26.6.13

1a) $Z_T = u_k \dfrac{U_n^2}{S_N} = 0{,}15 \cdot \dfrac{(20kV)^2}{40MVA} = 1{,}5\,\Omega$

$R_k = P_k \dfrac{U_n^2}{S_N^2} = 500kW \dfrac{(20kV)^2}{(40MVA)^2} = 0{,}125\,\Omega$

b) $P_L = G_L U_L^2$ aus VO ET2 (22.50) *

$G_L = \dfrac{P_L}{U_L^2} = \dfrac{25kW}{(20kV)^2} = 62{,}5\,\mu S$

c) $Q_L = -B_L U_L^2$ aus VO ET2 (22.50) *

$S_L = U_L I_L = \underbrace{U_N I_N}_{S_N} \cdot 0{,}25\% = 40MVA \cdot 0{,}25\% = 100kVA$

$Q_L = \sqrt{S_L^2 - P_L^2} = \sqrt{(100kVA)^2 - (25kW)^2} = 96{,}82\,kVAr$

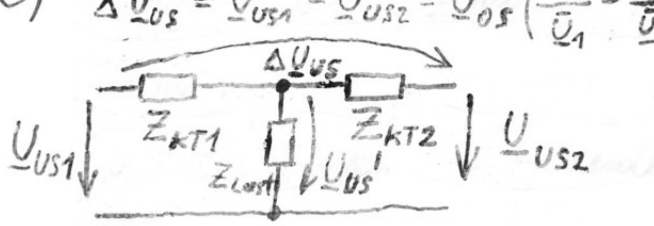
$B_L = -\dfrac{Q_L}{U_L^2} = -\dfrac{96{,}82kVAr}{(20kV)^2} = -242{,}1\,\mu S$

d) $Z_k' = \ddot{u}^2 \cdot Z_k = \left(\dfrac{110kV}{20kV}\right)^2 \cdot 1{,}5\,\Omega = 45{,}38\,\Omega$

* $\underline{S} = P + jQ = \underline{U} \cdot \underline{I}^* = \underline{U} \cdot \dfrac{\underline{U}^*}{\underline{Z}^*} = |\underline{U}|^2 \cdot \underline{Y}^* = U^2 (G + jB)^*$

$= U^2 (G - jB) \Rightarrow P = G U^2 \quad Q = -B U^2$

e) $\Delta \underline{U}_{US} = \underline{U}_{US1} - \underline{U}_{US2} = \underline{U}_{OS}\left(\dfrac{1}{\ddot{u}_1} - \dfrac{1}{\ddot{u}_2}\right) = \dfrac{110kV}{\sqrt{3}}\left(\dfrac{20kV}{110kV} - \dfrac{20kV}{118kV}\right) = 782{,}8\,V$



$\underline{U}_{US}' = \underline{U}_{US1} - \dfrac{Z_{KT1}}{Z_{KT1} + Z_{KT2}} \cdot \Delta \underline{U}_{US}$

$= \dfrac{20kV}{\sqrt{3}} - \dfrac{1{,}5\,\Omega}{1{,}5\,\Omega + 1{,}3\,\Omega} \cdot 782{,}8V$

$= 11{,}13\,kV$

1 f) $\underline{I}_k = \frac{\Delta \underline{U}_{US}}{Z_{kT1} + Z_{kT2}} = \frac{782{,}8\,V}{1{,}5\,\Omega + 1{,}3\,\Omega} = 279{,}6\ A$

g) Kurzschlussströme: $I_{k1} = \frac{U_{OS}}{\ddot{u}_1 Z_{kT1}} = \frac{\frac{110kV}{\sqrt{3}}}{\frac{110kV}{20kV} 1{,}5\,\Omega} = 7{,}698\,kA$

$I_{k2} = \frac{U_{OS}}{\ddot{u}_2 Z_{kT2}} = \frac{\frac{110kV}{\sqrt{3}}}{\frac{118kV}{20kV} 1{,}3\,\Omega} = 8{,}280\,kA$

Da der Kreisstrom viel kleiner ist als die Kurzschlussströme der Transformatoren, darf man die Transformatoren parallel-schalten, es ist jedoch nicht empfehlenswert, weil durch den Kreisstrom viel Energie verloren geht.

2 a) $\alpha = 0$

$\beta = \omega\sqrt{L'C'} = 2\pi \cdot 50\,Hz \sqrt{\frac{0{,}25\frac{\Omega}{km}}{2\pi 50\,Hz} \cdot 14\frac{nF}{km}} = 1{,}049 \cdot 10^{-3} \frac{1}{km}$

$L' = \frac{X'}{\omega}$

$\gamma = j\beta = j1{,}049 \cdot 10^{-3} \frac{1}{km}$

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

$\cosh(j\beta l) = \cos(\beta l)$

$\underline{U}_2 = \frac{\underline{U}_1}{\cos(\beta l)} = \frac{380kV}{\cos(1{,}049 \cdot 10^{-3}\frac{1}{km} \cdot 600km)} = 470{,}1\,kV$

c) $\underline{U}_2 = 1{,}05 \cdot \underline{U}_1$

$Z_W = \sqrt{\frac{L'}{C'}} = \sqrt{\frac{\frac{0{,}25\frac{\Omega}{km}}{2\pi 50\,Hz}}{14\frac{nF}{km}}} = 238{,}4\,\Omega$

2c) ff $\underline{U}_1 = \cosh(\gamma l)\,\underline{U}_2 + \sinh(\gamma l)\cdot \underline{Z}_W\,\underline{I}_2$

$$\sinh(j\beta l) = j\sin(\beta l)$$

$$\underline{I}_2 = \frac{\underline{U}_2}{\underline{Z}_2}$$

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

$$\underline{Z}_2 = \frac{j\sin(\beta l)\,\underline{Z}_W\,1{,}05\,\cancel{\underline{U}_1}}{(1-1{,}05\cos(\beta l))\,\cancel{\underline{U}_1}} =$$

$$= \frac{j\sin(1{,}049\cdot 10^{-3}\frac{1}{km}\,600km)\cdot 238{,}4\,\Omega\cdot 1{,}05}{1-1{,}05\cos(1{,}049\cdot 10^{-3}\frac{1}{km}\cdot 600km)} = j\,974{,}6\,\Omega$$

d) $\underline{Z}_2 = jX_2 = j\omega L_2$

$$L_2 = \frac{X_2}{\omega} = \frac{974{,}6\,\Omega}{2\pi\,50\,Hz} = 3{,}102\,H$$

e) Leitung wird unterhalb d. nat. Leistung betrieben

$Z_2 > Z_W$

Induktivität wird parallel geschaltet ⇒ Kapazität verkleinert sich ⇒ Phasenwinkel wird kleiner, was günstig ist

siehe S. 100 im Skriptum

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

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

$$= \frac{380\,kV}{\cos\left(1{,}049 \cdot 10^{-3} \frac{1}{km} \cdot 600\,km\right) + j \sin\left(1{,}049 \cdot 10^{-3} \frac{1}{km} \cdot 600\,km\right) \cdot \frac{238{,}4\,\Omega}{j980\,\Omega}}$$

$$= 399{,}3\,kV$$

g) $P_{nat} = \frac{U_n^2}{Z_w} = \frac{(380\,kV)^2}{238{,}4\,\Omega} = 605{,}7\,MW$

3 Leiter pro Bündel

$$P_{nat} = S_{therm} = \sqrt{3}\, U_n\, I_a = \sqrt{3}\, U_n\, 3\, I_{Einzel}$$

$$I_{Einzel} = \frac{P_{nat}}{\sqrt{3} \cdot 3 \cdot U_n} = \frac{605{,}7\,MW}{\sqrt{3} \cdot 3 \cdot 380\,kV} = 306{,}8\,A$$

h) $Q_1 = \mathrm{Im}(\underline{S}_1)$

$$\underline{S}_1 = \underline{U}_1 \underline{I}_1^* = \left(\cos(\beta l)\, \underline{U}_2 + j \sin(\beta l) \frac{\underline{Z}_W}{\underline{Z}_W} \underline{U}_2\right) \cdot \left(\frac{j \sin(\beta l)\, \underline{U}_2 + \cos(\beta l) \frac{\underline{Z}_W}{\underline{Z}_W} \underline{U}_2}{\underline{Z}_W}\right)^*$$

$$= \frac{|\underline{U}_2|}{\underline{Z}_W^*} \cdot \left| \cos(\beta l) + j \sin(\beta l) \right|^2$$

$$Q_1 = \mathrm{Im}(\underline{S}_1) = 0$$

3 a) $j\omega 3L_p + \frac{1}{j\omega \cdot C_E' \cdot l} = 0$

$$L_p = \frac{1}{\omega^2 3 C_E' \cdot l} = \frac{1}{(2\pi 50Hz)^2 3 \cdot 11\frac{nF}{km} \cdot 30km}$$

$$= 10{,}23\,H$$

b) $\underline{Z}_G = j\, x_d'' \cdot \frac{1}{\ddot{u}^2} \frac{U_N^2}{S_N} = j \cdot 0{,}12 \cdot \frac{(4kV)^2}{\left(\frac{4kV}{20kV}\right)^2 8MVA} = j\,6\,\Omega$

$\underline{Z}_T = j\, u_k \frac{U_N^2}{S_N} = j\,0{,}12 \cdot \frac{(20kV)^2}{8MVA} = j\,6\,\Omega$

$\underline{Z}_L = j\,X_{(1)}' \cdot l = j\,0{,}4\,\frac{\Omega}{km} \cdot 30km = j\,12\,\Omega$

c) symmetrisches System

$$\underline{Z}_{(0)} = \underbrace{\underline{Z}_{G(0)}}_{=0 \text{ siehe Abb 4-42}} + \underline{Z}_T + \overbrace{j X_{(0)}' \cdot l}^{X_{(0)} = 18\,\Omega} + \underbrace{\frac{j\omega 3L_p \cdot \frac{1}{j\omega C_E' \cdot l}}{j\omega 3L_p + \frac{1}{j\omega C_E' \cdot l}}}_{=\infty} = \infty$$

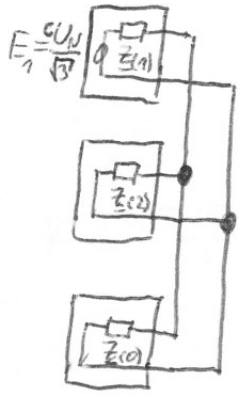
siehe auch S. 275 im Skriptum

$\underline{Z}_{(1)} = \underline{Z}_G + \underline{Z}_T + \underline{Z}_L = j6\,\Omega + j6\,\Omega + j12\,\Omega = j24\,\Omega$

$\underline{Z}_{(1)} = \underline{Z}_{(2)}$

d) $\underline{U}_{bN,F} = \underline{U}_{cN,F} = 0 \Rightarrow \underline{U}_{(1)} = \underline{U}_{(2)} = \underline{U}_{(0)}$

$\underline{I}_{a,F} = 0 \Rightarrow \underline{I}_{(1)} + \underline{I}_{(2)} + \underline{I}_{(0)} = 0$



3e) $\underline{I}_{(1)} = -\underline{I}_{(2)} = \frac{E_1}{\underline{Z}_{(1)} + \underline{Z}_{(2)}} = \frac{1{,}1 \cdot 20\,kV}{\sqrt{3} \cdot 2 \cdot j\,24\,\Omega} = -j\,264{,}6\,A$

Annahme $c = 1{,}1$

$\underline{I}_{(0)} = 0$ da exakt kompensiert ($\underline{Z}_{(0)} = \infty$)

f) $\underline{I}_a = \underline{I}_{(0)} + \underline{I}_{(1)} + \underline{I}_{(2)} = 0\,A$

$\underline{I}_b = \underline{I}_{(0)} + \underline{a}^2 \underline{I}_{(1)} + \underline{a}\,\underline{I}_{(2)} = \underbrace{(\underline{a}^2 - \underline{a})}_{-j\sqrt{3}}(-j\,264{,}6)\,A = -458{,}3\,A$

$\underline{I}_c = \underline{I}_{(0)} + \underline{a}\,\underline{I}_{(1)} + \underline{a}^2 \underline{I}_{(2)} = \underbrace{(\underline{a} - \underline{a}^2)}_{j\sqrt{3}}(-j\,264{,}6)\,A = 458{,}3\,A$

g) $\underline{U}_{aN,F} = 0$, $\underline{I}_{b,F} = \underline{I}_{c,F} = 0$

$\Rightarrow \underline{I}_{(1)} = \underline{I}_{(2)} = \underline{I}_{(0)}$

$\underline{I}_{(1)} = \frac{E_1}{\underline{Z}_{(1)} + \underline{Z}_{(2)} + \underbrace{\underline{Z}_{(0)}}_{=\infty}} = 0\,A$

$\underline{I}''_{k1p} = 0\,A$ Das ist der Sinn hinter der Petersonspule.

5 a) $\alpha = \frac{(q-1)\cdot q^n}{q^n - 1} = \frac{(1{,}084-1)\cdot 1{,}084^{15}}{1{,}084^{15}-1} = 0{,}1200 \frac{1}{a}$

1) $k = \frac{\alpha \cdot a + c}{T_m} + b + d$

$$= \frac{0{,}1200 \frac{1}{a} \cdot 700 \frac{€}{kW_{el}} + 90 \frac{€}{kW_{el} a}}{6800 \frac{h}{a}} + \frac{0{,}2 \frac{€}{m^3} \cdot 3{,}6 \frac{MJ}{kWh}}{0{,}59 \cdot 30 \frac{MJ}{m^3}} + 0{,}001 \frac{€}{kWh_{el}}$$

$$= 6{,}727 \frac{ct}{kWh_{el}}$$

2) $k = \frac{\alpha \cdot a + c}{T_m} + b + d$

$$= \frac{0{,}1200 \frac{1}{a} \cdot 700 \frac{€}{kW_{el}} + 90 \frac{€}{kW_{el} a}}{6800 \frac{h}{a}} + \frac{4 \frac{€}{m^3} \cdot 3{,}6 \frac{MJ}{kWh}}{0{,}59 \cdot 30 \frac{MJ}{m^3}} + 0{,}001 \frac{€}{kWh_{el}}$$

$$= 84{,}01 \frac{ct}{kWh_{el}}$$

b) $\alpha = \frac{(q-1)\cdot q^n}{q^n - 1} = \frac{(1{,}084-1)\cdot 1{,}084^{30}}{1{,}084^{30}-1} = 92{,}20 \cdot 10^{-3} \frac{1}{a}$

$$k = \frac{\alpha \cdot a + c}{T_m} + \underbrace{b + d}_{0} = \frac{92{,}20 \cdot 10^{-3} \frac{1}{a} \cdot 2400 \frac{€}{kW_{el}} + 80 \frac{€}{kW_{el} a}}{5000 \frac{h}{a}} = 6{,}026 \frac{ct}{kWh_{el}}$$

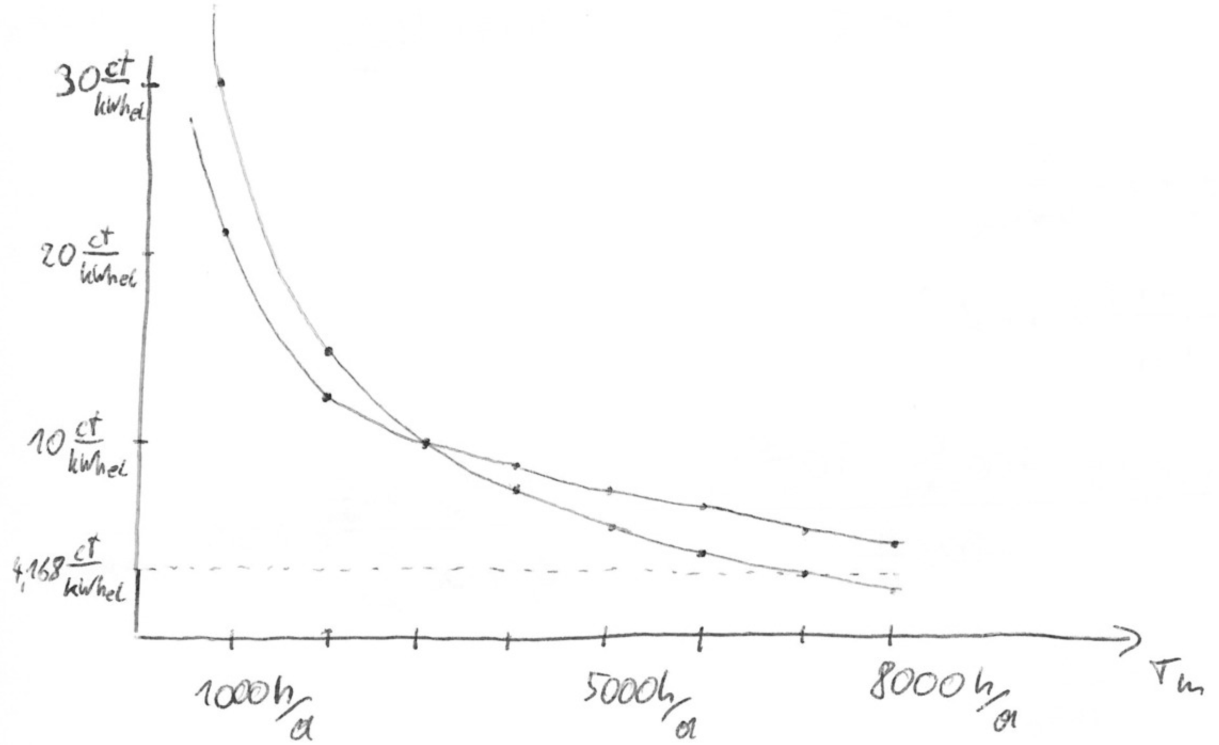
c) $k_{LWK} = \frac{\alpha_{GuD} a_{GuD} + c_{GuD}}{T_m} + b_{GuD} + d_{GuD}$

$$T_m = \frac{\alpha_{GuD} \cdot a_{GuD} + c_{GuD}}{k_{LWK} - b_{GuD} - d_{GuD}} = \frac{0{,}1200 \frac{1}{a} \cdot 700 \frac{€}{kW_{el}} + 90 \frac{€}{kW_{el} a}}{6{,}026 \frac{ct}{kWh_{el}} - \frac{0{,}2 \frac{€}{m^3} \cdot 3{,}6 \frac{MJ}{kWh}}{0{,}59 \cdot 30 \frac{MJ}{m^3}} - 0{,}001 \frac{€}{kWh_{el}}}$$

$$= 9364 \frac{h}{a}$$ (ein Jahr hat 8760 h)

d) $k_{GuD} = \dfrac{17{,}40 \frac{€}{kW\,a}}{T_m} + 0{,}04168 \frac{€}{kWh_{el}}$

$k_{LWK} = \dfrac{301{,}3 \frac{€}{kW_{el}\,a}}{T_m}$



$T_m = \dfrac{301{,}3 \frac{€}{kW_{el}\,a} - 174 \frac{€}{kW_{el}\,a}}{0{,}04168 \frac{€}{kWh_{el}}} = 3054\,h/a$ unter $3054 \frac{h}{a}$ hat das GUD niedrigere Stromgestehungskosten

e) Annahme: Erdgaspreis a. 1)

$k_{GuD} = \dfrac{\alpha_{LWK} \cdot a_{LWK} + C_{LWK}}{T_m}$

$T_m = \dfrac{\alpha_{LWK} \cdot a_{LWK} + C_{LWK}}{k_{GuD}} = \dfrac{92{,}20 \cdot 10^{-3} \frac{1}{a} \cdot 2400 \frac{€}{kW_{el}} + 80 \frac{€}{kW_{el}\,a}}{6{,}727 \frac{ct}{kWh_{el}}} =$

$= 4479 \frac{h}{a}$