1. a) A feeder supplies power first increasing at *r* %/a for the first 10 years and later on remains the same. The calculation period is 25 a, the interest rate is 8 %, the cost of losses 0.05 €/kWh and the utilization time for losses is 1500 h/a. U = 20 kV. Make a table showing the most favourable areas of use. The variables are the initial supplied power and annual growth percentage.

	r Ω/km	*x* Ω/km	Price k€/km	Ampacity (A)
Raven	0,537	0,362	11	280
Al 132	0,219	0,342	14	459

b) Is the capacity sufficient after 10 years if the growth percentage is 4 %/a starting from the year 0 power at the break-even point (1.64 MVA). Calculate the max lengths when the allowed voltage drop is 4 % (cos φ = 0,95).

2. A factory needs a new medium voltage (20 kV) feeder of length 5 km. The supplied max power of the feeder will be for the first 20 a, 1,5 MVA, $\cos\varphi = 0{,}9$. The interest rate is 8 %, the cost of losses 0.05 €/kWh and the utilization time for losses is 1500 h/a. The feeder type will be Raven or Al 132. How big is the error if the wrong feeder type is chosen? Also calculate the possible error when the max power is 2,0 MVA or 2,5 MVA. The assessment time, T = 20 years.

You need the following formulae:

$$\gamma = \frac{(1+r)}{(1+p)}, \quad \gamma_1 = \frac{(1+r)^2}{(1+p)} \quad \text{and} \quad \gamma_2 = \frac{1}{1+p}$$

(1), (2) and (3)

$$\kappa_{losses} = \gamma_1 \frac{\gamma_1^{t'} - 1}{\gamma_1 - 1} + \frac{(1+r)^{2t'}}{(1+p)^{t'}} \gamma_2 \frac{\gamma_2^{T-t'} - 1}{\gamma_2 - 1}$$

(4)

$$\kappa_{load} = \gamma \frac{\gamma^{t'} - 1}{\gamma - 1} + \frac{(1+r)^{t'}}{(1+p)^{t'}} \gamma_2 \frac{\gamma_2^{T-t'} - 1}{\gamma_2 - 1}$$

(5)

where

r is load growth
p is interest rate
T is review period and

t' is load growth period.

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We are dealing here with investment vs loss costs. A larger conductor section will have lower resistance, and therefore lower cost of losses, but higher investment costs. So, provided the smaller conductor can cope with the technical constraints, it is a matter of seeing whether a larger one would have lower total costs. So, first we will derive the formula I gave in ED&M04 for calculating the break-even apparent power that delineates the 1st year maximum power flow above which it is cost optimal to choose the larger conductor.

It is worth choosing the larger conductor "2" over the smaller conductor "1" if

$$C_{losses,1} - C_{losses,2} > C_{inv,2} - C_{inv,1} \qquad (1)$$

$(C_{inv} = c_{inv} l)$

where,

$C_{losses,1}$ is the NPV of the cost of losses over the entire operation time for feeder 1
$C_{losses,2}$ is the NPV of the cost of losses over the entire operation time for feeder 2
$C_{inv,1}$ is the investment cost for feeder 1
$C_{inv,2}$ is the investment cost for feeder 2

$$C_{losses,1} = \kappa_{losses} \frac{{S_0}^2}{U^2} r_1 l \, T_{losses} c_{losses} \qquad (2)$$

$$C_{losses,2} = \kappa_{losses} \frac{{S_0}^2}{U^2} r_2 l \, T_{losses} c_{losses} \qquad (3)$$

Putting (2) and (3) into (1)

$$\kappa_{losses} \frac{{S_0}^2}{U^2} (r_1 - r_2) l \, T_{losses} c_{losses} > c_{inv,2} l - C_{inv,1} l$$

$$S_0 > U \sqrt{\frac{c_{inv,2} - c_{inv,1}}{\kappa_{losses}(r_1 - r_2) T_{losses} c_{losses}}} \qquad (4)$$

Let's first calculate the break-even point for a load growth r = 4%/a for the first 10 years. P = 8%/a, t' = 10 a, T = 25 a.

$$\gamma = \frac{(1+r)}{(1+p)}, \quad \gamma_1 = \frac{(1+r)^2}{(1+p)} \text{ and } \gamma_2 = \frac{1}{1+p}$$

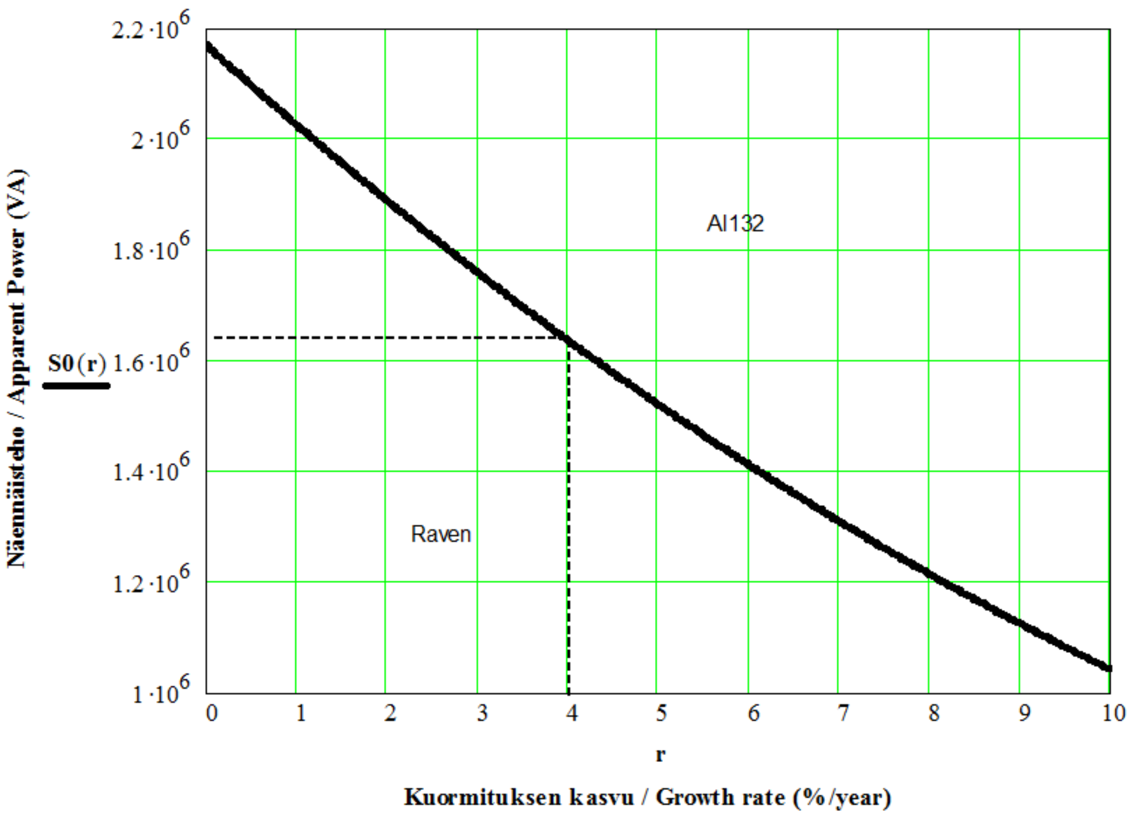
(1), (2) and (3)

$$\kappa_{losses} = \gamma_1 \frac{\gamma_1^{t'} - 1}{\gamma_1 - 1} + \frac{(1+r)^{2t'}}{(1+p)^{t'}} \gamma_2 \frac{\gamma_2^{T-t'} - 1}{\gamma_2 - 1}$$

$$\Rightarrow \kappa_{losses(r=4)} = 18.769 \Rightarrow S_0 = 20000 \sqrt{\frac{14000 - 11000}{18.769(0.537 - 0.219)1500 \cdot 5e{-5}}}$$

$$= \mathbf{1.64\ MVA}$$

If one makes S_0 a function of r, one gets the following plot:



b) The load in the first year S_0 is 1.64 MVA, so after 10 years:

$$S_{10} = 1.64(1+0.04)^{10} = 2.42 \text{ MVA}$$

$I = \frac{S_{10}}{\sqrt{3}\,U} = \frac{2.42 \cdot 10^6}{\sqrt{3}\; 20 \cdot 10^3} = 69.96$ A, which is fine for both conductor sizes, so no problems there.

Maximum length with acceptable voltage (4% voltage drop allowed, i.e. $U_d = 0.04$ pu):

$$\cos\varphi = 0.95 \Longrightarrow \sin\varphi = 0.312$$

$$P = S_{10}\cos\varphi = 2.3 \cdot 10^6 \text{ W} \Longrightarrow Q = S_{10}\sin\varphi = 0.757 \cdot 10^6 \text{ W}$$

$$U_d U = \frac{Prl + Qxl}{U} \Longrightarrow l = \frac{U_d U^2}{Pr + Qx} \qquad (5)$$

$$r_{raven} = 0.537\ \Omega/\text{km}$$
$$x_{raven} = 0.0.362\ \Omega/\text{km}$$
$$r_{Al132} = 0.219\ \Omega/\text{km}$$
$$x_{Al132} = 0.0.342\ \Omega/\text{km}$$

Putting the impedance values for the respective conductor sizes gives maximum lengths for Raven and Al 132 of **10.6 km** and **20.6 km**, respectively.

2. A factory needs a new medium voltage (20 kV) feeder of length 5 km. The supplied max power of the feeder will be for the first 20 a, 1,5 MVA, $\cos\varphi = 0{,}9$. The interest rate is 8 %, the cost of losses 0.05 €/kWh and the utilization time for losses is 1500 h/a. The feeder type will be Raven or Al 132. How big is the error if the wrong feeder type is chosen? Also calculate the possible error when the max power is 2,0 MVA or 2,5 MVA. The assessment time, T = 20 years.

Solution:

Note that there is no load growth, i.e., $r = 0$, and so $\kappa_{losses} = 9.818$

Let's make the loss functions (which here are made up of only investment and loss costs)

$$\Rightarrow C_{Raven}(S_{line}) = C_{investment,Raven} + \kappa_{losses}\left(\frac{S_{line}}{U}\right)^2 R_{Raven}T_{losses}c_{losses}$$

$$C_{Raven}(S_{line}) = 55000 + 9.818\left(\frac{S_{line}}{20\cdot 10^3}\right)^2 2.685\cdot 1500\cdot 0.00005 = 55000 + 4.943\cdot 10^{-9}\cdot {S_{line}}^2$$

So: $C_{Raven}(1.5\cdot 10^6)$ =66121 €, $C_{Raven}(2.0\cdot 10^6) = 74771$ €, $C_{Raven}(2.5\cdot 10^6) = 85892$ €

$$\Rightarrow C_{\mathrm{Al132}}(S_{line}) = C_{investment,\mathrm{Al132}} + \kappa_{losses}\left(\frac{S_{line}}{U}\right)^2 R_{\mathrm{Al132}}T_{losses}c_{losses}$$

$$C_{\mathrm{Al132}}(S_{line}) = 70000 + 9.818\left(\frac{S_{line}}{20\cdot 10^3}\right)^2 1.095\cdot 1500\cdot 0.00005 = 70000 + 2.016\cdot 10^{-9}\cdot {S_{line}}^2$$

So: $C_{\mathrm{Al132}}(1.5\cdot 10^6) = 74535$ €, $C_{\mathrm{Al132}}(2.0\cdot 10^6) = 78063$ €, $C_{\mathrm{Al132}}(2.5\cdot 10^6) = 82598$ €

Cost differences (the cost penalty of choosing the larger conductor)

$C_{\mathrm{Al132}}(1.5\cdot 10^6) - C_{Raven}(1.5\cdot 10^6) = 8414$ € will be overspent if $S_{line} = 1.5$ MVA

$C_{\mathrm{Al132}}(2.0\cdot 10^6) - C_{Raven}(2.0\cdot 10^6) = 3290$ € will be overspent if $S_{line} = 2.0$ MVA

$C_{\mathrm{Al132}}(2.5\cdot 10^6) - C_{Raven}(2.5\cdot 10^6) = -3290$ € will be saved if $S_{line} = 2.5$ MVA

So if $S_{line} = 2.5$ MVA, it is worth choosing the bigger conductor size