Integrirani pogonski sistemi

Modeliranje električnih pogonov

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Stacionarno obratovanje

Nesimetrične fazne napetosti

Za primer vzamemo nesimetrične fazne napetosti, ki imajo

- različno amplitudo,
- različno fazo

in jih lahko zapišemo kot

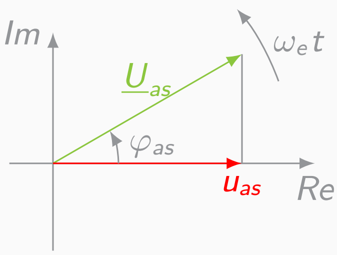
$$\begin{aligned} u_{as} &= U_{as}\cos(\omega_e t + \varphi_{as}) \\ u_{bs} &= U_{bs}\cos(\omega_e t + \varphi_{bs}) \\ u_{cs} &= -u_{as} - u_{bs}. \end{aligned}$$

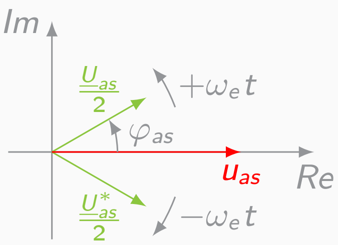
Zaradi pogoja $u_{as} + u_{bs} + u_{cs} = 0$ ničelne komponente ni.

Fazna napetost s kompleksnimi števili

Uporabimo preoblikovan Eulerjev izrek $\cos\theta = \frac{1}{2}(e^{j\theta} + e^{-j\theta})$ in za fazo a dobimo

$$u_{as} = U_{as}\cos(\omega_e t+\varphi_{as}) = U_{as}\,\mathrm{Re}\left[e^{j(\omega_e t+\varphi_{as})}\right] = \frac{1}{2}\left(U_{as}e^{j(\omega_e t+\varphi_{as})} + U_{as}e^{-j(\omega_e t+\varphi_{as})}\right).$$





Če združimo amplitudo U_{as} in začetni kot $e^{j\varphi_{as}}$ dobimo fazor napetosti

$$\underline{U}_{as} = U_{as}e^{j\varphi_{as}},$$

zato lahko zapišemo

$$u_{as} = \frac{1}{2}\underline{U}_{as}e^{j\omega_e t} + \frac{1}{2}\underline{U}^*_{as}e^{-j\omega_e t}.$$

Preoblikovanje prostorskega vektorja

Uporabimo definicijo prostorskega vektorja napetosti.

$$\boldsymbol{u}_s = \frac{2}{3}(u_{as} + \boldsymbol{a}u_{bs} + \boldsymbol{a}^2 u_{cs})$$
$$= \underbrace{\boxed{\frac{1}{3}\left(\underline{U}_{as} + \boldsymbol{a}\underline{U}_{bs} + \boldsymbol{a}^2\underline{U}_{cs}\right)}}_{\text{pozitivno zaporedje } \underline{U}_{+s}} e^{j\omega_e t} + \underbrace{\boxed{\frac{1}{3}\left(\underline{U}^*_{as} + \boldsymbol{a}\underline{U}^*_{bs} + \boldsymbol{a}^2\underline{U}^*_{cs}\right)}}_{\text{negativno zaporedje } \underline{U}_{-s}} e^{-j\omega_e t},$$

Drugi člen ob upoštevanju $z_1^* z_2^* = (z_1 z_2)^*$ preoblikujemo

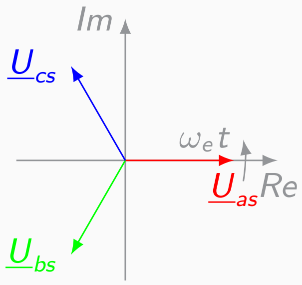
$$\left(\underline{U}^*_{as} + \boldsymbol{a}\underline{U}^*_{bs} + \boldsymbol{a}^2\underline{U}^*_{cs}\right) e^{-j\omega_e t} = \left(\underline{U}_{as} + \boldsymbol{a}^2\underline{U}_{bs} + \boldsymbol{a}\underline{U}_{cs}\right)^* e^{-j\omega_e t}$$

Vektor napetosti: $\boldsymbol{u}_s = \underline{U}_{+s} e^{j\omega_e t} + \underline{U}_{-s} e^{-j\omega_e t}$

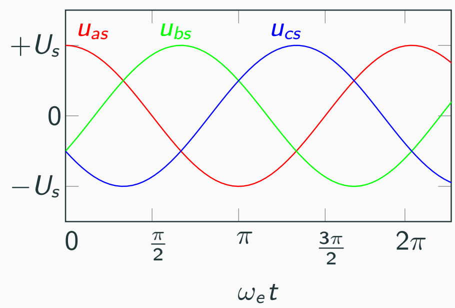
Simetrične fazne napetosti

$$\underline{U}_{as} = U_s e^{j0}$$
$$\underline{U}_{bs} = U_s e^{-j120}$$
$$\underline{U}_{cs} = U_s e^{-j240}$$

fazorski diagram



časovni potek



zato dobimo

$$\underline{U}_{+s} = \frac{1}{3}\left(U_s e^{j0} + \underline{a}U_s e^{-j120} + \underline{a}^2 U_s e^{-j240}\right) = \underline{U}_s$$
$$\underline{U}_{-s} = \frac{1}{3}\left(U_s e^{j0} + \underline{a}^2 U_s e^{j120} + \underline{a}U_s e^{j240}\right) = 0$$

prostorski vektor napetosti v naravnem KS

$$\boldsymbol{u}_s = \underline{U}_s e^{j\omega_e t}$$

Preoblikovanje napetostne enačbe

1. izhodiščna enačba

$$\boldsymbol{u}_s = R_s \boldsymbol{i}_s + \frac{d\boldsymbol{\psi}_s}{dt} + \mathrm{j}\omega\boldsymbol{\psi}_s$$
$$0 = R_r \boldsymbol{i}_r + \frac{d\boldsymbol{\psi}_r}{dt} + \mathrm{j}(\omega - \omega_r)\boldsymbol{\psi}_r$$

2. nastavek

Vektor napetosti je harmoničen $\boldsymbol{u}_s = \underline{U}_s e^{j\omega_e t}$, zato iščemo rešitev v obliki $\boldsymbol{i}_s = \underline{I}_s e^{j\omega_e t}$ in $\boldsymbol{\psi}_s = \underline{\Psi}_s e^{j\omega_e t}$.

3. izbira sinhronskega KS

$(\omega = \omega_e)$

$$\boldsymbol{u}_s^s = R_s \boldsymbol{i}_s^s + \frac{d\boldsymbol{\psi}_s^s}{dt} + \mathrm{j}\omega_e\boldsymbol{\psi}_s^s$$
$$0 = R_r \boldsymbol{i}_r^s + \frac{d\boldsymbol{\psi}_r^s}{dt} + \mathrm{j}(\omega_e - \omega_r)\boldsymbol{\psi}_r^s$$

4. transformacija veličin v SKS

(množenje z $e^{-j\omega_e t}$)

$$\boldsymbol{u}_s^s = \boldsymbol{u}_s e^{-j\omega_e t} = \underline{U}_s e^{j\omega_e} e^{-j\omega_e t} = \underline{U}_s$$
$$\boldsymbol{i}_s^s = \boldsymbol{i}_s e^{-j\omega_e t} = \underline{I}_s e^{j\omega_e} e^{-j\omega_e t} = \underline{I}_s$$
$$\boldsymbol{\psi}_s^s = \boldsymbol{\psi}_s e^{-j\omega_e t} = \underline{\Psi}_s e^{j\omega_e} e^{-j\omega_e t} = \underline{\Psi}_s$$

5. preoblikovana enačba

$$\underline{U}_s = R_s \underline{I}_s + \boxed{\frac{d\underline{\Psi}_s}{dt}} + \mathrm{j}\omega_e\underline{\Psi}_s$$
$$0 = R_r \underline{I}_r + \boxed{\frac{d\underline{\Psi}_r}{dt}} + \mathrm{j}(\omega_e - \omega_r)\underline{\Psi}_r$$

odvod

$$\frac{d\underline{\Psi}_s}{dt} = 0$$
$$\frac{d\underline{\Psi}_r}{dt} = 0$$

6. fazorska enačba

$$\underline{U}_s = R_s \underline{I}_s + \mathrm{j}\omega_e\underline{\Psi}_s$$
$$0 = R_r \underline{I}_r + \mathrm{j}s\omega_e\underline{\Psi}_r$$

Nastanek nadomestnega vezja

Drugo enačbo delimo s slipom ter magnetne sklepe izrazimo s tokovi

fluksi izraženi s tokovi

$$\underline{\Psi}_s = L_s \underline{I}_s + L_m \underline{I}_r$$
$$\underline{\Psi}_r = L_r \underline{I}_r + L_m \underline{I}_s$$

izločeni fluksi

$$\underline{U}_s = R_s \underline{I}_s + \mathrm{j}\omega_e(L_s \underline{I}_s + L_m \underline{I}_r)$$
$$0 = \frac{R_r}{s}\underline{I}_r + \mathrm{j}\omega_e(L_r \underline{I}_r + L_m \underline{I}_s).$$

Razstavimo lastni induktivnosti na stresano in medsebojno

stresana in magnetilna induktivnost

$$L_s = L_{ss} + L_m$$
$$L_r = L_{sr} + L_m$$

končna enačba

$$\underline{U}_s = R_s \underline{I}_s + \mathrm{j}\omega_e L_{ss}\underline{I}_s + \boxed{\mathrm{j}\omega_e L_m(\underline{I}_s + \underline{I}_r)}$$
$$0 = \frac{R_r}{s}\underline{I}_r + \mathrm{j}\omega_e L_{sr}\underline{I}_r + \boxed{\mathrm{j}\omega_e L_m(\underline{I}_s + \underline{I}_r)}.$$

Ker imata napetostni enačbi skupen člen, ju lahko interpretiramo kot