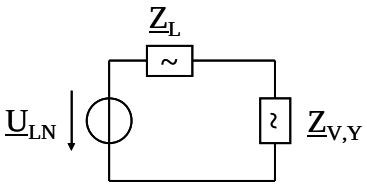
Lösung zur Klausur „Elektrische Energiesysteme“ vom 26.07.2010

Aufgabe 1

a)



$$\underline{Z}_{VY} = \frac{\underline{Z}_V}{3} = (3{,}33 + j1{,}67)\,\Omega$$

b)

$$\underline{I}_L = \frac{\underline{U}_{LN}}{\underline{Z}_L + \underline{Z}_{VY}} = \frac{400\ \text{V}}{(0{,}2 + j0{,}1 + 3{,}33 + j1{,}67)\,\Omega} = 101\ \text{A} \cdot e^{-j26{,}57°}$$

$$U_{VY} = I_L \cdot Z_{V,Y} = 101\ \text{A} \cdot \sqrt{3{,}33^2 + 1{,}67^2}\ \Omega = 377{,}3\ \text{V}$$

$$U_V = U_{V,Y} \cdot \sqrt{3} = 377{,}3\ \text{V} \cdot \sqrt{3} = 653{,}5\ \text{V}$$

$$I_V = \frac{I_L}{\sqrt{3}} = \frac{101\ \text{A}}{\sqrt{3}} = 58{,}3\ \text{A}$$

c)

$$I_C = U_{LN} \cdot \omega \cdot C = 400\ \text{V} \cdot 100\pi\ \text{s}^{-1} \cdot 10^{-4}\ \text{F} = 12{,}56\ \text{A}$$

$$I_{Vb} = \Im\{\underline{I}_L\} = 101\ \text{A} \cdot \sin 26{,}57° = 45{,}2\ \text{A}$$

oder

$$I_{Vb} = \Im\{\underline{I}_L\} = \Im\left\{\frac{\underline{U}_{LN}}{\underline{Z}_{VY}}\right\} = \Im\left\{\frac{400\ \text{V}}{(10/3 + j5/3)\Omega}\right\} = -\frac{400 \cdot 5/3}{(10/3)^2 + (5/3)^2}\ \text{A} = -48\ \text{A}$$

$\frac{I_{Vb}}{I_C} = 3{,}6$ bzw. $3{,}8 \Rightarrow$ 3 Kondensatoren

d)

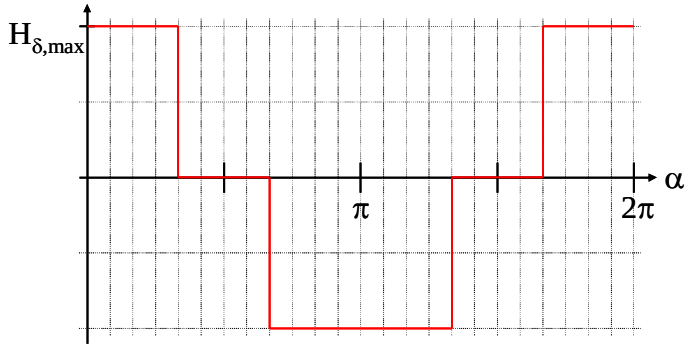
$$U_2' = \ddot{u} \cdot U_2 = \frac{w_1}{w_2} \cdot U_2$$

$$R_2' = \ddot{u}^2 \cdot R_2 = \left(\frac{w_1}{w_2}\right)^2 \cdot R_2$$

$$\underline{I}_g = \frac{1}{3} \cdot \left(\underline{a}^0 \cdot \underline{I}_1 + \underline{a}^2 \cdot \underline{I}_2 + \underline{a}^1 \cdot \underline{I}_3\right)$$

Aufgabe 2

a)



b)

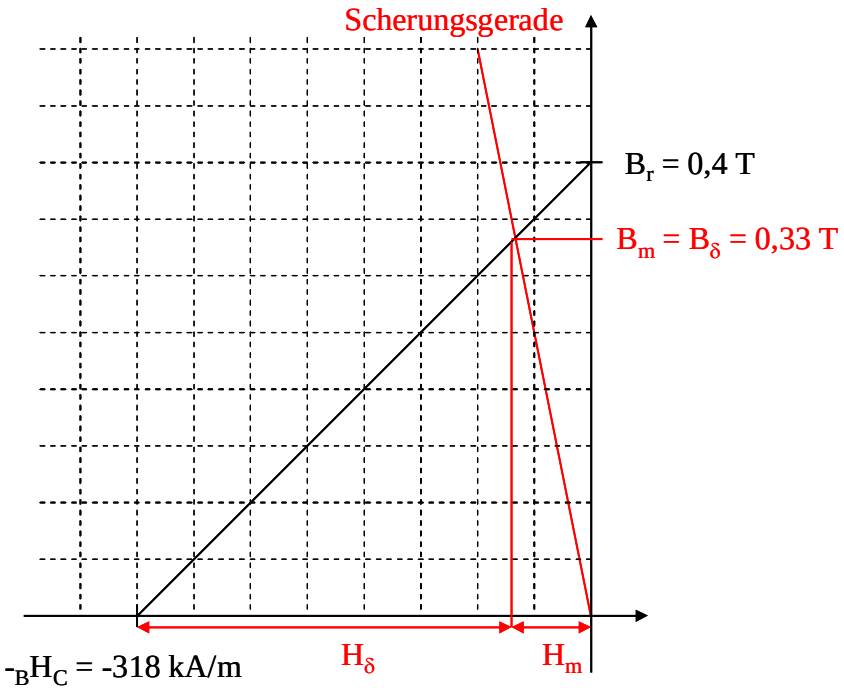


Diagramm mit optionaler graphischer Ermittlung

$$B_\delta = B_m = \frac{\mu_{rm} \cdot \delta}{h_m} \cdot B_r = 0{,}33\,\mathrm{T}$$

$$H_\delta = \frac{B_\delta}{\mu_0} = \frac{0{,}33\,\mathrm{T} \cdot \mathrm{Am}}{4\pi \cdot 10^{-7}\,\mathrm{Vs}} = 265\,\frac{\mathrm{kA}}{\mathrm{m}}$$

c)

$$n_0 = \frac{U_{aN}}{k\Phi} = 120\,\mathrm{s}^{-1} = 7200\,\mathrm{min}^{-1}$$

$$I_K = \frac{U_{aN}}{R_a} = \frac{12\,\mathrm{V}}{20\,\mathrm{m\Omega}} = 600\,\mathrm{A}$$

$$M_{iN} = \frac{k\phi}{2\pi} \cdot I_{aN} = 1{,}59\ \text{Nm}$$

d)

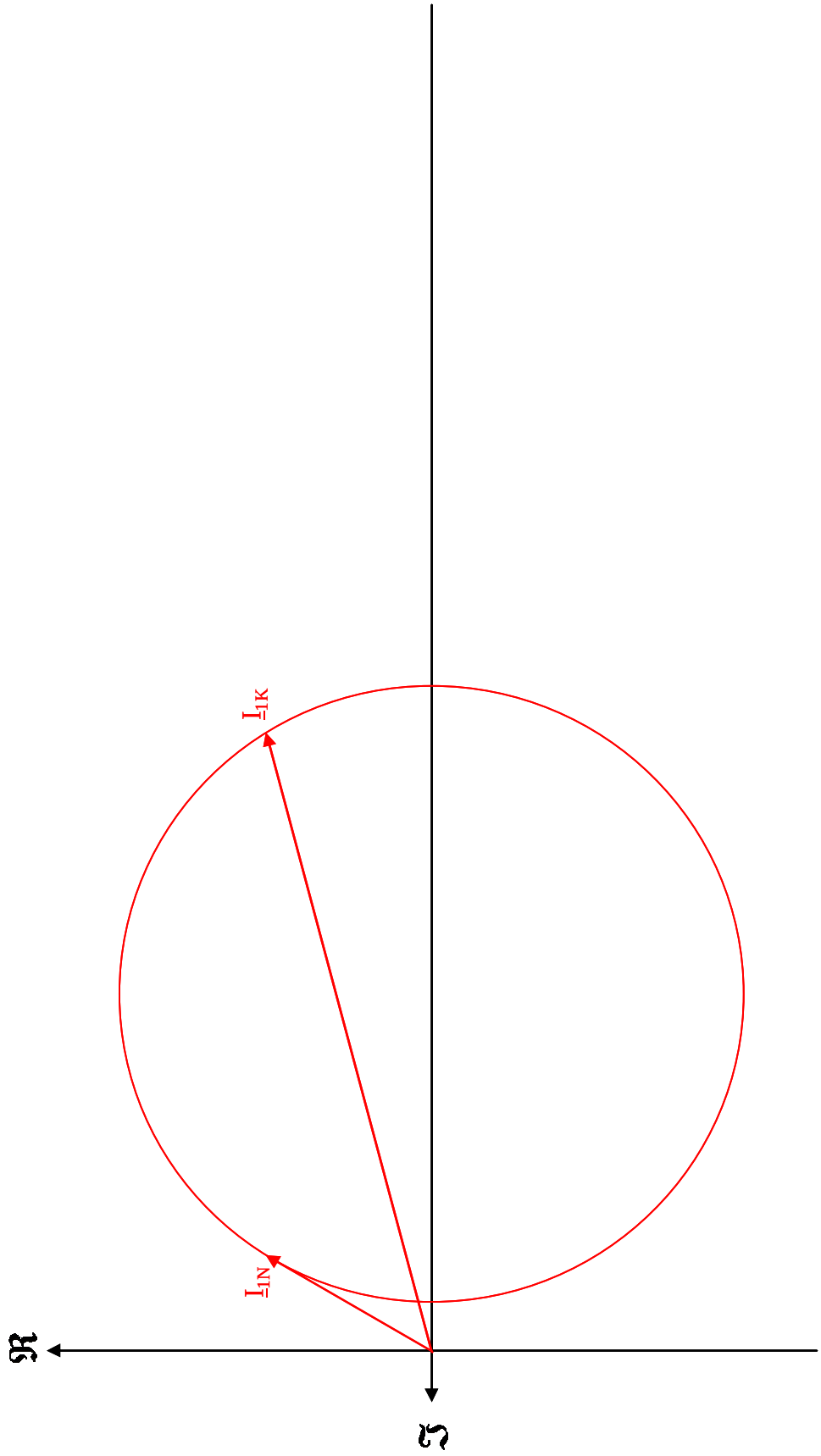
$$I_a = \frac{2\pi M_{id}}{k\phi} = 62{,}8\ \text{A}$$

$$U_a = U_i + R_a \cdot I_a = k\Phi \cdot n + R_a \cdot I_a = 0{,}1\ \text{Vs} \cdot \frac{5000\ \text{min}^{-1}}{60\ \text{s min}^{-1}} + 20\ \text{m}\Omega \cdot 62{,}8\ \text{A} = 9{,}59\ \text{V}$$

Vorwiderstand, Verstellung der Spannung über Netzgerät, Tiefsetzsteller o. ä.

Aufgabe 3:

a)



b)

I_{Kipp} = 37 A
(abgelesen)

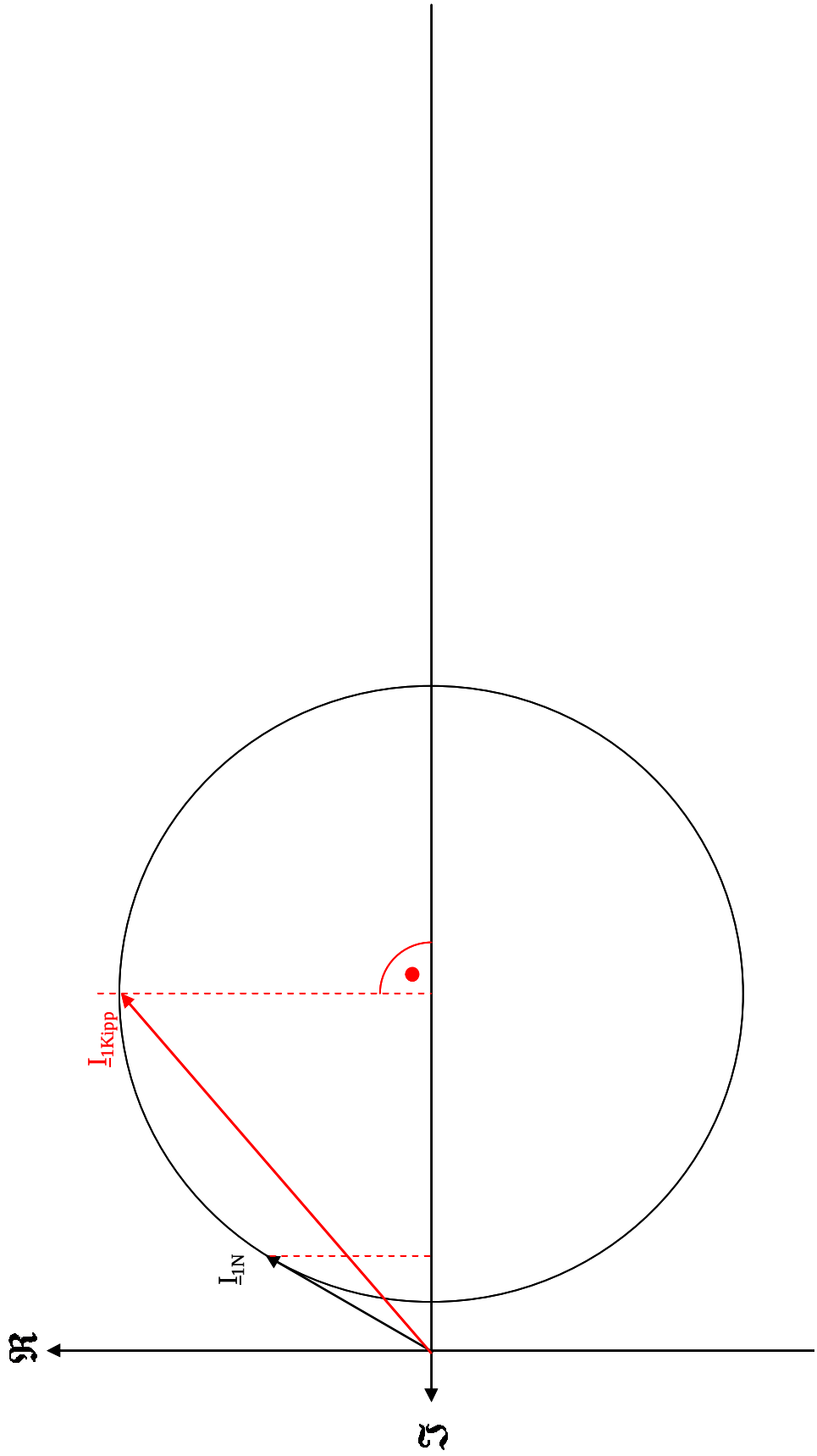
I_{WN}

= 2,5 cm·5 A/cm
= 12,5 A,

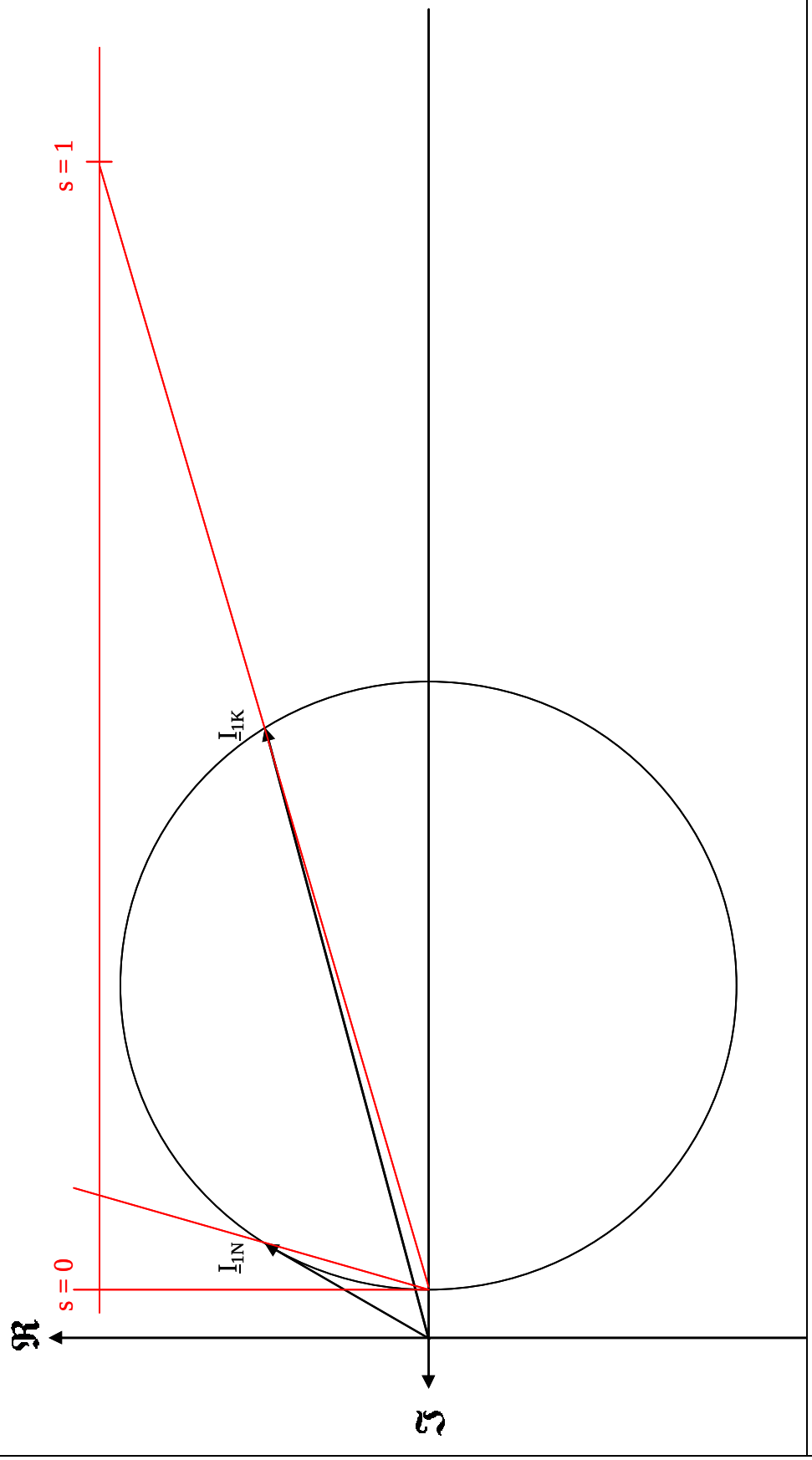
I_{WKipp}

= 4,9 cm·5 A/cm
= 24,5 A

M_{Kipp}/M_N
= 4,9 cm/2,5 cm
= 1,96



c), d)



$$s_N = \frac{s_N}{s_K} = \frac{1{,}55\,\text{cm}}{17{,}8\,\text{cm}} = 0{,}087$$

$$n_N = (1 - s_N) \cdot \frac{f_N}{p} = (1 - 0{,}087) \cdot \frac{50\,\text{Hz}}{2} = 22{,}8\,\text{Hz} = 1370\,\text{min}^{-1}$$

alternative rechnerische Lösung:

$$\left|\underline{I}_N - jI_M\right| = \left|\underline{I}_K - jI_M\right|$$

$$I_M = \frac{I_N^2 - I_K^2}{2\cdot\left(I_N\cdot\sin\left|\varphi_N\right| - I_K\cdot\sin\left|\varphi_K\right|\right)} = \frac{15^2 - 50^2}{2\cdot\left(15\cdot\sin 30° - 50\cdot\sin 75°\right)}\,\text{A} = 27{,}88\,\text{A}$$

$$I_{WKipp} = \left|\underline{I}_N - \underline{I}_M\right| = \left|15\cdot\cos 30° - j15\cdot\sin 30° + j27{,}88\right|\,\text{A} = 24{,}17\,\text{A}$$

$$I_0 = I_M - I_{WKipp} = 27{,}88\,\text{A} - 24{,}17\,\text{A} = 3{,}71\,\text{A}$$

$$I_{1Kipp} = \sqrt{I_{WKipp}^2 + I_M^2} = 36{,}90\,\text{A}$$

$$\frac{M_{Kipp}}{M_N} = \frac{I_{WKipp}}{I_N\cdot\cos\varphi_N} = \frac{24{,}17\,\text{A}}{15\,\text{A}\cdot\cos 30°} = 1{,}861$$

$$\frac{M_{Kipp}}{M_K} = \frac{I_{WKipp}}{I_K\cdot\cos\varphi_K} = \frac{24{,}17\,\text{A}}{50\,\text{A}\cdot\cos 75°} = 1{,}877$$

$$\frac{M_K}{M_{Kipp}} = \frac{2}{s_{Kipp} + \frac{1}{s_{Kipp}}}$$

$$\Rightarrow s_{Kipp}^2 - \frac{2\cdot M_{Kipp}}{M_K}s_{Kipp} + 1 = 0$$

$$\Rightarrow s_{Kipp} = \frac{M_{Kipp}}{M_K} - \sqrt{\left(\frac{M_{Kipp}}{M_K}\right)^2 - 1} = 1{,}877 - \sqrt{1{,}877^2 - 1} = 0{,}2886$$

$$\frac{M_N}{M_{Kipp}} = \frac{2}{\frac{s_{Kipp}}{s_N} + \frac{s_N}{s_{Kipp}}}$$

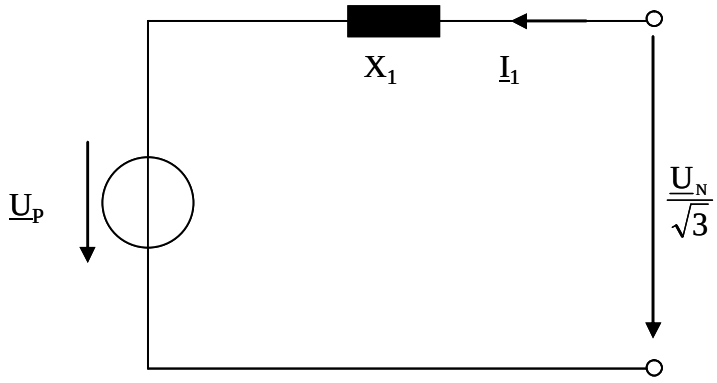
$$\Rightarrow s_{Kipp}^2 - 2\cdot s_N\cdot s_{Kipp}\cdot\frac{M_{Kipp}}{M_N} + s_N^2 = 0$$

$$\Rightarrow s_N = \left(\frac{M_{Kipp}}{M_N} - \sqrt{\left(\frac{M_{Kipp}}{M_N}\right)^2 - 1}\right)\cdot s_{Kipp} = 0{,}0841$$

$$n_N = \left(1 - s_N\right)\cdot\frac{f_N}{p} = \left(1 - 0{,}0841\right)\cdot\frac{50\,\text{Hz}}{2} = 22{,}90\,\text{Hz} = 1374\,\text{min}^{-1}$$

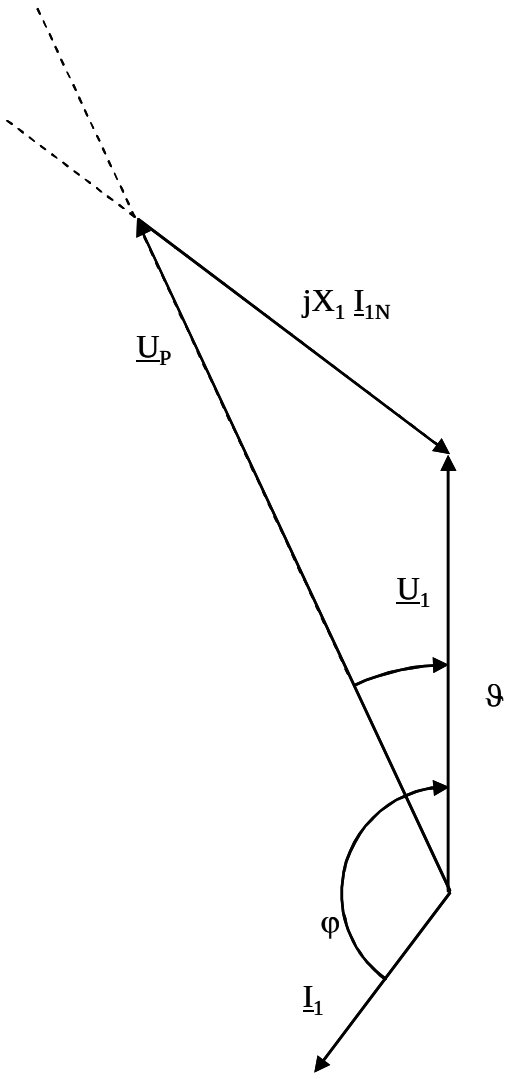
Aufgabe 4:

a)



$$\underline{I}_N = \frac{S_N}{U_N \cdot \sqrt{3}} \cdot e^{-j\arccos(\cos\varphi_N)} = \frac{250\,\text{kVA}}{5\,\text{kV} \cdot \sqrt{3}} \cdot e^{j\arccos(-0,8)} = 28{,}9\,\text{A} \cdot e^{j143°} = 28{,}9\,\text{A} \cdot e^{j2,49\,\text{rad}}$$

b)



Konstruktion:

Auftragen von $\underline{U}_1$ (in reeller Achse) und $\underline{I}_1$

senkrecht zu $\underline{I}_1$ Gerade durch Endpunkt $\underline{U}_1$ eintragen

Gerade durch Ursprung mit Phasenwinkel ϑ

Schnittpunkt der Geraden ergibt $\underline{U}_P$ und $jX_1\underline{I}_{1N}$

Ablesen liefert:

$U_P = 9{,}8\ \text{cm} \cdot 500\ \text{V/cm} = 4{,}9\ \text{kV}$

$X_1 I_{1N} = 5{,}2\ \text{cm} \cdot 500\ \text{V/cm} = 2{,}6\ \text{kV}$

$X_1 = 2{,}6\ \text{kV} / 29{,}8\ \text{A} = 87{,}2\ \Omega$

alternative rechnerische Lösung mit Sinus-Satz:

$\angle(jX_1\underline{I}_{1N},\underline{U}_1) = 180°-(\varphi-90°) = 126{,}87°$

$\angle(jX_1\underline{I}_{1N},\underline{U}_P) = 180°-126{,}87°-25°=28{,}13°$

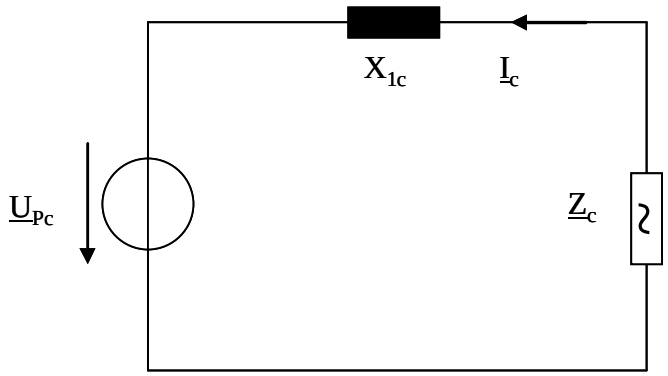
$$\frac{U_1}{\sin\angle(X_1\underline{I}_1,\underline{U}_P)} = \frac{U_P}{\sin\angle(X_1\underline{I}_1,\underline{U}_1)} = \frac{X_1 I_1}{|\vartheta|}$$

$$U_P = \frac{U_1\cdot\sin\angle(X_1\underline{I}_1,\underline{U}_1)}{\sin\angle(X_1\underline{I}_1,\underline{U}_P)} = \frac{5\text{ kV}\cdot\sin 126{,}87°}{\sqrt{3}\cdot\sin 28{,}13°} = 4{,}898\text{ kV}$$

$$X_1 I_1 = \frac{U_1\cdot|\sin\vartheta|}{\sin\angle(X_1\underline{I}_1,\underline{U}_P)} = \frac{5\text{ kV}\cdot\sin 25°}{\sqrt{3}\cdot\sin 28{,}13°} = 2{,}588\text{ kV}$$

$$X_1 = \frac{X_1 I_1\cdot\sqrt{3}\cdot U_N}{S_N} = \frac{2{,}588\text{ kV}\cdot\sqrt{3}\cdot 5\text{ kV}}{250\text{ kVA}} = 89{,}7\,\Omega$$

c)



$$I_c = \frac{U_{Pc}}{|jX_1+\underline{Z}_c|} = \frac{8\text{ kV}}{\sqrt{450^2+(150+450)^2}\,\Omega} = 10{,}67\text{ A}$$

$$P_c = 3\cdot I_c^2\cdot\Re\{\underline{Z}_c\} = 3\cdot(10{,}67\text{ A})^2\cdot 450\,\Omega = 153{,}6\text{ kW}$$

d)

Schenkelpolmaschine

Massenträgheit der Generatoren

Schutzklasse II oder doppelte Isolation oder Schutzisolation