Regimurile nesimetrice ale maşinii de inducţie

Alimentare statorică nesimetrică

Metoda componentelor simetrice la maşina de inducţie

Ipoteze :

- circuit magnetic liniar,
- parametrii constanți,
- regimul de motor,
- puterea rețelei foarte mare,
- regimurile sunt staționare.

Regimuri nesimetrice:

- rețeaua este nesimetrică, nesimetria nu depinde de sarcina motorului,
- rețeaua este simetrică, nesimetria se crează la bornele maşinii fiind dependentă de sarcină.

Metoda componentelor simetrice la maşina de inducţie

1. Tensiunile sunt nesimetrice

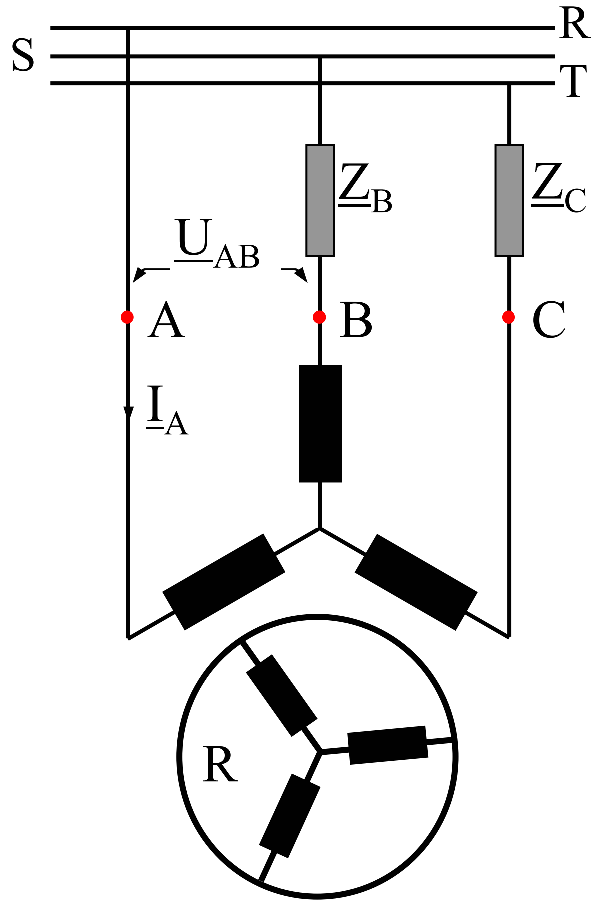
$$\begin{bmatrix} \underline{U}_d \\ \underline{U}_i \\ \underline{U}_h \end{bmatrix} = \frac{1}{3} \times \begin{vmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{vmatrix} \times \begin{vmatrix} \underline{U}_A \\ \underline{U}_B \\ \underline{U}_C \end{vmatrix}$$

2.Se crează nesimetria cu ajutorul unor impedanțe

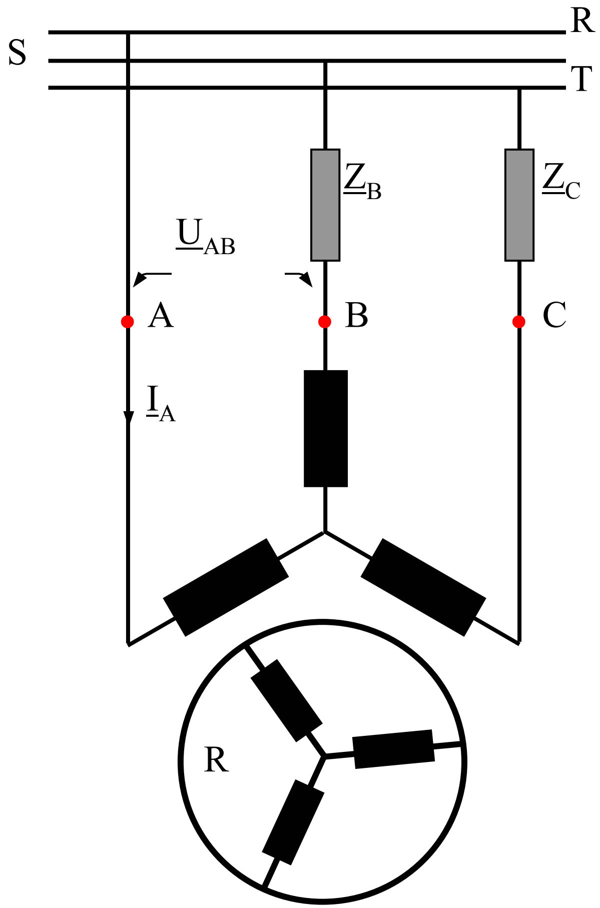
$$\underline{U}_A = \underline{U}_R$$

$$\underline{U}_B = \underline{U}_S - \underline{Z}_B \cdot \underline{I}_B$$

$$\underline{U}_C = \underline{U}_T - \underline{Z}_C \cdot \underline{I}_C$$



Metoda componentelor simetrice la maşina de inducţie



$$\underline{U}_A = \underline{U}_R$$

$$\underline{U}_B = \underline{U}_S - \underline{Z}_B \cdot \underline{I}_B$$

$$\underline{U}_C = \underline{U}_T - \underline{Z}_C \cdot \underline{I}_C$$

$$\begin{bmatrix} \underline{Z}_d \\ \underline{Z}_i \\ \underline{Z}_h \end{bmatrix} = \frac{1}{3} \times \begin{vmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{vmatrix} \times \begin{vmatrix} \underline{Z}_A \\ \underline{Z}_B \\ \underline{Z}_C \end{vmatrix}$$

Metoda componentelor simetrice la maşina de inducţie

Componentele simetrice ale tensiunii de alimentare:

$$\begin{bmatrix} \underline{U}_d \\ \underline{U}_i \\ \underline{U}_h \end{bmatrix}_A = \begin{bmatrix} \underline{U}_R \\ 0 \\ 0 \end{bmatrix} - \begin{vmatrix} \underline{Z}_h & \underline{Z}_i & \underline{Z}_d \\ \underline{Z}_d & \underline{Z}_h & \underline{Z}_i \\ \underline{Z}_i & \underline{Z}_d & \underline{Z}_h \end{vmatrix} \times \begin{vmatrix} \underline{I}_d \\ \underline{I}_i \\ \underline{I}_h \end{vmatrix}_A$$

Ecuațiile de tensiuni ale motorului de inducție

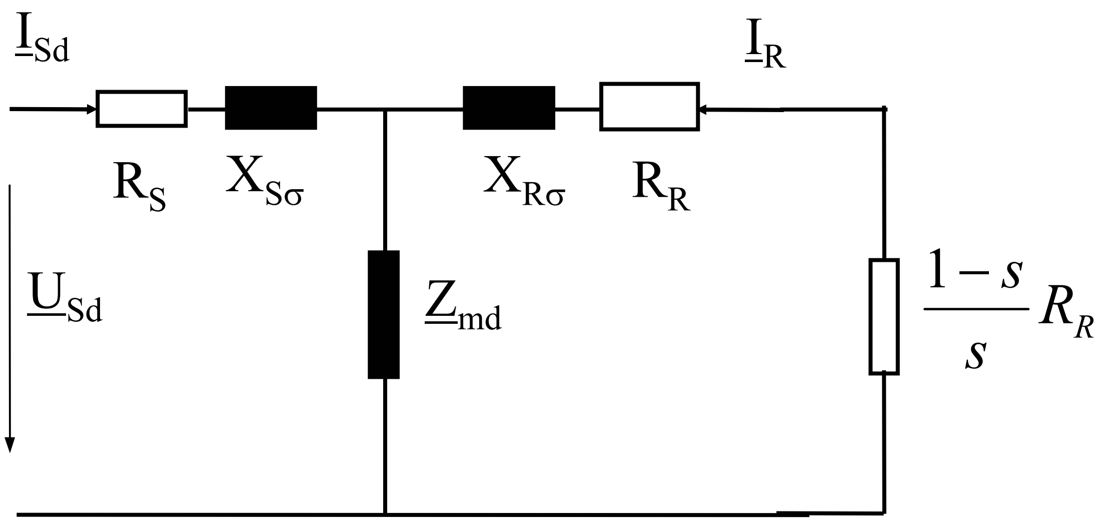
$$\underline{U}_d = \underline{Z}_{ed} \cdot \underline{I}_d$$

$$\underline{U}_i = \underline{Z}_{ei} \cdot \underline{I}_i$$

$$\underline{U}_h = \underline{Z}_{eh} \cdot \underline{I}_h$$

Parametrii maşinii de inducţie

1. **Sistem simetric de succesiune directă.**

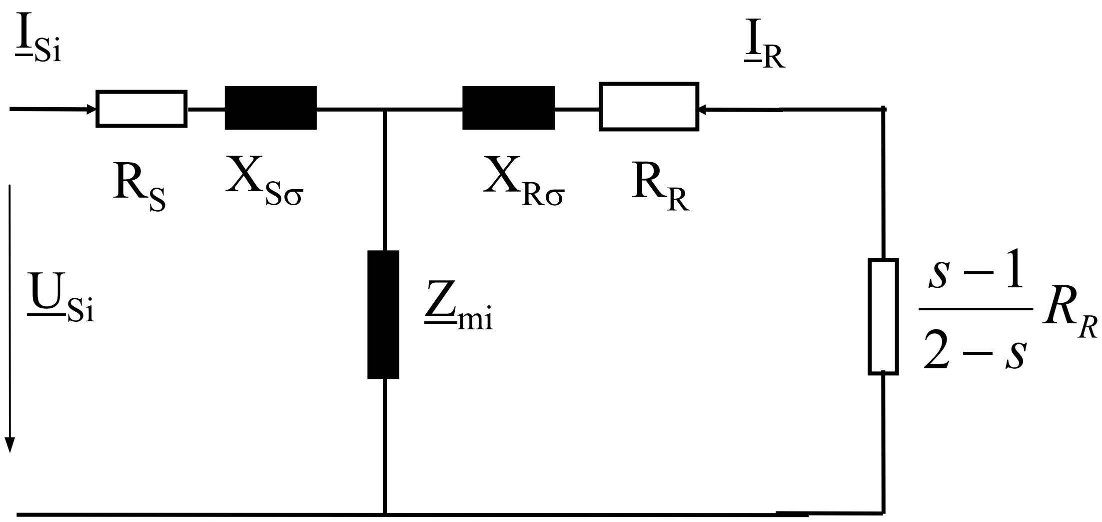


$$\underline{Z}_{ed} = \underline{Z}_S + \frac{\underline{Z}_{md} \cdot \underline{Z}_{Rd}}{\underline{Z}_{md} + \underline{Z}_{Rd}} \qquad \underline{Z}_{Rd} = \frac{R_R}{s} + jX_{R\sigma}$$

Parametrii maşinii de inducţie

2. **Sistem simetric de succesiune inversă**

Alunecarea $s_i = 2\text{-}s$



$$\underline{Z}_{ei} = \underline{Z}_S + \frac{\underline{Z}_{mi} \cdot \underline{Z}_{Ri}}{\underline{Z}_{mi} + \underline{Z}_{Ri}}$$

$$\underline{Z}_{Ri} = \frac{R_R}{2-s} + jX_{R\sigma}$$

Parametrii maşinii de inducţie

3. Sistemul homopolar

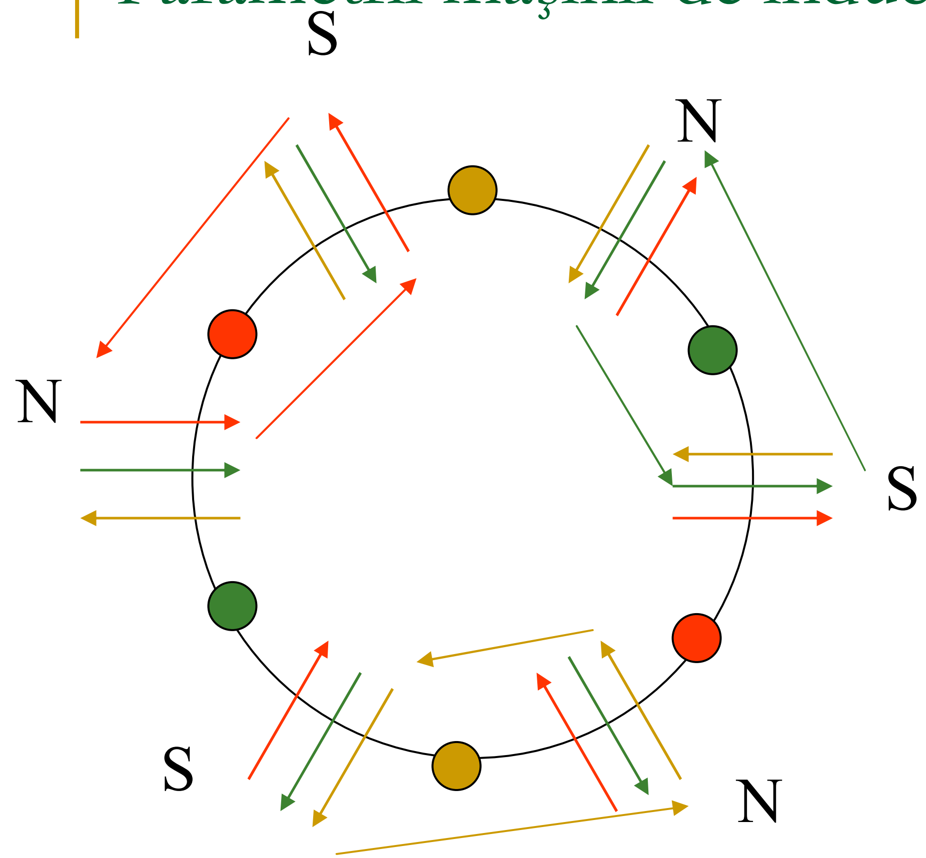
In statorul maşinii pot exista curenţi homopolari numai la conexiunea înfăşurărilor în stea cu nul şi triunghi întrerupt.

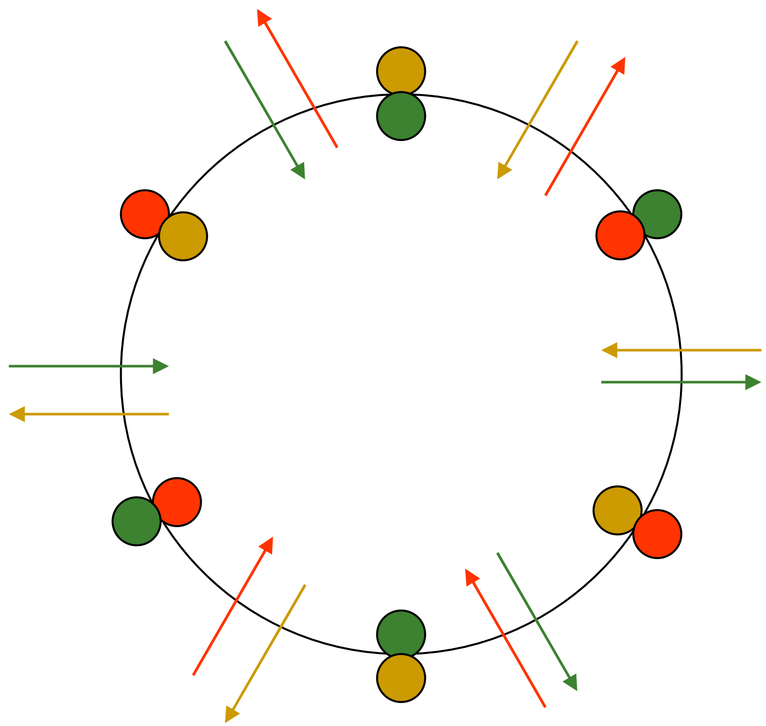
In rotorul maşinii pot exista curenţi homopolari numai la înfăşurarea în colivie.In acest caz înfăşurarea fiind diametrală reactanţa homopolară a rotorului este:

$$X_{Rh} = X_{R\sigma} + X_{arm}$$

Dacă există simultan în stator şi în rotor curenţi homopolari, atunci produc un cuplu homopolar, care are caracterul unui cuplu asincron.

Parametrii maşinii de inducţie





Câmpul homopolar la înfăşurare într-un strat, câmp pulsator cu

p_h - 3*p $\quad X_h = X_{S\sigma} + X_{\sigma arm}$

Câmpul homopolar la înfăşurarea în dublu strat cu scurtare $y = 2/3\ \tau$

$R_h \approx R_S \quad X_h = X_{\sigma arm}$

Regim nesimetric dependent de sarcină

Se consideră o maşina de inducție cu înfăşurarea conectată în stea.
în stator nu există curent homopolar

$$\underline{U}_d = \underline{Z}_{ed} \cdot \underline{I}_d$$

$$\underline{U}_i = \underline{Z}_{ei} \cdot \underline{I}_i$$

$$\underline{U}_h = \underline{Z}_{eh} \cdot \underline{I}_h$$

$$\begin{bmatrix} \underline{U}_d \\ \underline{U}_i \\ \underline{U}_h \end{bmatrix}_A = \begin{bmatrix} \underline{U}_R \\ 0 \\ 0 \end{bmatrix} - \begin{vmatrix} \underline{Z}_h & \underline{Z}_i & \underline{Z}_d \\ \underline{Z}_d & \underline{Z}_h & \underline{Z}_i \\ \underline{Z}_i & \underline{Z}_d & \underline{Z}_h \end{vmatrix} \times \begin{vmatrix} \underline{I}_d \\ \underline{I}_i \\ \underline{I}_h \end{vmatrix}_A$$

$$\underline{Z}_{ed} \cdot \underline{I}_d = \underline{U}_R - \underline{Z}_h \cdot \underline{I}_d - \underline{Z}_i \cdot \underline{I}_i$$

$$\underline{Z}_{ei} \cdot \underline{I}_i = -\underline{Z}_d \cdot \underline{I}_d - \underline{Z}_h \cdot \underline{I}_i$$

$$\underline{U}_R = \left(\underline{Z}_{ed} + \underline{Z}_h\right) \cdot \underline{I}_d + \underline{Z}_i \cdot \underline{I}_i$$

$$0 = \underline{Z}_d \cdot \underline{I}_d + \left(\underline{Z}_{ei} + \underline{Z}_h\right) \cdot \underline{I}_i$$

Regim nesimetric dependent de sarcină

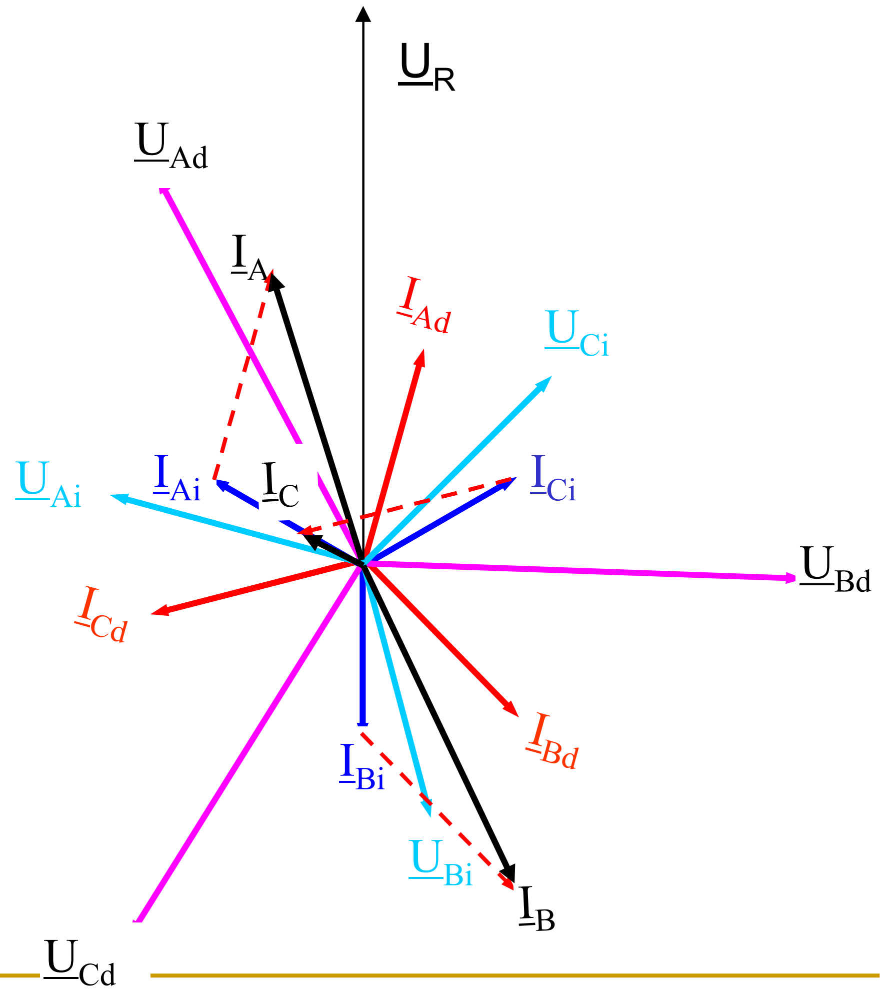
$$\underline{\Delta} = \left(\underline{Z}_{ed} + \underline{Z}_h\right)\cdot\left(\underline{Z}_{ei} + \underline{Z}_h\right) - \underline{Z}_d \cdot \underline{Z}_i$$

$$\underline{I}_{Ad} = \frac{\underline{U}_R \cdot \left(\underline{Z}_{ei} + \underline{Z}_h\right)}{\underline{\Delta}}$$

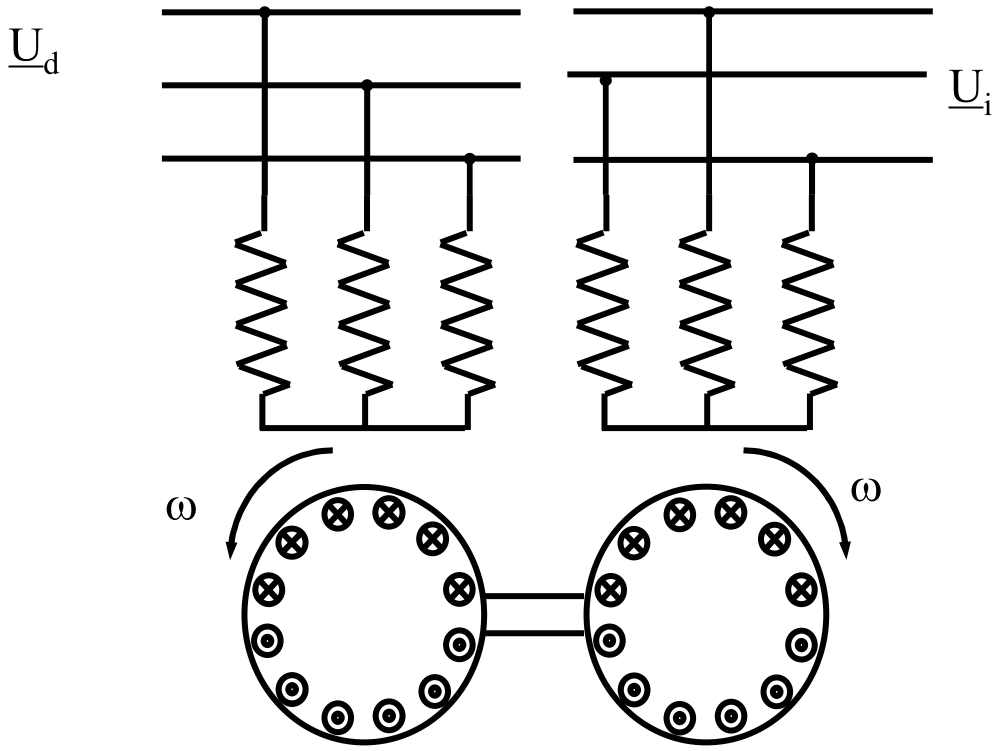
$$\underline{I}_{Ai} = -\frac{\underline{U}_R \cdot \underline{Z}_d}{\underline{\Delta}}$$

$$\underline{U}_d = \underline{Z}_{ed} \cdot \underline{I}_d$$

$$\underline{U}_i = \underline{Z}_{ei} \cdot \underline{I}_i$$



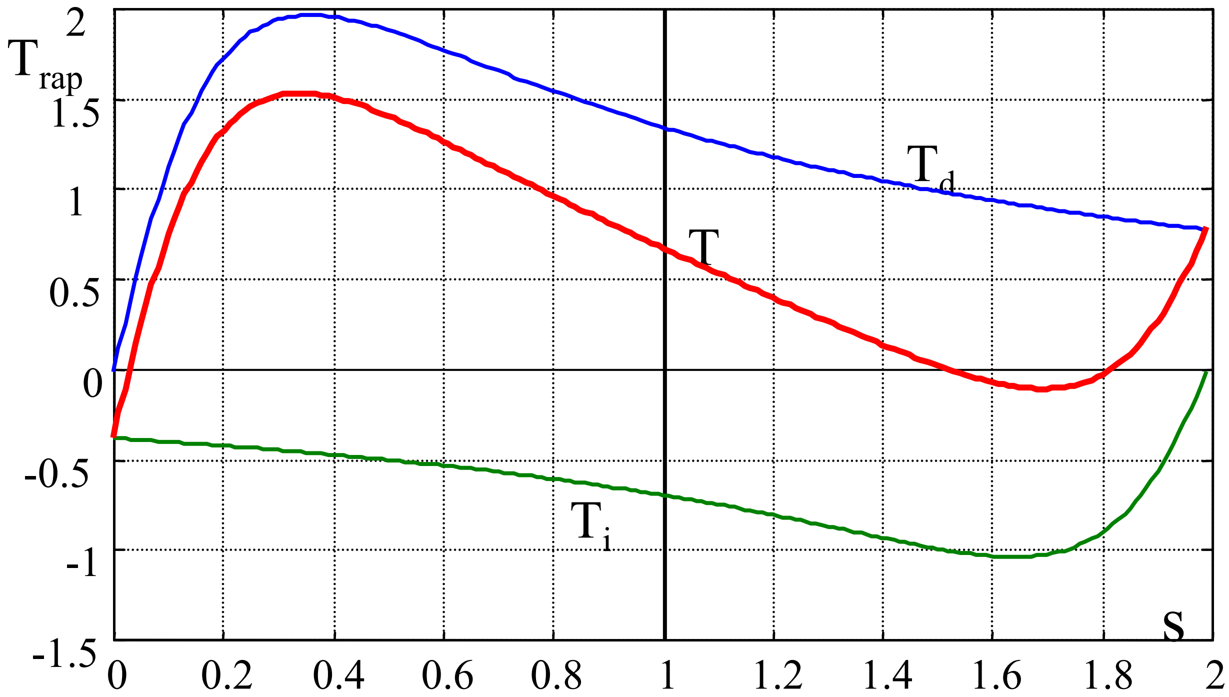
Regim nesimetric dependent de sarcină



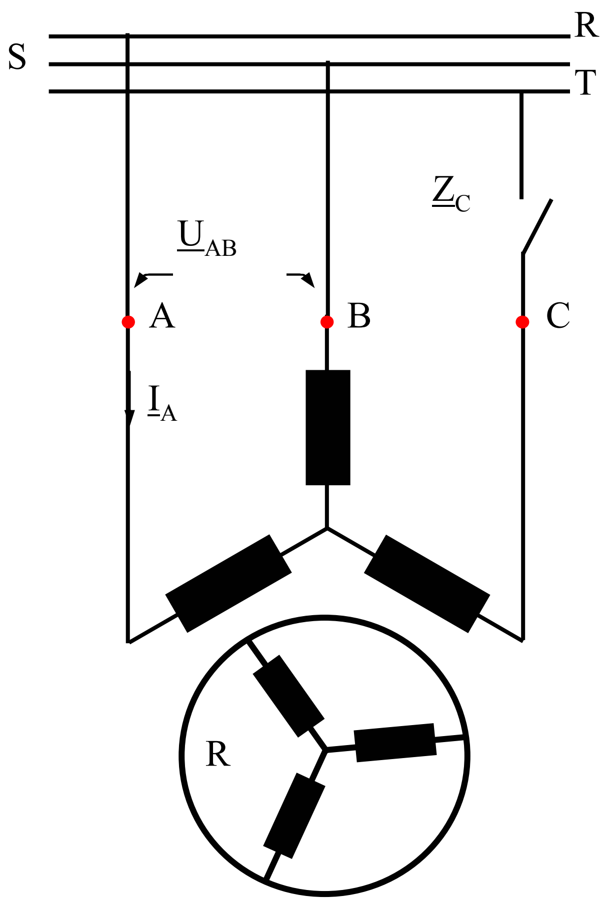
Cuplul electromagnetic

$$T_d = \frac{p \cdot m}{\omega} \frac{\frac{R_R}{s} U_d^2}{\left(R_S + \frac{R_R}{s}\right)^2 + \left(X_{S\sigma} + X_{R\sigma}\right)^2}$$

$$T_i = \frac{p \cdot m}{\omega} \frac{\frac{R_R}{2-s} U_i^2}{\left(R_S + \frac{R_R}{2-s}\right)^2 + \left(X_{S\sigma} + X_{R\sigma}\right)^2}$$



Regimul nesimetric cu o fază întreruptă



$$\underline{Z}_B = 0 \qquad \underline{Z}_C \to \infty$$

$$\begin{bmatrix} \underline{Z}_d \\ \underline{Z}_i \\ \underline{Z}_h \end{bmatrix} = \frac{1}{3} \times \begin{vmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{vmatrix} \times \begin{vmatrix} \underline{Z}_A \\ \underline{Z}_B \\ \underline{Z}_C \end{vmatrix}$$

$$\underline{Z}_d = \frac{1}{3} a^2 \cdot \underline{Z}_C$$

$$\underline{Z}_i = \frac{1}{3} a \cdot \underline{Z}_C$$

$$\underline{Z}_h = \frac{1}{3} \cdot \underline{Z}_C$$

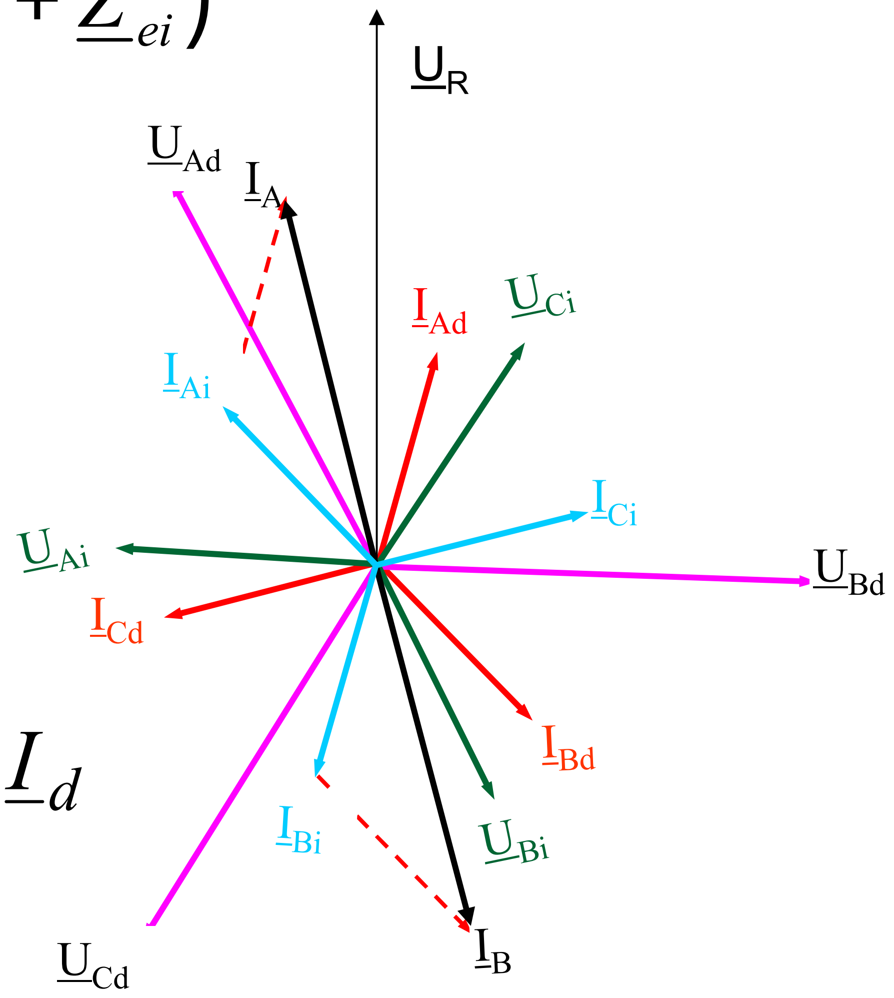
Regimul nesimetric cu o fază întreruptă

$$\underline{\Delta} = \underline{Z}_{ed} \cdot \underline{Z}_{ei} + \underline{Z}_h \cdot \left(\underline{Z}_{ed} + \underline{Z}_{ei}\right)$$

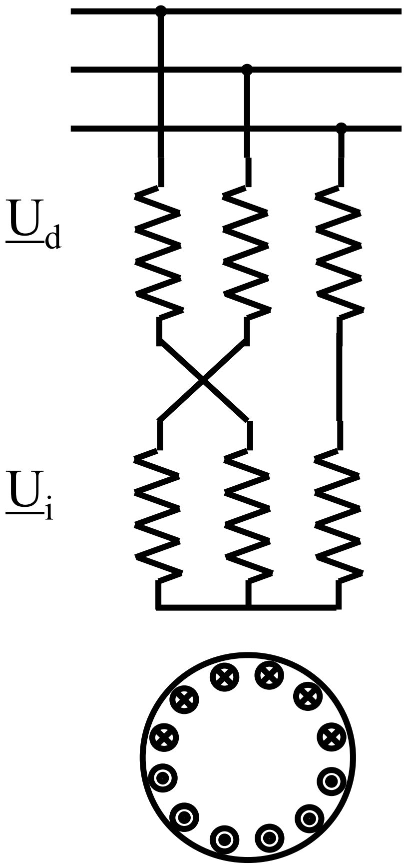
$$\underline{Z}_d \cdot \underline{Z}_i = \underline{Z}_h^2$$

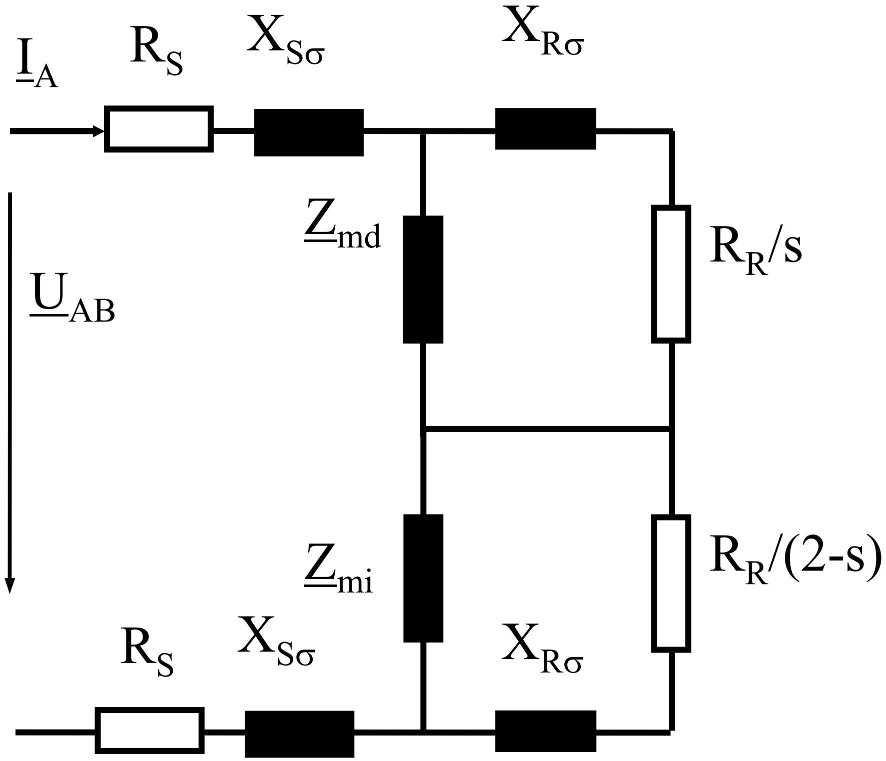
$$\underline{I}_d = \frac{\underline{U}_R}{\underline{Z}_{ed} + \underline{Z}_{ei}}$$

$$\underline{I}_i = -\frac{a^2 \cdot \underline{U}_R}{\underline{Z}_{ed} + \underline{Z}_{ei}} = -a^2 \cdot \underline{I}_d$$



Regimul nesimetric cu o fază întreruptă



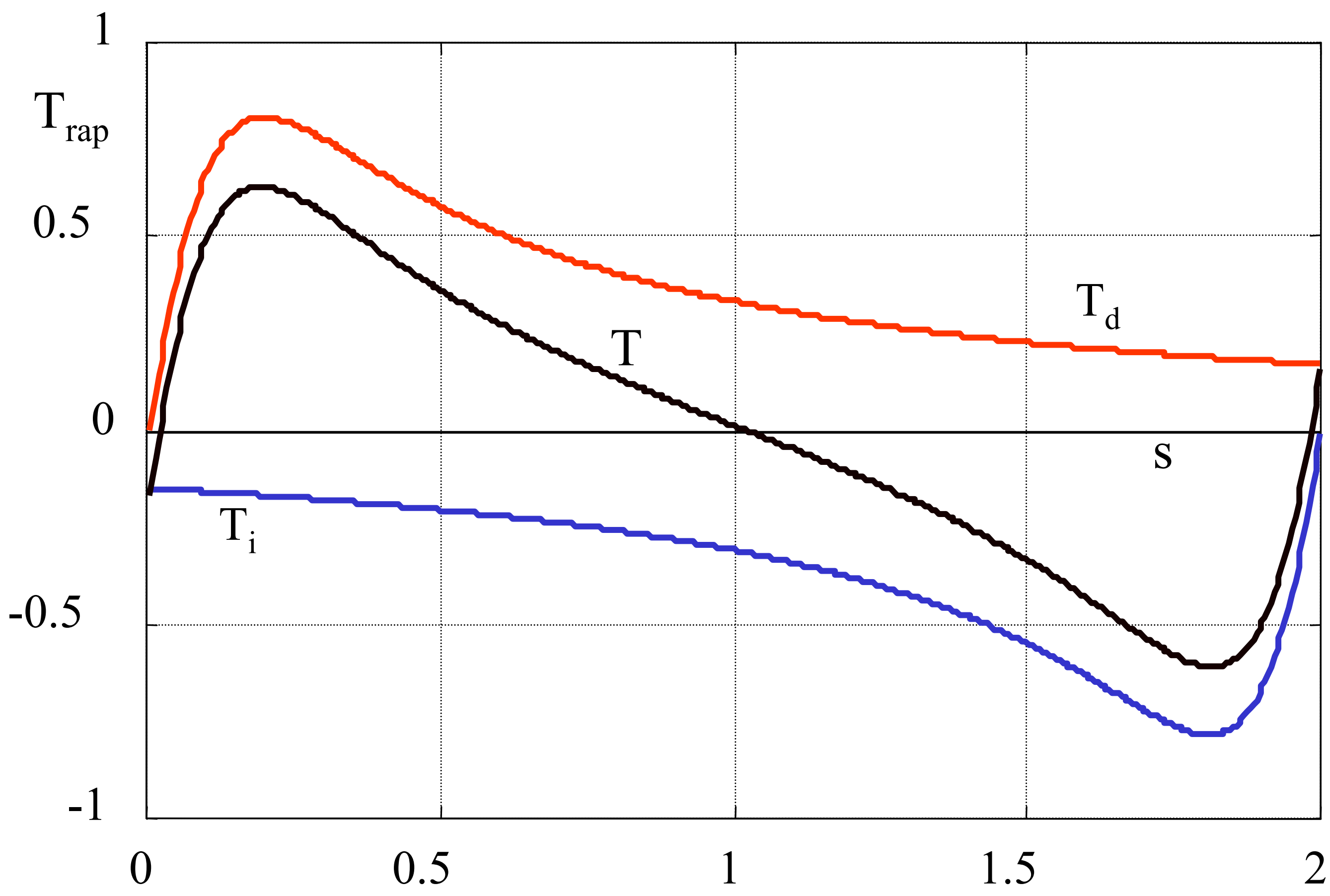


Regimul nesimetric cu o fază întreruptă

$$T_d = \frac{p \cdot m}{\omega} \frac{\frac{R_R}{s} U_d^2}{\left(R_S + \frac{R_R}{s} \right)^2 + \left(X_{S\sigma} + X_{R\sigma} \right)^2}$$

$$T_i = \frac{p \cdot m}{\omega} \frac{\frac{R_R}{2-s} U_i^2}{\left(R_S + \frac{R_R}{2-s} \right)^2 + \left(X_{S\sigma} + X_{R\sigma} \right)^2}$$

Regimul nesimetric cu o fază întreruptă



Exemplu

Datele motorului: $p = 3$

$Rs := 1.1 \quad \Omega$ $\quad Rr := 1.4 \quad \Omega$ $\quad Rm := 2.8 \quad \Omega$

$Xs\sigma := 2.4 \quad \Omega$ $\quad Xr\sigma := 3 \quad \Omega$ $\quad Xm := 39.8 \quad \Omega$

Parametrii de funcționare

$Us := 380 \quad V$ $\quad sd := 0.045$

Impedanțe înseriate

$Za := 0$ $\quad Zb := 0$ $\quad Zc := 1 + 14 \cdot i \quad \Omega$

Impedanțe de succesiune simetrice:

$$Zd := \frac{a^2 \cdot Zc}{3} \qquad Zi := a \cdot \frac{Zc}{3} \qquad Zh := \frac{Zc}{3}$$

$Zd = 3.875 - 2.622i \quad \Omega$ $\quad Zi = -4.208 - 2.045i \quad \Omega$ $\quad Zh = 0.333 + 4.667i \quad \Omega$

Exemplu

Impedanțele motorului

$$Zs := Rs + Xs\sigma \cdot 1i \qquad Zm := Rm + Xm \cdot 1i$$

$$Zrd := Xr\sigma \cdot 1i + \frac{Rr}{sd} \qquad Zri := Xr\sigma \cdot 1i + \frac{Rr}{2 - sd}$$

$$Zed := Zs + Zm \cdot \frac{Zrd}{(Zm + Zrd)} \qquad Zei := Zs + Zm \cdot \frac{Zri}{Zm + Zri}$$

$$Zed = 18.626 + 17.041i \quad \Omega \qquad Zei = 1.733 + 5.195i \quad \Omega$$

Exemplu

Componentele simetrice ale curenților;

$$Id := (Zei + Zh) \cdot \frac{Us}{\sqrt{3} \cdot \Delta}$$

$$Ii := -Zd \cdot \frac{Us}{\sqrt{3} \cdot \Delta}$$

$$\Delta := (Zed + Zh) \cdot (Zei + Zh) - Zd \cdot Zi$$

$$\Delta = -153.233 + 228.707i \quad \Omega$$

$$Id = 5.613 - 5.742i \quad A$$

$$Ii = 3.455 + 1.402i \quad A$$

Exemplu

Componentele simetrice ale tensiunii

$Ud := Zed \cdot Id$ $\qquad$ $Ui := Zei \cdot Ii$

$Ud = 202.396 - 11.313i$ V $\qquad$ $|Ud| = 202.712$ V

$Ui = -1.299 + 20.377i$ V $\qquad$ $|Ui| = 20.418$ V

Curentul pe faza A

$Ia := Id + Ii$

$Ia = 9.067 - 4.34i$ A $\qquad$ $|Ia| = 10.052$ A

Exemplu

Cuplul:

$$Td := 3 \cdot \frac{p}{100 \cdot \pi} \cdot (|Ud|)^2 \cdot \frac{\left(\frac{Rr}{sd}\right)}{\left(Rs + \frac{Rr}{sd}\right)^2 + (Xs\sigma + Xr\sigma)^2}$$

$Td = 34.334 \quad Nm$

$$Ti := 3 \cdot \frac{p}{100 \cdot \pi} \cdot (|Ui|)^2 \cdot \frac{\left(\frac{Rr}{2 - sd}\right)}{\left(Rs + \frac{Rr}{2 - sd}\right)^2 + (Xs\sigma + Xr\sigma)^2}$$

$Ti = 0.263 \quad Nm$

$T := Td - Ti \qquad T = 34.07 \quad Nm$

Exemplu

Componentele simetrice la întreruperea unei faze

Cu $Z_d * Z_i = Z^2_h$ $\quad\Delta := (Zed + Zei) \cdot Zh$

$$Id1 := \frac{Us}{\sqrt{3} \cdot (Zed + Zei)} \qquad Ii1 := -a \cdot Id1$$

$Id1 = 4.914 - 5.367i$ A $\quad Ii1 = -2.191 - 6.939i$ A

$Ud1 := Zed \cdot Id1$ $\quad Ud1 = 182.997 - 16.229i$ V

$|Ud1| = 183.715$ V

$Ui1 := Zei \cdot Ii1$ $\quad Ui1 = 32.253 - 23.405i$ V

$|Ui1| = 39.851$ V

Exemplu

Curentul de faza A

$$I1 := Id1 + Ii1 \qquad I1 = 2.723 - 12.307i \quad A$$

$$|I1| = 12.604 \quad A$$

Cuplul direct

$$Td1 := 3 \cdot \frac{p}{100 \cdot \pi} \cdot (|Ud1|)^2 \cdot \frac{\left(\frac{Rr}{sd}\right)}{\left(Rs + \frac{Rr}{sd}\right)^2 + (Xs\sigma + Xr\sigma)^2}$$

$$Td1 = 28.2 \quad Nm$$

Exemplu

Cuplul invers

$$Ti1 := 3 \cdot \frac{p}{100 \cdot \pi} \cdot (|Ui1|)^2 \cdot \frac{\left(\frac{Rr}{2 - sd}\right)}{\left(Rs + \frac{Rr}{2 - sd}\right)^2 + (Xs\sigma + Xr\sigma)^2}$$

$Ti1 = 1.004$ Nm

Cuplul rezultant

$T1 := Td1 - Ti1 \qquad T1 = 27.196$ Nm

Exemplu

La pornire: impedantele

$$Zr := Rr + X r\sigma \cdot 1i$$

$$Zep := Zs + Zm \cdot \frac{Zr}{(Zm + Zr)} \qquad Zep = 2.322 + 5.218i \quad \Omega$$

Componente de curenți

$$Idp := \frac{Us}{\sqrt{3} \cdot 2 \cdot Zep} \qquad Idp = 7.808 - 17.549i \quad A$$

$$Iip := -a \cdot Idp \qquad Iip = -11.294 - 15.536i \quad A$$

Exemplu

Curentul din faza A

$$Iap := Idp + Iip \qquad Iap = -3.486 - 33.085i \qquad |Iap| = 33.268 \quad A$$

Componente de tensiune

$$Udp := Zep \cdot Idp \qquad Udp = 109.697 \quad V$$

$$Uip := Zep \cdot Iip \qquad Uip = 54.848 - 95i \quad V$$

$$|Uip| = 109.697 \quad V$$

Exemplu

Cuplul de pornire

$$Tdp := 3 \cdot \frac{p}{100 \cdot \pi} \cdot (|Udp|)^2 \cdot \frac{(Rr)}{(Rs + Rr)^2 + (Xs\sigma + Xr\sigma)^2}$$

$Tdp = 13.63$ Nm

$$Tip := Tdp$$

$Tp := Tdp - Tip$ $Tp = 0$ Nm