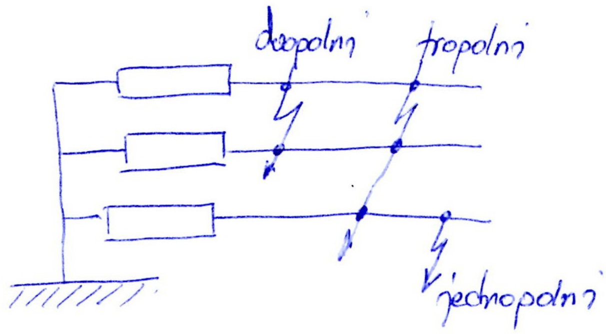
KRATKI SPOJ

- dvije vrste kvarova:
  1) uzdužni - prekid vodiča (struje nisu velike)
  2) poprečni - proboj izolacije (ovi kvarovi se nazivaju KS)
     - struja izlazi van (velika opasnost od termičkog razaranja mreže)

uzroci KS-a:

1) slom izolacije → zbog povećanja električnog naprezanja
   → zbog smanjenja čvrstoće izolacije
   → kombinacijom gore navedenog
   → električna naprezanja
     → pogonski napon
     → povišenje napona
     → unutrašnji prenaponi
     → atmosferski -ll-
     → utjecaj mreže višeg napona

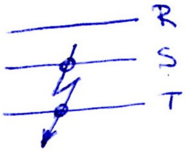
zemljospoj - nisu velike struje, nema termičkih naprezanja, ali utječe na kvalitetu napona



PRORACUN DVOPOLNOG KS-a

na mjestu kvara:

$$U_S = U_T$$
$$I_S = -I_T$$



$$[U_m^d] = [Z_\phi^d]\{[I^d] + [I_m^o]\}$$

$$[U_m^i] = [Z^i][I_m^i]$$

$$\left.\begin{aligned} U_S &= U^o + a^2U^d + aU^i \\ U_T &= U^o + aU^d + a^2U^i \end{aligned}\right\} \quad U^o + a^2U^d + aU^o = U^o + aU^d + a^2U^i$$

$$(a^2-a)\cdot U^d = (a^2-a)\,U^i$$

$$U^d = U^i \Rightarrow \text{analogno } I^d = -I^i$$

$$U_m^d = {}^zU_m^d + Z_{mm}^d I_m^d$$
$$U_m^i = Z_{mm}^i I_m^i$$

$${}^zU_m^d + Z_{mm}^d I_m^d = Z_{mm}^i I_m^i = -Z_{mm} I^d$$

$$I_m^d = -\frac{{}^zU_m^d}{Z_{mm}^d + Z_{mm}^i}$$

$$I_m^i = \frac{{}^zU_m^d}{Z_{mm}^d + Z_{mm}^i}$$

PRORAČUN DVOPOLNOG KS-a SA ZEMLJOM

$$U^d = {}^zU_m^d + Z_m^d \cdot I_m^d$$
$$U^i = Z^i I_m^i$$
$$U^o = Z^o \cdot I_m^o$$

$$U_S = U_T = 0$$
$$I_R = 0$$

$$I_m^d = -{}^zU_m^d \, \frac{Z_m^o + Z_m^i}{Z_{mm}^d \cdot Z_{mm}^i + Z_{mm}^d Z_{mm}^o + Z_{mm}^i Z_{mm}^o}$$

$$I_m^i = {}^zU_m^d \, \frac{Z_m^o}{\;}$$

$$I_m^o = {}^zU_m^d \left(\frac{Z_{mm}^i}{\;}\right)$$

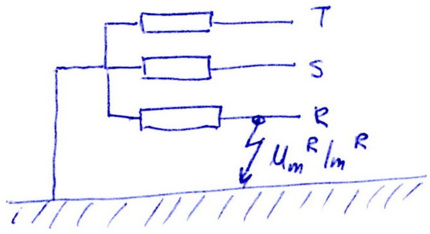
PRORAČUN JEDNOPOLNOG KRATKOG SPOJA

U bolesnom čvorištu postavljamo jednadžba:

$^{R}U_m = 0$

$^{R}I_m = I_m^d + I_m^i + I_m^o$

$^{T}I_m = {}^{S}I_m = 0$



$$\begin{vmatrix} {}^{R}U_m \\ {}^{S}U_m \\ {}^{T}U_m \end{vmatrix} = \begin{vmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{vmatrix} \begin{vmatrix} U_m^o \\ U_m^d \\ U_m^i \end{vmatrix} \rightarrow \begin{matrix} 0 = U_m^o + U_m^d + U_m^i \\ \left.\begin{matrix} {}^{T}I_m = 0 \\ {}^{S}I_m = 0 \end{matrix}\right\} \end{matrix}$$

$$0 = I_m^o + a I_m^d + a^2 I_m^i$$

$$0 = I_m^o + a^2 I_m^d + a I_m^i$$

$$\overline{I_m^o = I_m^d = I_m^i}$$

$$U_m^d = \sum_{j=1}^{n} I_j Z_{mj}^d + Z_{m,m}^d I_m^o \quad , \quad \sum_{j=1}^{n} I_j Z_{mj}^d = U_m^z$$

$$U_m^i = Z_{mm}^i \cdot I_m^o$$

$$U_m^o = Z_{mm}^o \cdot I_m^o$$

$$U_m^z + Z_{mm}^d I_m^o + Z_m^i I_m^o + Z_m^o I_m^o = 0$$

$$I_m^o = -\frac{U_m^z}{Z_{mm}^d + Z_{mm}^i + Z_{mm}^o}$$

$$I_{kr} = -3 I_m^o = \frac{3U_m^z}{Z_{mn}^d + Z_{mn}^i + Z_{mn}^o} = \frac{3U_n^z}{2Z_{mn}^d + Z_{mn}^o}$$

$U_m^z \rightarrow$ fazni napon trofazne mreže

PRORAČUN TOKOVA SNAGA

- zadano → snage (P i Q) u čvorištima tereta
  → konfiguracija mreže
  → iznos napona i djelatne snage u GENERATORSKIM ČVORIŠTIMA
  → napon u regulacijskim elektranama (referentno čvorište)
- cilj proračuna:
  → odrediti napon po iznos i kuta u svim čvorištima
- rezultati:
  → vektor napona svih čvorišta po iznosu i kutu
  → iznos radne i jalove snage kroz grane mreže
  → injekcije snage u čvorištima
  → gubici snage u mreži
  → snage ref. čvorišta
- podjela čvorišta:
  1) čvorišta tereta (poznat P i Q, traži se U i $\measuredangle\delta$)
  2) generatorska čvorišta (poznat $|V|$, P, Q_{min} i Q_{max}, traži se Q i $\measuredangle\delta$)
  3) čvorište regulacijske elekrane (poznat $|V|$, $\measuredangle\delta = 0$)

PRORAČUN KRATKOG SPOJA

- zadano → konfiguracija mreže (d, i, o)
  → uključeni generatori
  → mjesto kvara
- rezultati
  → tropolna struja (snaga), struje 1KS-a

METODA OTPORA (relativne veličine)

→ pretpostavljamo da su trofazne snage u stvarnoj mreži jednake snagama u reduciranoj

$$S = S'$$

$$U' = \frac{U_B}{U_n} \cdot U$$

iz $S = S' \Rightarrow \sqrt{3}\,UI = U'I'$

$$I' = \frac{\sqrt{3}\,UI}{U'} = \frac{\sqrt{3}\,UI}{\frac{U_B}{U_n}U} = \frac{\sqrt{3}}{U_B}U_n I$$

$$Z' = \frac{U'}{I'} = \frac{\frac{U_B}{U_n}U}{\frac{\sqrt{3}}{U_B}U_n I} = \left(\frac{U_B}{U_n}\right)^2 Z \qquad \text{ili} \qquad Y' = \left(\frac{U_n}{U_B}\right)^2 Y$$

JEDINIČNE VRIJEDNOSTI (per unit)

zadana bazna snaga, bazni napon jednak nazivnom

$$S_{p.u} = \frac{S}{S_B} \; ; \; U_{p.u} = \frac{U}{U_{B1}} \; ; \; I_{p.u} = \frac{I}{I_B} = \frac{\frac{S}{\sqrt{3}U}}{\frac{S_B}{\sqrt{3}U_B}} = \frac{S}{S_B} \cdot \frac{U_B}{U}$$

$$Z_{p.u} = \frac{Z}{Z_B} = Z \cdot \frac{1}{\frac{U_0^2}{S_B}} = Z\frac{S_B}{U_B^2} \qquad Y[p.u] = Y\frac{U_B^2}{S_B} \quad (U_B = U_n)$$

METODA REDUCIRANIH ADMITANCIJA

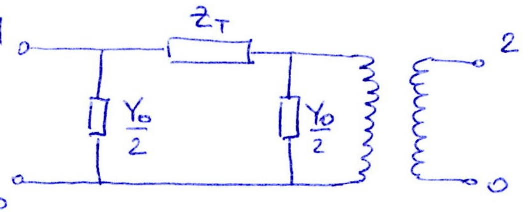
- proračun KS-a
- sve pretvaramo u admitanciju

$U_B = 1$ kV ili $S_B =$ [redacted] MVA

$$U_n = \frac{U}{U_n} \;,\; I_N = \sqrt{3}\,U_n I \;,\; Z_n = \frac{Z}{U_n^2} \;,\; Y_n = \frac{U_n^2}{Z} = U_n^2 \cdot Y$$

TRANSFORMATOR

IDEALNI TRAFO



S_n (MVA)
u_n (%)
U_{n1} (kV)
P_k (MW) – gubici KS

i(%) – struja mag.
P_0 (MW) – gubici PH
$\frac{w_1}{w_2}$ ⇒ prijenosni omjer

KRATKI SPOJ

– sekundar se kratko spoji, diže se napon primara dok ne potekne nazivna struja

$$u_{k\%} = \frac{I_n \cdot Z_T}{\frac{U_n}{\sqrt{3}}} \cdot 100\% = \frac{\frac{S_n}{\sqrt{3}U_n} \cdot Z_T}{\frac{U_n}{\sqrt{3}}} \cdot 100\% = Z_T \frac{S_n}{U_n^2} \cdot 100\% \Rightarrow Z_T = \frac{U_{n\%}}{100} \cdot \frac{U_n^2}{S_n}$$

$$P_k = 3 I_n^2 \cdot R = 3 \left(\frac{S_n}{\sqrt{3}U_n}\right)^2 R = \frac{S_n^2}{U_n^2} \cdot R$$

$$X = \sqrt{Z_T^2 - R^2} = \sqrt{u_k^2 \left(\frac{U_n^2}{S_n}\right)^2 - P_k^2 \left(\frac{U_n^2}{S_n^2}\right)^2} = \frac{U_n^2}{S_n} \sqrt{u_k^2 - \left(\frac{P_k}{S_n}\right)^2}$$

$$Z = R + jX = \frac{P_k U_n^2}{S_n^2} + j \frac{U_n^2}{S_n} \sqrt{u_k^2 - \left(\frac{P_k}{S_n}\right)^2}$$

$$Z = \frac{U_n^2}{S_n} \left[\frac{P_k}{S_n} + j \sqrt{u_{k\%}^2 - \left(\frac{P_k}{S_n}\right)^2} \right] \quad [\Omega]$$

PRAZNI HOD

– mjerimo na ulazu struju magnetiziranja

$$I_0 = \frac{U_{n1}}{\sqrt{3}} \cdot Y_0 \quad ; \quad Y_0 = \frac{I_0 \sqrt{3}}{U_n} = \frac{i_0 I_n \sqrt{3}}{U_n} = \frac{i_0 \frac{S_n}{\sqrt{3}U_n} \sqrt{3}}{U_n} = i_0 \frac{S}{U_n^2}$$

$$P_0 = 3 I^2 G_0 = 3 \left(\frac{U_n}{\sqrt{3}}\right)^2 G_0 \rightarrow G_0 = \frac{P_0}{U_n^2}$$

$$Y_0 = \frac{P_0}{U_n^2} - j \frac{S_n}{U_n^2} \sqrt{i_0^2 - \left(\frac{P_0}{S_n}\right)^2} = \frac{S_n}{U_n^2} \left[\frac{P_0}{S_n} - j \sqrt{i_0^2 - \left(\frac{P_0}{S_n}\right)^2} \right]$$

$$Z_{T\,p.u} = \frac{S_B}{S_n} \left[\frac{P_k}{S_n} + j \sqrt{u_k^2 - \left(\frac{P_k}{S_n}\right)^2} \right]$$

$$Y_{0\,p.u} = \frac{S_n}{S_B} \left[\frac{P_0}{S_n} - j \sqrt{i_0^2 - \left(\frac{P_0}{S_n}\right)^2} \right]$$

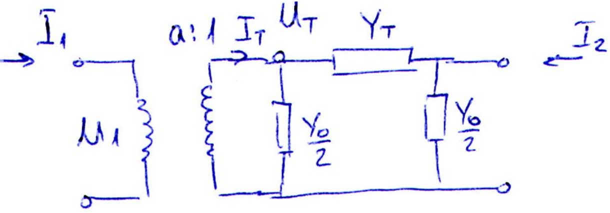
karak. veličine :

$u_{k\%} = 4\% \div 15\%\ U_n$

$P_k = 2{,}5\% \div 0{,}5\%\ S_n$

$i_0 = 2{,}5\% \div 0{,}5\%\ I_n$

$P_0 = 15\% \div 4\%\ P_k$



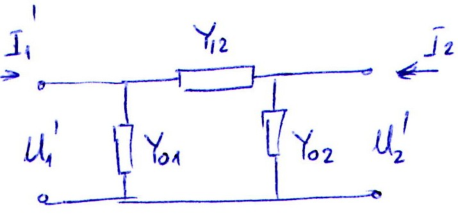
$$I_T = (U_T - U_2)\, Y_T + U_T \frac{Y_0}{2}$$

$$I_1 = \frac{I_T}{a} = (U_T - U_2)\frac{Y_T}{a} + \frac{U_T}{a}\frac{Y_0}{2}$$

$$\frac{U_1}{U_T} = a = \frac{I_T}{I_1}$$

$$I_1 = \left(\frac{U_1}{a} - U_1\right)\frac{Y_T}{a} + \frac{U_1}{a^2}\frac{Y_0}{2} = (U_1 - U_{2a})\frac{Y_T}{a^2} + U_1 \frac{Y_0}{2a^2}$$

$$I_2 = (U_2 - U_T)Y_T + U_2 \frac{Y_0}{2} = (U_2 a - U_1)\frac{Y_T}{a} + U_2 \frac{Y_0}{2}$$



$$I_1' = (U_1' - U_2')\, Y_{12} + U_1' Y_{01}$$

$$I_2' = (U_2' - U_1')\, Y_{12} + U_2' Y_{02}$$

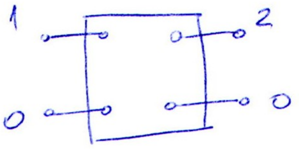
$$Y_{12} = \frac{Y_T}{a}$$

$$a = \frac{\frac{U_1}{U_{n1}}}{\frac{U_2}{U_{2n}}}$$

$$Y_{01} = \frac{Y_T}{a}\left(\frac{1}{a} - 1\right) + \frac{1}{a^2}\frac{Y_0}{2}$$

$$Y_{02} = Y_T\left(1 - \frac{1}{a}\right) + \frac{Y_0}{2}$$

ATRIČNI OBLIK TRANSFORMATORA



$$\begin{vmatrix} I_1 \\ I_2 \end{vmatrix} = \begin{vmatrix} Y_{12} + Y_{01} & -Y_{12} \\ -Y_{12} & Y_{12} + Y_{02} \end{vmatrix} \begin{vmatrix} U_1 \\ U_2 \end{vmatrix}$$

natrica admitancije [Y] → ii → zbroj poprečne i uzdužne adm.
ij → suprotni predznak međuadmitancije

ujet paralelnog rada → ista grupa spoja
→ isti prijenosni omjer
→ snage se razlikuju do 1/3

METODA GSZ

- mreža od n čvorišta → jedno referentno

$$\vec{U}_i - \vec{U}_{ref} = \sum_{\substack{j=1 \\ j \neq ref}}^{n} \vec{Z}_{ij} \vec{I}_j$$

matrica Y samo uzdužni parametri grana
poprečne admitancije → matrica Y'

POSTUPAK PRORAČUNA

1) – učitavanje podataka o mreži (konfiguracija, admitancija grana)
   – učitavanje podataka o injekcijama snaga u čvorištima

2) – formiranje Y matrice (samo uzdužne admitancije)
   – formiranje Y' matrice (samo poprečne admitancije)

3) računanje Z matrice → $[Z] = [Y]^{-1}$

4) početne vrijednosti napona čvorišta : $U_i^{(0)} = 1 + j0$ p.u.

5) računanje stanja u čvorištima : $I_i^{(0)} = \frac{S_i^*}{U_i^{*(0)}} - Y_i \cdot U_i^{(0)}$, $i = 1, 2, .. n-1$

6) računanje struja i napona u čvorištima:

$$U_i^{(1)} = U_{ref} + \sum_{j=1}^{i-1} Z I_j^{(1)} + \sum_{j=i}^{n-1} Z_{ij} I_j^{(0)}$$

) da li je uvjet zadovoljen :

$$| U_i^{(1)} - U_i^{(0)} | < \varepsilon \quad , \quad \varepsilon = 0{,}001 \div 0{,}0001$$

općenito :

$$U_i^{(n+1)} = U_{ref} + \sum_{j=1}^{i-1} Z_{ij} I_j^{(n+1)} + \sum_{j=i}^{n-i} Z_{ij} I_j^{(n)}$$

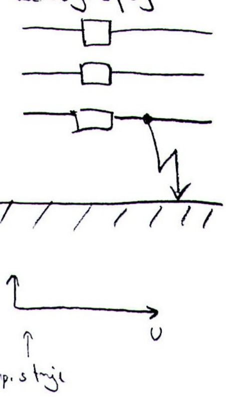
$$I_i^{(n+1)} = \frac{S_i^*}{U_i^{*(n+1)}} - Y_i' U_i^{(n+1)} \quad , \quad i = 1, 2, \ldots, n-1$$

- ne ulaze generatori u proračun

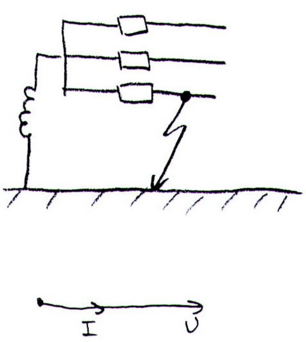
metoda povoljna za mali broj čvorišta (20) jer je konvergentna
dobra je za oko 100 čvorišta

• Vektorske slike

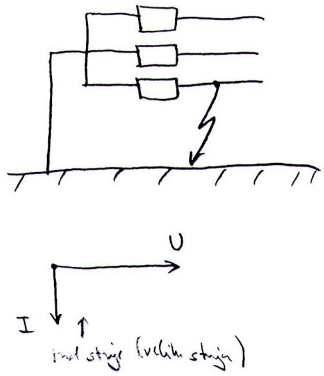
Zemljospoj



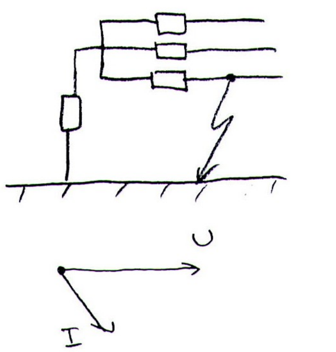
Zemljospoj (uzemljen preko L)



Mreža uzemljena direktno

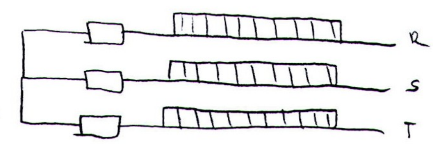


Mreža uzemljena preko otpora

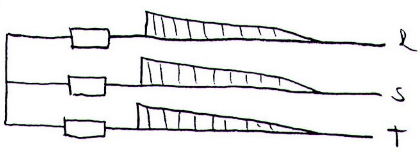


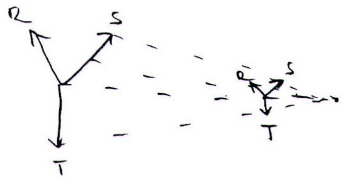
TROPOLNI KRATKI SPOJ

struje:



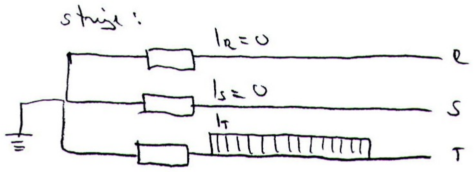
naponi



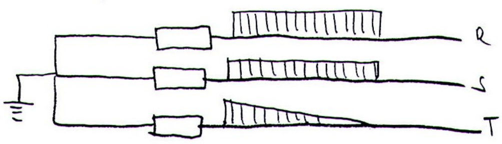


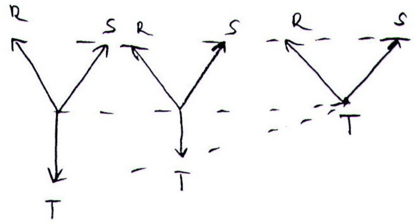
• JEDNOPOLNI KRATKI SPOJ

struje:



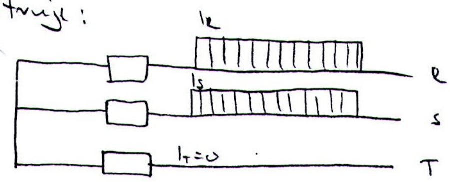
naponi:



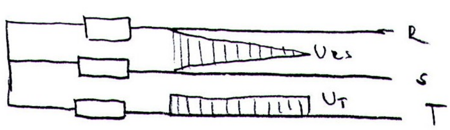


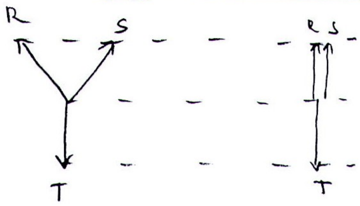
DVOPOLNI KRATKI SPOJ

struje:



naponi:





Simetrične komponente

$${}^RU_i = {}^0U_i + {}^dU_i + {}^iU_i$$

$${}^SU_i = {}^0U_i + a^2\,{}^dU_i + a\,{}^iU_i$$

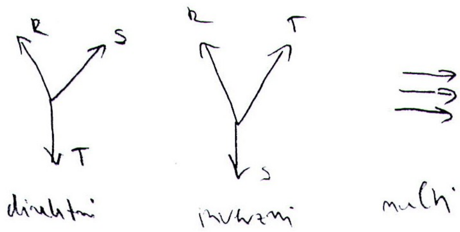
$${}^TU_i = {}^0U_i + a\,{}^dU_i + a^2\,{}^iU_i$$

$$\begin{vmatrix} {}^RU_i \\ {}^SU_i \\ {}^TU_i \end{vmatrix} = \begin{vmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{vmatrix} \begin{vmatrix} {}^0U_i \\ {}^dU_i \\ {}^iU_i \end{vmatrix}$$

$$a = -\frac{1}{2} + j\frac{\sqrt{3}}{2}$$

$$a^2 = -\frac{1}{2} - j\frac{\sqrt{3}}{2}$$

$$\begin{vmatrix} {}^0U_i \\ {}^dU_i \\ {}^iU_i \end{vmatrix} = \frac{1}{3} \begin{vmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{vmatrix} \begin{vmatrix} {}^RU_i \\ {}^SU_i \\ {}^TU_i \end{vmatrix}$$



SNAGE U ČVORIŠTIMA

$$\vec{S_i} = \vec{U_i} \cdot \vec{I_i}^* = P_i + jQ_i$$

$$\vec{S_i} = |\vec{U_i}| \cdot \sum_{j=1}^{m} |U_j||Y_{ij}| \left(\cos(\delta_i - \delta_j - \Theta_{ij}) + j\sin(\delta_i - \delta_j - \Theta_{ij})\right)$$

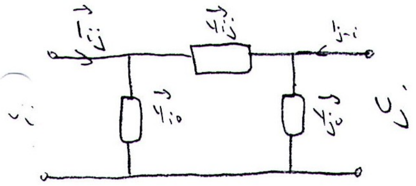
- djelatna snaga u čvorištu:

$$P = |\vec{U_i}| \sum_{j=1}^{m} U_j |Y_{ij}| \cos(\delta_i - \delta_j - \Theta_{ij})$$

- jalova snaga u čvorištu:

$$Q = |\vec{U_i}| \sum_{j=1}^{m} U_j |Y_{ij}| \sin(\delta_i - \delta_j - \Theta_{ij})$$

NAGE U GRANAMA



$$\vec{I}_{i-j} = (U_i - U_j)\, y_{ij} + U_i\, y_{i0}$$

$$\vec{S}_{i-j} = U_i \cdot I_{i-j}^* = U_i \left[(U_i - U_j)\, y_{i-j} + U_i\, y_{i0}\right]^*$$

, Y_{i-j} → uzdužna admitancija grane

$$\vec{S}_{j-i} = U_j \cdot I_{j-i}^* = U_j \left[(U_j - U_i)\, y_{i-j} + U_j\, y_{j0}\right]^*$$

gubici snage → $\Delta S = \vec{S}_{i-j} + \vec{S}_{j-i}$

$$\boxed{\Delta S = (U_i^* - U_j^*)\, y_{ij}^* (U_i - U_j) - (|U_i|^2 - |U_j|^2) \frac{B_{i-j}}{2}} \quad (1)$$

ORAČUNI TOKOVA SNAGA

- osnovne metode proračuna tokova snaga:
  - metoda Gauss-Seidel pomoću Z matrice
  - metoda Gauss-Seidel pomoću Y matrice
  - metoda Newton Raphson

STOSMJERNI MODEL TOKOVA SNAGA

$$P_i = \sum_{j=1}^{n} U_i U_j Y_{ij} \cos(\delta_i - \delta_j - \Theta_{ij})$$

$$Q_i = \sum_{j=1}^{n} U_i U_j Y_{ij} \sin(\delta_i - \delta_j - \Theta_{ij})$$

- pretpostavimo: $U_i \approx U_j \approx 1$

$$Y_{ij} = B_{ij} e^{j90^\circ}$$

$$Y_{ii} = B_{ii} e^{j90^\circ}$$

$$P_i = B_{ii} \cos(-90^\circ) + \sum_{\substack{j=1 \\ j \neq i}}^{n} B_{ij} \sin(\delta_i - \delta_j)$$

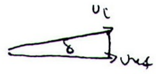
$$Q_i = B_{ii} \sin(90^\circ) - \sum_{\substack{j=1 \\ j \neq i}}^{n} B_{ij} \cos(\delta_i - \delta_j)$$

- zanemarimo Q $(Q_i = 0)$ $\rightarrow$ kut $(\delta_i - \delta_j)$ jako mali pa:

$$P_i = \sum_{\substack{j=1 \\ j \neq i}}^{n} B_{ij} (\delta_i - \delta_j)$$

$$P_i = \sum_{j=1}^{n-1} B_{ij} \delta_j \quad , \quad \delta_n = \delta_{ref} = 0$$

$$\delta_i = (U_i - U_{ref}) j$$



$$|P| = |B|\,|\delta|$$
$$\downarrow$$
$$(n-1)\times(n-1)$$

- kod matrice B su dijagonale (-), a vandijagonale (+)

$$|\Delta U| = j|B^{-1}| \cdot |P|$$

$$P_{i-j} = \frac{j(\Delta U_i - \Delta U_j)}{jX_{ij}}$$

$$P_{i-j} = -P_{j-i} \quad (\text{jer je } R=0, \text{ nema djelatnih gubitaka } P_{loss} = I^2 R)$$

u ovom modelu nema gubitaka tj. zanemareni su (u izmjeničnom modelu gubici idu u referentni element)

• MATEMATIČKI MODEL KRATKOG SPOJA

- stanje zdrave mreže:

$$\begin{vmatrix} U_1 \\ U_2 \\ \vdots \\ U_m \end{vmatrix} = \begin{vmatrix} Z_{11} & \cdots & Z_{1m} \\ \vdots & \ddots & \\ Z_{m1} & & Z_{mm} \end{vmatrix} \begin{vmatrix} I_1 \\ I_2 \\ \vdots \\ I_m \end{vmatrix}$$

ulaze sve admitancije (vodovi, gen, trafo, potrošači)

struje koje ulaze u čvorište

- stanje bolesne mreže:

$$\begin{vmatrix} U_1 \\ \vdots \\ U_m \end{vmatrix}^B = |Z| \cdot \left\{ \begin{vmatrix} I_1 \\ I_2 \\ \vdots \\ I_m \end{vmatrix} + \begin{vmatrix} 0 \\ \vdots \\ I_m \\ \vdots \\ 0 \end{vmatrix} \right\} \qquad I_k = -I_m$$

$$[U_m]^B = [U_m]^Z + [Z][I_m]$$

- tropolni KS →

$$^dU_m = 0$$

$$0 = U_m^Z + {}^dZ_{mm} I_m \rightarrow I_m = -\frac{U_m^Z}{^dZ_{mm}}$$

- nesimetrični KS →

$$[^dU_m]^B = [^dZ_{mm}] \cdot \{ |^dI_m| + |I_m^d| \}$$

$$[^iU_m]^B = [^iZ_{mm}][^iI_m]$$

$$[^0U_m]^B = [^0Z_{mm}][^0I_m]$$

METODA GSY

mreža od n čvorišta – jedno referentno

$$|\vec{I}| = |\vec{Y}||\vec{U}|$$

$$\vec{I}_{(n-1)} = \vec{Y}_{(n-1)1} U_1 + \vec{Y}_{(n-1)2} U_2 + \ldots + \vec{Y}_{(n-1)n} \cdot \vec{U}_n$$

$$\vec{U}_n = \frac{1}{Y_{nn}} \left[\vec{I}_n - \vec{Y}_{n1}\vec{U}_1 - \ldots - \vec{Y}_{n(n-1)} \vec{U}_{(n-1)} \right]$$

$$\vec{I}_n = \frac{\vec{S}_n^*}{\vec{U}_n^*}$$

$$U_n^{(1)} = \frac{1}{Y_{nn}} \left[\frac{S_n^*}{\vec{U}_n^*} - \vec{Y}_{1n}\vec{U}_n^{(0)} - \ldots Y_{n(n-1)} U_n^{(0)} \right]$$

→ općenito:

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

$$U_i^{(k+1)} = \frac{KL_i}{U_i^{(k)*}} - \sum_{j=1}^{i-1} YL_{ij} \cdot U_j^{(k+1)} - \sum_{j=i+1}^{n} YL_{ij} U_j^{(k)}$$

→ uvjet točnosti

$$|U_i^{(k+1)} - U_i^{(k)}| < \varepsilon$$

→ uz faktor ubrzanja → $\Delta U_2^{(1)} = U_2^{(1)} - U_2^{(0)}$ $\quad \alpha \to 1{,}2 \div 2$

$$U_{2\,\text{ubrzani}}^{(1)} = U_2^{(0)} + \alpha \Delta U_2^{(1)}$$

→ prednost metode → Y matrica ima manji elemente

→ nedostaci → mnogo iteracija

METODA NEWTON-RAPHSON

najefikasnija, najkonvergentnija metoda (mana → u svakoj iteraciji se rješava sustav linearnih jdžb)
10 iteracija (15, ako je sustav na rubu stabilnosti)

mreža od m čvorišta - jedno čvorište referentno

poznate snage u čvorištima:

- generatorsko i čvorište tereta → $P_i = U_i \cdot \sum_{j=1}^{m} U_j Y_{ij} \cos(\delta_i - \delta_j - \Theta_{ij})$, $i = 1, \ldots, m-1$

- čvorište tereta → $Q_i = U_i \sum_{j=1}^{m} U_j Y_{ij} \sin(\delta_i - \delta_j - \Theta_{ij})$, $i = 1, \ldots, m-g-1$

- potrebno izračunati: U_i $i = 1, \ldots, m-g-1$

δ_i, $i = 1, \ldots, m-1$

POSTUPAK PRORAČUNA

1) - učitavanje podataka o mreži (konfiguracija, admitancije grana)
 - učitavanje podataka o injekcijama snage u čvorištima

2) - početne vrijednosti napona čvorišta (pretpostavljamo rješenje)

$U_i^{(0)} = 1 + j0$ p.u.

3) - formiranje Y matrice

4) - računanje snaga u čvorištima:

$$P_{i\,rač}^{(0)} = \sum_{j=1}^{m} U_i^{(0)} \cdot U_j^{(0)} Y_{ij} \cos(\delta_i - \delta_j - \Theta_{ij}) \quad i = 1, \ldots, m-1$$

$$Q_{i\,rač}^{(0)} = \sum_{j=1}^{m} U_i^{(0)} U_j^{(0)} Y_{ij} \sin(\delta_i - \delta_j - \Theta_{ij}) \quad i = 1, \ldots, m-1-g$$

5) $\Delta P_i^{(0)} = P_{zad} - P_{i\,rač}^{(0)}$, $i = 1, \ldots, m-1$

$\Delta Q_i^{(0)} = Q_{zad} - Q_{i\,rač}^{(0)}$, $i = 1, \ldots m-1-g$

6) - provjera kriterija točnosti

$\Delta P_i^{(0)} < \varepsilon$

$\Delta P_i^{(0)} < \varepsilon$

7) Računanje $\Delta \delta_i^{(0)}, \Delta U_i^{(0)}$ pomoću $\Delta P_i^{(0)}$ i $\Delta Q_i^{(0)}$ i Jakobijeve matrice

$$\begin{vmatrix} \Delta P \\ \Delta Q \end{vmatrix} = \underbrace{|J|}_{\text{Jakobijeva matrica}} \begin{vmatrix} \Delta\delta \\ \Delta U \end{vmatrix} = \underbrace{\begin{vmatrix} J_1 & J_2 \\ J_3 & J_4 \end{vmatrix}}_{\text{podmatrice}} \begin{vmatrix} \Delta\delta \\ \Delta U \end{vmatrix} = \begin{vmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial U} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial U} \end{vmatrix} \begin{vmatrix} \Delta\delta \\ \Delta U \end{vmatrix}$$

$$J_1 = \frac{\partial P}{\partial \delta}$$

$$\frac{\partial P_i}{\partial \delta_i} = -U_i \sum_{\substack{j=1 \\ j\neq i}}^{n} U_j Y_{ij} \sin(\delta_i - \delta_j - \Theta_{ij})$$

$$\frac{\partial P}{\partial \delta_j} = U_i U_j Y_{ij} \sin(\delta_i - \delta_j - \Theta_{ij})$$

$$J_2 = \frac{\partial P}{\partial U}$$

$$\frac{\partial P_i}{\partial U_i} = 2U_i Y_{ii} \cos(-\Theta_{ii}) + \sum_{\substack{j=1 \\ j\neq i}}^{n} U_j Y_{ij} \cos(\delta_i - \delta_j - \Theta_{ij})$$

$$\frac{\partial P_j}{\partial U_j} = U_i Y_{ij} \cos(\delta_i - \delta_j - \Theta_{ij})$$

$$J_3 = \frac{\partial Q}{\partial \delta}$$

$$\frac{\partial Q_i}{\partial \delta_i} = U_i \sum_{\substack{j=1 \\ j\neq i}}^{n} U_j Y_{ij} \cos(\delta_i - \delta_j - \Theta_{ij})$$

$$\frac{\partial Q_j}{\partial \delta_j} = -U_i U_j Y_{ij} \cos(\delta_i - \delta_j - \Theta_{ij})$$

$$J_4 = \frac{\partial Q}{\partial U}$$

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

$$\frac{\partial Q_j}{\partial U_j} = U_i Y_{ij} \sin(\delta_i - \delta_j - \Theta_{ij})$$

- dimenzije Jacobijeve matrice →

$(n-1)\times(n-1)$	$(n-1)\times(n-1-g)$
$(n-1-g)\times(n-1)$	$(n-1-g)\times(n-1-g)$

$= (2n-g-2)\times(2n-g-2)$

→ uz zanemarenje J2 i J3 vrijedi:

$$\begin{vmatrix} \Delta P \\ \Delta Q \end{vmatrix} = \begin{vmatrix} J1 & 0 \\ 0 & J4 \end{vmatrix} \begin{vmatrix} \Delta\delta \\ \Delta U \end{vmatrix}$$

$$|\Delta\delta| = |J1|^{-1} |\Delta P|$$

$$|\Delta U| = |J4|^{-1} |\Delta Q|$$

→ općenito vrijedi:

$$P_{i\,rač}^{(k)} = \sum_{j=1}^{m} U_i^{(k)} U_j^{(k)} Y_{ij} \cos(\delta_i^{(k)} - \delta_j^{(k)} - \Theta_{ij}) \quad , \quad i = 1, \dots, m-1$$

$$Q_{i\,rač}^{(k)} = \sum_{j=1}^{m} U_i^{(k)} U_j^{(k)} Y_{ij} \sin(\delta_i^{(k)} - \delta_j^{(k)} - \Theta_{ij}), \quad i = 1, \dots, m-1-g$$

$$\Delta P_i^{(k)} = P_{izad} - P_{i\,rač}^{(k)}$$

$$\Delta Q_i^{(k)} = Q_{izad} - Q_{i\,rač}^{(k)}$$

Jakobijeve podmatrice:

$$J1 \rightarrow \left(\frac{\partial P_i}{\partial \delta_i}\right)^{(k)} = -U_i^{(k)} \sum_{\substack{j=1 \\ j \neq i}}^{m} U_j^{(k)} Y_{ij} \sin(\delta_i^{(k)} - \delta_j^{(k)} - \Theta_{ij}) \quad , j \neq ref$$

$$\left(\frac{\partial P_i}{\partial \delta_j}\right)^{(k)} = U_i^{(k)} U_j^{(k)} Y_{ij} \sin(\delta_i^{(k)} - \delta_j^{(k)} - \Theta_{ij}) \quad , i \neq j, j \neq ref.$$

$$J4 \rightarrow \left(\frac{\partial Q_i}{\partial U_i}\right)^{(k)} = 2 U_i^{(k)} Y_{ii} \sin(-\Theta_{ii}) + \sum_{\substack{j=1 \\ j \neq i}}^{m} U_j^{(k)} Y_{ij} \cdot \sin(\delta_i^{(k)} - \delta_j^{(k)} - \Theta_{ij}) \quad , j \neq ref$$

$$\left(\frac{\partial Q_i}{\partial U_j}\right)^{(k)} = U_i^{(k)} Y_{ij} \sin(\delta_i^{(k)} - \delta_j^{(k)} - \Theta_{ij}) \quad , i \neq j, j \neq ref.$$

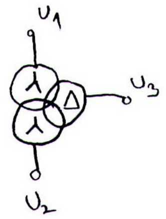
$$|\Delta\delta|^{k} = |J_1^{(k)}|^{-1} |\Delta P|^{(k)}$$

$$|\Delta U|^{(k)} = |J4^{(k)}|^{-1} |\Delta Q|^{(k)}$$

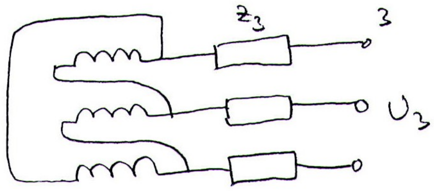
$$U_i^{(k+1)} = U_i^{(k)} + \Delta U_i^{(k)}$$

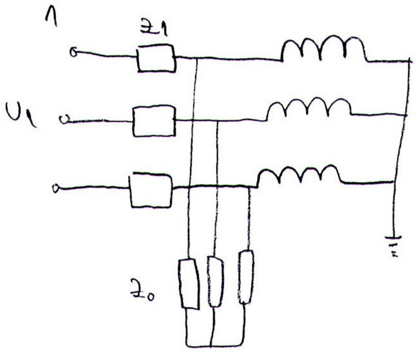
$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)}$$

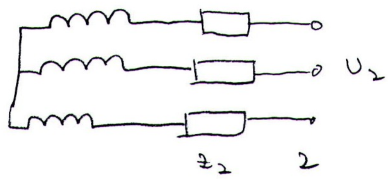
Tronamotni transformator



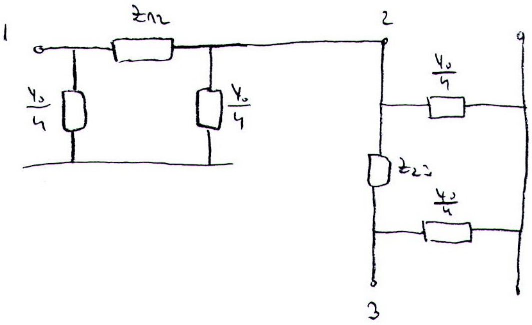
- svaki trafo tronamotni, ali se zanemaruje ako nema potrošnje







$$\left.\begin{aligned} Z_{12} &= Z_1 + Z_2 \\ Z_{13} &= Z_1 + Z_3 \\ Z_{23} &= Z_2 + Z_3 \end{aligned}\right\} \qquad \begin{aligned} Z_1 &= \frac{1}{2}\left(Z_{12} + Z_{13} - Z_{23}\right) \\ Z_2 &= \frac{1}{2}\left(Z_{12} + Z_{23} - Z_{13}\right) \\ Z_3 &= \frac{1}{2}\left(Z_{13} + Z_{23} - Z_{12}\right) \end{aligned}$$



- neka imamo mrežu od 100 čvorišta → Gauss-Seidel pomoću Z ↔ 5 iteracija
→ Gauss-Seidel pomoću Y ↔ 300 iteracija

GSZ- Najbolje radi za manji broj čvorišta (idealno je do 20 čvorišta), ali može se primjenjivati do 100 čvorišta (za 100 čvorišta matrica Z ima 10000 članova, pa se preko toga ne ide), no pozitivna strana jest da je metoda konvergentna i obično završi u 5-10 iteracija.

GSY- Nije konvergentnta pa ima hrpu iteracija,ne znam koja je pozitivna strana, ali se sjećam da Y matrica nešto ne ovisi o broju čvorišta ovo-ono.

Mislim da je stvar u tome da u GSZ nemres u Y matricu stavit generatorska cvorista,dok kod GSY mozes i zato je bolji GSY kaj se tog tice...jedino kaj je manje konvergentan...

mislim da jedino u newton raphson idu generatorska cvorista a GSY je bolji od GSZ za veliki broj cvorista jer Y matrica ima masu nula, pa je proracun jedne iteracije dosta brzi, a Z matrica ima sve pozitivne vrijednosti i treba dosta da se izracuna inverz, npr 100×100

U GSZ reduciraš Y matricu (križaš redak i stupac referentnog čvorišta), u GSY to ne radiš zato jer si potrp'o i generatorska čvorišta u Y matricu, tu ti se to vidi.

dobro za zapantiti je da je matrica inpedancije cvorisata singularna sto znaci da je determinanta nula i nema inverza, zato micemo jedan referentni redak kada racunamo Z matricu.