Design Project

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EEE 3003 Electromechanical Energy Conversion

→ In a transformer, its excitation branch components, series impedances, and in addition various losses voltage regulation and efficiency are very essential quantities that describe a transformer.

All of these quantities can be determined from a small set of initial data about the transformer and a few experimental tests, namely the open- & short-circuit test.

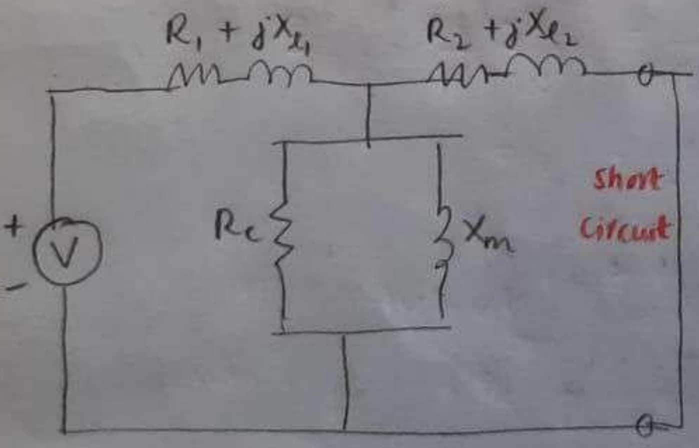
→ Suppose the given transformer is a 15KVA, 2300/230 V transformer, and its open and short circuit test results are:-

open circuit test → $V_{oc} = 230V$, $I_{oc} = 2.1A$, $P_{oc} = 50W$

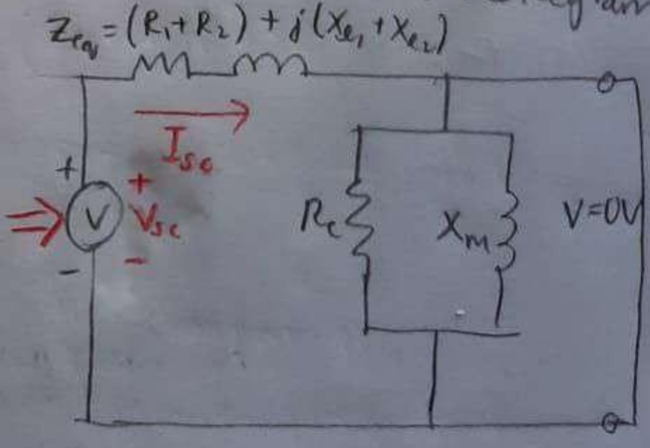
short circuit test → $V_{sc} = 47V$, $I_{sc} = 6.0A$, $P_{sc} = 160W$

→ The given transformer is a step-down one with rated primary voltage, $V_1 = 2300V$ & secondary, $V_2 = 230V$ and turns ratio, $a = 10$

→ since in short circuit test, the low voltage (here, secondary) side is short circuited and measurements are taken on the high-voltage (primary) side; we have the schematic diagram



HV primary ; LV secondary



when Z_{eq} referred to primary

now the series equivalent impedance, Z_{eq} can be found:-

$$\text{power factor} = PF = \cos\theta = \frac{P_{sc}}{V_{sc} I_{sc}} = \frac{160W}{(47V)(6A)} = 0.567$$

then:- $\theta = \cos^{-1}(PF) = 55.4^\circ$

then:- $Z_{eq} = \frac{V_{sc}}{I_{sc}\angle -\theta} = \frac{47V}{6A}\angle 55.4^\circ =$

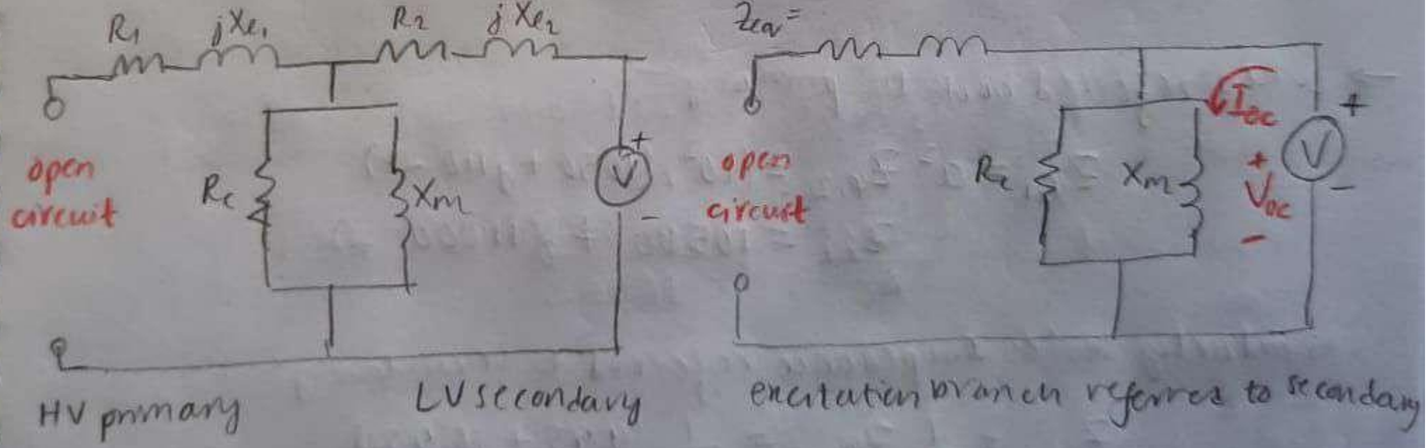
$$\boxed{Z_{eq} = 7.83\angle 55.4^\circ \ \Omega}$$

OR $R_{eq} = \frac{P_{sc}}{I_{sc}^2} = |Z_{eq}|\cos\theta = \boxed{4.45\ \Omega}$

and $X_{eq} = \sqrt{|Z_{eq}|^2 - R_{eq}} = |Z_{eq}|\sin\theta = \boxed{6.45\ \Omega}$

hence:- $\boxed{Z_{eq} = R_{eq} + jX_{eq} = 4.45 + j6.45\ \Omega}$

→ In an open circuit test, the HV side (primary) is open-circuited and measurements are taken on the LV (secondary) side, so:-



now the excitation branch impedance, Z_φ can be found:-

$$\text{power factor} = PF = \cos\theta = \frac{P_{oc}}{V_{oc} I_{oc}} = \frac{50W}{230V \cdot 2.1A} = 0.103$$

$$\theta = \cos^{-1}(PF) = 84.1^\circ$$

the excitation branch impedance corresponds to the parallel admittance, Y_φ, so:-

$$Y_\varphi = \frac{I_{oc}}{V_{oc}} \angle -\theta = \frac{2.1A}{230V} \angle -84.1^\circ$$

$$\boxed{Y_\varphi = 0.00913 \angle -84.1^\circ \, S}$$

where conductance:- $G_\varphi = |Y_\varphi| \cos(-84.1^\circ) = \boxed{0.00954 \, S}$

and susceptance:- $B_\varphi = |Y_\varphi| \sin(-84.1^\circ) = \boxed{-0.00908 \, S}$

then:- $\boxed{Y_\varphi = 0.00954 - j0.00908 \, S}$

then:- resistance:- $R_c = \frac{1}{G_\varphi} = \boxed{1050 \, \Omega}$

and reactance:- $|X_m| = \frac{1}{|B_\varphi|} = \boxed{110 \, \Omega}$

and Impedance:- $\boxed{Z_\varphi = R_c + jX_m = 1050 + j110 \, \Omega}$

→ when referred back to primary:-

$$Z_{\varphi,1} = a^2 Z_{\varphi,2} = (10^2)(1050 + j110 \, \Omega)$$

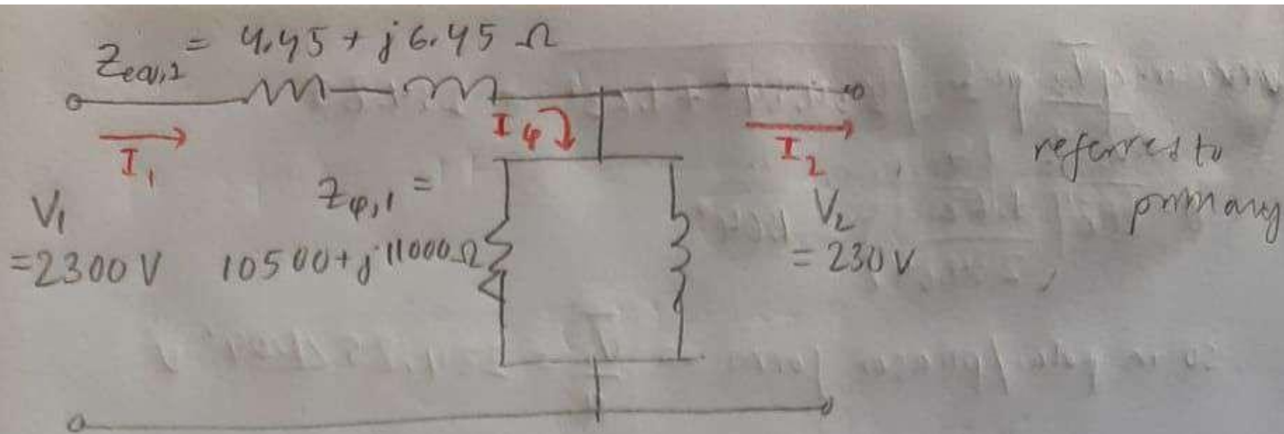
$$\boxed{Z_{\varphi,1} = 10500 + j11000 \, \Omega}$$

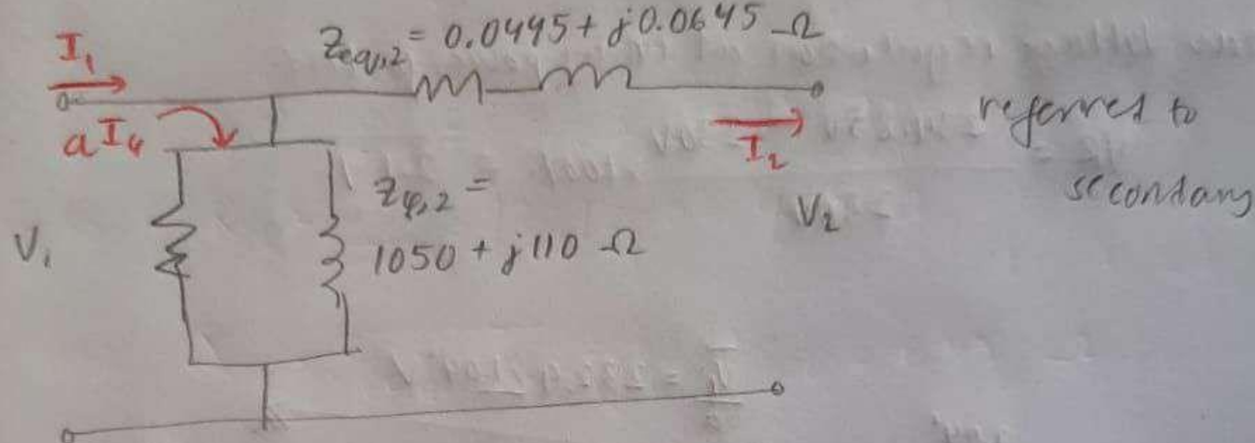
similarly series impedance referred to secondary:-

$$Z_{eq,2} = \frac{1}{a^2} Z_{eq,1} = \frac{1}{10^2}(4.45 + j6.45 \Omega)$$

$$\boxed{Z_{eq,2} = 0.0445 + j0.0645 \, \Omega}$$

then schematic symbols when components are referred to primary and secondary, respectively:-





→ The voltage regulation of a transformer is defined as

$$VR = \frac{V_{2,nl} - V_{2,fl}}{V_{2,fl}} \times 100\%$$

where at no load, secondary voltage → $V_{2,nl} = \frac{V_1}{a}$

which can be determined from the transformer phasor diagram

$$\frac{\vec{V}_1}{a} = \vec{V}_2 + R_{eq} \bar{I}_2 + jX_{eq} \bar{I}_2$$

but first $|I_2|$ = full load current on secondary $= \frac{S_{rated}}{V_{2,rated}} = \frac{15000\ VA}{230\ V} = \boxed{65.2\ A}$

assuming unity power factor → $I_2 = |I_2| \angle 0 = |I_2| \angle \cos^{-1} PF$

$$I_2 = 65.2 \angle 0 = 65.2\ A$$

then:- $\frac{\vec{V}_1}{a} = 230\angle 0°\ V + (0.0445\ \Omega)(65.2\angle 0°\ A) + j(0.0645\ \Omega)(65.2\angle 0\ A)$

$= 230\angle 0°\ V + 2.9\angle 0°\ V + j4.21\angle 0°\ V$

$$\boxed{\frac{\vec{V}_1}{a} = 232.9 + j4.21}$$

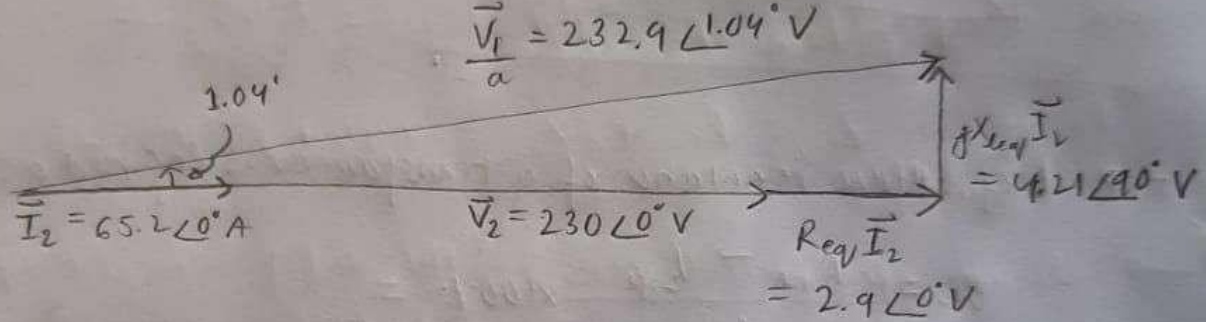
where $\left|\frac{\vec{V}_2}{a}\right| = \sqrt{234.84^2 + 1.62^2} = 234.85$

$\theta = \tan^{-1}\left(\frac{1.62}{234.84}\right) = 1.04°$

so in polar/phasor form $\rightarrow$ $\boxed{\frac{\vec{V}_2}{a} = 234.85\angle 1.04° \text{ V}}$

now voltage regulation at unity powerfactor.

$$VR = \frac{234.85\text{V} - 230\text{V}}{230\text{V}} \times 100\% = \boxed{2.1\%}$$



$\rightarrow$ the transformer losses can be determined:

copper loss $= P_{cu} = I_2^2 R_{eq} = (65.2)^2(0.0445\,\Omega) = \boxed{189 \text{ W}}$

core losses $= P_{core} = \frac{(V_{2,nc})^2}{R_c} = \frac{(234.85\text{ V})^2}{1050\,\Omega} = \boxed{52.5 \text{ W}}$

= hysteresis & eddy

$\rightarrow$ transformer efficiency is:

power output $= P_{out} = P_2 = V_2 I_2 \cos\theta = S_{2,rated} = \boxed{15,000 \text{ W}}$

power input $= P_{in} = P_{out} + P_{losses} = P_2 + P_{cu} + P_{core}$

$= 15,000\text{W} + 189\text{ W} + 52.5\text{ W} = \boxed{15241.5\text{W}}$

then efficiency $= \eta = \frac{P_{out}}{P_{in}} \times 100\% = \frac{P_2}{P_1 + P_{cu} + P_{core}} \times 100\%$

$$\boxed{\eta = 98.41\%}$$