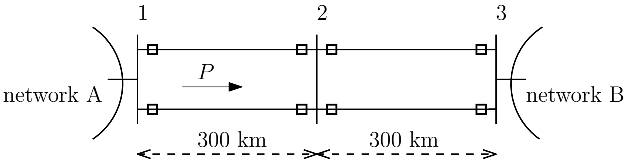
Exercises on overhead power lines (and underground cables)

1. From the laws of Electromagnetism it can be shown that $\ell\, c = \dfrac{1}{v^2}$ where v is the speed of propagation of electromagnetic waves in the environment that surrounds the conductors. Determine the expression of ℓc from those of ℓ and c (which were derived under some approximations) and compare it to the above exact value.
2. Show that placing the shunt admittance $g + j\omega c$ to the left of the series impedance $r + j\omega\ell$ instead of the right, as in slide 18 of Part 2, yields (luckily !) the same equations $d\bar{V}/dx = z\bar{I}, d\bar{I}/dx = y\bar{V}$.
3. What happens if a transmission line of length $\lambda/4$ ("quarter-wave" line) is connected to a network and left open at the other extremity? The line is assumed lossless, for simplicity.
4. Compute the natural power of :
   - a 380-kV line characterized by: $x = 0.3\Omega/\text{km}$, $b = 3\mu\text{S}/\text{km}$. Compare it to the thermal limit: 1350 or 1420 MVA;
   - a 150-kV cable characterized by: $x = 0.17\Omega/\text{km}$, $b = 60\mu\text{S}/\text{km}$. Compare it to the thermal limit: lower than 300 MVA.
5. Derive the expressions of the active and reactive power flows in a lossless line of arbitrary length as a function of the voltage magnitudes and phase angles at the terminal buses.

Exercise 6

A transmission corridor is planned to transmit 1000 MW between two 50-Hz networks, over a distance of 600 km, at a nominal voltage of 400 kV. The line is considered lossless, for simplicity, with the per-phase parameters $\omega \ell = 0.32\ \Omega/\text{km}$ and $\omega c = 3.2\ \mu\text{S/km}$. The networks are assumed to hold the voltages of the terminal buses at 400 kV[1].

1. Show that the maximum power that can be transferred in a single circuit is lower than 1000 MW.
2. Show that the transfer is possible with a double-circuit line. Compute the voltage at the mid-point of each circuit for a power transfer of respectively 1000 and 0 MW.
3. The double-circuit configuration is not *secure* since the 1000 MW cannot be transferred if one of the circuits is tripped. Consider the alternative configuration shown below. What is the maximum power transfer if one (of the four half-)line(s) is tripped ?



[1] to me more realistic, the Thévenin reactance of each network should be considered; it is ignored to keep the computations simple

4. To operate with a higher security margin, a compensator is connected to the middle bus 2 to hold the voltage of the latter at 400 kV. The compensator produces or consumes reactive power but no active power (losses are neglected). What is the maximum power transfer with all lines in service and when one of them is tripped ?
5. Which reactive power must the compensator be able to produce and consume to hold its terminal voltage at 400 kV for all power transfers between 0 and 1000 MW ?

Exercise 7

Consider the two cables with the following characteristics:

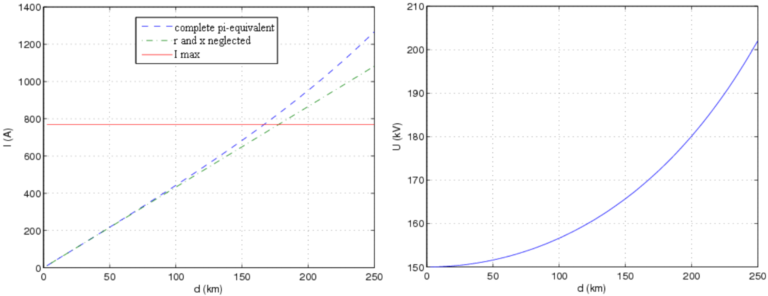
U_{nom} (kV)	S_{nom} (MVA)	r (Ω/km)	$\omega\,\ell$ (Ω/km)	$\frac{\omega\,c}{2}$ (μS/km)
150	200	0.07	0.17	25
36	20	0.11	0.13	50

Assume that each cable is connected under its nominal voltage at one end, and left open at the other end. Determine how the current entering the cable and the voltage at the open end evolve with the length d of the cable.

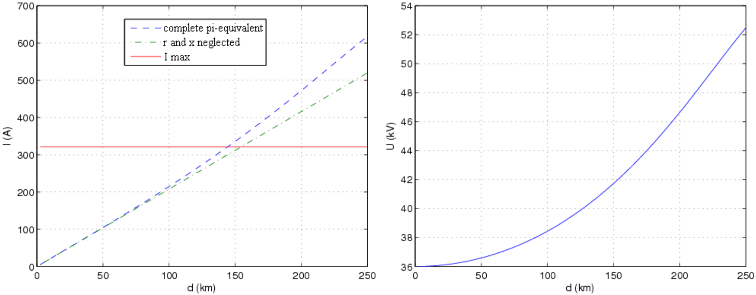
Perform the computation:

- using the complete pi-equivalent of the cable, and
- treating the cable as a shunt capacitor only.

The results are shown in the figures hereafter. They illustrate the difficulty of using AC cables over long distances.



150-kV cable: RMS value of current entering the cable and RMS voltage at the open end



36-kV cable: RMS value of current entering the cable and RMS voltage at the open end