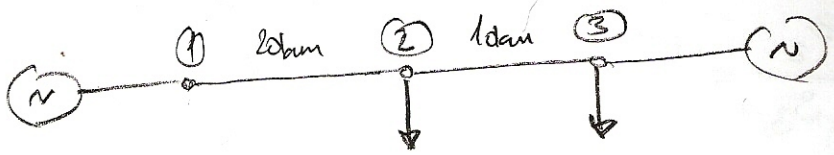
Řešení: 25. 5. '08.

1. ① – ref. uzlové místo

$U_n = 110\,kV$

$X_1 = 0.41\,\Omega/km$



$S_{teret_2} = 155\,MW$

$S_{teret_3} = 20\,MW$

$P_{gen_3} = 50\,MW$

$S_B = 100\,MW$

$X_1 = 0.41\,\Omega/km$

$X_{1-2} = X_1 \cdot l_{1-2} = 0.41\,\Omega/km \cdot 20\,km = j8.2\,\Omega$

$X_{2-3} = X_1 \cdot l_{2-3} = 0.41\,\Omega/km \cdot 10\,km = j4.1\,\Omega$

$$X_{1-2\,p.u.} = X_{1-2} \cdot \frac{S_B}{U_n^2} = j8.2 \cdot \frac{100}{110^2} = j0.067768\ p.u.$$

$$X_{2-3\,p.u.} = X_{2-3} \cdot \frac{S_B}{U_n^2} = j4.1 \cdot \frac{100}{110^2} = j0.033884\ p.u.$$

$$Y_{1-2} = \frac{1}{X_{1-2}} = \frac{1}{j0.067768} = -j14.75623\ p.u.$$

$$Y_{2-3} = \frac{1}{X_{2-3}} = \frac{1}{j0.033884} = -j29.51245\ p.u.$$

$$[Y] = \begin{bmatrix} Y_{12} & -Y_{12} & 0 \\ -Y_{12} & Y_{12}+Y_{23} & -Y_{23} \\ 0 & -Y_{23} & Y_{23} \end{bmatrix} = \begin{bmatrix} -j14.75623 & j14.75623 & 0 \\ j14.75623 & -j14.75623 + (-j29.51245) & j29.51245 \\ 0 & j29.51245 & -j29.51245 \end{bmatrix}$$

$$[Y] = \begin{bmatrix} -j44.26868 & j29.51245 \\ j29.51245 & -j29.51245 \end{bmatrix} \Rightarrow [Z] = [Y]^{-1}$$

$$[Z] = [Y]^{-1} = \begin{bmatrix} j0.067768 & j0.067768 \\ j0.067768 & j0.101652 \end{bmatrix}; \quad [B]^{-1} = [Z]$$

$$[P] = [B] \cdot [\delta] \Rightarrow [\delta] = [B]^{-1} \cdot [P] = [Z] \cdot [P]$$

$$\begin{bmatrix} \delta_2 \\ \delta_3 \end{bmatrix} = [Z] \cdot \begin{bmatrix} P_2 \\ P_3 \end{bmatrix} = [Z] \cdot \begin{bmatrix} -1.5 \\ 0.3 \end{bmatrix} = \begin{bmatrix} -j0.05471 \\ -j0.074545 \end{bmatrix} \Rightarrow$$

$P_2 = -155\ MW$

$P_2 = \frac{P_2}{S_B} = \frac{-155}{100} = -1.55\ p.u.$

$P_3 = P_{gen3} + P_{terh3} = 50 - 20 = 30$

$P_3 = \frac{P_3}{S_B} = \frac{30}{100} = 0.3\ p.u.$

$\Rightarrow \boxed{\delta_1 = \emptyset\ 1} ; \boxed{\delta_2 = -j0.084711} ; \boxed{\delta_3 = -j0.074545} ;$

$P_{1-2} = \frac{\delta_1 - \delta_2}{X_{1-2}} = (\delta_1 - \delta_2) \cdot Y_{1-2} = (0 - (-j0.084711)) \cdot (-j14.75625) = 1.25\ p.u.$

$P_{1-2} = P_{1-2\,p.u.} \cdot S_B = \underline{125\ MW}$

$P_{2-3} = \frac{\delta_2 - \delta_3}{X_{2-3}} = (\delta_2 - \delta_3) \cdot Y_{2-3} = (-j0.084711 + j0.074545) \cdot (-j29.51245)$

$P_{2-3} = -0.3\ p.u$

$P_{2-3} = P_{2-3\,p.u.} \cdot S_B = \underline{-30\ MW}$

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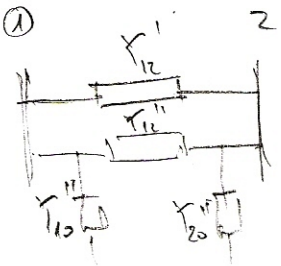
[2] PH. $\rightarrow$ $I_2 = \emptyset$

a) $U_2 = ?$ c) $S'_{1-2}, S''_{1-2}, S'_{2-1}, S''_{2-1}$

b) $S_1 = ?$ b) $\Delta S', \Delta S''$



$U_1 = 231 + j0\ kV$

T1: $S_n = 100\ MVA$

$P_{cu} = P_k = 150\ kW$

$u_k = 10\%$

$a = 220/110$

T2: $S_n = 100\ MVA$

$P_{cu} = P_k = 100\ kW$

$u_k = 7\%$

$a = 231/110$

P: $S_B = 100\ MVA$

$a_1 = \frac{\frac{U_{1str}}{U_{1mr}}}{\frac{U_{2str}}{U_{2mr}}} = \frac{\frac{220}{220}}{\frac{110}{110}} = 1$; $a_2 = \frac{\frac{U_{1str}}{U_{2str}}}{\frac{U_{1mr}}{U_{2mr}}} = \frac{\frac{231}{110}}{\frac{220}{110}} = \frac{\frac{231}{220}}{\frac{110}{110}} = 1.05$

$= \frac{U_{n1}}{S_n} \cdot \left[\frac{P_k}{S_n} + j\sqrt{U_k^2 - \left(\frac{P_k}{S_n}\right)^2} \right]$; $Z_{T_{p.u.}} = Z_T \cdot \frac{S_B}{U_{n1}^2}$; $Y_T = \frac{1}{Z_T}$

$$Z_{T_{p.u.}} = \frac{U_{n1}^2}{S_n} \cdot \left[\frac{P_k}{S_n} + j\sqrt{U_k^2 - \left(\frac{P_k}{S_n}\right)^2} \right] \cdot \frac{S_B}{U_{n1}^2} = \frac{S_B}{S_n} \cdot \left[\frac{P_k}{S_n} + j\sqrt{U_k^2 - \left(\frac{P_k}{S_n}\right)^2} \right]$$

$$Z_{T_1} = \frac{100}{100} \cdot \left[\frac{150 \cdot 10^3}{100 \cdot 10^6} + j\sqrt{0.1^2 - \left(\frac{150 \cdot 10^3}{100 \cdot 10^6}\right)^2} \right] = 0.0015 + j0.0999887 \text{ p.u.}$$

$$Y_{T_1} = \frac{1}{Z_{T_1}} = 0.15 - j9.998875 \text{ p.u.}$$

$$Z_{T_2} = \frac{100}{100} \cdot \left[\frac{100 \cdot 10^3}{100 \cdot 10^6} + j\sqrt{0.07^2 - \left(\frac{100 \cdot 10^3}{100 \cdot 10^6}\right)^2} \right] = 0.001 + j0.0699986$$

$$Y_{T_2} = \frac{1}{Z_{T_2}} = 0.204081 - j14.284256 \text{ p.u.}$$

T1: $Y'_{12} = \frac{Y_{T_1}}{a_1} = 0.15 - j9.998875$ p.u.

$Y'_{10} = \frac{Y_{T_1}}{a_1} \cdot \left(\frac{1}{a_1} - 1\right) = \emptyset$; $Y'_{20} = Y_{T_1} \cdot \left(1 - \frac{1}{a_1}\right) = \emptyset$

T2: $Y''_{12} = \frac{Y_{T_2}}{a_2} = \frac{0.204081 - j14.284256}{1.05} = 0.19436345 - j13.604054$

$Y''_{10} = \frac{Y_{T_2}}{a_2} \cdot \left(\frac{1}{a_2} - 1\right) = Y''_{12} \cdot \left(\frac{1}{a_2} - 1\right) = (0.19436345 - j13.604054) \cdot \left(\frac{1}{1.05} - 1\right)$

$$Y''_{10} = -0.0092554 + j0.647812 \text{ p.u.}$$

$Y''_{20} = Y_{T_2} \cdot \left(1 - \frac{1}{a_2}\right) = (0.204081 - j14.284256) \cdot \left(1 - \frac{1}{1.05}\right)$

$$Y''_{20} = 0.009971814 - j0.6802026 \text{ p.u.}$$

$$Y = \begin{bmatrix} Y'_{12} + Y''_{12} + Y''_{10} & -(Y'_{12} + Y''_{12}) \\ -(Y'_{12} + Y''_{12}) & Y'_{12} + Y''_{12} + Y''_{20} \end{bmatrix}$$

$$Y = \begin{bmatrix} 0.335108 - j22.95512 & -0.344364 + j23.60293 \\ -0.344364 + j23.60293 & 0.354082 - j24.28313 \end{bmatrix}$$

$$[I] = [Y] \cdot [U]$$

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = [Y] \cdot \begin{bmatrix} U_1 \\ U_2 \end{bmatrix} \Rightarrow \begin{bmatrix} I_1 \\ \emptyset \end{bmatrix} = [Y] \cdot \begin{bmatrix} U_1 \\ U_2 \end{bmatrix}$$

P.H. $\Rightarrow I_2 = \emptyset$

$$I_1 = Y_{11} \cdot U_1 + Y_{12} \cdot U_2$$
$$0 = Y_{21} \cdot U_1 + Y_{22} \cdot U_2$$

$$U_1 = 231 \angle 0$$

$$U_{1p.u} = \frac{U_1}{U_{1n}} = \frac{231}{220} = 1.05 \text{ p.u.}$$

$$-Y_{21} \cdot U_1 = Y_{22} \cdot U_2 \Rightarrow U_2 = -\frac{Y_{21}}{Y_{22}} \cdot U_1$$

$$U_2 = -\frac{-0.344364 + j23.60293}{0.335082 - j24.28313} \cdot 1.05 = \underline{1.020588 + j0.000008657 \text{ p.u.}}$$

$$\boxed{U_2 = 112.265 + j0.0009523 \text{ kV}} \quad |U_2| = 1.020588$$

$$I_1 = (0.335108 - j22.95512) \cdot 1.05 + (-0.344364 + j23.60293) \cdot U_2$$

$$\boxed{I_1 = 0.0002053 - j0.0140126 \text{ p.u.}}$$

$$S_1 = U_1 \cdot I_1^* = 1.05 \cdot (0.0002053 + j0.0140126) =$$

$$\boxed{S_1 = 0.00021557 + j0.0147125 \text{ p.u.}}$$

$$\boxed{S_1 = 0.021557 + j1.47125 \text{ MVA}}$$

$$S_{i-j} = U_i \cdot [(U_i - U_j) \cdot Y_{i-j} + U_i \cdot Y_{i-0}]^* = U_i \cdot (U_i^* - U_j^*) \cdot Y_{i-j}^* + |U_i|^2 \cdot Y_{i0}^*$$

$$S_{j-i} = U_j \cdot [(U_j - U_i) \cdot Y_{i-j} + U_j \cdot Y_{j0}]^* = U_j \cdot (U_j^* - U_i^*) \cdot Y_{i-j}^* + |U_j|^2 \cdot Y_{j0}^*$$

$$S'_{1-2} = U_1 \cdot (U_1^* - U_2^*) \cdot Y_{12}'^* + |U_1|^2 \cdot Y_{10}'^* = 1.05 \cdot (1.05 - (1.020588 - j0.000008657)) \cdot (0.15 + j9.998875) + 1.05^2 \cdot 0 = \underline{0.0045415 + j0.3087926 \text{ p.u.}}$$

$$S'_{2-1} = U_2 \cdot (U_2^* - U_1^*) \cdot Y_{12}'^* + |U_2|^2 \cdot Y_{20}'^* = (1.020588 + j0.000008657) \cdot (1.020588 - j0.000008657) - 1.05) \cdot (0.15 + j9.998875) + 1.0206^2 \cdot 0$$

$$\boxed{S'_{2-1} = -0.00441742 - j0.300143 \text{ p.u.}}$$

$S_{1-2}'' = U_1 \cdot (U_1^* - U_2^*) \cdot Y_{12}''^* + |U_1|^2 \cdot Y_{10}''^* = 1.05 \cdot (1.05 - (1.020588 - j0.000008657)) \cdot$
$\cdot (0.1943634 5 + j13.604054) + 1.05^2 \cdot (-0.002554 - j0.647812)$

$S_{1-2}'' = -0.0043253 - j0.294083$ p.u.

$S_{2-1}'' = U_2 \cdot (U_2^* - U_1^*) \cdot Y_{12}''^* + |U_2|^2 \cdot Y_{20}''^* = (1.020588 + j0.000008657) \cdot ((1.020588 -$
$- j0.000008657) - 1.05) \cdot (0.1943634 5 + j13.604054) + 1.0206^2 \cdot (0.0097181 4 +$
$+ j0.6802026) = 0.0044119 + j0.3001537$ p.u.

-gubici:

$\Delta S' = S_{1-2}' + S_{2-1}' = 0.00012976 + j0.00865$ p.u.

$\Delta S'' = S_{1-2}'' + S_{2-1}'' = 0.0000866 + j0.006071$ p.u.

$\Delta S' = 0.012976 + j0.865$ MVA

$\Delta S'' = 0.00866 + j0.6071$ MVA

$S_{1-2}' = 0.45415 + j30.8793$ MVA

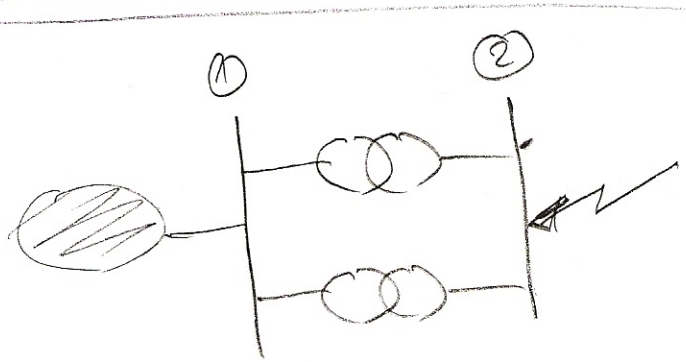
$S_{2-1}' = -0.441174 - j30.0143$ MVA

$S_{1-2}'' = -0.43253 - j29.4083$ MVA

$S_{2-1}'' = 0.44119 + j30.01537$ MVA

$S_1 = S_{1-2}' + S_{1-2}'' = 0.02162 + j1.471$ MVA

3. $S_n = 40$ MVA
$U_{n1} = 110$ kV
$U_{n2} = 10$ kV
$u_k = 10\%$
$X_m = j24.2\ \Omega$ na 110 kV-strani



$S_B = 40$ MVA

P. H. → mreža

$I_{kz} = ?$

$I_{mreže} = ?$

$U_{1p.u.}^z = \frac{U_1}{U_{1n}} = \frac{110}{110} = 1$ p.u. ; $U_{2p.u.}^z = \frac{U_2}{U_{2n}} = \frac{10}{10} = 1$

$$Z_T = \frac{U_n^2}{S_n}\left[\frac{P_k}{S_n} + j\sqrt{u_k^2 - \left(\frac{P_k}{S_n}\right)^2}\right] = \frac{U_n^2}{S_n}\cdot j\frac{u_k}{100} = j\frac{u_k}{100}\cdot\frac{U_n^2}{S_n}$$

$$Z_{T\,p.u.} = Z_T\cdot\frac{S_B}{U_n^2} = j\frac{u_k}{100}\cdot\frac{U_n^2}{S_n}\cdot\frac{S_B}{U_n^2} = j\frac{u_k}{100}\cdot\frac{S_B}{S_n}\;;\quad \boxed{S_B = S_n}$$

$$\boxed{Z_{T\,p.u.} = j\frac{u_k}{100}\ [\text{p.u.}]} \qquad \boxed{Y_{T\,p.u.} = \frac{1}{Z_{T\,p.u.}}} \qquad Y_T = -j\frac{1}{u_k}$$

$$Z_{T_1} = Z_{T_2} = j\frac{u_k}{100}\cdot\frac{S_B}{S_n} = j\frac{10}{100}\cdot\frac{40}{40} = j0.1\ \text{p.u.}$$

$$\boxed{Y_{T_1} = Y_{T_2} = -j10\ \text{p.u.} = Y_T}$$

$$X_m = 24.2\,\Omega \Rightarrow X_{m\,p.u.} = X_m\cdot\frac{S_B}{U_n^2} = j24.2\cdot\frac{40}{110^2} = j0.08\ \text{p.u.}$$

$$Y_m = \frac{1}{X_m} = \frac{1}{j0.08} = -j12.5\ \text{p.u.} \qquad \boxed{Y_m = -j12.5\ \text{p.u.}}$$

$$Y = \begin{bmatrix} Y_m + Y_{T_1} + Y_{T_2} & -(Y_{T_1} + Y_{T_2}) \\ -(Y_{T_1} + Y_{T_2}) & Y_{T_1} + Y_{T_2} \end{bmatrix} = \begin{bmatrix} Y_m + 2Y_T & -2Y_T \\ -2Y_T & 2Y_T \end{bmatrix}$$

$$Y = \begin{bmatrix} -j12.5 + 2\cdot(-j10) & -2\cdot(-j10) \\ -2\cdot(-j10) & 2\cdot(-j10) \end{bmatrix} = \begin{bmatrix} -j32.5 & +j20 \\ +j20 & -j20 \end{bmatrix} \Rightarrow [Z] = [Y]^{-1}$$

$$\begin{bmatrix} U_1^B \\ U_2^B \end{bmatrix} = \begin{bmatrix} U_1^Z \\ U_2^Z \end{bmatrix} + [Z]\cdot\begin{bmatrix} 0 \\ I_m \end{bmatrix} \qquad [Z] = \begin{vmatrix} j0.08 & j0.08 \\ j0.08 & j0.13 \end{vmatrix}$$

K.S. u čvorišču ② $\Rightarrow U_2^B = 0$

$$\begin{bmatrix} U_1^B \\ 0 \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \end{bmatrix} + [Z]\cdot\begin{bmatrix} 0 \\ I_m \end{bmatrix} \qquad 0 = U_2^Z + Z_{22}\cdot I_m$$

$$0 = 1 + Z_{mm}\cdot I_m = 1 + Z_{22}\cdot I_m \Rightarrow \boxed{I_m = -\frac{1}{Z_{22}} = -\frac{1}{j0.13}}$$

$$\boxed{I_m = j7.69231\ \text{p.u.}}$$

$$I_{ks}[A] = I_m\cdot\frac{S_B}{\sqrt{3}\cdot U_n} = j7.69231\cdot\frac{40\,MVA}{\sqrt{3}\cdot 10\,kV} = j17764{,}63\ A$$

$$I_{ks}[A] = -j17763{,}63\ A = -j17{,}764\ kA$$

$= U_1^2 + Z_{12} \cdot I_m = 1 + j0.08 \cdot j7.69231 = 1 - 0.6154 = 0.38462$ p.u.

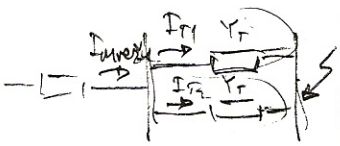
$U_1^B = 42.3076$ kV

$$I_{1-2} = \frac{U_1^B - U_2^B}{X_{1-2}} = \frac{0.38462 - 0}{j0.1} = -j3.8462 \text{ p.u.}$$ (struja grane T1)

$$I_{1-2} = I_{12\,p.u.} \cdot \frac{S_B}{\sqrt{3} \cdot U_n} = -j3.8462 \cdot \frac{40\,MVA}{\sqrt{3} \cdot 110\,kV} = 807,5\,A$$

$I_{mreže} = 2 \cdot I_{1-2} = 1614.985$ A

$I_{mreže} = 1614.985$ A ✓



$I_{mreže} = I_{T1} + I_{T2}$

$I_{mreže} = 2\,I_{T1}$

Rok: 6. 9. '08

1. $U_n = 110$ kV ; $S_B = 100$ MVA

$R_1 = 0.12\,\Omega/km$

$X_1 = 0.41\,\Omega/km$

$B_1 = 0.0028$ mS/km

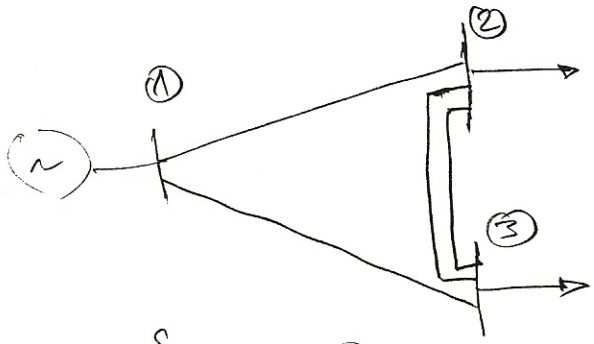
$l = 20$ km

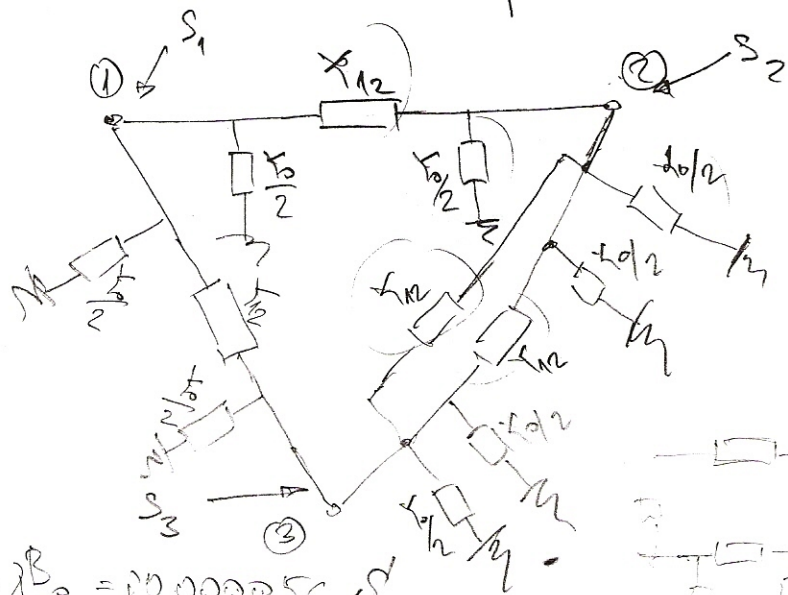
- naponi čvorišta:

$U_1 = 110 \angle 0°$ kV

$U_2 = 108.758 \angle -1.95°$ kV

$U_3 = 109.059 \angle -1.99°$ kV





[Y], S_1, S_2, S_3, $\sum S = ?$

$R = R_1 \cdot l = 2.4\,\Omega$

$X = X_1 \cdot l = 8.2\,\Omega$

$B = B_1 \cdot l = 0.000056$ S

$Z_V = R + jX = 2.4 + j8.2\,\Omega$

$Y_V = \frac{1}{Z_V} = \frac{1}{2.4 + j8.2} = Y_{12}$

$Y_0 = jB_0 = j0.000056$ S

$\frac{Y_0}{2} = \frac{jB_0}{2} = j0.000028$ S

$$Z_{V\,p.u.} = Z_V \cdot \frac{S_B}{U_n^2} = (2.4 + j8.2) \cdot \frac{100}{110^2} = 0.01983 + j0.06776 \text{ p.u.}$$

$$Y_{V\,p.u.} = \frac{1}{Z_{V\,p.u.}} = 3.9781 - j13.5918 \text{ p.u.} = Y_{12\,p.u.}$$

$$\left(\frac{Y_0}{2}\right)_{p.u.} = \frac{Y_0}{2} \cdot \frac{U_n^2}{S_B} = j0.000028 \cdot \frac{110^2}{100} = j0.003388 \text{ p.u.}$$

$$[Y] = \begin{bmatrix} Y_{12}+Y_{12}+\frac{Y_b}{2}+\frac{Y_b}{2} & -Y_{12} & -Y_{12} \\ -Y_{12} & Y_{12}+Y_{12}+Y_{12}+\frac{Y_b}{2}+\frac{Y_b}{2}+\frac{Y_b}{2} & -Y_{12}-Y_{12} \\ -Y_{12} & -Y_{12}-Y_{12} & Y_{12}+Y_{12}+Y_{12}+\frac{Y_b}{2}+\frac{Y_b}{2}+\frac{Y_b}{2} \end{bmatrix}$$

$$[Y] = \begin{bmatrix} 2Y_{12}+Y_b & -Y_{12} & -Y_{12} \\ -Y_{12} & 3Y_{12}+\frac{3}{2}Y_b & -2Y_{12} \\ -Y_{12} & -2Y_{12} & 3Y_{12}+\frac{3}{2}Y_b \end{bmatrix}$$

$$[Y] = \begin{bmatrix} 7.9562 - j27.1768 & -3.9781 + j13.5918 & -3.9781 + j13.5918 \\ -3.9781 + j13.5918 & 11.9343 - j40.7652 & -7.9562 + j27.1836 \\ -3.9781 + j13.5918 & -7.9562 + j27.1836 & 11.9343 - j40.7652 \end{bmatrix}$$

$$[I] = [Y] \cdot [U]$$

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = [Y] \cdot \begin{bmatrix} U_1 \\ U_2 \\ U_3 \end{bmatrix}$$

$U_1 = 110 + j0$ kV

$U_2 = 108.695 - j3.7007$ kV

$U_3 = 108.993 - j3.7871$ kV

$$a = \frac{|Z|}{\sqrt{1+(\operatorname{tg}\varphi)^2}} \qquad b = a \cdot \operatorname{tg}\varphi$$

$$U_{1p.u.} = \frac{U_1}{U_n} = \frac{110+j0}{110} = 1+j0 \text{ p.u.}$$

$$U_{2p.u.} = \frac{U_2}{U_n} = 0.988136 - j0.033643 \text{ p.u.}$$

$$U_{3p.u.} = \frac{U_3}{U_n} = 0.99085 - j0.034428 \text{ p.u.}$$

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = [Y] \cdot \begin{bmatrix} 1+j0 \\ 0.98814 - j0.03364 \\ 0.99085 - j0.03443 \end{bmatrix} = \begin{bmatrix} 1.01472 - j0.0082 \\ -0.50415 + j0.11741 \\ -0.50393 - j0.08245 \end{bmatrix}$$

$$S_1 = U_1 \cdot I_1^* = (1+j0)\cdot(1.01472 + j0.0082) = 1.01472 + j0.0082$$

$$S_2 = U_2 \cdot I_2^* = (0.988136 - j0.033643)\cdot(-0.50415 - j0.11741) = -0.50211 - j0.05905$$

$$S_3 = U_3 \cdot I_3^* = (0.99085 - j0.034428)\cdot(-0.50393 + j0.08245) =$$

$$= -0.49648 + j0.099045 \text{ p.u.}$$

$= 1.01472 + j0.0082$ p.u.

$S_2 = -0.50211 - j0.099055$ p.u.

$S_3 = -0.49648 + j0.099045$ p.u.

$\Delta S = S_1 + S_2 + S_3 = 0.01613 + j0.0082$

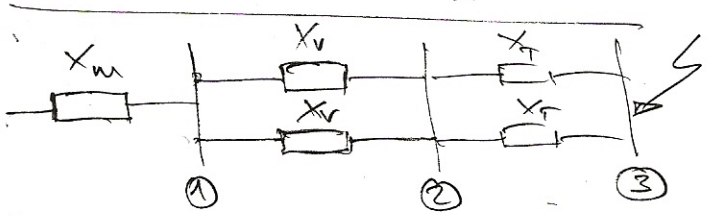
$\Delta S = 1.613 + j0.82$ MVA

2 ODBAU1: $U_n = 110$ kV, $X_1 = 0.41\ \Omega/km$, $l = 20$ km

TR: $S_n = 40$ MVA, $U_{n1} = 110$ kV, $U_{n2} = 20$ kV, $u_k = 10\%$

$X_{sm} = 12.1\ \Omega$ na 110 kV

$S_B = 40$ MVA



$U_{1p.u.} = \frac{U_1}{U_{sn}} = \frac{110}{110} = 1$ p.u.

$U_{2p.u.} = \frac{U_2}{U_{2n}} = \frac{110}{110} = 1$ p.u.

$U_{3p.u.} = \frac{U_3}{U_{sn}} = \frac{20}{20} = 1$ p.u.

$X_V = X_1 \cdot l = j8.2\ \Omega$

$X_{Vp.u.} = X_V \cdot \frac{S_B}{U_n^2} = j8.2 \cdot \frac{40}{110^2} = j0.02711$ p.u. ; $Y_{Vp.u.} = \frac{1}{X_{Vp.u.}} = \frac{1}{j0.0271} = -j36.8902$ p.u.

$Z_T = \frac{u_k}{100} \cdot \frac{U_n^2}{S_n}$; $Z_{Tp.u.} = \frac{u_k}{100} \cdot \frac{U_n^2}{S_n} \cdot \frac{S_B}{U_n^2} = j u_k = j0.1$ p.u.

$Y_T = \frac{1}{Z_T} = \frac{1}{j0.1} = -j10$ p.u.

$X_{sm} = j12.1\ \Omega \rightarrow X_{smp.u.} = X_m \cdot \frac{S_B}{U_n^2} = j12.1 \cdot \frac{40}{110^2} = j0.04$ p.u.

$Y_{sm} = \frac{1}{X_{sm}} = \frac{1}{j0.04} = -j25$ p.u.

$$Y = \begin{bmatrix} Y_{sm} + 2 \cdot Y_V & -2Y_V & 0 \\ -2Y_V & 2Y_V + 2Y_T & -2Y_T \\ 0 & -2Y_T & 2Y_T \end{bmatrix}$$

$$= \begin{bmatrix} -j98.7804 & +j73.7804 & 0 \\ +j73.7804 & -j93.7804 & +j20 \\ 0 & +j20 & -j20 \end{bmatrix} \Rightarrow [Z] = [Y]^{-1}$$

$$[Z] = \begin{bmatrix} j0.04 & j0.04 & j0.04 \\ j0.04 & j0.05355 & j0.05355 \\ j0.04 & j0.05355 & j0.10355 \end{bmatrix}$$

$$\begin{bmatrix} U_1^B \\ U_2^B \\ U_3^B \end{bmatrix} = \begin{bmatrix} U_1^Z \\ U_2^Z \\ U_3^Z \end{bmatrix} + [Z] \begin{bmatrix} 0 \\ 0 \\ I_m \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} + [Z] \cdot \begin{bmatrix} 0 \\ 0 \\ I_m \end{bmatrix}$$

- KS u čvorištu ③ : $U_3^B = 0$

$$U_3^B = U_3^Z + Z_{33} \cdot I_m = 1 + Z_{33} \cdot I_m = 0 \Rightarrow I_m = -\frac{1}{Z_{33}}$$

$$I_m = -\frac{1}{j0.10355} = j9.65717 \text{ p.u.}$$

$$I_{KS3} = I_m \cdot \frac{S_B}{\sqrt{3} \cdot U_{n_2}} = j9.65717 \cdot \frac{40\,MVA}{\sqrt{3} \cdot 20kV} = 11151,14 \text{ A}$$

$$\boxed{I_{KS3} = 11,151 \angle A} \qquad U_n = 20kV$$

---

3. GAUSS-SEIDEL postupak Y matrice

$U_n = 400kV$

$S_{teret_2} = 170 + j0$

$S_{teret_3} = 30 + j0$

$S_B = 100\,MVA$

$$Y = \begin{bmatrix} 1.25 - j24.94 & -1.25 + j24.94 & 0 \\ -1.25 + j24.94 & 3.74 - j74.81 & -2.49 + j49.88 \\ 0 & -2.49 + j49.88 & 2.49 - j49.82 \end{bmatrix}$$

$$S_{t_2} = \frac{S_{t_2}}{S_B} = \frac{170 + j0}{100} = 1.7 + j0 \text{ p.u.} \Rightarrow S_{t_2} = -1.7 - j0 \text{ p.u.}$$

$$S_{t_3} = \frac{S_{t_3}}{S_B} = \frac{30 + j0}{100} = 0.3 + j0 \text{ p.u.} \Rightarrow S_{t_3} = -0.3 - j0 \text{ p.u.}$$

$$U_{1p.u} = \frac{400kV}{400kV} = 1 \text{ p.u.} \; ; \; U_{2p.u.}^{(0)} = \frac{400}{400} = 1 \text{ p.u.} \; ; \; U_{3p.u.}^{(0)} = \frac{400}{400} = 1 \text{ p.u.}$$

opći član

$$U_i^{(k+1)} = \frac{KL_i}{(U_i^{(k)})^*} - \sum_{j=1}^{i-1} Y_{ij} \cdot U_j^{(k+1)} - \sum_{j=i+1}^{n} Y_{ij} \cdot U_j^{(k)} \; ; \; i = 1, \ldots, n \; / \; i \neq \text{ref. čv.}$$

$KL_i = \frac{S_i^*}{Y_{ii}}$; $YL_{ij} = \frac{Y_{ij}}{Y_{ii}}$;

PA: $U_2^{(0)} = 1+j0$ p.u.
$U_3^{(0)} = 1+j0$ p.u.

- čvorište (1) je referentno $\Rightarrow U_1 = 1+j0$ p.u.

$i \neq 1$; $i = 2, 3$

$$U_2^{(k+1)} = \frac{KL_2}{(U_2^{(k)})^*} - YL_{21} \cdot U_1 - YL_{23} \cdot U_3^{(0)}$$

$$U_3^{(k+1)} = \frac{KL_3}{(U_3^{(k)})^*} - YL_{31} \cdot U_1 - YL_{32} \cdot U_2^{(0)}$$

$$KL_2 = \frac{S_2^*}{Y_{22}} = \frac{-1.7+j0}{3.74-j74.81} = -0.0013323 - j0.022667$$

$$KL_3 = \frac{S_3^*}{Y_{33}} = \frac{-0.3+j0}{2.49-j49.88} = -0.000299 - j0.005999$$

$$YL_{21} = \frac{Y_{21}}{Y_{22}} = \frac{-1.25+j24.94}{3.74-j74.81} = -0.33338 \angle j0.00004222$$

$$YL_{23} = \frac{Y_{23}}{Y_{22}} = \frac{-2.49+j49.88}{3.74-j74.81} = -0.66675 + j0.0000489$$

$$YL_{31} = \frac{Y_{31}}{Y_{33}} = \frac{0}{2.49-j49.88} = 0$$

$$YL_{32} = \frac{Y_{32}}{Y_{33}} = \frac{-2.49+j49.88}{2.49-j49.88} = -1+j0$$

$k=0$

$$U_2^{(1)} = \frac{KL_2}{(U_2^{(0)})^*} - YL_{21} \cdot U_1 - YL_{23} \cdot U_3^{(0)} = \frac{-0.0013323 - j0.022667}{1-j0} - (-0.33338 - j0.00004222) \cdot (1+j0) - (-0.66675 + j0.0000489) \cdot (1+j0)$$

$U_2^{(1)} = 0.99879 - j0.022674$ p.u. ✓

$$U_3^{(1)} = \frac{KL_3}{(U_3^{(0)})^*} - YL_{31} \cdot U_1 - YL_{32} \cdot U_2^{(0)} = \frac{-0.000299 - j0.005999}{1-j0} - 0 \cdot 1 - (-1+j0) \cdot (1+j0)$$

$U_3^{(1)} = 0.9997 - j0.00599$ p.u. ✓

$|U_i^{(k+1)} - U_i^{(k)}| < \varepsilon$ $\quad |U_2^{(1)} - U_2^{(0)}| < \varepsilon$; $|U_3^{(1)} - U_3^{(0)}| < \varepsilon$

FAKTOR UBRZANJA, $\alpha = 1.2$

$\Delta U_2^{(1)} = U_2^{(1)} - U_2^{(0)} \rightarrow U_{2ubr}^{(1)} = U_2^{(0)} + \alpha \cdot \Delta U_2^{(1)}$; $\Delta U_3^{(1)} = U_3^{(1)} - U_3^{(0)} \rightarrow U_{3ubr}^{(1)} = U_3^{(0)} + \alpha \cdot \Delta U_3^{(1)}$

- referentno čvorište

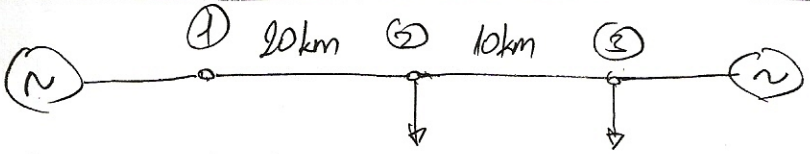
- vodovi: $U_n = 110\,kV$

$X_1 = 0.41\,\Omega/km$

$U_n = 110\,kV$ | $S_{t2} = 55\,MW + j25\,Mvar$ | $U_1 = 110\angle 0°$

$U_{ref} = 110\,kV$ | $S_{t3} = 50\,MW + j10\,Mvar$ | $U_2 = 109.979\angle -1.94°$

$S_B = 100\,MVA$ | $P_{gen3} = 50\,MW + j0\,Mvar$ | $U_3 = 110.000\angle -1.94°$



$X_{1-2} = X_1 \cdot l_{1-2} = j0.41\,\Omega/km \cdot 20km = j8.2\,\Omega \Rightarrow X_{1-2\,p.u.} = X_{1-2} \cdot \frac{S_B}{U_n^2} = j8.2 \cdot \frac{100}{110^2}$

$X_{2-3} = X_1 \cdot l_{2-3} = j0.41\,\Omega/km \cdot 10km = j4.1\,\Omega \rightarrow X_{2-3\,p.u.} = X_{2-3} \cdot \frac{S_B}{U_n^2} = j4.1 \cdot \frac{100}{110^2}$

$X_{1-2} = j0.067768\,p.u.$; $X_{2-3} = j0.033884\,p.u.$

$Y_{1-2} = \frac{1}{X_{1-2}} = -j14.7562$; $Y_{2-3} = \frac{1}{X_{2-3}} = -j29.5124$

$$[Y] = \begin{bmatrix} Y_{1-2} & -Y_{1-2} & 0 \\ -Y_{1-2} & Y_{1-2}+Y_{2-3} & -Y_{2-3} \\ 0 & -Y_{2-3} & Y_{23} \end{bmatrix} = \begin{bmatrix} -j14.7562 & j14.7562 & 0 \\ j14.7562 & -j44.2686 & +j29.5124 \\ 0 & j29.5124 & -j29.5124 \end{bmatrix}$$

$U_{1\,p.u.} = \frac{U_1}{U_n} = \frac{110\angle 0°}{110} = 1\angle 0°\,p.u. \Rightarrow \delta_1 = 0°$

$U_{2\,p.u.} = \frac{U_2}{U_n} = \frac{109.979}{110} = 0.99981\angle -1.94°\,p.u. \Rightarrow \delta_2^{(0)} = -1.94°$

$U_{3\,p.u.} = \frac{U_3}{U_n} = \frac{110}{110} = 1\angle -1.94\,p.u. \Rightarrow \delta_3^{(0)} = -1.94°$

$S_{t2} = \frac{S_{t2}}{S_B} = -0.55 - j0.25\,p.u. \Rightarrow S_2 = -0.55 - j0.25\,p.u.$; $P_{2,zad} = -0.55$, $Q_{2,zad} = -0.25$

$S_{t3} = \frac{S_{t3}}{S_B} = -0.5 - j0.1\,p.u.$

$P_{gen3} = \frac{P_{gen3}}{S_B} = 0.5 + j0\,p.u.$

$\Rightarrow S_3 = 0 - j0.1\,p.u.$; $P_{3,zad} = 0$, $Q_{3,zad} = -0.1$

$$[Y] = \begin{bmatrix} 14.7562\angle -90° & 14.7562\angle 90° & 0 \\ 14.7562\angle 90° & 44.2686\angle -90 & 29.5124\angle 90° \\ 0 & 29.5124\angle 90° & 29.5124\angle -90 \end{bmatrix}$$

za sva nezavisna čvorišta vrijedi:

$$P_{i,izr}^{(k)} = |U_i^{(k)}| \cdot \sum_{j=1}^{n} |U_j^{(k)}| \cdot |Y_{ij}| \cdot \cos(\delta_i^{(k)} - \delta_j^{(k)} - \vartheta_{ij}) \; ; \; i = 1, \dots, n \; ; \; i \neq ref.$$

$$Q_{i,izr}^{(k)} = |U_i^{(k)}| \cdot \sum_{j=1}^{n} |U_j^{(k)}| \cdot |Y_{ij}| \sin(\delta_i^{(k)} - \delta_j^{(k)} - \vartheta_{ij}) \; ; \; i = 1, \dots, n \; ; \; i \neq ref. \; i \neq gen.$$

$i \neq 1$, $i = 2, 3$

$$P_{2,izr}^{(0)} = U_2^{(0)} \sum_{j=1}^{3} U_j^{(0)} \cdot Y_{2j} \cos(\delta_2^{(0)} - \delta_j^{(0)} - \vartheta_{2j}) = U_2^{(0)} \cdot U_1 \cdot Y_{21} \cdot \cos(\delta_2^{(0)} - \delta_1 - \vartheta_{21}) +$$

$$+ U_2^{(0)} \cdot U_2^{(0)} \cdot Y_{22} \cdot \cos(\delta_2^{(0)} - \delta_2^{(0)} - \vartheta_{22}) + U_2^{(0)} \cdot U_3^{(0)} \cdot Y_{23} \cdot \cos(\delta_2^{(0)} - \delta_3^{(0)} - \vartheta_{23})$$

$$= 0.99981 \cdot 1 \cdot 14.7562 \cdot \cos(-1.94° - 0 - 90°) + 0.99981^2 \cdot 44.2686 \cdot$$

$$\cdot \cos(+90) + 0.99981 \cdot 1 \cdot 29.5124 \cdot \cos(-1.94° - (-1.94°) - 90))$$

$$\boxed{P_{2,izr}^{(0)} = -0.499445 \text{ p.u.}}$$

$$Q_{2,izr}^{(0)} = U_2^{(0)} \cdot \sum_{j=1}^{3} U_j^{(0)} \cdot Y_{2j} \sin(\delta_2^{(0)} - \delta_j^{(0)} - \vartheta_{2j}) = U_2^{(0)} \cdot U_1 \cdot Y_{21} \sin(\delta_2^{(0)} - \delta_1 - \vartheta_{21}) +$$

$$+ U_2^{(0)} \cdot U_2^{(0)} \cdot Y_{22} \cdot \sin(\delta_2^{(0)} - \delta_2^{(0)} - \vartheta_{22}) + U_2^{(0)} \cdot U_3^{(0)} \cdot Y_{23} \sin(\delta_2^{(0)} - \delta_3^{(0)} - \vartheta_{23})$$

$$= 0.99981 \cdot 1 \cdot 14.7562 \cdot \sin(-1.94° - 0 - 90°) + 0.99981^2 \cdot 44.2686 \cdot \sin(+90°) +$$

$$+ 0.99981 \cdot 29.5124 \cdot \sin(-90°)$$

$$= -14.745 + 44.25178 - 29.5068 = \underline{+0.0000468 \text{ p.u.}}$$

$$P_{3,izr}^{(0)} = U_3^{(0)} \cdot \sum_{j=1}^{3} U_j^{(0)} \cdot Y_{3j} \cdot \cos(\delta_3^{(0)} - \delta_j^{(0)} - \vartheta_{3j}) = \dots$$

$$Q_{3,izr}^{(0)} = U_3^{(0)} \cdot \sum_{j=1}^{3} U_j^{(0)} \cdot Y_{3j} \sin(\delta_3^{(0)} - \delta_j - \vartheta_{3j}) = \dots$$

$$\begin{vmatrix} \Delta P^{(k)} \\ \Delta Q^{(k)} \end{vmatrix} = \begin{vmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial U} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial U} \end{vmatrix} \cdot \begin{vmatrix} \Delta \delta \\ \Delta U \end{vmatrix}$$

$$\Delta P_i^{(k)} = P_{i,zad} - P_{i,izr}^{(k)} \; ; \; \Delta Q_i^{(k)} = Q_{i,zad} - Q_{i,izr}^{(k)}$$

$$\Delta P_2^{(0)} = P_{2,zad} - P_{2,izr}^{(0)} = -0.55 - (-0.499445) = -0.05055$$

$$\Delta Q_2^{(0)} = Q_{2,zad} - Q_{2,izr}^{(0)} = -0.25 - 0.0000468 = \underline{-0.2500468}$$

$$\Delta P_3^{(0)} = P_{3,zad} - P_{3,izr}^{(0)} = 0 - P_{3,izr}^{(0)} = \dots$$

$$\Delta Q_3^{(0)} = Q_{3,zad} - Q_{3,izr}^{(0)} = -0.1 - Q_{3,izr}^{(0)} = \dots$$

$$\left(\frac{\partial P_i}{\partial \delta_i}\right)^{(k)} = -|U_i^{(k)}| \cdot \sum_{\substack{j=1 \\ j\neq i}} |U_j^{(k)}| \cdot |Y_{ij}| \cdot \sin(\delta_i^{(k)} - \delta_j^{(k)} - \theta_{ij}) \qquad i \neq \text{ref. cv.}$$

$$\left(\frac{\partial P_i}{\partial \delta_j}\right)^{(k)} = |U_i^{(k)}||U_j^{(k)}| \cdot |Y_{ij}| \sin(\delta_i^{(k)} - \delta_j^{(k)} - \theta_{ij})$$

J_4:

$$\left(\frac{\partial Q_i}{\partial U_i}\right)^{(k)} = 2|U_i^{(k)}| \cdot |Y_{ii}| \cdot \sin(-\theta_{ii}) + \sum_{\substack{j=1 \\ j\neq i}}^{n} |U_j^{(k)}||Y_{ij}| \sin(\delta_i^{(k)} - \delta_j^{(k)} - \theta_{ij})$$

$$\left(\frac{\partial Q_i}{\partial U_j}\right)^{(k)} = |U_i^{(k)}| \cdot |Y_{ij}| \sin(\delta_i^{(k)} - \delta_j^{(k)} - \theta_{ij})$$

$$\Delta P = J_1 \cdot \Delta \delta \qquad \begin{vmatrix} \Delta P_2 \\ \Delta P_3 \end{vmatrix} = \begin{vmatrix} \frac{\partial P_2}{\partial \delta_2} & \frac{\partial P_2}{\partial \delta_3} \\ \frac{\partial P_3}{\partial \delta_2} & \frac{\partial P_3}{\partial \delta_3} \end{vmatrix} \cdot \begin{vmatrix} \Delta \delta_2 \\ \Delta \delta_3 \end{vmatrix}$$

$$\Delta Q = J_4 \cdot \Delta U$$

$$\begin{vmatrix} \Delta Q_2 \\ \Delta Q_3 \end{vmatrix} = \begin{vmatrix} \frac{\partial Q_2}{\partial U_2} & \frac{\partial Q_2}{\partial U_3} \\ \frac{\partial Q_3}{\partial U_2} & \frac{\partial Q_3}{\partial U_3} \end{vmatrix} \cdot \begin{vmatrix} \Delta U_2^{(0)} \\ \Delta U_3^{(0)} \end{vmatrix}$$

$$U_2^{(1)} = U_2^{(0)} + \Delta U_2^{(0)} \qquad \delta_2^{(1)} = \delta_2^{(0)} + \Delta \delta_2^{(0)}$$

$$U_3^{(1)} = U_3^{(0)} + \Delta U_3^{(0)} \qquad \delta_3^{(1)} = \delta_3^{(0)} + \Delta \delta_3^{(0)}$$

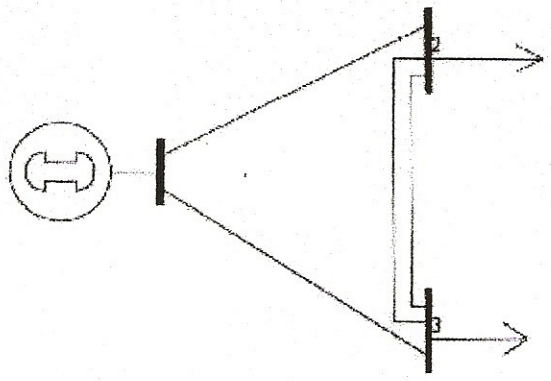
$$\begin{vmatrix} \Delta \delta_2 \\ \Delta \delta_3 \end{vmatrix} = J_1^{-1} \begin{vmatrix} \Delta P_2 \\ \Delta P_3 \end{vmatrix} \quad ; \quad \begin{vmatrix} \Delta U_2 \\ \Delta U_3 \end{vmatrix} = J_4^{-1} \begin{vmatrix} \Delta Q_2 \\ \Delta Q_3 \end{vmatrix}$$

numerička analiza elektroenergetskog sustava - pismeni i

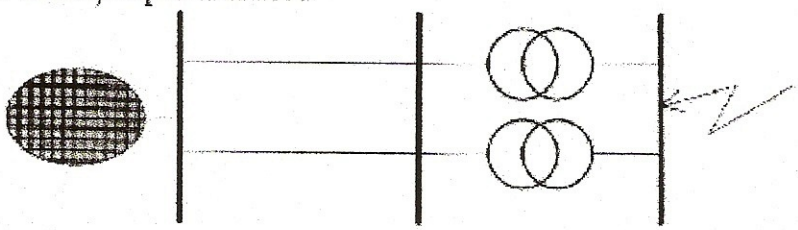
6.09.2008.

ime i prezime

<1> Odredi a) **matricu admitancije**, b) **injekcije snage u čvorištima,** te c) aktivne i reaktivne **gubitke** u cijeloj mreži na slici. Svi vodovi su jednaki i imaju parametre
U_n=110 kV;
R_1=0.12 Ω/km;
X_1=0.41 Ω/km;
B_1=0.0028 mS/km;
l=20 km.
Naponi čvorišta su
U_1=110 ∠0° kV;
U_2=108.758 ∠-1.95° kV;
U_3=109.059 ∠-1.99° kV.



Odredi struju tropolnog kratkog spoja u **ampetima**. Vodovi su jednaki i imaju parametre U_n=110 kV; X_1=0.41 Ω/km; l=20 km. Transformatori su jednaki i imaju parametre S_n=40 MVA; U_{n1}=110 kV; U_{n2}=20 kV; u_k=10%. Utjecaj vanjske mreže može se nadomjestiti reaktancijom 12.1 Ω na 110 kV. Mreža je u praznom hodu.



<3> Napravi jedan korak Gauss-Seidel metode pomoću Y-matrice. Početni naponi su nazivni U_n=400 kV.
S_{teret2}= 170+j0 MVA;
S_{teret3}= 30+j0 MVA;

Y matrica u pu vrijednostima na S_B=100MVA:

1,25 - j24,94	-1,25 + j24,94	
-1,25 + j24,94	3,74 - j74,81	-2,49 + j49,88
	-2,49 + j49,88	2,49 - j49,88

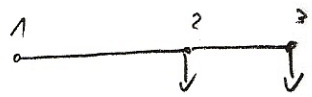
17,2

1) ODREDI NAPONE U MREŽI POMOĆU OBRNUTE NEWTON-RAPHSONOVE METODE.

DOVOLJNA JE JEDNA ITERACIJA

$S_{tereš2} = 100 + j0$ MVA

$S_{tereš3} = 105 + j0$ MVA



NR

ZADANO JE POČETNO STANJE:

$U_1 = 400 \angle 0°$ kV

$U_2 = 396,5 \angle -4,5°$ kV

$U_3 = 396 \angle -6°$ kV

Y MATRICA:

$$\begin{bmatrix} 1,25 - j24,94 & -1,25 + j24,94 & 0 \\ -1,25 + j24,94 & 3,74 - j74,81 & -2,49 + j49,88 \\ 0 & -2,49 + j49,88 & 2,49 - j49,88 \end{bmatrix}$$

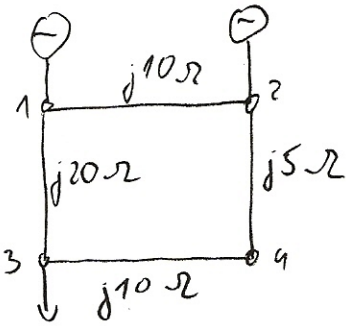
$$J1 = J4 = \begin{matrix} j74,81 & -j49,88 \\ -j49,88 & j49,88 \end{matrix}$$

2) ODREDI TOKOVE DJELATNE SNAGE U MREŽI PO ISTOSMJERNOM MODELU

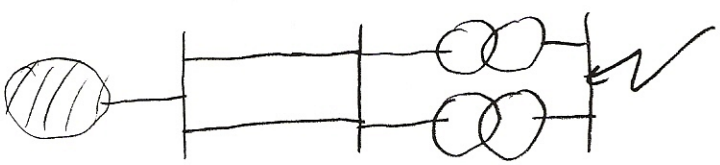
$P_{g2} = 100$ MW

$P_{t3} = 150$ MW

$U_n = 220$ kV

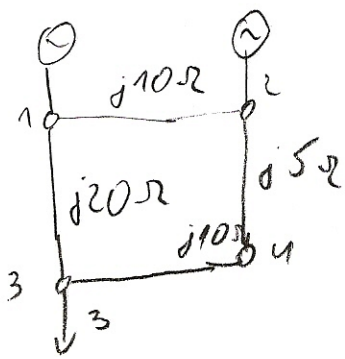


3) ODREDI STRUJU TROPOLNOG KS-a U AMPERIMA. VODOVI SU JEDNAKI I IMAJU PARAMETRE $U_n = 110$ kV, $x_1 = 0,41\ \Omega/km$, $l = 20$ km. TRANSFORMATORI SU JEDNAKI I IMAJU PARAMETRE $S_n = 40$ MVA, $U_{n1} = 110$ kV, $U_{n2} = 20$ kV, $u_k = 10\%$. UTJECAJ VANJSKE MREŽE SE NADOMJESTI REAKTANCIJOM 12,1 Ω na 110 kV. MREŽA JE U PRAZNOM HODU



$I_{KS} = 11,15$ kA

) ISTOSMJERNI MODEL



$P_{g2} = 100\ MW$

$P_{t3} = 150\ MW$

$U_n = 220\ kV$

$S_B = 100\ MVA$

$U_n = 220\ kV$

$P_{g2} = 1\ pu$

$P_{t3} = 1{,}5\ pu$

① REFERENTNO ČVORIŠTE

$$Y = \begin{bmatrix} -Y_{12}+Y_{13} & -Y_{12} & -Y_{13} & 0 \\ -Y_{12} & Y_{12}+Y_{24} & 0 & -Y_{24} \\ -Y_{13} & 0 & Y_{13}+Y_{34} & -Y_{34} \\ 0 & -Y_{24} & -Y_{34} & Y_{34}+Y_{24} \end{bmatrix}$$

$$Y_{pu} = \frac{U_n^2}{S_0} \cdot Y$$

$$Y_{12} = \frac{220^2}{100} \cdot \frac{1}{j10} = -j48{,}4$$

$Y_{24} = -j96{,}8$

$Y_{13} = -j24{,}2$

$Y_{34} = -j48{,}4$

$$Y = \begin{bmatrix} Y_{12}+Y_{24} & 0 & -Y_{24} \\ 0 & Y_{13}+Y_{34} & -Y_{34} \\ -Y_{24} & -Y_{34} & Y_{34}+Y_{24} \end{bmatrix} = \begin{bmatrix} -j145{,}2 & 0 & j96{,}8 \\ 0 & -j72{,}6 & j48{,}4 \\ j96{,}8 & j48{,}4 & -j145{,}2 \end{bmatrix}$$

$$Z = Y^{-1} \begin{bmatrix} j0{,}01607 & j0{,}00918 & j0{,}01377 \\ j0{,}00918 & j0{,}02296 & j0{,}01377 \\ j0{,}01377 & j0{,}01377 & j0{,}02066 \end{bmatrix}$$

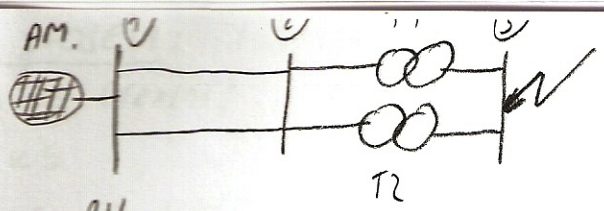
$$\begin{bmatrix} \delta_2 \\ \delta_3 \\ \delta_4 \end{bmatrix} = [Z] \cdot \begin{bmatrix} P_2 \\ P_3 \\ P_4 \end{bmatrix} = [Z] \cdot \begin{bmatrix} 1 \\ -1{,}5 \\ 0 \end{bmatrix} = \begin{bmatrix} j0{,}02984 \\ j0{,}04362 \\ j0{,}03444 \end{bmatrix} \begin{matrix} \delta_2 \\ \delta_3 \\ \delta_3 \end{matrix}$$

$$P_{1-2} = \frac{\delta_1 - \delta_2}{x_{12}} = \frac{0 - j0{,}02984}{j10} = -0{,}00298 \qquad P_{1-2} = -0{,}2984\ MW$$

$$P_{13} = \frac{\delta_1 - \delta_3}{x_{13}} = \frac{0 - j0{,}04362}{j20} = -0{,}00218 \qquad P_{1-3} = -0{,}2181\ MW$$

$$P_{2-4} = \frac{\delta_2 - \delta_4}{x_{24}} = \frac{j0{,}02984 - j0{,}03444}{j5} = -0{,}00092 \qquad P_{2-4} = -0{,}092\ MW$$

$$P_{3-4} = \frac{\delta_3 - \delta_4}{x_{34}} = \frac{j0{,}04362 - j0{,}03444}{j10} = 0{,}00092 \qquad P_{3-4} = 0{,}0918\ MW$$



3 POLNI KS $\quad \underline{I}_{KS} = ?$

V: $U_{nV} = 110\ kV$

$X_V = 0{,}41\ \Omega/km$

$l = 20\ km$

T: $S_n = 40\ MVA$

$U_{n1} = 110\ kV$

$U_{n2} = 20\ kV$

$u_R = 10\%$

AM: $12{,}1\ \Omega$ na $110\ kV$

$S_B = 40\ MVA$

$U_n = 110\ kV$

$Y_{AM\ p.u.} = \frac{U_n^2}{S_B} \cdot \frac{1}{X_{AM}} = \frac{110^2}{40} \cdot \frac{1}{12{,}1} = -j25$

$X_V = 0{,}41 \cdot 20 = 8{,}2\ \Omega$

$Y_{V\ p.u.} = \frac{U_n^2}{S_B} \cdot \frac{1}{X_V} = \frac{110^2}{40} \cdot \frac{1}{8{,}2} = -j36{,}89$

$Z_T = \frac{u_R[\%]}{100} \cdot \frac{U_n^2}{S_n} = \frac{10}{100} \cdot \frac{110^2}{40} = j30{,}25$

$Z_{T\ p.u.} = \frac{S_B}{U_n^2} \cdot Z = \frac{40}{110^2} \cdot j30{,}25 = j0{,}1$

$Y_{T\ p.u.} = -j10$ ✓

$$Y = \begin{bmatrix} Y_{AM} + 2Y_{VOD} & -2Y_{VOD} & 0 \\ -2Y_{VOD} & 2Y_{VOD} + 2Y_{TRAFO} & -2Y_{TRAFO} \\ 0 & -2Y_{TRAFO} & 2Y_{TRAFO} \end{bmatrix} = \begin{bmatrix} -j25 - 2 \cdot 36{,}89j & +2 \cdot 36{,}89j & 0 \\ +2 \cdot 36{,}89j & -2 \cdot 36{,}89j + 2j10 & \dots \\ 0 & +2 \cdot j10 & -2j10 \end{bmatrix}$$

$$Y = \begin{bmatrix} -98{,}78j & 73{,}78j & 0 \\ 73{,}78j & -93{,}78j & j20 \\ 0 & j20 & -j20 \end{bmatrix} \quad Z = [Y]^{-1} = \begin{bmatrix} \times & \times & \times \\ \times & \times & \times \\ \times & \times & j0{,}10355 \end{bmatrix}$$

$$\begin{bmatrix} U_1 \\ U_2 \\ 0 \end{bmatrix} = Z \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} + [Z] \begin{bmatrix} 0 \\ 0 \\ \underline{I}_m \end{bmatrix}$$

$$\underline{I}_m = \frac{-1}{Z_{33}} = \frac{-1}{-j0{,}10355} = +j9{,}65717$$

$$\underline{I}_{KS} = \underline{I}_m \cdot \frac{S_B}{\sqrt{3} \cdot U_n} = 9{,}65717 \cdot \frac{40 \cdot 10^3}{\sqrt{3}\ 110} = 2{,}02798\ kA$$

$$\frac{U_1}{U_2} = \frac{I_2}{I_1} \qquad I_2 = \frac{U_1}{U_2} \cdot I_1 = \frac{110}{20} \cdot 2{,}02798 = 11{,}15\ kA$$

TKI SPOJEVI: (ZEMLJA JE REF.)

3p KS (TROSM) → NAJOPASNIJI

2p KS

2p KS SA ZEMLJOM

1p KS (ZEMLJOSPOJ → AKO MREŽA NIJE UZEMLJENA)

PRIJE K.S-a

$$\begin{pmatrix} U_1^z \\ U_2^z \\ \vdots \\ U_n^z \end{pmatrix} = [Z] \cdot \begin{bmatrix} \underline{I}_1^g \\ \underline{I}_i^g \\ \vdots \\ 0 \end{bmatrix}$$

↑ DOBIJE SE IZ PRORAČUNA TOKOVA SNAGA

↓ GENERATORSKE STRUJE (GDJE NEMA GEN. STRUJA JE NULA)

POSLIJE K.S.

$$\begin{bmatrix} U_1^e \\ U_2^e \\ \vdots \\ 0 \\ \vdots \\ U_m^e \end{bmatrix} = \begin{bmatrix} U_1^z \\ U_i^z \\ \vdots \\ U_n^z \end{bmatrix} + [Z] \cdot \begin{bmatrix} 0 \\ 0 \\ \vdots \\ \underline{I}_m \\ \vdots \\ 0 \end{bmatrix}$$

m - mjesto KS

$$[U^e] = [Z] \cdot [\underline{I}_G] + [Z] \cdot [\underline{I}_{KS}]$$

$$[U^e] = [U^z] + [Z] [\underline{I}_{KS}]$$

$$U_m^e = \phi = U_m^z + Z_{mm} \cdot \underline{I}_m \Rightarrow \underline{I}_m = - \frac{U_m^z}{Z_{mm}}$$

TROPOLNI ⟶

$$\left.\begin{aligned} [U_1^e] &= U_1^z - \frac{Z_{1m}}{Z_{mm}} U_m^z \\ &\vdots \\ [U_n^e] &= U_m^z - \frac{Z_{nm}}{Z_{mm}} U_m^z \end{aligned}\right\}$$ distribucija napona u kabelskoj mreži

" - " IZ CIJELI IZ ČUDESI.