Průmyslová energetika
X15PEN

přednáška č. 10

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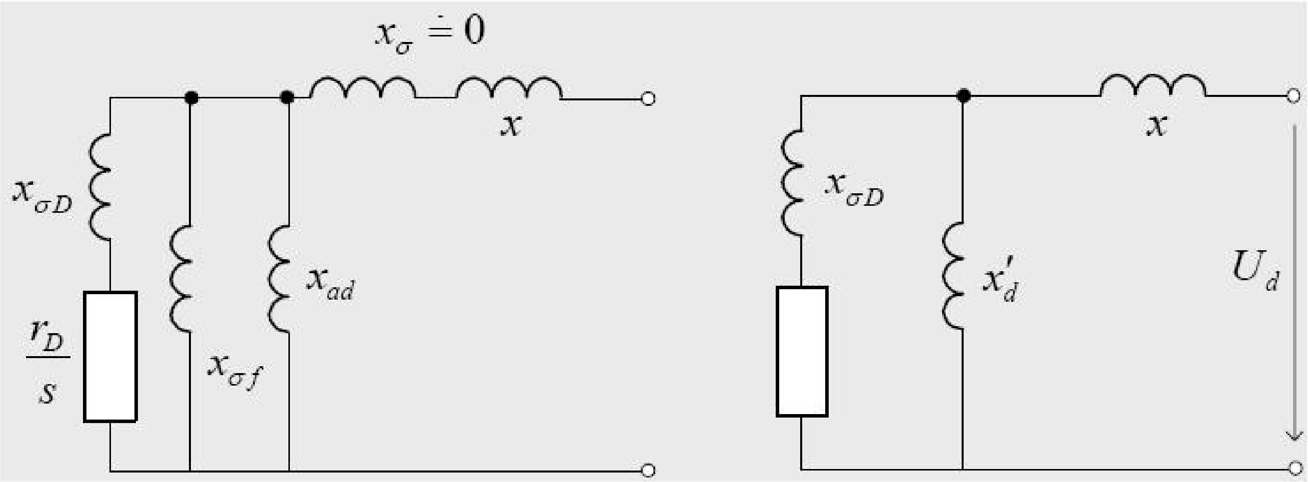
Tlumení podrobněji



Předpoklady:

1. $r \doteq 0,\ r_f \doteq 0,\ x\sigma \doteq 0$
2. tlumení jen v tlumícím vinutí.

$$x'_d \cong \frac{1}{\frac{1}{x_{\sigma f}} + \frac{1}{x_{ad}}},\ x''_d \cong \frac{1}{\frac{1}{x_{\sigma f}} + \frac{1}{x_{ad}} + \frac{1}{x_{\sigma D}}} \Rightarrow$$

$$\Rightarrow x_{\sigma D} \cong \frac{x'_d \cdot x''_d}{x'_d - x''_d},\ T''_d \cong \frac{x_{\sigma D}}{\omega_s \cdot r_D} \cong \frac{x'_d \cdot x''_d}{\omega_s \cdot r_D \left(x'_d - x''_d\right)}$$

Tlumení podrobněji

$$\frac{R_D}{\varepsilon} = \frac{x'_d \cdot x''_d}{x'_d - x''_d} \cdot \frac{1}{T''_d \cdot \omega_s \cdot \varepsilon} = \frac{x'_d \cdot x''_d}{x'_d - x''_d} \cdot \frac{1}{T''_d \cdot \omega \cdot \varepsilon}.$$

Pro malé skluzy: $\frac{r_D}{\varepsilon} \Rightarrow\gg$

$$i_D^2 = \underbrace{\left(\frac{U_D x'_d}{x + x'_d}\right)^2}_{napětí\ na\ tlumiči} \cdot \frac{1}{\underbrace{\left(\frac{r_D}{\varepsilon}\right)^2 + \omega_{\sigma D}^2}_{impedance\ tlumiče}}$$

$$P_D = i_D^2 \cdot \frac{r_D}{\varepsilon} = U_D^2 \left(\frac{x'_d}{x + x'_d}\right)^2 \cdot \frac{\frac{r_D}{\varepsilon}}{\left(\frac{r_D}{\varepsilon}\right)^2 + \frac{x'_d \cdot x''_d}{(x'_d - x''_d)^2}}$$

$$P_{Dd} \cong U_d^2 \cdot \frac{x'_d - x''_d}{(x + x'_d)^2} \cdot \frac{x'_d}{x''_d} \cdot \frac{T''_d \cdot \Delta\omega}{1 + (T''_d \cdot \Delta\omega)^2}.$$

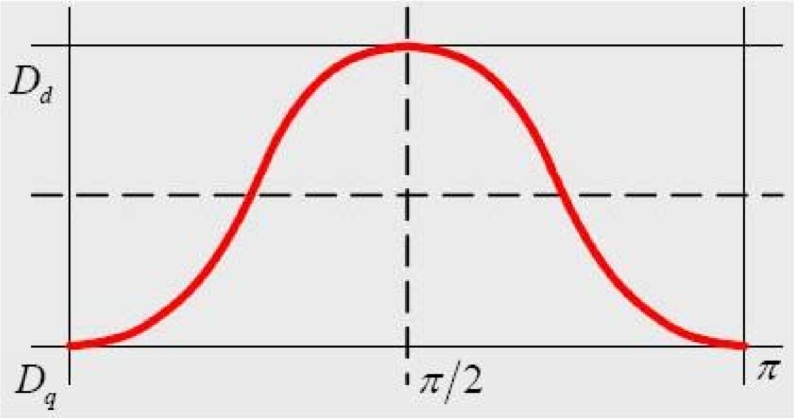
Tlumení podrobněji

Analogicky pro výkon P_{Dq}: $U_d = U \cdot \sin\delta, \quad U_q = U \cdot \cos\delta$

$$P_D = \left[U^2 \frac{(x_d' - x_d'') \cdot x_d' \cdot T_d''}{(x + x_d')^2 \cdot x_d'' \left(1 + (T_d'' \cdot \Delta\omega)^2\right)} \sin^2\delta + U^2 \frac{(x_q' - x_q'') \cdot x_q' \cdot T_q''}{(x + x_q')^2 \cdot x_q''} \cos^2\delta \right] \Delta\omega$$

,

$$U^2 \cdot \frac{(x_d' - x_d'') \cdot x_d' \cdot T_d''}{(x + x_d')^2 \cdot x_d'' \left(1 + (T_d'' \cdot \Delta\omega)^2\right)} = D_d \qquad U^2 \cdot \frac{(x_q' - x_q'') \cdot x_q' \cdot T_q''}{(x + x_q')^2 \cdot x_q''} = D_q .$$



Tlumení podrobněji

Skluz: $\varepsilon < 0 \Rightarrow G,\ \varepsilon > 0 \Rightarrow M$,

$$M_i = \frac{U^2 \cdot r \cdot \varepsilon}{r^2 + (X_i \cdot \varepsilon)^2} = \frac{U_s^2 \cdot \frac{X_i}{r}}{X_i\left[1 + \left(\frac{X_i}{r} \cdot \varepsilon\right)^2\right]},$$

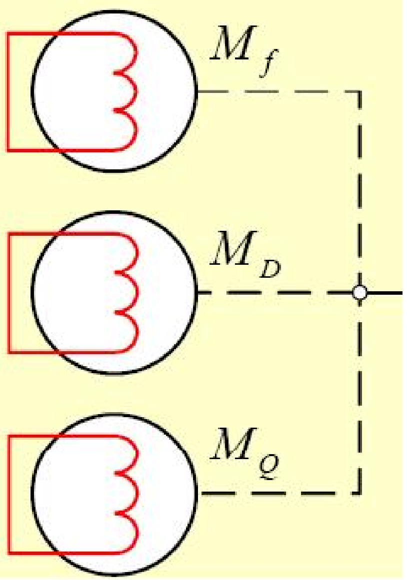
$$\frac{X_i}{r} = T_i,\quad X_i = \frac{X^{\square} \cdot X^{\blacktriangle}}{X^{\square} - X^{\blacktriangle}}$$

$$M_i = \frac{U^2 \cdot \varepsilon}{2} \cdot \frac{X^{\square} - X^{\blacktriangle}}{X^{\square} \cdot X^{\blacktriangle}} \cdot \frac{T_i}{1 + (T_i \cdot \varepsilon)^2}.$$

$$X = \frac{X_d \cdot X'_d}{X_d - X'_d},\ T'_d \text{ budič } f$$

$$X = \frac{X'_d \cdot X''_d}{X'_d - X''_d}, T''_d \text{ tlumič } D$$

$$X = \frac{X_q \cdot X''_q}{X_q - X''_q},\ T''_q \text{ tlumič } Q$$



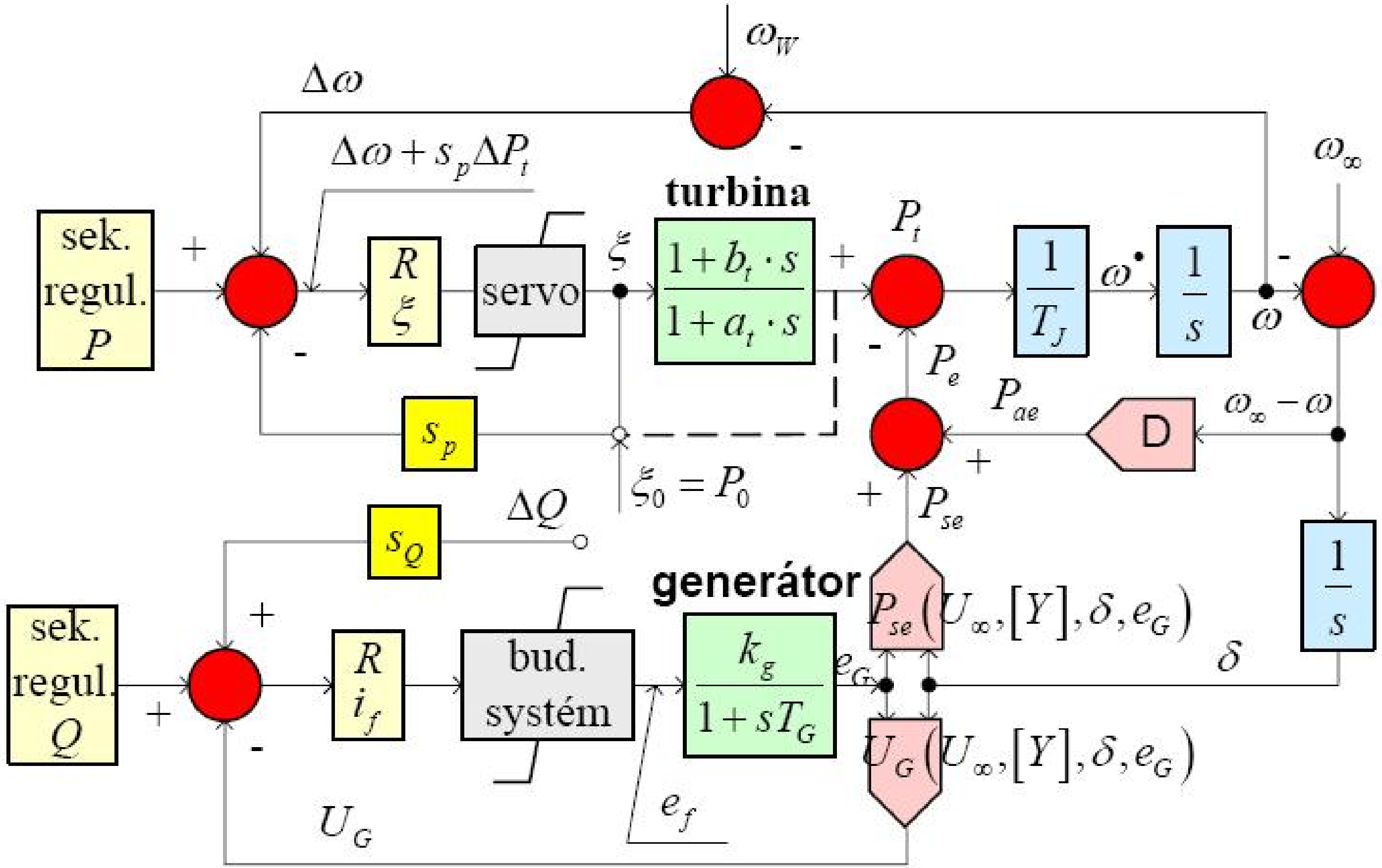
Tlumení podrobněji

obecný vztah pro tlumící moment jako funkce skluzu

$$M_A = M_f + M_D + M_Q,$$

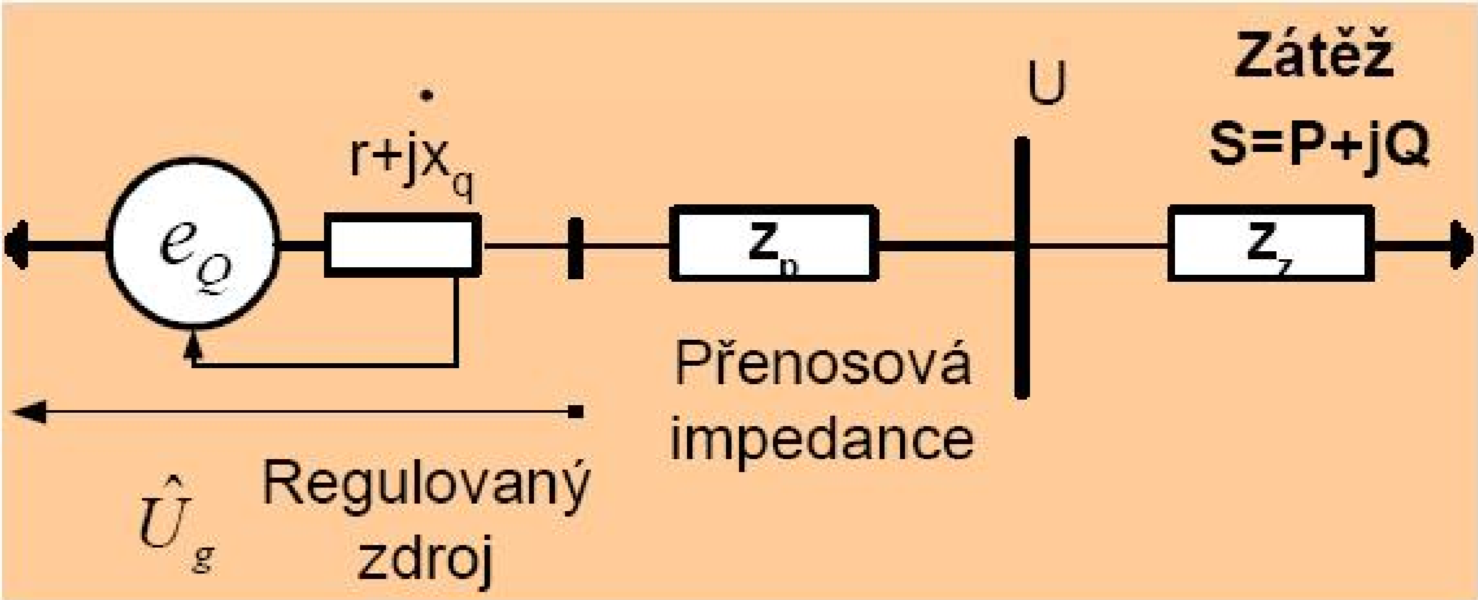
$$M_A = \frac{U^2 \cdot \varepsilon}{2}\left[\frac{(x_d - x_d')\cdot T_d'}{x_d\, x_d' \cdot \left(1+(T_d'\cdot\varepsilon)^2\right)} + \frac{(x_d' - x_d'')\cdot T_d''}{x_d'\, x_d'' \cdot \left(1+(T_d''\cdot\varepsilon)^2\right)} + \frac{(x_q - x_q'')\cdot T_q''}{x_q\, x_q'' \cdot \left(1+(T_q''\cdot\varepsilon)^2\right)}\right]$$

Model práce do velké soustavy

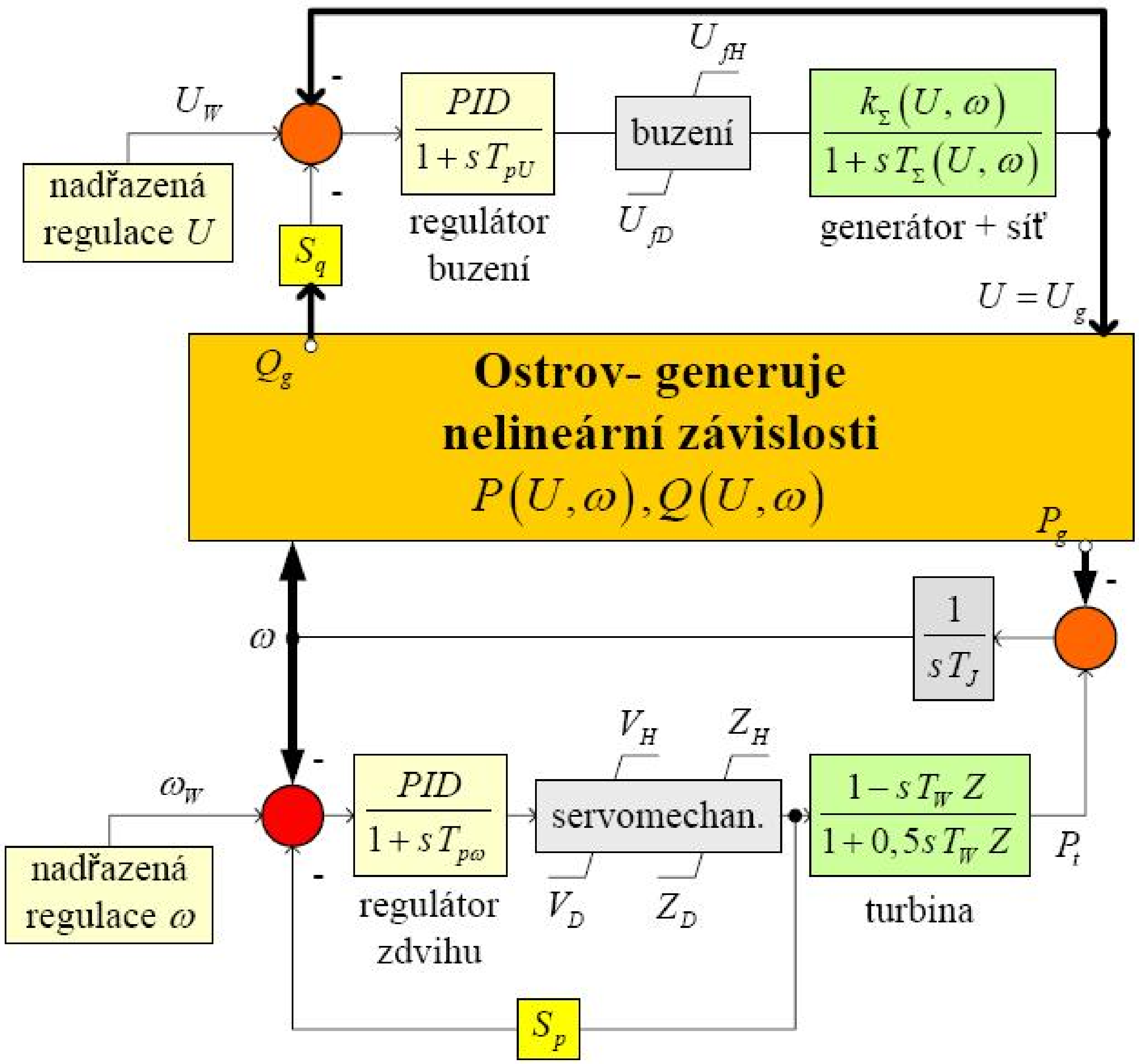


ξ – poměrný zdvih ventilu
U_f, i_f – budící napětí, proud
ω_∞, ω - kmit. soustavy, generátoru,
s_P, s_Q - statika P,Q
D - tlumení SG
δ - zátěž. úhel
P_t, P_e - mech. výkon turbíny, el. výkon zátěže
P_{ae}, P_{se} – asynchronní, synchronizační elektrické výkony

Ostrovní režim



Ostrovní režim



Ostrovní režim

$$\hat{Z}_{\Sigma} = r + jx_q + \underbrace{\hat{Z}_p}_{\substack{trafa\\ vedení}} + \underbrace{\hat{Z}_Z}_{U^2/S}, \qquad \hat{y}_{\Sigma} = \left(1/\hat{Z}_{\Sigma}\right) = y_{\Sigma}.e^{j\varepsilon}$$

$$e_Q = e'_q + i_d\left(x'_d - x_q\right) = e_q + i_d\left(x_d - x_q\right) \text{...} výchozí\ vztahy$$

$$e'_q = e_q + i_d\left(x_d - x'_d\right) \Rightarrow e'^{\bullet}_q = e^{\bullet}_q + i^{\bullet}_d\left(x_d - x'_d\right)$$

$$\hat{i} = e_Q y_{\Sigma}.e^{j\varepsilon} = i_q + ji_d = \left\{e_q + i_d\left(x_d - x_q\right)\right\} y_{\Sigma}.e^{j\varepsilon}$$

$$i_d = e_Q y_{\Sigma}.\sin\varepsilon = \left\{e_q + i_d\left(x_d - x_q\right)\right\} y_{\Sigma}.\sin\varepsilon$$

Ostrovní režim

$$i_d = \overbrace{\frac{1}{\left(1/y_\Sigma.\sin\varepsilon\right) - \left(x_d - x_q\right)}}^{k_\Sigma} e_q \Rightarrow i_d^\bullet = k_\Sigma e_q^\bullet$$

$$u_f.k_G = e_q + T_f.e_q'^\bullet = e_q + T_f e_q^\bullet + T_f \underbrace{k_\Sigma e_q^\bullet}_{i_d^\bullet}\left(x_d - x_d'\right)$$

$$u_f.k_G = e_q + e_q^\bullet.T_\Sigma; \qquad T_\Sigma = T_f\left\{1 + k_\Sigma\left(x_d - x_d'\right)\right\}$$

Ostrovní režim

$$e_Q = \hat{u} + jx_q \underbrace{\widehat{y_\Sigma}.e_Q}_{\hat{i}} \Rightarrow u = e_Q\sqrt{1+\left|x_q y_\Sigma\right|^2}$$

$$e_q = e_Q + \left(x_d - x_q\right)\overbrace{e_Q y_\Sigma \sin\varepsilon}^{i_d} \Rightarrow$$

$$u = e_q \frac{\sqrt{1+\left|x_q y_\Sigma\right|^2}}{\left\{1+\left(x_d - x_q\right) y_\Sigma \sin\varepsilon\right\}}$$

$$k_\Sigma = \frac{k_G\left\{1+\left(x_d - x_q\right) y_\Sigma \sin\varepsilon\right\}}{\sqrt{1+\left|x_q y_\Sigma\right|^2}}$$

Ostrovní režim

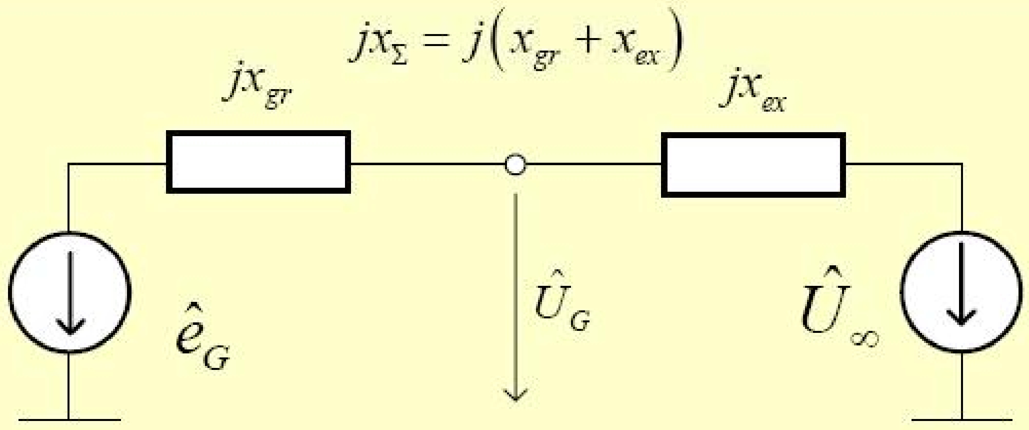
$$\frac{e_q(s)}{e_f(s)} = \frac{k_G}{1+sT_\Sigma}, \qquad \frac{u(s)}{e_f(s)} = \frac{k_\Sigma}{1+sT_\Sigma}$$

Charakteristiky výkonu zátěže:

$$P(U,\omega) = P_n \left(\frac{U}{U_n}\right)^{\beta_{qu}} \cdot \left(\frac{\omega}{\omega_n}\right)^{\beta_{q\omega}};$$

$$Q(U,\omega) = Q_n \left(\frac{U}{U_n}\right)^{\beta_{pu}} \cdot \left(\frac{\omega}{\omega_n}\right)^{\beta_{p\omega}}$$

Kruhový diagram



x_{ex} – externí (vnější) reaktance, x_{gr} – reprezentující reaktance generátoru (x_q, x'_d)

U…svorkové napětí generátoru e_G – reprezentující napětí. (e_Q, e')

$$e_Q = \hat{U}_\infty + jx_\Sigma \hat{I} = \hat{U}_G + jx_q \hat{I},$$

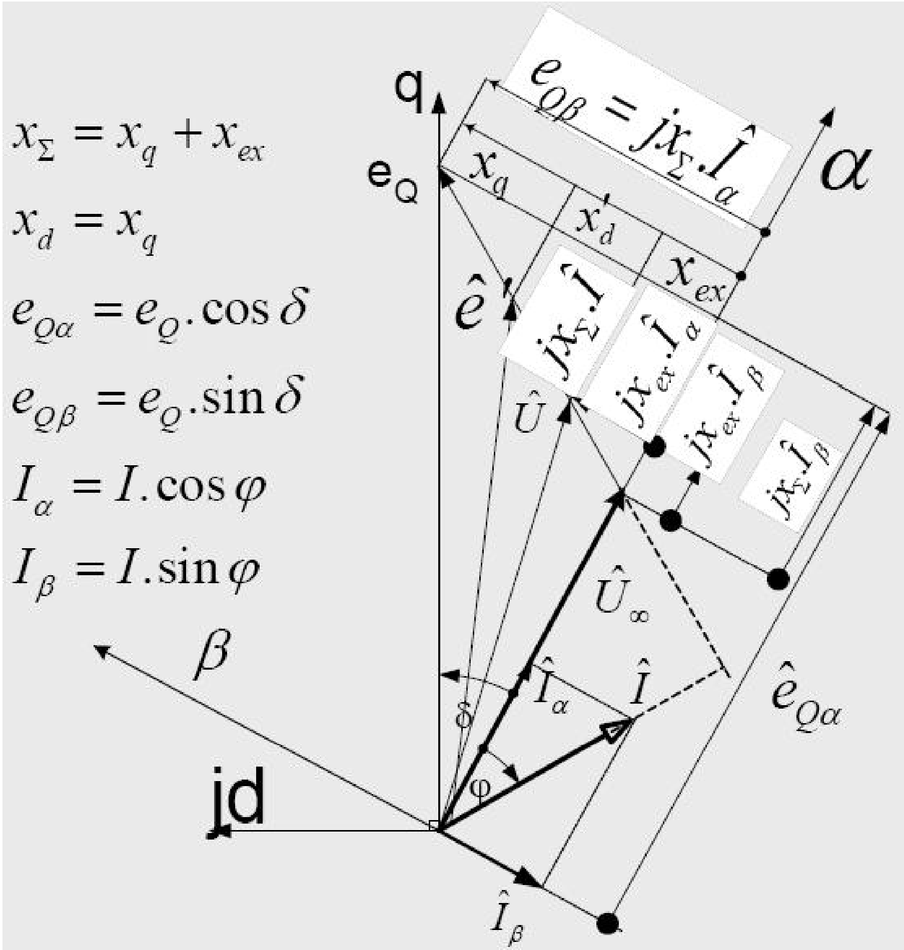
$$\hat{I} = \frac{e_Q - \hat{U}_\infty}{jx_\Sigma} = \frac{e_Q - \hat{U}_G}{jx_q} \Rightarrow \frac{x_{gr}}{x_\Sigma} = \frac{e_Q - \hat{U}_G}{e_Q - \hat{U}_\infty},$$

Kruhový diagram

$$e_Q = \hat{U}_\infty + jx_\Sigma \frac{e_Q - \hat{U}_G}{jx_q} \Rightarrow e_Q \left(\frac{x_q - (x_{ex} - x_q)}{x_q} \right) = U_\infty - \hat{U}_G \frac{x_\Sigma}{x_q}$$

$$\hat{e}_Q = \underbrace{-\hat{U}_\infty \frac{x_q}{x_{ex}}}_{\substack{\text{souřadnice} \\ \text{středu } \alpha_s}} + \underbrace{\hat{U}_G \frac{x_\Sigma}{x_{ex}}}_{\substack{\text{kružnice} \\ \text{pro } |U_G| = konst}} .$$

Kruhový diagram



Kruhový diagram

$$I_{\alpha} = \frac{e_{Q\beta}}{x_{\Sigma}} = \frac{e_Q . \sin\delta}{x_{\Sigma}} = I.\cos\varphi,$$

$$I_{\beta} = \frac{e_{Q\alpha} - u_{\infty}}{x_{\Sigma}} = \frac{e_Q . \cos\delta - u_{\infty}}{x_{\Sigma}} = -I\sin\varphi$$

$$\left(U_{\infty} + I_{\beta}.x_{ex}\right)^2 + \left(I_{\alpha}.x_{ex}\right)^2 = U_G^2 = konst$$

$$\left(U_{\infty} + \left(e_{Q\alpha} - U_{\infty}\right)\frac{x_{ex}}{x_{\Sigma}}\right)^2 + \left(e_{Q\beta}\frac{x_{ex}}{x_{\Sigma}}\right)^2 = U_G^2 \Rightarrow$$

$$U_{\infty}^2 - 2.U_{\infty}^2.\frac{x_{ex}}{x_{\Sigma}} + \left(U_{\infty}\frac{x_{ex}}{x_{\Sigma}}\right)^2 + 2\frac{x_{ex}}{x_{\Sigma}}e_{Q\alpha}U_{\infty} + \left(\frac{x_{ex}}{x_{\Sigma}}e_{Q\alpha}\right)^2 -$$

$$-2U_{\infty}e_{Q\alpha}\left(\frac{x_{ex}}{x_{\Sigma}}\right)^2 + \left(e_{Q\beta}\frac{x_{ex}}{x_{\Sigma}}\right)^2 = U_G^2$$

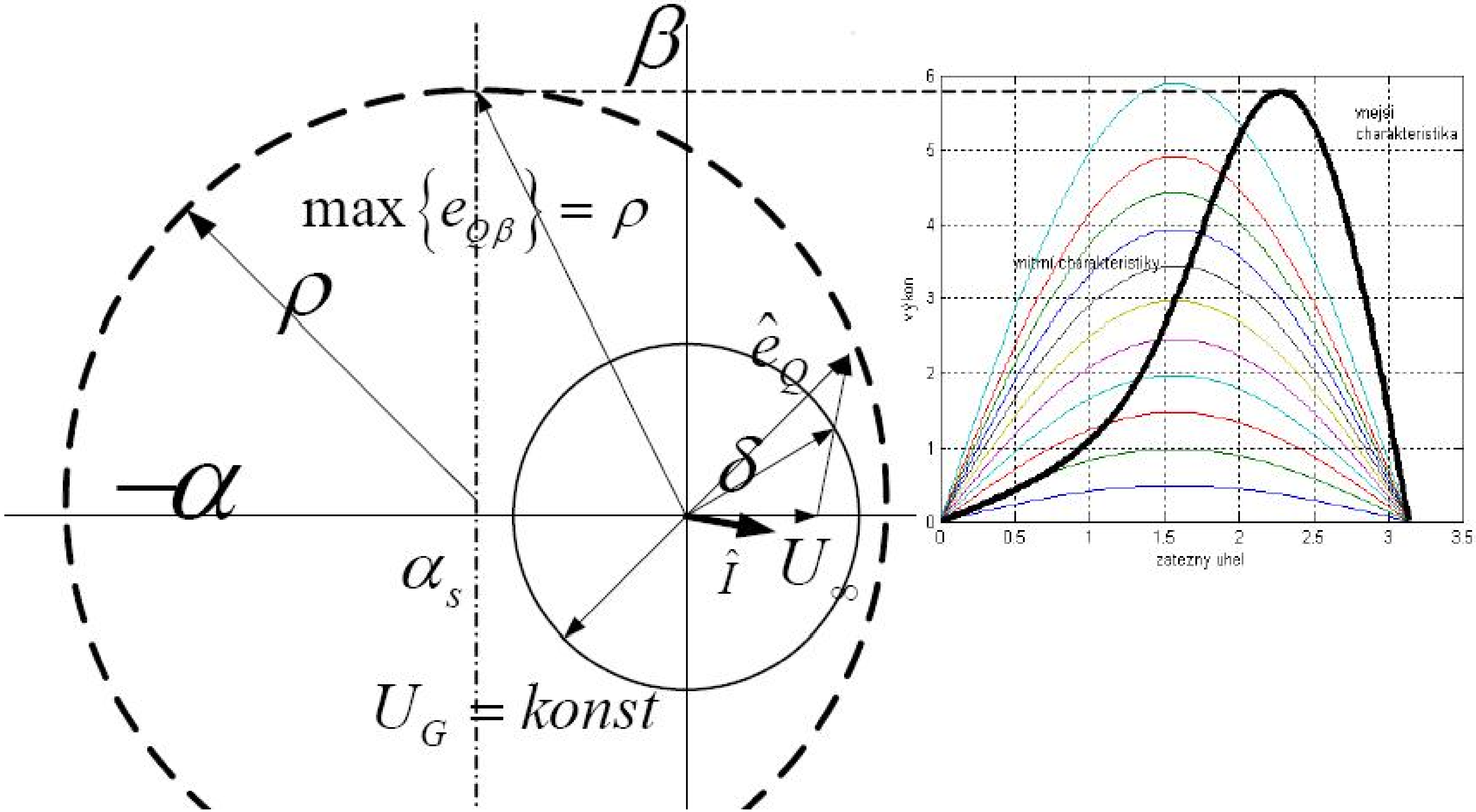
Kruhový diagram

$$\underbrace{\left(\frac{x_\Sigma}{x_{ex}}U_\infty\right)^2 - 2.U_\infty^2.\frac{x_\Sigma}{x_{ex}} + U_\infty^2 + 2\frac{x_\Sigma}{x_{ex}}e_{Q\alpha}U_\infty + e_{Q\alpha}^2 - 2U_\infty e_{Q\alpha}}_{U_\infty^2\left\{\left(\frac{x_\Sigma}{x_{ex}}\right)^2 - 2\left(\frac{x_\Sigma}{x_{ex}}\right)+1\right\} + 2U_\infty e_{Q\alpha}\left(\left(\frac{x_\Sigma}{x_{ex}}\right)-1\right) + e_{Q\alpha}^2 = \left(e_{Q\alpha} + \frac{x_q}{x_{ex}}U_\infty\right)^2} +$$

$$+e_{Q\beta}^2 = \left(\frac{x_\Sigma}{x_{ex}}U_G\right)^2 = \rho^2$$

$$\left(e_{Q\alpha} + \frac{x_q}{x_{ex}}U_\infty\right)^2 + e_{Q\beta}^2 = \left(e_{Q\alpha} - \alpha_s\right)^2 + e_{Q\beta}^2 = \underbrace{\left(\frac{x_\Sigma}{x_{ex}}U_G\right)^2}_{\rho^2}$$

Kruhový diagram



Kruhový diagram