1 Lastfluss- und Kurzschlussbetrachtung

Das ist jetzt erstellt worden.

a)

$$X_G = x_d \frac{U_2^2}{S_N} = 1{,}5 \frac{(0{,}4\,\mathrm{kV})^2}{400\,\mathrm{MV\,A}} = 0{,}6\,\mathrm{m\Omega} \tag{1}$$

$$R_G = 0\,\Omega \tag{2}$$

$$Z_{T1} = u_k \frac{U_2^2}{S_N} = 0{,}06 \frac{(0{,}4\,\mathrm{kV})^2}{5\,\mathrm{MV\,A}} = 1{,}92\,\mathrm{m\Omega} \tag{3}$$

$$R_{T1} = P_k \frac{U_2^2}{S_N^2} = 0{,}08\,\mathrm{MW} \frac{(0{,}4\,\mathrm{kV})^2}{(5\,\mathrm{MV\,A})^2} = 0{,}512\,\mathrm{m\Omega} \tag{4}$$

$$X_{T1} = \sqrt{Z_{T1}^2 - R_{T1}^2} = \sqrt{(1{,}92\,\mathrm{m\Omega})^2 - (0{,}512\,\mathrm{m\Omega})^2} = 1{,}85\,\mathrm{m\Omega} \tag{5}$$

$$Z_{T2} = u_k \frac{U_2^2}{S_N} = 0{,}06 \frac{(0{,}4\,\mathrm{kV})^2}{630\,\mathrm{kV\,A}} = 15{,}24\,\mathrm{m\Omega} \tag{6}$$

$$R_{T2} = P_k \frac{U_2^2}{S_N^2} = 9\,\mathrm{kW} \frac{(0{,}4\,\mathrm{kV})^2}{(630\,\mathrm{kV\,A})^2} = 3{,}628\,\mathrm{m\Omega} \tag{7}$$

$$X_{T2} = \sqrt{Z_{T2}^2 - R_{T2}^2} = \sqrt{(15{,}24\,\mathrm{m\Omega})^2 - (3{,}628\,\mathrm{m\Omega})^2} = 14{,}80\,\mathrm{m\Omega} \tag{8}$$

$$R_{L1} = R'l \left(\frac{U_2}{U_1}\right)^2 = 0{,}7\,\frac{\Omega}{\mathrm{km}} \cdot 6\,\mathrm{km} \cdot \left(\frac{0{,}4\,\mathrm{kV}}{20\,\mathrm{kV}}\right)^2 = 1{,}68\,\mathrm{m\Omega} \tag{9}$$

$$X_{L1} = X'l \left(\frac{U_2}{U_1}\right)^2 = 0{,}4\,\frac{\Omega}{\mathrm{km}} \cdot 6\,\mathrm{km} \cdot \left(\frac{0{,}4\,\mathrm{kV}}{20\,\mathrm{kV}}\right)^2 = 0{,}960\,\mathrm{m\Omega} \tag{10}$$

$$R_{L2} = R'l = 0{,}3\,\frac{\Omega}{\mathrm{km}} \cdot 4\,\mathrm{km} = 60\,\mathrm{m\Omega} \tag{11}$$

$$X_{L2} = X'l = 0{,}1\,\frac{\Omega}{\mathrm{km}} \cdot 4\,\mathrm{km} = 20\,\mathrm{m\Omega} \tag{12}$$

b)

$$\underline{Z}_{Ges,V} = (R_{T1} + R_{T2} + R_{L1} + R_{L2}) + \mathrm{j}\,(X_{T1} + X_{T2} + X_{L1} + X_{L2}) \tag{13}$$

$$= (0{,}512 + 3{,}628 + 1{,}68 + 60)\,\mathrm{m\Omega} + \mathrm{j}\,(1{,}85 + 14{,}8 + 0{,}96 + 20)\,\mathrm{m\Omega} \tag{14}$$

$$= (65{,}82 + 37{,}61)\,\mathrm{m\Omega} = 75{,}81 \cdot \mathrm{e}^{\mathrm{j}0{,}5191}\mathrm{m\Omega} \tag{15}$$

c)

$$\upsilon_p = 90^\circ - 0{,}517 \cdot \frac{180^\circ}{\pi} = 60{,}26^\circ \tag{16}$$

d)

$$X_G = x''_d \frac{U_2^2}{S_N} = 0{,}25 \frac{(400\,\mathrm{V})}{400\,\mathrm{MV\,A}} = 0{,}1\,\mathrm{m\Omega} \tag{17}$$

$$\underline{Z}_{k,Ges,V} = \underline{Z}_{Ges,V} + \mathrm{j}X_G = (65{,}82 + 37{,}71)\,\mathrm{m\Omega} \tag{18}$$

$$|\underline{Z}_{k,Ges,V}| = 75{,}86\,\mathrm{m\Omega} \tag{19}$$

$$S_k = c\frac{U_2^2}{|\underline{Z}_{k,Ges,V}|} = 1 \cdot \frac{(400\,\mathrm{V})^2}{75{,}86\,\mathrm{m\Omega}} = 2{,}109\,\mathrm{MV\,A} \tag{20}$$

e)

$$i''_{k3p} = c\frac{U_2}{\sqrt{3}Z_{k,Ges,V}} = 1{,}1 \cdot \frac{400\,\mathrm{V}}{\sqrt{3}\cdot 75{,}86\,\mathrm{m\Omega}} = 3{,}348\,\mathrm{kA} \tag{21}$$

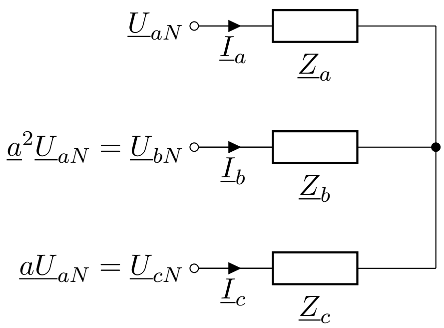
2 Drehstromkomponentensystem

a) Messschaltungen von S.49 und S.50 im Skriptum

$$\frac{\underline{I}_a}{\underline{I}_b} = \frac{\underline{Z}_b}{\underline{Z}_a} = \frac{1}{2} \tag{22}$$

$$\underline{Z}_{(0)} = \frac{\underline{U}_{(0)}}{\underline{I}_{(0)}} = \frac{\frac{1}{3}\left(\underline{U}_{aN} + \underline{U}_{bN} + \underline{U}_{cN}\right)}{\frac{1}{3}\left(\underline{I}_a + \underline{I}_b + \underline{I}_c\right)} = \frac{3U_{aN}}{\underline{I}_a\,(1+2+2)} \tag{23}$$

$$= \frac{3\left(\underline{I}_a\underline{Z}_a + \left(\underline{I}_a + \underline{I}_b + \underline{I}_c\right)\underline{Z}_N\right)}{5\underline{I}_a} = \frac{3\underline{I}_a\left(2\underline{Z}_b + 5\cdot\frac{1}{5}\underline{Z}_b\right)}{5\underline{I}_a} = \frac{9}{5}\underline{Z}_b \tag{24}$$



$$\underline{Z}_{(1)} = \frac{\underline{U}_{(1)}}{\underline{I}_{(1)}} = \frac{\frac{1}{3}\left(\underline{U}_{aN} + \underline{a}\underline{U}_{bN} + \underline{a}^2\underline{U}_{cN}\right)}{\frac{1}{3}\left(\underline{I}_a + \underline{a}\underline{I}_b + \underline{a}^2\underline{I}_c\right)} \tag{25}$$

$$\underline{U}_{aN} - \underline{Z}_a\underline{I}_a = \underline{U}_{bN} - \underline{Z}_b\underline{I}_b \tag{26}$$

$$\underline{I}_b = \frac{\underline{U}_{aN}\left(\underline{a}^2 - 1\right) + \underline{Z}_a\underline{I}_a}{\underline{Z}_b} \tag{27}$$

$$\underline{U}_{aN} - \underline{Z}_a\underline{I}_a = \underline{U}_{cN} - \underline{Z}_c\underline{I}_c \tag{28}$$

$$\underline{I}_c = \frac{\underline{U}_{aN}\left(\underline{a} - 1\right) + \underline{Z}_a\underline{I}_a}{\underline{Z}_c} \tag{29}$$

$$\underline{I}_a = -\underline{I}_b - \underline{I}_c = \frac{\underline{U}_{aN}}{\underline{Z}_b}\left(-\underline{a}^2 + 1 - \underline{a} + 1\right) - 4\underline{I}_a \tag{30}$$

$$5\underline{I}_a = 3\frac{\underline{U}_{aN}}{\underline{Z}_b} \tag{31}$$

$$\underline{I}_a = \frac{3}{5}\frac{\underline{U}_{aN}}{\underline{Z}_b} \tag{32}$$

$$\underline{Z}_{(1)} = \frac{3U_aN}{\underline{I}_a + \frac{\underline{U}_{aN}}{\underline{Z}_b}\underline{a}\left(\underline{a}^2 - 1\right) + 2\underline{a}\underline{I}_a + \frac{\underline{U}_{aN}}{\underline{Z}_b}\underline{a}^2\left(\underline{a} - 1\right) + 2\underline{a}^2\underline{I}_a} \tag{33}$$

$$= \frac{3\underline{U}_{aN}}{-\underline{I}_a + 3\frac{\underline{U}_{aN}}{\underline{Z}_b}} = \frac{3\underline{U}_{aN}}{-\frac{3}{5}\frac{\underline{U}_{aN}}{\underline{Z}_b} + 3\frac{\underline{U}_{aN}}{\underline{Z}_b}} = \frac{5}{4}\underline{Z}_b \tag{34}$$

$$\underline{Z}_{(2)} = \frac{\underline{U}_{(2)}}{\underline{I}_{(2)}} = \frac{\frac{1}{3}\left(\underline{U}_{aN} + \underline{a}^2\underline{U}_{bN} + \underline{a}\underline{U}_{cN}\right)}{\frac{1}{3}\left(\underline{I}_a + \underline{a}^2\underline{I}_b + \underline{a}\underline{I}_c\right)} = \frac{U_{aN}}{\underline{I}_a + \underline{a}^2\underline{I}_b + \underline{a}\underline{I}_c} \tag{35}$$

Wenn man $\underline{I}_b$ und $\underline{I}_c$ miteinander vertauscht, was man machen darf, weil $\underline{Z}_b = \underline{Z}_c$, dann hat man die selbe Gleichung wie für $\underline{Z}_{(1)}$, woraus folgt $\underline{Z}_{(2)} = \underline{Z}_{(1)}$.

b)

$$\underline{I}_{(0)} = \frac{1}{3}\left(kI_{ph} + \underline{a}^2 I_{ph} + \underline{a}I_{ph}\right) = \frac{1}{3}\left(k - 1\right)I_{ph} \tag{36}$$

$$\underline{I}_{(1)} = \frac{1}{3}\left(kI_{ph} + I_{ph} + I_{ph}\right) = \frac{1}{3}\left(k + 2\right)I_{ph} \tag{37}$$

$$\underline{I}_{(2)} = \frac{1}{3}\left(kI_{ph} + \underline{a}I_{ph} + \underline{a}^2 I_{ph}\right) = \frac{1}{3}\left(k - 1\right)I_{ph} \tag{38}$$

c)

$$\underline{U}_{(0)} = \underline{Z}_{(0)}\underline{I}_{(0)} = \frac{9}{5}\underline{Z}_b\frac{1}{3}\left(k - 1\right)I_ph = \frac{3}{5}\left(k - 1\right)\underline{Z}_b I_{ph} \tag{39}$$

$$\underline{U}_{(1)} = \underline{Z}_{(1)}\underline{I}_{(1)} = \frac{5}{4}\underline{Z}_b\frac{1}{3}\left(k + 2\right)I_ph = \frac{5}{12}\left(k + 2\right)\underline{Z}_b I_{ph} \tag{40}$$

$$\underline{U}_{(2)} = \underline{Z}_{(2)}\underline{I}_{(2)} = \frac{5}{4}\underline{Z}_b\frac{1}{3}\left(k - 1\right)I_ph = \frac{5}{12}\left(k - 1\right)\underline{Z}_b I_{ph} \tag{41}$$

d)

$$\underline{U}_a = \underline{U}_{(0)} + \underline{U}_{(1)} + \underline{U}_{(2)} = \left(\frac{3}{5}\left(k - 1\right) + \frac{5}{12}\left(k + 2\right) + \frac{5}{12}\left(k - 1\right)\right)\underline{Z}_b I_{ph} \tag{42}$$

$$= \left(\frac{43}{30}k - \frac{11}{60}\right)\underline{Z}_b I_{ph} \tag{43}$$

e)

$$\underline{U}_a = \left(\frac{43}{30} \cdot 0{,}619 - \frac{11}{60}\right)(15 + \mathrm{j}5)\,\Omega \cdot 13{,}05\,\mathrm{A} = (137{,}8 + \mathrm{j}45{,}93)\,\mathrm{V} \tag{44}$$

3 Pumpspeicherkraftwerk

a)

$$E = \rho V g \Delta h = 1000\,\frac{\mathrm{kg}}{\mathrm{m}^3} \cdot 0{,}6 \cdot 70 \cdot 10^6\,\mathrm{m}^3 \cdot 9{,}81\,\frac{\mathrm{m}}{\mathrm{s}^2} \cdot 150\,\mathrm{m} = 61{,}8 \cdot 10^{12}\,\mathrm{J} = 61{,}8\,\mathrm{TJ} \tag{45}$$

b)

$$P_{el} = \eta_H \eta_T \eta_{el} (1 - \varepsilon) \rho Q_N g \Delta h \tag{46}$$

$$= 0{,}94 \cdot 0{,}92 \cdot 0{,}96 \cdot (1 - 0{,}02) \cdot 1000\,\frac{\mathrm{kg}}{\mathrm{m}^3} \cdot 115\,\frac{\mathrm{m}^3}{\mathrm{s}} \cdot 9{,}81\,\frac{\mathrm{m}}{\mathrm{s}^2} \cdot 150\,\mathrm{m} = 137{,}68\,\mathrm{MW} \tag{47}$$

c)

$$t = \frac{V_{OS}\,(FS - FS_{min})}{Q_N} = \frac{70 \cdot 10^6\,\mathrm{m}^3 \cdot (0{,}6 - 0{,}4)}{115\,\frac{\mathrm{m}^3}{\mathrm{s}}} = 121{,}74 \cdot 10^3\,\mathrm{s} = 33{,}82\,\mathrm{h} \tag{48}$$

d)

$$P_{el} = \frac{\rho Q_{Pump} g \Delta h}{\eta_H \eta_P \eta_{el} (1 - \varepsilon)} = \frac{1000\,\frac{\mathrm{kg}}{\mathrm{m}^3} \cdot 115\,\frac{\mathrm{m}^3}{\mathrm{s}} \cdot 9{,}81\,\frac{\mathrm{m}}{\mathrm{s}^2} \cdot 150\,\mathrm{m}}{0{,}94 \cdot 0{,}88 \cdot 0{,}96 \cdot (1 - 0{,}02)} = 170{,}17\,\mathrm{MW} \tag{49}$$

e)

$$\eta_{Ges} = \eta_H^2 \eta_T \eta_P \eta_{el}^2 (1 - \varepsilon)^2 = 0{,}94^2 \cdot 0{,}92 \cdot 0{,}88 \cdot 0{,}96^2 \cdot (1 - 0{,}02)^2 = 0{,}6332 \tag{50}$$

f)

$$D = \sqrt{2g\Delta h}\,\frac{p}{2\pi f} = \sqrt{2 \cdot 9{,}81\,\frac{\mathrm{m}}{\mathrm{s}^2} \cdot 150\,\mathrm{m}} \cdot \frac{12}{2\pi 50\,\mathrm{Hz}} = 2{,}072\,\mathrm{m} \tag{51}$$

3 Fünf Sicherheitsregeln

Siehe Skriptum S.IX

4 Wirtschaftlichkeitsbetrachtung eines Solarkraftwerks

a)

$$T_m = \frac{E}{P} = \frac{1079\,\frac{\mathrm{GW\,h}}{\mathrm{a}}}{377\,\mathrm{MW}} = 2862{,}07\,\frac{\mathrm{h}}{\mathrm{a}} \tag{52}$$

b)

$$\beta_- = \frac{q^n - 1}{(q - 1)\,q^n} = \frac{1{,}05^{25} - 1}{(1{,}05 - 1)\,1{,}05^{25}} = 14{,}09\,\mathrm{a} \tag{53}$$

$$\alpha = \frac{1}{\beta_-} \tag{54}$$

$$K = \alpha A + Z = \frac{1}{14{,}09\,\mathrm{a}} \cdot 1600 \cdot 10^6\,\$ + 6 \cdot 10^6\,\frac{\$}{\mathrm{a}} + 2{,}2 \cdot 10^6\,\frac{\$}{\mathrm{a}} = 121{,}724 \cdot 10^6\,\frac{\$}{\mathrm{a}} \tag{55}$$

c)

$$\beta_{+} = \frac{(q^m - 1)\,q}{q-1} = \frac{\left(1{,}070^{25} - 1\right) 1{,}07}{1{,}07 - 1} = 67{,}6765 \tag{56}$$

$$B_{25} = A_{R,-m} q^m + Z\beta_{+} + Z + Z\beta_{-} + R_n q^{-n} \tag{57}$$

$$= 600 \cdot 10^6\,\$ \cdot 1{,}07^{25} + 121{,}724 \cdot 10^6\,\$ \cdot (67{,}6765 + 1) = 11{,}616 \cdot 10^9\,\$ \tag{58}$$

d)

$$p = \frac{\frac{B_{25}+G}{\beta_{+}}}{E} = \frac{\frac{11{,}616 \cdot 10^9\,\$ + 3 \cdot 10^9\,\$}{67{,}6765}}{1079 \cdot 10^6\,\mathrm{kW\,h}} = 0{,}200\,\frac{\$}{\mathrm{kW\,h}} \tag{59}$$