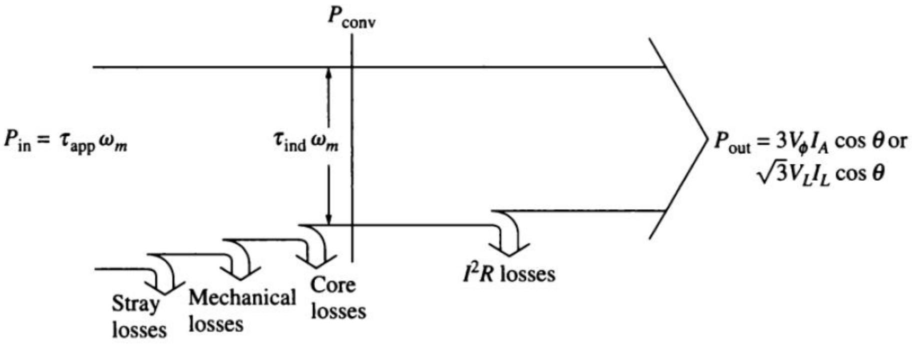
Magnetic Circuits & Linear DC Machine	Transformers
$\mathcal{F} = \phi \mathcal{R}$ $\quad \mathcal{R} = \frac{l_c}{\mu A}$ $\quad B = \mu H = \frac{\mu N i}{l_c}$	$\frac{\mathbf{V}_P}{\mathbf{V}_S} = a$ $\quad \frac{\mathbf{I}_P}{\mathbf{I}_S} = \frac{1}{a}$
$e_{\text{ind}} = (\mathbf{v} \times \mathbf{B}) \bullet \mathbf{l}$ $\quad \mathbf{F} = i(\mathbf{l} \times \mathbf{B})$	$\text{VR} = \frac{V_{S,\text{nl}} - V_{S,\text{fl}}}{V_{S,\text{fl}}} \times 100\%$ $\quad \eta = \frac{P_{\text{out}}}{P_{\text{out}} + P_{\text{loss}}} \times 100\%$
As Generator: $e_{\text{ind}} = V_B + iR$ **As Motor:** $e_{\text{ind}} = V_B - iR$	$\mathbf{V}_P = \mathbf{V}_S' + \mathbf{I}_S'\left(R_{\text{eq}} + jX_{\text{eq}}\right)$ $\mathbf{V}_S' = a\mathbf{V}_S$ $\quad \mathbf{I}_S' = \frac{\mathbf{I}_S}{a}$ $\text{VR} = \frac{V_P - aV_S}{aV_S} \times 100\%$ Referred to primary*
	$\mathbf{V}_P' = \mathbf{V}_S + \left(R_{\text{EQ}} + jX_{\text{EQ}}\right)\mathbf{I}_S$ $\mathbf{V}_P' = \frac{\mathbf{V}_P}{a}$ $\text{VR} = \frac{V_P/a - V_{S,\text{fl}}}{V_{S,\text{fl}}} \times 100\%$ No load voltage: referred to secondary*

Autotransformers	Three-phase Transformers
$\frac{\mathbf{V}_L}{\mathbf{V}_H} = \frac{N_C}{N_{\text{SE}} + N_C}$ $\quad \frac{\mathbf{I}_L}{\mathbf{I}_H} = \frac{N_{\text{SE}} + N_C}{N_C}$ $\frac{S_{\text{IO}}}{S_W} = \frac{N_{\text{SE}} + N_C}{N_{\text{SE}}}$	$\frac{V_{\text{LP}}}{V_{\text{LS}}} = \frac{\sqrt{3}V_{\phi P}}{\sqrt{3}V_{\phi S}} = a$ $\quad$ Y−Y $\frac{V_{\text{LP}}}{V_{\text{LS}}} = \frac{V_{\phi P}}{V_{\phi S}} = a$ $\quad$ Δ−Δ
When ‘transforming’ (hehe) a simple transformer to a step up/down autotransformer, use the rated power of the original transformer as S_W, i.e., the power in the windings	$\frac{V_{\text{LP}}}{V_{\text{LS}}} = \sqrt{3}a$ $\quad$ Y−Δ
The effective per-unit impedance of autotransformers is decreased by the power advantage factor, i.e., $\frac{S_{IO}}{S_W}$	$\frac{V_{\text{LP}}}{V_{\text{LS}}} = \frac{a}{\sqrt{3}}$ $\quad$ Δ−Y
	$Z_{\text{base}} = \frac{3(V_{\phi,\text{base}})^2}{S_{\text{base}}}$ $\quad I_{L,\text{base}} = \frac{S_{\text{base}}}{\sqrt{3}V_{L,\text{base}}}$

AC Machinery
$\theta_{se} = \frac{P}{2}\theta_{sm}$ $\quad f_{se} = \frac{P}{2}f_{sm}$ $\quad \omega_{se} = \frac{P}{2}\omega_{sm}$ $\quad f_{se} = \frac{n_{sm}P}{120}$
$i_{aa'}(t) = I_M \sin \omega t$ A $\quad \mathbf{B}_{aa'}(t) = B_M \sin \omega t \angle 0°$ T $i_{bb'}(t) = I_M \sin(\omega t - 120°)$ A $\quad \mathbf{B}_{bb'}(t) = B_M \sin(\omega t - 120°) \angle 120°$ T $i_{cc'}(t) = I_M \sin(\omega t - 240°)$ A $\quad \mathbf{B}_{cc'}(t) = B_M \sin(\omega t - 240°) \angle 240°$ T   To reverse direction of rotating magnetic field, swap any two of the three phases*

$$e_{\text{ind}} = \phi_{\max}\omega \sin \omega t \qquad E_{\max} = N_C \phi \omega \qquad E_A = \sqrt{2}\pi N_C \phi f$$

$$\tau_{\text{ind}} = k\mathbf{B}_R \times \mathbf{B}_S \qquad \tau_{\text{ind}} = kB_R B_{\text{net}} \sin \delta$$



Generator power flow*

$$\text{VR} = \frac{V_{\text{nl}} - V_{\text{fl}}}{V_{\text{fl}}} \times 100\% \qquad \text{SR} = \frac{n_{\text{nl}} - n_{\text{fl}}}{n_{\text{fl}}} \times 100\%$$

Synchronous Generator

$$E_A = \sqrt{2}\pi N_C \phi f \qquad E_A = K\phi\omega \qquad K = \frac{N_c}{\sqrt{2}}$$

$$\mathbf{V}_\phi = \mathbf{E}_A - jX_S\mathbf{I}_A - R_A\mathbf{I}_A \qquad P_{\text{conv}} = \frac{3V_\phi E_A}{X_S}\sin\delta$$

$$P_{\max} = \frac{3V_\phi E_A}{X_S} \qquad \tau_{\text{ind}} = \frac{3V_\phi E_A}{\omega_m X_S}\sin\delta$$

Static stability limit

$$Z_S = \sqrt{R_A^2 + X_S^2} = \frac{E_A}{I_A} = \frac{V_{\phi,oc}}{I_A} \qquad 2R_A = \frac{V_{\text{DC}}}{I_{\text{DC}}} \qquad \frac{\mathbf{2}}{\mathbf{3}}R_A = \frac{V_{\text{DC}}}{I_{\text{DC}}}$$

Y-Connected **Δ-Connected**

Identifying synchronous generator's parameters*

$$P = s_p\left(f_{nl} - f_{sys}\right) \qquad Q = s_p\left(V_{T,nl} - V_{T,fl}\right)$$

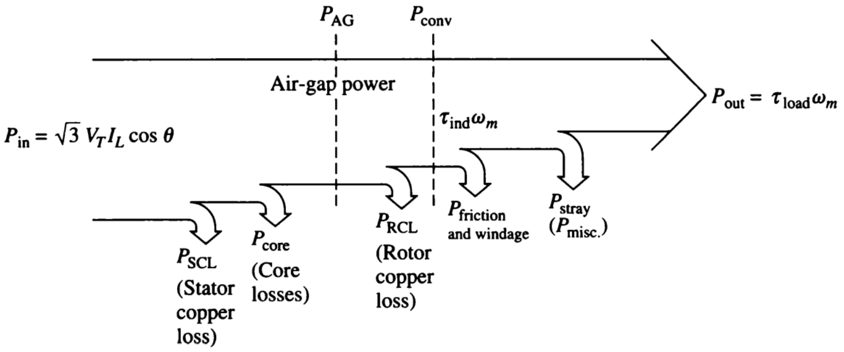
Adjusting governor set points adjusts f, and hence control the real power supplied by the generator

Adjusting field current adjusts V_T, and hence controls the reactive power supplied by the generator

Induction Motors

$$n_{\text{slip}} = n_{\text{sync}} - n_m \qquad s = \frac{n_{\text{sync}} - n_m}{n_{\text{sync}}}(\times 100\%) \qquad n_m = (1 - s)n_{\text{sync}}$$

$$f_{re} = sf_{se} \qquad f_{re} = \frac{P}{120}(n_{\text{sync}} - n_m)$$



$$P_{\text{RCL}} = 3I_2^2 R_2 \qquad P_{\text{SCL}} = 3I_1^2 R_1 \qquad P_{\text{conv}} = 3I_2^2 R_2\left(\frac{1-s}{s}\right)$$

$$P_{\text{core}} = 3E_1^2 G_C \qquad P_{\text{AG}} = 3I_2^2 \frac{R_2}{s}$$

$$P_{\text{RCL}} = sP_{\text{AG}} \qquad P_{\text{conv}} = (1-s)P_{\text{AG}} \qquad \tau_{\text{ind}} = \frac{P_{\text{conv}}}{\omega_m} = \frac{P_{\text{AG}}}{\omega_{\text{sync}}}$$

$$V_{\text{TH}} = V_\phi \frac{X_M}{\sqrt{R_1^2 + (X_1 + X_M)^2}} \qquad V_{\text{TH}} \approx V_\phi \frac{X_M}{X_1 + X_M}$$

$$R_{\text{TH}} \approx R_1 \left(\frac{X_M}{X_1 + X_M}\right)^2 \qquad X_{\text{TH}} \approx X_1$$

$$\tau_{\text{ind}} = \frac{3V_{\text{TH}}^2 R_2/s}{\omega_{\text{sync}}[(R_{\text{TH}} + R_2/s)^2 + (X_{\text{TH}} + X_2)^2]} \qquad s_{\max} = \frac{R_2}{\sqrt{R_{\text{TH}}^2 + (X_{\text{TH}} + X_2)^2}}$$

$$\tau_{\max} = \frac{3V_{\text{TH}}^2}{2\omega_{\text{sync}}[R_{\text{TH}} + \sqrt{R_{\text{TH}}^2 + (X_{\text{TH}} + X_2)^2}]}$$

Maximum torque occurs at a point (s_{max}) independent of change in V_T*
Maximum torque value is independent of change in rotor resistance R_2*

No-Load Test

$$P_{\text{in}} = 3I_1^2 R_1 + P_{\text{rot}}$$

$$P_{\text{rot}} = P_{\text{core}} + P_{\text{F\&W}} + P_{\text{misc}}$$

$$|Z_{\text{eq}}| = \frac{V_\phi}{I_{1,\text{nl}}} \approx X_1 + X_M$$

DC Test

$$2R_A = \frac{V_{\text{DC}}}{I_{\text{DC}}} \quad \textbf{Y-Connected}$$

$$\frac{2}{3} R_A = \frac{V_{\text{DC}}}{I_{\text{DC}}} \quad \boldsymbol{\Delta}\textbf{-Connected}$$

$$\text{PF} = \cos\theta = \frac{P_{\text{in}}}{\sqrt{3}V_T I_L}$$

Locked-Rotor Test

$$|Z_{\text{LR}}| = \frac{V_\phi}{I_1} = \frac{V_T}{\sqrt{3}I_L}$$

$$Z_{\text{LR}} = R_{\text{LR}} + jX'_{\text{LR}} = |Z_{\text{LR}}|\cos\theta + j|Z_{\text{LR}}|\sin\theta$$

$$R_{\text{LR}} = R_1 + R_2$$

$$X_{\text{LR}} = \frac{f_{\text{rated}}}{f_{\text{test}}} X'_{\text{LR}} = X_1 + X_2$$

DC Test: R_A is R_1*

	X_1 and X_2 as functions of X_{LR}	
Rotor Design	X_1	X_2
Wound rotor	$0.5\ X_{LR}$	$0.5\ X_{LR}$
Design A	$0.5\ X_{LR}$	$0.5\ X_{LR}$
Design B	$0.4\ X_{LR}$	$0.6\ X_{LR}$
Design C	$0.3\ X_{LR}$	$0.7\ X_{LR}$
Design D	$0.5\ X_{LR}$	$0.5\ X_{LR}$

DC Machines

$$e_{\text{ind}} = \frac{2}{\pi}\phi\omega_m \qquad \tau_{\text{ind}} = \frac{2}{\pi}\phi i$$

Armature loss: $P_A = I_A^2 R_A$

Field loss: $P_F = I_F^2 R_F$

$$\frac{E_{A2}}{E_{A1}} = \frac{K'\phi n_{m2}}{K'\phi n_{m1}}$$

Seprately Excited and Shunt DC Motor

Separately excited:

$$I_F = \frac{V_F}{R_F}$$
$$V_T = E_A + I_A R_A$$
$$I_L = I_A$$

Shunt:

$$I_F = \frac{V_T}{R_F}$$
$$V_T = E_A + I_A R_A$$
$$I_L = I_A + I_F$$

$$\omega_m = \frac{V_T}{K\phi} - \frac{R_A}{(K\phi)^2}\tau_{\text{ind}}$$

Series DC Motor

$$I_A = I_S = I_L$$
$$V_T = E_A + I_A(R_A + R_S)$$
$$\omega_m = \frac{V_T}{\sqrt{Kc}}\frac{1}{\sqrt{\tau_{\text{ind}}}} - \frac{R_A + R_S}{Kc}$$

Compound DC Motor

$$V_T = E_A + I_A(R_A + R_S)$$
$$I_A = I_L - I_F$$
$$I_F = \frac{V_T}{R_F}$$
$$I_F^* = I_F \pm \frac{N_{SE}}{N_F} I_A - \frac{\mathscr{F}_{AR}}{N_F}$$

See characteristic curves from book*

Separately Excited DC Generator

$$I_L = I_A$$
$$V_T = E_A - I_A R_A$$
$$I_F = \frac{V_F}{R_F}$$
$$I_F^* = I_F - \frac{\mathscr{F}_{AR}}{N_F}$$

Shunt DC Generator

$$I_A = I_F + I_L$$
$$V_T = E_A - I_A R_A$$
$$I_F = \frac{V_T}{R_F}$$

Series DC Generator

$$I_A = I_S = I_L$$
$$V_T = E_A - I_A(R_A + R_S)$$

Compound DC Generator

$$I_A = I_L + I_F$$
$$V_T = E_A - I_A(R_A + R_S)$$
$$I_F = \frac{V_T}{R_F}$$
$$\mathscr{F}_{\text{net}} = N_F I_F \pm N_{SE} I_A - \mathscr{F}_{AR}$$

See characteristic curves from book*

You made it this far! Good luck with your exams! ❤️

- Arctic Monkeys makes banger songs
- KitKat >> any chocolate
- Made by me! I should go sleep …