28.1.14

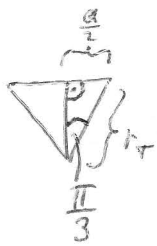
1a) $D_{AB} = \sqrt{(4m)^2 + (12m)^2} = 12{,}65m$

$D_{BC} = \sqrt{(2m)^2 + (6{,}5m)^2} = 6{,}801m$

$D_{AC} = \sqrt{(10m)^2 + (2{,}5m)^2} = 10{,}31m$

$D = \sqrt[3]{D_{AB} \cdot D_{BC} \cdot D_{AC}} = \sqrt[3]{12{,}65m \cdot 6{,}801m \cdot 10{,}31m} = 9{,}608m$

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



$= \sqrt[3]{3 \cdot \sqrt{\frac{200mm^2}{\pi}} \cdot \left(\frac{300mm}{2\sin(\frac{\pi}{3})}\right)^2} = 89{,}55mm$

$L_B' = \frac{\mu_0}{2\pi}\left(\ln\left(\frac{D}{r_B}\right) + \frac{1}{4n}\right) = \frac{4\pi \cdot 10^{-7}\frac{H}{m}}{2\pi}\left(\ln\left(\frac{9{,}608m}{0{,}08955m}\right) + \frac{1}{4 \cdot 3}\right)$

$= 951{,}8\,\frac{nH}{m} = 951{,}8\,\frac{\mu H}{km}$

b) $C_B' = \frac{2\pi\varepsilon_0\varepsilon_r}{\ln\left(\frac{D}{r_B}\right)} = \frac{2\pi\, 8{,}854\frac{pF}{m}}{\ln\left(\frac{9{,}608m}{0{,}08955m}\right)} = 11{,}90\,\frac{pF}{m} = 11{,}90\,\frac{nF}{km}$

c) $\alpha = \frac{R'}{2}\sqrt{\frac{C_B'}{L_B'}} + 0$

$= \frac{0{,}25\frac{\Omega}{km}}{3 \cdot 2}\sqrt{\frac{11{,}90\frac{nF}{km}}{951{,}8\frac{\mu H}{km}}} = 147{,}3 \cdot 10^{-6}\,\frac{1}{km}$

Anzahl Leiter pro Bündel

$\beta = \omega\sqrt{L_B' C_B'} = 2\pi\, 50Hz\sqrt{951{,}8\frac{\mu H}{km} \cdot 11{,}90\frac{nF}{km}} = 1{,}057 \cdot 10^{-3}\,\frac{1}{km}$

$\underline{\gamma} = \alpha + j\beta = (147{,}3 \cdot 10^{-6} + j\,1{,}057 \cdot 10^{-3})\,\frac{1}{km}$

d) $\underline{S}_1 = \underline{U}_1 \underline{I}_1^*$ $\qquad \cosh(j\beta l) = \cos(\beta l)$, $\sinh(j\beta l) = j\sin(\beta l)$

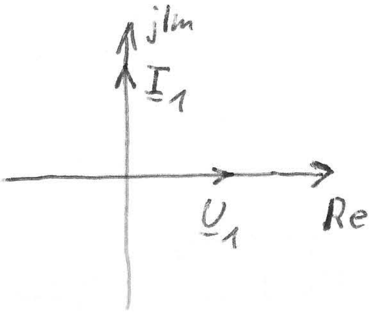
$\underline{U}_1 = \underline{U}_2 \cos(\beta l)$

$\underline{U}_2 = \frac{\underline{U}_1}{\cos(\beta l)}$ $\qquad \underline{Z}_W = Z_W$ da verlustlos

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

$\underline{S}_1 = \underline{U}_1\left(-j\frac{\underline{U}_1^*}{\underline{Z}_W^*}\tan(\beta l)\right) = -j|\underline{U}_1|^2\,\frac{\tan(\beta l)}{Z_W}$

1e) $\underline{I}_1 = j\,\frac{\underline{U}_1}{\underline{Z}_W}\tan(\beta l)$



f) $S_{therm} = \sqrt{3}\,U_{ab}\,I_{a} = \sqrt{3}\,U_{Nenn}\cdot 3\cdot I_{max} = \sqrt{3}\,380kV\cdot 3\cdot 350A$

$= 691{,}1\,MVA$

g) Blindleistung ist 0 wenn die Leitung mit dem Wellenwiderstand abgeschlossen ist.

2a) $\underline{X}_d'' = j\,x_d''\cdot\frac{U_1^2}{S_n} = j\,0{,}14\cdot\frac{(30kV)^2}{6MVA} = j\;21\;\Omega$

$\underline{Z}_T = j\,u_k\,\frac{U_1^2}{S_N} = j\,0{,}05\cdot\frac{(30kV)^2}{5MVA} = j\,9\,\Omega$

↑ $P_k = 0$

Symmetrisches System:

$\underline{Z}_{(0)} = \underline{X}''_{d(0)} + 2\underline{Z}_T + jX'_{(0)}\cdot l = 2\cdot j9\Omega + j\,0{,}7\,\frac{\Omega}{km}\cdot 10km = j\,25\Omega$

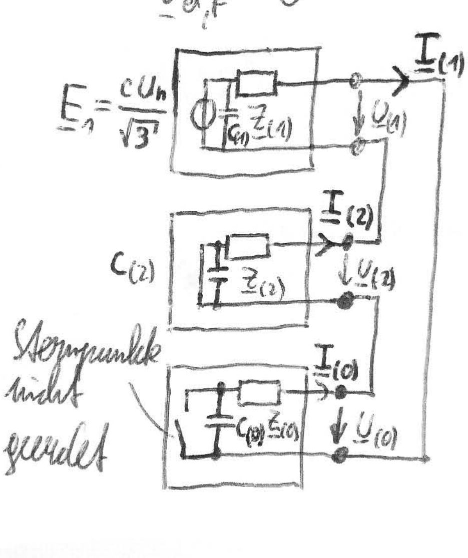
$\underline{X}''_{d(0)} = 0$ siehe Abb 4-42 $\quad C_{(0)} = C_E'\cdot l = 6\,\frac{nF}{km}\cdot 10km = 60nF$

$\underline{Z}_{(1)} = \underline{Z}_{(2)} = \underline{X}_d'' + 2\underline{Z}_T + jX'_{(1)}\cdot l = j21\Omega + j\,2\cdot 9\Omega + j\,0{,}2\,\frac{\Omega}{km}\cdot 10km = j\,41\Omega$

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

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

$\underline{U}_{(0)} + \underline{U}_{(1)} + \underline{U}_{(2)} = 0$



c) $\underline{I}_{(1)} = \frac{\underline{E}_1}{\underline{Z}_{(1)} + \underline{Z}_{(2)} + \underline{Z}_{(0)} + \frac{1}{j\omega C_{(0)}}} = \frac{1{,}1 \cdot 30\,kV}{\sqrt{3}\left(2 \cdot j\,41\,\Omega + j\,25\,\Omega + \frac{1}{j\,2\pi\,50\,Hz \cdot 60\,nF}\right)}$

Annahme $c = 1{,}1$

$\underline{I}_{(1)} = j\,359{,}1\,mA$

$\underline{I}_a = \underline{I}_{(0)} + \underline{I}_{(1)} + \underline{I}_{(2)} = 3\,\underline{I}_{(1)} = 3\,j\,359{,}1\,mA = j\,1{,}077\,A$

$I''_{k1p} = \underline{I}_a = j\,1{,}077\,A$

d) $\underline{U}_{(1)} = \underline{E}_1 - \underline{Z}_{(1)} \cdot \underline{I}_{(1)} = \underline{E}_1 \left(1 - \frac{\underline{Z}_1}{\underline{Z}_{(1)} + \underline{Z}_{(2)} + \underline{Z}_{(0)} + \frac{1}{j\omega C_{(0)}}}\right)$

$\underline{U}_{(2)} = -\underline{Z}_{(2)} \cdot \underline{I}_{(1)} = -\underline{E}_1 \frac{\underline{Z}_{(2)}}{\underline{Z}_{(1)} + \underline{Z}_{(2)} + \underline{Z}_{(0)} + \frac{1}{j\omega C_{(0)}}}$

$\underline{U}_{(0)} = -\left(\underline{Z}_{(0)} + \frac{1}{j\omega C_{(0)}}\right) \underline{I}_{(1)} = -\underline{E}_1 \frac{\underline{Z}_{(0)} + \frac{1}{j\omega C_{(0)}}}{\underline{Z}_{(1)} + \underline{Z}_{(2)} + \underline{Z}_{(0)} + \frac{1}{j\omega C_{(0)}}}$

mit $\frac{1}{j\omega C_{(0)}} \gg \underline{Z}_{(0)}, \underline{Z}_{(1)}, \underline{Z}_{(2)}$ (siehe Skriptum S. 272 u. 273)

$\underline{U}_{(1)} \approx \underline{E}_1$

$\underline{U}_{(2)} \approx 0$

$\underline{U}_{(0)} \approx -\underline{E}_1$

$\underline{U}_a = \underline{U}_{(0)} + \underline{U}_{(1)} + \underline{U}_{(2)} = 0$

$\underline{U}_b = \underline{U}_{(0)} + \underline{a}^2 \underline{U}_{(1)} + \underline{a}\,\underline{U}_{(2)} = (\underline{a}^2 - 1)\,\underline{E}_1$

$\underline{U}_c = \underline{U}_{(0)} + \underline{a}\,\underline{U}_{(1)} + \underline{a}^2 \underline{U}_{(2)} = (\underline{a} - 1)\,\underline{E}_1$

e) $j\omega 3 L_p + \frac{1}{j\omega C_{(0)}} = 0$

$X_p = \omega L_p = \frac{1}{\omega\, 3\, C_{(0)}} = \frac{1}{2\pi 50\,Hz \cdot 3 \cdot 60\,nF} = 17{,}68\,k\Omega$

f) Parallelschaltung zweier Petersenspulen: Einzelreaktanzen: $2\,X_p$
Summenreaktanz: $4\,X_p = 70{,}72\,k\Omega$

3a) Symmetrisches System

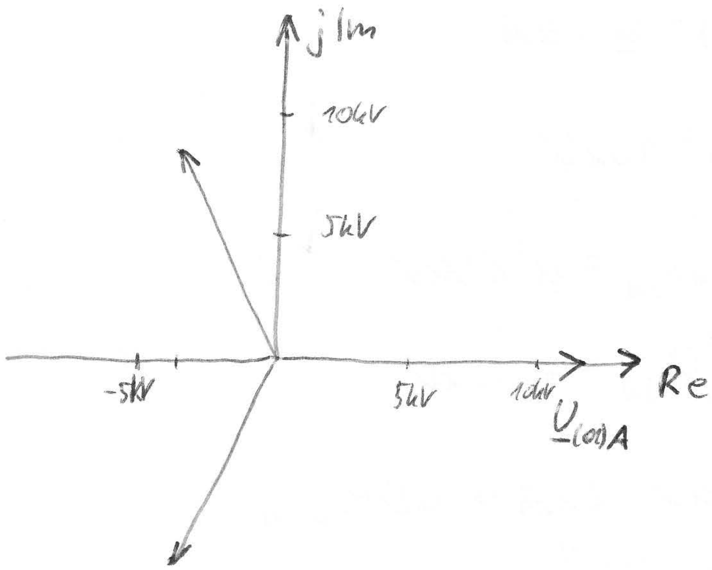
$$\Rightarrow \underline{Z}_{(0)A} = \underline{Z}_{Last} = 5\Omega$$

$$\underline{Z}_{(1)A} = \underline{Z}_{(2)A} = \underline{Z}_{Last} = 5\Omega$$

b) $$\underline{U}_{(a)A} = \underline{U}_{(0)A} + \underline{U}_{(1)A} + \underline{U}_{(2)A} = 2kV + 10kV + 1kV = 13kV$$

$$\underline{U}_{(b)A} = \underline{U}_{(0)A} + \underline{a}^2\underline{U}_{(1)A} + \underline{a}\,\underline{U}_{(2)A} = 2kV + \underline{a}^2 10kV + \underline{a}\,1kV = (-3{,}5 - j7{,}794)kV$$

$$\underline{U}_{(c)A} = \underline{U}_{(0)A} + \underline{a}\,\underline{U}_{(1)A} + \underline{a}^2\underline{U}_{(2)A} = 2kV + \underline{a}\,10kV + \underline{a}^2 1kV = (-3{,}5 + j7{,}794)kV$$



c) $$\underline{I}_a = \frac{\underline{U}_{(a)A}}{\underline{Z}_{Last}} = \frac{13kV}{5\Omega} = 2{,}6kA$$

$$\underline{I}_b = \frac{\underline{U}_{(b)A}}{\underline{Z}_{Last}} = \frac{(-3{,}5-j7{,}794)kV}{5\Omega} = (-0{,}700 - j\,1{,}559)kA$$

$$\underline{I}_c = \frac{\underline{U}_{(c)A}}{\underline{Z}_{Last}} = \frac{(-3{,}5+j7{,}794)kV}{5\Omega} = (-0{,}700 + j1{,}559)kA$$

d) $$\underline{S} = \underline{U}_{(a)A}\underline{I}_a^* + \underline{U}_{(b)A}\underline{I}_b^* + \underline{U}_{(c)A}\underline{I}_c^* =$$

$$= 13kV \cdot 2{,}6kA + (-3{,}5-j7{,}794)kV \cdot (-0{,}700+j1{,}559)kA + (-3{,}5+j7{,}794)kV \cdot (-0{,}700-j1{,}559)kA$$

$$\underline{S} = 63{,}00\,MVA$$

e) $\underline{I}_{(0)} = \frac{\underline{U}_{(0)A}}{\underline{Z}_{(0)A}} = 0\,A$

$\underline{I}_{(1)} = \frac{\underline{U}_{(1)A}}{\underline{Z}_{(1)A}} = \frac{10\,kV}{5\,\Omega} = 2\,kA$

$\underline{I}_{(2)} = \frac{\underline{U}_{(2)A}}{\underline{Z}_{(2)A}} = 0\,A$

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

$\underline{I}_b = \underline{I}_{(0)} + \underline{a}^2 \underline{I}_{(1)} + \underline{a}\,\underline{I}_{(2)} = \underline{a}^2\, 2\,kA$

$\underline{I}_c = \underline{I}_{(0)} + \underline{a}\,\underline{I}_{(1)} + \underline{a}^2 \underline{I}_{(2)} = \underline{a}\; 2\,kA$

$\underline{U}_{(a)A} = \underline{U}_{(0)A} + \underline{U}_{(1)A} + \underline{U}_{(2)A} = 10\,kV$

$\underline{U}_{(b)A} = \underline{U}_{(0)A} + \underline{a}^2 \underline{U}_{(1)A} + \underline{a}\,\underline{U}_{(2)A} = \underline{a}^2\, 10\,kV$

$\underline{U}_{(c)A} = \underline{U}_{(0)A} + \underline{a}\,\underline{U}_{(1)A} + \underline{a}^2 \underline{U}_{(2)A} = \underline{a}\; 10\,kV$

$\underline{S} = 3\, \underline{U}_{(a)A}\, \underline{I}_a^* = 3 \cdot 10\,kV \cdot 2\,kA = 60\,MVA$

5 a) $\alpha = \frac{(q-1)\cdot q^n}{q^n - 1} = \frac{(1{,}05-1)\cdot 1{,}05^{15}}{1{,}05^{15}-1} = 96{,}34 \cdot 10^{-3}\,\frac{1}{a}$

b) $k = \frac{\alpha \cdot a}{T_m}$

$T_m = \frac{\alpha \cdot a}{k} = \frac{96{,}34\cdot 10^{-3}\,\frac{1}{a} \cdot 750\,\frac{€}{kW}}{0{,}08\,\frac{€}{kWh}} = 903{,}2\,\frac{h}{a}$

c) $\beta_{-,4} = \frac{q^n - 1}{(q-1)\cdot q^n} = \frac{1{,}05^4 - 1}{(1{,}05-1)\cdot 1{,}05^4} = 3{,}546\,a$

d) $\beta_{-,11} = \frac{q^n - 1}{(q-1)\cdot q^n} = \frac{1{,}05^{11} - 1}{(1{,}05-1)\cdot 1{,}05^{11}} = 8{,}306\,a$

5e) Ertrag $E = k \cdot P \cdot T_m$

$$\frac{E}{P T_m} = k_4 = 8 \frac{ct}{kWh}$$

f) $\frac{E}{P T_m} = k_{11} = 4 \frac{ct}{kWh}$

g) $\frac{B}{P T_m} = k_4 \cdot \beta_{-,4} + k_{11} \cdot \beta_{-,11} \cdot q^{-4} = 8 \frac{ct}{kWh} \cdot 3{,}546a + 4 \frac{ct}{kWh} \cdot 8{,}306a \cdot 1{,}05^{-4}$

$= 55{,}70 \frac{ct \cdot a}{kWh}$

h) $T_m = \frac{\alpha \cdot a}{\frac{\left(\frac{B}{P T_m}\right)}{\beta_{-,15}}} = \frac{750 \frac{€}{kW}}{55{,}70 \frac{ct\,a}{kWh}} = 1{,}346 \frac{h}{a}$