4.10.12

1a) $E = \rho \cdot V \cdot g \cdot \Delta h = 1000 \frac{kg}{m^3} \cdot 0{,}4 \cdot 60 \cdot 10^6 m^3 \cdot 9{,}81 \frac{m}{s^2} \cdot 287 m$

$= 67{,}57 \, TJ$

b) $P_{el} = \dfrac{\rho \cdot Q \cdot g \cdot \Delta h}{\eta_H \cdot \eta_p \cdot \eta_{el} \cdot (1-\varepsilon)} =$

$= \dfrac{1000 \frac{kg}{m^3} \cdot 80 \frac{m^3}{s} \cdot 9{,}81 \frac{m}{s^2} \cdot 287 m}{0{,}94 \cdot 0{,}87 \cdot 0{,}96 \cdot (1-0{,}02)} = 292{,}7 \, MW$

c) $V_{os}' = (1-0{,}4) \, V_{os} = (1-0{,}4) \cdot 60 \cdot 10^6 m^3 = 36 \cdot 10^6 m^3$

$V_{us}' = 0{,}8 \cdot V_{us} = 0{,}8 \cdot 30 \cdot 10^6 m^3 = 24 \cdot 10^6 m^3$

$V_{us}' < V_{os}' \Rightarrow V_{os}'$ irrelevant

$t = \dfrac{V_{us}'}{Q} = \dfrac{24 \cdot 10^6 m^3}{80 \frac{m^3}{s}} = 83{,}3 h$

d) $E_{el} = P_{el} \cdot t = 292{,}7 MW \cdot 83{,}3 h = 24{,}38 \, GWh$

e) $E = \rho \cdot V \cdot g \cdot \Delta h = 1000 \frac{kg}{m^3} \cdot 0{,}8 \cdot 30 \cdot 10^6 m^3 \cdot 9{,}81 \frac{m}{s^2} \cdot 287 m$

$= 67{,}57 \, TJ = 18{,}77 \, GWh$

2 a) $a = 660 \frac{€}{kW_{el}}$

$$\alpha = \frac{(q-1)\cdot q^n}{q^n - 1} = \frac{(1{,}05-1)\cdot 1{,}05^{25}}{1{,}05^n - 1} = 70{,}95\cdot 10^{-3}\,\frac{1}{a}$$

$c = 97 \frac{€}{kW_{el}\,a}$

$$b = \frac{0{,}47\frac{€}{m^3}}{\eta \cdot H_u} = \frac{0{,}47\frac{€}{m^3}\cdot 3{,}6\frac{MJ}{kWh}}{0{,}58\cdot 30\frac{MJ}{m^3}} = 0{,}09724\,\frac{€}{kW_{el}h}$$

$d = 0{,}0015 \frac{€}{kWh_{el}}$

$$k = \frac{\alpha\cdot a + c}{T_m} + b + d = \frac{70{,}95\cdot 10^{-3}\frac{1}{a}\cdot 660\frac{€}{kW_{el}} + 97\frac{€}{kW_{el}a}}{7000\,\frac{h}{a}} +$$

$$+ 0{,}09724\frac{€}{kW_{el}h} + 0{,}0015\frac{€}{kW_{el}h}$$

$$= 11{,}93\,\frac{ct}{kW_{el}h}$$

b) $a = 3100 \frac{€}{kW_{el}}$

$$\alpha = \frac{(q-1)\cdot q^n}{q^n - 1} = \frac{(1{,}04-1)\cdot 1{,}04^{40}}{1{,}04^{40} - 1} = 50{,}52\cdot 10^{-3}\,\frac{1}{a}$$

$c = 88 \frac{€}{kW_{el}\,a}$

$b = d = 0$

$$k = \frac{\alpha\cdot a + c}{T_m} + b + d = \frac{50{,}52\cdot 10^{-3}\frac{1}{a}\cdot 3100\frac{€}{kW_{el}} + 88\frac{€}{kW_{el}a}}{5200\,\frac{h}{a}}$$

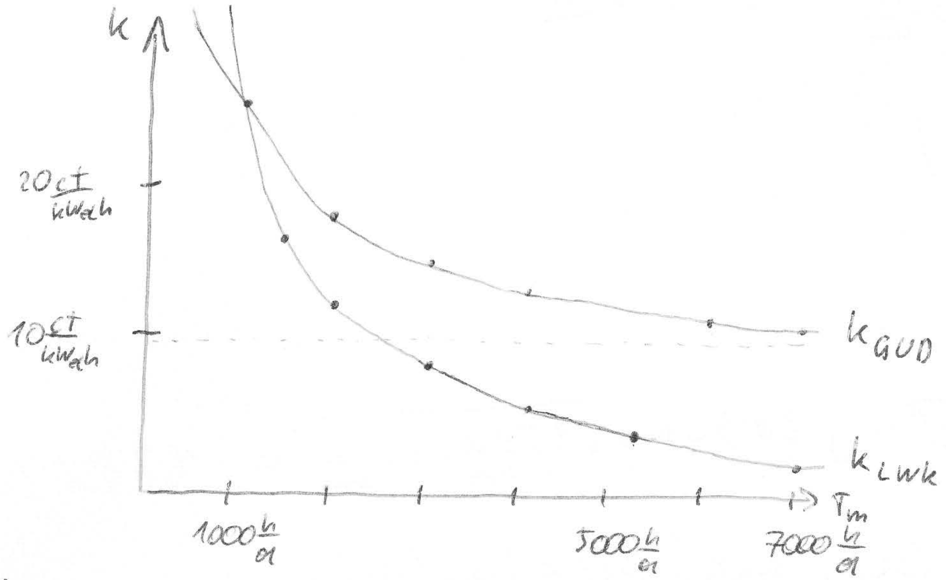
$$= 4{,}704\,\frac{ct}{kW_{el}h}$$

2c) $k_{GUD} = \frac{\alpha \cdot a + c}{T_m}$

$$T_m = \frac{\alpha \cdot a + c}{k_{GUD}} = \frac{50{,}52 \cdot 10^{-3} \frac{1}{a} \cdot 3100 \frac{€}{kW_{el}} + 88 \frac{€}{kW_{el}a}}{11{,}93 \frac{ct}{kW_{el}h}} = 2050 \frac{h}{a}$$

d) $k_{GUD} = \frac{143{,}8 \frac{€}{kW_{el}a}}{T_m} + 0{,}09874 \frac{€}{kW_{el}h}$

$k_{LWK} = \frac{244{,}6 \frac{€}{kW_{el}a}}{T_m}$



4a) $D_{AB} = \sqrt{(4m-(-8m))^2 + (24m-20m)^2} = 12{,}65m$

$D_{BC} = \sqrt{(-8m-(-6m))^2 + (20m-26m)^2} = 6{,}325m$

$D_{AC} = \sqrt{(4m-(-6m))^2 + (24m-26m)^2} = 10{,}20m$

$D = \sqrt[3]{D_{AB} \cdot D_{BC} \cdot D_{AC}} = \sqrt[3]{12{,}65m \cdot 6{,}325m \cdot 10{,}20m} = 9{,}345m$

$r_B = \sqrt[n]{n \cdot \sqrt{\frac{A}{\pi}} \cdot \left(\frac{a}{2\sin\left(\frac{\pi}{3}\right)}\right)^{n-1}} = \sqrt[3]{3 \cdot \sqrt{\frac{71{,}96mm^2}{\pi}} \cdot \left(\frac{200mm}{2 \cdot \sin\left(\frac{\pi}{3}\right)}\right)^2}$

$= 57{,}63mm$

$L_B' = \frac{\mu_0}{2\pi}\left(\ln\left(\frac{D}{r_B}\right) + \frac{1}{4n}\right) = \frac{4\pi \cdot 10^{-7} \frac{H}{m}}{2\pi}\left(\ln\left(\frac{9{,}345m}{0{,}05763m}\right) + \frac{1}{4 \cdot 3}\right) = 1{,}034 \frac{mH}{km}$

b) $R' = \frac{\rho \cdot \beta}{A \cdot 3} = \frac{0{,}0269 \frac{\Omega mm^2}{m} \cdot 1{,}07}{71{,}96 mm^2 \cdot 3} = 0{,}1333 \frac{\Omega}{km}$

$$\underline{Z}_W = \sqrt{\frac{R' + j\omega L'}{G' + j\omega C'}} = \sqrt{\frac{0{,}1333 \frac{\Omega}{km} + j\, 2\pi \cdot 50 Hz \cdot 1{,}5 \frac{mH}{km}}{j 2\pi \cdot 50 Hz \cdot 13 \frac{nF}{km}}}$$

$$|\underline{Z}_W| = \sqrt{\frac{\sqrt{(0{,}1333 \frac{\Omega}{km})^2 + (2\pi 50 Hz \cdot 1{,}5 \frac{mH}{km})^2}}{2\pi 50 Hz\, 13 \frac{nF}{km}}} = 346{,}3 \Omega$$

c) $\left(Z_W = \sqrt{\frac{L'}{C'}} = \sqrt{\frac{1{,}5 \frac{mH}{km}}{13 \frac{nF}{km}}} = 339{,}7 \Omega \right)$

$$\underline{U}_1 = \underline{U}_2 \cosh(\gamma l)$$

$$\underline{U}_2 = \frac{U_1}{\cosh(\gamma l)}$$

$$\gamma = j\beta = j\,\omega \sqrt{L'C'} = j\, 2\pi\, 50 Hz \sqrt{1{,}5 \frac{mH}{km} \cdot 13 \frac{nF}{km}} = j\, 1{,}387 \cdot 10^{-3} \frac{1}{km}$$

$$\cosh(j\beta l) = \cos(\beta l), \quad \sinh(j\beta l) = j \sin(\beta l)$$

$$\underline{U}_2 = \frac{380 kV}{\cos(1{,}387 \cdot 10^{-3} \frac{1}{km} \cdot 500 km)} = 494{,}1 kV$$

d) $\underline{U}_1 = \cosh(\gamma l)\, \underline{U}_2 + \sinh(\gamma l)\, \underline{Z}_W\, \underline{I}_2 = \underline{U}_2 \left(\cosh(\gamma l) + \sinh(\gamma l) \frac{\underline{Z}_W}{\underline{Z}_2} \right)$

$$\underline{I}_1 = \sinh(\gamma l) \frac{\underline{U}_2}{\underline{Z}_W} + \cosh(\gamma l)\, \underline{I}_2 = \underline{U}_2 \left(\sinh(\gamma l) \frac{1}{\underline{Z}_W} + \cosh(\gamma l) \frac{1}{\underline{Z}_2} \right)$$

$$\underline{Z}_1 = \frac{\underline{U}_1}{\underline{I}_1} = \frac{\cos(\beta l) + j \sin(\beta l) \frac{\underline{Z}_W}{\underline{Z}_2}}{j \sin(\beta l) \frac{1}{\underline{Z}_W} + \cos(\beta l) \frac{1}{\underline{Z}_2}} =$$

$$= \frac{\cos(1{,}387 \cdot 10^{-3} \frac{1}{km} \cdot 500 km) + j \sin(1{,}387 \cdot 10^{-3} \frac{1}{km}\, 500 km) \frac{339{,}7 \Omega}{j 75 \Omega}}{j \sin(1{,}387 \cdot 10^{-3} \frac{1}{km} \cdot 500 km) \frac{1}{339{,}7 \Omega} + \cos(1{,}387 \cdot 10^{-3} \frac{1}{km} \cdot 500 km) \frac{1}{j 75 \Omega}}$$

$$= j 437{,}7 \Omega$$

4e) $P_{nat} = \frac{U_n^2}{Z_W} = \frac{(380\,kV)^2}{339{,}7\,\Omega} = 425{,}1\,MW$

5a) $S = \sqrt{3}\,U_{12}\,I_1 = 3\,U_1\,I_1 = 3\,\frac{U_1^2}{Z_{Last}}$

$$Z_{Last} = 3\,\frac{U_1^2}{S_{Nenn}} = \frac{U_{Nenn}^2}{S_{Nenn}} = \frac{40V^2}{1{,}6kW} = 1\,\Omega$$

$\cos\varphi = 1 \Rightarrow \underline{Z}_{Last} = 1\,\Omega$

b) Symmetrisches System

$$\Rightarrow \underline{Z}_{(0)} = \underline{Z}_L + \underline{Z}_{Last} + 3\,\underline{Z}_N = 1\,\Omega + 1\,\Omega + 3\cdot 0{,}333\,\Omega$$

$$= 2{,}999\,\Omega$$

$$\underline{Z}_{(1)} = \underline{Z}_{(2)} = \underline{Z}_L + \underline{Z}_{Last} = 1\,\Omega + 1\,\Omega = 2\,\Omega$$

c) $\underline{I}_{(0)} = \frac{1}{3}(\underline{I}_a + \underline{I}_b + \underline{I}_c) = \frac{1}{3}(8A + \underline{a}^2 8A + \underline{a}\,10A) = \frac{2}{3}\underline{a}A = 0{,}6667\underline{a}A$

$\underline{I}_{(1)} = \frac{1}{3}(\underline{I}_a + \underline{a}\,\underline{I}_b + \underline{a}^2\underline{I}_c) = \frac{1}{3}(8A + 8A + 10A) = 8{,}667A$

$\underline{I}_{(2)} = \frac{1}{3}(\underline{I}_a + \underline{a}^2\underline{I}_b + \underline{a}\,\underline{I}_c) = \frac{1}{3}(8A + \underline{a}8A + \underline{a}^2 10A) = 0{,}6667\underline{a}^2A$

d) $\underline{U}_{(0)} = \underline{Z}_{(0)}\cdot\underline{I}_{(0)} = 2{,}999\,\Omega\cdot 0{,}6667\,\underline{a}A = 1{,}999\,\underline{a}V$

$\underline{U}_{(1)} = \underline{Z}_{(1)}\cdot\underline{I}_{(1)} = 2\,\Omega\cdot 8{,}667A = 17{,}33V$

$\underline{U}_{(2)} = \underline{Z}_{(2)}\cdot\underline{I}_{(2)} = 2\,\Omega\cdot 0{,}6667\underline{a}^2A = 1{,}333\,\underline{a}^2V$

e) $\underline{U}_a = \underline{U}_{(0)} + \underline{U}_{(1)} + \underline{U}_{(2)} = 1{,}999\,\underline{a}V + 17{,}33V + 1{,}333\,\underline{a}^2V = (15{,}66 + j0{,}5768)V$

$\underline{U}_b = \underline{U}_{(0)} + \underline{a}^2\underline{U}_{(1)} + \underline{a}\,\underline{U}_{(2)} = 1{,}999\underline{a}V + 17{,}33\underline{a}^2 + 1{,}333V = (-8{,}332 - j13{,}28)V$

$\underline{U}_c = \underline{U}_{(0)} + \underline{a}\,\underline{U}_{(1)} + \underline{a}^2\underline{U}_{(2)} = 1{,}999\underline{a}V + 17{,}33\underline{a}V + 1{,}333\underline{a}V = (-10{,}33 + j17{,}89)V$