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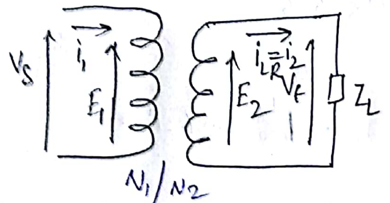
Tutorial Sheet-6

Q1 Given data :-

Transformer specifications – 1ϕ, 10KVA, 220/110V, 60Hz

Supply – 220V, 60Hz , Load – Rated, 0.8 PF leading

Ans(a)



→ ~~considering~~ Since ideal transformer is given the resistance and leakage reactance drops in primary and secondary circuits are neglected.

$r_1 = r_2 = x_1 = x_2 = 0$

Therefore the load terminal voltage for rated supply voltage be

$V_t = E_2$

$|I_{LR}|$ = Rated load current = $\dfrac{\text{Rated trns. KVA}}{\text{Rated terminal voltage}} = \dfrac{10\times10^3 \text{VA}}{110\text{V}} = 90.09\text{A}$

⟹ Thus the rated load KVA = Rated term. voltage x Rated load current

$= E_2 \times i_{LR}$

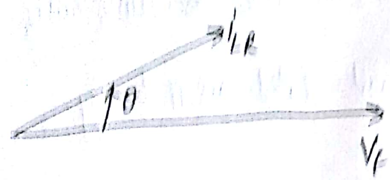
$$\boxed{\text{load KVA} = 110 \times 90.09 = 10 \text{ KVA}}$$

Ans(b) let the line impedance be Z_L

$Z_L = \dfrac{V_t}{i_{LR} \angle\theta}$

Given load power factor $\cos\theta = 0.8$

Power factor angle $\theta = \cos^{-1}(0.8) = 36.86$



Therefore $\vec{i_L} = |i_L| \angle \theta = 90.09 \angle 36.86$

Now $Z_L = \dfrac{\vec{V_L}}{\vec{i_L}} = \dfrac{110\angle 0^\circ}{90.09\angle 36.86} = 1.21\angle -36.86\ \Omega$

$$\boxed{Z_L = 1.21\angle -36.86 = 0.968 - 0.7258i\ \Omega}$$

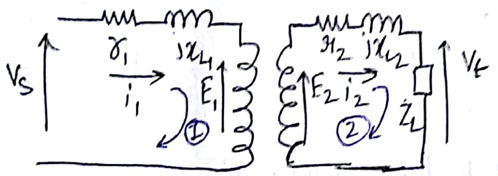
Q2 Given data :-

→ Transformer specifications → 2500/250V 500 KVA, 60Hz

→ equivalent circuit parameters → $r_1 = 0.1\Omega$, $x_{L1} = 0.3\Omega$, $r_2 = 0.001\Omega$,
$x_{L2} = 0.003\Omega$

→ load specifications → Rated load, U.P.F i.e. $\cos\theta = 1$, rated V_t

Transformer equivalent circuit



$V_s = 2500V$

On applying KVL in primary circuit loop 1

$$\vec{V_s} - \vec{i_1}(r_1 + jx_{L1}) = \vec{E_1}$$

$$\vec{V_s} - \vec{i_1}r_1 - \vec{i_1}jx_{L1} = \vec{E_1}$$ on taking the magnitude of complex vector

$$|E_1| = \sqrt{(V_s - i_1 r_1)^2 + (i_1 x_{L1})^2}$$

I_{ed} $\sqrt{\cancel{2500}}$ -

On applying KVL in secondary loop 2

$$\vec{E_2} = \vec{V_t} + \vec{i_2}(r_2 + jx_{L2})$$

$$\vec{E_2} = \vec{V_t} + \vec{i_2}r_2 + j\vec{i_2}x_{L2}$$

taking magnitude of complex vector

$$|E_2| = \sqrt{(V_2 + i_2 r_2)^2 + (i_2 x_{L2})^2}$$

Ratio of primary and secondary voltage $= \frac{|E_1|}{|E_2|}$

→ Now for rated load

$$i_2 = \frac{500 \times 10^3}{250} = 2 \times 10^3\,A$$

Turn ratio is

$$\frac{i_1}{i_2} = \frac{N_2}{N_1}$$

Therefore $i_1 = \frac{N_2 i_2}{N_1} = \frac{1}{10} \times 2 \times 10^3 = 200A$

→ Therefore

$\cancel{|E_1| = \sqrt{V_1 + i_1 r_1}}$

$$|E_1| = \sqrt{(V_1 - i_1 r_1)^2 + (i_1 X_{L_1})^2}$$

$$= \sqrt{(2500 - 200 \times 0.1)^2 + (200 \times 0.3)^2}$$

$$|E_1| = 2480.7257\,V$$

$$|E_2| = \sqrt{(V_2 + i_2 r_2)^2 + (i_2 X_{L_2})^2} = 252.071\,V$$

$$\frac{N_p}{N_s} = \frac{|E_1|}{|E_2|} = \frac{2480.7257}{252.071} = 9.841$$

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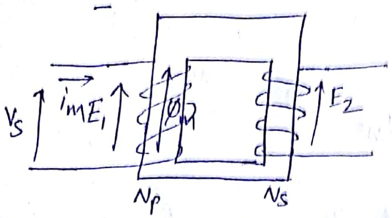
13 Given

Transformer — $N_p = 400$, $N_s = 1000$, $A = 60 \times 10^{-4} m^2$, $l = 0.7 m$,

Supply — 500V, 50Hz



Induced E.m.f in the primary winding can be written as

$$E_1 = N_p \frac{d\phi_m}{dt} \quad -(1)$$

for a balance single phase AC supply magnetizing flux can be written as

$$\phi_m = \phi_{max} \sin \omega t$$

Putting ϕ_m in eq.(1)

$$E_1 = N_p \phi_{max} \omega \cos \omega t$$

Maximum value of EMF induced be

$$E_{1max} = N_p \phi_{max} \cdot 2\pi f$$

$$E_{1max} = \frac{E_{1Rms}\sqrt{2}}{\sqrt{2}}$$

$$\Rightarrow \phi_{max} = \frac{E_{1Rms}\sqrt{2}}{2\pi f \times N_p}$$

$E_{1Rms} = 500V$, $N_p = 400$, $f = 50Hz$

then $\phi_{max} = \cancel{5.626 \times 10^{-4}}$ Wb $= 5.626 \times 10^{-3}$ Wb

Since $\phi = B \cdot A$

$\phi_{max} = B_{max} \cdot A$

$B_{max} \cdot A = 5.626 \times 10^{-3}$

$$B_{max} = \frac{5.626 \times 10^{-3}}{60 \times 10^{-4}}$$

$= 0.937 \; Wb/m^2$

Peak flux density $= 0.937 \approx 0.94 \; Wb/m^2$

from the B-H curve of the material the B_{max} is lying between

B	0.9	1.0
H	625	750

considering linearized change between the two point

$$\frac{y_1 - y_2}{x_1 - x_2} = \frac{\Delta y}{\Delta x}$$

$\frac{\Delta y}{\Delta x} = \frac{0.1}{125}$ and $y_1 - y_2 = 0.037$, $x_2 = 625$

therefore

$$x_1 = (y_1 - y_2)\frac{\Delta x}{\Delta y} + x_2$$

$= 0.037 \times \frac{125}{0.1} + 625 = 671.25$

Since $H = \frac{N i_m}{l}$

$\boxed{\text{magnetizing current } i_m = \frac{Hl}{N_p} = \frac{671.25 \times 0.7}{400} = 1.174\,A}$

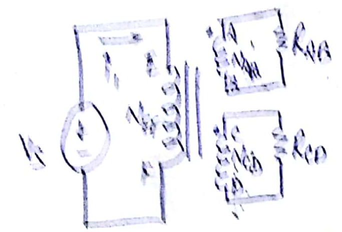
Given

Transformer — 1ϕ, 3 winding, $N_{EF} = 600$, $N_{AB} = 150$, $N_{CD} = 300$ turns

Load → $R_{AB} = 30\Omega$ and $R_{CD} = 15\Omega$

Supply — 18V (RMS)

Ans



on referring load resistances on primary side the equivalent circuit will be

$$R'_{AB} = \left(\frac{N_{EF}}{N_{AB}}\right)^2 \times R_{AB}$$

$$= \left(\frac{600}{150}\right)^2 \times 30 = 480\Omega$$

$$R'_{CD} = \left(\frac{N_{EF}}{N_{CD}}\right)^2 \times R_{CD} = \left(\frac{600}{300}\right)^2 \times 15 = 60\Omega$$

Equivalent load resistance $R_{eq} = \dfrac{R'_{AB} \times R'_{CD}}{R'_{AB} + R'_{CD}} = 53.33\,\Omega$

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Ans (b) Total current from supply

$$i_1 = \frac{E}{R_{eq}}$$

$$= \frac{16}{53.33} = 0.3A$$

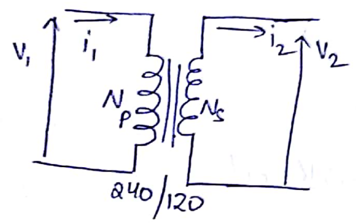
S Given data →

Transformer – 1Ø, 3 KVA, 240/120V, 60Hz

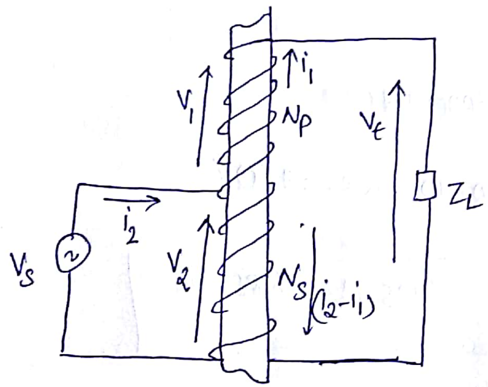
load → 330V, rated

Supply → 110V, 60Hz

ⓐ Let the original transformer be shown as



To satisfy the loading condition the two winding transformer needs ~~to~~ be reconnected as an auto transformer



(b) for an auto ~~trans~~ transformer the KVA ~~of~~ composes of transformed VA and conduction VA

$$\cancel{(KVA)_{A \cdot t} = (\text{Transformed})VA + (\text{Conduction})VA}$$

$$(KVA)_{A \cdot t} = (KVA)_{Tr} + (KVA)_{c}$$

Transformed $KVA = (KVA)_{tr} = V_2(i_2 - i_1)$

Conduction $KVA = (KVA)_c = (V_1 - V_2) i_1$

from 2 wdg transformer for rated load

$$i_2 = \frac{3 \times 10^3}{120} = 25A$$

$$i_1 = 12.5A$$

Therefore

$$(KVA)_{tr} = \cancel{2}110 \times 12.5 = \cancel{3000}\ 1375 \text{ VA}$$

$$(KVA)_c = (V_1 - V_2) \cdot i_1 = (330 - 110) \times 12.5 = 2750 \text{ VA}$$

$$\boxed{(KVA)_{A \cdot t} = 2750 + 1375 = 4125 \text{ VA} = 4.125 \text{ KVA}}$$

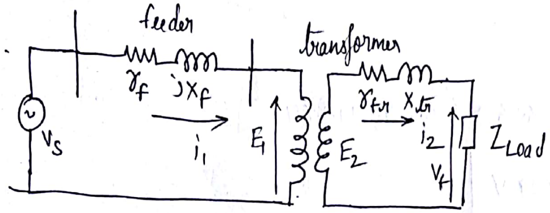
Given

Transformer -1ϕ, 10KVA, 220/440, 60Hz

equivalent circuit parameters = $(0.2875 + j\,1.125)$

feeder impedance $\rightarrow$ $0.15 + j0.4$

load $\rightarrow$ ~~@~~ 440V, 8KW



Refer the transformer equivalent leakage impedance on L.V side

$$(r'_{tr} + j\,x'_{tr}) = (r_{tr} + j\,x_{tr}) \times \left(\frac{220}{440}\right)^2$$

$$= (0.2875 + j1.125)\left(\frac{1}{2}\right)^2$$

$$= 0.071875 + 0.28125j\ \Omega$$

$\rightarrow$ Terminal voltage referred on LV side

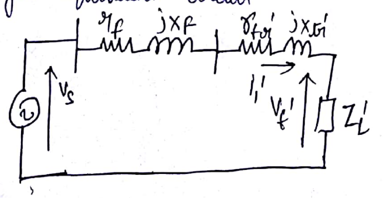
$$V'_t = 220V$$

load current $i_2 = \dfrac{8 \times 10^3\ W}{440 \times 0.8} = 22.727\ A$

$\rightarrow$ i_2 referred on LV side

$$i'_1 = 22.727 \times \frac{2}{2} = 45.44A$$

$\rightarrow$ Modified equivalent circuit



total series impedance

$$= (r_f + j x_f) + (r'_{tm} + j x'_{tm})$$

$$= (0.15 + j0.4) + (0.0718 + 0.281j)$$

$$Z_t = 0.2218 + j\,0.681$$

Applying KVA in the resultant circuit

$$V_S = \vec{V_t} + \vec{I_1'} \times Z_t$$

$$= 220\angle 0^\circ + 45.44\angle -36.86 \times (0.2218 + j0.681)$$

$$\boxed{V_S = 247.3353 \angle 4.339\ V}$$

Given

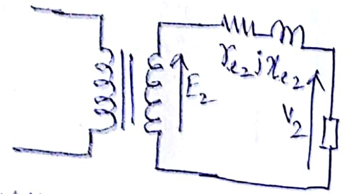
Transformer → 20KVA, 2500/500V, 1ϕ

equivalent circuit parameter → $r_1 = 8\,\Omega$, $x_1 = 17\,\Omega$; HV winding

LV winding : $r_2 = 0.3\,\Omega$, ~~0.7~~, $x_2 = 0.7\,\Omega$

Supply → 2500V,

Ans (a)



$$\text{Voltage regulation} = \frac{E_2 - V_2}{E_2} = \frac{i_2 r_{e_2} \cos\theta_2}{E_2} + \frac{i_2 x_{e_2} \sin\theta_2}{E_2}$$

for lagging P.f load

→ for leading P.f load

$$V.R = \frac{i_2 r_{e_2} \cos\theta_2}{E_2} - \frac{i_2 x_{e_2}}{E_2} \sin\theta_2$$

→ In case (a) load is 0.9 P.f lagging

$$r_{e_2} + j x_{e_2} = (r_1' + j x_1') + (r_2 + j x_2)$$

$$(r_1' + j x_1') = \left(\frac{N_2}{N_1}\right)^2 (r_1 + j x_1) = 0.32 + 0.68i$$

$$r_{e_2} + j x_{e_2} = (0.32 + 0.68i) + (0.3 + 0.7i)$$

$$= 0.62 + 1.38i$$

$$i_2 = \frac{\text{Rated KVA}}{V_t} = \frac{20\times10^3}{500} = 40\,A$$

$$V.R = \frac{i_2 r_{e2} \cos\theta_2}{E_2} + \frac{i_2 x_{e2}}{E_2} \sin\theta_2$$

$$= \frac{40\times0.62\times0.9}{500} + \frac{40\times1.38}{500}\times0.4358$$

$$= 0.04464 + 0.5681$$

$$= 0.1057$$

$$\boxed{VR\% = 10.57\%}$$

Ans (b) for 0.9 pf loading

$$V.R = \frac{i_2 r_{e2}}{E_2}\cos\theta_2 - \frac{i_2 x_{e2}}{E_2}\sin\theta_2$$

$$= \frac{40\times0.62\times0.9}{500} - \frac{40\times1.38}{500}\times0.4358$$

$$= 0.0396$$

$$\boxed{V.R\% = .396\%}$$

Given

Transformer – 1ϕ, 25 KVA, 2300/230V

$Z_{eq,H} = 4 + j5\,\Omega$, $R_{cL} = 450\,\Omega$, $X_{mL} = 300\,\Omega$

Ans → worst case voltage regulation will occur at a specific lagging power factor load

→ To determine the load Pf in that case ~~minima~~ ~~gfa~~

$$\frac{dV.R}{d\theta_2} = 0$$

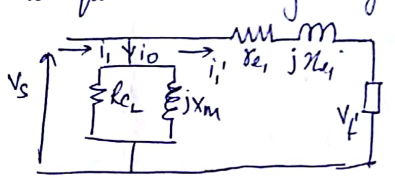
Since $V.R = \dfrac{i_2 r_{e_2} \cos\theta_2}{2} + \dfrac{i_2 x_{e_2} \sin\theta_2}{E_2}$

$$\frac{dV.R}{d\theta_2} = \frac{-i_2 r_{e_2} \sin\theta_2}{E_2} + \frac{i_2 x_{e_2} \cos\theta_2}{E_2} = 0$$

$$\tan\theta_2 = \frac{x_{e_2}}{r_{e_2}}$$

$$\theta_2 = \tan^{-1}\left(\frac{x_{e_2}}{r_{e_2}}\right)$$

Now equivalent circuit of transformer referred to primary will be



$r_{e_1} + jx_{e_1} = 4 + j5$ (given)

$V_t' = 2300$

$$i_1' = \frac{25 \times 10^3}{2300} = 10.869$$

$$\theta_2 = \tan^{-1}\left(\frac{5}{4}\right) = 51.34$$

Therefore

$\vec{i_1} = 10.869\angle -51.34$

Since worst V.R will be obtained for lagging P.f rated load then

$$V.R = \frac{i_1 r_{e1} \cos\theta}{E_1} + \frac{i_1 x_{e1} \sin\theta_1}{E_1}$$

$$= \frac{10.869 \times 4 \times \cos(51.34)}{2300} + \frac{10.869 \times 5 \times \sin(51.34)}{2300}$$

$V.R = 0.0303$ Pu

$\%\ V.R = 3.03\%$

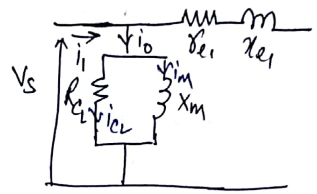
9 Given

Transformer → 4KVA, 200/400V, 50Hz

No load test : 200V, 0.7A, 0.6W.

SC test : 9V, 6A, 21.6 W

for No load test equivalent circuit of transformer will be



→ During No load test the copper losses in the windings are negligible hence all active power is consumed by core losses.

$$P_W = \frac{(V_S)^2}{R_{CL}}$$

$$R_{CL} = \frac{(200)^2}{60} = 666.66$$

$$i_{CL} = \frac{V_S}{R_{CL}} = 0.3A$$ (core loss component of current)

Active Power can be written as

$$P_W = V_S \cdot i_0 \cdot \cos\theta$$

$$60 = 200 \times 0.7 \times \cos\theta$$

$$\cos\theta = 0.4285$$

$$i_M = i_0 \sin\theta = 0.7 \times 0.903 = 0.6324A$$

(b) During short circuit test ~~no~~ active power consumed is con... Consumed in ohmic losses

$$P = i_{sc}^2 \times R_{eq}$$

$$21.6 = (6)^2 \times R_{eq}$$

$$R_{eq} = 0.6$$

~~the~~ To determine the leakage reactance

$$Z_l = \frac{V}{i_{sc}} = 1.5$$

$$\sqrt{(R_{eq})^2 + (X_{eq})^2} = Z_l = 1.5$$

$$X_{eq} = \sqrt{(Z_l)^2 - (R_{eq})^2}$$

$$X_{eq} = 1.89$$

Now for a rated load terminal voltage can be written as

$$\vec{V_t} = \vec{E_2} - \vec{I_2}\,(r_{eq} + j\,x_{eq})$$

$$|i_{2rated}| = \frac{4 \times 10^3}{400} = 10$$

→ for 0.8 lagging power factor

$$\vec{I_2} = 10\angle -36.86$$

$$V_t = 400\angle 0^\circ - 10\angle -36.86\,(0.6 + 1.89j)$$

$$\boxed{V_t = 387.05\angle -1.719}$$

→ for 0.8 leading

$$\vec{i_2} = 10\angle +36.86$$

$$\boxed{V_t = 406.96\angle -2.636\ V}$$

10 Given

Transformer = 10 KVA, 2400/240V, 60Hz

Core loss = 100W, copper loss at 0.5 load = 60W

Ans (a)

Efficiency $\eta = \frac{V i \cos\phi}{V i \cos\phi + P_{losses}} \times 100$

$P_{loss} = P_{CL} + P_{OL}$ ($P_{CL} \rightarrow$ core loss, $P_{OL} \rightarrow$ ohmic losses)

Given

P_{OL} (0.5 load) = 60W

for full load

$P_{OL} = (\frac{1}{0.5})^2 \times P_{OL}(0.5)$

$P_{OL} = (\frac{1}{0.5})^2 \times 60W = 240W$

$\eta = \frac{KVA \times \cos\phi}{KVA \times \cos\phi + P_{CL} + P_{OL}} \times 100 = \frac{10 \times 0.8 \times 10^3}{10 \times 0.8 \times 10^3 + 100 + 240} \times 100 = 95.92\%$

(b) For maximum efficiency

$\frac{d\eta}{di_2} = 0$ condition needs to be evaluated

$\eta = \frac{V_2 i_2 \cos\phi}{V_2 i_2 \cos\phi + P_{CL} + i_2^2 \times R_{eq}}$ — (1)

$\frac{d\eta}{di_2} = 0$

on differentiating eq (1) with respect to i_2

condition for max η is

$P_{CL} = P_{OL}$

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let ~~x KVA~~ n. KVA is the load ~~per~~ for maximum η then

$$n^2 P_{OL} = P_{CL}$$

$$n = \sqrt{\frac{P_{CL}}{P_{OL}}}$$

$$n = \sqrt{\frac{100}{240}}$$

$$n = 0.6454$$

efficiency at this load is

$$\eta = \frac{n \times KVA \times \cos\phi}{n \times KVA \times \cos\phi + 2 P_{CL}} \times 100$$

$$= \frac{0.6455 \times 10 \times 0.9 \times 10^3}{0.6455 \times 10 \times 0.9 + 2 \times 100 \times 10^{3}} \times 100 = 96.67\%$$

(c) All day efficiency

$$\eta = 1 - \frac{\text{Daily loss Kwh}}{\text{Daily input Kwh}}$$

Ohmic losses = full load ohmic loss × $(n)^2$ × hrs (n = proportion of load to full load)

Total P_{OL} = $(0.7)^2 \times 0.8 \times 240 \times 10 + (0.9)^2 \times 0.9 \times 8 \times 240$

= ~~97.52 Kwh~~ ~~97.52 Kwh~~ 2.340 Kwhr

Total core loss = core loss × 24 hr = 100 × 24 = 2.4 Kwh

Total i/p = 0.7 × 0.8 × 10 × 10 + 0.9 × 0.9 × 8 × 10

= 97.52 Kwh

$$\boxed{\eta\% = 1 - \frac{2.34 + 2.4}{97.52} = 95.93\%}$$