Ampacities of All-Aluminum Conductor

<table>
<thead>
<tr>
<th>Conductor</th>
<th>Stranding</th>
<th>Ambient = 25°C</th>
<th>Ambient = 40°C</th>
<th>Ambient = 75°C</th>
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**Geometric Mean Radius (GMR)**

\[
L'_{\text{GMR}} = \frac{\mu_0}{2\pi} \ln \left( \frac{1}{\text{GMR}} \right)
\]

Inductance of conductor up to a distance of 1 unit (e.g. 1 foot)

\[
L'_{\text{GMR}} = \frac{\mu_0}{2\pi} \ln \left( \frac{1}{\text{GMR}} \right)
\]

Inductance of conductor in H per meter length with return path at distance D

Per definition the GMR of a specific conductor or conductor arrangement is the radius of an infinitely thin tube with the same internal inductance as the conductor itself out to a 1-foot radius
Alternative Formula used in Practice

\[ X' = 2\pi f \frac{\mu_0}{2\pi} \ln \frac{D}{GMR} = 2\pi 60 \frac{f}{60} \frac{\mu_0}{2\pi} \ln \frac{D}{GMR} \]

Substituting \( \ln (\text{base e}) \) by \( \log (\text{base 10}) \)
Inserting \( \mu_0 = 4\pi 10^{-7} \text{Vs/Am} \)
Expanding 1 mile = 1609.344 m

\[ X' = 2\pi 60 \frac{f}{60} \frac{4\pi 10^{-7}}{2\pi} \frac{1609.344}{\log(e)} \log \frac{D}{GMR} \]

\[ X' = 0.2794 \frac{f}{60} \log \frac{D}{GMR} \]

in \( \Omega/\text{mile} \) (per conductor)

Example: Line Impedance

- Calculate the impedance of a two phase T-line at 60° C built from AAC conductor that shall carry 100 A at an ambient temperature of 40°C, no wind. The phases are 3 m apart and the line is operated on a 60 Hz system.
From Table (slide 1, Lecture 15) we find the conductor size to be NO
b) Resistance @ 60°F per conductor

From Table we get
\[ R_{10} = 0.187 \cdot \frac{\Omega}{\text{mile}} \]
\[ R_{100} = 0.209 \cdot \frac{\Omega}{\text{mile}} \]

At 60°F the resistance will be
\[ R_{60} = R_{100} + \frac{R_{10} - R_{100}}{1} (60 - 50) \]
\[ R_{60} = 0.187 + \frac{0.209 - 0.187}{1} (60 - 50) \]
\[ R_{60} = 0.187 + 0.146 \cdot 10 = 0.187 + 1.46 \]
\[ R_{60} = 1.646 \Omega \text{ mile} \]

in 51 miles:
\[ 12 = 12.25 \text{ mm} = 0.489 \text{ in} \]
\[ R_{51} = \frac{0.189 \cdot 10^2}{1000 \cdot 0.3048} = 0.624 \Omega \text{ mile} \]

or in 0.5 mile:
\[ R_{0.5} = 0.624 \cdot \frac{1}{0.5} = 1.248 \Omega \text{ mile} \]

b) Inductance (per conductor):
\[ L = \frac{M}{\mu_0} \left( \frac{1}{4} + \frac{\ln D}{D} \right) = \frac{2}{\ln 2} \cdot \frac{M}{\mu_0} \cdot \frac{D}{\ln D} \]

Given: (from Table) \[ L = 0.011 \text{ ft} \]
\[ D = 3 \text{ in} = 3 \cdot \frac{1}{0.0305 \text{ ft}} = 99.69 \text{ ft} \]
\[ L = \frac{2\pi \cdot \frac{0.01}{0.0305}}{8} \cdot \frac{99.69}{0.01} = 13.58 \mu \text{H} \text{ mile}^{-1} \]

Reactance \[ X_r' = 2\pi \cdot L_r' = 2\pi \cdot 0.01 \cdot 2.715 = 10.24 \mu \text{H} \text{ mile}^{-1} \]
also \[ X_r' = 0.273 \cdot \frac{D}{\ln D} \cdot \ln \frac{D}{\ln D} = 0.273 \cdot \frac{99.69}{0.01} \cdot \frac{0.01}{0.01} = 8.236 \mu \text{H} \text{ mile}^{-1} \]

Impedance of line (both conductors)
\[ Z = 2(\bar{R} + j\bar{X}) = 2(1.005 + j0.8236) = 2.01 + j1.647 \Omega \text{ mile}^{-1} \]
Transposed 3-phase T-Line

- Reactance of 3-phase T-Line per phase (w/o proof)
  \[ X' = 0.2794 \frac{f}{60} \log \frac{D}{GMR} \Omega/mile \quad X' = 2\pi f \frac{\mu_0}{2\pi} \ln \frac{D}{GMR} \Omega/m \]

- Restoring balanced conditions by the method of transposition of lines
  - Average inductance of each phase will be the same
  - Each phase occupies each position for the same fraction of the total length of the line

Capacitance per length of Two-Wire T-Line

Between phases
\[ C_{ab} = \frac{q}{V_{ab}} = \frac{\pi \varepsilon}{\ln \frac{D}{r}} \]

Between phase and neutral (at \( V_{an} = V_{ab}/2 \))
\[ C_{an} = \frac{q}{V_{an}} = \frac{2\pi \varepsilon}{\ln \frac{D}{r}} \]

- \( \varepsilon = \varepsilon_0 = 8.85 \cdot 10^{-12} \text{ As/Vm} \)
- Between phase and ground
  \[ C_{bg} = \frac{q}{V_{bg}} = \frac{2\pi \varepsilon}{\ln \frac{2h}{r}} \]
**Equivalent Balanced Capacitance - Equilateral Spacing**

\[ C'_{an} = \frac{2\pi \varepsilon}{\ln \frac{GMD}{r}} = \frac{2\pi \times 8.85 \times 10^{-12} \log_{10}(e)}{\log_{10} \frac{GMD}{r}} \]

\[ C'_{an} = \frac{0.0241}{\log_{10} \frac{GMD}{r}} \text{ nF/m} \]

**Practical Equation**

\[ C = \frac{0.0389}{\log_{10} \left( \frac{GMD}{r} \right)} \mu F/\text{mile} \]

**Line Shunt Admittance**

- **Admittance per length from C’**
  - e.g. in \( \mu \text{S/mile} \)
  \[ Y'_{c} = j2\pi f C' = \frac{f}{60 \log_{10} \left( \frac{GMD}{r} \right)} \]

\[ X'_{c} = \frac{-j}{Y'_{c}} \text{ in M\Omega/mile} \]

- **Large spacing between phases decreases Y’**
  - High voltage lines tend towards smaller Y’
  - Cables have much larger Y’ than overhead lines

- **Increasing the conductor radius increases Y’**
  - Bundling of conductors of HV lines increases charging current

- **Additional influencing parameters**
  - Line sag, tower geometry, etc.
  - Very elaborate calculations → tabulated values
Example

Calculate the resistance, inductive reactance, and capacitive reactance per phase and for the overhead line shown. Assume the line operates at 60 Hz.

\[ GMD_φ = \frac{3}{2}d_{12} d_{23} d_{13} = \frac{3}{2}(45.6)(88)(45.6) \]

\[ = 56.8 \text{ in} = 4.73 \text{ ft} \]

\[ Z_a = (0.3263 + j0.2794) \left( \frac{60}{60} \log_{10} \left( \frac{4.73}{0.0244} \right) \right) \]

\[ = 0.326 + j0.639 \ \Omega/\text{mi} \]

\[ r_g = \frac{1}{4} \text{dia} = \frac{1}{4}(0.720 \text{ in}) \cdot \frac{1}{12} = 0.03 \text{ ft} \]

\[ C = \frac{0.0389}{\log_{10}(4.73/0.03)} = 0.177 \mu F/\text{mi/phs} \]

\[ X_C = \frac{1}{2\pi \cdot 60 \cdot 0.177 \mu F} = 149.9 \ \Omega/\text{mi} \]

HW #8

- A balanced 3-phase impedance type load is rated 3 MVA at 4.16 kV, with a lagging power factor of 0.75. It is supplied by a generator via a 2 km long overhead transmission line. The GMD of the conductors is 50 in. The generator is rated 4 MVA at 4.16 kV with a synchronous impedance of j1pu.
  - Size the conductor for that load assuming an ambient temperature of 25°C, no wind, and allowing a conductor temperature of 100°C.
  - For 4.16 kV at the load what is the voltage regulation of the T-Line?
  - What is the magnitude of the induced voltage of the generator in pu?