Ampacities of All-Aluminum Conductor

Conductor	Stranding	Conductor Temp. = 75°C				Conductor Temp. = 100°C			
		Ambient = 25°C		Ambient = 40°C		Ambient = 25°C		Ambient = 40°C	
		No Wind	Wind	No Wind	Wind	No Wind	Wind	No Wind	Wind
6	7	60	103	46	85	77	124	67	111
4	7	83	138	63	114	107	166	92	148
2	7	114	185	86	152	148	223	128	199
1	7	134	214	101	175	174	258	150	230
1/0	7	157	247	118	203	204	299	176	266
2/0	7	184	286	139	234	240	347	207	309
3/0	7	216	331	162	271	283	402	243	358
4/0	7	254	383	190	313	332	466	286	414
250	7	285	425	213	347	373	518	321	460
250	19	286	427	214	348	375	519	322	462
266.8	7	298	443	223	361	390	539	335	479
266.8	19	299	444	224	362	392	541	337	481
300	19	325	479	243	390	426	584	367	519
336.4	19	351	515	262	419	461	628	397	559
350	19	361	527	269	428	474	644	408	572
397.5	19	394	571	293	464	517	697	445	619
450	19	429	617	319	501	564	755	485	671
477	19	447	640	332	519	588	784	506	697
477	37	447	641	333	520	589	785	507	697
500	19	461	658	342	534	606	805	521	716

Geometric Mean Radius (GMR)

$$L_1' = \frac{\mu_0}{2\pi}\left(\frac{\mu_r}{4} + \ln\frac{D}{r}\right) = \frac{\mu_0}{2\pi}\left(\underbrace{\frac{\mu_r}{4} + \ln\frac{1}{r}} + \ln\frac{D}{1}\right)$$

$$L_{GMR}' = \frac{\mu_0}{2\pi}\ln\frac{1}{GMR}$$

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

$$\boxed{L_1' = \frac{\mu_0}{2\pi}\ln\frac{D}{GMR}}$$

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 (base e) by log (base 10)
Inserting μ_0 = 4π10^{-7} Vs/Am
Expanding 1 mile = 1609.344 m

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

$$\boxed{X^{'} = 0.2794 \frac{f}{60} \log \frac{D}{GMR}}$$ **in Ω/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 1/0

a.) Resistance @60Hz per conductor

from table we get $R'_{50°C} = 0.1837 \frac{\Omega}{1000 ft}$

(lecture 14, slide 9) $R_{75°C} = 0.2002 \frac{\Omega}{1000 ft}$

at 60°C the resistance will be $R_{60°C} = R_{50°C} + \frac{R_{75} - R_{50}}{75 - 50}(60-50)$

$$R_{60°C} = 0.1837 + \frac{0.0165}{25} \cdot 10 = 0.1903 \frac{\Omega}{1000 ft}$$

in SI units : $1 ft = 12 in = 12 \cdot 25.4 mm = 304.8 mm = 0.3048 m$

1 mile = 1609.344 m = 5280 ft

$$R_{60°C} = \frac{0.1903 \frac{\Omega}{1000 ft}}{1000 ft \, 0.3048 \frac{m}{ft}} = 0.6243 \, m\Omega/m$$

or in Ω/mile $R_{60°C} = 0.6243 \frac{m\Omega}{m} \cdot 1609.344 \frac{m}{mile} = 1.005 \frac{\Omega}{mile}$

b.) Inductance (per conductors)

$$L_1 = \frac{\mu_0}{\pi}\left(\frac{1}{4} + \ln\frac{D}{r}\right) = 2 \cdot L'_1 = 2 \cdot \frac{\mu_0}{2\pi} \ln\frac{D}{GMR}$$

GMR (from table) = 0.0111 ft

$$D = 3m = 3m \frac{1}{0.3048 \frac{m}{ft}} = 9.843 ft$$

$$L'_1 = \frac{2\cancel{4\pi}10^{-7}}{\cancel{2\pi}} \cdot \ln\frac{9.843}{0.0111} = 1.358 \, \mu H m^{-1}$$

Reactance $X'_1 = 2\pi f \cdot L'_1 = 2\pi 60 \cdot 2.715 = 1.024 m\Omega/m = 0.8236 \frac{m\Omega}{mile}$

also $X'_1 = 0.2794 \cdot \frac{f}{60} \cdot \log\frac{D}{GMR} = 0.2794 \cdot \frac{60}{60} \log\frac{9.843}{0.0111} = 0.8236 \frac{\Omega}{mile}$

Impedance of line (both conductors)

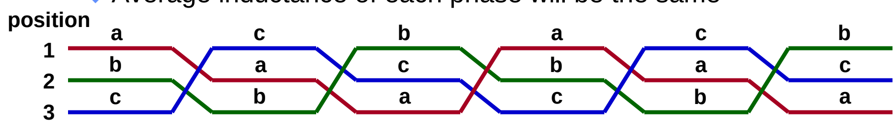
$$Z'_{12} = 2(R' + j\omega X') = 2(1.005 + j0.8236) = (2.01 + j1.647) \frac{\Omega}{mile}$$

Transposed 3-phase T-Line

- **Reactance of 3-phase T-Line per phase (w/o proof)**

$$X' = 0.2794 \frac{f}{60} \log \frac{D}{GMR} \quad \Omega\text{/mile} \qquad X' = 2\pi f \frac{\mu_0}{2\pi} \ln \frac{D}{GMR} \quad \Omega\text{/m}$$

- **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

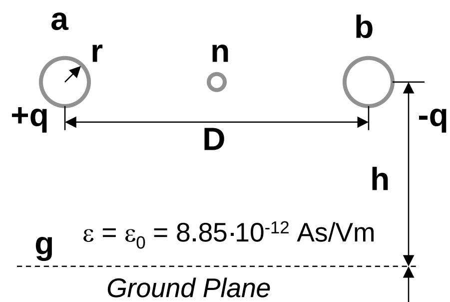
Capacitance per length of Two-Wire T-Line

Between phases

$$C_{ab} = \frac{q}{V_{ab}} = \frac{\pi \varepsilon}{\ln \frac{D}{r}}$$

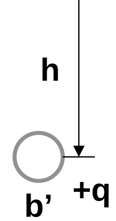
Between phase and neutral (at $V_{an} = V_{ab}/2$)

$$C_{an} = \frac{q}{V_{an}} = \frac{2\pi \varepsilon}{\ln \frac{D}{r}}$$

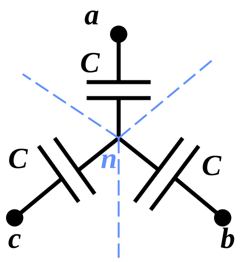


Between phase and ground

$$C_{bg} = \frac{q}{V_{bg}} = \frac{2\pi \varepsilon}{\ln \frac{2h}{r}}$$



Equivalent Balanced Capacitance - Equilateral Spacing



GMD_ϕ = geometric mean distance between conductors

r_ϕ = conductor radius

$$GMD_\phi = \sqrt[3]{d_{ab}\, d_{bc}\, d_{ca}}$$

$$C'_{an} = \frac{2\pi\,\varepsilon}{\ln\dfrac{GMD}{r}} = \frac{2\pi\, 8.85\cdot 10^{-12}\log_{10}(e)}{\log_{10}\dfrac{GMD}{r}}$$

$$C'_{an} = \frac{0.0241}{\log_{10}\dfrac{GMD}{r}} \quad \text{nF/m}$$

Practical Equation

$$C = \frac{0.0389}{\log_{10}\left(\dfrac{GMD}{r}\right)}$$

μF/mile

Line Shunt Admittance

- **Admittance per length from C'**
  - e.g. in μS/mile

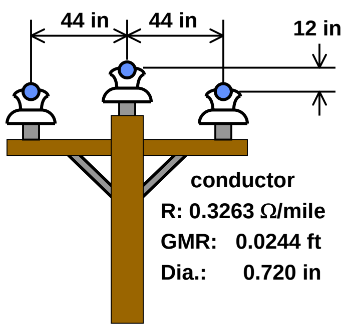
$$Y'_C = j2\pi f\, C' = \frac{f}{60}\,\frac{14.665}{\log_{10}\left(\dfrac{GMD_\phi}{r_\phi}\right)}$$

$$X'_C = \frac{-j}{\left|Y'_C\right|} \quad \text{in M}\Omega\text{/mile}$$

- **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



$$GMD_\phi = \sqrt[3]{d_{12}\, d_{23}\, d_{13}} = \sqrt[3]{(45.6)(88)(45.6)}$$

$$= 56.8 \text{ in} = 4.73 \text{ ft}$$

$$Z_a = (0.3263) + j\,0.2794 \frac{(60)}{60} \log_{10}\left(\frac{4.73}{0.0244}\right)$$

$$= 0.326 + j0.639 \quad \Omega/\text{mi}$$

$$r_\phi = \tfrac{1}{2} dia = \tfrac{1}{2}(0.720 \text{ in}) \cdot \tfrac{1}{12} = 0.03 \text{ ft}$$

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

$$X_C = 1/(2\pi\, 60 \cdot 0.177\ \mu\text{F}) = 149.9 \quad \Omega\,\text{mi}$$

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?