CHASE LOTTO

$\boxed{\text{ECE385}}$

HW3

① A 1ϕ, 25 kVA, 2300/230V TRANSFORMER:

$$Z_{eq,H} = 4 + j5\,\Omega$$
$$R_{c,L} = 450\,\Omega$$
$$X_{M,L} = 300\,\Omega$$

ⓐ Determine efficiency @ FULL LOAD @ rated voltage, 0.85 pf lagging.

ⓑ Determine percentage loading of XF @ which efficiency is maximized & calculate this efficiency if pf is 0.85 and load voltage is 230V.

ⓐ

$$\boxed{\eta = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out} + P_{cu} + P_{core}}}$$

$\underline{P_{out}} = S_{rated} \cdot pf = (25k)(0.85) = \underline{21.25k\,W}$

At rated voltage, the low side has current $(S = IV)$: $I_L = \frac{S_{rated}}{V_{L,rated}} = \frac{25k}{230} = 108.7A$

To the high side $\Rightarrow a = \frac{2300}{230} = 10$, $I_H = \frac{I_L}{a} = \frac{108.7}{10} = 10.87A$

$$\therefore \underline{P_{cu}} = \mathrm{Re}\{Z_{eq,H}\} I_H^2 = 4(10.87)^2 = \underline{472.6W}$$

Then, active losses from core resistance on low-side @ rated voltage:

$$\Rightarrow \underline{P_c} = \frac{V_{L,rated}^2}{R_{c,L}} = \frac{230^2}{450} = \underline{117.6W}$$

$$\therefore \eta = \frac{P_{out}}{P_{out} + P_{cu} + P_c} = \frac{21256}{21.25k + 472.6 + 117.6} = 0.9730 \Rightarrow \boxed{\eta = 97.30\%}$$

ⓑ $\cancel{\frac{d\eta}{dP_{out}} = \frac{(P_{out}+P_{cu}+P_c)(1) - P_{out}(N)}{(P_{out}+P_{cu}+P_c)^2} = ?}$

↳ this says $P_{cu} = P_c$ when η is maximized..

$\therefore P_c = P_{cu} = 117.6W$, $P_{cu,FL} = I_H^2 R_{eq,H} = 472.6W$

From textbook, $X = \left(\frac{P_c}{P_{cu,FL}}\right)^{1/2} = \left(\frac{117.6}{472.6}\right)^{1/2} = 0.499 \Rightarrow \boxed{X = 49.9\%}$

Since percent loading is 49.9%. The load the transformer sees is $S_{rated} X$

or $(49.9\%)(25kVA) = 12470.9\,kW = P_{out}$. This load coupled w/ a pf = 0.85

$$\Rightarrow \eta = \frac{P_{out}}{P_{out} + \underbrace{P_{cu} + P_c}_{\text{equal b/c }\eta\text{ maximized}}} = \frac{12470.9}{12470.9 + 117.6 + 117.6} = 0.9815 \Rightarrow \boxed{\eta = 98.15\%}$$

② 1φ, 10kVA, 460/120V, 60Hz transformer has an efficiency of 96% when it delivers 9kW @ 0.9pf. This transformer is connected as an autotransformer to supply load to a 460V circuit from a 580V source.

ⓐ Show autotransformer connection

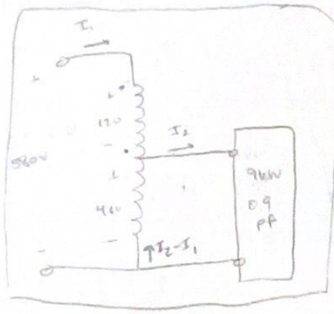
ⓑ Determine max kVA the autotransformer can supply to the 460V circuit.

ⓒ Determine η for full-load @ 0.9 pf.

ⓑ 48.36kVA
ⓒ 99.1%

ⓐ $\eta = 96\%$ for LOAD; 9kW, 0.9 pf

$\cancel{a = \frac{460}{120} = 3.833}$



$\frac{V_1}{V_2} = \frac{580}{460} = 1.26 = a$

This works since $460 + 120 = \underline{580}$.

ⓑ Max kVA.

BOTTOM $I_2 = \frac{S_{rated}}{460V} = \frac{10kVA}{460V} = 21.7A$

TOP $I_1 = \frac{S_{rated}}{120V} = \frac{10kVA}{120V} = \underline{83.3A}$

So we draw 83.3A from the 580V source

$\therefore S_{max} = (580V)(83.3A) = \boxed{48.3kVA}$

ⓒ Determine η, FL @ 0.9pf.

→ $S_{rated} = 48.3kVA$

96% efficient for 9kW, so $\frac{9kW}{TOTAL} = \frac{.96}{1} \Rightarrow 9kW = .96(TOTAL) \Rightarrow TOTAL = \frac{9kW}{.96} = 9375W$

So losses $P_{loss} = TOTAL - 9k = 9.375k - 9k = 375W$ losses.

$\Rightarrow \eta = \frac{S_{rated} \cdot pf}{S_{rated} \cdot pf + LOSSES} = \frac{48.3k(0.9)}{48.3k(0.9) + 375} = 0.9914 \Rightarrow \boxed{\eta = 99.14\%}$

③ A 1ϕ, 200kVA, 2100/210V, 60Hz XF. $Z_{EQ,H} = 0.25 + j1.5\,\Omega$ w/ THE LOW-SIDE SHORT CIRCUITED. $Y_{EQ,L} = 0.025 - j0.075\ \mho$ w/ HIGH-SIDE OPEN CIRCUITED.

ⓐ TAKING XF RATING AS BASE, DETERMINE BASE VALUES FOR HIGH + LOW VOLTAGE SIDES.

$\boxed{S_{base,H} = S_{base,L} = 200kVA}$

$\boxed{V_{base,H} = 2100V}$

$\boxed{V_{base,L} = 210V}$

$$I_{base,H} = \frac{S_{base,H}}{V_{base,H}} = \frac{200kVA}{2100V} = \boxed{95.24A = I_{base,H}}$$

$$I_{base,L} = \frac{S_{base,L}}{V_{base,L}} = \frac{200kVA}{210V} = \boxed{952.4A = I_{base,L}}$$

$$Z_{base,H} = \frac{V_{base,H}}{I_{base,H}} = \frac{2100V}{95.24A} = \boxed{22.05\Omega = Z_{base,H}}$$

$$Z_{base,L} = \frac{V_{base,L}}{I_{base,L}} = \frac{210V}{952.4A} = \boxed{0.2205\Omega = Z_{base,L}}$$

ⓑ DETERMINE THE PER-UNIT VALUE OF THE EQUIVALENT RESISTANCE AND LEAKAGE REACTANCE OF THE TRANSFORMER

$$Z_{EQ,H,pu} = \frac{Z_{EQ,H}}{Z_{BASE,H}} = \frac{0.25 + j1.5\,\Omega}{22.05\,\Omega} = \boxed{0.0113 + j0.068\,pu}$$

ⓒ DETERMINE PER UNIT VALUE OF THE EXCITATION CURRENT @ RATED VOLTAGE.

$$Y = \frac{1}{Z} = \frac{1}{V/I} = I/V \Rightarrow I = YV \quad (*)$$

$$I_m = Y_{eq} \cdot V_{rated} = (0.025 - j0.075\ \mho)(210V) = 5.25 - j15.75A \Rightarrow |I_m| = \sqrt{5.25^2 + 15.75^2} = 16.6A$$

$$\Rightarrow I_{m,pu} = \frac{|I_m|}{I_{base,L}} = \frac{16.6A}{952.4A} = \boxed{0.0174\,pu = I_{m,pu}}$$

ⓓ DETERMINE PER-UNIT VALUE OF THE TOTAL POWER LOSS IN THE TRANSFORMER @ FULL-LOAD OUTPUT CONDITION.

* P_{core} is constant, P_{cu} is dependent on current.

COPPER

$$P_{cu,FL} = I_{base,H}^2 \cdot R_{eq,H} = (95.24)^2(0.25) = 2.268kW$$

$$\Rightarrow P_{cu,FL,pu} = \frac{P_{cu,FL}}{S_{base,H}} = \frac{2.268kW}{200kVA} = 0.01134\,pu$$

CORE

$$P_{core} = \frac{V_{rated}^2}{R_{core}} = \frac{210^2}{\frac{1}{0.025}} = 210^2(0.025) = 1103W$$

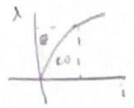
$$\Rightarrow P_{core,pu} = \frac{P_{core}}{S_{base}} = \frac{1103}{200k} = 0.00552\,pu$$

$$\Rightarrow P_{loss,pu} = P_{core,pu} + P_{cu,pu,FL} = 0.01134 + 0.00552 = \boxed{0.01686\,pu}$$

(4) THE λ-i RELATIONSHIP OF A E.M SYSTEM IS GIVEN BY:

$$\lambda = \frac{1.2\sqrt{i}}{g} \rightarrow i = \left(\frac{\lambda g}{1.2}\right)^2$$

WHERE THE AIRGAP $g = 10$cm, AND $i = 2$A. DETERMINE THE MECHANICAL FORCE ON THE MOVING PART.



(a) ENERGY.

$$W_f = \int_0^{\lambda} i\,d\lambda = \int_0^{\lambda} \frac{\lambda^2 g^2}{(1.2)^2}\,d\lambda = \frac{g^2}{(1.2)^2} \cdot \int_0^{\lambda} \lambda^2 d\lambda = \frac{g^2}{(1.2)^2} \cdot \frac{1}{3}\lambda^3 \Big|_0^{\lambda} = \frac{g^2}{(1.2)^2} \cdot \frac{1}{3}\lambda^3$$

$$\Rightarrow W_f = \frac{\lambda^3 g^2}{4.32}$$

(2.27) $$\Rightarrow f_m = -\frac{\partial W_f(\lambda, g)}{\partial g}\Big|_{\lambda = \text{constant}} = -\frac{\partial}{\partial g}\left(\frac{\lambda^3 g^2}{4.32}\right) = \frac{-2g\lambda^3}{4.32} = \frac{-2(10\times10^{-2})}{4.32}\left(\frac{1.2\sqrt{2}}{10\times10^{-2}}\right)^3 = -226.27\text{N}$$

$$\Rightarrow \boxed{f_m = -226.3\text{N}}$$

(b) COENERGY.

$$W_f' = \int_0^{i} \lambda\,di = \int_0^{i} \frac{1.2\sqrt{i}}{g}\,di = \frac{1.2}{g}\int_0^{i} \sqrt{i}\,di = \frac{1.2}{g}\cdot\frac{2}{3} i^{3/2}\Big|_0^{i} = \frac{0.8}{g} i^{3/2}$$

$$\Rightarrow f_m = \frac{\partial W_f'(i, g)}{\partial g}\Big|_{i = \text{constant}} = \frac{\partial}{\partial g}\left(\frac{0.8}{g} i^{3/2}\right) = \frac{-0.8 i^{3/2}}{g^2} = \frac{-0.8(2)^{3/2}}{(10\times10^{-2})^2} = -226.27\text{N}$$

$$\Rightarrow \boxed{f_m = -226.3\text{N}}$$

BOTH ARE THE SAME. ✓

(5) ELECTROMAGNETIC LIFT SYSTEM. $N = 2500$ TURNS. $B_g = 1.25T$. ASSUME IDEAL CORE.
$\hookrightarrow R_c = 0$.

(a) $g = 10mm$

(i) DETERMINE COIL CURRENT

<u>AMPERE'S LAW</u>: $Ni = \Phi R \Rightarrow i = \frac{\Phi R}{N} = \frac{BA \frac{g_{eff}}{\mu A}}{N} = \frac{B g_{eff}}{\mu N} = \frac{B_g \cdot g_{eff}}{\mu_0 N}$

Here we can model as 2 equal airgaps, $A_1 = 40mm$, $A_2 = (20+20)mm$

$\therefore$ we have $g_{eff} = 2g$

$\therefore \quad i = \frac{B_g 2g}{\mu_0 N} = \frac{1.25 \cdot 2 \cdot 0.01}{4\pi \times 10^{-7} \cdot 2500} = \boxed{7.96A}$

(ii) DETERMINE ENERGY STORED IN MAGNETIC SYSTEM.

$$W_f = \frac{B_g^2}{2\mu_0} \times Vol_g = \frac{(1.25)^2}{2 \times 4\pi \times 10^{-7}} \left(\underset{l}{(10mm)}\underset{A}{(80mm + 40mm + 20mm)}\underset{d}{(40mm)}\right)$$

$\Rightarrow \boxed{W_f = 19.89J}$

(iii) DETERMINE FORCE ON LOAD

$$f_m = \frac{B_g^2}{2\mu_0} \cdot Area = \frac{(1.25)^2}{2 \times 4\pi \times 10^{-7}} (40mm)(80mm) = \boxed{1989N}$$

(iv) DETERMINE MASS OF LOAD.

$F = ma \Rightarrow m = F/a = 1989/9.81 = \boxed{202.75\ kg}$

(b) $g = 2mm$. Refind i.

$$i = \frac{2B_g g}{\mu_0 N} = \frac{2(1.25)(2mm)}{4\pi \times 10^{-7}(2500)} = \boxed{1.59A}$$