TRANSFORMATORI

$U = 4.44 \cdot f \cdot N \cdot \Phi_{max}$ $\quad B_{max} = \frac{\Phi_{max}}{S}$ [T]

Φ [Vs]

zakon protjecanja: $\oint H dl = NI = \theta$

$H_{max} \cdot l_{sr} = N \cdot I_{max} = \theta_{max}$ $\quad (l_{sr} = 2 l_{sr} \pi = D_{sr} \pi)$ $\quad B = \mu H$

Ohmov zakon za mag. krug:

$\Phi = \frac{NI}{R_m} = \frac{\theta}{R_m}$, $R_m = \frac{1}{\mu} \cdot \frac{l_{sr}}{S}$, $I_{max} = \sqrt{2} \cdot I$

$L = \frac{N \cdot \Phi_{max}}{I_{max}} = \frac{N \cdot B_{max} \cdot S}{\sqrt{2} \cdot I} = \frac{N \cdot S}{\sqrt{2} \cdot I} \cdot \frac{\sqrt{2} \cdot N \cdot I \cdot \mu}{l_{sr}} = \frac{N^2 \mu S}{l_{sr}} = \frac{N^2}{R_m}$, $X = \omega L$

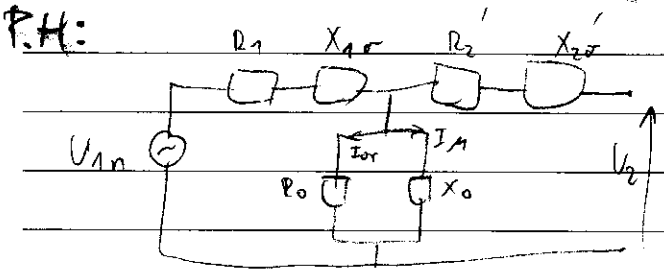
$P_h = k_h f \cdot B$ $\quad P_v = k_v f^2 B$

Ukupni prijenosni omjer paralelnih trafoa: $\frac{U_1}{U_2} = \frac{U_{11}}{U_{21}} \cdot \frac{U_{12}}{U_{22}}$

$U_{1T2} = U_{2T1}$ $\quad U_2 I_2 = U_{1T2} \cdot \frac{U_2}{U_1}$

NADOMJESNE SHEME

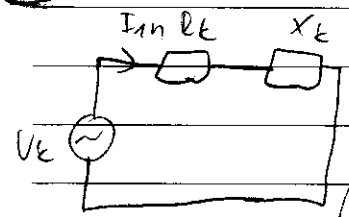
P.H:



$a = \frac{U_{1n}}{U_2}$ $\quad P_0 = \frac{U_{1n}^2}{R_0}$ $\quad I_{or} = \frac{U_{1n}}{R_0}$

$I_0^2 = I_{or}^2 + I_\mu^2$ $\quad X_0 = \frac{U_{1n}}{I_\mu}$

KS:



$Z_k = \frac{U_k}{I_{1n}}$ $\quad R_k = \frac{P_k}{I_{1n}^2}$

$X_k = \sqrt{Z_k^2 - R_k^2}$

ako nije drukčije zadano:

$X_{1\sigma} = X_{2\sigma}' = \frac{X_k}{2}$

$R_1 = R_2' = \frac{R_k}{2}$

relativne mjerodavnosti: $S_n = U_n I_n$ (√3) → 3f

$Z_b = \frac{U_{1n}^2}{S_n}$

1 (100%)

$l_0\% = \frac{l_0}{Z_b} \cdot 100\% = \frac{U_{1n}}{I_{or}\%} \cdot 100\%$ → $\frac{I_{or}}{I_{1n}}$

$X_0\% = \frac{X_0}{Z_b} \cdot 100\% = \frac{U_{1n}}{I_\mu}$

$R_{k\sigma}' = R_k\% = \frac{\frac{R_k}{2}}{Z_b} \cdot 100\%$

$X_{1\sigma} = X_{2\sigma}' = \frac{\frac{X_k}{2}}{Z_b} \cdot 100\%$

Općenito kad nad. shema:

$I_{1n} = \frac{S_n}{U_{1n}}$ $I_{2n} = \frac{S_n}{U_{2n}}$ $u_r = \frac{P_k}{S_n} \cdot 100\%$, $u_k = \sqrt{u_r^2 + u_\sigma^2}$, $u_{\sigma 25} = u_{\sigma 75}$ → ne mijenja se s temp

$b = \frac{235+75}{235+25}$ → faktor za Cu za preračunavanje (otpora) snage s 25° na 75°

$P_k = P_{cu} + P_{dod} = (R_{1cu} + R'_{2cu}) \cdot I_1^2 + P_{dod}$

$P_{cu_{25}} = I_{1n}^2 R_{1cu} + I_{2n}^2 \cdot R_{2cu}$

$P_{cu75} = b \cdot P_{cu25}$ + $P_{dod75} = \frac{P_{dodcu}}{b} = P_{k75}$

$R_{k\%} = u_{r\%}$, $X_{k\%} = u_{\sigma\%}$

$R_{k\%} = \frac{R_k}{Z_b} = \frac{\frac{P_k}{I_{1n}^2}}{\frac{U_{1n}^2}{S_n}} = \frac{P_k}{S_n} = u_r$ $Z_{k\%} = \frac{Z_k}{Z_b} = \frac{\frac{U_k}{I_{1n}}}{\frac{U_{1n}^2}{S_n}} = \frac{U_k}{U_{1n}} = u_k$

$R_{1\%} = \frac{R_{1cu}}{Z_b} \cdot b$ $R'_{2cu\%} = \frac{R_{2cu}}{Z_b} \cdot a^2 \cdot b$

$R_{dod\%} = R_{k\%} - R_{1\%} - R'_{2cu\%}$ $R'_{2\%} = R'_{2cu\%} + R_{dod\%}$

- kad struja ks. nije nazivna: $\frac{I_k}{I_{kn}} = \frac{U_k}{U_{kn}}$

- neovisno o spoju trafoa: $R_t = \frac{R_{st}}{2}$

- VAŽNO: kod 3-f trafoa - $P = 3I^2R$ isto i kod P_{dod}

$I = \frac{U_n}{\sqrt{3}R}$ $R_0 = \frac{U_f^2}{\frac{P_0}{3}} = \frac{(\sqrt{3}U_f)^2}{P_0} = \frac{U_l^2}{P_0}$

- pad napona u trafou: $\Delta u = \alpha (u_r \cos\varphi_2 + u_\sigma \sin\varphi_2 + 0.005\alpha (u_r \cos\varphi_2 - u_r \sin\varphi_2)^2)$

$\alpha = \frac{S}{S_n} = \frac{I_2}{I_{2n}}$ - kad je cos1 kap → sinφ < 0

gledano s primara: $\Delta V = \Delta u \cdot U_{1n} \Rightarrow U_2' = U_{1n} - \Delta V$

gledano sa sek.: $\Delta V = \Delta u \cdot U_{2n} \Rightarrow U_2 = U_{2n} - \Delta u$

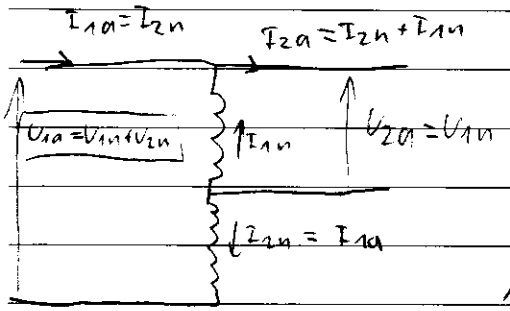
KORISNOST:

$\eta = 1 - \frac{P_0 + \alpha^2 P_{k75}}{P} = 1 - \frac{P_0 + \alpha^2 P_{kn}}{\alpha S_n \cos\varphi}$

$\frac{d\eta}{d\alpha} = 0 \Rightarrow \boxed{\alpha_{max} = \sqrt{\frac{P_0}{P_{kn}}}}$ za $\eta = \eta_{max}$

nazivna korisnost: $\alpha = 1$, $\cos\varphi = 1$

AUTOTRANSFORMATOR I TIPSKA SNAGA



$$I_{1a}=I_{2n}=\frac{S_n}{U_{2n}}$$

$$S_a=U_{1a}I_{1a}=(U_{1n}+U_{2n})I_{2n}=\frac{U_{1a}}{U_{1a}-U_{2a}}\cdot S_n$$

$$u_E=\frac{U_{1E}}{U_n} \qquad u_{Ea}=u_E\cdot\frac{U_{1a}-U_{2a}}{U_{1a}}$$

$$\eta_a=\frac{S_a\cos\varphi-P_0+P_E}{S_a\cos\varphi}$$

PARALELNI RAD TRANSFORMATORA

$$S_{dop}=u_{Emin}\sum\frac{S_{ni}}{u_{Ei}} \qquad S_i=S_{ni}\cdot\frac{S\cdot u_{E\,min}}{S_{dop}\cdot u_{Ei}}$$

$$z_{Ei}=\frac{U_n^2\cdot u_{Ei}}{100\cdot S_{ni}} \qquad d_i=\frac{u_{Emin}}{u_{Ei}}\cdot d$$

$$\eta=1-\frac{P_{01}+d_1^2P_{T1}+P_{02}+d_2^2P_{T2}+\dots}{S_{dop}\cos\varphi}$$

ZAGRIJAVANJE TRANSFORMATORA

- od početne nadtemperature ϑ_0: $\vartheta=\vartheta_0+(\vartheta_m-\vartheta_0)\cdot\left(1-e^{-\frac{t}{T}}\right)$
  - hladno stanje $\rightarrow \vartheta_0=0$
- konačno zagrijanje ϑ_m prop. je ukupnim gubicima u trafou:

$$\frac{\vartheta_{m1}}{\vartheta_{mn}}=\frac{P_0+d_1^2P_T}{P_0+P_T}$$

- dok temp. okoline pada, dozvoljena nadtemperatura raste ∇
  $\vartheta_{mn}+\theta_{ok}=\vartheta_{m1}+\theta_{ok}$

GRAFIČAR LUDBREG

SINKRONI STROJEVI

PROTJECANJE, IND. NAPON

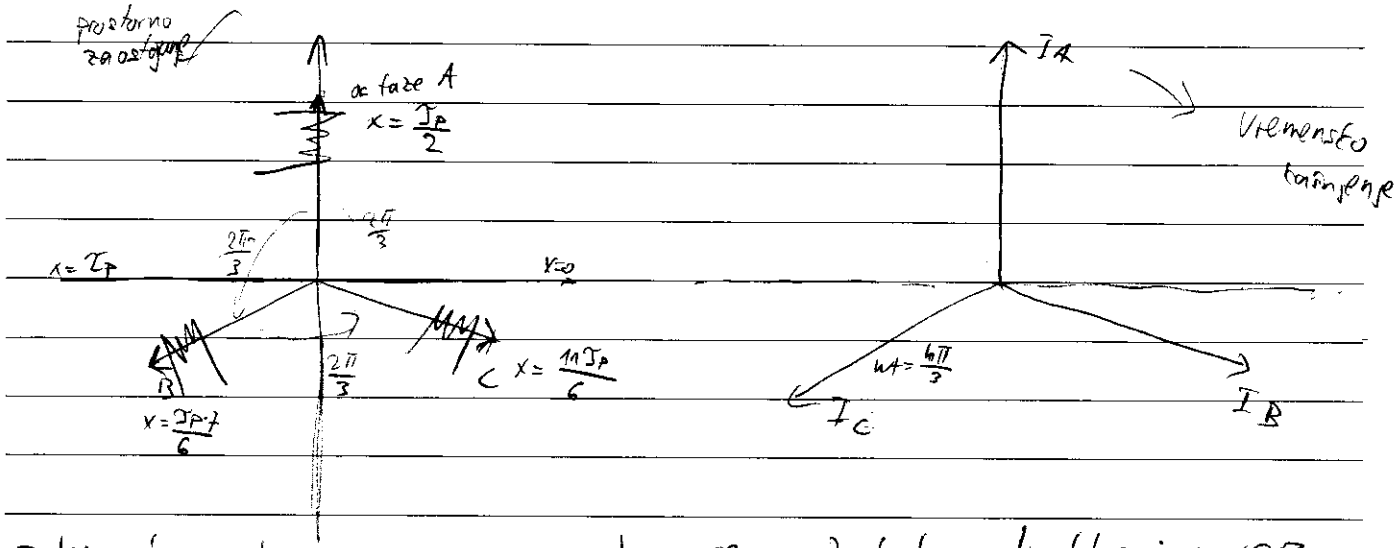
$n = \frac{60f}{p}$, $\mathcal{L}'_{m\delta} = \frac{1}{\Lambda'_\delta} = \frac{\delta}{\mu_0} = \frac{\delta}{4\pi \cdot 10^{-7}}$

obretno protjecanje:

$\Theta_\delta = B_\delta \cdot \mathcal{L}'_{m\delta}$ [A] $\Rightarrow$ stvoreno pulzirajućim protjecanjima triju faznih namota

$\Theta_{1f} = \frac{2}{3}\Theta_\delta$ $\quad \Theta = NI$ $\quad \omega = 2\pi f = 2\pi \frac{n}{60} = \frac{n\pi}{30}$

$E = Blv$, $v = \omega r$



Pulsirajuća protjecanja $\Rightarrow$ rastave se na 2 obretna: direktno i inverzno:

po namotima

$\Theta_{x,t,A} = \Theta_{1A} \cos\omega t \sin\frac{\pi}{\tau_p}x$

$\Theta_{x,t,B} = \Theta_{1B} \cos\left(\omega t - \frac{2\pi}{3}\right)\sin\left(\frac{\pi}{\tau_p}x - \frac{2\pi}{3}\right)$

$\Theta_{x,t,C} = \Theta_{1C} \cos\left(\omega t - \frac{4\pi}{3}\right)\sin\left(\frac{\pi}{\tau_p}x - \frac{4\pi}{3}\right)$

$\Theta_{x,t,A} = \frac{1}{2}\Theta_1 \sin\left(\frac{\pi}{\tau_p}x - \omega t\right) + \frac{1}{2}\Theta_1 \sin\left(\frac{\pi}{\tau_p}x + \omega t\right)$

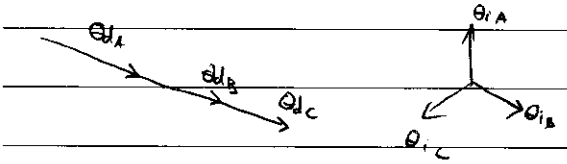
$\Theta_{x,t,B} = \frac{1}{2}\Theta_1 \sin\left(\frac{\pi}{\tau_p}x - \omega t\right) + \frac{1}{2}\Theta_1 \sin\left(\frac{\pi}{\tau_p}x + \omega t - \frac{4\pi}{3}\right) +$

$\Theta_{x,t,C} = \frac{1}{2}\Theta_1 \sin\left(\frac{\pi}{\tau_p}x - \omega t\right) + \frac{1}{2}\Theta_1 \sin\left(\frac{\pi}{\tau_p}x + \omega t - \frac{2\pi}{3}\right)$

↳ Vk. protjecanje je sastavljeno od 3 direktna

Svake faze, koja su u svakom trenutku na istom položaju u prostoru

$\sum \Theta_{x,t,ABC} = \Theta_d + \Theta_i = \frac{3}{2}\Theta_1 \sin\left(\frac{\pi}{\tau_p}x - \omega t\right) + 0$



SINKRONI STROJEVI

$n = \frac{60f}{p}$ — p broj pari polova

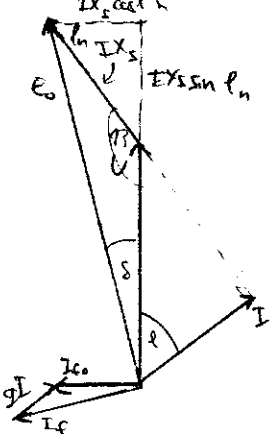
TURBOGENERATOR - s neistaknutim polovima

HIDROGENERATOR - s istaknutim polovima

VEKTORSKO – FAZORSKI DIJAGRAM

1) napon U okomito iz ishodišta
2) struja pod kutem φ odnosi na U. ind → desno (1) kap → lijevo (2)
3) od vrha U okomito na I ide IX_s
4) E_0 se dobije spajanjem ishodišta s vrhom IX_s. δ je kut između U, E_0 → kut opterećenja
5) $I_{f0} \perp U$, $I_f \perp E_0$
6) spoj vrhova fazora I_f i I_{f0} je gI → reakcija armature $\parallel I$

1) 2)

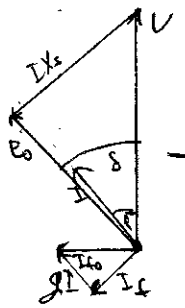


TURBO-GENERATOR:

$\frac{\sin\alpha}{\sin\beta} = \frac{a}{b}$

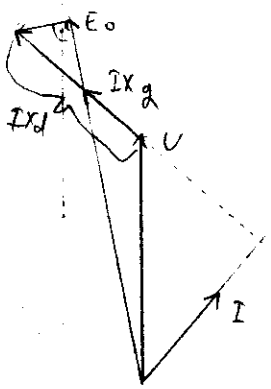
$\frac{a}{\sin\alpha} = \frac{b}{\sin\beta} = \frac{c}{\sin\gamma}$

$E_0^2 = U_n^2 + (IX_d)^2 - 2U_n IX_d \cos\beta$



→ cos φ kap.

HIDROGENERATOR: - izražene su reaktancije u d i q osi → X_d i X_q



$tg\,\psi = \frac{IX_q + U_n \sin\varphi}{U_n \cos\varphi} \Rightarrow \psi$

$E_0 = \sqrt{(U_n - (IX_q \cos\psi)^2} + IX_d \sin\psi$

RAZVIJENA SNAGA I MOMENT

$$\underline{P} = \frac{\underline{E}_{oph} \cdot \underline{U}_n}{\underline{X}_d} \cdot \sin\delta + \frac{U_n^2}{2}\left(\frac{1}{\underline{X}_q} - \frac{1}{\underline{X}_d}\right)\sin 2\delta$$

$\cos 2\alpha = 2\cos^2\alpha - 1$

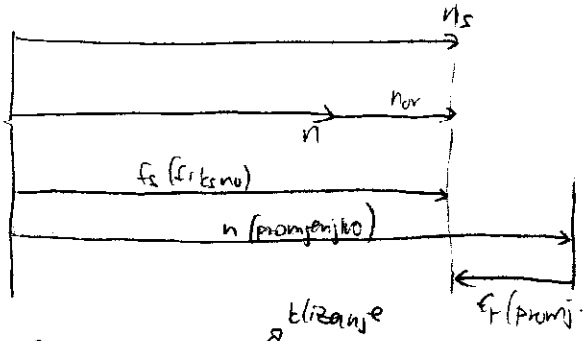
MAX snaga: $\frac{dP}{d\delta} = 0 \Rightarrow \delta_{pr}$ (prekretno)

reluktantna snaga

$$P_{pr} = \underline{P}_{pr} \cdot S_n$$

$$\left.\begin{aligned} \underline{I}_d X_d &= U_n \cos\delta \\ \underline{I}_q X_q &= U_n \sin\delta \end{aligned}\right\} \quad I = \sqrt{I_d^2 + I_q^2}$$

ASINKRONI MOTORI



- stat. i rot polje se vrte istom brzinom
- ukupna brzina vrtnje rotorskog polja u odnosu na jednu fiksnu točku statora (n_s) je zbroj brzine obretnog polja rotora u odnosu na rotor (n_{or}) i brzine rotora na jednu fiksnu točku statora

$n_s = \frac{60 f_s}{p}$ [min^{-1}] $s = \frac{n_s - n}{n_s}$ (klizanje) → razlika brzine vrtnje rotora n i obretnog polja n_s

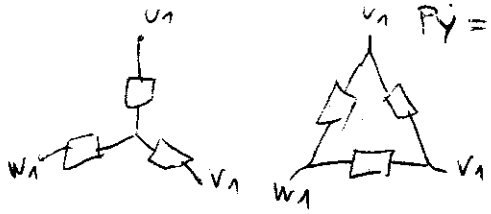
$f_r = s \cdot f_s$ → frek. rotorskih struja → može biti < 0

$n_{r,rotor} = n_s - n_{rotor}$ (n_{or}, n)
↳ brzina v. obr. projecanja rotora v odnosu na rotor

$n_{r,statora} = n_{r\,rotor} + n_{rotor}$ (n_s)
↳ obr. projecanja rel. v odn. na stator

$n_{rs} = n_{r,statora} - n_{s,statora}$
↳ rot. projecanja v odnosu na statorsko

Snaga: $P = \sqrt{3} \cdot U_l \cdot I_l \cdot \cos\varphi$ $P_\Delta = \sqrt{3} \cdot U_f \cdot \sqrt{3} \cdot I_f = 3 U_f I_f \cos\varphi$

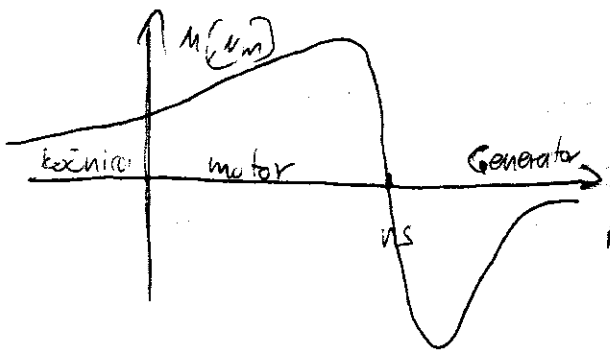


$P_Y = \sqrt{3} \cdot \sqrt{3} \cdot U_f \cdot I_f = 3 U_{f\Delta} I_{fY}$

$M_{tY} = M_{t\Delta} \cdot \left(\frac{U_{fY}}{U_{f\Delta}}\right)^2$

- Pregrijavanje namota Δ ili Y → provjeriti fazne struje. Ako su iste, nema pregrijavanja

GEN-MOT-EOČ:

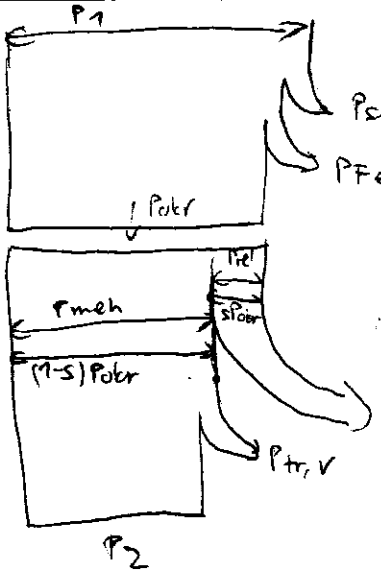


$n_s = \frac{60 f_s}{p}$

JALOVA SNAGA:

Prek $Q = 3 \cdot U \cdot I \cdot \sin\varphi$

Gubici:



P_{otr} - snaga obrtnog magnetskog polja

P_{rel} → gubici u namotu (rotorski gubici)

P_1 - snaga iz mreže

P_2 → snaga na osovini

P_{el} → gubici namotaja statora

P_{fes} → gubici u Fe statoru

P_{gs} → ukupni stat. gub.

Moment na osovini: $M_{2n} = \frac{P_{2n}}{n_n \cdot \pi} \cdot 30$

$P_{1n} = \sqrt{3} U_1 \cdot \cos\varphi$

P_{2n} → zadano u zadatku

$\eta = \frac{P_2}{P_1}$

$P = M \cdot \omega = \frac{n_n \pi}{30}$

Mala klizanja: $\frac{R_r}{s_n} \gg X_{\sigma r}$

napon između kliznih kolutova

Struja faze rotora: $I_{r\xi} = \frac{E_{ro}}{\sqrt{3}\sqrt{\left(\frac{R_r}{s}\right)^2 + X_{\sigma r,0}^2}}$

otpor rotora po fazi

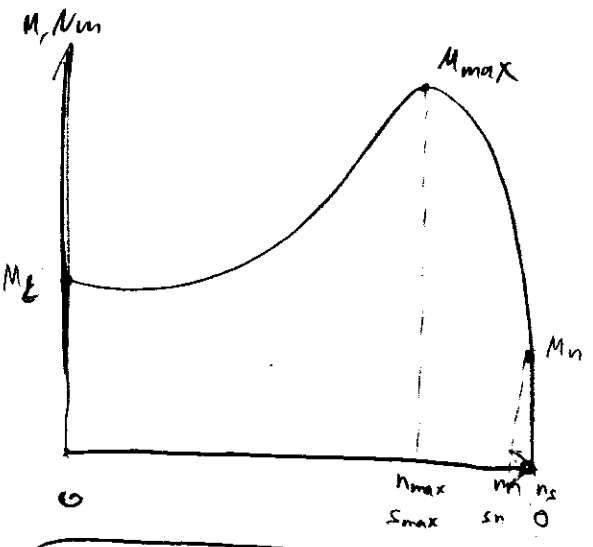
$R_r = \frac{R_{s+}}{2}$ → otpor između kliznih kolutova rotora

~~(otpor između statorskih)~~

$\Rightarrow P_{rel} = 3 \cdot I_r^2 \cdot R_r$

$E_{ro,f} = \frac{E_{ro}}{\sqrt{3}}$

- kavezni motor: $p = 2$ (4-polni) → kolutni isto
- nazivni podaci $\Rightarrow P_{2n}$



Elektromagnetski moment: $M_{em} = \frac{P_{otr}}{n_s \cdot \pi} \cdot 30$

kratki spoj:

[redacted] $P_{sel} = \frac{3}{2} I_s^2 \cdot R_{s+}$

$M_\xi + M_{tr} = \frac{P_{rel}}{n_s \pi} \cdot 30$

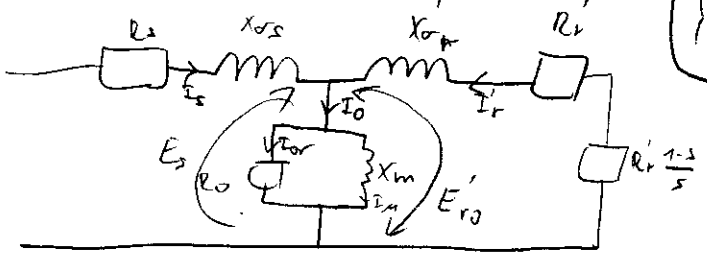
nazivni napon (preračunavanje):

$I_{\xi n} = I_\xi \cdot \frac{U_n}{U_\xi}$ $P_{\xi n} = P_\xi \left(\frac{U_n}{U_\xi}\right)^2$

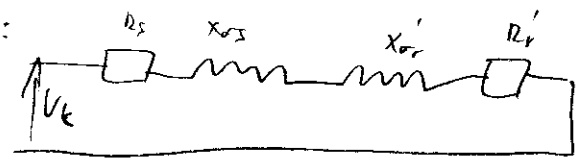
$P_{reln} = P_{\xi n} - \frac{3}{2} I_{\xi n}^2 R_{s+}$ $M_{\xi n} = M_\xi \cdot \left(\frac{U_n}{U_\xi}\right)^2$

$M_{\xi n} + M_{tr,r} = \frac{P_{reln}}{n_s \pi} \cdot 30$

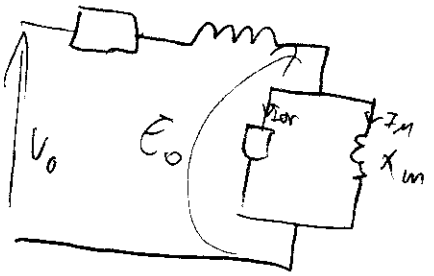
PH i ES:



ES:



PH:



KS: $R_k = R_s + R_r'$

$P_k = 3 I_k^2 R_k = 3 I_k^2 (R_s + R_r')$, $I_k = \frac{I_{vl}}{\sqrt{3}}$ (Y ili Δ)

$z_k = \frac{U_k}{I_k}$ $\quad x_k = \sqrt{z_k^2 - R_k^2}$ $\quad X_{\sigma s} = X_{\sigma r}' = \frac{X_k}{2}$

NAPOMENA: kod P.H. bilo AM, bilo TRAFOA, računa se sa naponima, a ne strujama ▽ 0

PH: $I_0 = \frac{I_{vl}}{\sqrt{3}}$ (Y ili Δ) ; $z_0 = \frac{U_0}{I_0}$

$P_0' = P_0 - 3 I_0^2 R_s$ → uzi gubici P.H. → PFe i Pmeh

$E_0 \approx U_0 - I_0 X_{\sigma s}$

$P_{Fe} = 3 \frac{E_0^2}{R_0}$; $I_{0r} = \frac{E_0}{R_0}$; $I_M = \sqrt{I_0^2 - I_{0r}^2}$ (÷√3 → Δ)

→ R_0 = ?

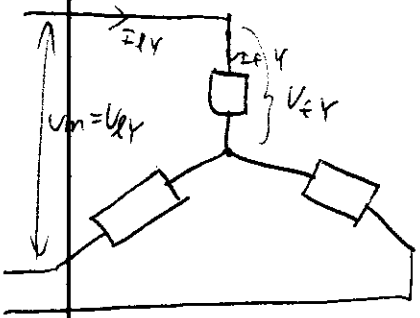
$X_m = \frac{E_0}{I_M}$

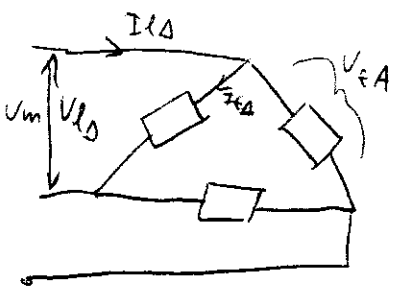
- kod PH se R_s zanemaruje

općenito kod nad. shema:

$\vec{I}_s = I_n \cos\varphi + j I_n \sin\varphi \Rightarrow \vec{I}_r = -\vec{I}_0 + \vec{I}_s$

Klossova jednadžba (pojednostavljen oblik): $\frac{M_n}{M_{max}} = \frac{2}{\frac{s_n}{s_{max}} + \frac{s_{max}}{s_n}}$





$U_{f\Delta} = U_{l\Delta} = U_m$

$I_{f\Delta} = \frac{I_{l\Delta}}{\sqrt{3}}$

$U_{fY} = \frac{U_{lY}}{\sqrt{2}} = \frac{U_m}{\sqrt{3}}$

$I_{fY} = I_{lY}$

$U_{lY} = U_{l\Delta}$

$\frac{I_{fY}}{I_{f\Delta}} = \frac{U_{fY}}{U_{f\Delta}} = \frac{1}{\sqrt{3}}$

$\frac{I_{lY}}{I_{l\Delta}} = \frac{I_{fY}}{\sqrt{3} I_{f\Delta}} = \frac{1}{3} \Rightarrow I_{lY} = \frac{1}{3} I_{l\Delta}$

PRESPAJANJA
Y → Δ

Zadovoljan potrošač, to je naš cilj !

Potezna stvar => **Tkn**

2. DIO

- ako se v rotorske krugove dodaju vanjski otpori: $I_{or} = konst$

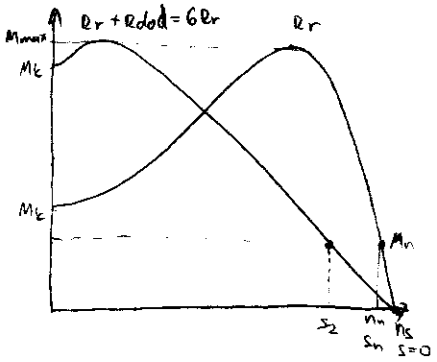
- Moment kojim je motor opterećen: $\frac{M_n}{s_n} = \frac{M_1}{s_1}$

- Naponsko-frekv. pretvarač: $n_s - n_1 = n_{s2} - n_2$

$$P_{rel} = s \cdot P_{okr} = s\frac{P_{meh}}{1-s} \approx \frac{s}{1-s} P_2 = \frac{s}{1-s} M_2 \omega_2 = \frac{s}{1-s} M_2 \omega_s (1-s) = s M_2 \frac{n_s \pi}{30}$$

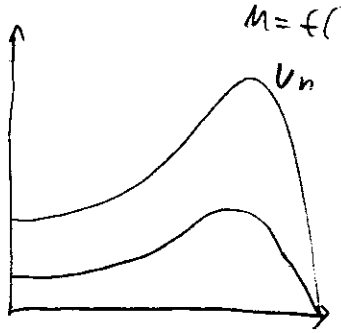
DODAVANJE OTPORA:

$$I_r = konst = \frac{E_{ro}}{\sqrt{\left(\frac{R_r}{s_1}\right)^2 + X_\sigma^2}} = \frac{E_{ro}}{\sqrt{\left(\frac{R_r + R_{dod}}{s_2}\right)^2 + X_\sigma^2}} \Rightarrow \frac{R_r}{s_1} = \frac{R_r + R_{dod}}{s_2}$$

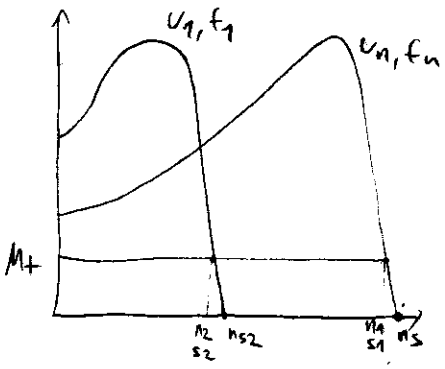


smanjenje napona -> moment je proporcionalan na^2

$M = f(U^2)$



smanjenje U i f $\left(\frac{U}{f} = konst\right)$



$$\frac{M_n}{s_n} = \frac{M_1}{s_1}$$

$$n_s - n_1 = n_{s2} - n_2$$