

ANALIZA ELEKTROENERGETSKOG SUSTAVA

Predavanje br. 10.

- PROBLEMATIKA KRATKOG SPOJA

- Dvije vrste kvarova:

1. Uzdužni kvarovi – prekid vodiča
2. Poprečni kvarovi – proboj izolacije (Ovi kvarovi nazivaju se kratki spojevi)

- Uzroci kratkih spojeva:

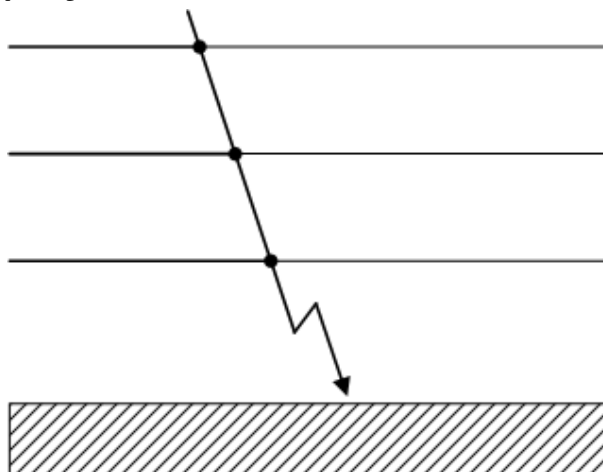
1. Slom izolacije
 - a) Zbog povećanja električnog naprezanja
 - b) Zbog smanjenja čvrstoće izolacije
 - c) Zbog kombinacije uzroka pod a) i b)

– Električna naprezanja izolacije:

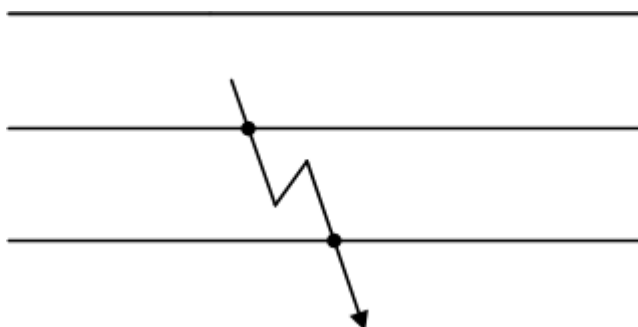
- a) Pogonski napon
- b) Povišenje napona (Ferantijev efekt, zemljospoj)
- c) Unutrašnji prenaponi (sklapanje, ferorezonancija)
- d) Atmosferski prenaponi
- e) Utjecaj mreže višeg napona (najgori: dodir)

- VRSTE KRATKIH SPOJEVA

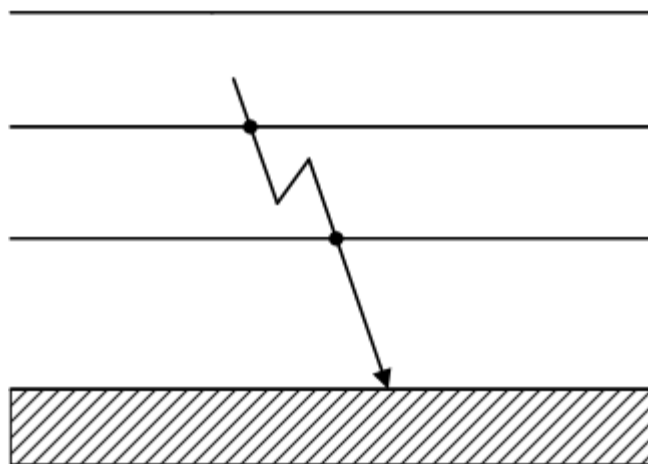
a) Tropolni kratki spoj



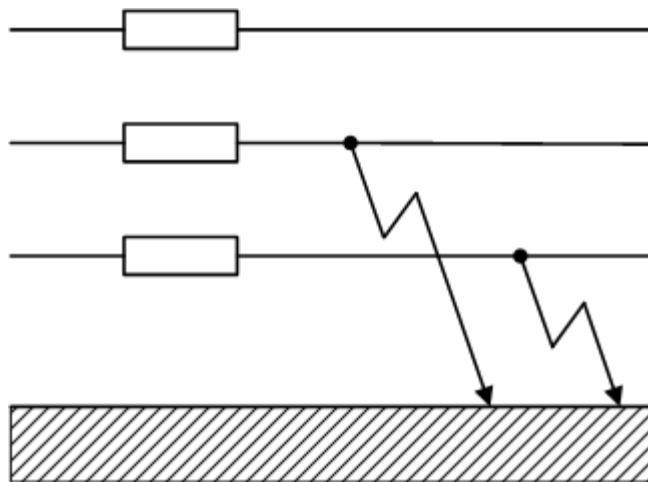
b) Dvopolni kratki spoj



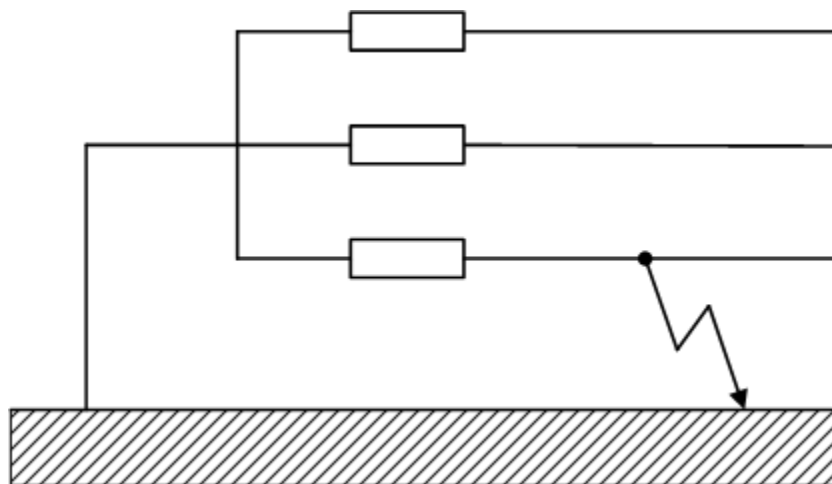
c) Dvopolni kratki spoj sa zemljom



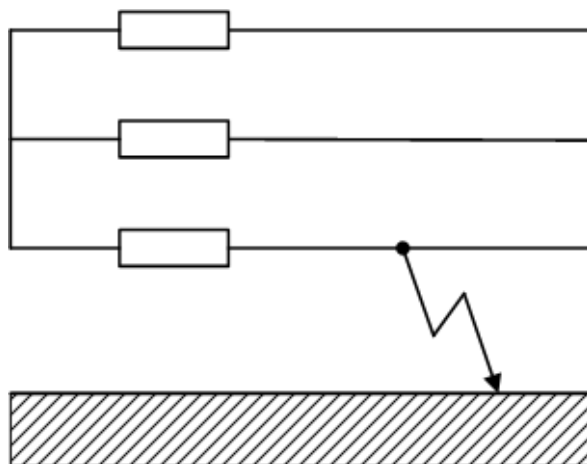
d) Dvostruki zemljospoj neuzemljene mreže



e) Jednopolni kratki spoj

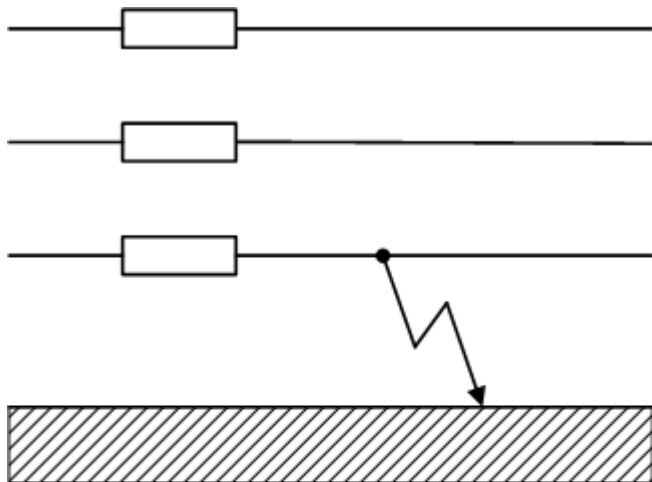


f) Zemljospoj

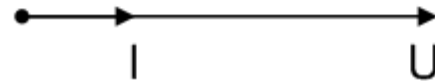
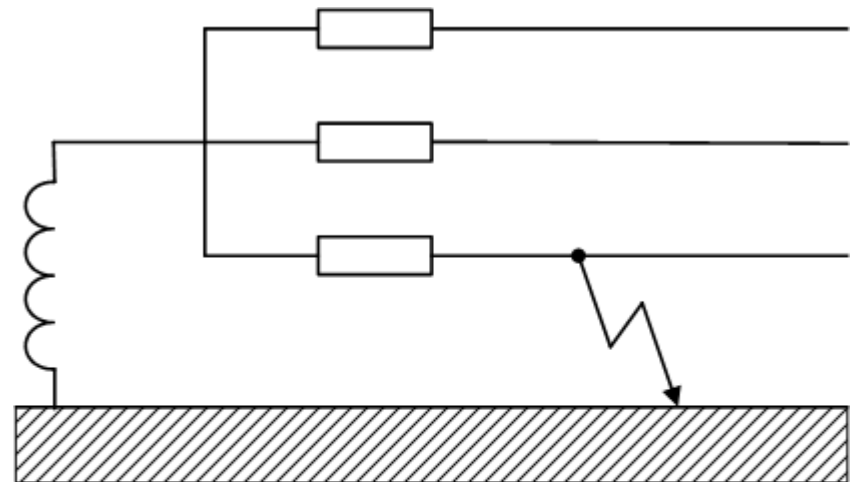


- Vektorska slika (kvalitativna):

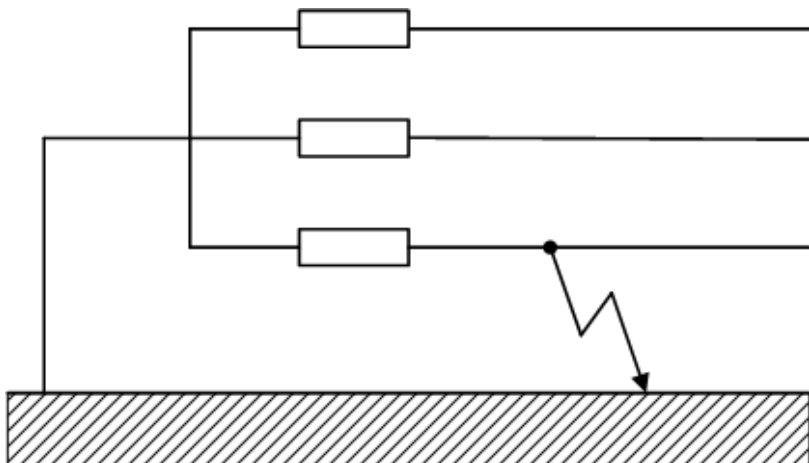
Zemljospoj (izolirana mreža)



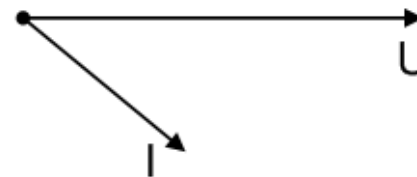
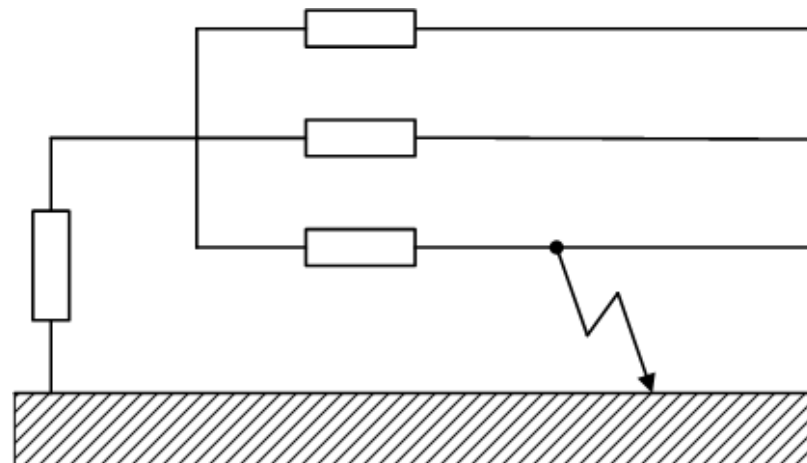
Zemljospoj (mreža uzemljena preko induktiviteta)



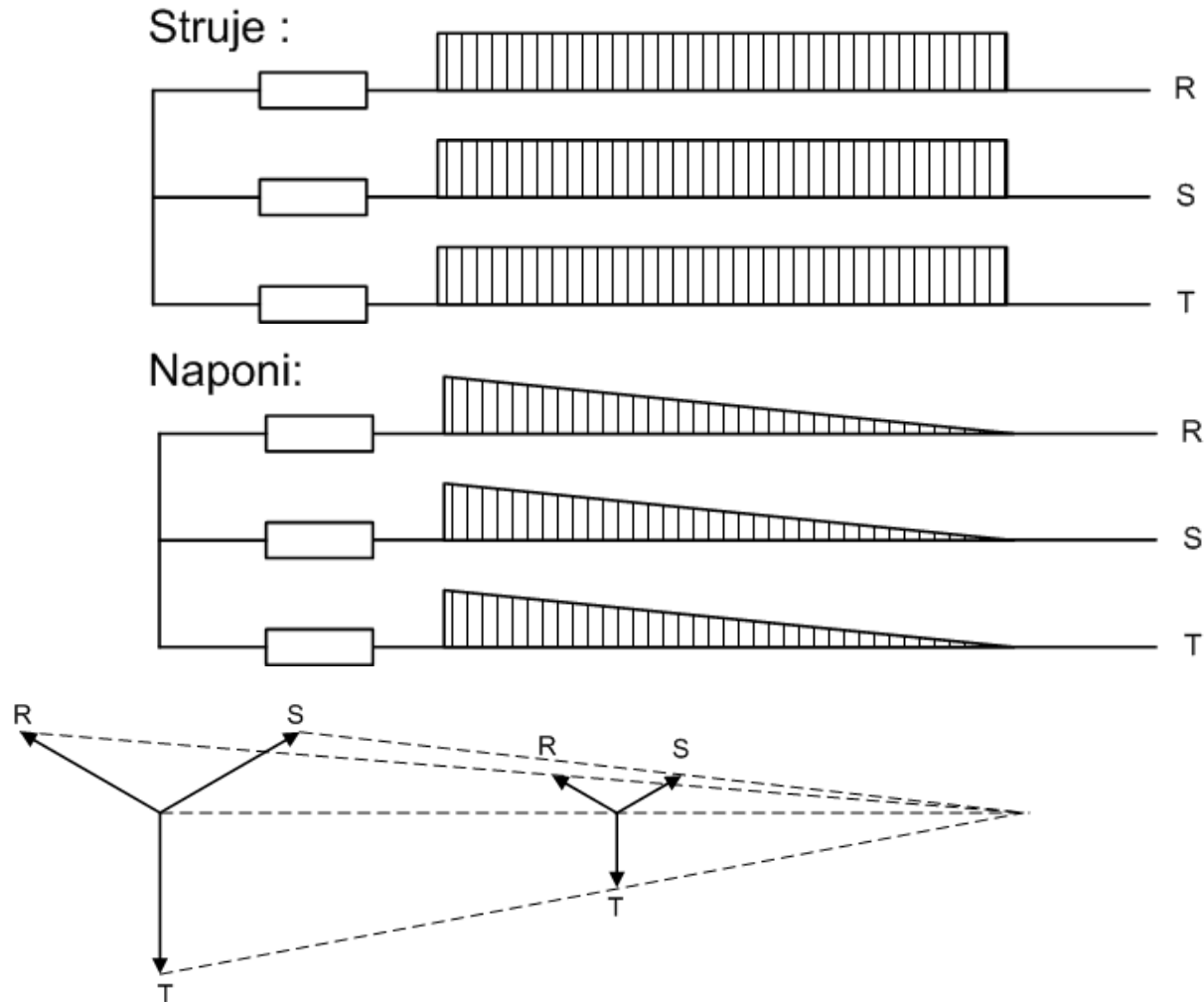
Mreža uzemljena direktno



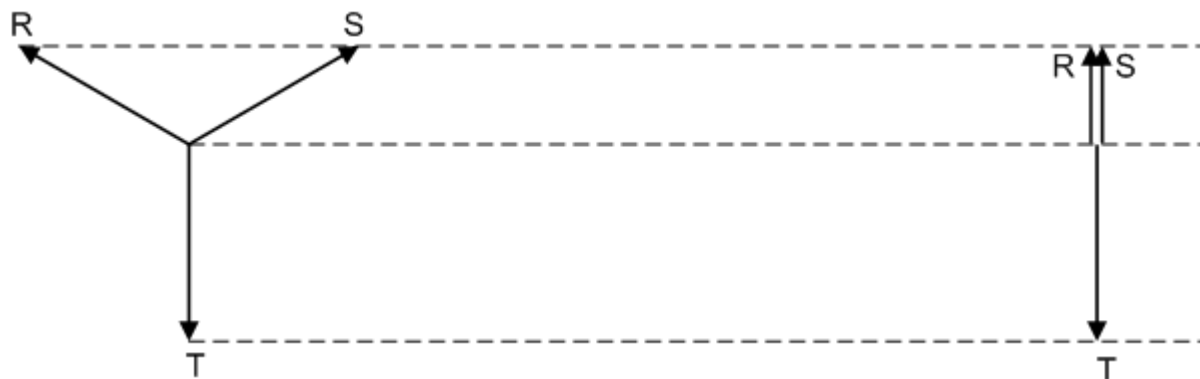
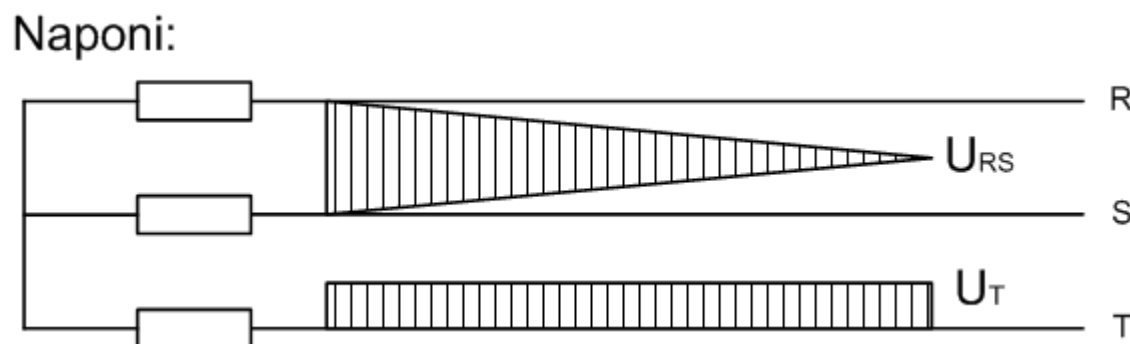
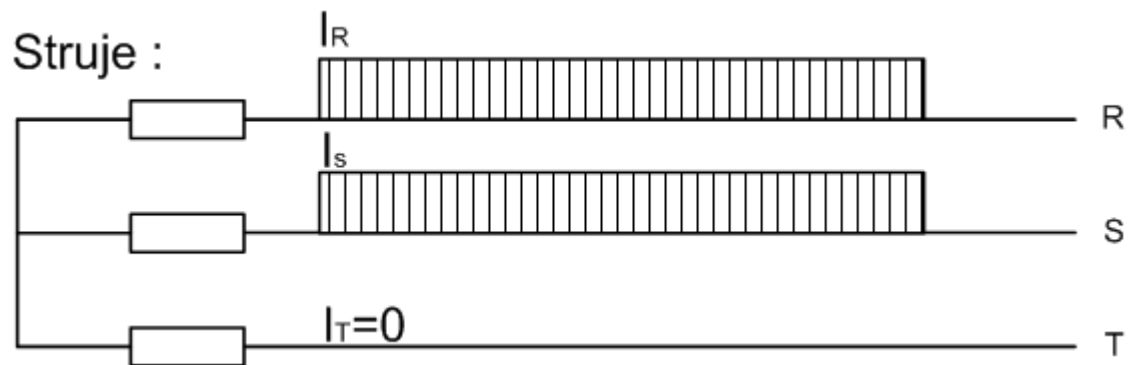
Mreža uzemljena preko otpora



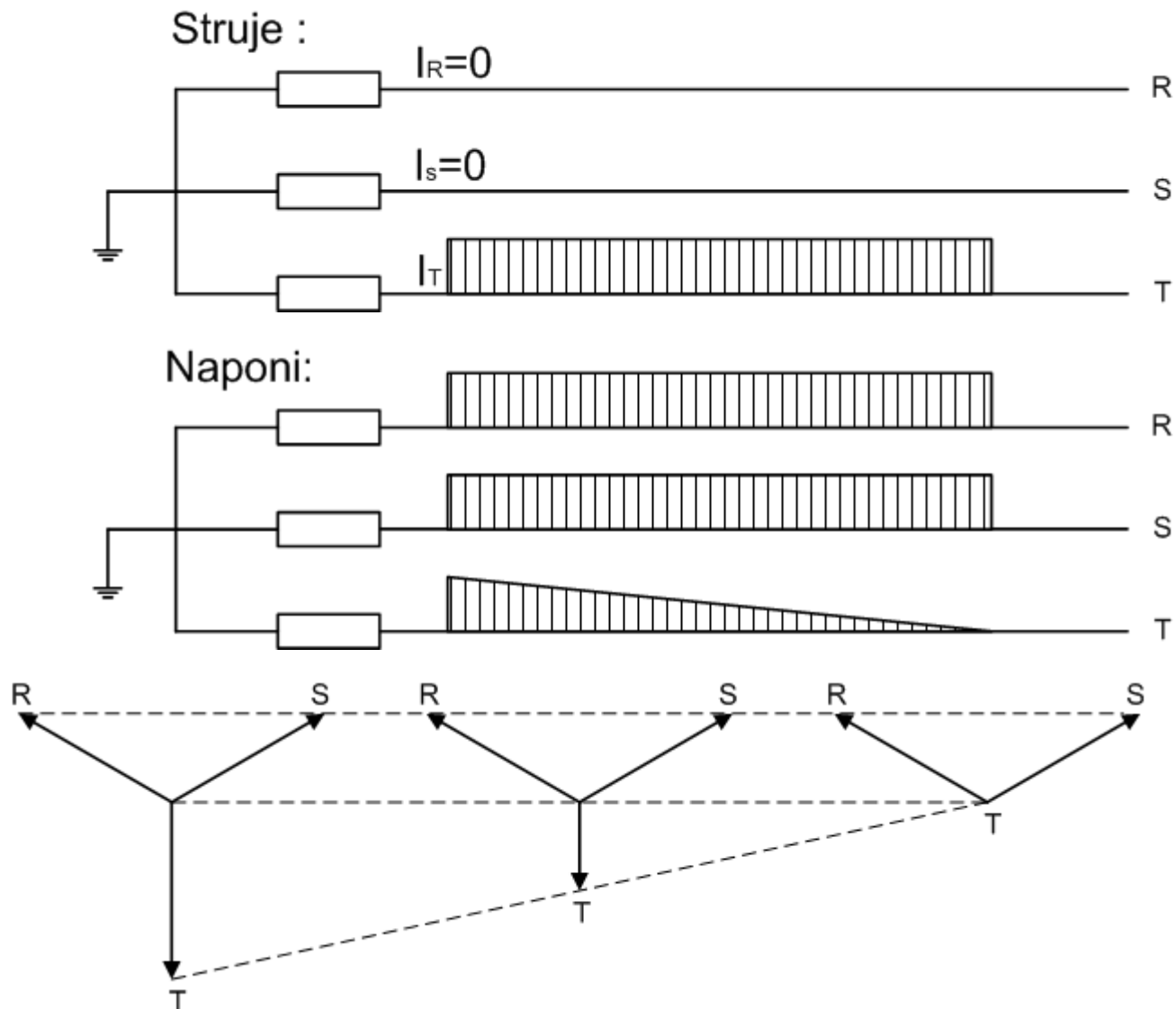
- Vektorske slike kratkog spoja:
 - TROPOLNI KRATKI SPOJ



– DVOPOLNI KRATKI SPOJ



– JEDNOPOLNI KRATKI SPOJ



- RELEJNA ZAŠTITA

- Uređaji koji automatski upravljaju iskapčanjem u mreži ako nastane kratki spoj
- Zahtjevi:
 1. Osjetljivost
 2. Kritičnost
 3. Brzina
 4. Selektivnost
 5. Pouzdanost (rezerva)

- Generacije uređaja za zaštitu od kratkog spoja

| Generacija | Uređaj | Način mjerenja | Udešavanje vremeske zaštite | Kriterij za djelovanje |
|------------|-------------------------|----------------|-----------------------------|----------------------------|
| 1 | Osigurači | Primarno | Donekle | Nadstrujno |
| 2 | Okidači | Primarno | Grubo | Nadstrujno ili podnaponski |
| 3 | Elektromehanički releji | Sekundarno | Dobro | Složen |
| 4 | Statički releji | Sekundarno | Fino | Složen |
| 5 | Kompjutori (numerički) | Daljinsko | Egzaktno po potrebi | Proizvoljno |

- SIMETRIČNE KOMPONENTE

$${}^R U_i = {}^0 U_i + {}^d U_i + {}^i U_i$$

$${}^S U_i = {}^0 U_i + {}^d U_i \cdot a^2 + {}^i U_i \cdot a$$

$${}^T U_i = {}^0 U_i + {}^d U_i \cdot a + {}^i U_i \cdot a^2$$

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

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

$$\begin{vmatrix} {}^R U_i \\ {}^S U_i \\ {}^T U_i \end{vmatrix} = \begin{vmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{vmatrix} \cdot \begin{vmatrix} {}^0 U_i \\ {}^d U_i \\ {}^i U_i \end{vmatrix}$$

$$\begin{vmatrix} {}^0 U_i \\ {}^d U_i \\ {}^i U_i \end{vmatrix} = \frac{1}{3} \cdot \begin{vmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{vmatrix} \cdot \begin{vmatrix} {}^R U_i \\ {}^S U_i \\ {}^T U_i \end{vmatrix}$$

• MATEMATIČKI MODEL KRATKOG SPOJA

- Prije nastanka kratkog spoja mreža se matematički prikazuje pomoću MATRIČNE JEDNADŽBE. To se naziva stanje u ZDRAVOJ MREŽI.

$$\begin{bmatrix} U_1 \\ U_2 \\ \vdots \\ U_m \\ \vdots \\ U_n \end{bmatrix} = \begin{bmatrix} Z_{11} & \cdots & Z_{1n} \\ \vdots & \ddots & \vdots \\ Z_{n1} & \cdots & Z_{nn} \end{bmatrix} \cdot \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_n \end{bmatrix}$$

- Vektor napona čvorišta U^Z se dobije umnoškom matrice impedancije čvorišta zdrave mreže i vektora struja koje ulaze u čvorište. Struje su struje generatora i/ili potrošača. Matricu impedancije čvorišta dobije se inverzijom matrice admitancije čvorišta u koju su ušle sve admitancije (vodovi, generatori, transformatori, i potrošači).

- Model električnih prilika u bolesnoj mreži

$$\begin{bmatrix} U_1 \\ \vdots \\ U_m \\ \vdots \\ U_n \end{bmatrix}^B = |Z| \cdot \left\{ \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_n \end{bmatrix} + \begin{bmatrix} 0 \\ \vdots \\ I_m \\ \vdots \\ 0 \end{bmatrix} \right\}$$

$$I_k = -I_m$$

$$\begin{bmatrix} {}^dU_1 \\ \vdots \\ {}^dU_m \\ \vdots \\ {}^dU_n \end{bmatrix}^B = \begin{bmatrix} U_1 \\ \vdots \\ U_m \\ \vdots \\ U_n \end{bmatrix}^Z + \begin{bmatrix} {}^dZ_{1m} \cdot I_m \\ \vdots \\ {}^dZ_{mm} \cdot I_m \\ \vdots \\ {}^dZ_{nm} \cdot I_m \end{bmatrix}$$

Za tropski kratki spoj:

$${}^dU_m = 0$$

$$0 = U_m^z + {}^dZ_{mm} \cdot I_m$$

$$I_m = -\frac{U_m^z}{{}^dZ_{mm}}$$

$$\begin{bmatrix} {}^dU_1 \\ \vdots \\ {}^dU_m \\ \vdots \\ {}^dU_n \end{bmatrix}^B = \begin{bmatrix} U_1^z - \frac{{}^dZ_{1m}}{{}^dZ_{mm}} \cdot U_m^z \\ \vdots \\ 0 \\ \vdots \\ U_n^z - \frac{{}^dZ_{nm}}{{}^dZ_{mm}} \cdot U_m^z \end{bmatrix}$$

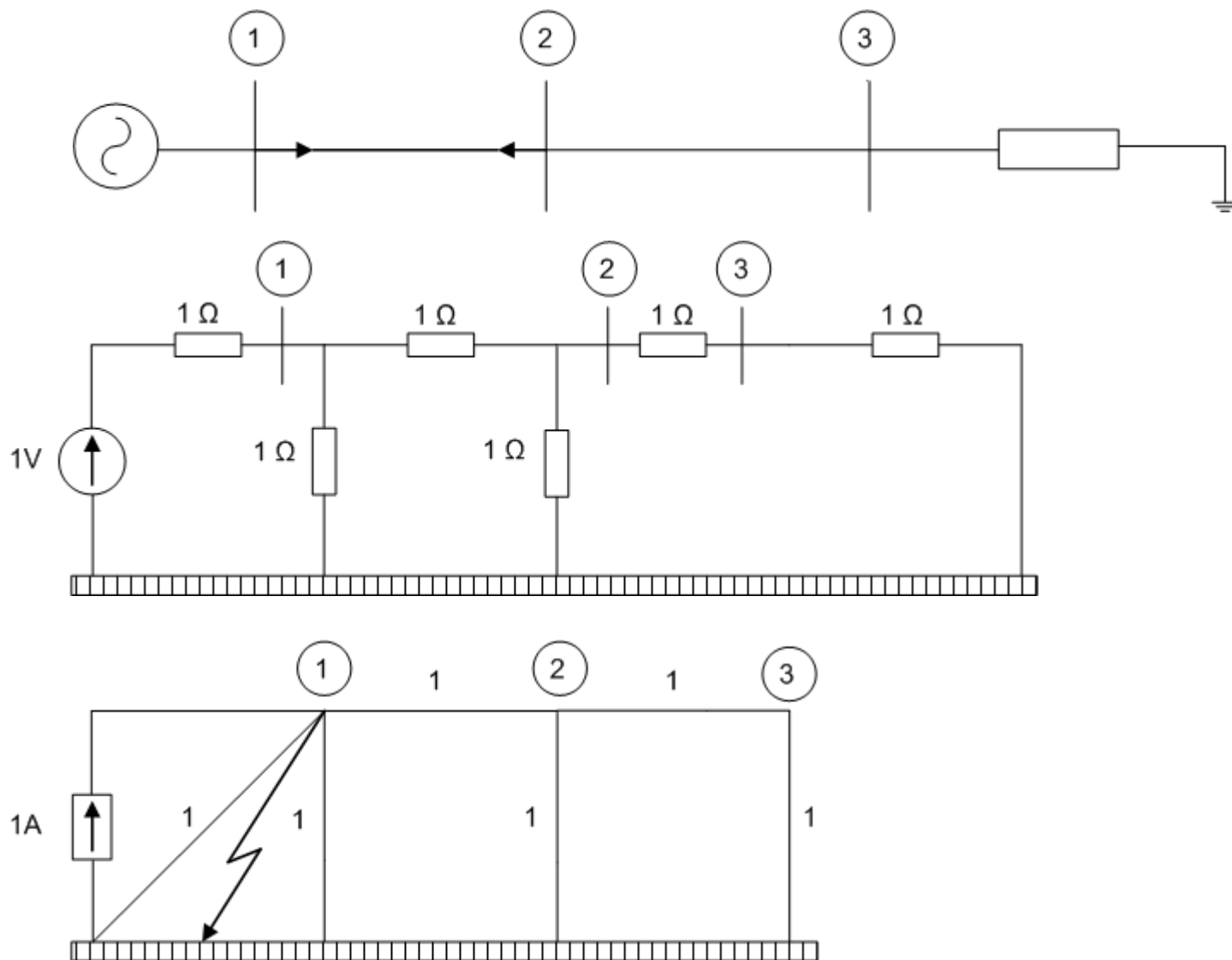
Ako postoji nesimetrični kratki spoj:

$${}^dU = \begin{bmatrix} {}^dU_1 \\ \vdots \\ {}^dU_m \\ \vdots \\ {}^dU_n \end{bmatrix} = \begin{bmatrix} {}^dZ_{11} & \cdots & {}^dZ_{1n} \\ \vdots & \ddots & \vdots \\ {}^dZ_{n1} & \cdots & {}^dZ_{nn} \end{bmatrix} \cdot \left\{ \begin{bmatrix} {}^dI_1 \\ {}^dI_2 \\ \vdots \\ {}^dI_n \end{bmatrix} + \begin{bmatrix} 0 \\ \vdots \\ {}^dI_m \\ \vdots \\ 0 \end{bmatrix} \right\}$$

$${}^iU = \begin{bmatrix} {}^iU_1 \\ \vdots \\ {}^iU_m \\ \vdots \\ {}^iU_n \end{bmatrix} = \begin{bmatrix} {}^iZ_{11} & \cdots & {}^iZ_{1n} \\ \vdots & \ddots & \vdots \\ {}^iZ_{n1} & \cdots & {}^iZ_{nn} \end{bmatrix} \cdot \begin{bmatrix} 0 \\ 0 \\ \vdots \\ {}^iI_m \\ \vdots \\ 0 \end{bmatrix}$$

$${}^0U = \begin{bmatrix} {}^0U_1 \\ \vdots \\ {}^0U_m \\ \vdots \\ {}^0U_n \end{bmatrix} = \begin{bmatrix} {}^0Z_{11} & \cdots & {}^0Z_{1n} \\ \vdots & \ddots & \vdots \\ {}^0Z_{n1} & \cdots & {}^0Z_{nn} \end{bmatrix} \cdot \begin{bmatrix} 0 \\ 0 \\ \vdots \\ {}^0I_m \\ \vdots \\ 0 \end{bmatrix}$$

- Primjer: Tropolni kratki spoj



$$Y = \begin{vmatrix} 3 & -1 & 0 \\ -1 & 3 & -1 \\ 0 & -1 & 2 \end{vmatrix}$$

$$Y^{(1)} = \begin{vmatrix} 3 & -1 & 0 \\ -1 & 3 - \frac{1}{2} & \frac{1}{2} \\ 0 & -\frac{1}{2} & \frac{1}{2} \end{vmatrix} = \begin{vmatrix} 3 & -1 & 0 \\ -1 & \frac{5}{2} & \frac{1}{2} \\ 0 & -\frac{1}{2} & \frac{1}{2} \end{vmatrix}$$

$$Y^{(2)} = \begin{vmatrix} \frac{1}{3} & -\frac{1}{3} & 0 \\ \frac{1}{3} & \frac{5}{2} - \frac{1}{3} & \frac{1}{2} \\ 0 & -\frac{1}{2} & \frac{1}{2} \end{vmatrix} = \begin{vmatrix} \frac{1}{3} & -\frac{1}{3} & 0 \\ \frac{1}{3} & \frac{13}{6} & \frac{1}{2} \\ 0 & -\frac{1}{2} & \frac{1}{2} \end{vmatrix}$$

$$Y^{(3)} = \begin{vmatrix} 0.385 & 0.154 & 0.077 \\ 0.154 & 0.461 & 0.23 \\ 0.077 & 0.23 & 0.615 \end{vmatrix} = Z$$

$$\begin{vmatrix} {}^dU_1 \\ {}^dU_2 \\ {}^dU_3 \end{vmatrix}^B = |Z| \cdot \begin{vmatrix} 1 \\ 0 \\ 0 \end{vmatrix} + |Z| \cdot \begin{vmatrix} I_1 \\ 0 \\ 0 \end{vmatrix}$$

$$\begin{vmatrix} {}^dU_1 \\ {}^dU_2 \\ {}^dU_3 \end{vmatrix}^B = \begin{vmatrix} 0.385 \\ 0.154 \\ 0.077 \end{vmatrix} + \begin{vmatrix} 0.385 \cdot {}^dI_1 \\ 0.154 \cdot {}^dI_1 \\ 0.077 \cdot {}^dI_1 \end{vmatrix} = \begin{vmatrix} 0 \\ 0 \\ 0 \end{vmatrix} \quad \begin{aligned} {}^dU_1 &= 0.385 + 0.385 \cdot {}^dI_1 = 0 \\ {}^dI_1 &= -1 \end{aligned}$$

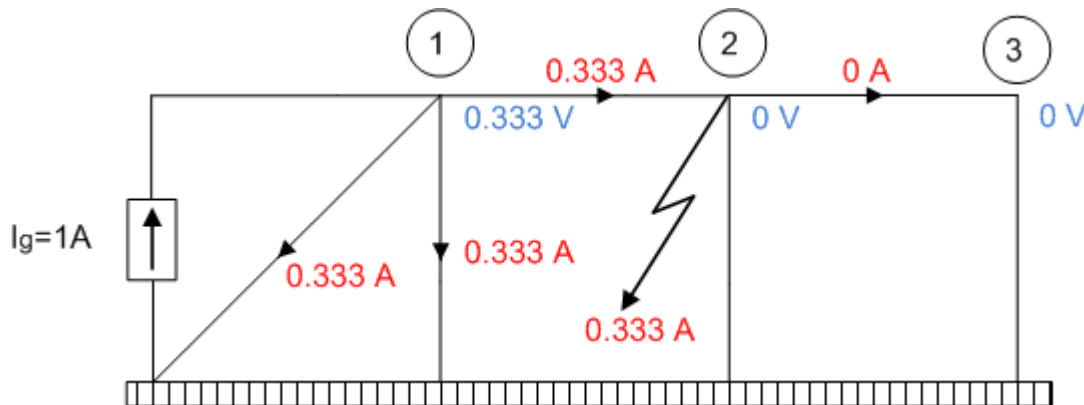
Struje generatora: 1A; Svi naponi: 0.

Kratki spoj u čvorištu 2.

$${}^dU^B = 0 = 0.154 \cdot 1 + 0.461 \cdot {}^dI_2$$

$${}^dI_2 = -\frac{0.154}{0.461} \text{ A} = -0.334 \text{ A}$$

$$\begin{vmatrix} {}^dU_1 \\ {}^dU_2 \\ {}^dU_3 \end{vmatrix}^B = \begin{vmatrix} 0.385 \\ 0.154 \\ 0.077 \end{vmatrix} - |Z| \cdot \begin{vmatrix} 0 \\ 0.334 \\ 0 \end{vmatrix} = \begin{vmatrix} 0.333 \\ 0 \\ 0 \end{vmatrix}$$



Izvor daje:
1 A - 0.333 A = 0.667 A

Kratki spoj u čvorištu 3.

$$\begin{bmatrix} {}^dU_1 \\ {}^dU_2 \\ {}^dU_3 \end{bmatrix}^B = \begin{bmatrix} {}^dU_1 \\ {}^dU_2 \\ {}^dU_3 \end{bmatrix}^Z + |Z| \cdot \begin{bmatrix} 0 \\ 0 \\ I_3 \end{bmatrix}$$

$$\begin{bmatrix} {}^dU_1 \\ {}^dU_2 \\ {}^dU_3 \end{bmatrix}^B = \begin{bmatrix} 0.385 \\ 0.154 \\ 0.077 \end{bmatrix} + \begin{bmatrix} Z_{13} \cdot {}^dI_3 \\ Z_{23} \cdot {}^dI_3 \\ Z_{33} \cdot {}^dI_3 \end{bmatrix}$$

$${}^dU_3^B = 0 = 0.077 + Z_{33} \cdot {}^dI_3$$

$${}^dI_3 = -\frac{0.077}{0.615} \text{ A} = -0.125 \text{ A}$$

$$\begin{bmatrix} {}^dU_1 \\ {}^dU_2 \\ {}^dU_3 \end{bmatrix}^B = \begin{bmatrix} 0.385 \\ 0.154 \\ 0.077 \end{bmatrix} + \begin{bmatrix} 0.077 \cdot (-0.125) \\ 0.23 \cdot (-0.125) \\ 0.615 \cdot (-0.125) \end{bmatrix} = \begin{bmatrix} 0.375 \\ 0.125 \\ 0 \end{bmatrix}$$

