First exam revision

#صلاح الدين حوراني#

* magnetic

$F \rightarrow$ (mmf) magnet-motive-force

ϕ magnetic flux

R_m reluctance

$$\phi = \frac{F}{R_m}$$

$$\Sigma \phi = 0$$

MecH-FAMiLY

* electric

$V \rightarrow$ (emf) electric-mutive-force

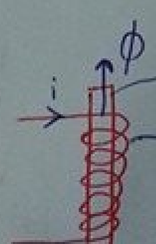
I current

R resistance

$$V = IR \longrightarrow I = \frac{V}{R}$$

$$\Sigma I = 0$$

* right hand rule



thumb with flux

hand orientation with current

$$F = \phi R_m = N(i)$$

* $F = N(i)$ [ampere . turn (A.t)]

* $R_m = \dfrac{l}{\mu_r \mu_0 A}$ $\left[\dfrac{A.t}{Wb}\right]$

* μ $\left[\dfrac{Wb}{A.t.m}\right]$

* ϕ [weber (Wb)]

* μ_r is the relative permibility $= \dfrac{\mu}{\mu_0}$ [unitless]

* μ_r for air $= 1$

* $\mu_0 = 4\pi \times 10^{-7}$ $\dfrac{Wb}{A.t.m}$

* losses

hysterisis loss

$$P_h = \underbrace{K_h}_{\text{volume dependent}} B_{max}^{n} f V$$

eddy-current loss

$$P_e = \underbrace{K_e}_{\text{thickness dependent}} B_{max}^{2} f^{2} V \frac{t^2}{\rho}$$

t – thickness

ρ – resistivity

to reduce eddy-current losses

① increase the resistivity of the material

② reduce the thickness of the material

* $\underbrace{P_{total}}_{P_{core}} = P_h + P_e$

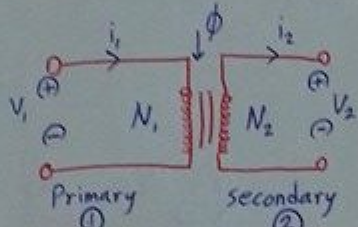
* if flux is given as a function of time $\phi = f(t)$

$$V = N\left(\frac{d\phi}{dt}\right)$$

$$\phi = \frac{1}{N}\underbrace{\int V.dt}_{\text{integration}}$$

integration = area under the curve

Transformers :-



$$\boxed{\text{turns ratio } (a) = \frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}}$$

$P = V_1 I_1 = V_2 I_2$ [volt. ampere (V.A)]
same to Watt (W)

* there are high voltage side and low voltage side

* $a = \frac{N_1}{N_2} > 1$ ⟶ primary is HV and secondary is LV

$(N_1 > N_2)$
(step down)

$a = \frac{N_1}{N_2} < 1$ ⟶ primary is LV and secondary HV

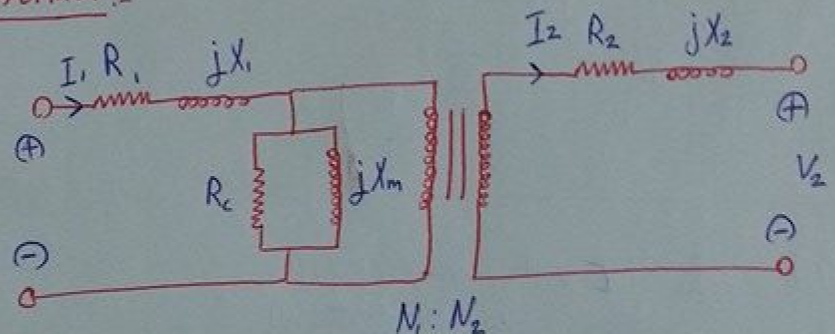
$(N_1 < N_2)$
(step up)

Example:-

①	②
2200 V	220
10 kVA	10 kVA
low current	high current

$$i_H = \frac{10{,}000}{2200} = \underline{\underline{\quad}}\ A < i_L = \frac{10{,}000}{220} = \underline{\underline{\quad}}\ A$$

Actual transformer:-



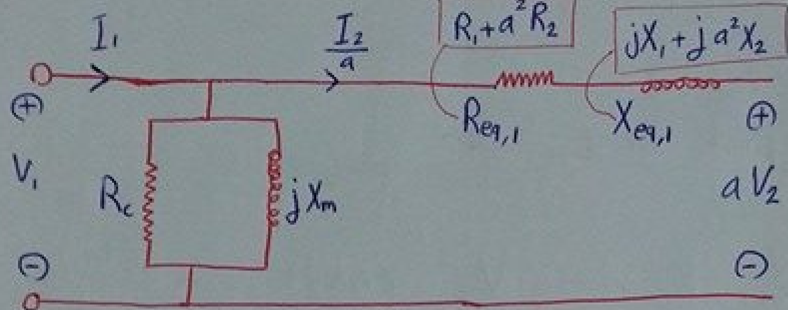
~~Referred to primary~~

$$a = \frac{V_1}{V_2} = \frac{I_1 R_1}{I_2 R_2} = \left(\frac{1}{a}\right)\left(\frac{R_1}{R_2}\right)$$

$$\boxed{a^2 = \frac{R_1}{R_2}}$$

referred to primary

$$I_1 = \frac{I_2}{a} \quad , V_1 = a V_2 \quad , N_1 = a N_2 \quad , R_1 = (a)^2 R_2$$



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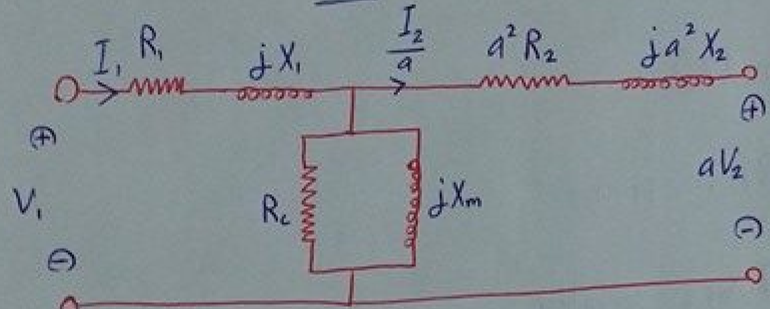
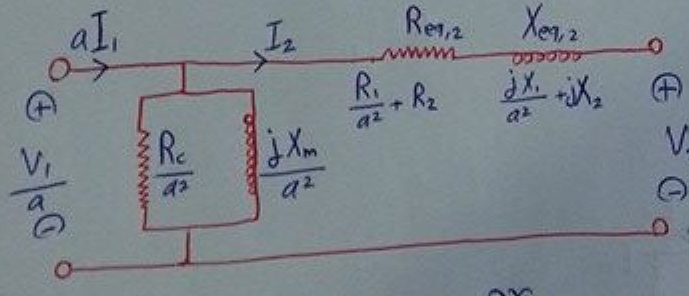


referred to secondary

$$I_2 = a I_1 \quad , V_2 = \frac{V_1}{a} \quad , N_2 = \frac{N_1}{a} \quad , R_2 = \frac{R_1}{a^2}$$



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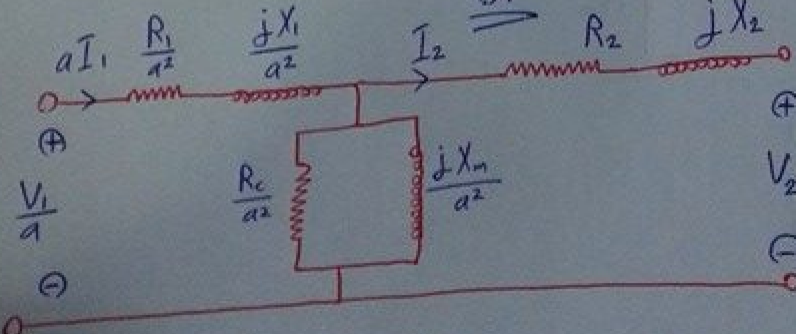


Primary or secondary referred

open circuit and short circuit test :-

OCT : V_{oc} , I_{oc} , P_{oc} $\longrightarrow$ V_{oc} (rated)

SCT : V_{sc} , I_{sc} , P_{sc} $\longrightarrow$ I_{sc} (rated)

* 10 kVA 2200/220

find $R_{eq,HV} \longrightarrow R_{eq,①}$ ~ Primary

find $X_{eq,LV} \longrightarrow X_{eq,②}$ ~ secondary

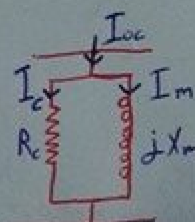
open circuit test :-

$$R_c = \frac{(V_{oc})^2}{P_{oc}} \longrightarrow V = IR,\ P = IV = I^2R = \frac{(V)^2}{R}$$

$$R = \frac{(V)^2}{P}$$

$$I_c = \frac{V_{oc}}{R_c}$$

$$X_m = \frac{V_{oc}}{I_m}$$



$$(I_{oc})^2 = (I_m)^2 + (I_c)^2$$

$$I_m = \sqrt{(I_{oc})^2 - (I_c)^2}$$

Short circuit test:-

$$R_{eq,1} = \frac{P_{sc}}{I_{sc}^2}$$

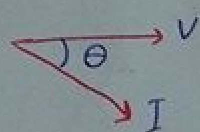
$$Z_{eq,1} = \frac{V_{sc}}{I_{sc}}$$

$$X_{eq,1} = \sqrt{(Z_{eq,1})^2 - (R_{eq,1})^2}$$

$$* \; pf\Big|_{ocT} = \frac{P_{oc}}{V_{oc} I_{oc}}$$

$$pf\Big|_{scT} = \frac{P_{sc}}{V_{sc} I_{sc}}$$

$* \; pf = \cos\theta$



we have 3 - cases:-

① lagging

→

② unity

$\theta = 0$

→ ?

③ leading

→

Example:- $pf = 0.8$ lagging

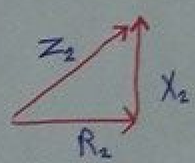
$$\cos^{-1}(0.8) = -38^\circ$$

Voltage regulation — must always be ~~reffered~~ referred to secondary

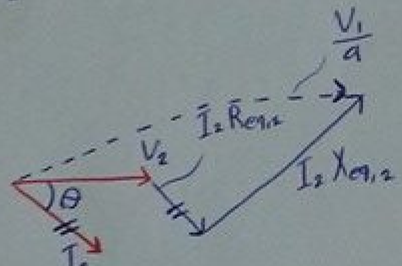
$$\boxed{VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100}$$

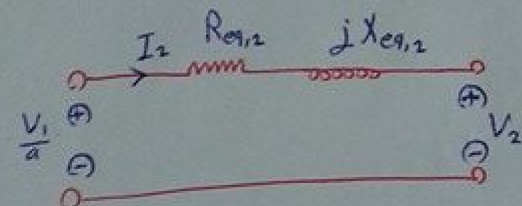
$NL \equiv$ no load

$FL \equiv$ full load



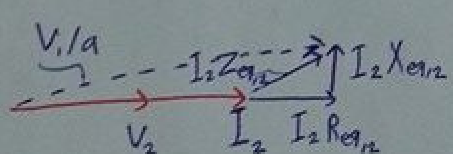
lagging



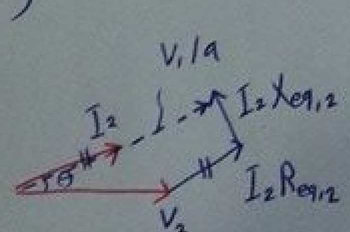


$$\frac{V_1}{a} = I_2 R_{eq,2} + I_2 X_{eq,2} + V_2$$

* unity



* leading



* $VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$

$$V_{NL} = \frac{V_1}{a} = V_2 + I_2 (R_{eq,2} \cos\theta + X_{eq,2} \sin\theta)$$

$$V_{FL} = V_2$$

Example page 16

10 kVA , 2200 / 220

OCT : 220 V , 2.5 A , 100 W

SCT : 150 V , 4.55 A , 215 W

$R_{eq,1} \Rightarrow R_{eq,2} = 0.104\,\Omega$

$X_{eq,1} \Rightarrow X_{eq,2} = 0.313\,\Omega$

VR must be calculated at referred to secondary side

$V_{FL} = V_2 = 220\,V$

① $V_{NL} = 220 + \left(\frac{10{,}000}{220}\right)\left[0.104\,(0.8) + 0.313\,(-0.6)\right]$

lagging

$= 232\,V \rightarrow VR|_{lagging} = 5.5\%$

② $V_{NL} = 220 + 45.5\,[0.104(1)] = \underline{\quad\quad} V$

$VR|_{unity} = 2.15\%$

③ $V_{NL} = 220 + 45.5\,[0.104\,(0.8) + 0.313\,(0.6)]$

approximate voltage regulation:-

$$VR = \frac{I_2}{V_2}\left[R_{eq,2}\cos\theta + X_{eq,2}\sin\theta\right] \times 100$$

Efficiencies :-

$$\eta = \frac{P_{out}}{P_{in}} \times 100$$

$$P_{in} = P_{out} + P_{losses} \longrightarrow \eta = \frac{P_{in} - P_{losses}}{P_{in}} \times 100 = \frac{P_{out}}{P_{out} + P_{losses}} \times 100$$

* there two types of losses , iron and copper losses

* $$\eta = \frac{V_2 I_2 \cos\theta}{V_2 I_2 \cos\theta + [P_i + I_2^2 R_{eq,2}]} \times 100$$

$$I_2 \longrightarrow 0 \quad \text{or} \quad I_2 \longrightarrow \infty \Longrightarrow \eta = 0$$

* maximum η at unity power factor and iron loss = copper loss

* iron loss < copper loss

* $$\eta_{max} = \frac{V_2 I_2}{V_2 I_2 + 2P_i}$$, $\underbrace{P_{oc}}_{\text{open circuit power}} = \underbrace{P_i}_{\text{iron Power}}$

* $P_c = P_i = I_2^2 R_{eq,2}$ at maximum η

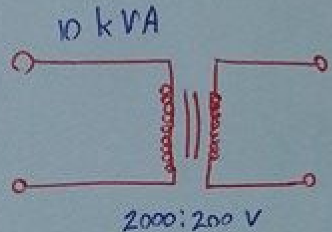
$$I_2\Big|_{\eta_{max}} = \sqrt{\frac{P_i}{R_{eq,2}}}$$

$$*\;k = \sqrt{\frac{P_{oc}}{P_{sc}}}$$

$$*\;\eta_{max} = \frac{V_2 I_{2,FL}\, k \cos\theta}{\underbrace{V_2 I_{2,FL}\, k}_{\text{kVA given}} \cos\theta + 2P_i}$$

Autotransformers :- one winding, two sides and no insulation

usual transformer



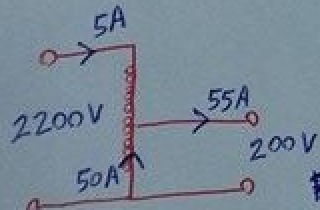
$$I_H = \frac{10{,}000}{2{,}000} = 5\text{ A}$$

$$I_L = \frac{10{,}000}{200} = 50\text{ A}$$

autotransformers

2000 / 200 V

5 / 50 A



VA = 11,000 on both sides

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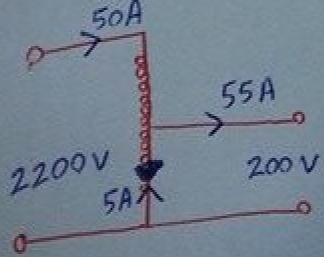
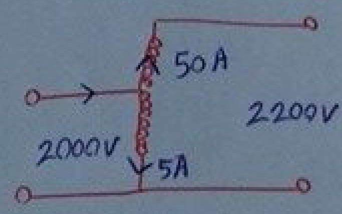


VA = 110,000 on both sides



VA = 110,000 on both sides