

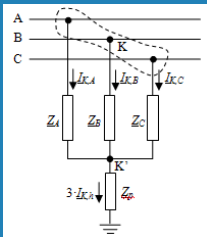
SISTEME ELECTROENERGETICE

Capitolul 4-1

NESIMETRII TRANSVERSALE

Principii de modelare

Nesimetria transversala generica



$$\begin{aligned} \underline{U}_{K,A} &= \underline{U}'_K + \underline{Z}_A \cdot \underline{I}_{K,A} \\ \underline{U}_{K,B} &= \underline{U}'_K + \underline{Z}_B \cdot \underline{I}_{K,B} \\ \underline{U}_{K,C} &= \underline{U}'_K + \underline{Z}_C \cdot \underline{I}_{K,C} \\ \underline{U}_{K'} &= \underline{Z}_p \cdot \underline{I}_p = 3 \cdot \underline{Z}_p \cdot \underline{I}_{K,h} \end{aligned}$$

Principii de modelare

Principiu: una din cele 3 faze are o stare diferita de a celorlalte doua – **faza de referinta**.

De exemplu, considerand faza A ca faza de referinta:

$$\begin{aligned} \underline{U}_{K,A} &= \underline{U}_{K,h} + \underline{U}_{K,d} + \underline{U}_{K,i} \\ \underline{U}_{K,B} &= \underline{U}_{K,h} + a^2 \cdot \underline{U}_{K,d} + a \cdot \underline{U}_{K,i} \\ \underline{U}_{K,C} &= \underline{U}_{K,h} + a \cdot \underline{U}_{K,d} + a^2 \cdot \underline{U}_{K,i} \end{aligned}$$

Principii de modelare

$$\begin{aligned} \underline{U}_{K,d} &= \underline{U}_{K,0} - \underline{Z}_{K,d} \cdot \underline{I}_{K,d} \\ \underline{U}_{K,i} &= 0 - \underline{Z}_{K,i} \cdot \underline{I}_{K,i} \\ \underline{U}_{K,h} &= 0 - \underline{Z}_{K,h} \cdot \underline{I}_{K,h} \end{aligned}$$

unde $\underline{Z}_{K,h}$, $\underline{Z}_{K,d}$ și $\underline{Z}_{K,i}$ reprezintă impedanțele echivalente asociate schemelor de secvență homopolară, directă și inversă.

Schema de secvență directă este singura activă, t.e.m. a sursei se notează $\underline{U}_{K,0}$.

Principii de modelare

Studiul tipurilor standard de nesimetrii

Prin alegerea convenabilă a impedanțelor Z_A , Z_B , Z_C și Z_p (tinzând spre 0 sau ∞).

Exemplu ($Z_p = 0$):

Scurtcircuitul monofazat metalic:

$$Z_A = 0 \text{ și } Z_B = Z_C = \infty$$

Scurtcircuitul monofazat metalic:

$$Z_A = r_a \neq 0 \text{ și } Z_B = Z_C = \infty$$

Principii de modelare

Condiții la limită

Pentru fiecare tip de nesimetrie se pot scrie anumite condiții la limită, care descriu de fapt ecuațiile la locul de defect în marimi de faza.

Exemplu - Scurtcircuitul monofazat metalic:

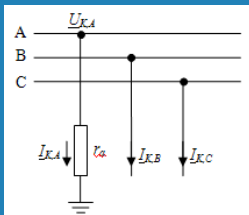
- tensiunea pe faza defectă este nulă ($\underline{U}_{K,A} \equiv 0$),
- curenții transversali ai fazelor sănătoase sunt nuli ($\underline{I}_{K,B} = \underline{I}_{K,C} \equiv 0$).

Principii de modelare

Organigrama de principiu pentru tratarea nesimetriilor transversale.

1. Se stabilesc și se scriu condițiile la limită în mărimi de fază pentru nesimetria considerată.
2. Se transpun condițiile la limită în mărimi de secvență.
3. Se deduce modul de conectare a schemelor de secvență și se construiește schema echivalentă.
4. Folosind schema echivalentă, se deduce expresia curentului de secvență directă.
5. Folosind curentul de secvență directă, se determină expresiile pentru celelalte mărimi de secvență necunoscute (curenți și tensiuni).
6. Se determină expresiile curenților și tensiunilor de fază la locul de defect.
7. Se întocmesc diagramele fazoriale pentru mărimile de fază și cele de secvență.

Scurtcircuitul monofazat



Notatie: **FN**

Conditii la limita

$$\begin{aligned} \underline{U}_{K,A} &= r_a \cdot \underline{I}_{K,A} \\ \underline{I}_{K,B} &= 0 \\ \underline{I}_{K,C} &= 0 \end{aligned}$$

Scurtcircuitul monofazat

Trecerea condițiilor la limita in marimi de secventa:

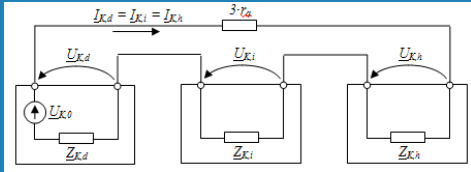
$$\begin{aligned} \underline{U}_{K,h} + \underline{U}_{K,d} + \underline{U}_{K,i} &= r_a \cdot (\underline{I}_{K,h} + \underline{I}_{K,d} + \underline{I}_{K,i}) \\ \underline{I}_{K,h} + a^2 \cdot \underline{I}_{K,d} + a \cdot \underline{I}_{K,i} &= 0 \\ \underline{I}_{K,h} + a \cdot \underline{I}_{K,d} + a^2 \cdot \underline{I}_{K,i} &= 0 \end{aligned}$$

$$\underline{I}_{K,h} = \underline{I}_{K,d} = \underline{I}_{K,i} = \frac{1}{3} \cdot \underline{I}_{K,A}$$

$$\underline{U}_{K,h} + \underline{U}_{K,d} + \underline{U}_{K,i} = 3 \cdot r_a \cdot \underline{I}_{K,d}$$

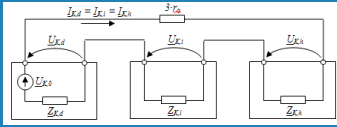
Scurtcircuitul monofazat

Scheme de secventa conectate in serie:



Scurtcircuitul monofazat

Prin aplicarea teoremei II Kirchoff:



$$I_{K,d} = I_{K,i} = I_{K,h} = \frac{U_{K,0}}{Z_{K,d} + Z_{K,i} + Z_{K,h} + 3 \cdot r_a}$$

Scurtcircuitul monofazat

Tensiunile de secventa:

$$U_{K,d} = U_{K,0} - Z_{K,d} \cdot I_{K,d} = \frac{Z_{K,i} + Z_{K,h} + 3 \cdot r_a}{Z_{K,d} + Z_{K,i} + Z_{K,h} + 3 \cdot r_a} \cdot U_{K,0}$$

$$U_{K,i} = -Z_{K,i} \cdot I_{K,i} = -\frac{Z_{K,i}}{Z_{K,d} + Z_{K,i} + Z_{K,h} + 3 \cdot r_a} \cdot U_{K,0}$$

$$U_{K,h} = -Z_{K,h} \cdot I_{K,h} = -\frac{Z_{K,h}}{Z_{K,d} + Z_{K,i} + Z_{K,h} + 3 \cdot r_a} \cdot U_{K,0}$$

Scurtcircuitul monofazat

Curentul de scurtcircuit monofazat:

$$\underline{I}_{K,A} = 3 \cdot \underline{I}_{K,d} = \frac{3 \cdot \underline{U}_{K,0}}{\underline{Z}_{K,d} + \underline{Z}_{K,i} + \underline{Z}_{K,h} + 3 \cdot r_a}$$

si tensiunea pe faza defecta:

$$\underline{U}_{K,A} = r_a \cdot \underline{I}_{K,A} = \frac{3 \cdot r_a}{\underline{Z}_{K,d} + \underline{Z}_{K,i} + \underline{Z}_{K,h} + 3 \cdot r_a} \cdot \underline{U}_{K,0}$$

Scurtcircuitul monofazat

Tensiunile pe fazele sanatoase:

$$\begin{aligned} \underline{U}_{K,B} &= \underline{U}_{K,h} + a^2 \cdot \underline{U}_{K,d} + a \cdot \underline{U}_{K,i} = \\ &= -\frac{1}{2} \cdot \frac{3 \cdot \underline{Z}_{K,h} + 3 \cdot r_a}{\underline{Z}_{K,d} + \underline{Z}_{K,i} + \underline{Z}_{K,h} + 3 \cdot r_a} \cdot \underline{U}_{K,0} - \\ &- j \cdot \frac{\sqrt{3}}{2} \cdot \frac{\underline{Z}_{K,h} + 2 \cdot \underline{Z}_{K,i} + 3 \cdot r_a}{\underline{Z}_{K,d} + \underline{Z}_{K,i} + \underline{Z}_{K,h} + 3 \cdot r_a} \cdot \underline{U}_{K,0} \end{aligned}$$

$$\begin{aligned} \underline{U}_{K,C} &= \underline{U}_{K,h} + a \cdot \underline{U}_{K,d} + a^2 \cdot \underline{U}_{K,i} = \\ &= -\frac{1}{2} \cdot \frac{3 \cdot \underline{Z}_{K,h} + 3 \cdot r_a}{\underline{Z}_{K,d} + \underline{Z}_{K,i} + \underline{Z}_{K,h} + 3 \cdot r_a} \cdot \underline{U}_{K,0} + \\ &+ j \cdot \frac{\sqrt{3}}{2} \cdot \frac{\underline{Z}_{K,h} + 2 \cdot \underline{Z}_{K,i} + 3 \cdot r_a}{\underline{Z}_{K,d} + \underline{Z}_{K,i} + \underline{Z}_{K,h} + 3 \cdot r_a} \cdot \underline{U}_{K,0} \end{aligned}$$

Scurtcircuitul monofazat

Cazul particular – **metalic** ($r_a = 0$)

Curentii de secventa:

$$\underline{I}_{K,d} = \underline{I}_{K,i} = \underline{I}_{K,h} = -j \cdot \frac{1}{X_{K,d} + X_{K,i} + X_{K,h}} \cdot \underline{U}_{K,0}$$

Tensiunile de secventa:

$$\begin{aligned} \underline{U}_{K,d} &= \frac{X_{K,i} + X_{K,h}}{X_{K,d} + X_{K,i} + X_{K,h}} \cdot \underline{U}_{K,0} \\ \underline{U}_{K,i} &= -\frac{X_{K,i}}{X_{K,d} + X_{K,i} + X_{K,h}} \cdot \underline{U}_{K,0} \\ \underline{U}_{K,h} &= -\frac{X_{K,h}}{X_{K,d} + X_{K,i} + X_{K,h}} \cdot \underline{U}_{K,0} \end{aligned}$$

Scurtcircuitul monofazat

Cazul particular – metalic ($r_a = 0$)

Curentii de faza:

$$\underline{I}_{K,A} = 3 \cdot \underline{I}_{K,d} = -j \cdot \frac{3}{X_{K,d} + X_{K,i} + X_{K,h}} \underline{U}_{K,0}$$

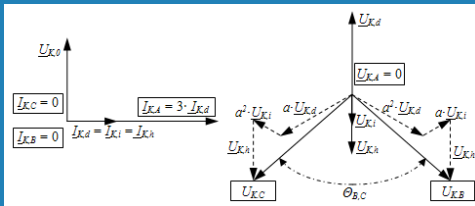
$$\underline{I}_{K,B} = \underline{I}_{K,C} = 0$$

Tensiunile de faza:

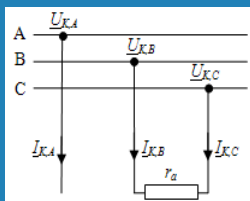
$$\begin{aligned} \underline{U}_{K,A} &= 0 \\ \underline{U}_{K,B} &= \underline{U}_{K,h} + a^2 \cdot \underline{U}_{K,d} + a \cdot \underline{U}_{K,i} = \\ &= \frac{(a^2 - 1) \cdot X_{K,h} + (a^2 - a) \cdot X_{K,i}}{X_{K,d} + X_{K,i} + X_{K,h}} \underline{U}_{K,0} \\ \underline{U}_{K,C} &= \underline{U}_{K,h} + a \cdot \underline{U}_{K,d} + a^2 \cdot \underline{U}_{K,i} = \\ &= \frac{(a - 1) \cdot X_{K,h} - (a^2 - a) \cdot X_{K,i}}{X_{K,d} + X_{K,i} + X_{K,h}} \underline{U}_{K,0} \end{aligned}$$

Scurtcircuitul monofazat

Diagrame fazoriale



Scurtcircuitul bifazat



Notatie: **2F**

Conditii la limita

$$\begin{aligned} \underline{I}_{K,A} &= 0 \\ \underline{I}_{K,B} + \underline{I}_{K,C} &= 0 \\ \underline{U}_{K,B} - \underline{U}_{K,C} &= r_a \cdot \underline{I}_{K,B} \end{aligned}$$

Scurtcircuitul bifazat

Ecuatiile de curenți conduc la:

$$\underline{I}_{K,h} = \frac{1}{3} \cdot (\underline{I}_{K,A} + \underline{I}_{K,B} + \underline{I}_{K,C}) = 0$$

Concluzie: schema de secventa homopolara – in gol.

Relatia intre ceilalti curenți de secventa:

$$\underline{I}_{K,A} = 0 \Rightarrow \underline{I}_{K,h} + \underline{I}_{K,d} + \underline{I}_{K,i} = 0 \Rightarrow \underline{I}_{K,d} + \underline{I}_{K,i} = 0$$

Scurtcircuitul bifazat

Ecuatiile de tensiuni, prelucrate succesiv:

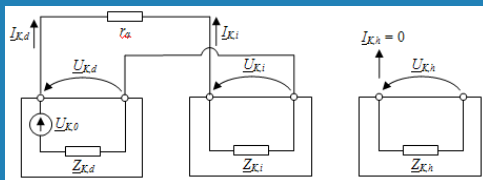
$$(\underline{U}_{K,h} + a^2 \cdot \underline{U}_{K,d} + a \cdot \underline{U}_{K,i}) - (\underline{U}_{K,h} + a \cdot \underline{U}_{K,d} + a^2 \cdot \underline{U}_{K,i}) = r_a \cdot (\underline{I}_{K,h} + a^2 \cdot \underline{I}_{K,d} + a \cdot \underline{I}_{K,i})$$

$$(a^2 - a) \cdot \underline{U}_{K,d} - (a^2 - a) \cdot \underline{U}_{K,i} = r_a \cdot (a^2 - a) \cdot \underline{I}_{K,d}$$

$$\underline{U}_{K,d} = \underline{U}_{K,i} - r_a \cdot \underline{I}_{K,d}$$

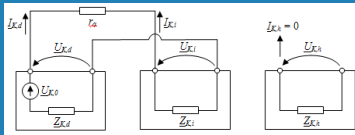
Scurtcircuitul bifazat

Schemele de secventa *d* & *i* conectate in serie:



Scurtcircuitul bifazat

Prin aplicarea teoremei II Kirchoff:



$$\underline{I}_{K,d} = -\underline{I}_{K,i} = \frac{\underline{U}_{K,0}}{\underline{Z}_{K,d} + \underline{Z}_{K,i} + r_a}$$

Scurtcircuitul bifazat

Tensiunile de secventa:

$$\underline{U}_{K,d} = \underline{U}_{K,0} - \underline{Z}_{K,d} \cdot \underline{I}_{K,d} = \frac{\underline{Z}_{K,i} + r_a}{\underline{Z}_{K,d} + \underline{Z}_{K,i} + r_a} \cdot \underline{U}_{K,0}$$

$$\underline{U}_{K,i} = -\underline{Z}_{K,d} \cdot \underline{I}_{K,i} = \frac{\underline{Z}_{K,i}}{\underline{Z}_{K,d} + \underline{Z}_{K,i} + r_a} \cdot \underline{U}_{K,0}$$

$$\underline{U}_{K,h} = 0$$

Scurtcircuitul bifazat

Curentul de scurtcircuit bifazat:

$$\begin{aligned} \underline{I}_{K,B} &= -\underline{I}_{K,C} = \underline{I}_{K,h} + a^2 \cdot \underline{I}_{K,d} + a \cdot \underline{I}_{K,i} = \\ &= a^2 \cdot \underline{I}_{K,d} + a \cdot \underline{I}_{K,i} = (a^2 - a) \cdot \underline{I}_{K,d} = \\ &= -j \cdot \sqrt{3} \cdot \underline{I}_{K,d} = -j \cdot \frac{\sqrt{3} \cdot \underline{U}_{K,0}}{\underline{Z}_{K,d} + \underline{Z}_{K,i} + r_a} \end{aligned}$$

si tensiunea pe faza sanatoasa:

$$\begin{aligned} \underline{U}_{K,A} &= \underline{U}_{K,h} + \underline{U}_{K,d} + \underline{U}_{K,i} = \underline{U}_{K,d} + \underline{U}_{K,i} = \\ &= \frac{2 \cdot \underline{Z}_{K,i} + r_a}{\underline{Z}_{K,d} + \underline{Z}_{K,i} + r_a} \cdot \underline{U}_{K,0} \end{aligned}$$

Scurtcircuitul bifazat

Tensiunile pe fazele defecte:

$$\begin{aligned}\underline{U}_{K,B} &= \underline{U}_{K,h} + a^2 \cdot \underline{U}_{K,d} + a \cdot \underline{U}_{K,i} = a^2 \cdot \underline{U}_{K,d} + a \cdot \underline{U}_{K,i} = \\ &= \frac{-\underline{Z}_{K,i} + a^2 \cdot r_a}{\underline{Z}_{K,d} + \underline{Z}_{K,i} + r_a} \cdot \underline{U}_{K,0}\end{aligned}$$

$$\begin{aligned}\underline{U}_{K,C} &= \underline{U}_{K,h} + a \cdot \underline{U}_{K,d} + a^2 \cdot \underline{U}_{K,i} = a \cdot \underline{U}_{K,d} + a^2 \cdot \underline{U}_{K,i} = \\ &= \frac{-\underline{Z}_{K,i} + a \cdot r_a}{\underline{Z}_{K,d} + \underline{Z}_{K,i} + r_a} \cdot \underline{U}_{K,0}\end{aligned}$$

Scurtcircuitul bifazat

Cazul particular – metalic ($r_i = 0$)

Curentii de secventa:

$$\begin{aligned}\underline{I}_{K,h} &= 0 \\ \underline{I}_{K,d} &= -\underline{I}_{K,i} = -j \cdot \frac{1}{X_{K,d} + X_{K,i}} * \underline{U}_{K,0}\end{aligned}$$

Tensiunile de secventa:

$$\begin{aligned}\underline{U}_{K,h} &= 0 \\ \underline{U}_{K,d} &= \underline{U}_{K,i} = \frac{X_{K,i}}{X_{K,d} + X_{K,i}} * \underline{U}_{K,0}\end{aligned}$$

Scurtcircuitul bifazat

Cazul particular – metalic ($r_i = 0$)

Curentii de faza:

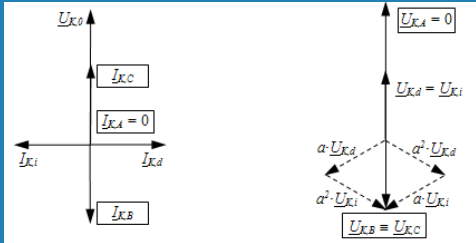
$$\begin{aligned}\underline{I}_{K,A} &= 0 \\ \underline{I}_{K,B} &= -\underline{I}_{K,C} = -\frac{\sqrt{3}}{X_{K,d} + X_{K,i}} * \underline{U}_{K,0}\end{aligned}$$

Tensiunile de faza:

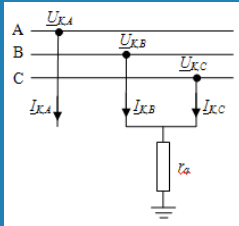
$$\begin{aligned}\underline{U}_{K,A} &= \frac{2 \cdot X_{K,i}}{X_{K,d} + X_{K,i}} * \underline{U}_{K,0} \\ \underline{U}_{K,B} &= \underline{U}_{K,C} = -\frac{X_{K,i}}{X_{K,d} + X_{K,i}} * \underline{U}_{K,0}\end{aligned}$$

Scurtcircuitul bifazat

Diagrame fazoriale



Scurtcircuitul bifazat cu pamant



Notatie: **2FN**

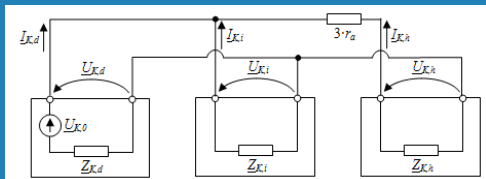
Conditii la limita

$$\begin{aligned} \underline{I}_{K,A} &= 0 \\ \underline{U}_{K,B} &= \underline{U}_{K,C} \\ \underline{U}_{K,B} &= r_a \cdot (\underline{I}_{K,B} + \underline{I}_{K,C}) \end{aligned}$$

Scurtcircuitul bifazat cu pamant

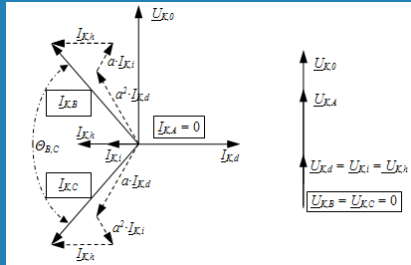
Ecuatia de curenți conduce la:

$$\underline{I}_{K,h} + \underline{I}_{K,d} + \underline{I}_{K,i} = 0$$

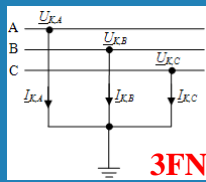
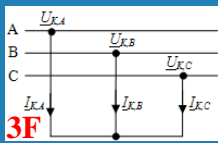


Scurtcircuitul bifazat cu pamant

Diagrame fazoriale



Scurtcircuitul trifazat



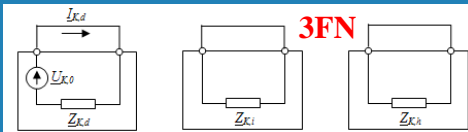
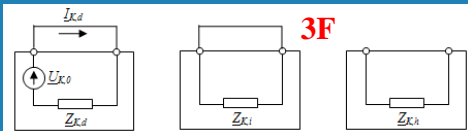
Conditii la limita

$$\begin{aligned} I_{K,A} + I_{K,B} + I_{K,C} &= 0 \\ \underline{U}_{K,A} &= \underline{U}_{K,B} = \underline{U}_{K,C} \end{aligned}$$

$$\underline{U}_{K,A} = \underline{U}_{K,B} = \underline{U}_{K,C} = 0$$

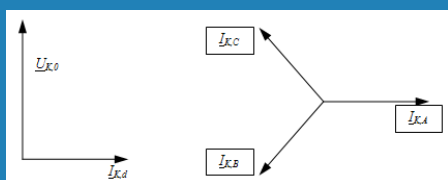
Scurtcircuitul trifazat

Scheme echivalente



Scurtcircuitul trifazat

Diagrame fazoriale



SFARSIT
