Power Engineering 3

Tutorial 3 (Transformers) Solutions

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Subject: TRANSFORMERS TUTORIAL Date: 24/2/11

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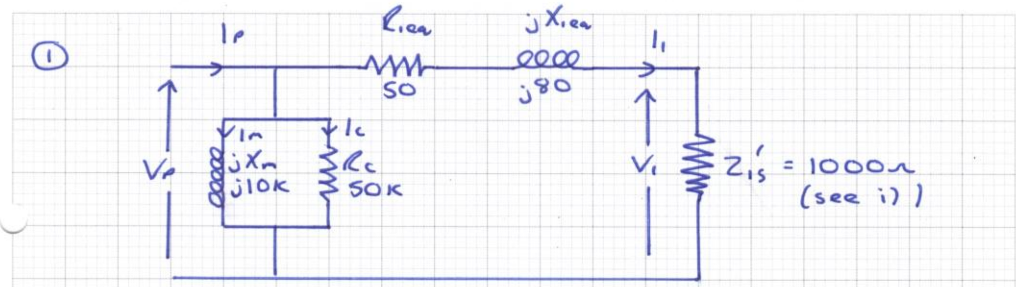

i) TURNS RATIO $= \dfrac{V_p}{V_{soc}} = \dfrac{10{,}000}{400} = \underline{\underline{25}}$

$$Z'_{1s} = \left(\frac{n_p}{n_s}\right)^2 Z_s = 25^2 \times 1.6 = \underline{\underline{1000\,\Omega}}$$

ii) $\bar{V}_p = \bar{I}_1 Z_T$ where $Z_T = 50 + j80 + 1000$

$Z_T = 1050 + j80$

$Z_T = 1053\angle 4.35°$

$$\Rightarrow \bar{I}_1 = \frac{\bar{V}_p}{Z_T}$$

$$\Rightarrow \bar{I}_1 = \frac{10{,}000\angle 0°}{1053\angle 4.35°} = \underline{\underline{9.5\angle -4.35°}}$$

$$\bar{I}_s = \left(\frac{n_p}{n_s}\right)\bar{I}_1 = 25 \times 9.5\angle -4.35° = \underline{\underline{237.5\angle -4.35°}}$$

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iii) $\bar{V}_1 = \bar{I}_1 . Z_{1s}'$

RESISTIVE COMPONENT

$\Rightarrow \bar{V}_1 = 9.5 \angle -4.35^\circ \times 1000 \angle 0^\circ$

$\Rightarrow \bar{V}_1 = \underline{\underline{9500 \angle -4.35^\circ}}$

$\bar{V}_S = \left(\frac{n_s}{n_p}\right) \bar{V}_1 = \frac{1}{25} \times 9500 \angle -4.35^\circ$

$\Rightarrow \bar{V}_S = \underline{\underline{380 \angle -4.35^\circ}}$

iv) IRON LOSS $P_{iron} = \frac{V_P^2}{R_C} = \frac{10{,}000^2}{50{,}000}$

$= \underline{\underline{2kW}}$

COPPER LOSS $P_{cu} = I_1^2 R_{1eq} = 9.5^2 \times 50$

$= 4512W = \underline{\underline{4.51kW}}$

v) MAGNETISING CURRENT $\bar{I}_m = \frac{\bar{V}_P}{jX_m} = \frac{10{,}000 \angle 0^\circ}{10{,}000 \angle 90^\circ} = \underline{\underline{1 \angle -90^\circ}}$

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(vi) $\bar{I}_p = \bar{I}_1 + \bar{I}_m + \bar{I}_c$

$\bar{I}_1 = 9.5\angle{-4.35^\circ} \equiv 9.47 - j0.75$

$\bar{I}_m = 1\angle{-90^\circ} \equiv 0 - j1$

$\bar{I}_c = \dfrac{\bar{V}_p}{R_c} = \dfrac{10{,}000\angle 0^\circ}{50{,}000\angle 0^\circ} = 0.2\angle 0^\circ \equiv 0.2 + j0$

$\Rightarrow \bar{I}_p = 9.47 - j0.75 - j1 + 0.2$

$\Rightarrow \bar{I}_p = 9.67 - j1.75 \equiv \underline{\underline{9.83\angle{-10.3^\circ}}}$

(vii) $\bar{V}_{R1eq} = \bar{I}_1 R_{1eq} = 9.5\angle{-4.35^\circ} \times 50\angle 0^\circ$

$\Rightarrow \bar{V}_{R1eq} = \underline{\underline{475\angle{-4.35^\circ}}}$

VOLTAGE DROP ACROSS R_{1eq}

$\bar{V}_{X1eq} = \bar{I}_1\, jX_{1eq} = 9.5\angle{-4.35^\circ} \times 80\angle 90^\circ$

$\Rightarrow \bar{V}_{X1eq} = \underline{\underline{760\angle 85.65^\circ}}$

VOLTAGE DROP ACROSS X_{1eq}

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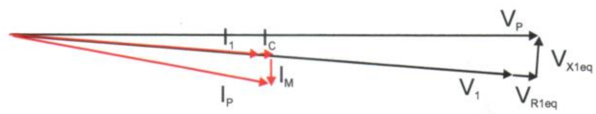
J.0625

Transformer Tutorial Q1

Phasor Arithmetic:

$V_P = V_1 + V_{R1eq} + V_{X1eq}$

$I_P = I_1 + I_M + I_C$



Scale 1cm = 1kV

Scale 1cm = 2A

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(2) VOLTAGE REGULATION $= \dfrac{V_{SOC} - V_{SL}}{V_{SOC}} \times 100\%$

$= \dfrac{400 - 380}{400} \times 100\%$

$= \underline{\underline{5\%}}$

Efficiency $= \dfrac{\text{OUTPUT POWER}}{\text{OUTPUT POWER + LOSSES}} \times 100\%$

$\Rightarrow$ Efficiency $= \dfrac{V_S I_S \cos\phi}{V_S I_S \cos\phi + P_{iron} + P_{cu}} \times 100\%$

$\Rightarrow$ Efficiency $= \dfrac{380 \times 237.5 \times \cos 0^\circ}{380 \times 237.5 \times 1 + 2000 + 4512} \times 100\%$

$\Rightarrow$ Efficiency $= \underline{\underline{93.3\%}}$

note V_S + I_S are in phase since load is totally resistive

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(5)

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(3) MAXIMUM EFFICIENCY IS WHEN COPPER LOSS EQUALS IRON LOSS

COPPER LOSS IS LOAD DEPENDANT + IRON LOSS IS NOT $\Rightarrow$

WANT COPPER LOSS = IRON LOSS = $\underline{\underline{2000\,W}}$

Therefore $I_1^2 R_{1eq} = 2000$

$$\Rightarrow I_1^2 = \frac{2000}{50} = 40$$

$$\Rightarrow I_1 = \underline{\underline{6.32\,A}}$$

$$|V_P| = |I_1|\,|Z_T| \qquad \text{where } Z_T = (Z_{1s}' + 50) + j80$$

call this A_1 for simplicity!

$$\Rightarrow |Z_T| = \frac{10{,}000}{6.32} = 1582.3$$

$$\Rightarrow |Z_T|^2 = 2503605$$

$$\Rightarrow (A_1 + 50)^2 + 80^2 = 2503605$$

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$$\Rightarrow \quad A_1^2 + 100A_1 + 2500 + 6400 = 2503605$$

$$\Rightarrow \quad A_1^2 + 100A_1 - 2494705 = 0$$

Solution $\quad A_1 = \dfrac{-b \pm (b^2 - 4ac)^{\frac{1}{2}}}{2a}$

$$\Rightarrow \quad A_1 = \frac{-100 \pm (10000 + 9978820)^{\frac{1}{2}}}{2}$$

$$\Rightarrow \quad A_1 = \frac{-100 + 3160}{2}$$

$$\Rightarrow \quad A_1 = 1530 = Z_{1s}'$$

$\Rightarrow$ ACTUAL SECONDARY LOAD RESISTANCE

$$Z_L = \left(\frac{n_s}{n_p}\right)^2 . Z_{1s}' = \left(\frac{1}{25}\right)^2 \times 1530$$

$$\Rightarrow \quad Z_L = \underline{\underline{2.45\,\Omega}}$$

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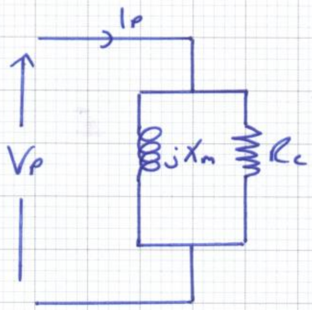
(4) OPEN CIRCUIT TEST :



TURNS RATIO

$$\frac{n_p}{n_s} = \frac{V_p}{V_{soc}} = \frac{230}{110}$$

$$= \underline{\underline{2.09}}$$

$$P_{in} = \frac{V_p^2}{R_c} \Rightarrow R_c = \frac{V_p^2}{P_{in}} = \frac{230^2}{30}$$

$$\Rightarrow R_c = \underline{\underline{1763\,\Omega}}$$

Apparent Power $S = V_p I_p = 230 \times 2 = 460\text{VA}$

$$Q^2 = S^2 - P^2 = 460^2 - 30^2 = 210700$$

$$\Rightarrow Q = 459\text{ VAr}$$

$$Q = \frac{V_p^2}{X_m} \Rightarrow X_m = \frac{V_p^2}{Q} = \frac{230^2}{459} = \underline{\underline{115\,\Omega}}$$

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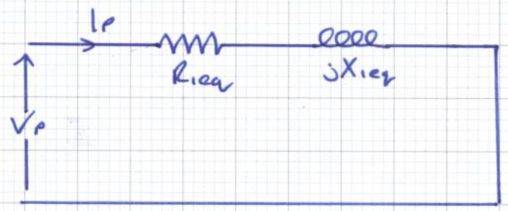
SHORT CIRCUIT TEST



$$P_{in} = I_p^2 R_{1eq} \Rightarrow R_{1eq} = \frac{P_{in}}{I_p^2} = \frac{200}{22^2}$$

$$\Rightarrow \underline{\underline{R_{1eq} = 0.41\,\Omega}}$$

Apparent Power $S = V_p I_p = 40 \times 22 = 880\,VA$

$$Q^2 = S^2 - P^2 = 880^2 - 200^2 = 734400$$

$$\Rightarrow Q = 856\,VAr$$

$$Q_{in} = I_p^2 X_{1eq} \Rightarrow X_{1eq} = \frac{Q_{in}}{I_p^2} = \frac{856}{22^2}$$

$$\cancel{\Rightarrow Q_{in} =} \quad \underline{\underline{X_{1eq} = 1.76\,\Omega}}$$

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5 $V_{rms\text{-}max} = 4.44\, N\, f\, B_{max}\, A_c$

A_c is cross sectional Area to flow of flux:

$\Rightarrow A_c = 20\times10^{-3} \times 30\times10^{-3} = 600\times10^{-6}\ m^2 \times$ STACK FACTOR

$\Rightarrow V_{rms\text{-}max} = 4.44 \times 200 \times 50 \times 1.3 \times 600\times10^{-6} \times$ STACK FACTOR

$\Rightarrow V_{rms\text{-}max} = \underline{\underline{34.6\,V}} \times 0.95 = \underline{\underline{32.9\,V}}$

Current max

Current Density Limit (A/mm²)

Area (mm²)

Fill Factor

$$\text{Current max} = \frac{J \times \overbrace{40\times25} \times 0.8}{N}$$

Number of Turns

$$\Rightarrow \text{Current max} = \frac{2\times40\times25\times0.8}{200}$$

$\Rightarrow$ Current max $= \underline{\underline{8\,A}}$

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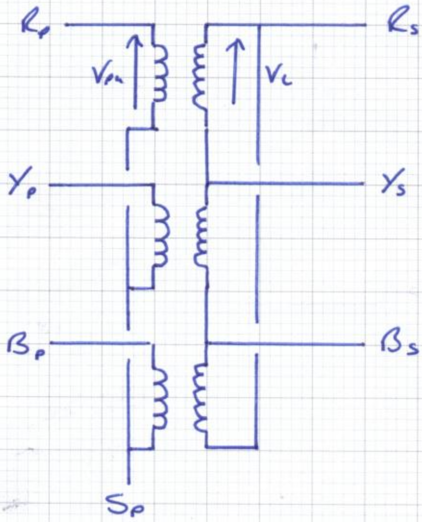
(6) Input Line Voltage = 12 kV

Output line Voltage = 6.6 kV

Wired as YΔ :



⇒ SECONDARY LINE VOLTAGE LAGS PRIMARY LINE VOLTAGE BY 30°

$$\text{BANK RATIO} = \frac{V_{LP}}{V_{LS}} = \frac{12000}{6600} = \underline{\underline{1.818}}$$

$$\text{PHASE RATIO} = \frac{1}{\sqrt{3}} \cdot \text{BANK RATIO} = \underline{\underline{1.051}}$$

(TURNS RATIO)

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