)
- \(H_{31} \approx H_3\)

How close? See printouts included in notebook...

This decreases value of denominator and results in increased \(C\).

- Earth increases capacitance
- Reduction of ground clearance increases capacitance
- Increase in phase spacing increases capacitance
- Reduction in conductor radius decreases capacitance
Bundled Conductors

\[ C_n = \frac{0.0388}{\log_{10} \frac{D_{sc}}{D_{bc}}} \]

\[ D_{bc} = \frac{3}{\sqrt[3]{D_{12}D_{23}D_{31}}} \]

Parallel Circuit Three Phase Lines
(Double Circuit)

\[ C_n = \frac{0.0388}{\log_{10} \frac{D_{sc}}{D_{bc}}} \quad D_{bc} = \text{same as for inductance calculations} \]

\[ D_{sc} = \text{same except use } r \text{ instead of } D_{s} \]

**EX:**

10 Mile Line - Ostrich

\[ R = 3.372 \, \Omega \]

\[ D_{bc} = \sqrt[3]{10^2(20)} = 12.6 \, \text{A} \]

\[ X_L = \frac{7.64 \, \Omega}{18.1 \, K \Omega} \]

\[ X_C = \frac{18.1 \, K \Omega}{1.686 \, \Omega} \]

Bundled: 6" gauge

\[ R = \frac{5.79 \, \Omega}{13.866 \, K \Omega} \]

\[ X_L = \frac{13.866 \, K \Omega}{1.913 \, \mu F} \]

\[ D = 0.68 \Rightarrow 0.57^2 = r = 0.28 \]

\[ D_s = 0.229' \]

\[ D_{sc} = \sqrt{(0.229)(5)} = 0.107' \]

\[ D_{bc} = \sqrt{(0.28)(5)} = 0.118' \]

(Table A.1 @ 50°C)
Summary

<table>
<thead>
<tr>
<th>Single phase 2 wire</th>
<th>Multi-conductor R of parallel combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R$</td>
<td>$R_{ac}$</td>
</tr>
<tr>
<td>$L$</td>
<td>$.7411 \log \frac{D}{r_i} \ \text{mH/mi}$</td>
</tr>
<tr>
<td>$C_n$</td>
<td>$.0388 \ \text{mF/\log}\frac{D}{r} \ \text{mi}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3φ EQUIL</th>
<th>3φ UNSYM</th>
<th>3φ Bundled</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R$</td>
<td>$1\ \Omega$</td>
<td>$R/N$</td>
</tr>
<tr>
<td>$L$</td>
<td>$.7411 \log \frac{D}{D_s} \ \text{mH/mi}$</td>
<td></td>
</tr>
<tr>
<td>$C_n$</td>
<td>$.0388 \ \text{mF/\log}\frac{D}{D_{sc}} \ \text{mi}$</td>
<td></td>
</tr>
</tbody>
</table>