Průmyslová energetika
X15PEN

přednáška č. 9

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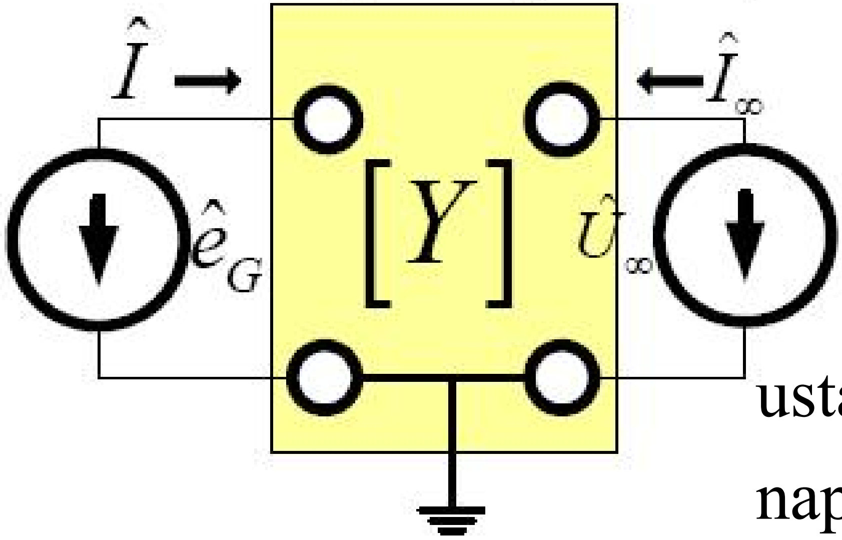
Vztahy pro regulaci napětí

Model bloku pro regulaci napětí



$$\begin{bmatrix} \hat{I} \\ \hat{I}_\infty \end{bmatrix} = \begin{bmatrix} \hat{Y}(1,1) & \hat{Y}(1,2) \\ \hat{Y}(2,1) & \hat{Y}(2,2) \end{bmatrix} \begin{bmatrix} \hat{e}_G \\ \hat{U}_\infty \end{bmatrix}$$

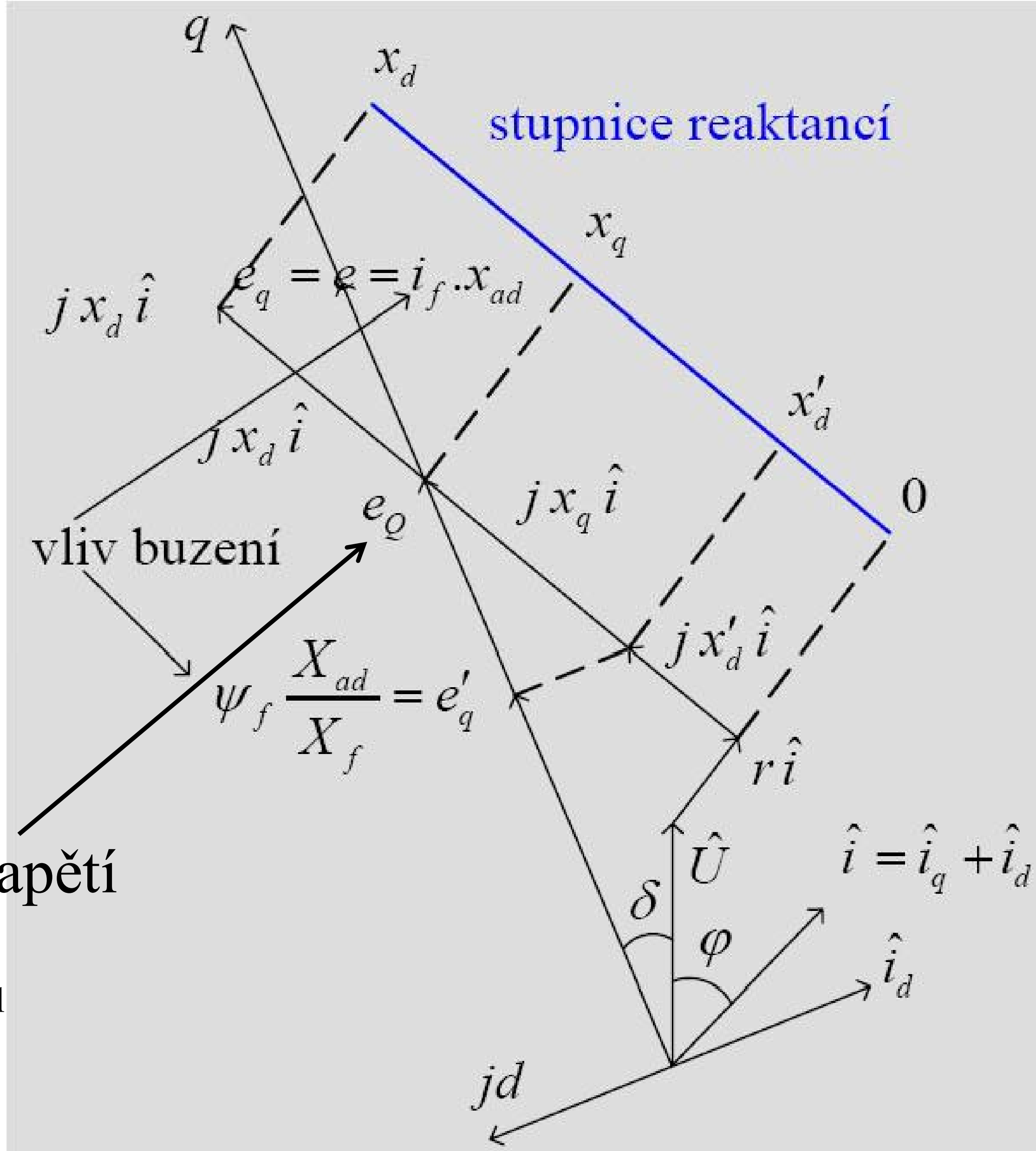
ustálené vnitřní elektromotorické napětí stroje

$$e_Q = e'_q + i_d\left(x'_d - x_q\right) = e_q + i_d\left(x_d - x_q\right)$$

vnitřní napětí za reaktancí x_q

přechodné vnitřní elektromotorické napětí stroje

Fázorový diagram



vnitřní zdroj napětí

za reaktancí x_q

Základní vztahy pro e_f, e_q a e'_q

$$u_f = r_f . i_f + \dot{\psi}_f, \quad K_{G0} = \frac{x_{ad}}{r_f}, \quad \textit{zesílení gen.}$$

tj. rotační napětí → $i_f . x_{ad}$

$$\underbrace{u_f . K_{G0}}_{e_f = \text{obraz } u_f \text{ na statoru}} = \underbrace{i_f . x_{ad}}_{e = e_q} + \frac{x_{ad}}{r_f} \dot{\psi}_f$$

tj. transformační napětí → $\frac{x_{ad}}{r_f} \dot{\psi}_f$

$$e'_q = \underbrace{\psi_f \frac{x_{ad}}{x_f}}_{z \text{ rovnic stroje}} = \underbrace{e_q + i_d \left(x_d - x'_d \right)}_{z \text{ fázorového diagramu}}$$

$$e_f = e_q + \underbrace{\frac{x_f}{r_f}}_{T_f = T_{d0}} \underbrace{\frac{x_{ad}}{x_f} \dot{\psi}_f}_{\dot{e}'_q}$$

Základní vztahy pro e_f, e_q a e'_q

$$e_f = \underbrace{e_q + T_{d0}\left(\dot{e}_q + \left(x_d - x'_d\right).\dot{i}_d\right)}_{\text{výstupem je....... } e_q} = \underbrace{e'_q - i_d\left(x_d - x'_d\right) + T_{d0}.\dot{e}'_q}_{\text{výstupem je ..... } e'_q}$$

poměrné vnitřní napětí vyvolané budičem - tím chceme regulovat napětí u_∞

$$e_q = \frac{e_f - \left(x_d - x'_d\right).s.i_d}{1 + sT_{d0}}$$

$$e'_q = \frac{e_f + \left(x_d - x'_d\right).i_d}{1 + sT_{d0}}$$

Rovnice pro $e_f - e_q$, δ

výpočet proudu statoru je-li výstup modelu napětí e_q:

$$\hat{I} = \widehat{Y}(1,1).\hat{e}_G + \widehat{Y}(2,1).\hat{U}_\infty = i_q + ji_d$$

$$\hat{I} = \underbrace{y_{11}.e^{j\varepsilon_{11}}}_{\widehat{Y}(1,1)}.\underbrace{\left[e_q + i_d\left(x_d - x_q\right)\right]}_{\hat{e}_G = e_Q} + \underbrace{y_{21}.e^{j\varepsilon_{21}}}_{\widehat{Y}(2,1)}.\underbrace{u_\infty.e^{-j\delta_\infty}}_{\hat{U}_\infty}$$

z imaginární složky:

$$i_d = \underbrace{\frac{y_{11}.\sin\varepsilon_{11}}{1 - y_{11}\left(x_d - x_q\right).\sin\varepsilon_{11}}}_{K_e}.e_q + \underbrace{\frac{y_{21}.\sin\left(\varepsilon_{21} - \delta_\infty\right)}{1 - y_{11}\left(x_d - x_q\right).\sin\varepsilon_{11}}}_{K'_\delta}u_\infty$$

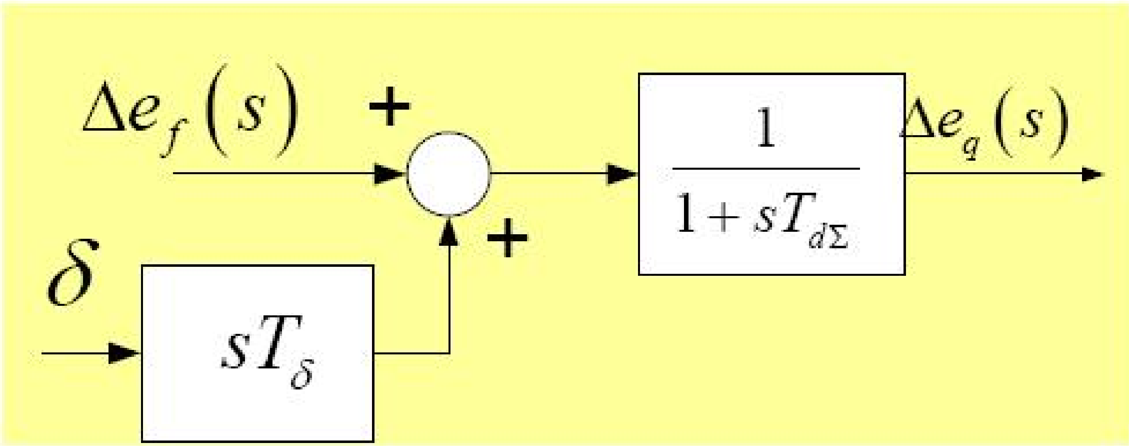
$$\dot{i}_d = \dot{e}_q.K_e - K'_\delta.\cos\left(\varepsilon_{21} - \delta_\infty\right).\dot{\delta}_\infty;\;\; e_f = \underbrace{e_q + T_{d0}\left(\dot{e}_q + \left(x_d - x'_d\right).\dot{i}_d\right)}_{\text{výstupem je } e}$$

$$e_f = e_q + T_{d0}\left(\dot{e}_q + \left(x_d - x'_d\right).\left\{\dot{e}_q.K_e - K'_\delta.\cos\left(\varepsilon_{21} - \delta_\infty\right)\dot{\delta}_\infty\right\}\right)$$

$$e_f = e_q + T_{d0}\left(\dot{e}_q\left[1 + \left(x_d - x'_d\right).K_e\right] - \dot{\delta}_\infty.\left[K'_\delta.\cos\left(\varepsilon_{21} - \delta_\infty\right)\right]\right)$$

Rovnice pro e_f - e_q , δ

$$e_f(s) = e_q(s)\left\{1 + s\underbrace{T_{d0}\left[1 + (x_d - x'_d)K_e\right]}_{T_{d\Sigma}}\right\} - s\delta_\infty . \underbrace{\left[K'_\delta . \cos(\varepsilon_{21} - \delta_\infty)\right]}_{T_\delta}$$



Rovnice pro $e_f - e'_q$, δ

výpočet proudu statoru je-li výstup modelu napětí e'_q **:**

$$\hat{I} = \underbrace{y_{11}.e^{j\varepsilon_{11}}}_{\hat{Y}(1,1)} . \left[\underbrace{e'_q + i_d\left(x'_d - x_q\right)}_{E_g = e_Q} \right] + \underbrace{y_{21}.u_\infty e^{j(\varepsilon_{21}-\delta_\infty)}}_{\hat{Y}(2,1).\hat{U}_\infty}$$

$$i_d = y_{11}e'_q.\sin\varepsilon_{11} + y_{11}i_d\left(x'_d - x_q\right)\sin\varepsilon_{11} + y_{21}u_\infty\sin\left(\varepsilon_{21} - \delta_\infty\right)$$

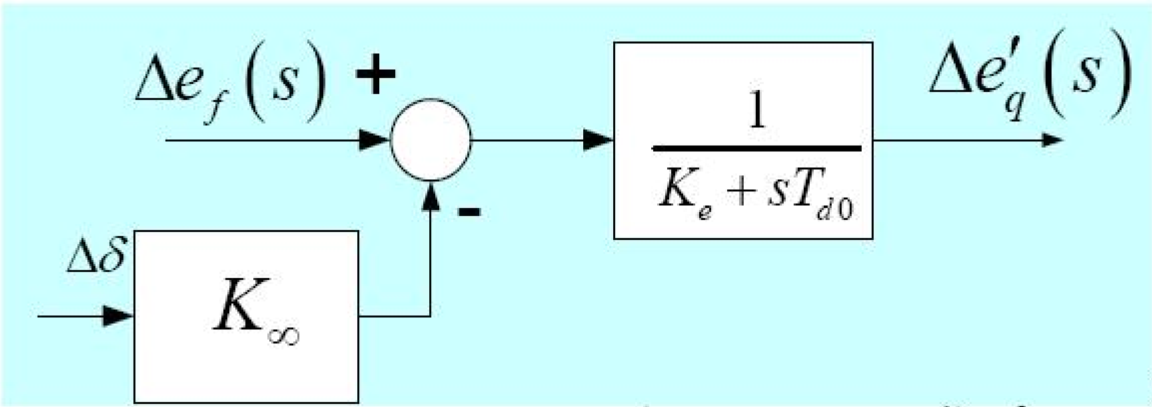
$$i_d = \underbrace{\frac{y_{11}.\sin\varepsilon_{11}}{1 - y_{11}\left(x'_d - x_q\right).\sin\varepsilon_{11}}}_{K_{e'}} .e'_q + \underbrace{\frac{y_{21}.u_\infty .}{1 - y_{11}\left(x_d - x_q\right).\sin\varepsilon_{11}}}_{K'_\delta} \sin\left(\varepsilon_{21} - \delta_\infty\right)$$

$$e_f = e_q + T_{d0}.e'^{\bullet}_q = \underbrace{e'_q - i_d\left(x_d - x'_d\right)}_{e_q} + T_{d0}.e'^{\bullet}_q$$

Rovnice pro ef – e′q , δ

$$e_f = e'_q.\underbrace{\{1 - K_{e'}(x_d - x'_d)\}}_{K_e} - \underbrace{K'_\delta(x_d - x'_d)}_{K_\delta}.\sin(\varepsilon_{21} - \delta_\infty) + T_{d0}.\dot{e}'_q$$

$$\Delta e_f(s) = \Delta e'_q(K_e + sT_{d0}) + \underbrace{K_\delta \cos(\varepsilon_{21} - \delta_\infty)_0}_{K_\infty}\Delta\delta_\infty(s)$$



Rovnice pro stroj zapojený v síti

$$\underbrace{\begin{bmatrix} i_0 \\ i_d \\ i_q \\ i_f \\ i_D \\ i_Q \end{bmatrix}}_{\left[i_{\Re}\right]} = \underbrace{\begin{bmatrix} \left[T_p\right] & [0] \\ [0] & \left[1_d\right] \end{bmatrix}}_{[W]} \cdot \underbrace{\begin{bmatrix} i_a \\ i_b \\ i_c \\ i_f \\ i_D \\ i_Q \end{bmatrix}}_{\left[i_{\wp}\right]}$$

$$\textit{transformace } \wp \Rightarrow \Re$$

$$\wp = \{abcfDQ\} \quad \text{..přirozený systém}$$

$$\Re = \{0dqfDQ\} \quad \text{..rotorový systém}$$

$$\left[i_{\Re}\right] = [W] \cdot \left[i_{\wp}\right]$$

$$[W]^{-1} = [W]^T$$

Rovnice pro stroj zapojený v síti

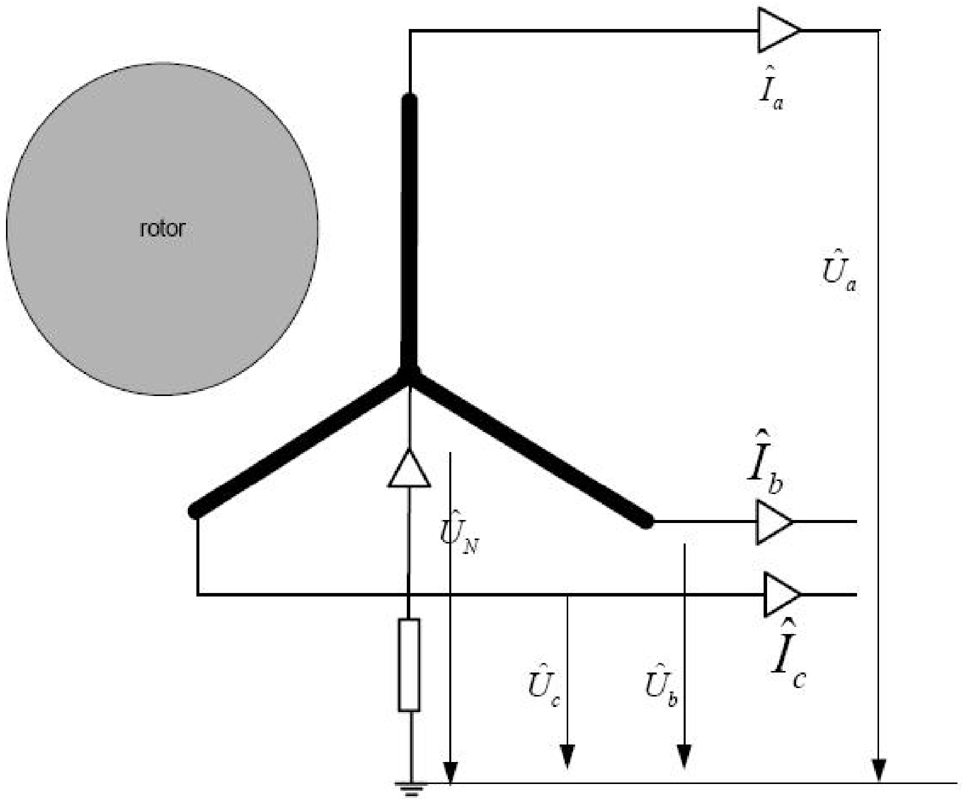
$$\underbrace{\begin{bmatrix} \psi_a \\ \psi_b \\ \psi_c \\ \hline \psi_f \\ \psi_D \\ \psi_Q \end{bmatrix}}_{\psi_\wp} = \underbrace{\left[\begin{array}{ccc|ccc} L_{aa} & L_{ab} & L_{ac} & L_{af} & L_{aD} & L_{aQ} \\ L_{ba} & L_{bb} & L_{bc} & L_{bf} & L_{bD} & L_{bQ} \\ L_{ca} & L_{cb} & L_{cc} & L_{cf} & L_{cD} & L_{cQ} \\ \hline L_{fa} & L_{fb} & L_{fc} & L_{ff} & L_{fD} & L_{fQ} \\ L_{Da} & L_{Db} & L_{Dc} & L_{Df} & L_{DD} & L_{DQ} \\ L_{Qa} & L_{Qb} & L_{Qc} & L_{Qf} & L_{QD} & L_{QQ} \end{array}\right]}_{L_\wp} \cdot \underbrace{\begin{bmatrix} i_a \\ i_b \\ i_c \\ \hline i_f \\ i_D \\ i_Q \end{bmatrix}}_{i_\wp}$$

$$L_\wp = \left[\begin{array}{c|c} L_{SS} & L_{SR} \\ \hline L_{SR}^T & L_{RR} \end{array}\right]$$

Rovnice pro stroj zapojený v síti

$$\begin{bmatrix} \bar{U}_{abc} \\ \bar{U}_{fDQ} \end{bmatrix} = -\begin{bmatrix} [R_{abc}] & [0] \\ [0] & [R_{fDQ}] \end{bmatrix} \cdot \begin{bmatrix} \bar{i}_{abc} \\ \bar{i}_{fDQ} \end{bmatrix} - \begin{bmatrix} \bar{\psi}_{abc} \\ \bar{\psi}_{fDQ} \end{bmatrix}^{\bullet} + \begin{bmatrix} \bar{U}_{N} \\ \bar{0} \end{bmatrix}$$

$$\bar{U}_N = -R_N[1].\bar{i}_{abc} - L_n[1].\dot{\bar{i}}_{abc}$$



Rovnice pro stroj zapojený v síti

$$\underbrace{[W]\begin{bmatrix}\bar{U}_{abc}\\ \bar{U}_{fDQ}\end{bmatrix}}_{\begin{bmatrix}\bar{U}_{0dq}\\ \bar{U}_{fDQ}\end{bmatrix}} = -\underbrace{[W]\begin{bmatrix}[R_{abc}] & 0\\ 0 & [R_{fDQ}]\end{bmatrix}[W]^{-1}}_{\begin{bmatrix}[R_{abc}] & [0]\\ [0] & [R_{fDQ}]\end{bmatrix}}\underbrace{[W]\begin{bmatrix}\bar{i}_{abc}\\ \bar{i}_{fDQ}\end{bmatrix}}_{\begin{bmatrix}\bar{i}_{0dq}\\ \bar{i}_{fDQ}\end{bmatrix}} - \underbrace{[W]\begin{bmatrix}\bar{\psi}_{abc}\\ \bar{\psi}_{fDQ}\end{bmatrix}^{\bullet}} + [W]\begin{bmatrix}\bar{U}_{N}\\ \bar{0}\end{bmatrix}$$

Rovnice pro stroj zapojený v síti

$$\overline{\psi}_{odq}^{\bullet} = [T_p].\overline{\psi}_{abc}^{\bullet} + [T_p]^{\bullet}.\overline{\psi}_{abc}$$

$$[W]\begin{bmatrix}\overline{U}_N \\ \overline{0}\end{bmatrix} = \begin{bmatrix}\overline{U}_{N0dq} \\ \overline{0}\end{bmatrix} = -\begin{bmatrix}3R_N i_0 \\ \overline{0} \\ \overline{0}\end{bmatrix} - \begin{bmatrix}3L_N i_0^{\bullet} \\ \overline{0} \\ \overline{0}\end{bmatrix},$$

$$\begin{bmatrix}\overline{\psi}_{odq} \\ \overline{\psi}_{fDQ}\end{bmatrix} = [L_{\Re}]\begin{bmatrix}\overline{i}_{odq} \\ \overline{i}_{fDQ}\end{bmatrix}$$

$$[T_p]\overline{\psi}_{abc}^{\bullet} = \overline{\psi}_{odq}^{\bullet} - \overline{T}_p^{\bullet}.[\psi_{abc}] = \overline{\psi}_{odq}^{\bullet} - \underbrace{[T_p]^{\bullet}[T_p^{-1}].\overline{\psi}_{odq}}$$

$$-\omega\begin{bmatrix}0 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0\end{bmatrix}\overline{\psi}_{odq} = -\begin{bmatrix}0 \\ -\omega\psi_q \\ -\omega\psi_d\end{bmatrix}$$

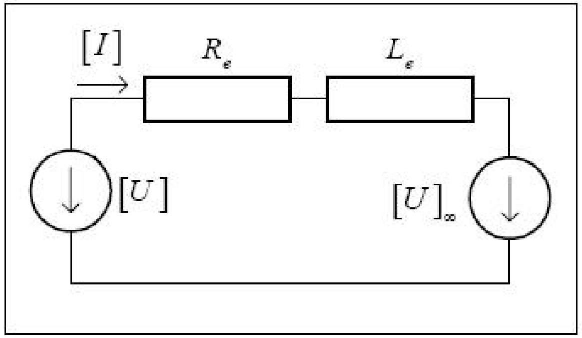
$$\begin{bmatrix}\overline{U}_{odq} \\ \overline{U}_{fDQ}\end{bmatrix} = -\begin{bmatrix}[R_{abc}] & 0 \\ 0 & [R_{fDQ}]\end{bmatrix}\begin{bmatrix}\overline{i}_{odq} \\ \overline{i}_{fDQ}\end{bmatrix} - \begin{bmatrix}\overline{\psi}_{odq}^{\bullet} \\ \overline{\psi}_{fDQ}^{\bullet}\end{bmatrix} + \omega\begin{bmatrix}0 \\ -\psi_q \\ \psi_d\end{bmatrix}$$

Rovnice pro stroj zapojený v síti

$$\bar{U} \qquad [R+\omega N] \qquad \bar{i} \qquad [L] \qquad \bar{i}^{\bullet}$$

$$\begin{bmatrix} U_d \\ -U_f \\ 0 \\ U_q \\ 0 \end{bmatrix} = -\left[\begin{array}{ccc|cc} r & 0 & 0 & \omega L_q & \omega l_{aq} \\ 0 & r_f & 0 & 0 & 0 \\ 0 & 0 & r_D & 0 & 0 \\ \hline -\omega L_d & -\omega l_{ad} & -\omega l_{ad} & r & 0 \\ 0 & 0 & 0 & 0 & r_Q \end{array}\right] \begin{bmatrix} i_d \\ i_f \\ i_D \\ i_q \\ i_Q \end{bmatrix} - \left[\begin{array}{ccc|cc} L_d & l_{ad} & l_{ad} & 0 & 0 \\ l_{ad} & L_f & l_{aq} & 0 & 0 \\ l_{ad} & l_{ad} & L_D & 0 & 0 \\ \hline 0 & 0 & 0 & L_q & l_{aq} \\ 0 & 0 & 0 & l_{aq} & L_Q \end{array}\right] \begin{bmatrix} i_d \\ i_f \\ i_D \\ i_q \\ i_Q \end{bmatrix}^{\bullet}$$

Rovnice pro stroj zapojený v síti



Propojené zdroje

$$\overline{f}_{odq} = \left[T_p\right].\overline{f}_{abc};$$

$$\overline{f}_{abc} = \left[T_p\right]^{-1}.\overline{f}_{odq}$$

$$\overline{f}_{abc}^{\bullet} = \left(\left[T_p\right].\overline{f}_{abc}\right)^{\bullet} = \left[T_p\right]^{\bullet}.\overline{f}_{abc} + \left[T_p\right].\overline{f}_{abc}^{\bullet} \Rightarrow$$

$$\Rightarrow \overline{i}_{abc}^{\bullet} = \left(\left[T_p\right]^{-1}\overline{i}_{odq}^{\bullet} - \left[T_p\right]^{-1}\left[T_p\right]^{\bullet}.\overline{i}_{abc}\right)$$

$$\overline{U}_{abc} = \overline{U}_{abc,\infty} + R_e.\overline{i}_{abc} + L_e.\overline{i}_{abc}^{\bullet},$$

$$\left[T_p\right].\overline{U}_{abc} = \left[T_p\right].\overline{U}_{abc,\infty} + R_e.\left[T_p\right].\overline{i}_{abc} + L_e\left[T_p\right]\overline{i}_{abc}^{\bullet}$$

$$\overline{U}_{0dq} = \overline{U}_{0dq,\infty} + R_e\overline{i}_{0dq} + L_e\overline{i}_{odq}^{\bullet} - L_e\underbrace{\left[T_p\right]^{\bullet}.\overbrace{\left[T_p\right]^{-1}.\overline{i}_{0dq}}^{\overline{i}_{abc}}}_{\omega\begin{bmatrix}0 & 0 & 0\\ 0 & 0 & -1\\ 0 & 1 & 0\end{bmatrix}\overline{i}_{0dq}}$$

Rovnice pro stroj zapojený v síti

$$\bar{U}_{0dq} = \bar{U}_{0dq,\infty} + R_e.\bar{i}_{odq} + L_e\left(\begin{bmatrix} i_o \\ i_d \\ i_q \end{bmatrix}^{\bullet} - \omega\begin{bmatrix} 0 \\ -i_q \\ i_d \end{bmatrix}\right)$$

Rovnice pro stroj zapojený v síti

$$\overline{U}_{odq} = U_{\infty}\begin{bmatrix} 0 \\ -\sin(\delta-\alpha) \\ \cos(\delta-\alpha) \end{bmatrix} + R_e.\overline{i}_{odq} + L_e.\overline{i}^{\bullet}_{odq} - \omega L_e \begin{bmatrix} 0 \\ -i_q \\ i_d \end{bmatrix},$$

$$-[L]\overline{i}^{\bullet} = [R+\omega N].\overline{i} + \begin{bmatrix} -U_{\infty}\sin(\delta-\alpha) + R_e i_d + L_e i_d^{\bullet} + \omega L_e i_q \\ -U_f \\ 0 \\ U_{\infty}\cos(\delta-\alpha) + R_e i_q + L_e i_q^{\bullet} - \omega L_e i_d \end{bmatrix}$$

Rovnice pro stroj zapojený v síti

$$-[L].\overline{i}^{\bullet} = \left[\overline{\overline{R}} + \omega\overline{\overline{N}}\right].\overline{i} + \begin{bmatrix} -U_{\infty}\sin(\delta-\alpha) \\ -U_f \\ 0 \\ U_{\infty}\cos(\delta-\alpha) \end{bmatrix}$$

+ pohybová rovnice

$\overline{\overline{R}} = r + R_e$, $\overline{\overline{L}}_d = L_d + L_e$, $\overline{\overline{L}}_q = L_q + L_e$.

respektování sítě → korigovat parametry v rovnicích stroje

Elektrický moment stroje

$$M_{el} = \frac{1}{2}\bar{i}_{\wp}^{T} \cdot \frac{d}{d\gamma} L(\gamma).\bar{i}_{\wp} = \frac{1}{2}\bar{i}_{\Re}^{T} \cdot [W].\frac{d}{d\gamma}\left([W]^{-1}[L_{\Re}][W]\right).[W]^{T}.\bar{i}_{\Re}$$

$$M_{el} = \frac{1}{2}\bar{i}_{\Re}^{T} \cdot [L_{\Re}] \cdot \frac{d[W]}{d\gamma}[W]^{T}\,\bar{i}_{\Re} + \frac{1}{2}\bar{i}_{\Re}^{T} \cdot [W]\frac{d[W]^{-1}}{d\gamma}[L_{\Re}] \cdot \bar{i}_{\Re}$$

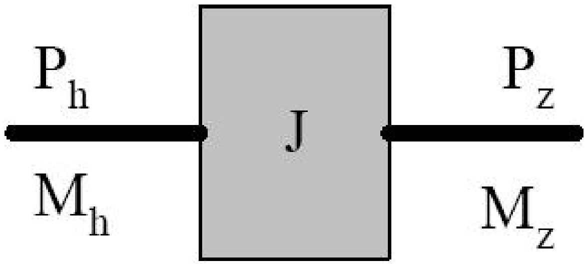
$$M_{el} = \frac{1}{2}\bar{i}_{\Re}^{T}[W]\frac{d[W]^{T}}{d\gamma} \cdot [L_{\Re}] \cdot \bar{i}_{\Re} + \frac{1}{2}\bar{i}_{\Re}^{T} \cdot [W]\frac{d[W]^{T}}{d\gamma}[L_{\Re}] \cdot \bar{i}_{\Re}$$

$$M_{el} = \bar{i}_{\Re}^{T} \bullet \underbrace{[W] \cdot \frac{d[W]^{-1}}{d\gamma}}_{\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}} \bullet \underbrace{[L_{\Re}] \cdot \bar{i}_{\Re}}_{[\psi_R]}$$

$$M_d = \begin{bmatrix} i_0 & i_d & i_q & i_f & i_D & i_Q \end{bmatrix} \cdot \begin{bmatrix} 0 & \psi_q & -\psi_d & 0 & 0 & 0 \end{bmatrix}^{T} = i_d\psi_q - i_q\psi_d$$

Pohybová rce – mechanická část

Rotační zásobník



akumulovaná energie:

$$E_J(t) = \frac{1}{2} J \cdot \Omega_m^2(t)$$

výkonová bilance:

$$P_h(t) - P_z(t) = \dot{E}_J = J \cdot \dot{\Omega}(t) \cdot \Omega(t) \quad \Rightarrow$$

$$\underbrace{\frac{P_h(t)}{\Omega(t)}}_{M_h(t)} - \underbrace{\frac{P_z(t)}{\Omega(t)}}_{M_z(t)} = J \cdot \dot{\Omega}(t) = M_\Delta(t)$$

pohybová rovnice

$$\int_0^{\Omega_b} J \, d\Omega = \int_0^{\tau_J} M_b \, dt \;\Rightarrow J \cdot \Omega_b = M_b T_J, \; T_J = J \frac{\Omega_b^2}{S_b} = J \frac{\Omega_b}{M_b}$$

Pohybová rce – mechanická část

$$M_{\Delta}(t) = \underbrace{M_0 + \Delta M_h(t, \xi_h, \Omega)}_{M_h(t,\xi_h,\Omega)} - \underbrace{\{M_0 + \Delta M_z(t, \xi_z, \Omega)\}}_{M_z(t,\xi_z,\Omega)}$$

$$M_{\Delta}(t) = J\left(\Omega_0 + \Delta\Omega(t)\right)^{\bullet} = J \cdot \Delta\Omega^{\bullet}(t)$$

převedení do poměrných hodnot:

$$\tilde{M}_{\Delta}(t) = \frac{J \cdot \Delta\Omega^{\bullet}(t)}{M_b} = \frac{J \cdot T_J \cdot \Delta\Omega^{\bullet}(t)}{J\Omega_b} = T_J \cdot \Delta\tilde{\Omega}^{\bullet}$$

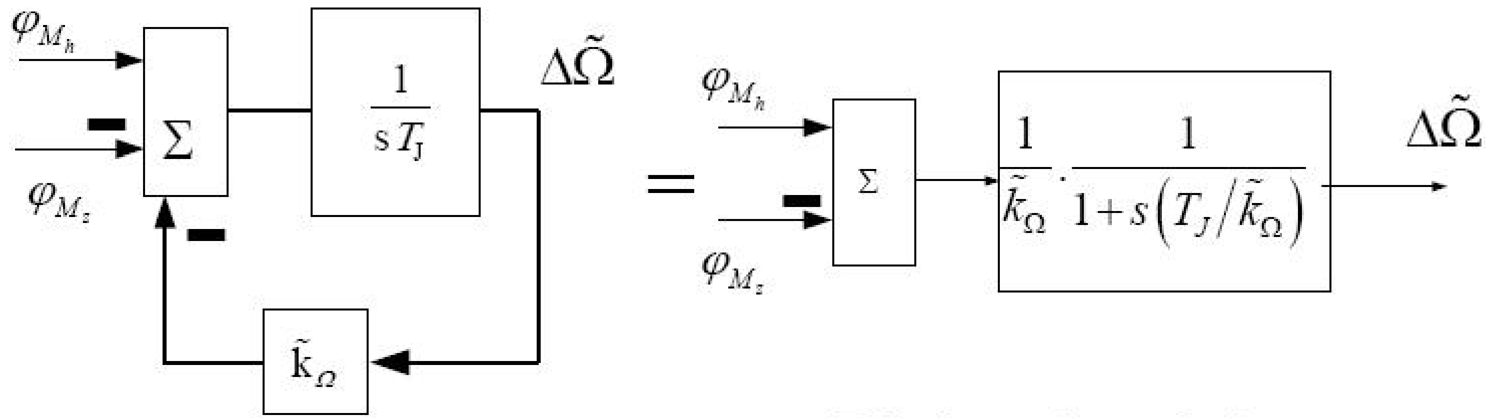
Pohybová rce – mechanická část

$$\Delta M_i\left(t,\xi_i,\Omega\right)=\frac{\partial M_i}{\partial \xi_i}\Delta\xi_i+\frac{\partial M_i}{\partial \Omega}\Delta\Omega; \qquad i=h,z$$

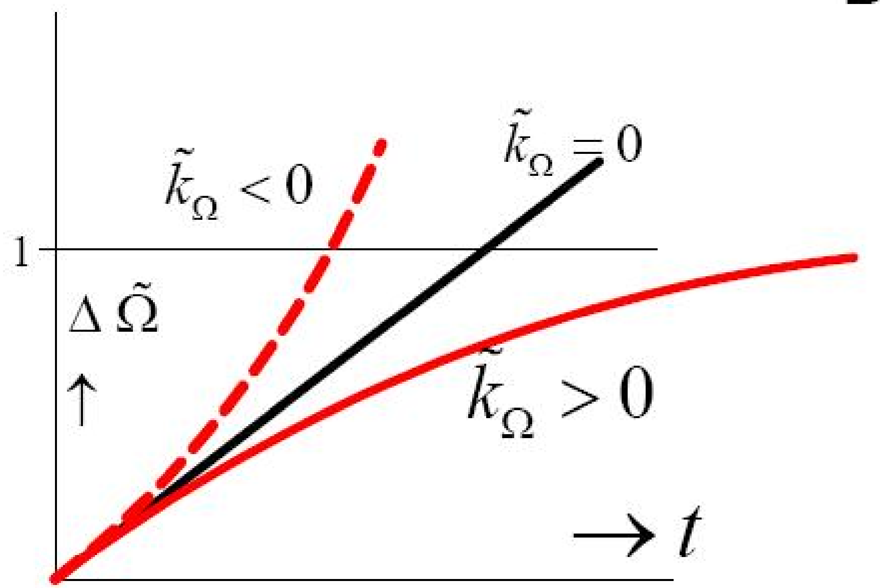
$$\underbrace{\left(\frac{\Delta M_i\left(t,\xi_i,\Omega\right)}{M_b}\right)}_{\Delta\tilde{M}_i}=\underbrace{\left(\frac{\dfrac{\partial M_i}{M_b}}{\dfrac{\partial \xi_i}{\xi_{ib}}}\right)}_{\partial\tilde{M}_i/\partial\tilde{\xi}_i}\cdot\underbrace{\left(\frac{\Delta\xi_i}{\xi_{ib}}\right)}_{\Delta\tilde{\xi}_i}+\underbrace{\left(\frac{\dfrac{\partial M_i}{M_b}}{\dfrac{\partial \Omega}{\Omega_b}}\right)}_{\partial\tilde{M}_i/\partial\tilde{\Omega}}\cdot\underbrace{\left(\frac{\Delta\Omega}{\Omega_b}\right)}_{\Delta\tilde{\Omega}}$$

$$T_J\cdot s\Delta\tilde{\Omega}=\underbrace{\frac{\partial\tilde{M}_h}{\partial\tilde{\xi}_h}}_{\varphi_{Mh}}\cdot\Delta\tilde{\xi}_h-\underbrace{\frac{\partial\tilde{M}_z}{\partial\tilde{\xi}_x}}_{\varphi_{Mz}}\Delta\tilde{\xi}_z\cdot-\underbrace{\left(\frac{\partial\tilde{M}_z}{\partial\tilde{\Omega}}-\frac{\partial\tilde{M}_h}{\partial\tilde{\Omega}}\right)}_{\tilde{k}_\Omega}\varphi_\Omega$$

Pohybová rce – mechanická část



Blokové schéma



Přechodová charakteristika

Odvození pohybové rovnice

Definice a vztahy:		
Ω_m / Ω_{sm}	rad.s^{-1}	mech. úhlová rychlost/synchronní
Ω_e / Ω_{se}	rad.s^{-1}	elektr. úhlová rychlost/synchronní
n_p	-	počet pólových dvojic
$J = GD^2/4$	kg.m^2	moment setrvačnosti
M_J	N.m	akcelerační moment
$\Omega_{\Delta m} = d\delta_m / dt$	rad.s^{-1}	přírůstek úhlové rychlosti
$H = \dfrac{\frac{1}{2} J\Omega_{sm}^2}{S_b} = \dfrac{T_J}{2}$	s	akumulovaná energie na jednotku výkonu,
$T_J = J\Omega_{sm}^2 / S_b$	s	mechanická časová konstanta
$\tilde{T}_J = T_J \cdot \Omega_{se}$	rad	mechanická časová konstanta p.u.
$\tilde{t} = t/t_b = \Omega_{se} \cdot t$	rad	poměrný čas
$\mathbf{S_b}$	MVA	bázový (vztažný) výkon
$M_b = S_b / \Omega_{sm}$	MVA	bázový moment
$P = \Omega_m \cdot M$	MW	vazba výkon ↔ moment
$\varepsilon = \{\Omega - \Omega_b\} / \Omega_b$	p.u.	skluz

Pohybová rovnice

$$\sum M = \underbrace{M_J}_{\substack{setrvačné\\hmoty}} + \underbrace{M_h}_{\substack{hnací\\moment}} + \underbrace{M_z}_{\substack{zátěžný\\moment}} + \underbrace{M_D}_{\substack{tlumicí\\moment}} = 0 \,/\, systém \;\; M/G$$

$$J\frac{d\Omega_m}{dt} = \underbrace{M_h - M_z \pm M_D}_{\Delta M} = M_J \qquad /systém\, smíšený$$

$$P_T = P_G + W^{\bullet}_{kin} + P_{\Delta}$$

$$W_{kin} = \frac{1}{2}J\omega^2 = \frac{1}{2}J\delta^{\bullet 2}$$

$$W^{\bullet}_{kin} = J\omega\omega^{\bullet} = J\delta^{\bullet}\delta^{\bullet\bullet} \approx J\omega_0\omega^{\bullet}$$

Pohybová rovnice

$$\frac{J\omega_0}{S_B} = \frac{1/2 J\omega_0^2 2}{S_B\omega_0} = \frac{W_{0,kin}}{\pi f_0 S_B} = \frac{H}{\pi f_0}$$

$$P_\Delta = P_{as} + k\omega^2 \approx D.S_B.\delta^\bullet$$

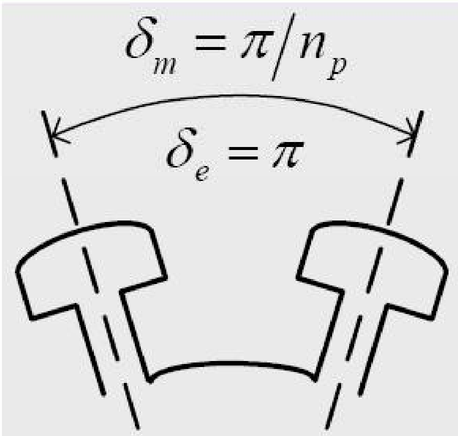
$$\frac{P_T}{S_B} = \frac{H}{\pi f_0}\delta^{\bullet\bullet} + D.\delta^\bullet + \frac{P_G}{S_B}$$

Přírůstkový tvar

$$\frac{H}{\pi f_0}\delta^{\bullet\bullet} + D.\delta^\bullet + \frac{\Delta P_G}{S_B} - \frac{\Delta P_T}{S_B} = 0$$

Pohybová rovnice

$$\underbrace{\left(\Omega_{sm}+\Delta\Omega_m\right)}_{\Omega_m}^{\bullet} = \Delta\Omega_m^{\bullet} = \delta_m^{\bullet\bullet} = \frac{1}{n_p}\delta_e^{\bullet\bullet}$$



$$\Omega_e = n_p \cdot \Omega_m,\ \delta_m^{\bullet} = \Delta\Omega_m$$

$$J\underbrace{\left(\overbrace{\delta_e / n_p}^{\delta_m}\right)^{\bullet\bullet}}_{\Omega_m^{\bullet}} = \frac{J}{n_p}\delta_e^{\bullet\bullet} = M_J = M_\Delta$$

$$\frac{M_J}{M_b} = \frac{J}{M_b \cdot n_p}\cdot\delta_e^{\bullet\bullet} = \underbrace{\left(\frac{J\Omega_{sm}^2}{S_b}\right)}_{T_J}\cdot\frac{\delta_e^{\bullet\bullet}}{\Omega_{sm}n_p} = \tilde{M}_J = \tilde{M}_\Delta$$

Pohybová rovnice

$$\frac{T_J}{n_p \cdot \Omega_{sm}} \cdot \ddot{\delta}_e = \frac{T_J}{\Omega_{se}} \cdot \frac{d^2\delta_e}{\underbrace{dt^2}_{\left(d\tilde{t}^2/\Omega_{se}^2\right)}} = \overbrace{\tilde{T}_J}^{\Omega_{se} T_J} \frac{d^2\delta_e}{d\tilde{t}^2} = \tilde{M}_J = \tilde{M}_\Delta$$

pohybová rovnice v p.u.,

$$\Delta\tilde{M} = \frac{M_h - M_z}{M_b} = \frac{P_h - P_z}{\Omega_m} \cdot \frac{\Omega_{sm}}{S_b} = \frac{\Delta\tilde{P}}{\tilde{\Omega}} = \frac{\Delta\tilde{P}}{1 + \Delta\tilde{\Omega}}$$

$$\tilde{T}_J \cdot \frac{d^2\delta_e}{d\tilde{t}^2} = \frac{\Delta\tilde{P}}{1 + \Delta\tilde{\Omega}} \doteq \Delta\tilde{P} \Rightarrow / \left|\Delta\tilde{\Omega}\right| \leq 0.01$$

Tlumící výkon

$$p = R_e\left\{u \cdot i^*\right\} = u_q i_q + u_q i_q,$$

$$q = I_m\left\{u \cdot i^*\right\} = u_d i_q - u_q i_d$$

členění výkonů

$$u_q = -i_q r - \underbrace{\psi_q^{\bullet}}_{\sim 0} + \omega\underbrace{\left(l_d i_d + l_{ad}\left(i_f + i_D\right)\right)}_{\psi_d}$$

$$u_q = x_d . i_d + \underbrace{x_{ad} . i_f}_{e} + \underbrace{x_{ad} . i_D}_{e_{tD}} - i_q . r$$

$$ju_d = -ji_d . r - \underbrace{j\psi_d^{\bullet}}_{\sim 0} - j\omega\underbrace{\left(l_q i_q + l_{aq} i_Q\right)}_{\psi_q} = -jx_q i_q - j\underbrace{x_{aq} i_Q}_{e_{tQ}} - ji_d . r$$

$$p = \underbrace{e i_q + i_q\left(x_d - x_q\right) - r\left(i_d^2 + i_q^2\right)}_{p_{syn.}} + \underbrace{e_{tD} i_q - e_{tQ} i_D}_{p_{as.} \cong D.\delta^{\bullet}},$$

Tlumící výkon

$$u_d = u.\cos\delta = e - i_d.x_d = e'_q - i_d.x'_d \Rightarrow i_d = e - u.\cos\delta / x_d$$

$$e'_q = \underbrace{u.\cos\delta}_{u_d} + \underbrace{\{(e - u.\cos\delta)/x_d\}}_{i_d}.x'_d = u.\cos\delta.\{(x_d - x'_d)/x_d\} + e.x'_d/x_d$$

$$e'^{\bullet}_q = -u.\sin\delta_0.\{(x_d - x'_d)/x_d\}\delta^{\bullet} + e^{\bullet}x'_d/x_d$$

$$u_f = e + T_{d0}.e'^{\bullet}_q = e - T_{d0}u.\sin\delta_0.\{(x_d - x'_d)/x_d\}\delta^{\bullet} + T_{d0}e^{\bullet}x'_d/x_d$$

$$u_f(s) = e(s)(1 + s.T'_d) - u.T_{d0}.\sin\delta_0\{(x_d - x'_d)/x_d\}s\delta,$$

$$T'_d = T_{d0}.x'_d/x_d$$

$$pro\ \Delta u_f = 0 \Rightarrow \Delta e(s) = \frac{x_d - x'_d}{x_d}.\frac{T_{d0}u.\sin\delta_0}{T'_d s + 1}s.\delta$$

$$\Delta p_e = \underbrace{\frac{eu\cos\delta_0}{x_d}}_{\partial p_e/\partial\delta}\Delta\delta + \underbrace{\frac{u.\sin\delta_0}{x_d}}_{\partial p_e/\partial e}.\underbrace{\frac{x_d - x'_d}{x_d}.\frac{T_{d0}u.\sin\delta_0}{T'_d s + 1}s.\delta}_{\Delta e}$$

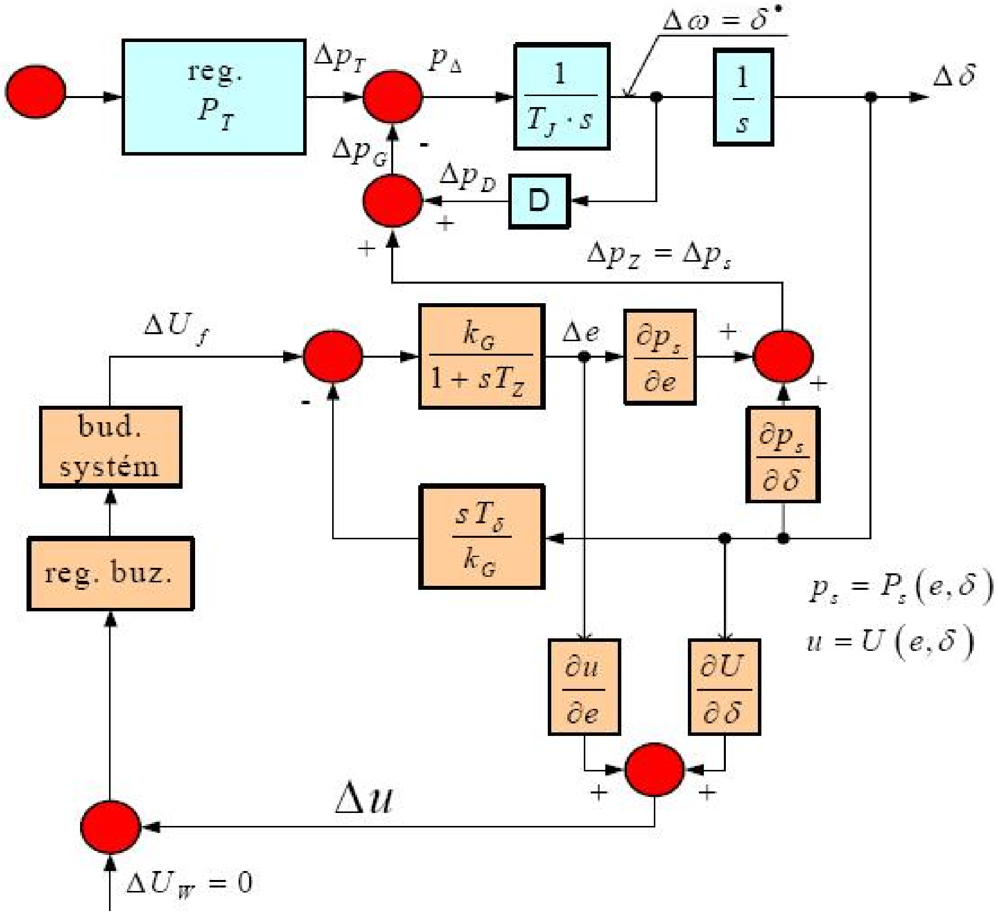
$$D = \frac{x_d - x'_d}{x_d.x'_d}.\frac{T'_d.}{1 + sT'_d}(u.\sin\delta_0)^2$$

Regulace stroje

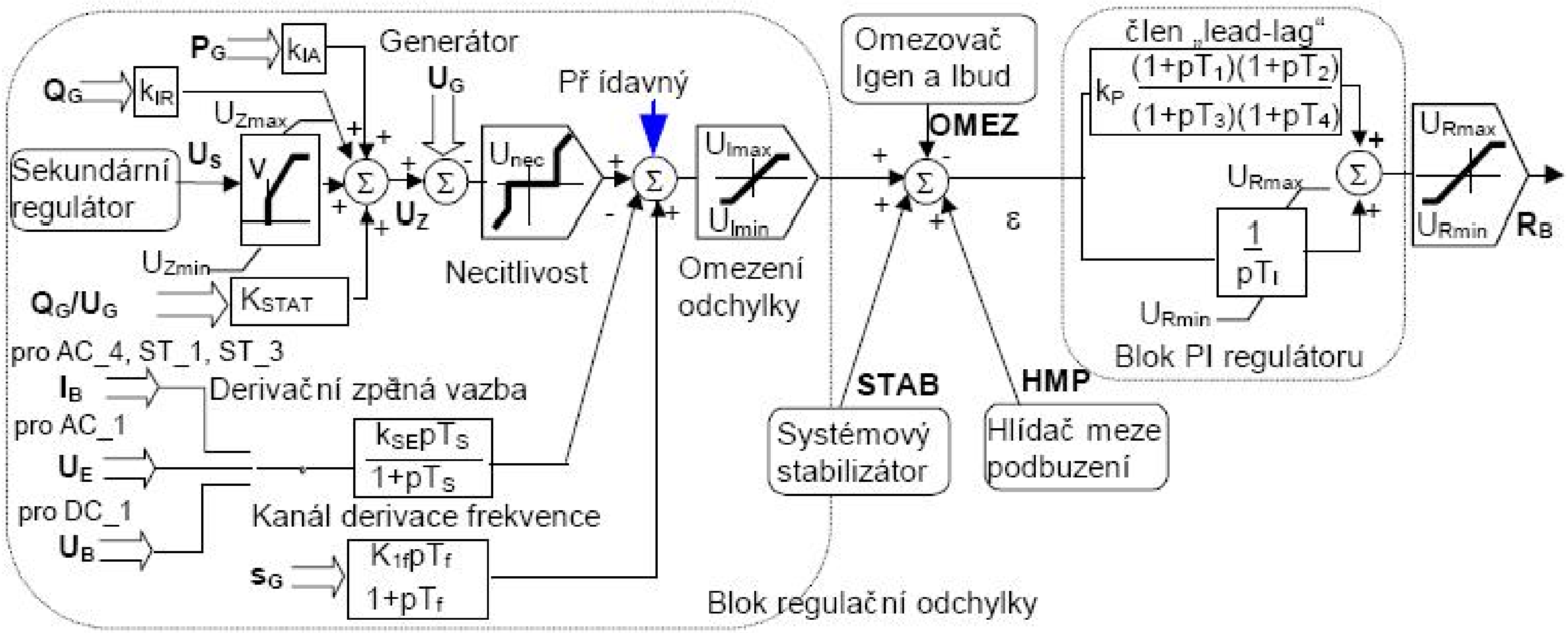
$$\left(T_j \cdot s^2 + D.s + C\right) \cdot \Delta\delta(s) + B.\Delta e(s) = 0$$

$$C = \left(\partial P_s / \partial\delta\right) ..synchronizační\ výkon,\ B = \left(\partial P_s / \partial e\right)$$

Schéma linearizovaného obvodu:



Regulace buzení



Regulace turbíny