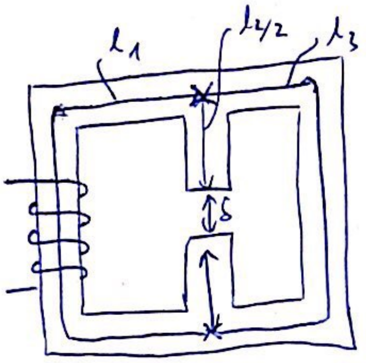
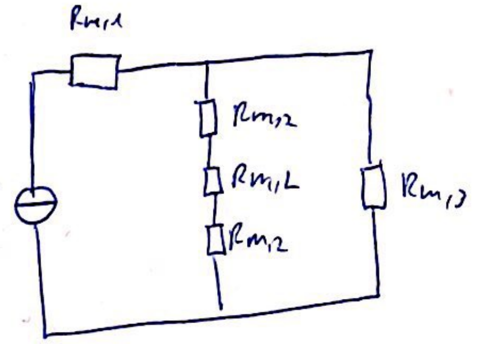
Elektroenergiesysteme – Gedächtnisprotokoll (3)

Aufgabe (1.)



Ersatzschaltbild: $NI\uparrow$



$$\hat{R}_{m,2} = 2R_{m,2} + R_{m,L} = \frac{2\frac{l_2}{2} + \delta\mu_r}{A\cdot\mu_0\mu_r}$$

$$R_{m,3} = \frac{l_3}{\mu_0\mu_r A}$$

$$R_{m,1} = \frac{l_1}{\mu_0\mu_r A}$$

$$R_{ges} = R_{m,1} + (\hat{R}_{m,2} \,\|\, R_{m,3})$$

$$R_{ges} = \frac{l_1}{\mu_0\mu_r A} + \frac{\frac{(l_2+\delta\mu_r)\, l_3}{A^2\mu_0^2\mu_r^2}}{\frac{l_2+l_3+\delta\mu_r}{A\mu_0\mu_r}}$$

$$R_{ges} = \frac{(l_2+\delta\mu_r)\,l_3}{(l_2+l_3+\delta\mu_r)\,A\mu_0\mu_r} + \frac{l_1}{\mu_0\mu_r A}$$

$$\Rightarrow R_{m,ges} = \frac{(l_2+\delta\mu_r)\,l_3\,\mu_0\mu_r A + l_1(l_2+l_3+\delta\mu_r)\,A\mu_0\mu_r}{(l_2+l_3+\delta\mu_r)\,\mu_0^2\mu_r^2 A^2}$$

$$R_{m,ges} = \frac{(l_2+\delta\mu_r)\,l_3 + l_1(l_2+l_3+\delta\mu_r)}{(l_2+l_3+\delta\mu_r)\,\mu_0\mu_r A}$$

$\Rightarrow \Phi = B\cdot A$ & $\Phi_1 \cdot R_{m,ges} = -N\cdot i \to \Phi = -N\cdot i / R_{ges}$

$$\to B = \frac{\Phi}{A} = -\frac{N\cdot i}{R_{m,ges}\cdot A} = \cancel{N\cdot i\,(l_2+\delta\mu_r)\,l_3 + l_1(l_2+l_3+\delta\mu_r)}$$

$$B = -\frac{(l_2+l_3+\delta\mu_r)\,\mu_0\mu_r}{(l_2+\delta\mu_r)\,l_3 + l_1(l_2+l_3+\delta\mu_r)}\cdot N\cdot i$$

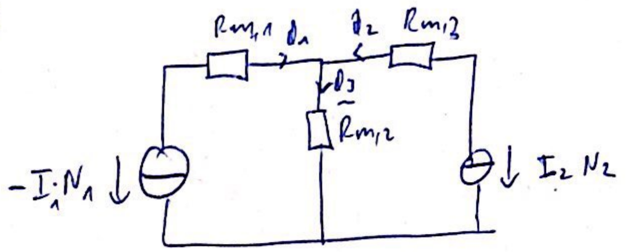
Scanned with CamScanner

b) mit $N \frac{d\Phi}{dt} = L \frac{di}{dt} \Rightarrow$

$$N \cdot \frac{d\Phi}{dt} = N \cdot \frac{d}{dt} \frac{N \cdot i(t)}{R_{ges}} = N \cdot \frac{N}{R_{ges}} \cdot \frac{di(t)}{dt} = \frac{N^2}{R_{m,ges}} \frac{di(t)}{dt} \overset{!}{=} L \frac{di(t)}{dt}$$

$$\Rightarrow L = \frac{N^2}{R_{m,ges}} = N^2 \cdot \frac{(l_2+l_3+\delta\mu_r)\,\mu_0\mu_r A}{(l_2+\delta\mu_r)\,l_3 + l_1(l_2+l_3+\delta\mu_r)}$$

c)



gewollt i_2, sodass $\Phi_1 = 0$

$$\Phi_3 = \Phi_1 + \Phi_2 \overset{\Phi_1 \overset{!}{=} 0}{\Longleftrightarrow} \boxed{\Phi_2 = \Phi_3}$$

$$\Rightarrow M_1: \; -I_1 N_1 = R_{m,1}\Phi_1 + \Phi_3 \cdot \tilde{R}_{m,2} = \Phi_3 \tilde{R}_{m,2} = \Phi_2 \cdot \tilde{R}_{m,2}$$

$$I_2 N_2 = R_{m,3}\Phi_2 + \Phi_3 \cdot \tilde{R}_{m,2} = \Phi_2 (R_{m,3} + \tilde{R}_{m,2})$$

mit $\Phi_2 = -\frac{I_1 N_1}{\tilde{R}_{m,2}}$ & $\Phi_2 = \frac{I_2 N_2}{\tilde{R}_{m,2} + R_{m,3}}$

$$\Rightarrow -\frac{I_1 N_1}{\tilde{R}_{m,2}} = \frac{I_2 N_2}{\tilde{R}_{m,2} + R_{m,3}} \Rightarrow i_2(t) = -\frac{\tilde{R}_{m,2} + R_{m,3}}{\tilde{R}_{m,2}} \cdot \frac{N_1}{N_2} i_1(t)$$

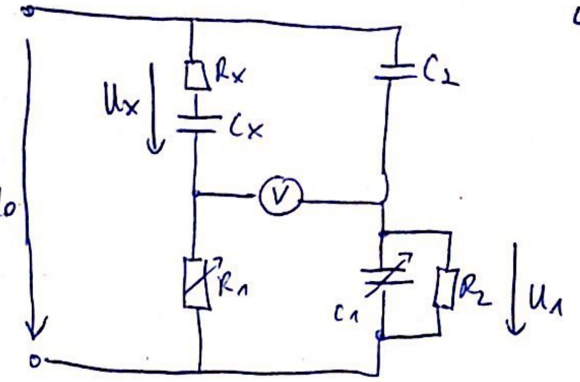
$$\rightsquigarrow \tilde{R}_{m,2} + R_{m,3} = \frac{l_2 + \delta\mu_r}{\mu_0\mu_r A} + \frac{l_3}{\mu_0\mu_r A} = \frac{l_2 + l_3 + \mu_r\delta}{\mu_0\mu_r A}$$

$$\Rightarrow -\frac{\tilde{R}_{m,2} + R_{m,3}}{R_{m,3}} = -\frac{l_2 + l_3 + \mu_r\delta}{l_3}$$

$$\Rightarrow \boxed{i_2(t) = -\frac{l_2 + l_3 + \mu_r\delta}{l_3} \frac{N_1}{N_2} i_1(t)}$$

Elektroenergiesysteme – Gedächtnisprotokoll ③

Aufgabe ②



a) → hoher Innenwiderstand:

$$\rightarrow U_x = \frac{R_x + \frac{1}{j\omega C_x}}{R_x + R_1 + \frac{1}{j\omega C_x}} U_0 = \frac{1 + j\omega C_x R_x}{1 + j\omega C_x (R_x + R_1)} U_0$$

$$\rightarrow \boxed{U_1 = \frac{Z}{Z + \frac{1}{j\omega C_2}} \cdot U_0}$$

mit $Z = \frac{R_2 \cdot \frac{1}{j\omega C_1}}{R_2 + \frac{1}{j\omega C_1}} = \frac{R_2}{1 + j\omega C_1 R_2}$

$$\Rightarrow U_1 = \frac{\frac{R_2}{1 + j\omega C_1 R_2}}{\frac{R_2}{1 + j\omega C_1 R_2} + \frac{1}{j\omega C_2}} U_0 = \frac{R_2}{R_2 + \frac{1 + j\omega C_1 R_2}{j\omega C_2}} U_0 = \frac{j\omega C_2 R_2}{j\omega C_2 R_2 + 1 + j\omega C_1 R_2} U_0$$

$$\boxed{U_1 = \frac{j\omega C_2 R_2}{1 + j\omega R_2 (C_1 + C_2)} U_0}$$

b) $U_1 \stackrel{!}{=} U_x$ wie lauten C_x & R_x

$$\rightarrow \frac{j\omega C_2 R_2}{1 + j\omega R_2 (C_1 + C_2)} = \frac{1 + j\omega C_x R_x}{1 + j\omega C_x (R_x + R_1)}$$

$$\rightarrow j\omega C_2 R_2 (1 + j\omega C_x (R_x + R_1)) = (1 + j\omega C_x R_x)(1 + j\omega R_2 (C_1 + C_2))$$

$$\rightarrow j\omega C_2 R_2 - \omega^2 C_2 R_2 C_x (R_x + R_1) = 1 - \omega^2 C_x R_x R_2 (C_1 + C_2) + j\omega C_x R_x + j\omega R_2 (C_1 + C_2)$$

(I) $-\omega^2 C_2 R_2 C_x (R_x + R_1) = 1 - \omega^2 C_x R_x R_2 (C_1 + C_2)$

(II) $\omega C_2 R_2 = \omega C_x R_x + \omega R_2 (C_1 + C_2)$

aus (II) $C_x = \frac{\omega C_2 R_2 - \omega R_2 (C_1 + C_2)}{\omega R_x} = \frac{R_2 (C_2 - C_1 - C_2)}{R_x} = -C_1 \frac{R_2}{R_x}$

wie kann das negativ sein

$$\Rightarrow \text{in (I)} \quad +\omega^2 C_2 R_2 \cdot \frac{R_2}{R_x} C_1 (R_x + R_1) = 1 + \omega^2 R_2^2 C_1 (C_1 + C_2)$$

$$\Rightarrow \omega^2 C_2 R_2^2 C_1 R_x + \omega^2 C_2 R_2^2 C_1 R_1 = R_x + \omega^2 R_2 C_1 (C_1 + C_2) R_x$$

$$\Rightarrow R_x \left[\omega^2 C_2 R_2^2 C_1 - \omega^2 R_2 C_1 (C_1 + C_2) - 1\right] = -\omega^2 C_2 R_2^2 C_1 R_1$$

$$R_x = \frac{\omega^2 C_2 R_2^2 C_1 R_1}{\omega^2 C_2 R_2^2 C_1 - \omega^2 R_2 C_1 (C_1 + C_2) - 1}$$

Scanned with CamScanner

somit $C_x = -C_1 R_2 \cdot \dfrac{\omega^2 C_2 R_2^2 C_1 - \omega^2 R_2 C_1 (C_1+C_2) - 1}{\omega^2 C_2 R_2^2 C_1 R_1}$

$$C_x = \frac{\omega^2 R_2 C_1 [C_1 + C_2] + 1 - \omega^2 C_2 R_2^2 C_1}{\omega^2 C_2 R_2 R_1}$$

$$u_0(t) = \begin{cases} u_0 & 0 \leq t < \frac{T}{2} \\ -u_0 & \frac{T}{2} \leq t < T \end{cases}$$

$$\rightarrow U_0(p) = \int_0^\infty u_0(t) e^{-pt} dt = \int_0^{\frac{T}{2}} U_0 e^{-pt} dt - \int_{\frac{T}{2}}^{T} u_0 e^{-pt} dT$$

$$u_0(p) = \left[-\frac{u_0}{p} e^{-pt} \right]_0^{T/2} + \left[\frac{u_0}{p} e^{-pt} \right]_{T/2}^{T}$$

$$= -\frac{u_0}{p} e^{-p\frac{T}{2}} + \frac{u_0}{p} + \frac{u_0}{p} e^{-pT} - \frac{u_0}{p} e^{-p\frac{T}{2}}$$

$$= \frac{u_0}{p} \left[1 - 2e^{-p\frac{T}{2}} + e^{-pT} \right]$$

d) $G(p) = \dfrac{k_1}{\beta p + \gamma} = \hat{u}_1$ Ansteuerung mit $u_0(p)$

$$u_1(p) = G(p) \cdot u_0(p) = \frac{k_1}{\beta p + \gamma} \frac{u_0}{p} \left[1 - 2e^{-p\frac{T}{2}} + e^{-pT} \right]$$

$$U_1(p) = \frac{k_1 u_0}{p(\beta p + \gamma)} - \frac{2k_1 u_0}{p(\beta p + \gamma)} e^{-p\frac{T}{2}} + \frac{k_1 u_0}{p(\beta p + \gamma)} e^{-pT}$$

$$U_1(p) = \frac{k_1 u_0}{\beta} \frac{1}{p(p + \frac{\gamma}{\beta})} - \frac{2k_1 u_0}{\beta} \frac{1}{p(p + \frac{\gamma}{\beta})} e^{-p\frac{T}{2}} + \frac{k_1 u_0}{\beta} \frac{1}{p(p + \frac{\gamma}{\beta})} e^{-pT}$$

$$u_1(t) = \frac{k_1 u_0}{\beta} \frac{e^{-\frac{\gamma}{\beta}t} - 1}{\frac{\gamma}{\beta}} - \frac{2k_1 u_0}{\beta} \frac{e^{-\frac{\gamma}{\beta}(t - T/2)} - 1}{\frac{\gamma}{\beta}} + \frac{k_1 u_0}{\beta} \frac{e^{-\frac{\gamma}{\beta}(t-T)} - 1}{\frac{\gamma}{\beta}}$$

$$U_1(t) = \frac{k_1 u_0}{\gamma} e^{-\frac{\gamma}{\beta}t} - \frac{2k_1 u_0}{\gamma} e^{-\frac{\gamma}{\beta}(t - \frac{T}{2})} + \frac{k_1 u_0}{\gamma} e^{-\frac{\gamma}{\beta}(t-T)} \quad //$$

Scanned with CamScanner

Elektroenergiesysteme - Gedächtnisprotokoll (3.)

zu Nr. (2.)

e) wollt nun periodisch → wie ging das nochmal?

f.: Durch seine Impulsantwort, also durch Anregung mit einem idealen Puls;

d.h. einem Diracstoß.

Aufgabe (3.)

I_R & U_{RM} sollen in Phase sein. , da U_{RM} die Phase 0° aufweist,

muss I_R rein reell sein (wie U_{RM})

da N & M nicht verbunden: $I_R + I_S + I_T \overset{!}{=} 0 \rightarrow I_S = -I_R - I_T$ & $U_{NM} = U_{SM}$

$$I_T = \frac{U_{TM}}{\frac{1}{j\omega L}} = j\omega L U_{TM} \qquad I_R = \frac{U_{RM}}{R_R + j\omega L_R}$$

$$I_S = -j\omega L U_{TM} - \frac{1}{R_R + j\omega L_R} U_{RM} = \left(-j\omega L \cdot U_Y e^{-j\frac{4\pi}{3}} - \frac{1}{R_R + j\omega L_R} \cdot U_Y \cdot e^{j0}\right) e^{j\omega t}$$

$\rightarrow I_S =$ ↯

$$I_R = \frac{U_{RM} - U_{NM}}{Z_R} = \frac{U_{RM} - U_{SM}}{Z_R} = \frac{U_Y\left(1 - e^{-j\frac{2\pi}{3}}\right) e^{j\omega t}}{R_R + j\omega L_R}$$

$$I_R = \frac{U_Y\left(1 - \left(-\frac{1}{2} + \frac{\sqrt{3}}{2} j\right)\right)\left[\cos(\omega t) + j\sin(\omega t)\right]\left[R_R - j\omega L_R\right]}{R_R^2 + (\omega L)^2}$$

$\mathrm{Im}\{I_R\} \overset{!}{=} 0$ $\qquad I_R = \frac{U_Y}{R_R^2 + (\omega L)^2}\left(1{,}5 + \frac{\sqrt{3}}{2} j\right)\left[\cos(\omega t) R_R - j\omega L_R \cos(\omega t) + j R_R \sin(\omega t) + \omega L_R \sin(\omega t)\right]$

Scanned with CamScanner

$\cancel{I_R = (1{,}5 + \frac{\sqrt{3}}{2} j)\,(\cos(\omega t) R_R + \omega L_R \sin(\omega t)) + j\,[R_R \sin(\omega t) - \omega L_R \cos(\omega t)]) \cdot \frac{U_Y}{R_R^2 + (\omega L)^2}}$

~~I_R~~ Damit $\underline{I}_R$ in Phase zu $\underline{U}_{RM}$ muss gelten:

$$\sphericalangle(\underline{I}_R) = \sphericalangle(I_R \cdot e^{j\omega t}) = \sphericalangle(\underline{U}_{RM}) = \sphericalangle(U_{RM} \cdot e^{j\omega t})$$

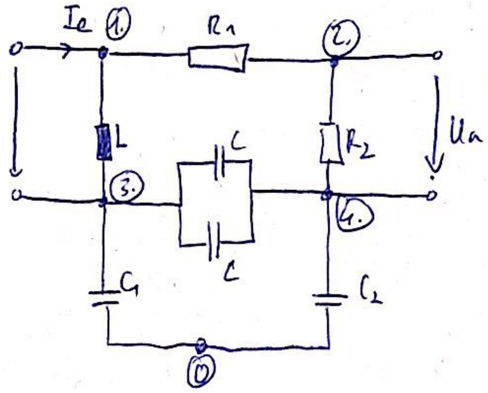
$$\rightarrow \underline{I}_R = \frac{U_{RM} - U_{SM}}{R_R + j\omega L_R} = \frac{U_Y\,(1 - e^{-j\frac{2\pi}{3}})}{R_R + j\omega L_R} = U_Y \cdot \frac{(1 - e^{-j\,2\pi/3})(R_R - j\omega L_R)}{R_R^2 + (\omega L_R)^2}$$

$$\underline{I}_R = \frac{U_Y}{R_R^2 + (\omega L_R)^2}\,(1{,}5 - \frac{\sqrt{3}}{2} j)\,(R_R + j\omega L_R)$$

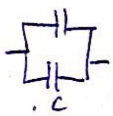
$\cancel{\mathrm{Im}\{\underline{I}_R\}}$ $\mathrm{Im}\{\underline{I}_R\} \overset{!}{=} 0 \rightarrow 0 = -\frac{\sqrt{3}}{2} R_R + 1{,}5\,\omega L_R$

$$\rightarrow \frac{\sqrt{3}}{2} R_R = 1{,}5\,\omega L_R \rightarrow \boxed{R_R \overset{!}{=} \sqrt{3}\,\omega L_R}$$

b)



$U_1(p)$	$U_2(p)$	$U_3(p)$	$U_4(p)$	=
$-(\frac{1}{pL} + \frac{1}{R_1})$	$\frac{1}{R_1}$	$\frac{1}{pL}$	0	$-\dot{I}_e(p)$
$\frac{1}{R_1}$	$-(\frac{1}{R_1} + \frac{1}{R_2})$	0	$\frac{1}{R_2}$	0
$\frac{1}{pL}$	0	$-(\frac{1}{pL} + (\frac{1}{2pC})^{-1} + \frac{1}{pC_1})$	$(\frac{1}{2pC})^{-1}$	0
0	$\frac{1}{R_2}$	$(\frac{1}{2pC})^{-1}$	$-(\frac{1}{R_2} + (\frac{1}{2pC})^{-1} + \frac{1}{pC_2})$	0

mit  $\hat{=}\ Z$

$$Z = \frac{\frac{1}{(pC)^2}}{\frac{2}{pC}} = \frac{1}{2pC}$$

c) Verwenden der Cramerschen Regel:

$$\frac{U_a(p)}{U_e(p)} = \frac{U_2(p) - U_4(p)}{U_1(p) - U_3(p)} = \frac{\det(U_2) - \det(U_4)}{\det(U_1) - \det(U_3)}$$

Scanned with CamScanner

Elektroenergiesysteme - Gedächtnisprotokolle (3.)

Zur Nummer (3)

d)

$I_1(p)$	$I_2(p)$	
$pL+R_2+\frac{1}{pC}$	$-\frac{1}{pC}$	$U_e(p)$
$-\frac{1}{pC}$	$\frac{1}{pC}+pL+R_2$	0

$$U_a(p) = I_2(p)\, R_2 = \frac{\det I_2}{\det I} R_2$$

$$\Rightarrow F(p) = \frac{U_a(p)}{U_e(p)} = \frac{I_2(p)\, R_2}{U_e(p)} = \frac{\det(I_2)\, R_2}{\det I \cdot U_e(p)}$$

$$\det(I_2) = \begin{vmatrix} pL+R_2+\frac{1}{pC} & U_e(p) \\ -\frac{1}{pC} & 0 \end{vmatrix} = \frac{U_e(p)}{pC}$$

$(\frac{1}{pC}+pL+R_2)(\frac{1}{pC}+pL+R_2)$

$$\det(I_0) = \begin{vmatrix} pL+R_2+\frac{1}{pC} & -\frac{1}{pC} \\ -\frac{1}{pC} & \frac{1}{pC}+pL+R_2 \end{vmatrix} = \left(\frac{1}{pC}+pL+R_2\right)^2 - \frac{1}{p^2C^2}$$

$$= \frac{1}{p^2C^2} + \frac{L}{C} + \frac{R_2}{pC} + \frac{L}{C} + p^2L^2 + pLR_2 + \frac{R_2}{pC} + pLR_2 + R_2^2 - \frac{1}{p^2C^2}$$

$$= p^2L^2 + p(2LR_2) + \left(\frac{2L}{C} + R_2^2\right) + \frac{1}{p}\left(2\frac{R_2}{C}\right).$$

$$\Rightarrow F(p) = \frac{\frac{U_e(p)}{pC} \cdot R_2}{U_e(p)\left[p^2L^2 + p(2LR_2) + \left(\frac{2L}{C}+R_2^2\right) + \frac{1}{p}\left(2\cdot\frac{R_2}{C}\right)\right]}$$

$$F(p) = \frac{R_2}{p^3L^2C + p^2\, 2LR_2C + p\left[2L + CR_2^2\right] + 2R_2}$$

$\rightsquigarrow A = R_2 \quad B = L^2C \quad C = 2LR_2 \quad D = 2L + CR_2^2 \quad E = 2R_2$

e)
$$|F(j\omega)| = \left|\frac{R_2}{-j\omega^3L^2C - \omega^2\, 2LR_2 + j\omega\left[2L + CR_2^2\right] + 2R_2}\right|$$

$$= \left|\frac{R_2}{2R_2 - \omega^2 2LR_2 + j\omega\left[2L + CR_2^2 - \omega^2L^2C\right]}\right|$$

$$= \frac{R_2}{\sqrt{(2R_2 - \omega^2 2LR_2)^2 + \omega^2\left[2L + CR_2^2 - \omega^2L^2C\right]^2}}$$

Scanned with CamScanner

$$|F(j\omega)| = \frac{R_2}{\sqrt{(2R_2 - 2\omega^2 L R_2^2)^2 + \omega^2[2L + CR_2^2 - \omega^2 L^2 C]^2}}$$

$$F\left(j\frac{1}{\sqrt{LC}}\right) = \frac{R_2}{\sqrt{(2R_2 - \frac{2}{LC} L R_2^2)^2 + \frac{1}{LC}[2L + CR_2^2 - \frac{1}{LC} L^2 C]^2}}$$

$$= \frac{R_2}{\sqrt{(2R_2 - \frac{2R_2^2}{C})^2 + \left[\frac{2}{LC} + \frac{R_2^2}{CL^2} - \frac{1}{LC^2}\right]^2}} \qquad \frac{c^2 L^2}{c^2 \cdot L^2}$$

$$= \frac{R_2 C^2 L^2}{\sqrt{(2C^2 R_2 L^2 - 2R_2^2 L^2 C)^2 + [2LC + R_2 C - L]^2}}$$ vereinfacht sich nicht??

$$\arg\{F(j\omega)\} = -\tan^{-1}\left(\frac{\omega[2L + CR_2^2 - \omega^2 L^2 C]}{2R_2 - \omega^2 \cdot 2 \cdot L \cdot R_2}\right)$$

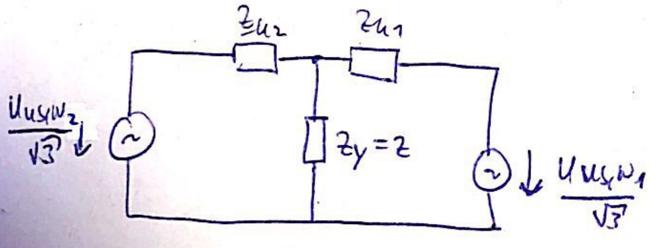
Aufgabe 4.

b) $Z_{k_1} = u_{k_1} \cdot \frac{U_{US1}^2}{S_{N_1}} = 21{,}62\, m\Omega$

$Z_{k_2} = u_{k_2} \cdot \frac{U_{US2}^2}{S_{N_2}} = 19{,}13\, m\Omega$

a) → Verbraucher in Sternschaltung umwandeln → $Z_\Delta = 3 Z_Y$ → $Z_Y = \frac{1}{3} Z_\Delta = Z$

Ersatzschaltbild (laut Skript Seite 197) (einphasig)



Elektroenergiesysteme – Ergebnisprotokoll (3.)

zu Nummer (4.)

c) $$\underline{I}_A = \frac{\ddot{\underline{u}}_2 - \ddot{\underline{u}}_1}{\underline{Z}_{u1} + \underline{Z}_{u2}^{*}} \cdot \frac{U_G}{\sqrt{3}}$$

$$\ddot{u}_2 = \frac{U_{OS,2}}{U_{US,2}} e^{j\,11 \cdot 30°} = \frac{270}{0{,}4} \cdot e^{j\,330°}$$

$$\ddot{u}_1 = \frac{U_{OS,1}}{U_{US,1}} e^{j\,2 \cdot 30°} = \frac{270}{0{,}4} \cdot e^{j\,60°}$$

$$I_A = \frac{\frac{270}{0{,}4}\left(e^{j330°} - e^{j60°}\right)}{21{,}62\,m\Omega + 14{,}13\,m\Omega} \cdot \frac{100\,kV}{\sqrt{3}} = (350 - j1306)\,kA$$

?