PRIJENOS I DISTRIBUCIJA ELEKTRIČNE ENERGIJE

# 7. PRORAČUNI PRIJENOSA ELEKTRIČNE ENERGIJE

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# 7. PRORAČUNI PRIJENOSA ELEKTRIČNE ENERGIJE

7.1 MOGUĆNOSTI PRORAČUNA PRIJENOSA ELEKTRIČNE ENERGIJE

7.2 PRORAČUN PRIJENOSA ELEKTRIČNE ENERGIJE PRIMJENOM NADOMJESNIH TOKOVA ZA VODOVE

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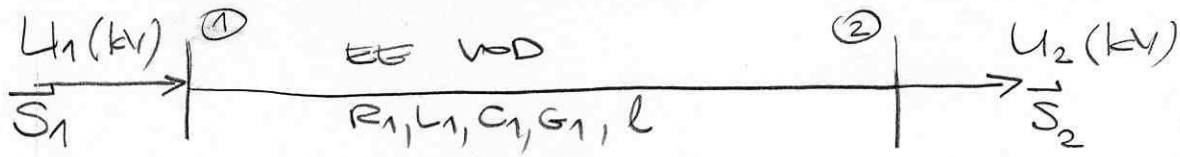
7.5 PRORAČUN PADOVA NAPONA I GUBITAKA SNAGE NA ZRAČNOM VODU

# 7.1 MOGUĆNOSTI PRORAČUNA PRIJENOSA ELEKTRIČNE ENERGIJE ELEKTROENERGETSKIM VODOVIMA




## TOČAN PRORAČUN PRIJENOSA EL. ENERGIJE

1. PRIMJENOM PRIJENOSNIH JEDNADŽBI
2. PRIMJENOM TOČNIH NADOMJESNIH Π I T MODELA (S KOREKCIJSKIM FAKTORIMA)

## PRIBLIŽAN PRORAČUN PRIJENOSA EL. ENERGIJE

1. ZA NADZEMNE EE VODOVE $l < 200$ km ;
   KABELSKE EE VODOVE $l < 100$ km

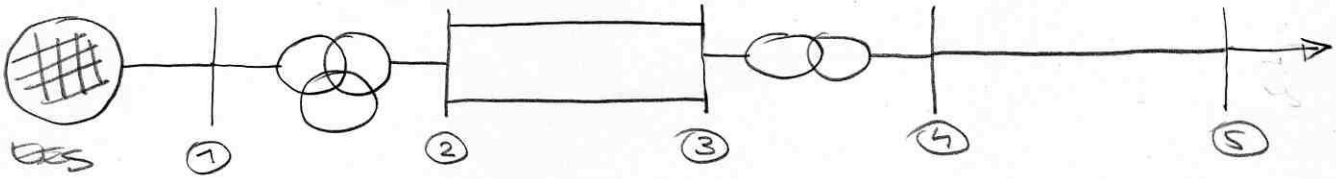
   PRIMJENOM PRIBLIŽNIH NADOMJESNIH Π ; T MODELA

2. ZA NADZEMNE EE VODOVE $l > 200$ km ;
   KABELSKE EE VODOVE $l > 100$ km

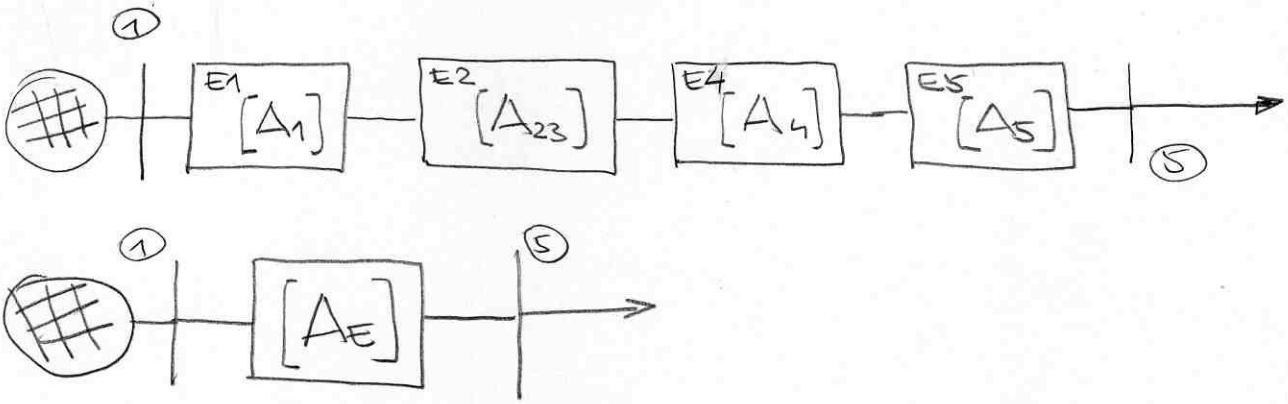
   PRIMJENOM LANCA PRIBLIŽNIH NADOMJESNIH Π ; T MODELA ZA DIONICE EE VODA KRAĆE OD $l$ 200 (100) km

# PRORAČUNI PRIJENOSA ELEKTRIČNE ENERGIJE SLOŽENIM PRIJENOSNIM SUSTAVOM

SLOŽENI PRIJENOSNI SUSTAV : PRIMJER




GRUPIRANJE : ELEMENTE PRIJENOSNOG SUSTAVA NADOMJESTIMO NADOMJESNIM MREŽNIM JEDNADŽBAMA $[A_i]$




$$[A_E] = [A_1][A_{23}][A_4][A_5]$$

$$[A_E] = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$$

$$\begin{bmatrix} \vec{V}_1 \\ \vec{I}_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} \vec{V}_5 \\ \vec{I}_5 \end{bmatrix}$$

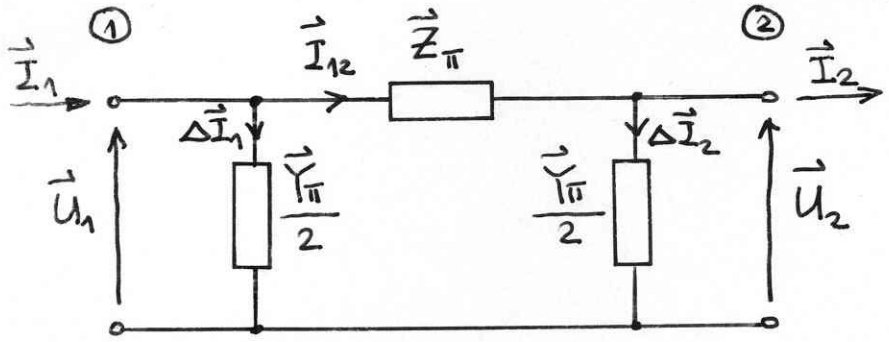
# 7.2 PRORAČUN PRIJENOSA ELEKTRIČNE ENERGIJE PRIMJENOM NADOMJESNIH MODELA EE VODOVA

VOD ODREĐENIH JEDINIČNIH KONSTANTI I ODREĐENE DUŽINE MOŽEMO PRIKAZATI NADOMJESNIM ČETVEROPOLOM.
U PRAKSI SE ELEMENTI ČETVEROPOLA RASPOREĐUJU PO : a) $\Pi$ SHEMI
b) T SHEMI

EKVIVALENTNE (NADOMJESNE) SHEME ODNOSNO ČETVEROPOLI VODOVA SLUŽE ZA RAČUNSKO I EKSPERIMENTALNO ODREĐIVANJE PRILIKA NA KRAJEVIMA VODA, DOK PRILIKE DUŽ VODA NE ODGOVARAJU ONIMA DUŽ ČETVEROPOLA.

## a) $\Pi$ SHEMA VODA

– TOČNA EKVIVALENTNA SHEMA VODA S KONCENTRIRANIM PARAMETRIMA

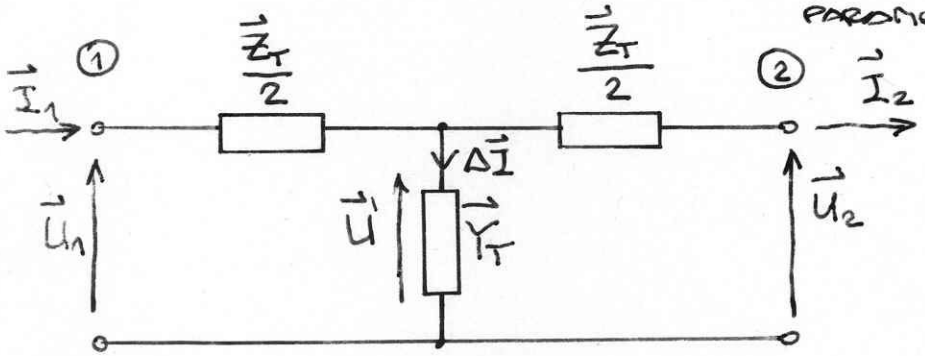



$$\vec{Z}_\Pi = \vec{Z}_c \, sh\gamma l = \vec{Z}\,\frac{sh\Theta}{\Theta}$$

$$\frac{\vec{Y}_\Pi}{2} = \frac{1}{\vec{Z}_c}\,\frac{ch\gamma l - 1}{sh\gamma l} = \frac{\vec{Y}}{2}\,\frac{th\,\Theta/2}{\Theta/2}$$

## b) T SHEMA VODA

– TOČNA EKVIVALENTNA SHEMA VODA S KONCENTRIRANIM PARAMETRIMA




$$\vec{Y}_T = \frac{1}{\vec{Z}_c}\,sh\gamma l = \vec{Y}\,\frac{sh\Theta}{\Theta}$$

$$\frac{\vec{Z}_T}{2} = \vec{Z}_c\,\frac{ch\gamma l - 1}{sh\gamma l} = \frac{\vec{Z}}{2}\,\frac{th\,\Theta/2}{\Theta/2}$$

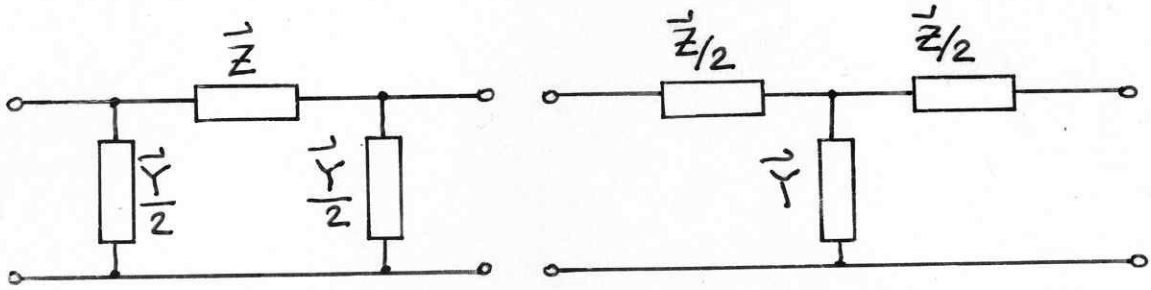
KOREKCIJSKI FAKTORI : $\frac{\sh\Theta}{\Theta}$ ; $\frac{\th\Theta/2}{\Theta/2}$

- RAČUNANJEM
- IZ WOODRUFFOVIH DIJAGRAMA

## c) PRIBLIŽNA $\Pi$ i T SHEMA VODA

KOD KRAĆIH VODOVA KOREKCIONI FAKTORI TEŽE

$\frac{\sh\Theta}{\Theta} \to 1$ $\qquad$ $\frac{\th\Theta/2}{\Theta/2} \to 1$




$\Pi$ SHEMA $\qquad$ T SHEMA

$\vec{Z}_\Pi = \vec{Z}$

$\frac{\vec{Y}_\Pi}{2} = \frac{\vec{Y}}{2}$

$\frac{\vec{Z}_T}{2} = \frac{\vec{Z}}{2}$

$\vec{Y}_T = \vec{Y}$

PRIBLIŽNE SHEME SU DOVOLJNE TOČNE (0,5%) ZA PRORAČUN PRIJENOSA NA

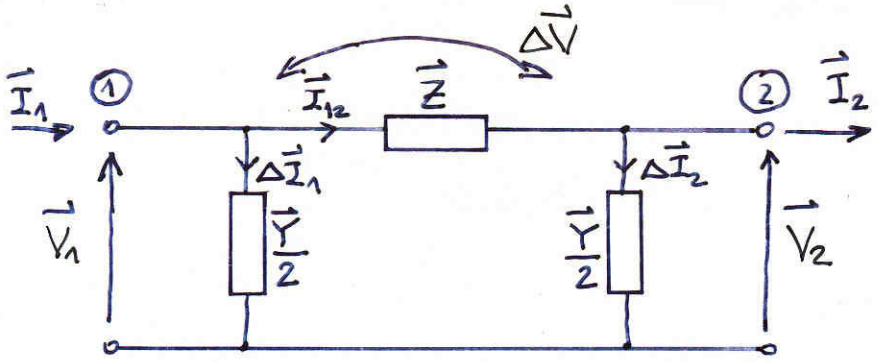
- NADZEMNIM VODOVIMA $\quad l \leq 200$ km
- KABELSKIM VODOVIMA $\quad l \leq 100$ km

NADZEMNE VODOVE $l > 200$ km TREBA PODIJELITI NA SEKTORE KRAĆE OD 200 km, TE SVAKI SEKTOR PRIKAZATI PRIBLIŽNOM EKVIVALENTNOM SHEMOM, A ONDA FORMIRATI LANAC ČETVEROLA.

PRORAČUN PRIJENOSA :

- TOČAN - TOČNA EKVIVALENTNA SHEMA VODA
- PRIBLIŽAN - PRIBLIŽNA EKVIVALENTNA SHEMA VODA

# PRORAČUN PRIJENOSA POMOĆU Π SHEME




$\vec{V}_1, \vec{V}_2$ fazni naponi

$\vec{Z} = R + jX$

$\frac{\vec{Y}}{2} = \frac{G}{2} + j\frac{B}{2}$

1. ZADANE PRILIKE NA KRAJU VODA : $U_2$ , $P_2, Q_2$

$P_2, Q_2$ - TROFAZNE SNAGE ; $\pm Q_2$ IND/KAP.

$U_2$ - LINIJSKI NAPON $\quad V_2 = U_{2L}/\sqrt{3}$

$\vec{V}_2 = V_2 \angle 0°$ FAZNI NAPON

STRUJA $\vec{I}_2$ : $\quad \vec{S}_2 = P_2 + jQ_2 = 3\vec{V}_2 \vec{I}_2^{\,*}$

$$\vec{I}_2^{\,*} = \frac{P_2 + jQ_2}{3\vec{V}_2} \rightarrow \vec{I}_2 = \frac{P_2 - jQ_2}{3V_2}$$

TIJEK PRORAČUNA :

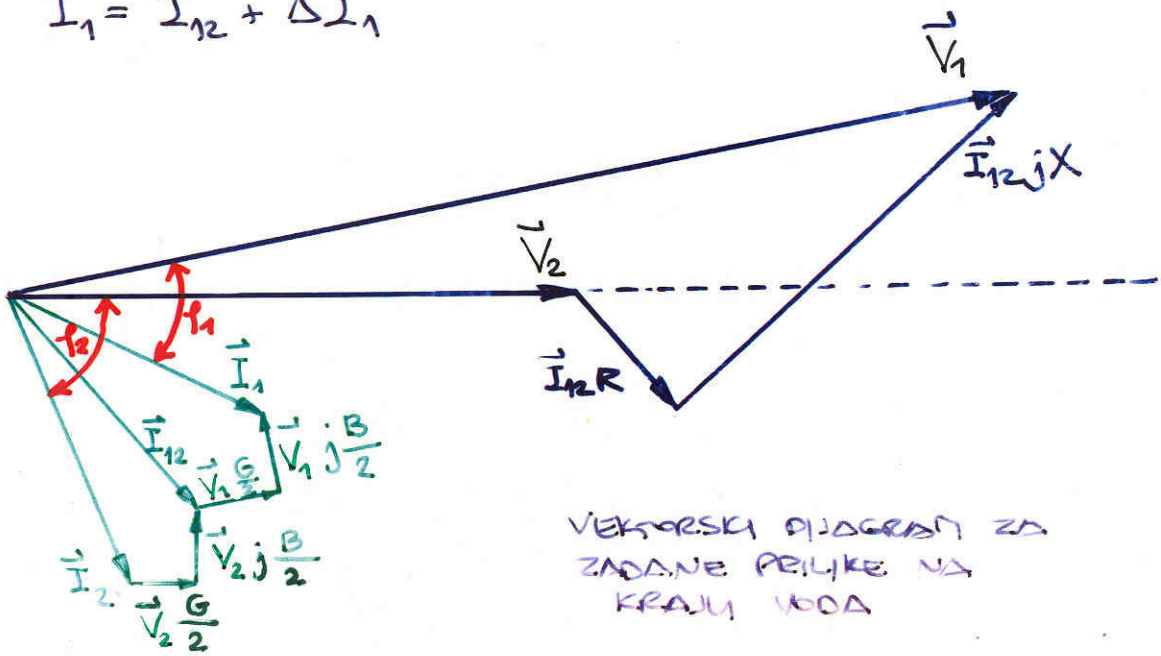
$$\Delta\vec{I}_2 = \vec{V}_2 \cdot \frac{\vec{Y}}{2}$$

$$\vec{I}_{12} = \vec{I}_2 + \Delta\vec{I}_2$$

$$\vec{V}_1 = \vec{V}_2 + \Delta\vec{V} = \vec{V}_2 + \vec{I}_{12}\vec{Z}$$

$$\Delta\vec{I}_1 = \vec{V}_1 \frac{\vec{Y}}{2}$$

$$\vec{I}_1 = \vec{I}_{12} + \Delta\vec{I}_1$$




VEKTORSKI DIJAGRAM ZA ZADANE PRILIKE NA KRAJU VODA

## 2. ZADANE PRILIKE NA POČETKU VODA : $U_1$, $P_1$, $Q_1$

$P_1, Q_1$ TROFAZNE SNAGE ; $\pm Q$ IND./KAP.

$U_1$ - LINIJSKI NAPON $\quad V_1 = U_1 / \sqrt{3}$

$\vec{V}_1 = V_1 \angle 0°$ FAZNI NAPON

STRUJA $\vec{I}_1$ :

$$\vec{S}_1 = P_1 + jQ_1 = 3\vec{V}_1 \vec{I}_1^*$$

$$\vec{I}_1 = \frac{P_1 - jQ_1}{3V_1}$$

TIJEK PRORAČUNA:

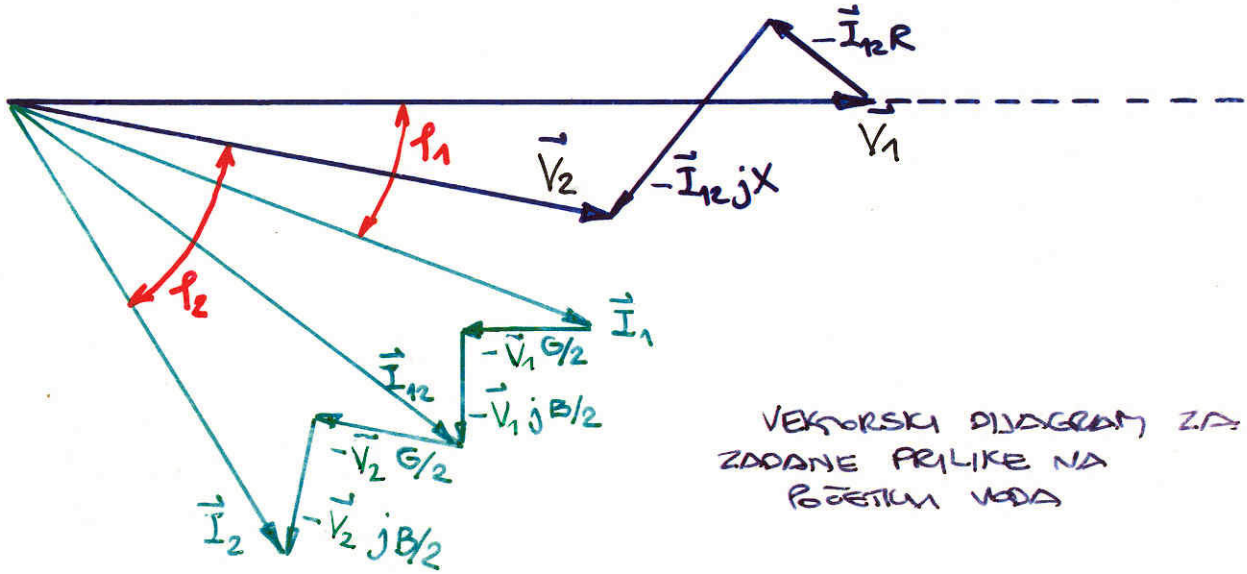
$$\Delta\vec{I}_1 = \vec{V}_1 \frac{\vec{Y}}{2}$$

$$\vec{I}_{12} = \vec{I}_1 - \Delta\vec{I}_1$$

$$\vec{V}_2 = \vec{V}_1 - \Delta\vec{V} = \vec{V}_2 - \vec{I}_{12}\vec{Z}$$

$$\Delta\vec{I}_2 = \vec{V}_2 \frac{\vec{Y}}{2}$$

$$\vec{I}_2 = \vec{I}_{12} - \Delta\vec{I}_2$$

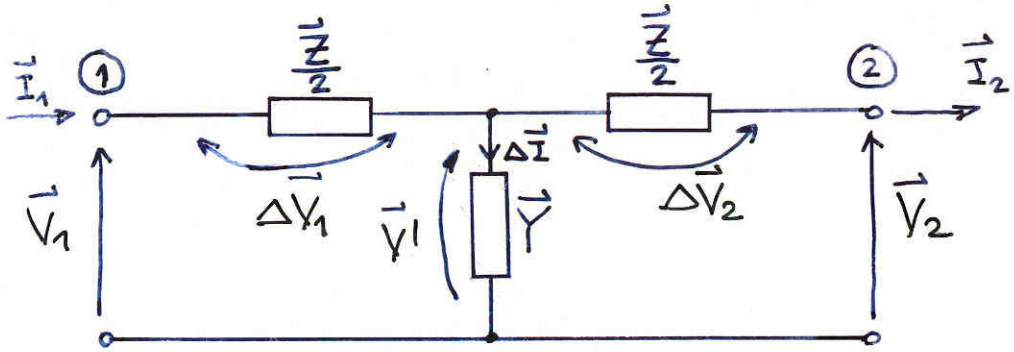



VEKTORSKI DIJAGRAM ZA ZADANE PRILIKE NA POČETKU VODA

PRORAČUN PRIJENOSA POMOĆU $\Pi$ SHEME

- GRAFIČKI
- ANALITIČKI
  - TOČAN
  - PRIBLIŽAN

# PRORAČUN PRIJENOSA POMOĆU T SHEME




$$\frac{\vec{Z}}{2} = \frac{R}{2} + j\frac{X}{2}$$

$$\vec{Y} = G + jB$$

1. ZADANE PRILIKE NA KRAJU VODA: $U_2$, $P_2$, $Q_2$

$$\vec{V}_2 = V_2 \angle 0° \quad \text{FAZNI NAPON}$$

$$\vec{S}_2 = P_2 + jQ_2 = 3\,\vec{V}_2\,\vec{I}_2^{\,*}$$

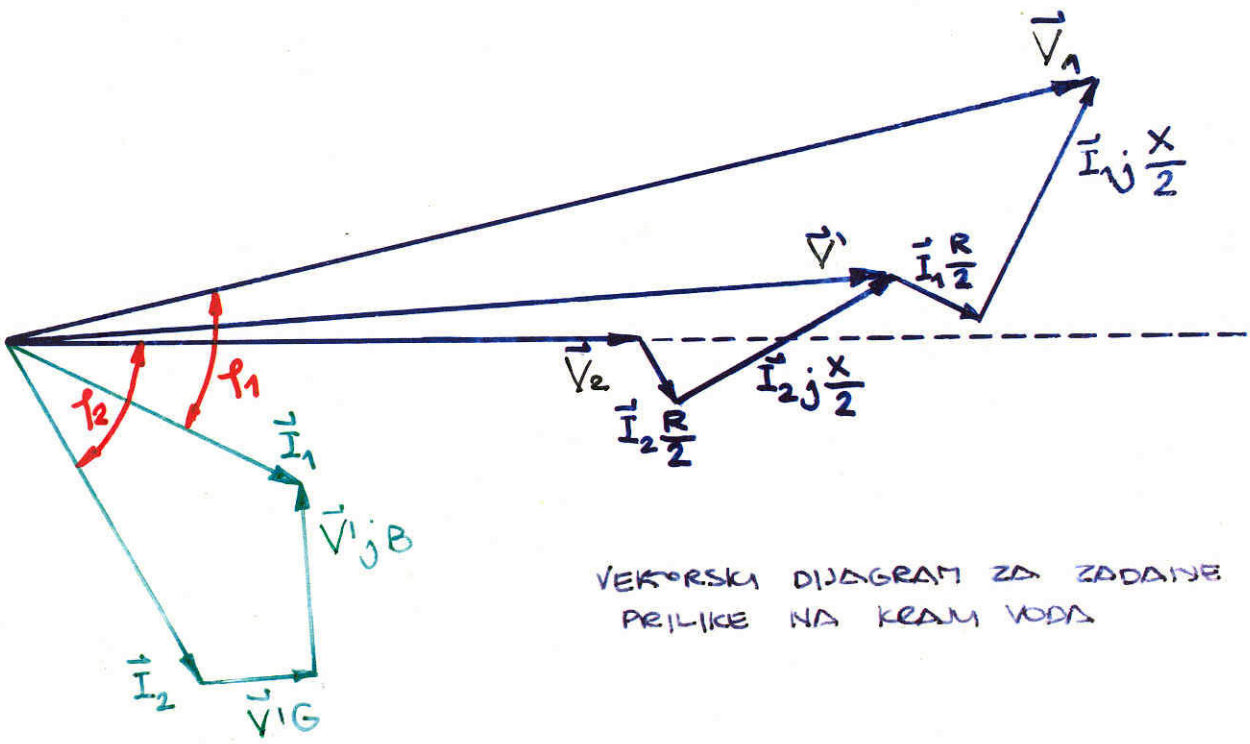
$$\vec{I}_2 = \frac{P_2 - jQ_2}{3\,V_2}$$

$$\vec{V}' = \vec{V}_2 + \Delta\vec{V}_2 = \vec{V}_2 + \vec{I}_2\frac{\vec{Z}}{2}$$

$$\Delta\vec{I} = \vec{V}'\cdot\vec{Y}$$

$$\vec{I}_1 = \vec{I}_2 + \Delta\vec{I}$$

$$\vec{V}_1 = \vec{V}' + \Delta\vec{V}_1 = \vec{V}' + \vec{I}_1\frac{\vec{Z}}{2}$$




VEKTORSKI DIJAGRAM ZA ZADANE PRILIKE NA KRAJU VODA

2. ZADANE PRILIKE NA POČETKU VODA : $U_1, P_1, Q_1$

$\vec{V}_1 = V_1 \angle 0°$ FAZNI NAPON

$\vec{S}_1 = P_1 + jQ_1 = 3\vec{V}_1 \vec{I}_1^*$

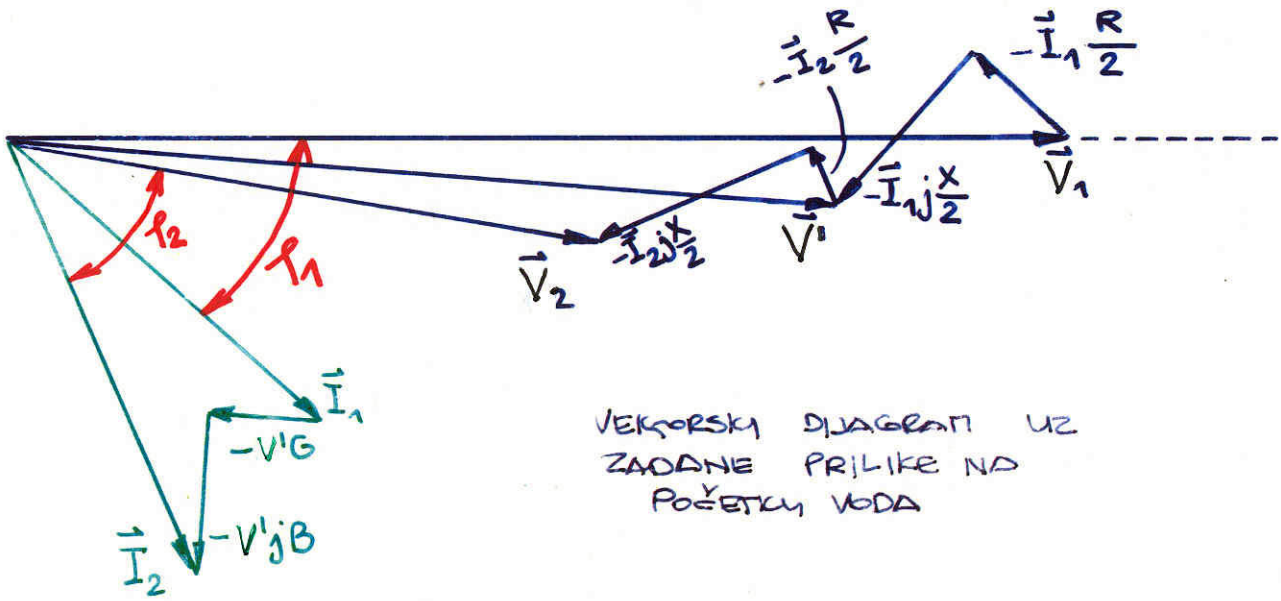
$\vec{I}_1 = \frac{P_1 - jQ_1}{3V_1}$

$\vec{V}' = \vec{V}_1 - \Delta\vec{V}_1 = \vec{V}_1 - \vec{I}_1 \frac{\vec{Z}}{2}$

$\Delta\vec{I} = \vec{V}' \cdot \vec{Y}$

$\vec{I}_2 = \vec{I}_1 - \Delta\vec{I}$

$\vec{V}_2 = \vec{V}' - \Delta\vec{V}_2 = \vec{V}' - \vec{I}_2 \frac{\vec{Z}}{2}$




VEKTORSKI DIJAGRAM UZ ZADANE PRILIKE NA POČETKU VODA

## PRORAČUN PRIJENOSA POMOĆU LANCA ČETVEROPOLA

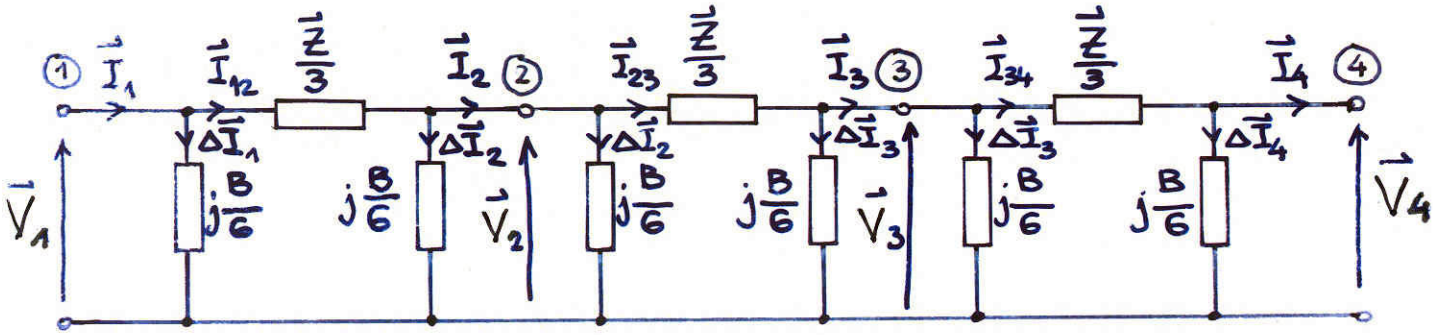
PRORAČUN PRIJENOSA NA DUGIM VODOVIMA $l > 200$ km

1. TOČAN PRORAČUN – PARAMETRE DUGIH VODOVA SE ODREDI TOČNIM POSTUPKOM (SA KOREKCIONIM FAKTORIMA)

2. PRIBLIŽNI PRORAČUN – DUGI VOD SE PODIJELI NA SEKTORE $\Delta l < 200$ km
   – ZA SVAKI SEKTOR SE NAĐE EKVIVALENTNA SHEMA I PRIKAŽE LANAC ČETVEROPOLA

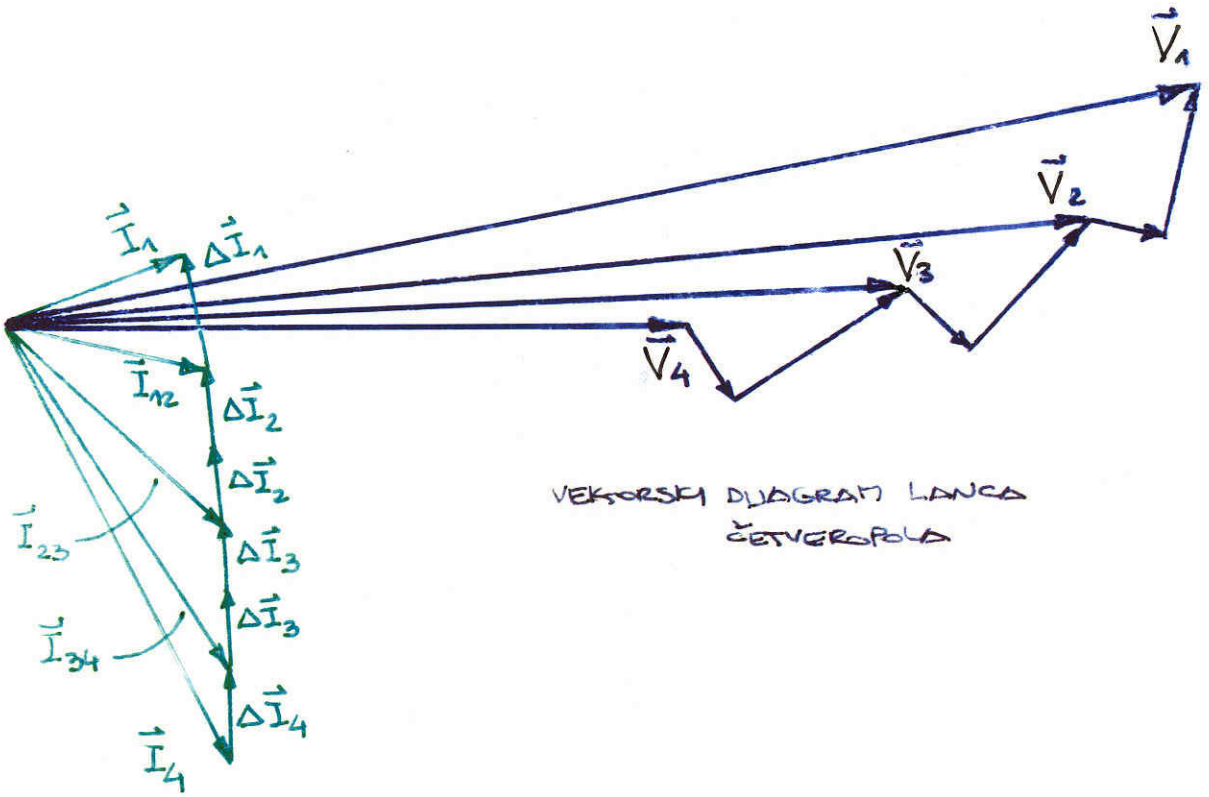
- PARAMETRE EKVIVALENTNE SHEME SVAKOG SEKTORA ODREDIMO PRIBLIŽNIM POSTUPKOM

PRIMJER: NEKA SU ZADANE EL. PRILIKE NA KRAJU VODA DUGOG IZMEĐU 400 I 600 km. PROVESTI PRORAČUN PRIJENOSA POMOĆU LANCA ČETVEROPOLA. ODVOD VODA ZANEMAREN.




LANAC ČETVEROPOLA

ZADANO: $\vec{V}_4, \vec{I}_4 \rightarrow \vec{V}_4 = V_4 \angle 0^\circ$

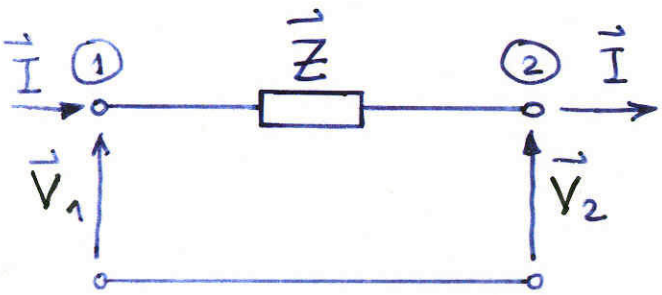



VEKTORSKI DIJAGRAM LANCA ČETVEROPOLA

# PRORAČUN PRIJENOSA NA SREDNJENAPONSKIM VODOVIMA

- PRORAČUN PRIJENOSA NA VODOVIMA VRLO VISOKOG NAPONA:
  - PARAMETRE EKVIVALENTNE SHEME ODREĐUJEMO NA BAZI $R, L, C, G$
- PRORAČUN PRIJENOSA NA VODOVIMA VISOKOG NAPONA
  $U < 200$ kV ($l < 200$ km)
  - PARAMETRE EKVIVALENTNE SHEME ODREĐUJEMO NA BAZI $R, L, C$ – ZANEMARENJE ODVODA $G$

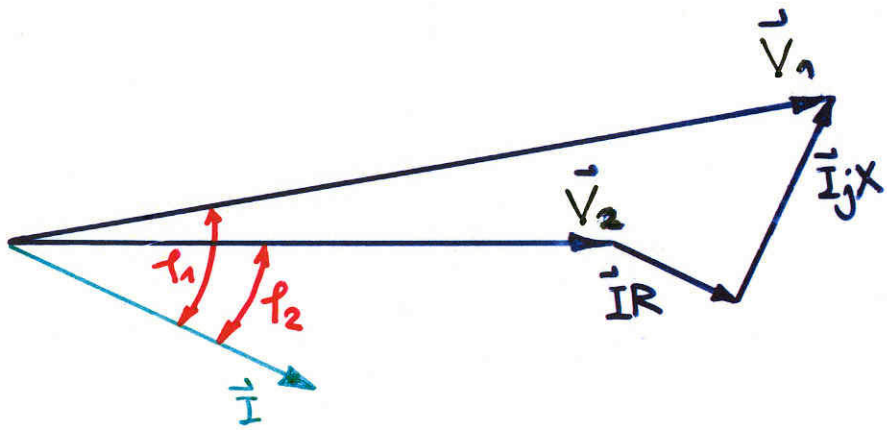
- PRORAČUN PRIJENOSA NA VODOVIMA SREDNJEG NAPONA:
  - STRUJE KROZ POPREČNE GRANE SU ZANEMARIVE U ODNOSU NA POGONSKU STRUJU, PA SE POPREČNE GRANE ($C, G$) ZANEMARUJU
  - PARAMETRI EKVIVALENTNE SHEME ODREĐUJU SE NA BAZI $R, L$ → $\vec{Z} = R + jX$



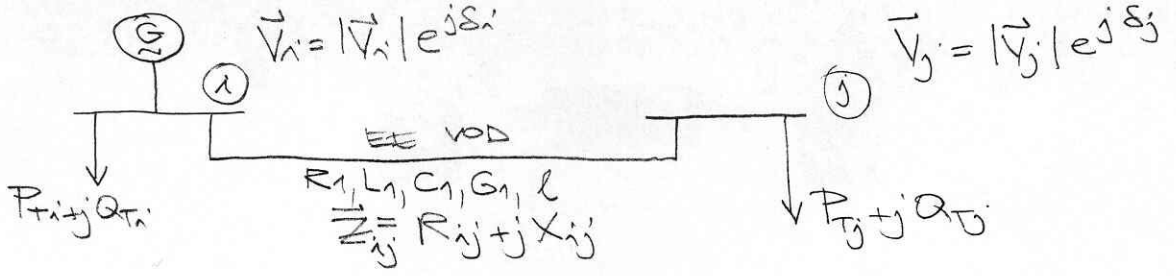

$$\vec{Z} = R + jX$$

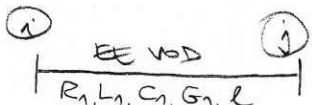
$$\vec{I}_1 = \vec{I}_2 = \vec{I}$$

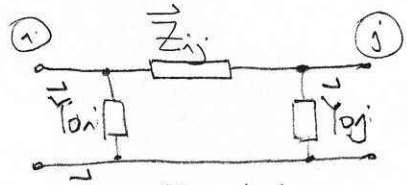
$$\vec{V}_1 = \vec{V}_2 + \vec{I}\,\vec{Z}$$



# 7.3 TOKOVI SNAGE NA ~~EE~~ VODU



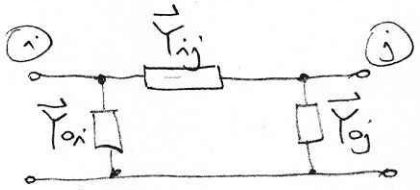




$\vec{Z}_{ij} = R_{ij} + jX_{ij}$

$\vec{Y}_{oi} = \frac{\vec{Y}}{2}$ $\vec{Y}_{oj} = \frac{\vec{Y}}{2}$

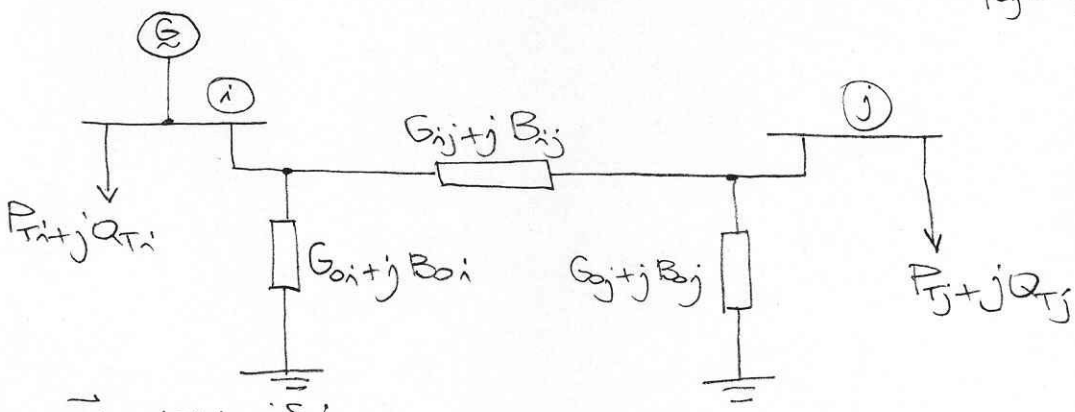
$\vec{Y} = G + jB$




$\vec{Y}_{ij} = \frac{1}{\vec{Z}_{ij}} = G_{ij} + jB_{ij}$

$\vec{Y}_{oi} = \frac{\vec{Y}}{2} = G_{oi} + jB_{oi}$

$\vec{Y}_{oj} = \frac{\vec{Y}}{2} = G_{oj} + jB_{oj}$




$\vec{V}_i = |\vec{V}_i| e^{j\delta_i}$

$\vec{S}_i = \vec{S}_{Gi} - \vec{S}_{Ti}$

$S_i = P_i + jQ_i$

$$\vec{S}_{ij} = 3\,\vec{V}_i\,\vec{I}_{ij} = 3\,\vec{V}_i\left[\vec{V}_i\left(G_{oi}+jB_{oi}\right) + \left(\vec{V}_i - \vec{V}_j\right)\left(G_{ij}+jB_{ij}\right)\right]^* =$$

$$= 3|\vec{V}_i| e^{j\delta_i}\left[|\vec{V}_i| e^{-j\delta_i}\left(G_{oi}-jB_{oi}\right) + \left(|\vec{V}_i| e^{-j\delta_i} - |\vec{V}_j| e^{-j\delta_j}\right)\left(G_{ij}-jB_{ij}\right)\right] =$$

$$= 3|\vec{V}_i| e^{j\delta_i}\left[|\vec{V}_i| e^{-j\delta_i}\left(G_{oi}-jB_{oi}\right) + |\vec{V}_i| e^{-j\delta_i}\left(G_{ij}-jB_{ij}\right) - |\vec{V}_j| e^{-j\delta_j}\left(G_{ij}-jB_{ij}\right)\right]$$

$$= 3\left[|\vec{V}_i|^2\left(G_{oi}-jB_{oi}\right) + |\vec{V}_i|^2\left(G_{ij}-jB_{ij}\right) - |\vec{V}_i||\vec{V}_j| e^{j(\delta_i-\delta_j)}\left(G_{ij}-jB_{ij}\right)\right]$$

$$= 3\left[|\vec{V}_i|^2\left(G_{oi}+G_{ij}\right) - j|\vec{V}_i|^2\left(B_{oi}+B_{ij}\right) - |\vec{V}_i||\vec{V}_j| e^{j\delta_{ij}} G_{ij} + \right.$$

$$\left. + j|\vec{V}_i||\vec{V}_j| e^{j\delta_{ij}} B_{ij}\right]$$

$$= 3\left[|\vec{V}_i|^2\left(G_{oi}+G_{ij}\right) - j|\vec{V}_i|^2\left(B_{oi}+B_{ij}\right) - |\vec{V}_i||\vec{V}_j| G_{ij}\cos\delta_{ij} - j|\vec{V}_i||\vec{V}_j| G_{ij}\sin\delta_{ij}\right.$$

$$\left. + j|\vec{V}_i||\vec{V}_j| B_{ij}\cos\delta_{ij} - |\vec{V}_i||\vec{V}_j| B_{ij}\sin\delta_{ij}\right]$$

$$= 3\left[|\vec{V}_i|^2\left(G_{oi}+G_{ij}\right) - |\vec{V}_i||\vec{V}_j|\left(G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij}\right) - j|\vec{V}_i|^2\left(B_{oi}+B_{ij}\right)\right.$$

$$\left. - j|\vec{V}_i||\vec{V}_j|\left(G_{ij}\sin\delta_{ij} - B_{ij}\cos\delta_{ij}\right)\right]$$

$$P_{ij} = Re\{\vec{S}_{ij}\} = 3\left[|\vec{V}_i|^2 (G_{oi} + G_{ij}) - |\vec{V}_i||\vec{V}_j|(G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij})\right]$$

$$Q_{ij} = Im\{\vec{S}_{ij}\} = 3\left[-|\vec{V}_i|^2 (B_{oi} + B_{ij}) - |\vec{V}_i||\vec{V}_j|(G_{ij}\sin\delta_{ij} - B_{ij}\cos\delta_{ij})\right]$$

Uz predpostavku $R=0$, $G=0$

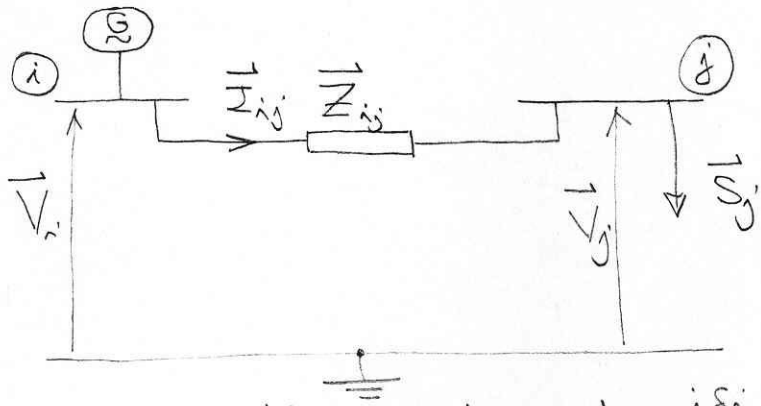
$$P_{ij} = -3|\vec{V}_i||\vec{V}_j| B_{ij}\sin\delta_{ij} = -|\vec{U}_i||\vec{U}_j| B_{ij}\sin\delta_{ij} = \frac{|\vec{U}_i||\vec{U}_j|}{X_{ij}}\sin\delta_{ij}$$

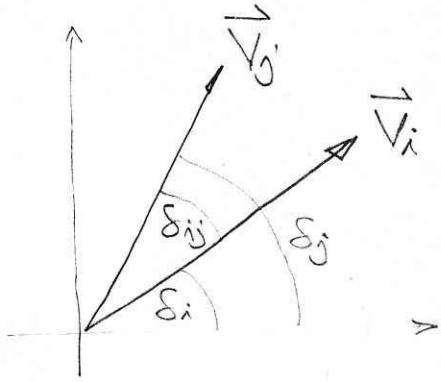
$$Q_{ij} = -3|\vec{V}_i|^2 (B_{oi} + B_{ij}) + 3|\vec{V}_i||\vec{V}_j| B_{ij}\cos\delta_{ij}$$

$$= -|\vec{U}_i|^2 (B_{oi} + B_{ij}) + |\vec{U}_i||\vec{U}_j| B_{ij}\cos\delta_{ij}$$

# 7.4 PRIJENOSNA MOĆ (SNAGA) EE VODOVA

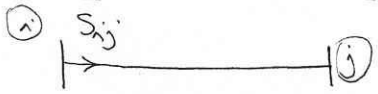
- PRIJENOSNA MOĆ (SNAGA) EE VODOVA U STATIČKIM UVJETIMA RADA EE MREŽA – OGRANIČENJE – – GRANICA STATIČKE STABILNOSTI




$$\vec{V}_i = |\vec{V}_i| e^{j\delta_i} \qquad \vec{V}_j = |\vec{V}_j| e^{j\delta_j}$$

$$\vec{I}_{ij} = \frac{\vec{V}_i - \vec{V}_j}{\vec{Z}_{ij}}$$




$$\vec{S}_{ij} = -\vec{S}_{ji} \qquad \vec{S}_{ij} = P_{ij} + jQ_{ij}$$

$$\vec{S}_{ij} = 3\vec{V}_i \vec{I}_{ij}^{\,*} = 3\vec{V}_i \frac{\vec{V}_i^{\,*} - \vec{V}_j^{\,*}}{\vec{Z}_{ij}^{\,*}} = 3\frac{|\vec{V}_i|^2 - |\vec{V}_i||\vec{V}_j| e^{j(\delta_i - \delta_j)}}{R_{ij} - jX_{ij}}$$

$$\delta_{ij} = \delta_i - \delta_j$$

$$\vec{S}_{ij} = P_{ij} + jQ_{ij} \qquad P_{ij} = \mathrm{Re}\{\vec{S}_{ij}\}$$

$$\vec{S}_{ij} = 3\frac{|\vec{V}_i|^2 - |\vec{V}_i||\vec{V}_j|\cos\delta_{ij} - j|\vec{V}_i||\vec{V}_j|\sin\delta_{ij}}{R_{ij} - jX_{ij}} \cdot \frac{R_{ij} + jX_{ij}}{R_{ij} + jX_{ij}}$$

$$\vec{S}_{ij} = 3\frac{|\vec{V}_i|^2 R_{ij} - |\vec{V}_i||\vec{V}_j|\cos\delta_{ij} R_{ij} - j|\vec{V}_i||\vec{V}_j|\sin\delta_{ij} R_{ij} +}{R_{ij}^2 + X_{ij}^2}$$

$$\frac{+j|\vec{V}_i|^2 X_{ij} - j|\vec{V}_i||\vec{V}_j|\cos\delta_{ij} X_{ij} + |\vec{V}_i||\vec{V}_j|\sin\delta_{ij} X_{ij}}{}$$

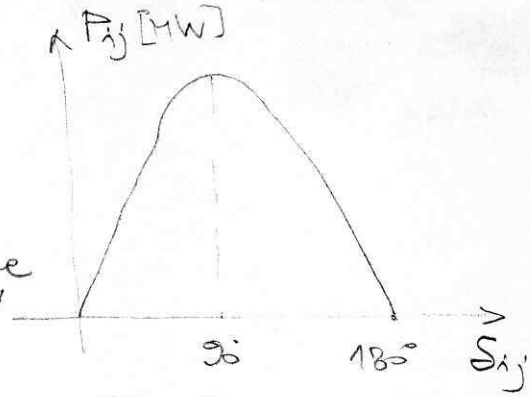
$$P_{ij} = \mathrm{Re}\{\vec{S}_{ij}\} = 3\frac{1}{R_{ij}^2 + X_{ij}^2}\left[R_{ij}|\vec{V}_i|^2 - R_{ij}|\vec{V}_i||\vec{V}_j|\cos\delta_{ij} + \right.$$

$$\left. + X_{ij}|\vec{V}_i||\vec{V}_j|\sin\delta_{ij}\right]$$

VISOKONAPONSKI ~~EE~~ VODOVI $R \ll X$ pa $R = 0$

$$P_{ij} = 3 \frac{1}{X_{ij}^2} X_{ij} |\vec{V}_i| |\vec{V}_j| \sin \delta_{ij}$$

$$P_{ij} = 3 \frac{|\vec{V}_i| |\vec{V}_j|}{X_{ij}} \sin \delta_{ij}$$




$\delta_{ij} = 90$ granica ~~stabilne~~ stabilnosti

$P_{ij} = P_{max} \cdot \sin \delta_{ij}$

Maksimalna ~~teorijska~~ prijenosna moć (snaga) ~~EE~~ voda

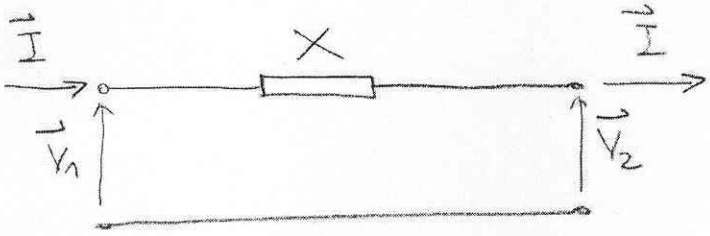
$$P_{ij} = P_{ij\,max} = 3 \frac{|\vec{V}_i| |\vec{V}_j|}{X_{ij}} = \frac{|\vec{U}_i| |\vec{U}_j|}{X_{ij}}$$

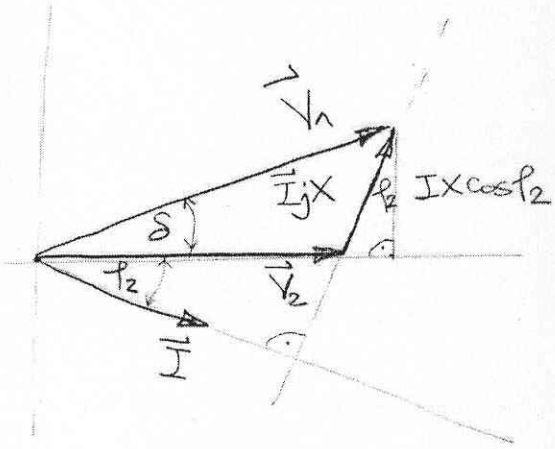
# GRANIČNA SNAGA PRIJENOSA

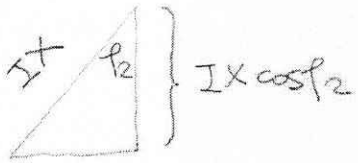
- GRANIČNA SNAGA PRIJENOSA NEKIM PRIJENOSNIM SUSTAVOM – KOLIKO SE DJELATNE SNAGE MOŽE STABILNO PRENOSITI
- ZANEMARUJU SE DJELATNI OTPORI U UZDUŽNIM GRANAMA I POPREČNE GRANE MODELA ELEMENATA

$X = \text{konst.}$ $U_1 = \text{konst.}$ $U_2 = \text{konst.}$

PRIJENOSNI SUSTAV:




$$\sin\delta = \frac{IX\cos\varphi_2}{V_1} \cdot \frac{V_2}{V_2} = \frac{IX\cos\varphi_2 V_2}{V_1 V_2}$$

$$P_2 = V_2 I \cos\varphi_2 \qquad P_1 = P_2 = P$$

$$\sin\delta = \frac{X \cdot P}{V_1 V_2} \Rightarrow \boxed{P = \frac{V_1 V_2}{X}\sin\delta}$$

SNAGA TROFAZNOG SUSTAVA

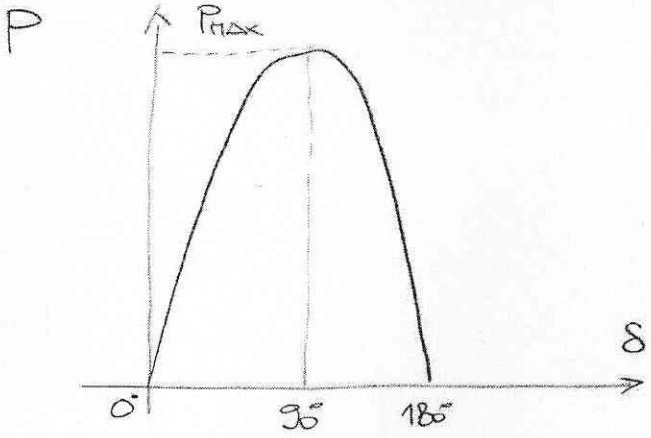
$$P = 3\frac{V_1 V_2}{X}\sin\delta = 3\frac{\frac{U_1}{\sqrt{3}}\frac{U_1}{\sqrt{3}}}{X}\sin\delta$$

$$\boxed{P = \frac{U_1 U_2}{X}\sin\delta}$$

# MAKSIMALNA SNAGA PRIJENOSA

$\delta = 90°$

$$P_{MAX} = \frac{U_1 U_2}{X}$$

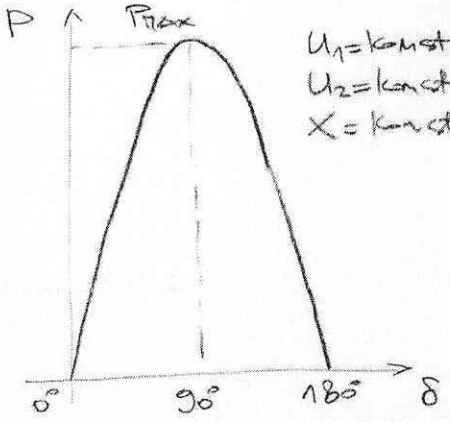



- PODRUČJE $0 - 90°$
  PODRUČJE STABILNOG RADA
- PODRUČJE $90° - 180°$
  PODRUČJE NESTABILNOG RADA

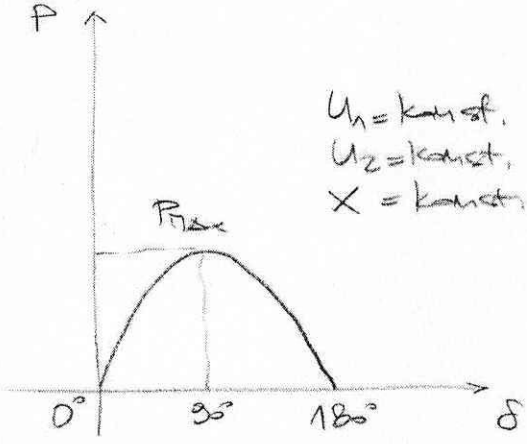
VODEĆE PRAVILO

$P_{opt} \leq \frac{2}{3} P_{max}$

$\delta = 42°$




JAKI PRIJENOSNI SUSTAV



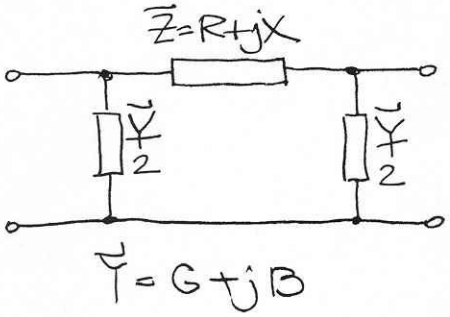

SLABI PRIJENOSNI SUSTAV

# 7,5 PAD NAPONA I GUBITAK NAPONA NA EL.EN. VODU

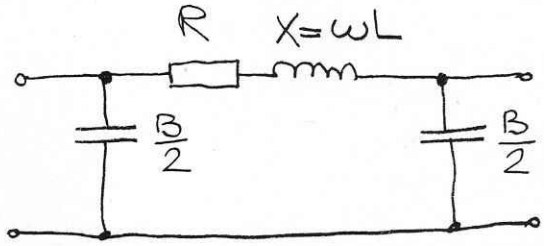
## GUBICI SNAGE NA EL.EN. VODU

# PAD NAPONA I GUBITAK NAPONA NA EL. EN. VODU

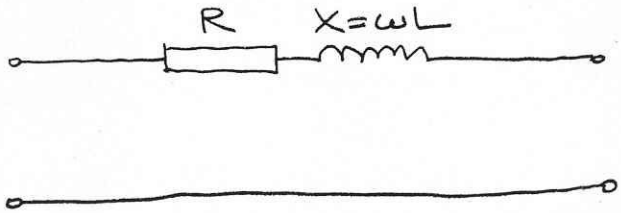
EL. EN. VOD – KONSTANTE R, L, C, G




$\approx$



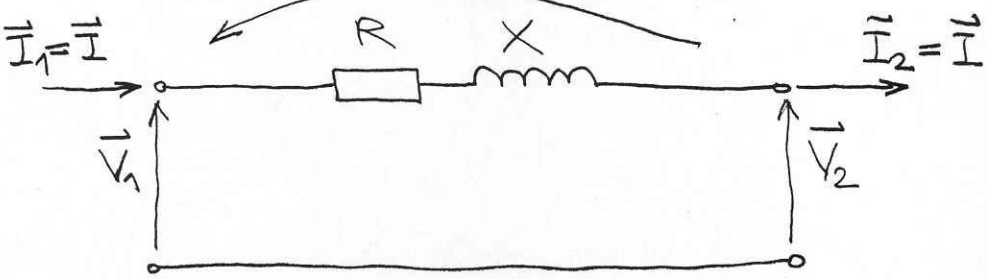

ZANEMARENJE $G=0$




UZ ZANEMARENJE KAPACITETA VODA (KAPACITIVNA POPREČNA STRUJA)

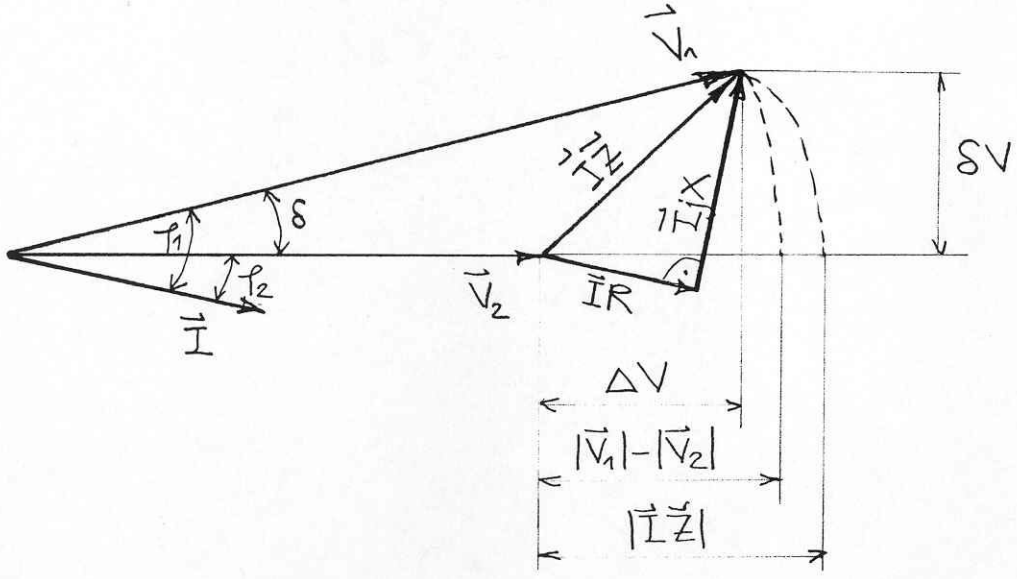
$\vec{Z}=R+jX=R+j\omega L$

EL. EN. VOD: $\Delta\vec{V}=\vec{I}\vec{Z}$




$\vec{Z}=R+jX$

$\Delta\vec{V}=\vec{I}\vec{Z}$



PAD NAPONA : $\Delta\vec{V} = \vec{V}_1 - \vec{V}_2 = \vec{I}\,\vec{Z}$

$\vec{V}_1 = \vec{V}_2 + \Delta\vec{V} = \vec{V}_2 + \vec{I}\,\vec{Z}$

UZDUŽNA KOMPONENTA PADA NAPONA $\Delta V = Re(\Delta\vec{V})$

POPREČNA KOMPONENTA PADA NAPONA $\delta V = Im(\Delta\vec{V})$

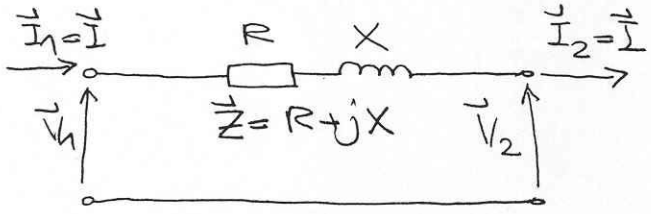
$\Delta\vec{V} = \Delta V + j\,\delta V$

GUBITAK NAPONA $gV = |\vec{V}_1| - |\vec{V}_2|$

$|\Delta\vec{V}| > gV > \Delta V$

$|\vec{I}\vec{Z}| > |\vec{V}_1| - |\vec{V}_2| > \Delta V$

a) ZADANE EL. PRILIKE NA KRAJU VODA : $\vec{V}_2, \vec{I}_2$



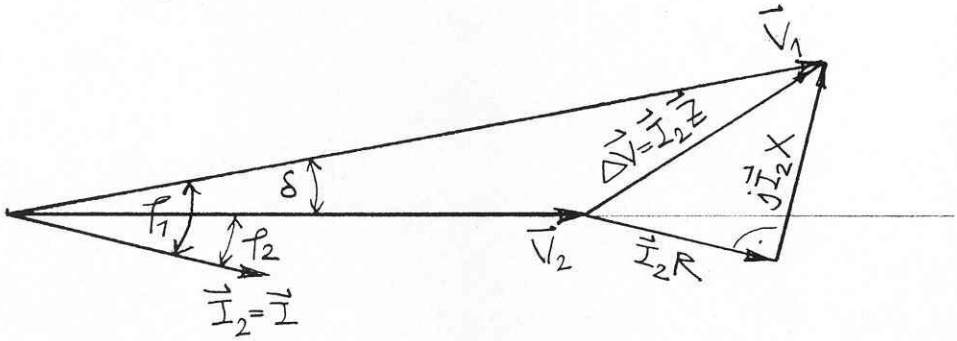

$\vec{Z} = R + jX = R + j\omega L$

$\vec{V}_2 = V_2 \angle 0^\circ \qquad \vec{U}_2 = U_2 \angle 0^\circ$

$\vec{S}_2 = P_2 + jQ_2 = 3\vec{V}_2\vec{I}_2^{\,*} = \sqrt{3}\,\vec{U}_2\vec{I}_2^{\,*}$

$\vec{S}_2 = P_2 + jQ_2$ TROFAZNA SNAGA

$\pm Q_2$




$\vec{V}_2 = V_2 \angle 0^\circ$

PAD NAPONA : $\Delta\vec{V} = \vec{I}_2\vec{Z}$

$\vec{S}_2 = P_2 + jQ_2 = 3\vec{V}_2\vec{I}_2^{\,*}$ $\qquad \vec{Z} = R + jX$

$\vec{I}_2^{\,*} = \dfrac{\vec{S}_2}{3\vec{V}_2} \qquad \vec{I}_2 = \dfrac{\vec{S}_2^{\,*}}{3\vec{V}_2^{\,*}} = \dfrac{P_2 - jQ_2}{3V_2}$

$$\Delta\vec{V} = \vec{I}_2 \cdot \vec{Z} = \frac{P_2 - jQ_2}{3V_2}(R + jX)$$

$$\Delta\vec{V} = \frac{P_2R + Q_2X}{3V_2} + j\frac{P_2X - Q_2R}{3V_2} = \Delta V + j\delta V$$

FAZNI PAD NAPONA:

$$\Delta\vec{V} = \frac{P_2R + Q_2X}{3V_2} + j\frac{P_2X - Q_2R}{3V_2}$$

$$\Delta\vec{V} = \frac{P_2R + Q_2X}{\sqrt{3}U_2} + j\frac{P_2X - Q_2R}{\sqrt{3}U_2}$$

LINIJSKI PAD NAPONA:

$$\Delta\vec{U} = \frac{P_2R + Q_2X}{U_2} + j\frac{P_2X - Q_2R}{U_2}$$

$$\Delta\vec{U} = \frac{P_2R + Q_2X}{\sqrt{3}V_2} + j\frac{P_2X - Q_2R}{\sqrt{3}V_2}$$

$$\Delta\vec{U} = \Delta U + j\delta U$$

$$|\vec{V}_1| = \sqrt{(V_2 + \Delta V)^2 + (\delta V)^2} \qquad |\vec{U}_1| = \sqrt{(U_2 + \Delta U)^2 + (\delta U)^2}$$

$$\delta = \operatorname{arc\,tg}\frac{\delta V}{V_2 + \Delta V} \qquad \delta = \operatorname{arc\,tg}\frac{\delta U}{U_2 + \Delta U}$$

KAKO JE: $\delta V \ll V_2 + \Delta V \rightarrow \delta \ll \rightarrow \delta V \approx 0$

$$\Delta\vec{V} = \Delta V = \frac{P_2R + Q_2X}{3V_2} = \frac{P_2R + Q_2X}{\sqrt{3}U_2}$$

$$\Delta\vec{U} = \Delta U = \frac{P_2R + Q_2X}{U_2} = \frac{P_2R + Q_2X}{\sqrt{3}V_2}$$

UZ ZANEMARENJE GUBITAKA NA VODU: $P_2 + jQ_2 = P_1 + jQ_1 = P + jQ$

$P_1 = P_2 = P \quad Q_1 = Q_2 = Q$

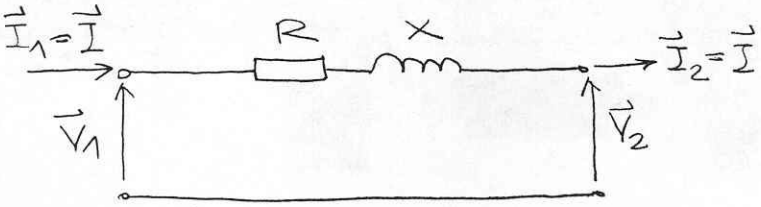
NAPON $V_2 \rightarrow$ PROSJEČAN NAPON $V_m$

$$\Delta V = \frac{PR + QX}{3V_m} \qquad \Delta U = \frac{PR + QX}{U_m}$$

RELATIVNI PAD NAPONA:

$$\Delta v = \frac{\Delta V}{V_m} = \frac{PR + QX}{3V_m^2} \qquad \Delta u = \frac{\Delta U}{U_m} = \frac{PR + QX}{U_m^2}$$

b) ZADANE EL. PRILIKE NA POČETKU VODA : $\vec{V}_1, \vec{I}_1$

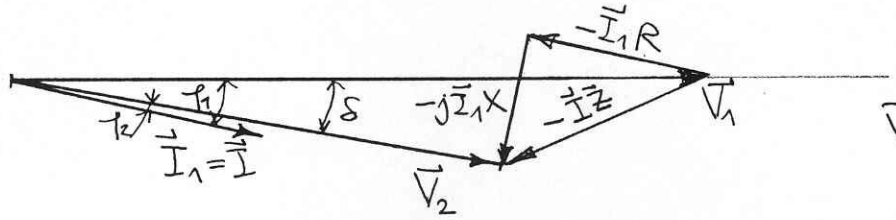



$\vec{Z}=R+jX=R+j\omega L$

$\vec{V}_1=V_1\angle 0^\circ \quad \vec{U}_1=U_1\angle 0^\circ$

$\vec{S}_1=P_1+jQ_1=3\vec{V}_1\vec{I}_1^*=\sqrt{3}\vec{U}_1\vec{I}_1^*$

$\vec{S}_1=P_1+jQ_1$ TROFAZNA SNAGA




$\vec{V}_1=V_1\angle 0^\circ$

PAD NAPONA : $\Delta\vec{V}=\vec{I}_1\vec{Z}$

$\vec{S}_1=P_1+jQ_1=3\vec{V}_1\vec{I}_1^* \qquad \vec{Z}=R+jX$

$\vec{I}_1^*=\frac{\vec{S}_1}{3\vec{V}_1} \qquad \vec{I}_1=\frac{\vec{S}_1^*}{3\vec{V}_1^*}=\frac{P_1-jQ_1}{3V_1}$

$\Delta\vec{V}=\vec{I}_1\vec{Z}=\frac{P_1-jQ_1}{3V_1}(R+jX)$

$\Delta\vec{V}=\frac{P_1R+Q_1X}{3V_1}+j\frac{P_1X-Q_1R}{3V_1}=\Delta V+j\delta V$

FAZNI PAD NAPONA: $\Delta\vec{V}=\frac{P_1R+Q_1X}{3V_1}+j\frac{P_1X-Q_1R}{3V_1}=\frac{P_1R+Q_1X}{\sqrt{3}U_1}+j\frac{P_1X-Q_1R}{\sqrt{3}U_1}$

LINIJSKI PAD NAPONA: $\Delta\vec{U}=\frac{P_1R+Q_1X}{U_1}+j\frac{P_1X-Q_1R}{U_1}=\frac{P_1R+Q_1X}{\sqrt{3}V_1}+j\frac{P_1X-Q_1R}{\sqrt{3}V_1}$

$\vec{V}_2=\vec{V}_1-\Delta\vec{V} \qquad \vec{U}_2=\vec{U}_1-\Delta\vec{U}$

$|\vec{V}_2|=\sqrt{(V_1-\Delta V)^2+(\delta V)^2} \qquad |\vec{U}_2|=\sqrt{(U_1-\Delta U)^2+(\delta U)^2}$

$\delta=\text{arc tg}\,\frac{\delta V}{V_1-\Delta V} \qquad \delta=\text{arc tg}\,\frac{\delta V}{U_1-\Delta U}$

KAKO JE: $\delta V \ll V_1 - \Delta V \rightarrow \delta \ll \rightarrow \delta V \approx 0$

$$\vec{\Delta V} = \Delta V = \frac{P_1 R + Q_1 X}{3 V_1} = \frac{P_1 R + Q_1 X}{\sqrt{3} U_1}$$

$$\vec{\Delta U} = \Delta U = \frac{P_1 R + Q_1 X}{U_1} = \frac{P_1 R + Q_1 X}{\sqrt{3} U_1}$$

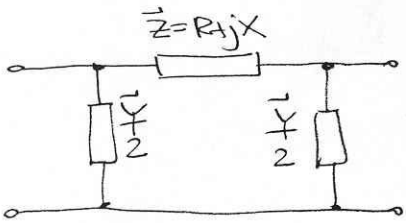
UZ $P_1 = P_2 = P$ , $Q_1 = Q_2 = Q$ I $V_1 \rightarrow V_m$

$$\Delta V = \frac{PR + QX}{3 V_m} \qquad \Delta U = \frac{PR + QX}{U_m}$$

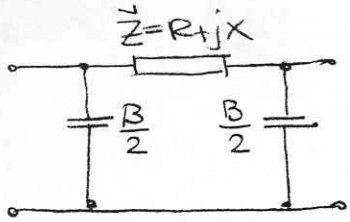
RELATIVNI PAD NAPONA:

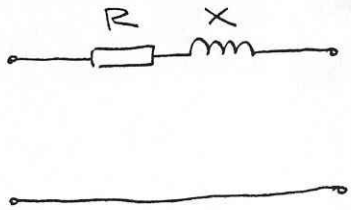
$$\Delta v = \frac{\Delta V}{V_m} = \frac{PR + QX}{3 V_m^2} \qquad \Delta u = \frac{PR + QX}{U_m^2} = \frac{\Delta U}{U_m}$$

# GUBICI SNAGE NA EL. EN. VODU

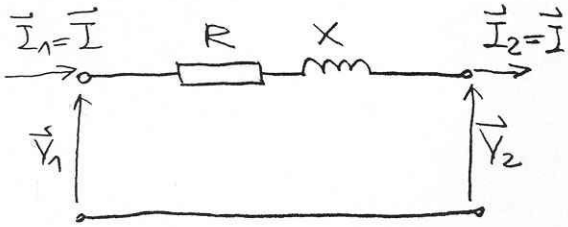



$\vec{Y} = G+jB$




$\vec{Z} = R+jX = R+j\omega L$




$\vec{Z} = R+jX = R+j\omega L$

GUBITAK SNAGE : $\Delta\vec{S} = \Delta\vec{V}\cdot\vec{I}^* = \vec{I}\cdot\vec{Z}\,\vec{I}^*$

TROFAZNI GUBITAK SNAGE : $\Delta\vec{S} = 3\,\Delta\vec{V}\cdot\vec{I}^* = 3\,\vec{I}\cdot\vec{Z}\cdot\vec{I}^*$

$$\Delta\vec{S} = \Delta P + j\,\Delta Q$$

$\Delta P$ = DJELATNI (AKTIVNI) GUBITAK SNAGE

$$\Delta P = Re(\Delta\vec{S}) = Re\left(3\vec{I}\,\vec{Z}\,\vec{I}^*\right) = Re\left(3|\vec{I}|^2\vec{Z}\right)$$

$$\Delta P = Re\left[3|\vec{I}|^2(R+jX)\right] = 3|\vec{I}|^2 R$$

$\Delta Q$ = JALOVI (REAKTIVNI) GUBITAK SNAGE

$$\Delta Q = Im(\Delta\vec{S}) = Im\left(3\vec{I}\,\vec{Z}\,\vec{I}^*\right) = Im\left(3|\vec{I}|^2\vec{Z}\right)$$

$$\Delta Q = Im\left[3|\vec{I}|^2(R+jX)\right] = 3|\vec{I}|^2 X$$

STRUJA KROZ VOD :

$\vec{S} = P+jQ$ TROFAZNA SNAGA VODA

$\vec{S} = 3\vec{V}\vec{I}^*$

$$\vec{I}^* = \frac{\vec{S}}{3\vec{V}} \qquad \vec{I} = \frac{\vec{S}^*}{3\vec{V}^*} = \frac{P-jQ}{3\vec{V}^*}$$

$$|\vec{I}| = \frac{|\vec{S}^*|}{3|\vec{V}^*|} = \frac{\sqrt{P^2+Q^2}}{3V}$$

$$\Delta P = 3|\vec{I}|^2 R = 3\frac{P^2+Q^2}{9V_m^2}R = \frac{P^2+Q^2}{3V_m^2}R = \frac{P^2+Q^2}{U_m^2}R$$

$$\Delta Q = 3|\vec{I}|^2 Q = 3\frac{P^2+Q^2}{9V_m^2}X = \frac{P^2+Q^2}{3V_m^2}X = \frac{P^2+Q^2}{U_m^2}X$$

a) ZADANE EL. PRILIKE NA KRAJU VODA

$\vec{V}_2, \vec{U}_2 \qquad \vec{S}_2 = P_2 + jQ_2$

$$\vec{I}_2 = \frac{P_2 - jQ_2}{3V_2} \qquad |\vec{I}_2|^2 = \frac{P_2^2+Q_2^2}{9V_2^2}$$

$$\Delta P = 3|\vec{I}_2|^2 R = 3\frac{P_2^2+Q_2^2}{9V_2^2}R = \frac{P_2^2+Q_2^2}{3V_2^2}R = \frac{P_2^2+Q_2^2}{U_2^2}R$$

$$\Delta Q = 3|\vec{I}_2|^2 X = 3\frac{P_2^2+Q_2^2}{9V_2^2}X = \frac{P_2^2+Q_2^2}{3V_2^2}X = \frac{P_2^2+Q_2^2}{U_2^2}X$$

b) ZADANE EL. PRILIKE NA POČETKU VODA

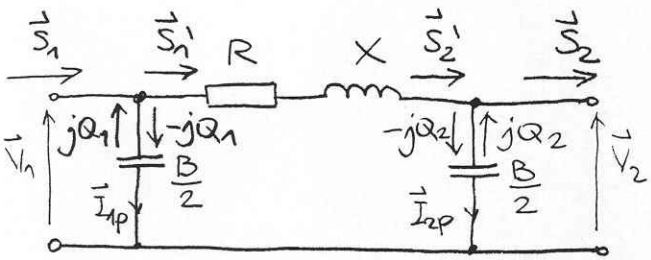
$\vec{V}_1, \vec{U}_1 \qquad \vec{S}_1 = P_1 + jQ_1$

$$\vec{I}_1 = \frac{P_1 - jQ_1}{3V_1} \qquad |\vec{I}_1|^2 = \frac{P_1^2+Q_1^2}{9V_1^2}$$

$$\Delta P = 3|\vec{I}_1|^2 R = 3\frac{P_1^2+Q_1^2}{9V_1^2}R = \frac{P_1^2+Q_1^2}{3V_1^2}R = \frac{P_1^2+Q_1^2}{U_1^2}R$$

$$\Delta Q = 3|\vec{I}_1|^2 X = 3\frac{P_1^2+Q_1^2}{9V_1^2}X = \frac{P_1^2+Q_1^2}{3V_1^2}X = \frac{P_1^2+Q_1^2}{U_1^2}X$$

EL. EN. VOD :




KAPACITET PROIZVODI INDUKTIVNU JALOVU SNAGU

$$Q_1 = I_{1p}U_1 = U_1\frac{B}{2}U_1 = U_1^2\frac{B}{2}$$

$$Q_2 = I_{2p}U_2 = U_2\frac{B}{2}U_2 = U_2^2\frac{B}{2}$$

$$\vec{S}_2 = \vec{S}_2' + jQ_2 \qquad \vec{S}_2' = \vec{S}_2 - jQ_2$$

$$\vec{S}_1' = \vec{S}_2' + \Delta\vec{S} = \vec{S}_2' + \Delta P + j\Delta Q$$

$$\Delta P = \frac{(P_2')^2+(Q_2')^2}{U_2^2}R \qquad \Delta Q = \frac{(P_2')^2+(Q_2')^2}{U_2^2}X$$

$$\vec{S}_1' = \vec{S}_1 + jQ_1$$

$$\vec{S}_1 = \vec{S}_1' - jQ_1$$

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