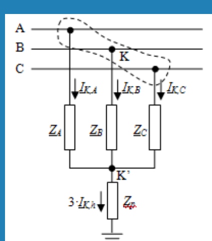
SISTEME ELECTROENERGETICE

Capitolul 4 - 1

NESIMETRII TRANSVERSALE

Principii de modelare

Nesimetria transversala generica



$$\underline{U}_{K,A} = \underline{U}'_{K} + \underline{Z}_{A} \cdot \underline{I}_{K,A}$$
$$\underline{U}_{K,B} = \underline{U}'_{K} + \underline{Z}_{B} \cdot \underline{I}_{K,B}$$
$$\underline{U}_{K,C} = \underline{U}'_{K} + \underline{Z}_{C} \cdot \underline{I}_{K,C}$$
$$\underline{U}_{K'} = \underline{Z}_{p} \cdot \underline{I}_{p} = 3 \cdot \underline{Z}_{p} \cdot \underline{I}_{K,h}$$

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

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

unde $\underline{Z}_{K,h}$, $\underline{Z}_{K,d}$ şi $\underline{Z}_{K,i}$ reprezintă impedanţele echivalente asociate schemelor de secvenţă homopolară, directă şi inversă.

Schema de secvenţă directă este singura activa, t.e.m. a sursei se noteaza $\underline{U}_{K,0}$.

Principii de modelare

Studiul tipurilor standard de nesimetrii

Prin alegerea convenabilă a impedanţelor $\underline{Z}_A$, $\underline{Z}_B$, $\underline{Z}_C$ şi $\underline{Z}_p$ (tinzând spre 0 sau ∞).

Exemplu ($\underline{Z}_p = 0$):
Scurtcircuitul monofazat metalic:
$\underline{Z}_A = 0$ şi $\underline{Z}_B = \underline{Z}_C = \infty$
Scurtcircuitul monofazat metalic:
$\underline{Z}_A = r_a \neq 0$ şi $\underline{Z}_B = \underline{Z}_C = \infty$

Principii de modelare

Conditii la limita

Pentru fiecare tip de nesimetrie se pot scrie anumite condiţii la limită, care descriu de fapt ecuatiile la locul de defect in marimi de faza.

Exemplu - Scurtcircuitul monofazat metalic:

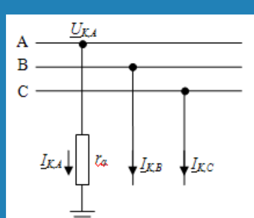
- tensiunea pe faza defectă este nulă ($\underline{U}_{K,A} \equiv 0$),
- curenţii transversali ai fazelor sănătoase sunt nuli ($\underline{I}_{K,B} = \underline{I}_{K,C} \equiv 0$).

Principii de modelare

Organigrama de principiu pentru tratarea nesimetriilor transversale.

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

Scurtcircuitul monofazat



Notatie: **FN**

Conditii la limita

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

Scurtcircuitul monofazat

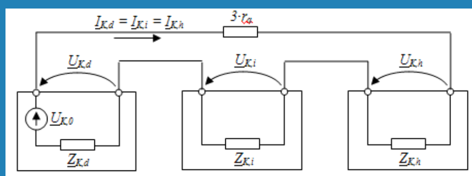
Trecerea conditiilor la limita in marimi de secventa:

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

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

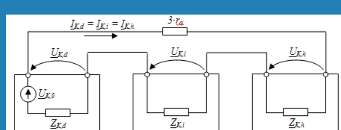
Scurtcircuitul monofazat

Scheme de secventa conectate in serie:



Scurtcircuitul monofazat

Prin aplicarea teoremei II Kirchoff:



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

Scurtcircuitul monofazat

Tensiunile de secventa:

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

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

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

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:

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

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

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:

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

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

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

Scurtcircuitul monofazat

Cazul particular – metalic ($r_a = 0$)

Curentii de faza:

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

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

Tensiunile de faza:

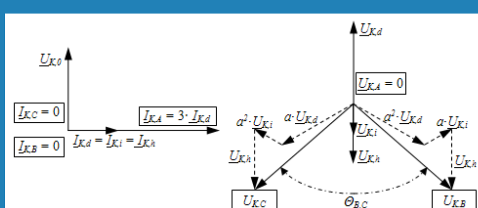
$$\underline{U}_{K,A} = 0$$

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

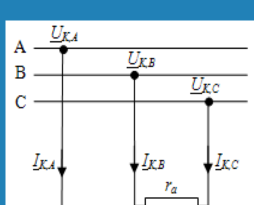
$$\underline{U}_{K,C} = \underline{U}_{K,h} + a \cdot \underline{U}_{K,d} + a^2 \cdot \underline{U}_{K,i} = \frac{(a - 1) \cdot X_{K,h} - (a^2 - a) \cdot X_{K,i}}{X_{K,d} + X_{K,i} + X_{K,h}} \cdot \underline{U}_{K,0}$$

Scurtcircuitul monofazat

Diagrame fazoriale



Scurtcircuitul bifazat



Notatie: **2F**

Conditii la limita

$$\underline{I}_{K,A} = 0$$

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

$$\underline{U}_{K,B} - \underline{U}_{K,C} = r_a \cdot \underline{I}_{K,B}$$

Scurtcircuitul bifazat

Ecuatiile de curenti 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 curenti de secventa:

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

Scurtcircuitul bifazat

Ecuatiile de tensiuni, prelucrate succesiv:

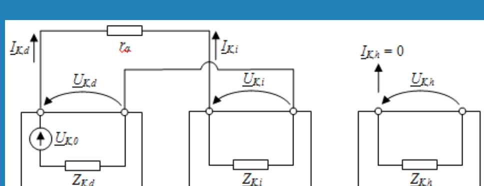
$$(\underline{U}_{K,h} + a^2\cdot\underline{U}_{K,d} + a\cdot\underline{U}_{K,i}) - (\underline{U}_{K,h} + a\cdot\underline{U}_{K,d} + a^2\cdot\underline{U}_{K,i}) = \\ = r_a\cdot(\underline{I}_{K,h} + a^2\cdot\underline{I}_{K,d} + a\cdot\underline{I}_{K,i})$$

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

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

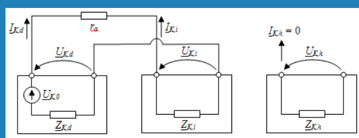
Scurtcircuitul bifazat

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:

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

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

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

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:

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

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

Scurtcircuitul bifazat

Cazul particular – metalic ($r_a = 0$)

Curentii de secventa:

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

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

Tensiunile de secventa:

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

$$\underline{U}_{K,d} = \underline{U}_{K,i} = \frac{X_{K,i}}{X_{K,d} + X_{K,i}} * \underline{U}_{K,0}$$

Scurtcircuitul bifazat

Cazul particular – metalic ($r_a = 0$)

Curentii de faza:

$$\underline{I}_{K,A} = 0$$

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

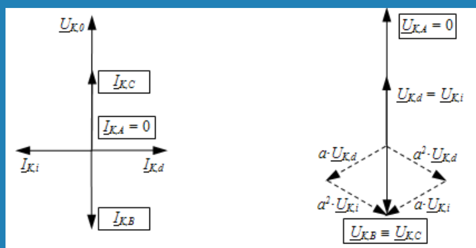
Tensiunile de faza:

$$\underline{U}_{K,A} = \frac{2 \cdot X_{K,i}}{X_{K,d} + X_{K,i}} * \underline{U}_{K,0}$$

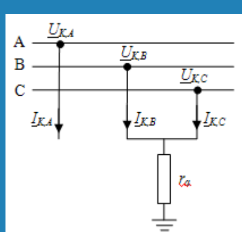
$$\underline{U}_{K,B} = \underline{U}_{K,C} = -\frac{X_{K,i}}{X_{K,d} + X_{K,i}} * \underline{U}_{K,0}$$

Scurtcircuitul bifazat

Diagrame fazoriale



Scurtcircuitul bifazat cu pamant



Notatie: **2FN**

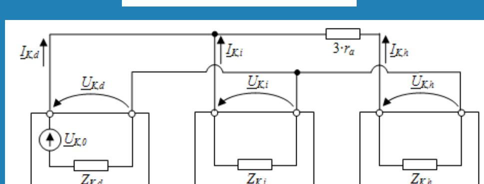
Conditii la limita

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

Scurtcircuitul bifazat cu pamant

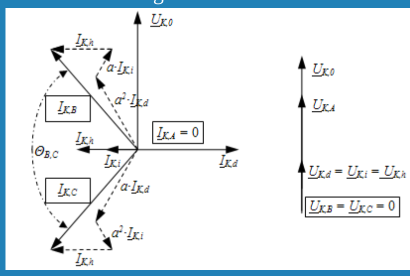
Ecuatia de curenti conduce la:

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

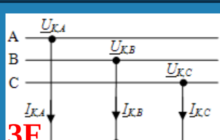


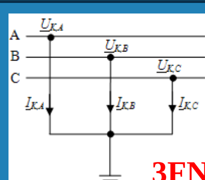
Scurtcircuitul bifazat cu pamant

Diagrame fazoriale



Scurtcircuitul trifazat





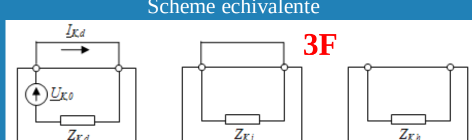
Conditii la limita

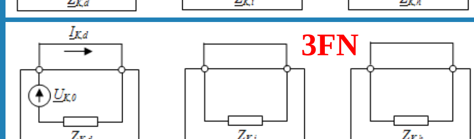
$$\underline{I}_{K,A} + \underline{I}_{K,B} + \underline{I}_{K,C} = 0$$
$$\underline{U}_{K,A} = \underline{U}_{K,B} = \underline{U}_{K,C}$$

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

Scurtcircuitul trifazat

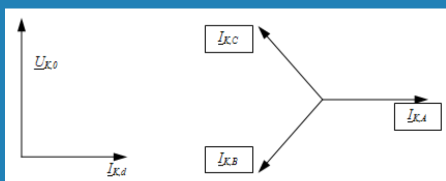
Scheme echivalente





Scurtcircuitul trifazat

Diagrame fazoriale



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