Průmyslová energetika
X15PEN

přednáška č. 8

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Elektromechanická přeměna

$\overline{\psi}$ $\overline{i}, \overline{u}$	VEKTOR CÍVK. TOKŮ, PROUDŮ A NAPĚTÍ
γ $\omega = d\gamma / dt$	ÚHEL SOUŘADNIC ÚHLOVÁ RYCHLOST
$\left[L(\gamma)\right]$	MATICE INDUKČNOSTÍ
$\left[R_{\%}\right].$	DIAG. MATICE REZISTANCÍ
p	VÝKON

vazba tok $\Leftrightarrow$ proud

$$\overline{u} - \overline{R}_{\%} \cdot \overline{i} = \overline{\psi}^{\bullet}$$

$$\overline{\psi} = \left[L(\gamma)\right] \cdot \overline{i}$$

napěťová rovnice

$$\overline{\psi}^{\bullet} = \left[L(\gamma)\right] \cdot \overline{i}^{\bullet} +$$

$$+ \left[L(\gamma)\right]^{\bullet} \cdot \overline{i}$$

Základní rovnice modelu

$$\bar{i}^{\bullet} = \left[L(\gamma)\right]^{-1}\left\{ \underbrace{\bar{u} - \bar{R}_{\%}.\bar{i}}_{\bar{\psi}^{\bullet}} - \left[L(\gamma)\right]^{\bullet}\bar{i} \right\}$$

$$\bar{i}^{\bullet} = \left[L(\gamma)\right]^{-1}\left\{ \bar{u} - \left(\bar{R}_{\%} + \left[L(\gamma)\right]^{\bullet} \right).\bar{i} \right\}$$

výkonová bilance:

$$p = \bar{i}^{T}\bar{u} = \underbrace{\bar{i}^{T}\left[R_{\%}\right].\bar{i}}_{\text{výkon na odporech}} + \bar{i}^{T}\left[L(\gamma)\right].\bar{i}^{\bullet} + \bar{i}^{T}\left[L(\gamma)\right]^{\bullet}.\bar{i}$$

$$W_{mag} = \frac{1}{2}\bar{i}^{T}\left[L(\gamma)\right]\bar{i}$$ **energie elektromag. pole**

Základní rovnice modelu

$$W^{\bullet}_{mag} = \frac{1}{2}\left(\underbrace{\bar{i}^{T}\left[L(\gamma)\right]\bar{i}^{\bullet} + \bar{i}^{\bullet T}\left[L(\gamma)\right]\bar{i}}_{2.\bar{i}^{T}\left[L(\gamma)\right]\bar{i}^{\bullet}} + \bar{i}^{T}\left[L(\gamma)\right]^{\bullet}\bar{i} \right)$$

$$W^{\bullet}_{mag} = \bar{i}^{T}\left[L(\gamma)\right]\bar{i}^{\bullet} + \frac{\bar{i}^{T}\left[L(\gamma)\right]^{\bullet}\bar{i}}{2}$$

$$p = \bar{i}^{T}.\bar{R}_{\%}.\bar{i} + \underbrace{W^{\bullet}_{mag}}_{\substack{výkon \\ mag.pole}} + \underbrace{\frac{1}{2}\bar{i}^{T}\underbrace{\left[L(\gamma)\right]^{\bullet}}_{\omega\cdot\frac{d}{d\gamma}\left[L(\gamma)\right]}\bar{i}}_{\substack{výkon\ \ konvertovaný \\ do\ mechanické\ formy \\ p_{el}=\omega M_{el}}}$$

Základní rovnice modelu

$\Rightarrow$ Konečný vztah pro volné proudy systému:

MODEL:

1. $$\bar{i}^{\bullet} = \left[L(\gamma)\right]^{-1}\left\{\bar{U} - \left(\omega\frac{d}{d\gamma}\left[L(\gamma)\right] + \bar{R}_{\%}\right)\bar{i}\right\}$$

2. pohybová rovnice

$$M_{setr} + M_{hnací} + M_{brzdící} + M_{tlum} = 0$$

Model zdroje v dq

$$\vec{\psi} = \left(\psi_q + j\psi_d\right).e^{j\omega t} \qquad \text{..........}\textit{prostorový fázor toku}$$

$$\vec{\psi}^{\bullet} = \vec{u}_i = \left(\psi_q^{\bullet} + j\psi_d^{\bullet}\right).e^{j\omega t} + j\omega.\left(\psi_q + j\psi_d\right).e^{j\omega t} \ \text{...}\textit{induk.napětí}$$

$$\vec{\psi}^{\bullet} = \underbrace{\left(\psi_q^{\bullet} - \omega\psi_d\right)}_{u_{iq}}.e^{j\omega t} + j\underbrace{\left(\psi_d^{\bullet} + \omega\psi_q\right)}_{u_{id}}.e^{j\omega t}$$

$$\underbrace{\left(u_q + ju_d\right).e^{j\omega t}}_{\vec{u}} = -r.\underbrace{\left(i_q + ji_d\right).e^{j\omega t}}_{\vec{i}} - \underbrace{\left(u_{iq} + ju_{id}\right).e^{j\omega t}}_{\vec{u}_i}$$

$$u_q = -r.i_q - \psi_q^{\bullet} + \omega\psi_d \quad , \qquad ju_d = j\left(-r.i_d - \psi_d^{\bullet} - \omega\psi_q\right)$$

$$u_f = r_f.i_f + \psi_f^{\bullet} \quad , \qquad 0 = r_D.i_D + \psi_D^{\bullet} \quad , \qquad 0 = r_Q.i_Q + \psi_Q^{\bullet}$$

Model zdroje v dq

$$\begin{bmatrix} u_q \\ u_d \\ u_f \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} r & & & & \\ & r & & 0 & \\ & & r_f & & \\ & 0 & & r_D & \\ & & & & r_Q \end{bmatrix} \begin{bmatrix} -i_q \\ -i_d \\ i_f \\ i_D \\ i_Q \end{bmatrix} + \underbrace{\dot{\begin{bmatrix} -\psi_q \\ -\psi_d \\ \psi_f \\ \psi_D \\ \psi_Q \end{bmatrix}}}_{transf.} + \underbrace{\begin{bmatrix} \omega\psi_d \\ -\omega\psi_q \\ 0 \\ 0 \\ 0 \end{bmatrix}}_{rotační}$$

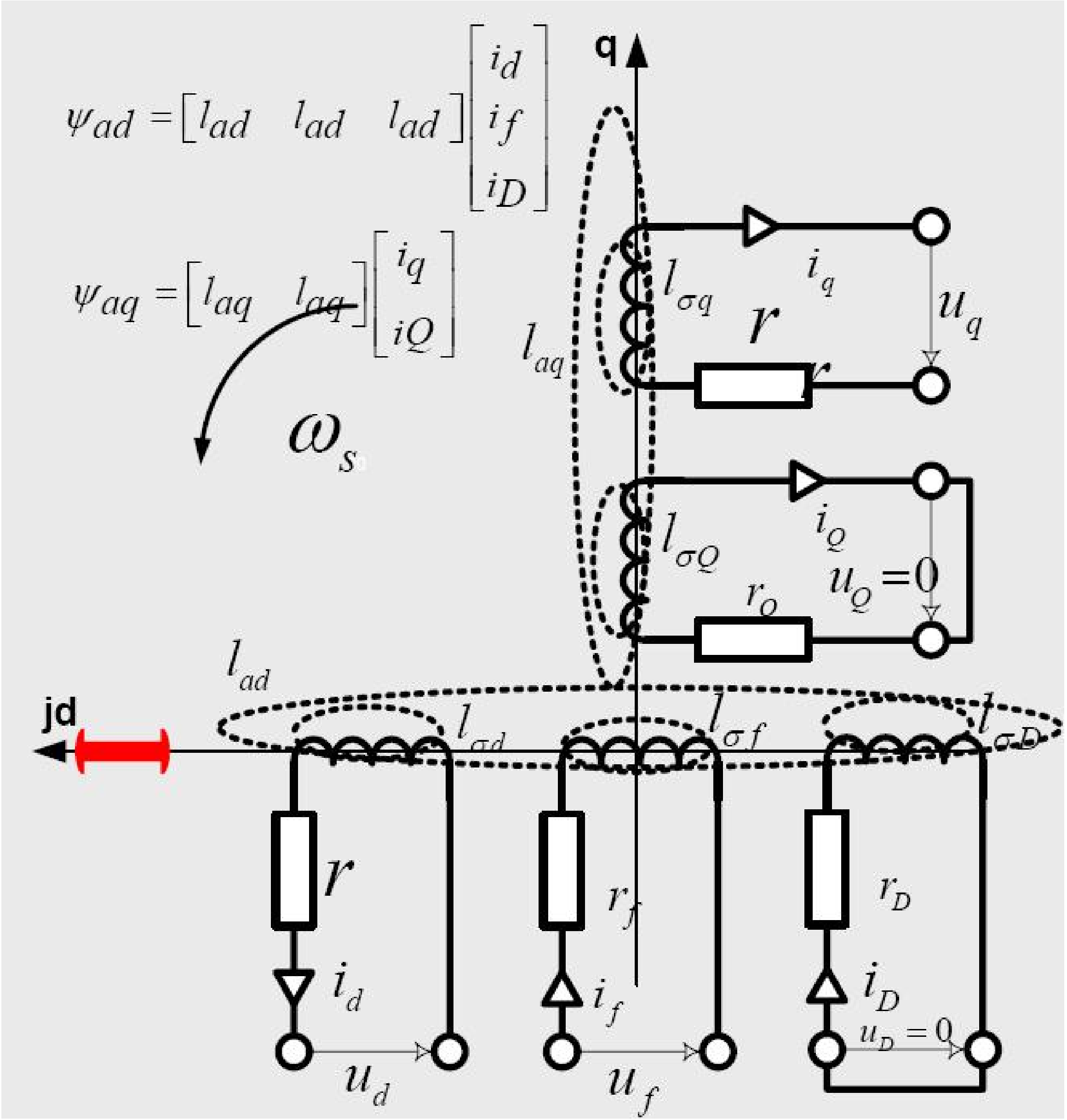
cívkové toky:

$$l_d = l_{ad} + l_{\sigma d}$$
$$l_q = l_{aq} + l_{\sigma q}$$
$$l_D = l_{ad} + l_{\sigma D}$$
$$l_q = l_{aq} + l_{\sigma d}$$
$$l_Q = l_{aq} + l_{\sigma Q}$$

$$\begin{bmatrix} \psi_d \\ \psi_f \\ \psi_D \end{bmatrix} = \begin{bmatrix} l_d & l_{ad} & l_{ad} \\ l_{ad} & l_f & l_{ad} \\ l_{ad} & l_{ad} & l_D \end{bmatrix} \begin{bmatrix} i_d \\ i_f \\ i_D \end{bmatrix}$$

$$\begin{bmatrix} \psi_d \\ \psi_Q \end{bmatrix} = \begin{bmatrix} l_q & l_{aq} \\ l_{aq} & l_Q \end{bmatrix} \begin{bmatrix} i_d \\ i_Q \end{bmatrix}$$

Model zdroje v dq



Model zdroje v dq

$$u_d = -r.i_d - \overbrace{\left\{(l_{ad}+l_\sigma)i_d + l_{ad}(i_f+i_D)\right\}^{\bullet}}^{\psi_d^{\bullet}} - \underbrace{\omega\overbrace{\left(l_q i_q + l_{aq} i_Q\right)}^{\psi_q}}_{u_{\omega d}}$$

$$u_q = -r.i_q - \overbrace{\left\{(l_{aq}+l_\sigma)i_q + l_{aq} i_Q\right\}^{\bullet}}^{\psi_q^{\bullet}} - \underbrace{\omega\overbrace{\left(l_d i_d + l_{ad}(i_f+i_D)\right)}^{\psi_d}}_{u_{\omega q}}$$

$$u_f = r_f.i_f + \overbrace{\left\{(l_{ad}+l_{\sigma f})i_f + l_{ad}(i_d+i_D)\right\}^{\bullet}}^{\psi_f^{\bullet}}$$

$$0 = r_D.i_D + \overbrace{\left\{(l_{ad}+l_{\sigma D})i_D + l_{ad}(i_f+i_D)\right\}^{\bullet}}^{\psi_D^{\bullet}} = r_Q.i_Q + \overbrace{\left\{(l_{ad}+l_{\sigma Q})i_Q + l_a(i_f+i_q)\right\}^{\bullet}}^{\psi_Q^{\bullet}}$$

Zdroj v dq – ustálený stav

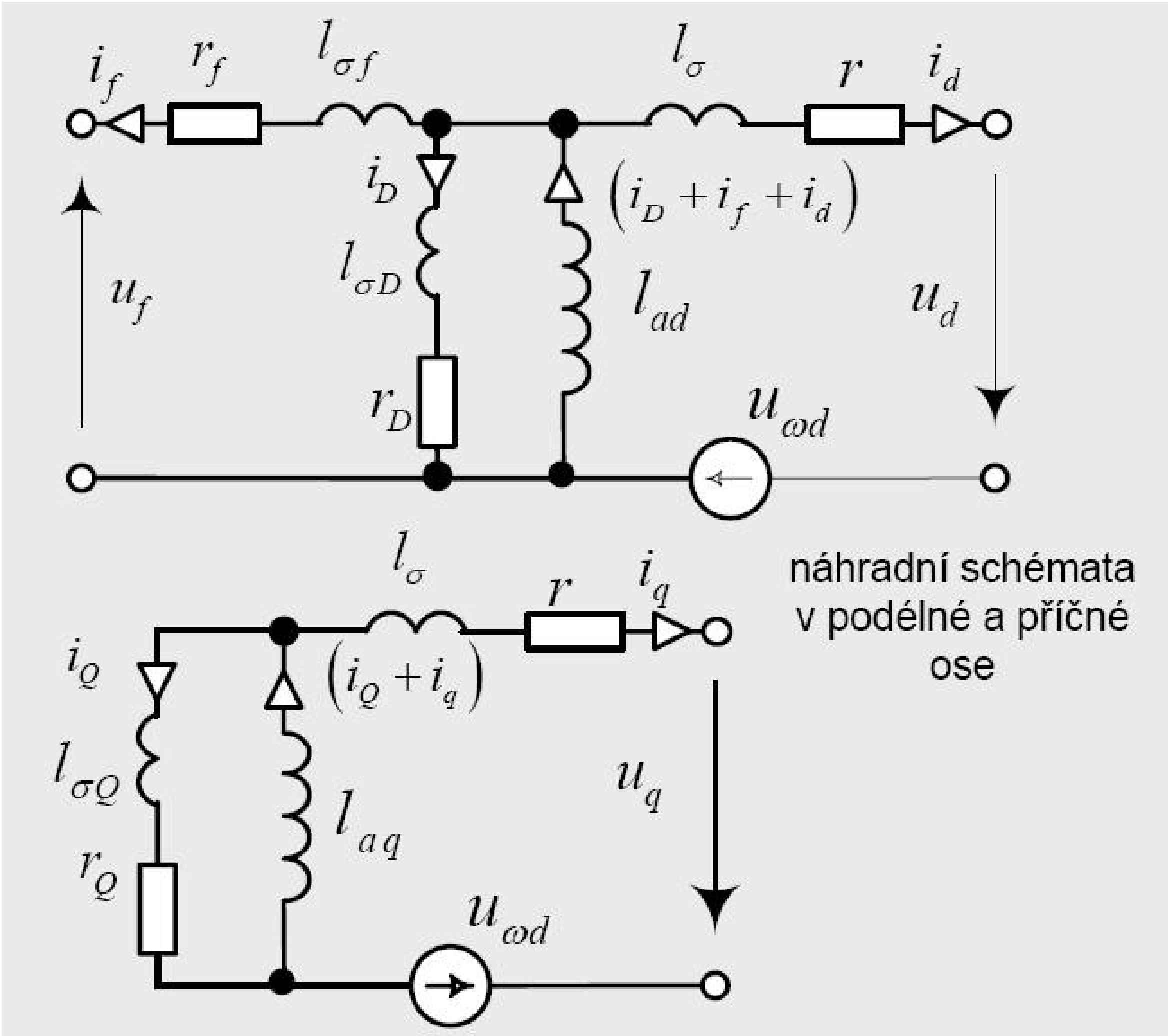
$$\left(\;\right)^{\bullet} = 0 \Rightarrow i_d = i_Q = 0, \quad \omega = 1 \Rightarrow l_q = x_q, l_d = x_d$$

$$ju_d = -r.ji_d - jx_q.i_q \qquad u_q = -ri_q - jx_d.ji_d + \overbrace{l_{ad}.i_f}^{e}$$

$$e = \underbrace{u_q + ju_d}_{\hat{u}} + jx_q.i_q + jx_d ji_d \pm ji_d jx_d$$

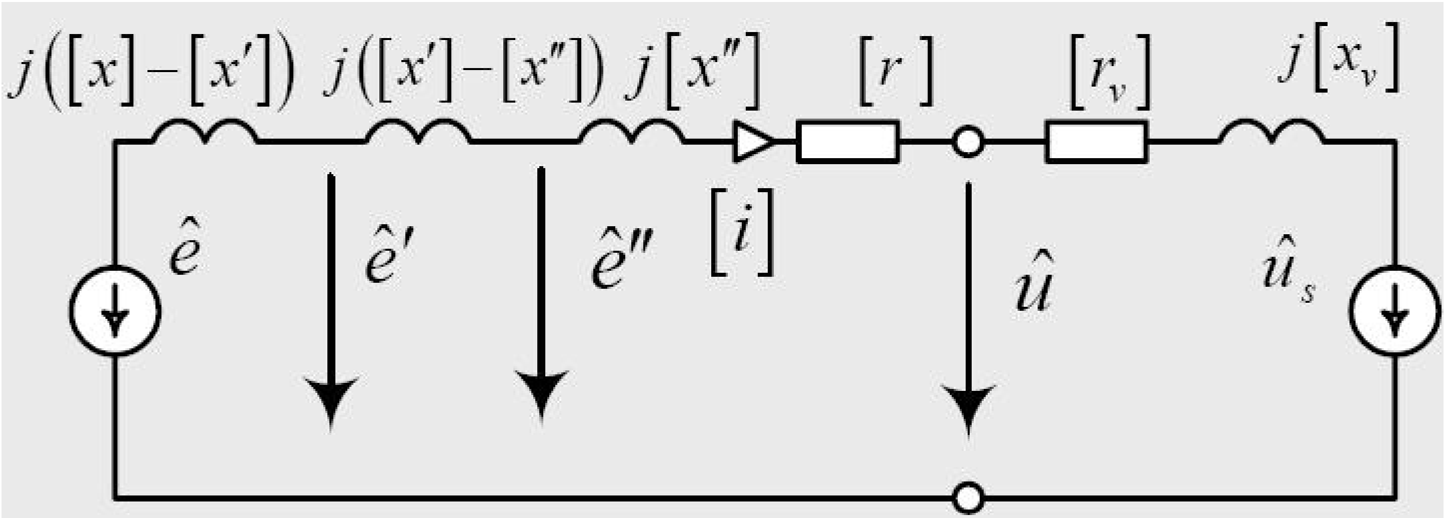
$$e = \hat{u} + \left(r + jx_q\right)\overbrace{\left(i_q + ji_d\right)}^{\hat{i}} + \overbrace{ji_d.j\left(x_d - x_q\right)}^{\text{reálné číslo (v ose q)}}$$

Zdroj v dq – náhradní schéma



náhradní schémata v podélné a příčné ose

Zdroj v dq – náhradní schéma



Zdroj v dq – ustálený stav

- Pro tvorbu hybridní matice i-Ψ (ale např. i [H] – viz. Simultánní poruchy) platí:

$$\begin{bmatrix} \bar{x}_1 \\ \bar{x}_2 \end{bmatrix} = \begin{bmatrix} [a_{11}] & [a_{12}] \\ [a_{21}] & [a_{22}] \end{bmatrix} \begin{bmatrix} \bar{y}_1 \\ \bar{y}_2 \end{bmatrix} \qquad \textit{dílčí} \quad \textit{inverze}$$

$$\begin{bmatrix} \bar{x}_1 \\ \bar{y}_2 \end{bmatrix} = \begin{bmatrix} [a_{11}] - [a_{12}][a_{22}]^{-1}[a_{21}], & [a_{12}][a_{22}]^{-1} \\ -[a_{22}]^{-1}[a_{21}], & [a_{22}]^{-1} \end{bmatrix} \begin{bmatrix} \bar{y}_1 \\ \bar{x}_2 \end{bmatrix}$$

Zdroj v dq – ustálený stav

$$\begin{bmatrix}\psi_d \\ i_f \\ i_D\end{bmatrix} = \begin{bmatrix} l''_d & (l''_d - l_\sigma)/l_{\sigma f} & (l''_d - l_\sigma)/l_{\sigma D} \\ \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet \end{bmatrix} \begin{bmatrix} i_d \\ \psi_f \\ \psi_D \end{bmatrix}$$

$$l''_d = l_\sigma + \left(\frac{1}{l_{ad}} + \frac{1}{l_{\sigma f}} + \frac{1}{l_{\sigma D}} \right)^{-1}$$

$$\begin{bmatrix}\psi_d \\ i_f\end{bmatrix} = \begin{bmatrix} l'_d & (l'_d - l_\sigma)/l_{\sigma f} \\ \bullet & \bullet \end{bmatrix} \begin{bmatrix} i_d \\ \psi_f \end{bmatrix}, \; l'_d = l_\sigma + \left(\frac{1}{l_{ad}} + \frac{1}{l_{\sigma f}} \right)^{-1}$$

$$\begin{bmatrix}\psi_q \\ i_Q\end{bmatrix} = \begin{bmatrix} l'_q & (l'_q - l_\sigma)/l_{\sigma Q} \\ \bullet & \bullet \end{bmatrix} \begin{bmatrix} i_q \\ \psi_Q \end{bmatrix}, l'_q = l_\sigma + \left(\frac{1}{l_{aq}} + \frac{1}{l_{\sigma Q}} \right)^{-1}$$

Zdroj v dq – ustálený stav

$$\frac{d\psi}{dt} = 0 \Rightarrow u_q = -r.i_q + \omega\psi_d, \qquad ju_d = -r.ji_d - \omega\psi_q,$$

$$u_q = \omega \begin{bmatrix} l''_d & \dfrac{l''_d - l_{\sigma d}}{l_{\sigma f}} & \dfrac{l''_d - l_{\sigma d}}{l_{\sigma D}} \end{bmatrix} \begin{bmatrix} i_d \\ \psi_f \\ \psi_D \end{bmatrix} - r.i_q$$

$$u_q = x''_d.i_d + \underbrace{\omega(l''_d - l_{\sigma d}).(\frac{\psi_f}{l_{\sigma f}} + \frac{\psi_D}{l_{\sigma D}})}_{e''_q} - r.i_q$$

$$u_d = -\omega.\psi_q - r.i_d = -\omega \begin{bmatrix} l''_q & \dfrac{l''_q - l_{\sigma Q}}{l_{\sigma q}} \end{bmatrix} \begin{bmatrix} i_q \\ \psi_Q \end{bmatrix} - r.i_d$$

$$u_q = x''_d.i_d + e''_q - r.i_q, \quad u_d = -x''_q.i_q + e''_d - r.i_d$$

Zdroj v dq – ustálený stav

$$u_q = \omega \begin{bmatrix} l'_d & \dfrac{l'_d - l_{\sigma d}}{l_{\sigma f}} \end{bmatrix} \begin{bmatrix} i_d \\ \psi_f \end{bmatrix} - r.i_q$$

$$u_q = x'_d.i_d + e'_q - r.i_q, \qquad u_d = -r.i_d - x_q.i_q$$

Zdroj v dq – ustálený stav

$$u_q = -r.i_q - jx_d.ji_d + e \qquad ju_d = -r.ji_d - jx_q.i_q$$

$$\begin{bmatrix} e \\ j0 \end{bmatrix} = \begin{bmatrix} u_q \\ ju_d \end{bmatrix} + \left(\begin{bmatrix} r & 0 \\ 0 & r \end{bmatrix} + j \begin{bmatrix} 0 & x_d \\ x_q & 0 \end{bmatrix} \right) \begin{bmatrix} i_q \\ ji_d \end{bmatrix}$$

$$\overline{e} = \overline{u} + \left(\overline{r}_{\%} + j[x] \right).\overline{i}$$

$$u_q = -r.i_q - jx'_d.ji_d + e'_q \qquad ju_d = -r.ji_d - jx_q.i_q$$

$$\begin{bmatrix} e''_q \\ je''_d \end{bmatrix} = \begin{bmatrix} u_q \\ ju_d \end{bmatrix} + \left(\begin{bmatrix} r & 0 \\ 0 & r \end{bmatrix} + j \begin{bmatrix} 0 & x'_d \\ x_q & 0 \end{bmatrix} \right) \begin{bmatrix} i_q \\ ji_d \end{bmatrix}$$

$$\overline{e}' = \overline{u} + \left(\overline{r}_{\%} + j[x'] \right).\overline{i}$$

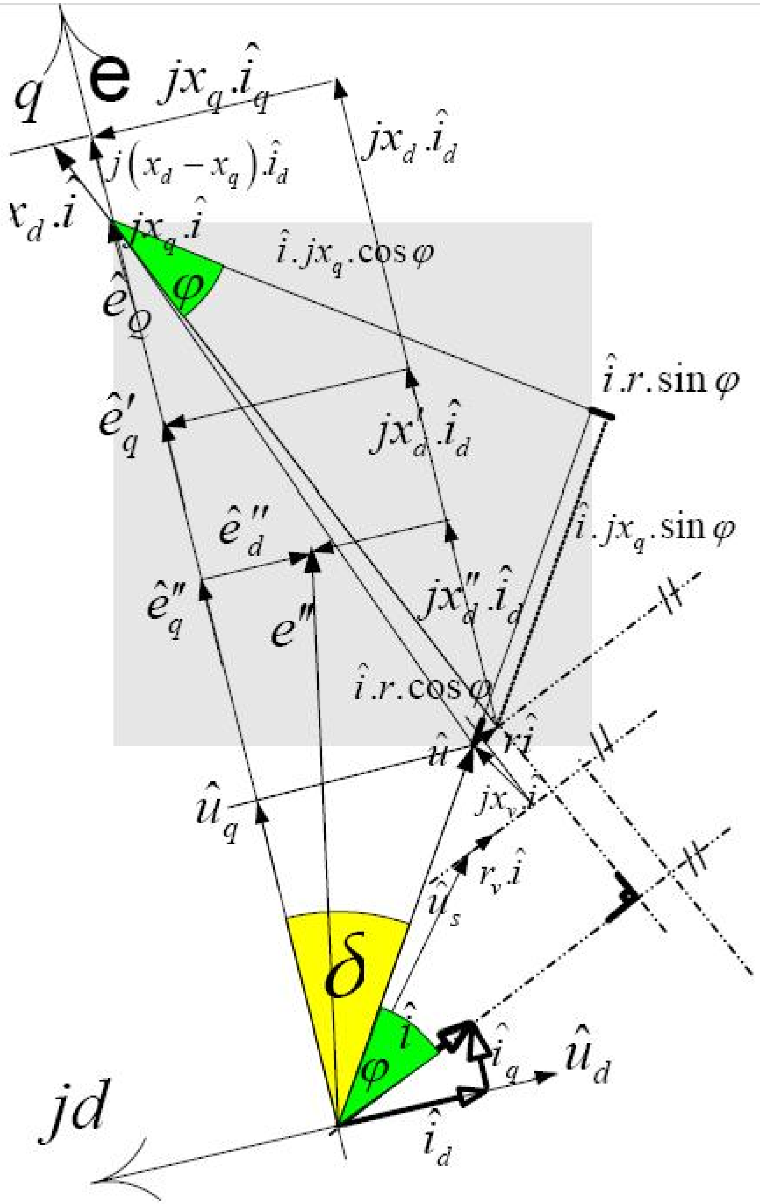
Zdroj v dq – ustálený stav

$$u_q = -r.i_q - jx''_d.ji_d + e''_q \qquad ju_d = -r.ji_d - jx''_q.i_q + je''_d$$

$$\begin{bmatrix} e''_q \\ je''_d \end{bmatrix} = \begin{bmatrix} u_q \\ ju_d \end{bmatrix} + \left(\begin{bmatrix} r & 0 \\ 0 & r \end{bmatrix} + j \begin{bmatrix} 0 & x''_d \\ x''_q & 0 \end{bmatrix} \right) \begin{bmatrix} i_q \\ ji_d \end{bmatrix}$$

$$\overline{e}'' = \overline{u} + \left(\overline{r}_{\%} + j\left[x''\right] \right).\overline{i}$$

Zdroj v dq – fázorový diagram



Volba počátečních podmínek

$$\bar{S} = \hat{u}.\hat{i}^* = \left(u_q + ju_d\right).\left(i_q - ji_d\right)$$

$$\bar{S} = \underbrace{u_q.i_q + u_d.i_d}_{P} + j\underbrace{\left(u_d.i_q - u_q.i_d\right)}_{Q}$$

$$i_d = i.\cos\left(\varphi + \delta + \pi/2\right),$$

$$i_q = i.\cos\left(\varphi + \delta\right),$$

$$\left|\hat{i}\right| = \frac{\sqrt{P^2 + Q^2}}{u}, \quad \varphi = arctg\left(\frac{Q}{P}\right)$$

$$\delta = arctg\left(\frac{i.\left(x_q.\cos\varphi - r.\sin\varphi\right)}{u + i.\left(x_q.\sin\varphi + r.\cos\varphi\right)}\right)$$

$$\left|e'_Q\right| = \sqrt{\left\{u + i.\left(x_q.\sin\varphi + r.\cos\varphi\right)\right\}^2 + \left\{i.\left(x_q.\cos\varphi - r.\sin\varphi\right)\right\}^2}$$

Jednoduchý dyn. model

$$\psi_{ad} = l_{ad}.\left(i_d + i_f + i_D\right) = \psi_d - l_\sigma.i_d = \psi_f - l_{\sigma f}.i_f = \psi_D - l_{\sigma D}.i_d$$

$$i_d = \frac{\psi_d - \psi_{ad}}{l_\sigma}, \quad i_f = \frac{\psi_f - \psi_{ad}}{l_{\sigma f}}, \quad i_D = \frac{\psi_D - \psi_{ad}}{l_{\sigma D}}$$

$$\psi_{aq} = l_{aq}.\left(i_q + i_Q\right) = \psi_q - l_\sigma.i_q = \psi_Q - l_{\sigma Q}.i_Q$$

$$i_q = \frac{\psi_q - \psi_{aq}}{l_\sigma}, \quad i_Q = \frac{\psi_Q - \psi_{aq}}{l_{\sigma Q}}$$

$$\frac{1}{l_{md}} = \frac{1}{l_{ad}} + \frac{1}{l_{\sigma d}} + \frac{1}{l_{\sigma f}} + \frac{1}{l_{\sigma D}} \quad , \frac{1}{l_{mq}} = \frac{1}{l_{aq}} + \frac{1}{l_{\sigma q}} + \frac{1}{l_{\sigma Q}}$$

Jednoduchý dyn. model

$$\psi_{ad} = \psi_d \frac{l_{md}}{l_\sigma} + \psi_f \frac{l_{md}}{l_{\sigma f}} + \psi_D \frac{l_{md}}{l_{\sigma D}} \qquad \text{algebraické vazby}$$

$$\psi_{aq} = \psi_q \frac{l_{mq}}{l_\sigma} + \psi_Q \frac{l_{mq}}{l_{\sigma Q}}$$

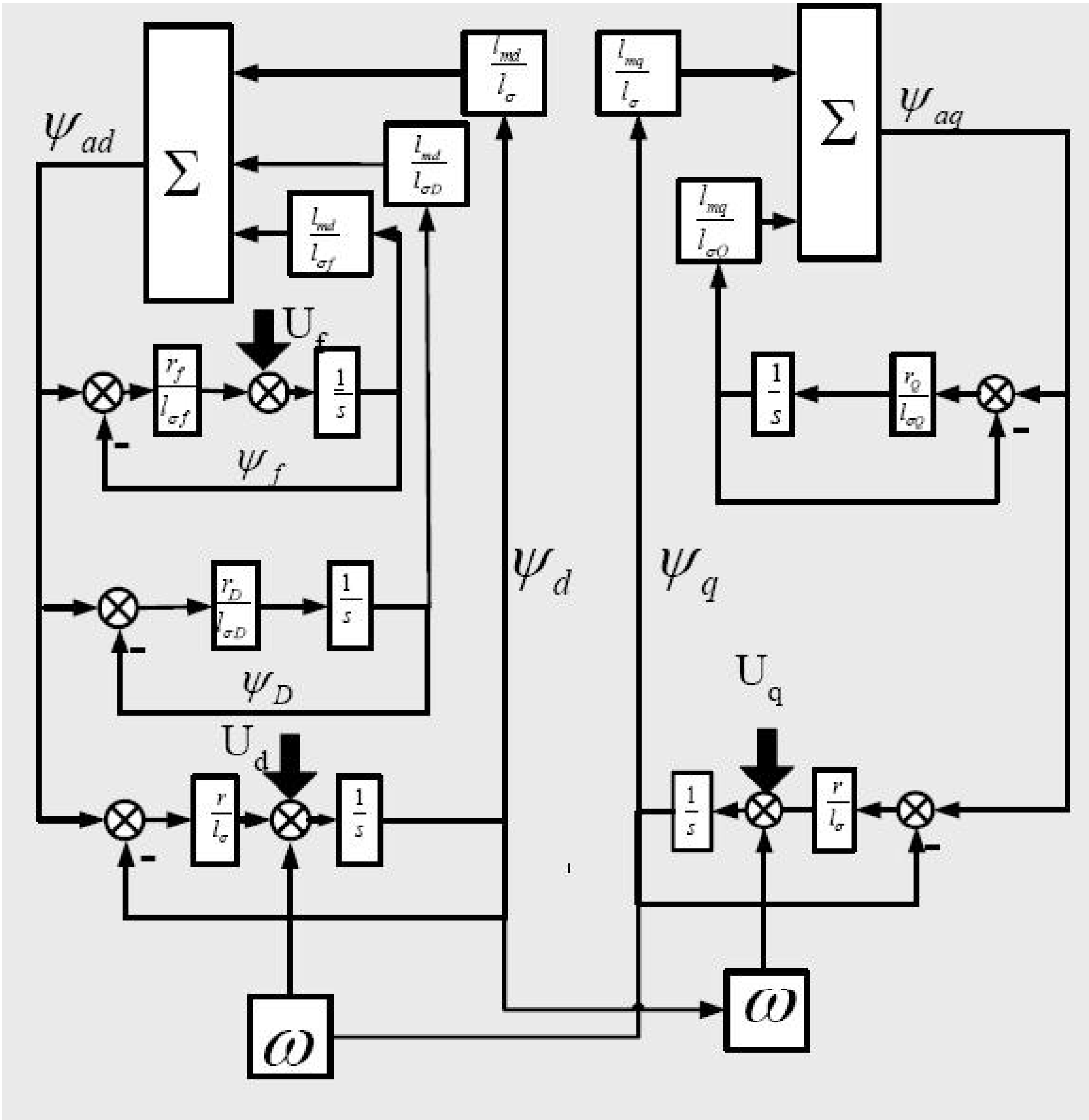
$$\psi_d^{\bullet} = -u_d - \frac{r}{l_\sigma}\left(\psi_d - \psi_{ad}\right) - \omega \psi_q \qquad \text{diferenciální rovnice}$$

$$\psi_q^{\bullet} = -u_q - \frac{r}{l_\sigma}\left(\psi_q - \psi_{aq}\right) + \omega \psi_d$$

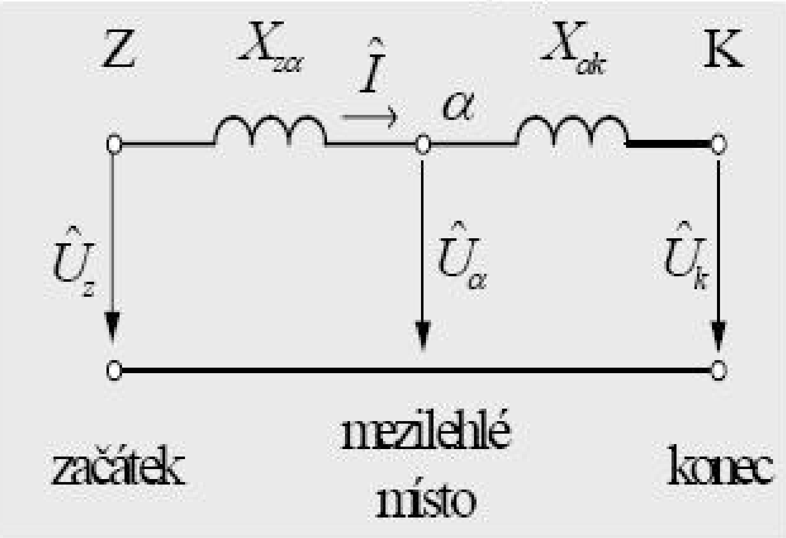
$$\psi_f^{\bullet} = u_f - \frac{r_f}{l_{\sigma f}}\left(\psi_f - \psi_{ad}\right)$$

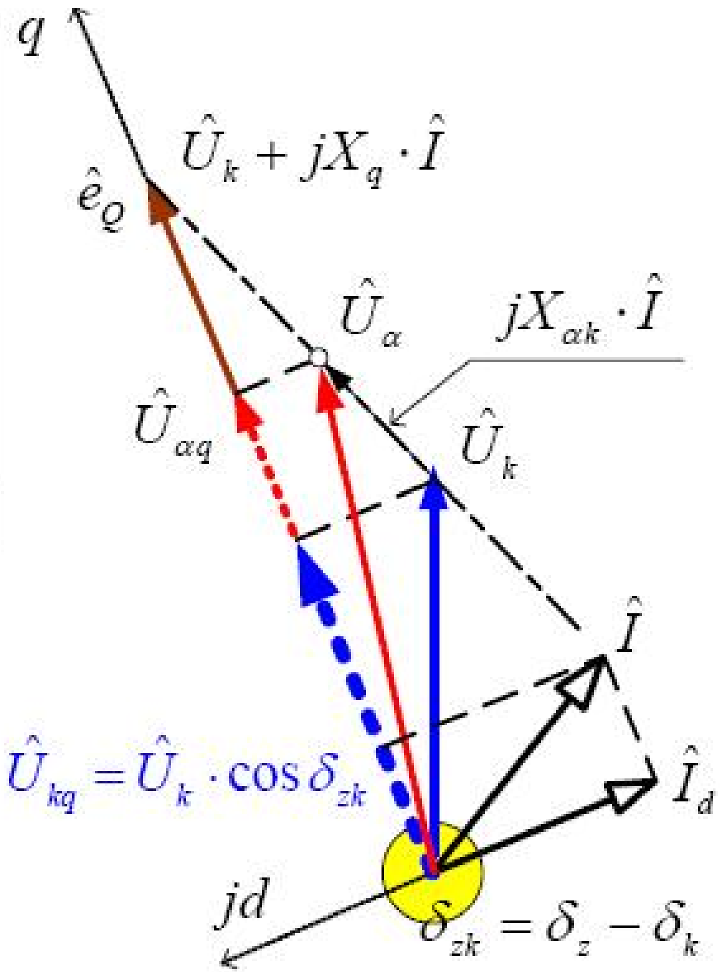
$$\psi_D^{\bullet} = -\frac{r_D}{l_{\sigma D}}\left(\psi_D - \psi_{ad}\right), \quad \psi_Q^{\bullet} = -\frac{r_Q}{l_{\sigma Q}}\left(\psi_Q - \psi_{aq}\right),$$

Jednoduchý dyn. model



Zdroj v dq – vztahy pro výkony





$$S_z = \hat{U}_z \cdot \hat{I}^*, \quad S_k = \hat{U}_k \cdot \hat{I}^*,$$

$$\hat{I} = \left(\hat{U}_z - \hat{U}_k\right) / \left(jX_{zk}\right),$$

$$\hat{I}^* = \left(\hat{U}_z^* - \hat{U}_k^*\right) / \left(-jX_{zk}\right),$$

Zdroj v dq – vztahy pro výkony

$$S_k = j\hat{U}_k \cdot \frac{\hat{U}_z^* - \hat{U}_k^*}{X_{zk}} = -j\frac{U_k^2}{X_{zk}} + j\frac{U_k \cdot U_z}{X_{zk}} \cdot e^{j\delta_{zk}}$$

$$S_z = j\hat{U}_z \cdot \left(\hat{U}_z^* - \hat{U}_k^*\right) / X_{zk} = j\frac{U_z^2}{X_{zk}} - j\frac{U_z \cdot U_k}{X_{zk}} \cdot e^{j\delta_{zk}}$$

$$S_z = \underbrace{\frac{U_z \cdot U_k}{X_{zk}} \cdot \sin\delta_{zk}}_{P_z} + j\underbrace{\left(\frac{U_z^2}{X_{zk}} - \frac{U_z \cdot U_k}{X_{zk}} \cdot \cos\delta_{zk}\right)}_{Q_z}$$

$$S_k = \underbrace{-\frac{U_k \cdot U_z}{X_{zk}} \cdot \sin\delta_{zk}}_{P_k} + j\underbrace{\left(-\frac{U_k^2}{X_{zk}} + \frac{U_k \cdot U_z}{X_{zk}} \cos\delta_{zk}\right)}_{Q_k}$$

Zdroj v dq – činný výkon

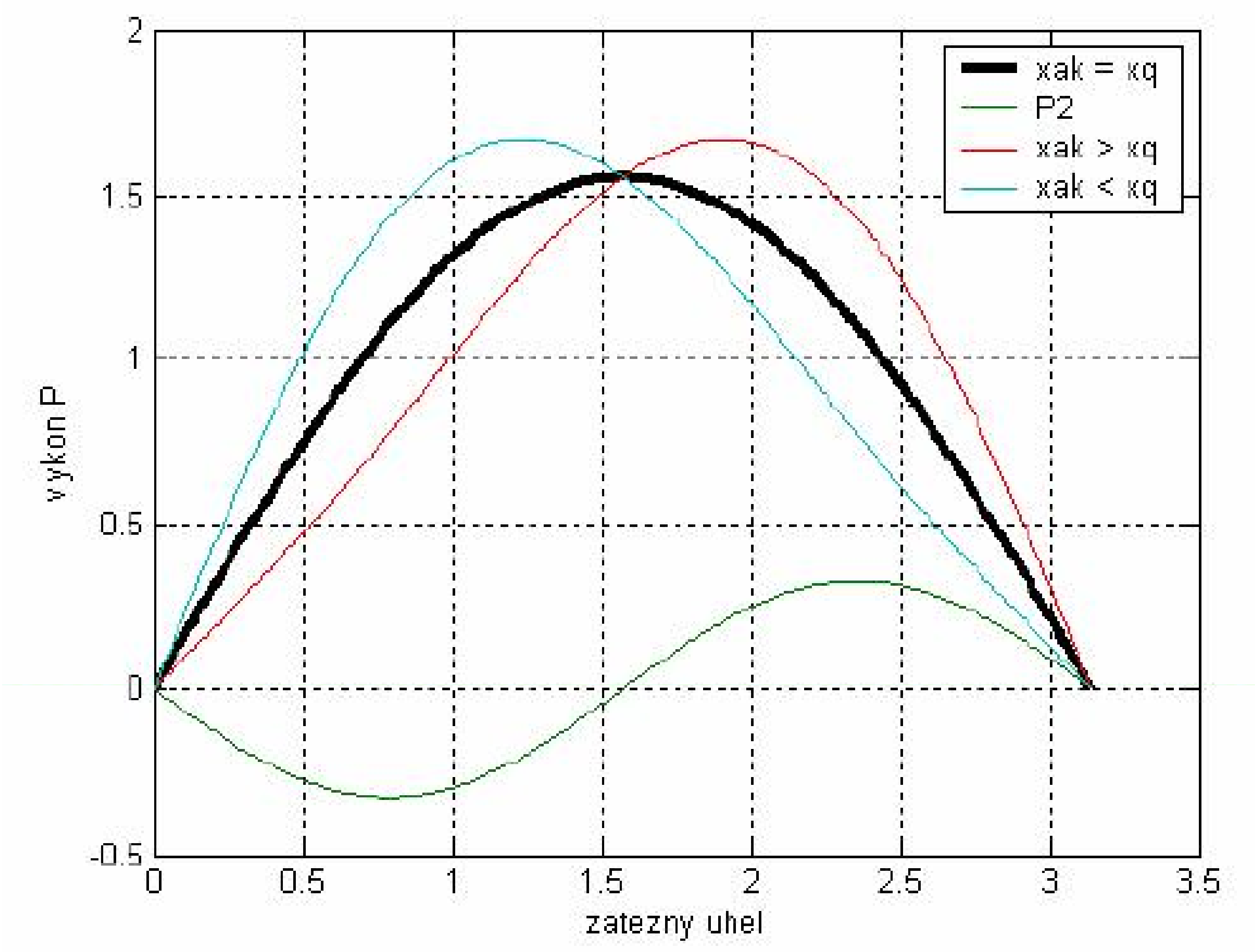
$$\left.\begin{aligned}\hat{U}_{\alpha q} &= \hat{U}_{kq} + jX_{\alpha k}\cdot \hat{I}_d\\ \hat{e}_Q &= \hat{U}_{kq} + jX_q\cdot \hat{I}_d\end{aligned}\right. \Rightarrow \frac{\hat{U}_{\alpha q}-\hat{U}_{kq}}{\hat{e}_Q-\hat{U}_{kq}} = \frac{X_{\alpha k}}{X_q},$$

$$e_Q = \frac{X_q}{X_{\alpha k}}\left(U_{\alpha q}-U_{kq}\right)+U_{kq} = \frac{X_q}{X_{\alpha k}}\cdot U_{\alpha q}+U_{kq}\cdot\frac{X_{\alpha k}-X_q}{X_{\alpha k}}.$$

$$P = \frac{e_Q\cdot U_k}{X_q}\cdot\sin\delta_{zk} = \frac{\left(\frac{X_q}{X_{\alpha k}}U_{\alpha q}+U_{kq}\cdot\frac{X_{\alpha k}-X_q}{X_{\alpha k}}\right)\cdot U_k}{X_q}\sin\delta_{zk},$$

$$P = \frac{U_{\alpha q}\cdot U_k}{X_{\alpha k}}\cdot\sin\delta_{zk}+\frac{X_{\alpha k}-X_q}{X_{\alpha k}\cdot X_q}\cdot U_k^2.\underbrace{\left(\sin\delta_{zk}\cdot\cos\delta_{zk}\right)}_{0.5\sin 2\delta_{zk}},$$

Zdroj v dq – činný výkon



Zdroj v dq – jalový výkon

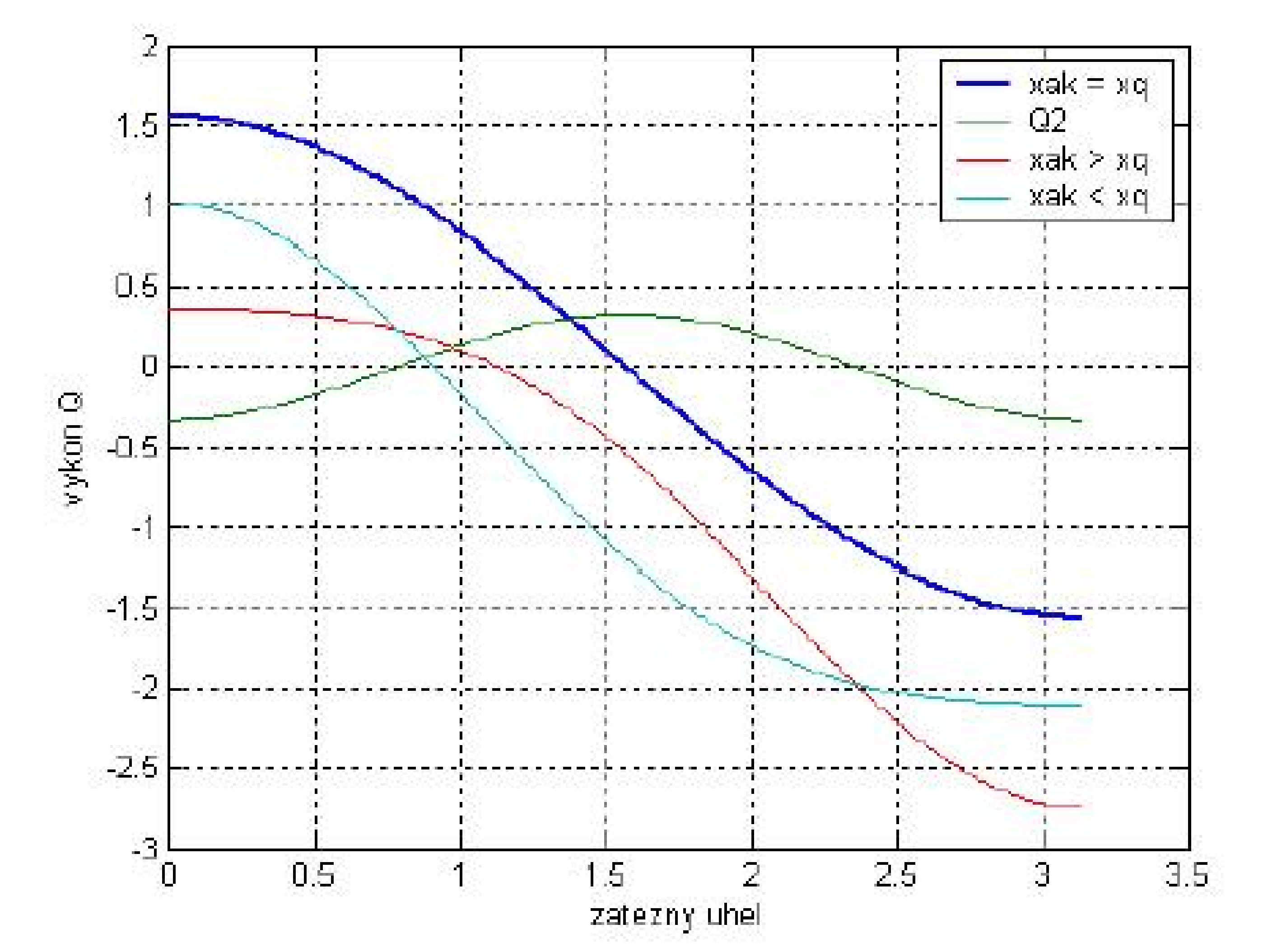
$$Q = -\frac{U_k^2}{X_{zk}} + \frac{U_z \cdot U_k}{X_{zk}} \cdot \cos\delta_{zk} = -\frac{U_k^2}{X_q} + \frac{\left(\frac{X_q}{X_{\alpha k}} U_{\alpha q} + U_{kq} \cdot \frac{X_{\alpha k} - X_q}{X_{\alpha k}}\right) U_k \cos\delta_{zk}}{X_q} =$$

$$= -\frac{U_k^2}{X_q} + \frac{U_{\alpha k} \cdot U_k}{X_{\alpha k}} \cdot \cos\delta_{zk} + U_k \cdot U_k \cdot \cos\delta_{zk} \cos\delta_{zk} \cdot \frac{X_{\alpha k} - X_q}{X_{\alpha k} \cdot X_q} =$$

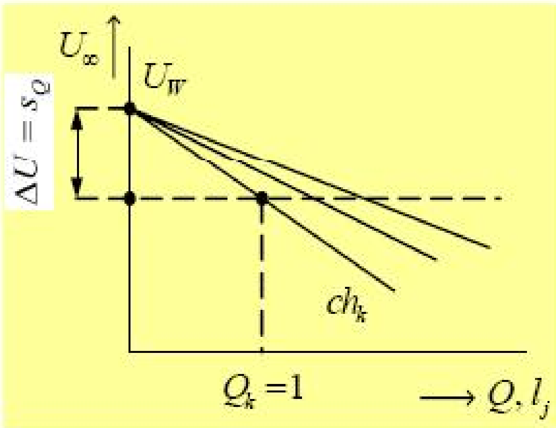
$$= -\frac{U_k^2}{X_q} + \frac{U_{\alpha k} \cdot \overbrace{U_k \cos\delta_{zk}}^{U_{kq}}}{X_{\alpha k}} + \frac{U_k^2 \left(X_{\alpha k} - X_q\right) \overbrace{\left(1 + \cos 2\delta_{zk}\right)}^{2\cos\delta_{zk}\cos\delta_{zk}}}{2X_{\alpha k} \cdot X_q} \overbrace{\pm \frac{U_k^2}{2X_q}}^{vnucená\,0}$$

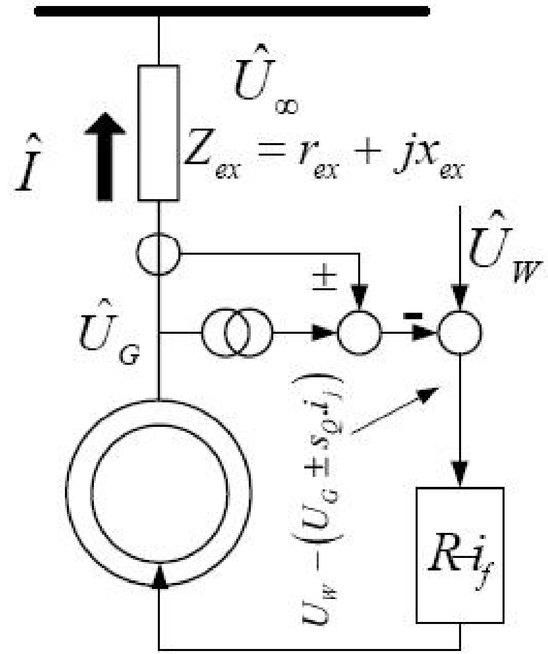
$$Q = \frac{U_{\alpha q} \cdot U_k}{X_{\alpha k}} \cos\delta_{zk} - \frac{U_k^2}{2}\left(\frac{X_{\alpha k} + X_q}{X_q X_{\alpha k}}\right) + \frac{U_k^2}{2}\left(\frac{X_{\alpha k} - X_q}{X_q X_{\alpha k}}\right) \cos 2\delta_{zk}$$

Zdroj v dq – jalový výkon



Regulace U-Q





$S_g = P_g + jQ_g$ výkon zdroje,

$S_L = P_L + jQ_L$ celkové zatížení.

$$U_G = U_\infty + x_{ex} \cdot i_j = U_W \pm s_Q \cdot i_j .$$

Rovnice charakteristiky (k):

– kompaundace

+ stabilizace

$$U_\infty = U_W - \underbrace{\left(x_{ex} \mp s_Q\right)}_{s_{Q\Sigma}} \cdot i_j$$

Regulace U-Q

statika s_Q pro minimalizaci $P_\Delta(Q)$:

$$P_\Delta = \sum_k R_k \cdot I_k^2 = \sum_k R_k \cdot \underbrace{\frac{P_k^2 + Q_k^2}{U_s^2}}_{I_k^2}, \quad P_{gk} = P_k + P_{\Delta k},$$

$$\mathsf{L} = P_\Delta + \lambda\left(Q_L - \sum_k Q_k\right) = \sum_k R_k \cdot \frac{P_k^2 + Q_k^2}{U_\infty^2} + \lambda\left(Q_L - \sum_k Q_k\right)$$

$$\frac{\partial \mathsf{L}}{\partial Q_k} = \frac{2R_k \cdot Q_k}{U_\infty^2} - \lambda = 0 \Rightarrow Q_k = \frac{\lambda \cdot U_\infty^2}{2R_k}$$

$$\Delta U = s_{Qk} \cdot Q_k \Rightarrow Q_k = \frac{\Delta U}{s_{Qk}} = \frac{\lambda U_\infty^2}{2R_k} \Rightarrow$$

$$\frac{R_k}{s_{Qk}} = \frac{\lambda U_\infty^2}{2\Delta U} = \text{konst., podmínka pro volbu statiky}$$

Regulace P-f

primární regulace:

$$\underbrace{\Delta f}_{\text{změna frekvence}} + \underbrace{s_P}_{\text{statika}} \cdot \underbrace{\Delta P}_{\text{změna výkonu}} = 0$$

$$\underbrace{k}_{\text{výkonové číslo}} \cdot \underbrace{\Delta f}_{\text{změna frekvence}} + \underbrace{\Delta P}_{\text{změna výkonu}} = 0$$