Electrical Machines (I)

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Summary

* First Material:

CHAPTER (1):

Amper's law: $\oint \vec{H} \cdot d\vec{l} = Ni$

$\boxed{H l_c = Ni}$

Total flux: $\phi = \int B \cdot dA$

$\boxed{\phi = BA} \rightarrow B = \mu H$

$Ni = \phi \mathcal{R}$, $\mathcal{R} = \frac{l}{\mu A}$

* Magnetic ccts using airgab:

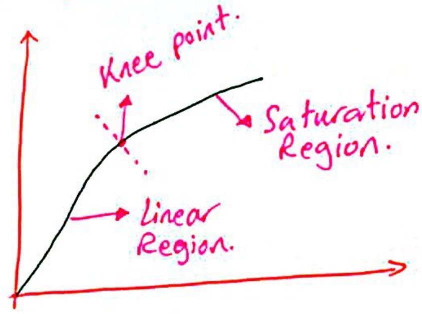
$\boxed{B_g = \frac{\phi}{A_g}}$, $\boxed{B_c = \frac{\phi}{A_c}}$

$A_g = \text{factor} * A_c$

if $A_c = a * b$

$\boxed{A_g = [a+g] * [b+g]}$

* Magnetization curve "B-H curve":



* Area of Hysteresis loop represent: Energy Density

$A_h \equiv J/m^3$

* Core Losses:

$P_c = P_h + P_e$

P_h → Hysteresis losses.

P_e → Eddey current losses.

$\Rightarrow$ $P_h = f A_h V$

$A_h = B_m^n K_h$

$\boxed{P_e = V K_e B_m^2 f^2 \tau^2}$

Stacking Factor: $\equiv \frac{\text{volume of ferromagnetic material}}{\text{Total volume of the core.}}$

* Self Inductance:

$$e = -N \frac{d\phi}{dt}$$

$$\boxed{L = \frac{N^2}{\mathcal{R}} = \frac{N^2 \mu A}{l}}$$

* For a 4-poles Machine:

$$NI = H_P L_P + H_g L_g + \frac{1}{2} H_R L_R + \frac{1}{2} H_y L_y$$

$H_P, H_R, H_y \Rightarrow$ from B-H curve.

$H_g \Rightarrow B_g$ given $\Rightarrow B_g = \mu_0 H_g$.

CHAPTER (2):

Transformer: → Power Transformer. / → Instrument Transformer.

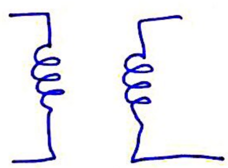
Classification of Transformer: Unit Trans. ⟶ Substation Trans. ⟶ Distribution Trans.

* Turns Ratio $\boxed{(a) = \frac{V_P}{V_S} = \frac{e_P}{e_S} = \frac{i_S}{i_P} = \frac{N_P}{N_S}}$

* $\boxed{|S_S| = |S_P| \quad P_P = P_S}$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_P}{P_S} = \frac{P_S}{P_P} = 1 = 100\%$$

$\boxed{Z_P = \frac{V_P}{I_P}}$, $\boxed{Z_S = \frac{V_S}{I_S}}$, $Z_P = a^2 Z_S$



Reflect to a side $* a^2$ ⟵ $a:1$ ⟶ Reflect to 1 side $/ a^2$.

Linkage flux $(\lambda) = \sum_{i=1}^{N} \phi_i$

Average flux $\bar{\phi} = \frac{\lambda}{N}$

$\Rightarrow e = \frac{d\lambda}{dt} = N\frac{d\bar{\phi}}{dt}$

for primary:

$$\bar{\phi}_P = \phi_m + \phi_{LP}$$

$$e_P = \underbrace{N_P * \frac{d\phi_m}{dt}}_{e_{pm}} + \underbrace{N_P * \frac{d\phi_{LP}}{dt}}_{e_{PL}}$$

$e_P = e_{Pm} + e_{PL}$

for secondary:

$$\bar{\phi}_s = \phi_m + \phi_{Ls}$$

$$e_s = \underbrace{N_s\frac{d\phi_m}{dt}}_{e_{sm}} + \underbrace{N_s\frac{d\phi_{Ls}}{dt}}_{e_{sL}}$$

$e_s = e_{sm} + e_{sL}$

$$\frac{e_{pm}}{e_{sm}} = \frac{N_P}{N_s}$$

※ No-load:

*losses in practical transformer:

$$\text{Losses} = P_h + P_e + i_P^2 R_P.$$

$$i_P = i_m + i_c$$

* P_e is max. when $\phi = 0$.

$i_{ext} = I_{m_1}\cos\omega t + I_{m_2}\cos 2\omega t + I_{m_3}\cos 3\omega t + \ldots$

if +ve & -ve cycles Identical:

$i_{ext} = I_{m_1}\cos\omega t + I_{m_3}\cos 3\omega t + I_{m_5}\cos 5\omega t + \ldots$

if we have: $a:1$

reflect to primary:

$$R_{eq} = R_p + a^2 R_s$$
$$X_{eq} = X_p + a^2 X_s$$

reflect to secondary:

$$R_{eq} = R_s + \frac{R_p}{a^2}$$
$$X_{eq} = X_s + \frac{X_p}{a^2}$$

$$Z_{eq} = R_{eq} + j X_{eq}.$$

*** S/C Test:**

we find R_{eq} & X_{eq}.

find R_{eq} from:

$$\boxed{P_{sc} = I_{sc}^2 R_{eq}}$$

find X_{eq} from:

$$|Z_{eq}| = \frac{|V_{sc}|}{|I_{sc}|} = \sqrt{R_{eq}^2 + X_{eq}^2}$$

or using:

$$Z_{eq} = |Z_{eq}| \angle \theta \qquad \theta = \cos^{-1}\left(\frac{P_{sc}}{I_{sc} V_{sc}}\right)$$
$$= R_{eq} + j X_{eq}.$$

*** O/C Test:**

we find R_c & X_m.

find R_c from:

$$\boxed{P_{oc} = V_{oc}^2 / R_c}$$

find X_m from:

$$|Y| = \frac{|I_{oc}|}{|V_{oc}|} = \sqrt{\left(\frac{1}{R_c}\right)^2 + \left(\frac{1}{X_m}\right)^2}$$

or using:

$$Y = |Y| \angle -\theta \qquad \theta = \cos^{-1}\left(\frac{P_{oc}}{I_{oc} V_{oc}}\right)$$
$$= \frac{1}{R_c} - j\frac{1}{X_m}$$

*** PU system:**

$$\text{PU value} = \frac{\text{Actual value}}{\text{Base value}}$$

usually we select V & S as a base values.

$$\boxed{Z_{new}(PU) = Z_{old}(PU) * \left(\frac{V_{old}}{V_{new}}\right)^2 * \left(\frac{S_{new}}{S_{old}}\right)}$$

※ Second Material:

*** voltage regulation:**

$$V_R\% = \frac{|V_L(NL)| - |V_L(FL)|}{|V_L(FL)|} * 100\%$$

* for inductive & resistive:

$|E_s| > |V_s| \Rightarrow VR$ +ve.

* for capacitive:

$|E_s| < |V_s| \Rightarrow VR$ −ve.

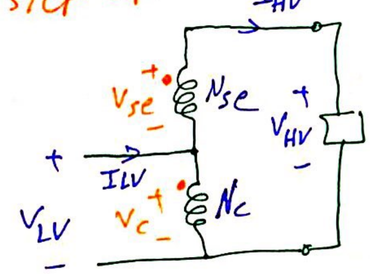
*** efficiency:**

$$\eta = \frac{output}{input}$$

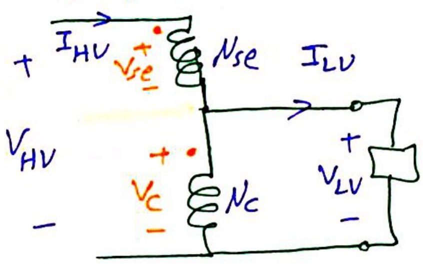
input = output + losses (electrical, core).

*** AutoTransformer:**

step-up:



step-down:



$$I_{HV} = I_{se} + I_c$$

$$S_i = S_o$$

$$I_c N_c = I_{se} N_{se}$$

$$\frac{V_c}{V_{se}} = \frac{N_c}{N_{se}}$$

$$\frac{V_{HV}}{V_{LV}} = \frac{I_{LV}}{I_{HV}} = \frac{N_{se} + N_c}{N_c}$$

$$\boxed{\frac{S_{io}}{S_w} = \frac{N_c + N_{se}}{N_{se}}}$$

*** relation between $Zeq_{conv.}(PU)$ & $Zeq_{Auto}(PU)$:**

$$Zeq_{Auto}(PU) = Zeq_{conv}(PU) \Big/ \left(\frac{N_c + N_{se}}{N_{se}}\right)$$

***

* inrush current:

Very high current >> I_{rated}

under condition:

$\phi = 2\phi_m$; $\phi_m = \frac{V_m}{N\omega}$

@ $V=0$ when $t=0$.

* 3 phase:

Y-Y & Δ-Δ: $\boxed{\frac{V_L}{V_\ell} = a}$

Y-Δ: $\boxed{\frac{V_L}{V_\ell} = \sqrt{3}\,a}$

Δ-Y: $\boxed{\frac{V_L}{V_\ell} = \frac{a}{\sqrt{3}}}$

⇒ 4 possible cases of phase shift: 0, 180°, −30°, 30°

12:00, 6:00, 1:00, 11:00

in +ve seq.: HV leads by 30° LV.

in −ve seq.: HV lags by 30° LV.

* ratio of line voltages:

effective turns ratio: $a_{eff} = \frac{V_{LL}}{V_{\ell\ell}} = \frac{N_H}{N_L/\sqrt{3}}$ in Y-Δ.

* O/C Test: $\boxed{P_{oc} = \frac{W_1+W_2}{3}}$, $\boxed{V_{oc} = \frac{V}{\sqrt{3}}}$, $\boxed{I_{oc} = \text{Ammeter reading}}$

* S/C Test: $\boxed{P_{sc} = \frac{W_1+W_2}{3}}$, $\boxed{V_{sc} = \frac{V}{\sqrt{3}}}$, $\boxed{I_{sc} = |I|_{rated} = \text{Ammeter reading}}$

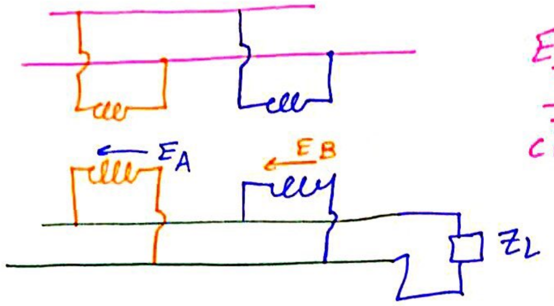
Conventional:
- O/C : rated voltage $= V_{oc}$.
- S/C : rated current $= I_{sc}$

* 3-ph PU:

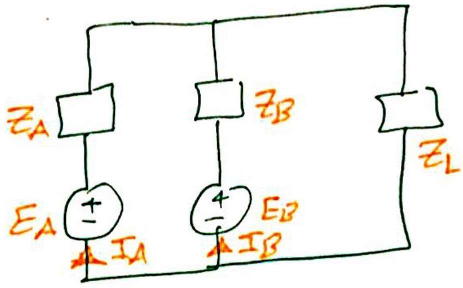
$S_{1\phi} = \frac{S_{3\phi}}{3}$ $V_{1\phi} = \frac{V_{LL}}{\sqrt{3}}$

$Z_b = \frac{V_{LL}^2}{S_{3\phi}}$

* Parallel operation:



Equivalent circuit $\Longrightarrow$



$$\boxed{I_A = \frac{E_A - V}{Z_A} \qquad I_B = \frac{E_B - V}{Z_B}}$$

$$V = \frac{\frac{E_A}{Z_A} + \frac{E_B}{Z_B}}{\frac{1}{Z_A} + \frac{1}{Z_B} + \frac{1}{Z_L}}$$

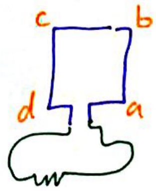
* if $E_A = E_B$:

$$I_A = I_L \frac{Z_B}{Z_A + Z_B} \quad \& \quad I_B = I_L \frac{Z_A}{Z_A + Z_B}$$

CHAPTER(3):

$$e \triangleq (v \times B) \cdot L$$

for a loop



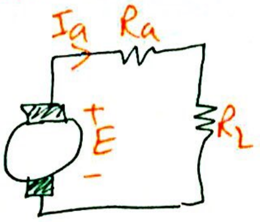
$$e = 2vBL \sin\theta_{ab}$$

$v = \omega \cdot r$ & $\phi = BA$

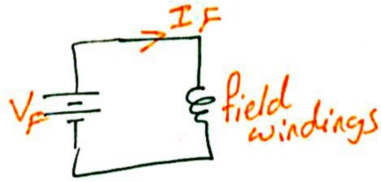
$$e = \omega \phi \sin\theta_{ab}$$

$E_m = 2vBL = \omega \phi_m$

* Armature circuit:



* Field circuit:



$$\tau = A B_s I_a \sin\theta = K (B_s \times B_R)$$

where K:

$$\boxed{K = \frac{A L}{\mu N}}$$

* Rotating Magnetic Field:

$$\boxed{\begin{aligned} i_a &= I_m \sin\omega t \\ i_b &= I_m \sin(\omega t - 120) \\ i_c &= I_m \sin(\omega t - 240) \end{aligned}}$$

$$\boxed{\begin{aligned} H_{aa'} &= H_m \sin\omega t \angle 0^\circ \\ H_{bb'} &= H_m \sin(\omega t - 120) \angle 120^\circ \\ H_{cc'} &= H_m \sin(\omega t - 240) \angle 240^\circ \end{aligned}}$$

$$\boxed{\begin{aligned} B_{aa'} &= B_m \sin(\omega t) \angle 0 \\ B_{bb'} &= B_m \sin(\omega t - 120) \angle 120^\circ \\ B_{cc'} &= B_m \sin(\omega t - 240) \angle 240^\circ \end{aligned}}$$

$$B_R = 1.5 B_m (\sin\omega t - j\cos\omega t)$$

$$\boxed{f_e = P f_m}$$

* Final Material:

* synch. AC gen.:

$$\Rightarrow A_P = \frac{2\pi r l}{P}$$

$$\boxed{e_{total} = 2 B_m l v \cos(\omega_m t)}$$

$$E_m = N \phi \omega_e$$

$$E_{m\,rms} = 4.44 \phi N f_e$$

$$\rightarrow E_{m\,rms} = 4.44 K_d K_p \phi N f_e$$

$$K_\omega = K_p K_d$$

$$\boxed{\begin{aligned} K_p &= \sin\left(\frac{\rho}{2}\right) \\ K_d &= \frac{\sin\left(\frac{n\gamma}{2}\right)}{n \sin(\gamma/2)} \end{aligned}}$$

ρ → coils pitch.

γ → slot pitch. $\left(\frac{360}{\#\text{ of slots}}\right)$.

n: number of phase belts. $= \boxed{\frac{\#\text{ of slots}}{3 * P}}$

P → number of poles.

$$\boxed{\begin{aligned} &\text{Pole pitch} = 180^\circ \text{ elec.} \\ &\text{Pole pitch} = \frac{360}{P} \text{ mech.} \end{aligned}}$$

P → # of poles.

* synch. Reactance:

$$X_s = X + X_a$$

$$\boxed{\begin{aligned} P_{in} &= P_{mech} = \tau_{app} \omega_m \\ P_{out} &= 3 V_\phi I_\phi \cos\theta = \sqrt{3} V I_\phi \cos\theta \\ P_{conv} &= 3 E I_\phi \cos\gamma = \sqrt{3} E I_\phi \cos\gamma \end{aligned}}$$

$$\rightarrow P_{conv} = \tau_{ind} \omega_m$$

* when R_a is neglected:

$$\boxed{\begin{aligned} P_{out} &= P_{conv}. \\ P_{out} &= \frac{3 V_\phi E \sin\delta}{X_s} \end{aligned}}$$

→ From it find τ_{ind}:

$$\tau_{ind} = P_{out}/\omega_m$$

* R_a & X_s :

DC/Test: $R_{a(DC)} = \frac{1}{2}\left(\frac{V.}{A.}\right) \implies R_{a(AC)} = \text{factor} * R_{a(DC)}$.

O/C Test: → vary I_F & take the voltmeter reading ≡ Generated voltage. (E)

S/C Test: → vary I_F & take the Ammeter reading $\equiv (I_a) \equiv \frac{E}{Z_{eq}}$.

we obtain X_s from: $X_s = \sqrt{|Z_{eq}|^2 - R_a^2}$

* SCR:

$\implies SCR = \frac{I_{F(O/C)}}{I_{F(S/C)}}$ also: $SCR = \frac{1}{X_s (PU)}$

$\boxed{\text{speed Droop} = \frac{n_{nL} - n_{fL}}{n_{fL}} * 100\%}$, $P = S_P (f_{nL} - f_{fL})$

* Housing Diagram:

$P_L = P_1 + P_2 \implies \boxed{P_L = S_{P_1}(f_{NL_1} - f_{sys}) + S_{P_2}(f_{NL_2} - f_{sys})}$

$f = n\,P$ → pair pole.

* Gen. Connected to ∞-system:

$P_\infty = P_L - P_1$.

* Armature windings:

Lap winding: $a = mP$ → Number of poles.

wave winding: $a = 2m$

simplex → $m = 1$
duplex → $m = 2$
Triplex → $m = 3$

* Voltage induced in DC gen.:

in a single turn: $e = \frac{P \phi \omega}{\pi}$

for voltage per path: $e = \frac{n P \phi Z}{a}$

* $\boxed{\tau_{ind} = \frac{P \phi I}{\pi}}$, $\boxed{\underset{\text{total Torque}}{T} = \frac{P \phi Z I_a}{2\pi a}}$

* For shunt Motor:

$$\underbrace{E I_a}_{\text{Converted power.}} = \underbrace{I V}_{\text{input power.}} - \underbrace{(I_a^2 R_a + I_F V_F)}_{\text{electrical Losses.}}$$

$$P_{conv} = E I_a = \tau_{ind} \cdot \omega_m$$

$$\tau_{ind} = \frac{E I_a}{\omega_m}$$

* speed Equation: $\boxed{\omega = \frac{V - I_a R_a}{K \phi}}$

$$\omega = \frac{V}{K\phi} - \frac{R_a}{KK'\phi^2} T$$

* speed Regulation:

$$SR = \frac{\omega_{nL} - \omega_{FL}}{\omega_{FL}}$$

* * *

Good * * *

* * * Luck.