Power Unit

Grade: 20/20

100/100

University of Jordan | Faculty of Engineering & Technology | Electrical Engineering Department
EE371: Electrical Machines I | First Exam | First Semester 2015-2016 | 02/11/2015 | Time: 1 Hour

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**Questions 1 (25 mark)** **SHOW YOUR CALCULATIONS** $\mu_o = 4\pi\times10^{-7}$ H/m

In the magnetic system shown in Fig. 1,

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| | | | |
|---|---|---|---|
| $l_1 = 300$ mm | $l_2 = 100$ mm | $l_3 = 300$ mm | $I = 0.5$ A |
| $A_1 = 200$ mm$^2$ | $A_2 = 400$ mm$^2$ | $A_3 = 200$ mm$^2$ | $N = 25$ |
| $\mu_{r1} = 2250$ | $\mu_{r2} = 1350$ | $\mu_{r3} = 2250$ | |

Draw the equivalent magnetic circuit and determine the following:

a. the reluctances $\Re_1$, $\Re_2$ and $\Re_3$ of the paths $l_1$, $l_2$ and $l_3$.

b. the flux $\phi$ and flux density $B$ in the three branches of the core $\phi_1$, $\phi_2$, $\phi_3$, $B_1$, $B_2$, and $B_3$.

b. the core inductance $L$.

$\mathcal{R} = \frac{L}{\mu A}$

$\mathcal{R}_1 = \mathcal{R}_3 = \frac{300\times10^{-3}}{2250\,\mu_0(200\times10^{-6})}$

$\mathcal{R}_1 = \mathcal{R}_3 = 530.5$ k At/wb

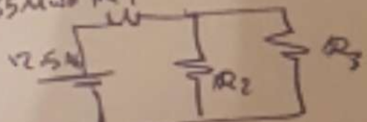
$\mathcal{R}_2 = \frac{100\times10^{-3}}{1350\,\mu_0(400\times10^{-6})}$

$\mathcal{R}_2 = 147.4$ k At/wb

$\mathcal{F} = NI$

$\mathcal{F} = 0.5\times25 = 12.5$ At

$\phi_1 = \frac{\mathcal{F}}{\mathcal{R}_{eq}} = \frac{12.5}{646k} = 19.35\,\mu$wb




$\phi_2 = \phi_1\frac{\mathcal{R}_3}{\mathcal{R}_3+\mathcal{R}_2} = 15.14\,\mu$wb

$\phi_3 = \phi_1 - \phi_2 = 4.2\,\mu$wb

(4) $\frac{di}{dt} = N\frac{d\phi}{dt}$

$L = N\frac{\phi}{I}$

$B = \frac{\phi}{A}$

$B_1 = \frac{19.35\mu}{200\times10^{-6}}$ T

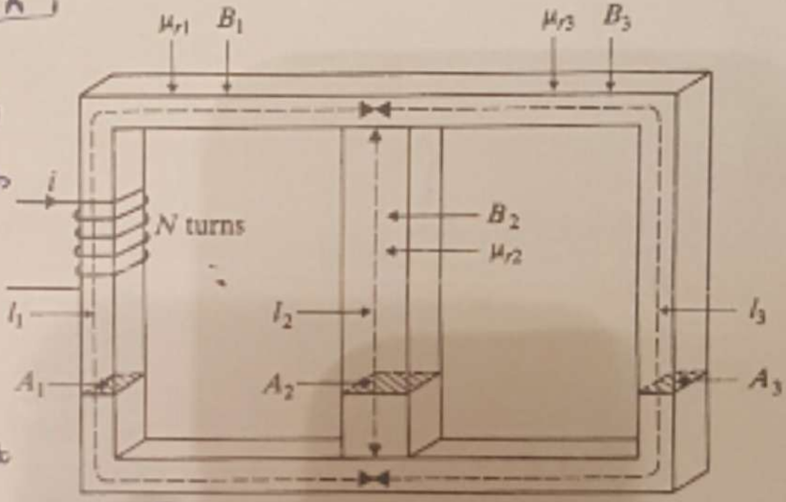



Fig. 1

| | |
|---|---|
| $\Re_1 =$ | 530.5k At/wb |
| $\Re_2 =$ | 147.4k At/wb |
| $\Re_3 =$ | 530.5k At/wb |
| $\phi_1 =$ | 19.35 $\mu$wb |
| $\phi_2 =$ | 15.14 $\mu$wb |
| $\phi_3 =$ | 4.2 $\mu$wb |
| $B_1 =$ | 0.097 T |
| $B_2 =$ | ~~0.0403~~ 0.038 T |
| $B_3 =$ | 0.021 T |
| $L =$ | 0.97 mH |

**Question #2 (25 marks)** **SHOW YOUR CALCULATIONS**

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The core loss in a certain electrical apparatus operating at its rated voltage and frequency of $V_1$ = 240 V and $f_1$ = 25 Hz is $P_{c1}$ = 1500 W. When the apparatus is connected to a 50-Hz source whose voltage $V_2$ is adjusted such as to cause the flux density $B_2$ to be 70.7% of its rated value ($B_1$), the core loss becomes $P_{c2}$ = 2000 W. Assume the Steinmetz exponent $n$ = 2, determine:

a. the new source voltage, $V_2$.

b. $P_{e1}$, $P_{h1}$, $P_{e2}$ and $P_{h2}$.

$\frac{B_2}{B_1} = 0.707$ $\quad \frac{V_1}{V_2} = \frac{B_1}{B_2} \cdot \frac{f_1}{f_2}$

| | |
|---|---|
| $V_2$ = | 339.36 V |
| $P_{e1}$ = | 500 W |
| $P_{h1}$ = | 1000 W |
| $P_{e2}$ = | 1000 W |
| $P_{h2}$ = | 1000 W |

$P_{c1} = P_{h1} + P_{e1}$

$1500 = k_h f B_1^n + k_e (f t B_1)^2$

$2000 = k_h f B_2^n + k_e (f_2 t B_2)^2$

$\frac{P_{h2}}{P_{h1}} = \frac{f_2}{f_1} \cdot \left(\frac{B_2}{B_1}\right)^2$

$P_{h2} = P_{h1}$ — (1)

$\frac{P_{e2}}{P_{e1}} = \left(\frac{f_2}{f_1}\right)^2 * \left(\frac{B_2}{B_1}\right)^2$

$P_{e2} = 2 P_{e1}$ — (2)

~~solving for (1) and (2):~~

$\frac{240}{V_2} = \frac{25}{50} \cdot \frac{B_1}{B_2}$

$V_2 = (240)\left(\frac{50}{25}\right)\left(\frac{B_2}{B_1}\right)$

$V_2 = 339.36\ V$

$2000 = P_{h1} + 2 P_{e1}$

$1500 = P_{h1} + P_{e1}$

$500 = P_{e1} = 500W$ $\quad P_{e2} = 1000 W$

$P_{h1} = 1000W$

$P_{h2} = 1000W$

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**Question #3 (25 marks)** **SHOW YOUR CALCULATIONS** 25

The following measurements were obtained from tests carried out on a 10-kVA, 2300/230-V, 50-Hz distribution transformer:

| Test | O.C.T (HV winding open) | S.C.T (LV winding shorted) |
|---|---|---|
| Voltage | $V_{oc} = 230$ V | $V_{sc} = 120$ V |
| Current | $I_{oc} = 0.45$ A | $I_{sc} = 4.5$ A |
| Power | $P_{oc} = 70$ W | $P_{sc} = 240$ W |

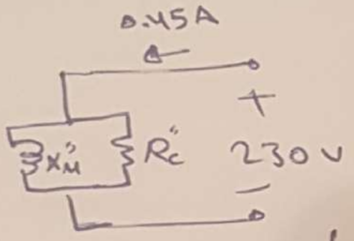
Draw and determine the equivalent circuit parameters of the transformer referred to the low-voltage side (secondary).

| | |
|---|---|
| $R''_C =$ | 769.23 Ω |
| $X''_M =$ | 694.44 Ω |
| $R''_{eq} =$ | 0.1185 Ω |
| $X''_{eq} =$ | 0.2384 Ω |

O.C.T (secondary) (LV)

$\cos\theta = \frac{P_{oc}}{I_{oc} \cdot V_{oc}}$

$\cos\theta = 0.676$

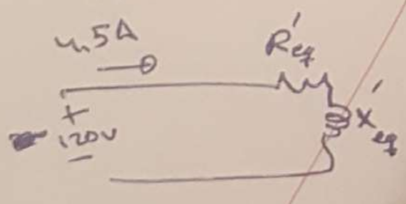



$Y'' = \frac{I_{oc}}{V_{oc}} \angle -\theta = (1.3 - j1.44)$ m ℧

$R_c'' = \frac{1}{1.3m} = 769.23$ Ω

$X_m'' = \frac{1}{1.44m} = 694.44$ Ω

S.C.T (primary HV) as $I_{rated\ primary} = \frac{10k}{2300} = 4.34$ A

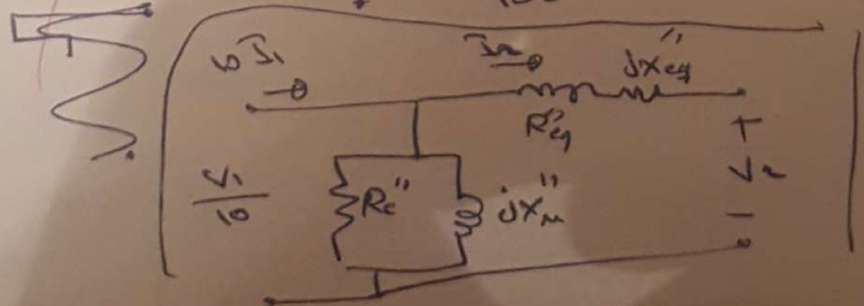



$Z' = \frac{V_{sc}}{I_{sc}} \angle \cos^{-1}\left(\frac{P}{I_{sc} V_{sc}}\right)$

$Z' = 11.85 + j23.89$ Ω

$R'_{eq} = 11.85$ Ω $X_{eq} = 23.89$ Ω

$R''_{eq} = \frac{11.85}{100}$ Ω $X''_{eq} = \frac{23.84}{100}$ Ω



**Question #4 (25 marks)** **SHOW YOUR CALCULATIONS**

A single-phase 10-kVA, 2200/220-V transformer has the following parameters:

$R_1 = 4.0\ \Omega$, $R_2 = 0.04\ \Omega$, $X_1 = 5.0\ \Omega$, $X_2 = 0.05\ \Omega$, $R_c = 35\ k\Omega$, $X_m = 4.0\ k\Omega$

The transformer is supplying its rated load to a load at 220 V and 0.8 PF lagging.

a. Draw the approximate equivalent circuit of this transformer, showing values of the elements referred to the high-voltage side (primary).
b. Determine the input voltage $V_1$ of the transformer to meet the above load.
c. Calculate the full-load voltage regulation at 0.8 PF lagging.
d. Calculate the full-load efficiency at 0.8 PF lagging.

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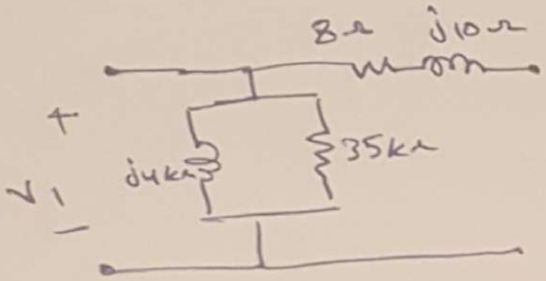
(a)



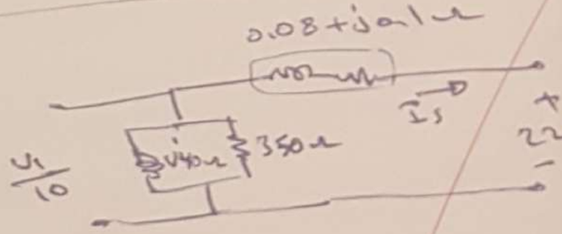

| | |
|---|---|
| $R_c$ = | 35 kΩ |
| $X_m$ = | 4 kΩ |
| $R'_{eq}$ = | 8 Ω |
| $X'_{eq}$ = | 10 Ω |
| $V_1$ = | 2256.4 V |
| % V.R FL | 2.56 % |
| % ηFL | 96.26 % |

?!

$P = VI \cos\theta$

$R_{eq_1} = R_1 + 100 R_2$

$X_{eq_1} = R_{eq_1} + 100 X_{eq_2}$




$I_s = \frac{10k}{220 \times 0.8}$

$I_s = \frac{10k}{220} \angle -\cos^{-1}(0.8)$

$I_s = 45.45 \angle -36.9$ A

$\frac{V_1}{10} = 220 + I_s(0.08 + j0.1)$

$\frac{V_1}{10} = 225.64 \angle 0.37$ V

(b) $|V_1| = 2256.4$ V

$P_{cu} = I_s^2 \times R''_{eq}$
$= (45.45)^2 \times 0.08$
$= 165.25$ W

(c) $VR = \frac{\frac{V_1}{10} - V_{fl}}{V_{fl}} \times 100\% = \frac{225.64 - 220}{220} \times 100\%$

$VR = 2.56\ \%$

(d) $\eta = \frac{P_{out}}{P_{out} + P_{cu} + P_{core}}$

$= \frac{10k \times 0.8}{10k \times 0.8 + 145.5 + 165.25}$ (= 96.26%)

$P_{core} = \frac{(\frac{V_1}{a})^2}{R_c''} = 145.5$ W