Positive Sequence Impedance

Positive sequence impedances are used for fault calculations in electrical systems. For a flat non-transposed configuration with no circulating currents, the positive sequence impedances sometimes yield unexpected results. This bulletin explains the reason for these surprising results.

$$Z = R + j\,\omega\,L$$

where,

R	= AC resistance at operating temperature	Ω/m
ω	= 2 · π · f = angular frequency = 314 at f = 50 Hz	rad/s
L	= inductance	H/m

For trefoil configuration there are no surprises in the results since inductances are equal.

$$L_R = L_W = L_B = \frac{\mu_O}{2 \cdot \pi} \cdot \ln\left(\frac{S}{q}\right) \qquad \text{H/m}$$

where,

q	= Equivalent radius of conductor	mm
S	= Axial spacing between conductors	mm
μ_O	= Magnetic permeability of free space = $4 \cdot \pi \cdot 10^{-7}$	H/m

Note that $\mu_O / (2\pi) = 2 \cdot 10^{-7}$ H/m

The equivalent radius of the conductor q, takes into account the internal inductance of the conductor.

$$q = \frac{d}{2} \cdot e^{-0,25} \qquad \text{mm}$$

d = Conductor diameter mm

For flat configuration:

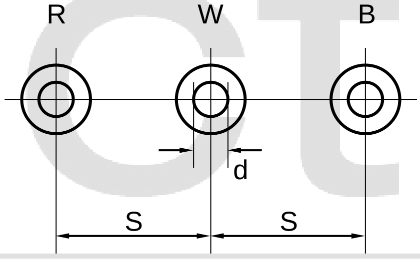


Figure 1: Flat arrangement

Reference: SIEMENS " Power cables and their applications" Part 1, Pg 323 by Lothar Heinhold. The phase rotation used is (α,1,α^2), where α = -1/2 + j√(3)/2.

White phase (reference phase):

$$L_W = 2\cdot 10^{-7}\cdot \ln\left(\frac{S}{q}\right) \qquad \text{H/m}$$

$$Z_W = R_W + j\cdot\omega\cdot L_W \qquad \Omega\text{/m}$$

$$= R + j\cdot\omega\cdot 2\cdot 10^{-7}\cdot \ln\left(\frac{S}{q}\right) \qquad \Omega\text{/m}$$

$$= R + j\,0{,}06283\cdot \ln\left(\frac{S}{q}\right) \qquad \Omega\text{/km}$$

Red phase (leading phase):

$$L_R = 2\cdot 10^{-7}\cdot\left(\ln\left(\frac{\sqrt{2}\cdot S}{q}\right) - j\frac{\sqrt{3}}{2}\ln(2)\right) \qquad \text{H/m}$$

$$Z_R = R_R + j\cdot\omega\cdot L_R \qquad \Omega\text{/m}$$

$$= R + j\cdot\omega\cdot 2\cdot 10^{-7}\cdot\left(\ln\left(\frac{\sqrt{2}\cdot S}{q}\right) - j\frac{\sqrt{3}}{2}\ln(2)\right) \qquad \Omega\text{/m}$$

$$= (R + 0{,}03772) + j\left(0{,}06283\cdot \ln\left(\frac{S}{q}\right) + 0{,}02178\right) \qquad \Omega\text{/km}$$

Blue phase (lagging phase):

$$L_B = 2\cdot 10^{-7}\cdot\left(\ln\left(\frac{\sqrt{2}\cdot S}{q}\right) + j\frac{\sqrt{3}}{2}\ln(2)\right) \qquad \text{H/m}$$

$$Z_B = R_B + j\cdot\omega\cdot L_B \qquad \Omega\text{/m}$$

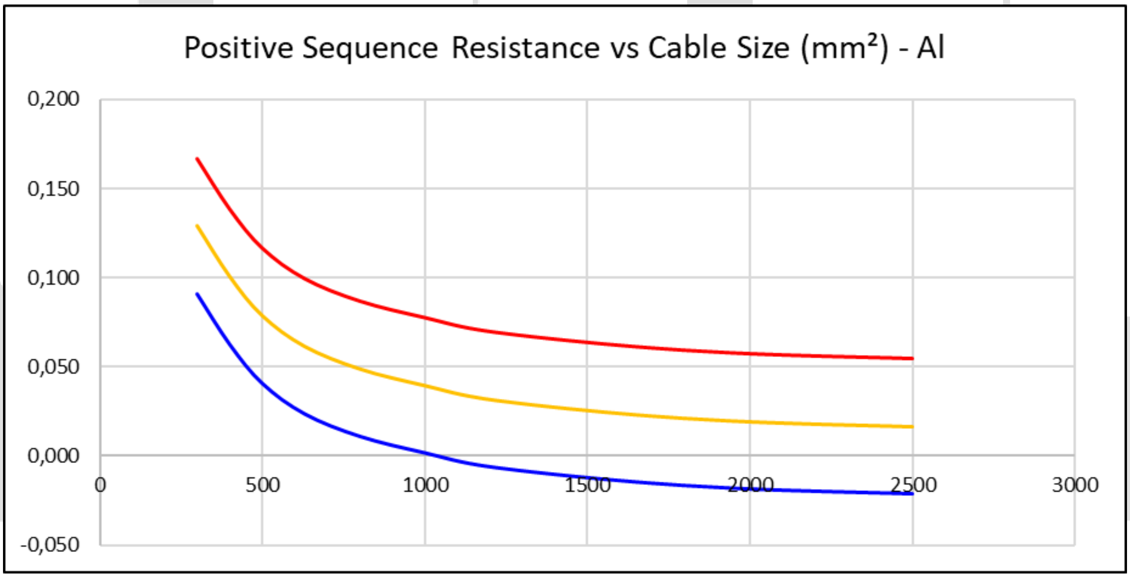
$$= R + j\cdot\omega\cdot 2\cdot 10^{-7}\cdot\left(\ln\left(\frac{\sqrt{2}\cdot S}{q}\right) + j\frac{\sqrt{3}}{2}\ln(2)\right) \qquad \Omega\text{/m}$$

$$= (R - 0{,}03772) + j\left(0{,}06283\cdot \ln\left(\frac{S}{q}\right) + 0{,}02178\right) \qquad \Omega\text{/km}$$

The positive sequence resistance is equal to the R_{ac} (90°C) for the middle phase, but differs by 0,0377 Ω/km for the leading and lagging phases.

Typical impedances for XLPE cable, flat configuration:

Cable	Red (Ω/km)		Yellow (Ω/km)		Blue (Ω/km)	
	R	X	R	X	R	X
300 Al 132	0,167	0,219	0,129	0,197	0,091	0,219
630 Al 132	0,099	0,202	0,062	0,180	0,024	0,202
1000 Al 132	0,077	0,192	0,040	0,170	0,002	0,192
1600 Al 132	0,062	0,183	0,024	0,162	-0,014	0,183
2500 Al 132	0,054	0,176	0,017	0,155	-0,021	0,176
300 Cu 132	0,115	0,220	0,078	0,198	0,040	0,220
630 Cu 132	0,076	0,201	0,038	0,180	0,001	0,201
1000 Cu 132	0,064	0,192	0,026	0,170	-0,012	0,192
1600 Cu 132	0,055	0,184	0,017	0,163	-0,021	0,184
2500 Cu 132	0,050	0,176	0,012	0,155	-0,025	0,176



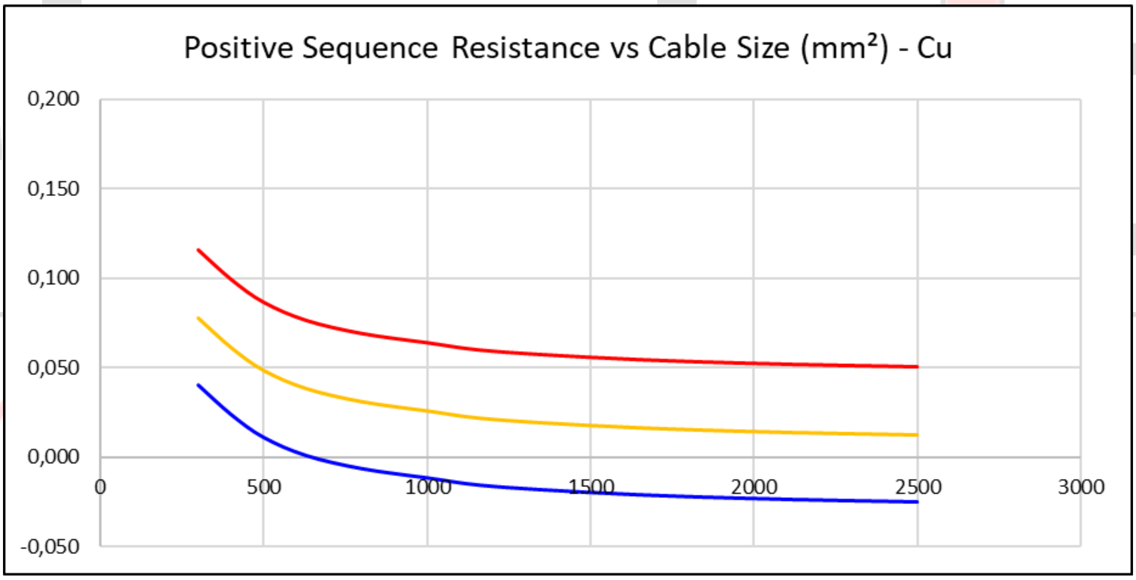


Figure 2: Positive sequence resistance for different cable sizes