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EE100: Assignment 3

5 Problems from Practice Set 2.1

Q.1 (2 of Problems Ch.14) Determine the coefficient of coupling when $L_M = 1\ \mu H$, $L_1 = 8\ \mu H$ and $L_2 = 2\ \mu H$.

$$\because \quad L_M = k\sqrt{L_1 \cdot L_2}$$

$$k = \frac{L_M}{\sqrt{L_1 \cdot L_2}}$$

$$k = \frac{1\mu}{\sqrt{8\mu \times 2\mu}}$$

$$\boxed{k = \frac{1}{4}}$$

Hence, coefficient of coupling is 0.25.

Q.2 (4 of Problems Ch.14) A certain transformer has 250 turns in its primary winding. In order to double the voltage, how many turns must be in the secondary winding?

Let primary voltage V_p be V.

$\therefore$ secondary voltage V_s is 2V.

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$$\because \frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$\therefore N_s = N_p \cdot \frac{V_s}{V_p}$$

$$N_s = 250 \cdot \frac{2V}{V}$$

$$\boxed{N_s = 500}$$

There must be 500 turns in the secondary winding in order to double the voltage.

Q.3 (9 of Problems Ch.14) To step 120 V down to 30 V, what must the turn ratio be?

$$\because \frac{V_p}{V_s} = a$$

$$\therefore a = \frac{120}{30}$$

$$a = 4 \qquad \left(a = \frac{N_p}{N_s}\right)$$

$\therefore$ the turn ratio should be 4 in order to step-down the 120 V to 30 V.

Q.4 (14 of Problems Ch.14) Determine I_{sec} in the figure. What is the value of R_L?

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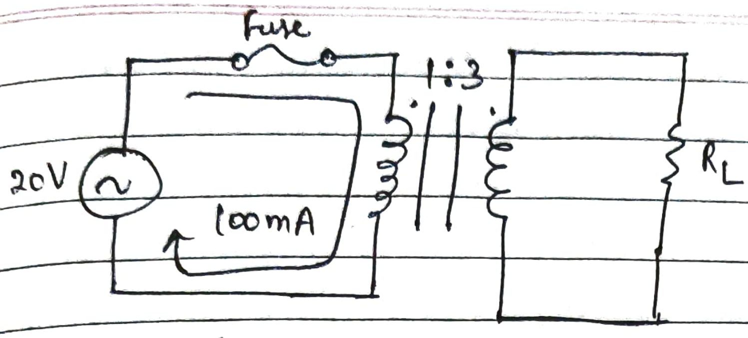

the turn ratio is given, $a = \frac{1}{3}$

$\because \frac{I_{pri}}{I_{sec}} = \frac{1}{a}$

$\therefore I_{sec} = a\,(I_{pri})$

$I_{sec} = \frac{1}{3}(100mA)$ $(I_{pri} = 100mA)$

$$\boxed{\therefore I_{sec} = \frac{100mA}{3}}$$

and, $\because V_{sec} = \frac{V_{pri}}{a}$

$\therefore V_{sec} = \frac{20 \times 3}{1}$

$$\boxed{\therefore V_{sec} = 60\ V}$$

Using Ohm's Law, in secondary circuit,

$R_L = \frac{V_{sec}}{I_{sec}} = \frac{60 \times 3}{100 \times 10^{-3}}$

$$\boxed{\therefore R_L = 1.8\ k\Omega}$$

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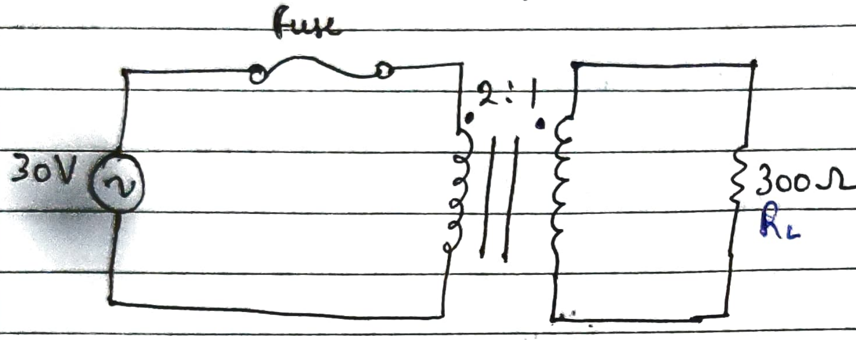
Q.5 (15 of Problems Ch.14) Determine the following quantities in the given circuit

(a) Primary current (b) Secondary current
(c) Secondary voltage (d) Power in the load.



given, $a = 2$
$V_p = 30\ V$

$\because \frac{V_p}{V_s} = a$

$\therefore V_s = \frac{30V}{2}$

$$\boxed{V_s = 15\ V}$$

Using Ohm's law in secondary circuit,

$$I_s = \frac{V_s}{R_L} = \frac{15}{300} = 50\,mA$$

$$\boxed{I_s = 50\ mA}$$

$\because \frac{I_p}{I_s} = \frac{1}{a}$

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$$\therefore \quad I_p = \frac{50\,mA}{2}$$

$$\boxed{I_p = 25\,mA}$$

power in the load, $P_L = I_s^2 R_L$

$$= (50 \times 10^{-3})^2 \times 300$$

$$\boxed{P_L = 750\,mW}$$

(a) Primary current = 25 mA
(b) Secondary current = 50 mA
(c) Secondary voltage = 15 V
(d) Power in the load = 750 mW

Any 5 problems from Practice Set 2.2

Q.6 (2nd of Chapman Chapter 2) A single phase ~~transformer~~ power system is shown. The power source feeds a 100 KVA 14/2.4 KV transformer through a feeder impedance of $38.2 + j140\,\Omega$. The transformer's equivalent series impedance referred to its low-voltage side is $0.10 + j0.4\,\Omega$. The load on the transformer is 90KW at 0.8 PF lagging and 2300 V.

(a) What is the voltage at the power source of the system?
(b) What is the voltage regulation of the transformer?
(c) What is the efficiency of the system?

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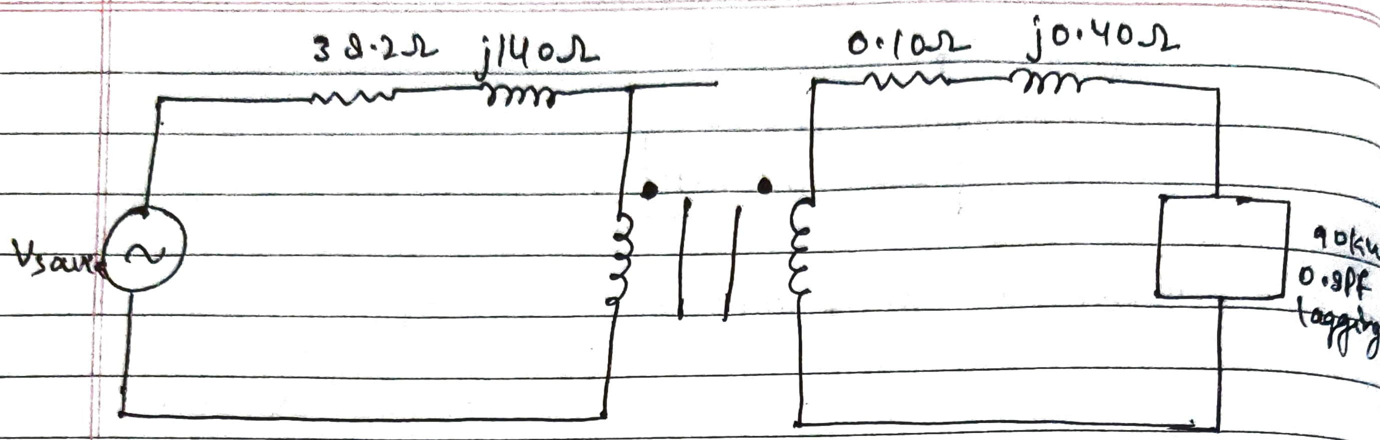

The turn ratio 'a' of transformer is $= \frac{14}{2.4} = 5.833$.

Let us refer the circuit to secondary side,

∴ feeder's impedance to secondary side will be $= \frac{(38.2 + j\,140)\,\Omega}{a^2}$

$= (1.12 + j\,4.12)\,\Omega$

The secondary current I_s is given by,

$$I_s = \frac{90\text{ kW}}{(2400)(0.8)} = 46.88\text{ A}$$

∵ the power factor is 0.8 and lagging, so the impedance angle is $\theta = \cos^{-1}(0.8) = 36.87^\circ$ and the phasor current is

$$I_s = 46.88\,\angle{-36.87^\circ}\text{ A}$$

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(a) The voltage at the power source of this system referred to secondary side is

$$V_{source,s} = V_s + I_s Z_{line,s} + I_s Z_{eq}$$

$$V_{source,s} = 2400\angle 0^\circ + 46.88\angle -36.87^\circ (1.22 + j4.51)$$

$$= 2576\angle 3^\circ \text{ V}$$

$\therefore$ voltage at power source $= 2576\angle 3^\circ \times a$

$= 2576\angle 3^\circ \times 5.833$

$$\boxed{\text{Voltage at power source} = 15.05\angle 3^\circ \text{ KV}}$$

(b) To find the voltage regulation, we must find the voltage at primary of transformer (referred to secondary) V_p'.

$$V_p' = V_s + I_s Z_{eq}$$

$$V_p' = 2400\angle 0^\circ + (46.88\angle -36.87^\circ)(0.10 + j0.40\,\Omega)$$

$$= 2415\angle 0.3^\circ \text{ V}$$

There is a voltage drop of 15 V under these load conditions. Therefore, voltage regulation of the transformer is

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$$\boxed{VR = \frac{2415 - 2400}{2400} \times 100\% = 0.63\%}$$

(c) The overall efficiency of the power system will be ratio of output power to input power.

output power = 90 KW

input power $P_{IN} = P_{out} + P_{loss}$

$= P_{out} + I^2R$

$= (90\ KW) + (46.00)(1.22\ \Omega)$

$= 92.68\ KW$

$$\therefore \boxed{\eta = \frac{90\ K}{92.68\ K} \times 100\% = 97.1\%}$$

Q.7 (3 of Chapman) The secondary winding of an ideal transformer has a terminal voltage of $V_s(t) = 282.8 \sin(377t)$ V. The turn ratio of the transformer is 100 : 200. If the secondary current of the transformer is $i_s(t) = 7.07 \sin(377t - 36.87°)$, what is the primary current of this transformer? What are its voltage regulation and efficiency?

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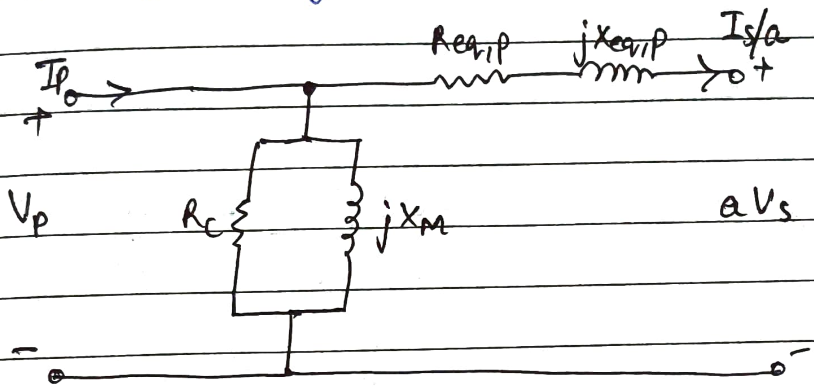
The impedances of the transformer referred to primary side are

$R_{eq} = 0.20\Omega$ $R_C = 300\Omega$

$X_{eq} = 0.80\Omega$ $X_m = 100\Omega$

The equivalent circuit (referred to primary side) is given.



the secondary voltage (in rms)

$$V_s = \frac{282.8}{\sqrt{2}} \angle 0° = 200 \angle 0° \text{ V}$$

and secondary current (rms),

$$I_s = \frac{7.07}{\sqrt{2}} \angle -36.87° = 5 \angle -36.87° \text{ A}$$

the secondary voltage reffered to primary side is

$$V_s' = aV_s = 0.5 V_s = 100 \angle 0° \text{ V}$$

the secondary current reffered to primary side,

$$I_s' = I_s/a = 10 \angle -36.87° \text{ A}$$

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the primary circuit voltage, therefore, is

$$V_P = V_S' + I_S'(R_{eq} + jX_{eq})$$

$$V_P = 100\angle 0^\circ + 10\angle -36.87^\circ (0.20 + j\,0.80\,\Omega)$$

$$= 106.5\angle 2.8^\circ \text{ V}$$

The excitation current of this transformer is,

$$I_{Ex} = I_C + I_M = \frac{106.5\angle 2.8^\circ}{300\angle 0^\circ} + \frac{106.5\angle 2.8^\circ}{j00\angle 90^\circ}$$

$$I_{ex} = 1.12\angle -68.8^\circ \text{ A}$$

$\therefore$ total primary current of the transformer,

$$I_P = I_S' + I_{ex} = 10\angle -36.87^\circ + 1.12\angle -68.8^\circ$$

$$= 11\angle -40^\circ \text{ A}$$

$\therefore$ voltage regulation of transformer

$$VR = \frac{V_P - aV_S}{aV_S} \times 100\%$$

$$\boxed{VR = \frac{106.5 - 100}{100} \times 100 = 6.5\%}$$

input power to the transformer $P_{IN} = V_P I_P \cos\theta$

$$P_{IN} = (106.5)(11\,A)\cos(2.8-(-40))$$

$$P_{IN} = (106.5)(11)\cos(42.8)$$

$$P_{IN} = 860\,W$$

The output power, $P_{out} = V_s I_s \cos\theta$

$$= (200)(5)\cos(36.87)$$

$$= 800\,W$$

$$\therefore \boxed{\text{efficiency} = \frac{800}{860} \times 100\% = 93.0\%}$$

Q. (6 of Chapman) A 1000 VA 230/115 V transformer has been tested to determine its equivalent circuit. The results of the test are

OC test (on secondary)	SC test (primary)
$V_{OC} = 115\,V$	$V_{SC} = 17.1\,V$
$I_{OC} = 0.11\,A$	$I_{SC} = 8.7\,A$
$P_{OC} = 3.9\,W$	$P_{SC} = 38.1\,W$

(a) Find the equivalent circuit of this transformer referred to low-voltage side.

(b) Find the transformer's volltage regulation at rated conditions and

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(1) 0.8 PF lagging
(2) 1 PF
(3) 0.8 PF leading

(e) Determine its efficiency at rated conditions and 0.8 PF lagging.

(a)

Open-circuit Test (referred to secondary)

$$\phi = \cos^{-1}\left(\frac{P_{oc}}{I_{oc} \cdot V_{oc}}\right) = \cos^{-1}\left(\frac{3.9}{(115)(0.11)}\right)$$

$$\phi = 72^\circ$$

$$|Y_E| = \frac{I_{oc}}{V_{oc}} = \frac{0.11}{115} = 0.0009565 \text{ S}$$

$$Y_E = 0.0009565 \angle -72^\circ \text{ S}$$

$$Y_E = 0.0002956 - j\,0.0009096 \text{ S}$$

$$\because Y_E = \frac{1}{R_C} - j\frac{1}{X_m}$$

$$R_{cS} = \frac{1}{0.0002956}\,\Omega = 3382.9\,\Omega$$

$$X_{mS} = \frac{1}{0.0009096}\,\Omega = 1099.4\,\Omega$$

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Short-Circuit Test

$$\theta = \cos^{-1}\left(\frac{P_{sc}}{V_{sc} I_{sc}}\right) = \cos^{-1}\left(\frac{38.1}{17.1 \times 8.7}\right)$$

$$\theta = 75.2^\circ$$

$$|Z_E| = \frac{V_{sc}}{I_{sc}} = \frac{17.1}{8.7} = 1.97\,\Omega$$

$$\because Z_E = R_{eq} + j X_{eq}$$

$$R_{eq,P} = 1.97 \cos(75.2^\circ)$$
$$= 0.503\,\Omega$$

$$X_{eq,P} = 1.97 \sin(75.2^\circ)$$
$$= 1.905\,\Omega$$

the low-voltage side is the secondary side.

$$\therefore R_{eq,S} = (R_{eq,P})\left(\frac{115}{230}\right)^2$$
$$= 0.126\,\Omega$$

$$X_{eq,S} = X_{eq,P}\left(\frac{115}{230}\right)^2$$

$$= 0.476\,\Omega$$

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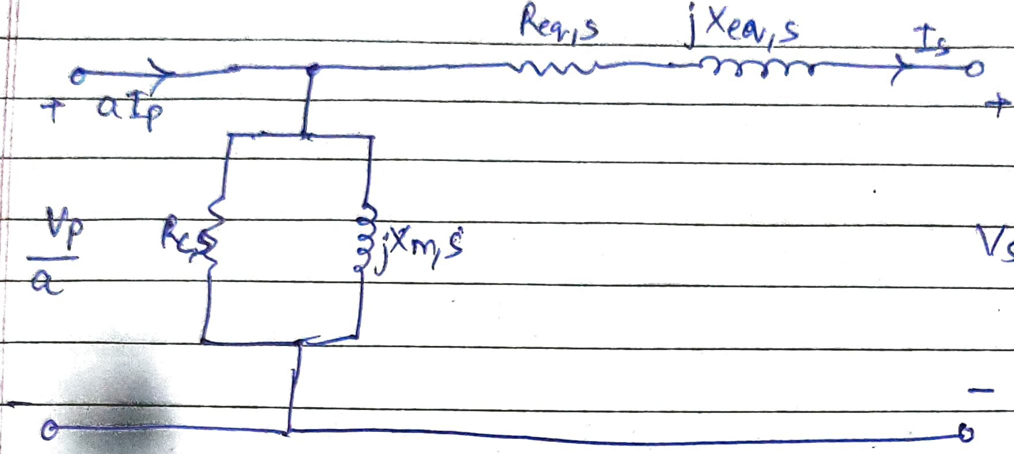
- equivalent circuit of the transformer referred to secondary is



$R_{eq,S} = 0.126\,\Omega$

$X_{eq,S} = 0.476\,\Omega$

$R_{C,S} = 3382.9\,\Omega$

$X_{m,S} = 1099.4\,\Omega$

(b) The rated secondary current is,

$$I_S = \frac{1000}{115} = 8.70\text{ A}$$

We will now calculate primary voltage referred to secondary side and use voltage regulation equation for each power factor.

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(1) 0.8 PF lagging -

$V_p' = V_s + I_s (Z_{eq})$

$= 115\angle 0^\circ + 8.7\angle -36.87^\circ \,(0.126 + j0.476)$

$V_p' = 118.4 \angle 1.3^\circ$ V

$$\therefore \boxed{VR = \frac{118.4 - 115}{115} \times 100\% = 2.96\%}$$

(2) 1 PF -:

$V_p' = V_s + Z_{eq} I_s = 115\angle 0^\circ \text{ V} + 8.7\angle 0^\circ (0.126 + j0.476)$

$V_p' = 116.2 \angle 2.04^\circ$ V

$$\boxed{VR = \frac{116.2 - 115}{115} \times 100\% = 1.04\%}$$

(3) 0.8 PF leading -:

$V_p' = V_s + I_s Z_{eq} = 115\angle 0^\circ + 8.7\angle -36.87^\circ (0.126 + j0.476)$

$V_p' = 113.5 \angle 2^\circ$ V

$$\boxed{VR = \frac{113.5 - 115}{115} \times 100\% = -1.3\%}$$

(c) At rated conditions and 0.8 PF lagging, the output power

$$P_{out} = V_s I_s \cos\theta = (115)(8.7)(0.8)$$
$$= 800 W$$

The copper and core losses are,

$$P_{cu} = I_s^2 R_{eq,s} = (8.7)^2 \times (0.126) = 9.5 W$$

$$P_{core} = \frac{(V_P')^2}{R_c} = \frac{(118.4)^2}{3383} = 4.1 W$$

$\therefore$ efficiency $\eta = \frac{P_{out}}{P_{out} + P_{cu} + P_{core}}$

$$= \frac{800}{813.6} \times 100\%$$

$$\boxed{\eta = 98.3\%}$$

Q.9 (7 of Chapman) A 30-KVA, 8000/230V distribution transformer has an impedance referred to primary of $20 + j100\,\Omega$. The components of the excitation branch referred to the primary side are $R_c = 100\,K\Omega$ and $X_m = 20\,K\Omega$.

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(a) If the primary voltage is 7967 V and the load impedance is $Z_L = 2 + j0.7\,\Omega$, what is the secondary voltage of the transformer? What is the voltage regulation of the transformer?

(b) If the load is disconnected and a capacitor of $-j3.0\,\Omega$ is connected in its place, what is the secondary voltage of transformer? What is its voltage regulation?

(a) the turn ratio is $a = \frac{8000}{230} = 34.78$.

thus the load impedance referred to primary side is,

$$Z_{L,P} = (34.78)^2 (2 + j0.7)$$

$$Z_{LP} = (2419.3 + j\,846.8)\ \Omega$$

$\therefore$ the referred secondary current is

$$I'_{sp} = \frac{7967\angle 0^\circ}{(20 + j100) + (2419 + j846.8)}$$

$$I'_s = \frac{7967\angle 0^\circ}{2616\angle 21.2^\circ} = 3.045\angle -21.2^\circ\ A$$

and the referred secondary voltage

$$V'_s = I'_s Z_L = 3.045\angle -21.2^\circ\,(2419 + j846.8)$$

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$$V_s' = 7804 \angle -1.9 \ V$$

∴ the actual secondary voltage,

$$V_s = \frac{V_s'}{a} = \frac{7804 \angle -1.9^\circ}{34.78}$$

$$\boxed{V_s = 224.4 \angle -1.9^\circ \ V}$$

∴ Voltage regulation

$$VR = \frac{7967 - 7804}{7804} \times 100\%$$

$$\boxed{VR = 2.09\%}$$

(b) Load impedance referred to primary side

$$Z_{LP} = (34.78)^2 (-j \, 3\Omega)$$

$$= -j \, 3629 \ \Omega$$

∴ referred secondary current

$$I_s' = \frac{7967 \angle 0^\circ \ V}{(20 + j100) + (-j3629)} = \frac{7967 \angle 0^\circ}{3529 \angle -89.7^\circ}$$

$$I_s' = 2.258 \angle 89.7^\circ \ A$$

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and the referred secondary voltage

$$V_s' = I_s' Z_L' = (2.258 \angle 89.7^\circ)(-j\,3629\,\Omega)$$

$$V_s' = 8194 \angle -0.3^\circ \text{ V}$$

∴ actual secondary voltage

$$\boxed{V_s = \frac{V_s'}{a} = \frac{8914 \angle -0.3^\circ}{34.78} = 256.3 \angle -0.3^\circ \text{ V}}$$

∴ voltage regulation,

$$VR = \frac{7967 - 8914}{8194} \times 100\%$$

$$\boxed{VR = -10.6\%}$$

Q.10 (20 of chapman) A 50 kVA 20k/480V 60Hz single phase distribution transformer is tested with the following results

OC test

secondary

$V_{oc} = 480$ V

$I_{oc} = 4.1$ A

$P_{oc} = 620$ W

SC test

primary

$V_{sc} = 1130$ V

$I_{sc} = 1.3$ A

$P_{sc} = 550$ W

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(a) Find per-unit equivalent circuit for the transformer at 60 Hz.
(b) What is efficiency of transformer at rated conditions and unity PF? What is voltage regulation at these conditions.
(c) What would the ratings of this transformer be if it were operated on a 50 Hz power system?
(d) Sketch the equivalent circuit of this transformer referred to primary side if it is operating at 50 Hz.
(e) What is the efficiency at rated conditions on 50 Hz power system, 1 PF. Calculate voltage regulation.
(f) How does the efficiency of a transformer at rated conditions and 60 Hz compare to the same physical device running at 50 Hz?

(a) base impedance referred to primary side

$$Z_{base,P} = \frac{V_p^2}{S} = \frac{(20K)^2}{50\,KVA} = 8\,K\Omega$$

base impedance referred to secondary side

$$Z_{base,S} = \frac{V_S^2}{S} = \frac{(480)^2}{50K} = 4.608\,\Omega$$

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OC test

$$\theta = -\cos^{-1}\left(\frac{P_{oc}}{I_{oc} \cdot V_{oc}}\right) = -\cos^{-1}\left(\frac{620\,W}{(480)(4.1)}\right)$$

$$\theta = -71.6^\circ$$

$$|Y_{ex}| = \frac{I_{oc}}{V_{oc}} = \frac{4.1}{480} = 0.00854\,S$$

$$Y_{ex} = \frac{1}{R_c} - \frac{j}{X_m} = 0.00854\angle{-71.6^\circ}$$

$$R_c = 370\,\Omega \text{ and } X_m = 123\,\Omega$$

excitation branch elements can be expressed in per unit as

$$R_c = \frac{370}{4.608} = 80.3\text{ pu}$$

$$X_m = \frac{123}{4.608} = 26.7\text{ pu}$$

SC test

$$|Z_e| = \frac{V_{sc}}{I_{sc}} = \frac{1130}{1.3} = 869\,\Omega$$

$$\theta = \cos^{-1}\left(\frac{P_{sc}}{I_{sc} \cdot V_{sc}}\right) = \cos^{-1}\left(\frac{550}{1130 \times 1.3}\right) = 68^\circ$$

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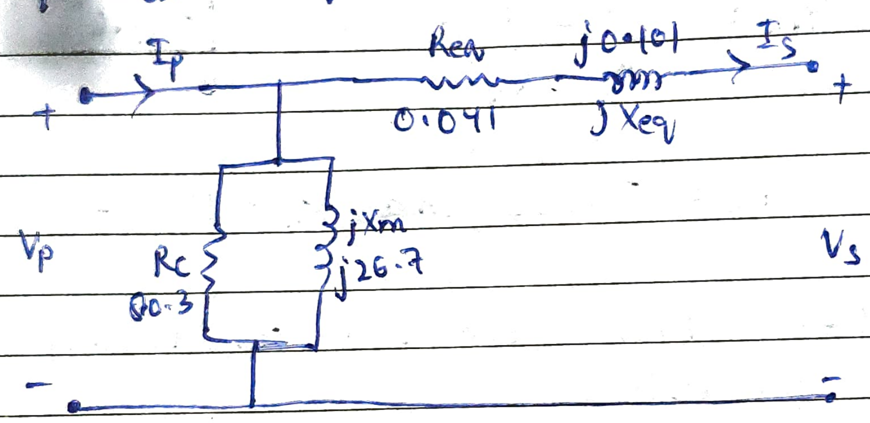
$Z_{eq} = R_{eq} + j X_{eq} = 869 \angle 68^\circ = (326 + j\,806)\,\Omega$

$\therefore$ per unit impedances

$$R_{eq} = \frac{326}{8000} = 0.041 \text{ pu}$$

$$X_{eq} = \frac{806}{8000} = 0.101 \text{ pu}$$

$\therefore$ per-unit equivalent circuit



(b) per unit primary voltage at rated conditions and 1 PF

$$V_p = V_s + I_s Z_{eq}$$

$$V_p = 1\angle 0^\circ + 1\angle 0^\circ\,(0.041 + j\,0.101)$$

$$V_p = 1.046 \angle 5.54^\circ \text{ pu}$$

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per unit power consumed by Req

$$P_{eq} = I^2 R = (1\,pu)^2\,(0.041\,pu) = 0.041\,pu$$

per unit power consumed by Rc

$$P_c = \frac{V_P^2}{R_C} = \frac{(1.046)^2}{80.3} = 0.0136\,pu$$

$$\boxed{\text{efficiency} = \frac{1}{1 + 0.041 + 0.0136} \times 100\% = 94.8\%}$$

and voltage regulation is

$$\boxed{VR = \frac{1.46 - 1}{1} \times 100\% = 4.6\%}$$

(c) the voltage and apparent power ratings of this transformer must be reduced in direct proportion to the decrease in frequency in order to avoid flux saturation effects in the core. At 50 Hz, the ratings are,

$$S_{rated} = \frac{50}{60}(50\,KVA) = 41.7\,KVA$$

$$V_{P,rated} = \frac{50}{60}(20\,K) = 16667\,V$$

$$V_{S,rated} = \frac{50}{60}(480) = 400\,V$$

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(d) the transformer parameters referred to primary side at 60 Hz are:

$$R_c = Z_{base} R_{c,pu} = (8k\Omega)(80.3) = 642 k\Omega$$

$$X_m = Z_{base} X_{m,pu} = (8k\Omega)(26.7) = 214 k\Omega$$

$$R_{eq} = Z_{base} R_{eq,pu} = (8k\Omega)(0.041) = 328\Omega$$

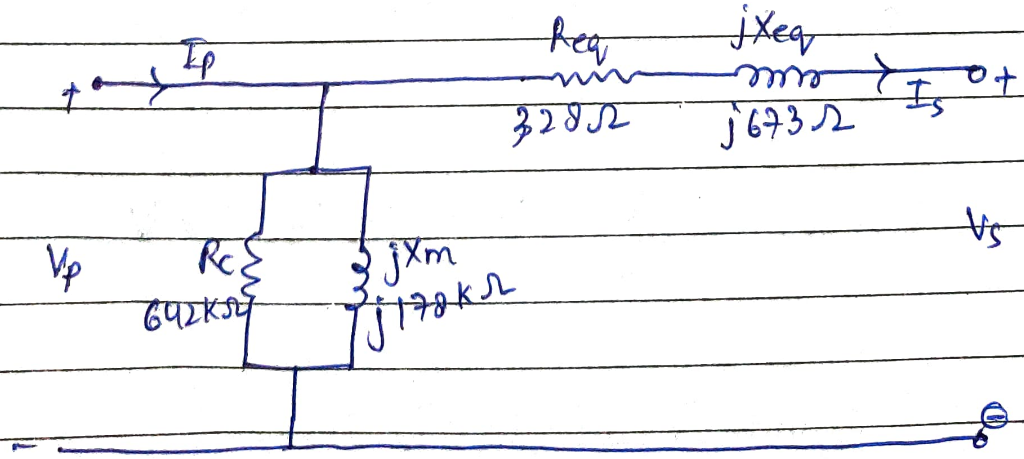
$$X_{eq} = Z_{base} X_{eq,pu} = (8k\Omega)(0.101) = 808\Omega$$

At 50 Hz, the resistance will be unaffected but the reactances are reduced. At 50 Hz, the reactances are

$$X_m = \frac{50}{60}(214) = 178 k\Omega$$

$$X_{eq} = \frac{50}{60}(808\Omega) = 673\Omega$$

∴ equivalent circuit referred to primary at 50 Hz.



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(e) base impedance at 50Hz referred to primary

$$Z_{base,p} = \frac{V_p^2}{S} = \frac{(16667)^2}{41.7\,KVA} = 6.66\,k\Omega$$

base impedance at 50Hz referred to secondary

$$Z_{base,s} = \frac{V_s^2}{S} = \frac{(400)^2}{41.7\,KVA} = 3.837\,V$$

the excitation branch elements can be expressed in per unit as

$$R_C = \frac{642\,k\Omega}{6.66\,k\Omega} = 96.4\,pu$$

$$X_m = \frac{178\,k\Omega}{6.66\,k\Omega} = 26.7\,pu$$

the per unit primary voltage at rated conditions and 1 PF,

$$V_p = V_s + I_s Z_{eq}$$

$$V_p = 1\angle 0^\circ + (1\angle 0^\circ)(0.0492 + j\,0.101)$$

$$V_p = 1.054\angle 5.49^\circ\ pu$$

per unit power consumed by Req

$$P_{eq} = I^2 R = 0.0492\ pu$$

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per unit power consumed by R_c is

$$P_c = \frac{V_p^2}{R_c} = \frac{(1.054)^2}{96.4} = 0.0115 \text{ pu}$$

$\therefore$ efficiency $= \dfrac{1}{1 + 0.0492 + 0.0115} \times 100\%$

$$\boxed{\eta = 94.3\%}$$

and voltage regulation VR,

$$\boxed{VR = \frac{1.054 - 1}{1} \times 100\% = 5.4\%}$$

(f) The efficiency at 50 Hz and 60 Hz are almost same, but the total apparent power rating of the transformer at 50 Hz must be less than the apparent power rating at 60 Hz by the ratio 50/60. In other words, the efficiencies are similar, but the power handling capacity is reduced.

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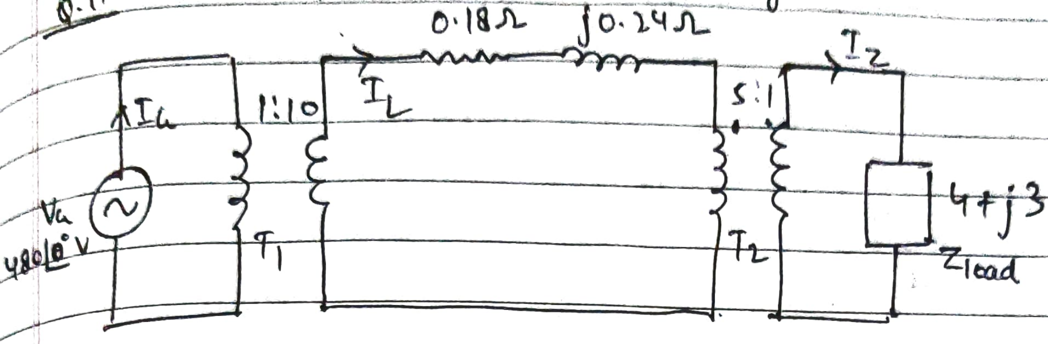
Any 5 Problems from Home Work

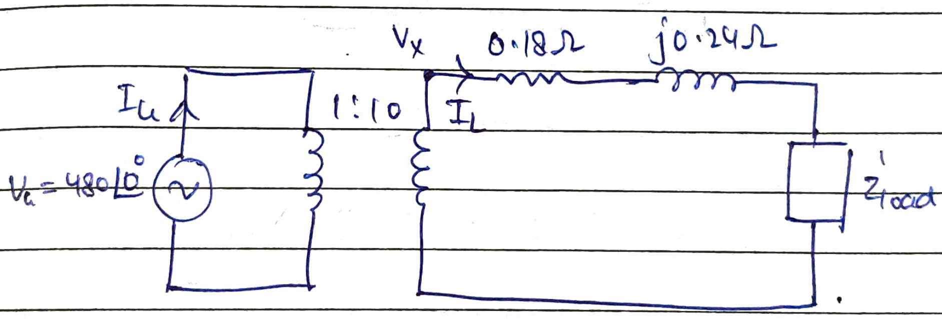
Q.11. Find I_L, I_a, I_2 and efficiency.



given $a_1 = 0.1$ and $a_2 = 5$

load impedance referred to primary of T_2,

$$Z'_{load} = a_2^2 Z_{load} = 100 + j75$$



$$\frac{V_a}{V_x} = a_1$$

$$V_x = 10 V_a = 4800 \text{ V}$$

$$\therefore I_L = \frac{V_x}{Z_{line} + Z'_{load}}$$

$$I_L = \frac{4800}{100.18 + j75.24} = 38.3 \text{ A}$$

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$\boxed{I_L = 38.3 A}$

$\therefore \quad I_Z = 5 I_L$

$\boxed{I_Z = 191.5 A}$

and $I_G = I_L \times 10 = 383 A$

$\boxed{I_G = 383 A}$

power reaching the load, P_Z

$P_Z = I_Z^2 R_Z = (191.5)^2 \times 4$

$\boxed{P_Z = 146.689 kW}$

power loss in line, P_L,

$P_L = I_L^2 R_L = (38.3)^2 \times (0.18)$

$\boxed{P_L = 264 \Omega}$

power generated by source, P_G,

$P_G = P_L + P_Z = 146.689 kW + 0.264 kW$

$\boxed{P_G = 146.953 kW}$

$\therefore$ efficiency $\eta = \frac{P_Z}{P_G} = \frac{146.689}{146.953} \times 100\%$

$\boxed{\eta = 99.82\%}$

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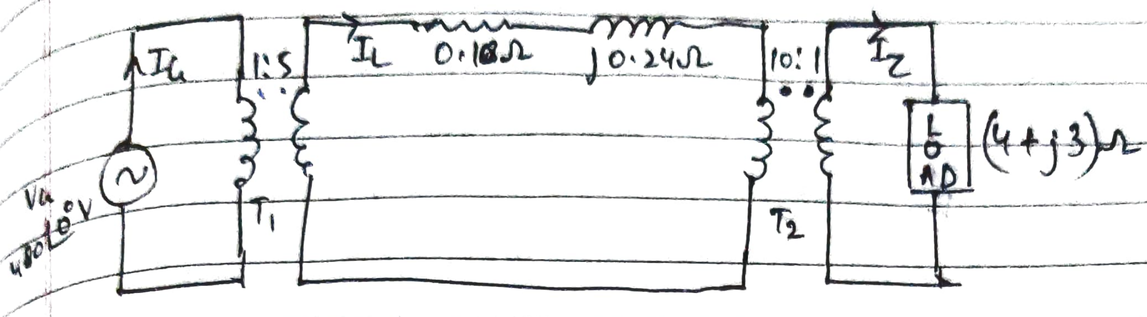
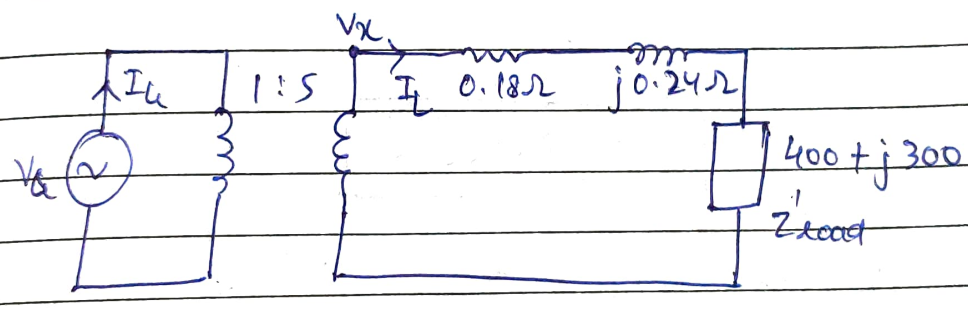
Q.12 . Find I_G, I_L, I_G and efficiency.



given $a_1 = 0.2$ and $a_2 = 10$

load impedance referred to primary of T_2,

$$Z'_{load} = a_2^2 \, Z_{load} = (400 + j\,300)\,\Omega$$



$$\because \quad \frac{V_G}{V_x} = a_1$$

$$V_x = \frac{V_G}{0.2} = 2400\ V$$

$$\therefore \quad I_L = \frac{2400}{(400.18 + j300.24)} = 4.797\ A$$

$$\boxed{I_L = 4.797\ A}$$

$$\therefore \boxed{I_2 = 47.97\ A}$$

$$\therefore \boxed{I_G = 23.985\ A}$$

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power loss in line P_L

$$P_L = I_L^2 R_L = (4.797)^2 \times 0.18 = 4.14\Omega$$

$$\boxed{P_L = 4.14\Omega}$$

power reaching the load, P_Z

$$P_Z = I_Z^2 R_Z = (\cancel{4}47.97)^2 \times 4$$

$$\boxed{P_Z = 9.204KW}$$

power generated by source, P_a

$$P_a = P_L + P_Z$$

$$\boxed{P_a = 9.208\ KW}$$

$\therefore$ efficiency $\eta = \frac{P_Z}{P_a} \times 100\%$

$$= \frac{9.204}{9.208} \times 100\%$$

$$\boxed{\eta = 99.95\%}$$

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Q.13. Draw equivalent circuit (referred to secondary) for the 20KVA, 8000/240 A transformer.

OC test (secondary)	SC test (primary)
$V_{oc} = 240\,V$	$V_{sc} = 489\,V$
$I_{oc} = 7.133\,A$	$I_{sc} = 2.5\,A$
$P_{oc} = 400\,W$	$P_{sc} = 240\,W$

$$a = 8000/240 = 33.33$$

OC test

$$\theta = \cos^{-1}\left(\frac{P_{oc}}{V_{oc} \cdot I_{oc}}\right) = \cos^{-1}\left(\frac{400}{240 \times 7.133}\right)$$

$$\theta = 76.487^\circ$$

$$|Y_E| = \frac{I_{oc}}{V_{oc}} = \frac{7.133}{240} = 0.0297\,S$$

$$Y_E = 0.0297 \angle -76.487^\circ$$

$$= 0.0069398 - j\,0.028877$$

$$= \frac{1}{R_c} - j\frac{1}{X_m}$$

$$\therefore\ R_{c,S} = 144.1\,\Omega$$

$$X_{m,S} = 34.63\,\Omega$$

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SC test

$$\phi = \cos^{-1}\left(\frac{P_{sc}}{V_{sc} \cdot I_{sc}}\right) = \cos^{-1}\left(\frac{240}{489 \times 2.5}\right)$$

$$\phi = 78.678^\circ$$

$$|Z_{sc}| = \frac{V_{sc}}{I_{sc}} = 195.6\,\Omega$$

$$Z_{sc} = 195.6 \angle 78.678^\circ\,\Omega$$

$$Z_{sc} = 38.4 + j\,191.79\,\Omega$$

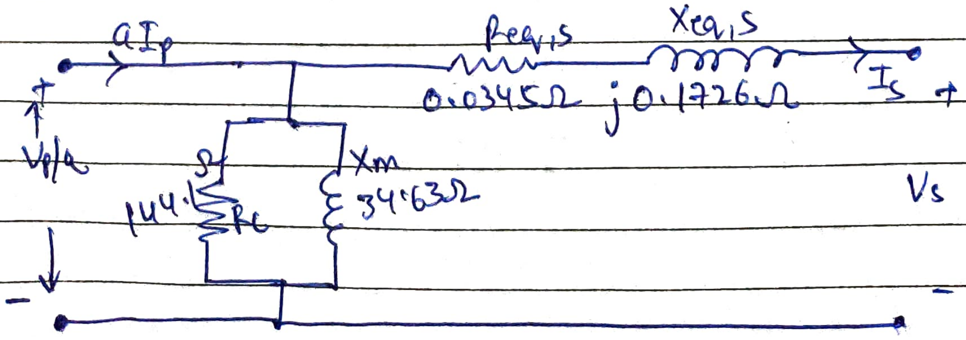
$$= R_{eq} + jX_{eq}$$

$\therefore$ $R_{eq,p} = 38.4\,\Omega$
$X_{eq,p} = 191.79\,\Omega$

$$\therefore R_{eq,s} = \frac{38.4}{(33.33)^2} = 0.0345\,\Omega$$

$$X_{eq,s} = \frac{191.79}{(33.33)^2} = 0.1726\,\Omega$$

equivalent circuit referred to Secondary,



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Q.14 Power rating : 15KVA, 2300/230V

OC (Secondary) | SC (primary)

$V_{oc} = 230V$ | $V_{sc} = 47V$

$I_{oc} = 2.1A$ | $I_{sc} = 6A$

$P_{oc} = 50W$ | $P_{sc} = 160W$

Find VR and efficiency for PF = 0.8 lagging.

given $a = \frac{2300}{230} = 10$

OC Test

$$\phi_{oc} = \cos^{-1}\left(\frac{P_{oc}}{V_{oc} \cdot I_{oc}}\right) = 84.06^\circ.$$

$$|Y_E| = \frac{I_{oc}}{V_{oc}} = 0.00913 \text{ S}$$

$$Y_E = 0.00913 \angle -84.06^\circ \text{ S}$$

$$Y_E = \frac{1}{R_c} - \frac{j}{X_m}$$

$$\therefore R_{c,S} = 1.058 \text{ k}\Omega$$

$$X_{m,S} = 110.13 \Omega$$

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SC Test :-

$$\phi_{sc} = \cos^{-1}\left(\frac{P_{sc}}{V_{sc} \cdot I_{sc}}\right) = 55.43^\circ$$

$$|Z_{sc}| = \frac{V_{sc}}{I_{sc}} = 7.833\ \Omega$$

$$Z_{sc} = 7.833 \angle 55.43^\circ\ \Omega$$

$$Z_{sc} = R_{eq} + jX_{eq}$$

$$\therefore R_{eq,p} = 4.44\ \Omega$$
$$X_{eq,p} = 6.45\ \Omega$$

Now, $I_{s,rated} = \frac{S_{rated}}{V_{rated}} = \frac{15\ KVA}{230}$

$$I_{s,rated} = 65.22\ A$$

$$\therefore \bar{I_s} = 65.22 \angle -36.87^\circ\ A$$

$$\therefore V_p' = V_s + I_s(R_{eq} + jX_{eq})$$

$$= 230 \angle 0^\circ + (65.22 \angle -36.87^\circ)(0.0444 + j0.0645)$$

$$V_p' = 234.84 \angle 0.397^\circ\ V$$

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$\therefore$ voltage regulation VR

$$VR = \frac{234.34 - 230}{230} \times 100\%$$

$$= \frac{4.34}{230} \times 100\%$$

$$\boxed{VR = 2.1\%}$$

power in secondary,

$$P_{out} = V_s I_s \cos\phi$$

$$= (230)(65.22)\{\cos(36.87)\}$$

$$\therefore P_{out} = P_s = 12000.46\ W$$

$$P_{cu} = (I_s)^2 R_{eq}$$

$$= 188.86\ W$$

$$P_{core} = \frac{(V_p')^2}{R_c} = 52.126\ W$$

$$\boxed{\therefore \text{efficiency} = \frac{P_{out}}{P_{out} + P_{cu} + P_{core}} = 98.03\%}$$

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Q15 Repeat Problem 14 for PF = 1.

$I_{s,rated} = 65.22\,A$

$\bar{I}_{s,rated} = 65.22\angle 0^\circ\,A$

$V_p' = V_s + I_s(R_{eq} + jX_{eq})$

$= 230\angle 0^\circ + (65.22\angle 0^\circ)(0.0444 + j\,0.0645)$

$V_p' = 230\angle 0^\circ + 5.107\angle 55.457^\circ$

$= 230 + 2.896 + j\,4.207$

$V_p' = 232.896 + j\,4.207$

voltage regulation,

$$VR = \frac{232.933 - 230}{230} \times 100\%$$

$$\boxed{VR = 1.28\%}$$

output power,

$P_s = V_s I_s \cos\phi$

$= (230)(65.22) \times 1$

$$\boxed{P_{out} = P_s = 15000.6\,W}$$

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$$P_{cu} = (I_s)^2 R_{eq}$$

$$= (65.22)^2 \times 0.044$$

$$P_{cu} = 188.86 \text{ W}$$

$$P_{core} = \frac{(V_p')^2}{R_c}$$

$$= \frac{(232.933)^2}{1058}$$

$$P_{core} = 51.283 \text{ W}$$

$$\eta = \frac{P_{out}}{P_{out} + P_{cu} + P_{core}} \times 100\%$$

$$= \frac{15000.6}{15000.6 + 188.86 + 51.283} \times 100\%$$

$$\boxed{\eta = 98.42\%}$$

Q.16 List and describe the types of losses that occur in a transformer. Accordingly, draw the transformer's equivalent circuit.

The different types of losses in a transformer are –

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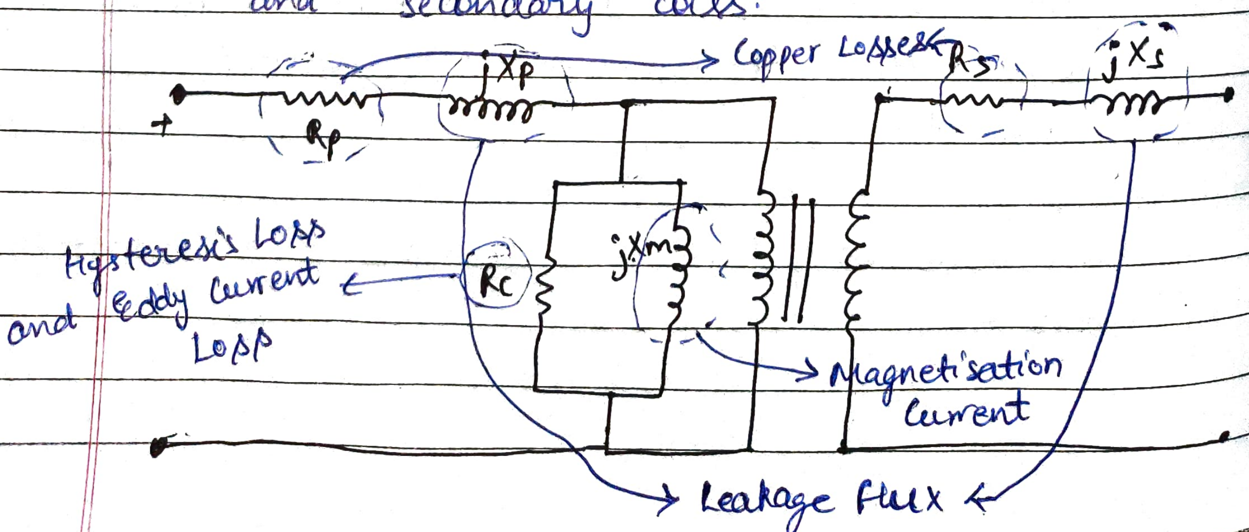
(i) Copper Losses: Copper losses are the resistive heating losses in the primary and secondary windings of a transformer. They are proportional to square of current in the windings.

(ii) Eddy Current Losses-: These are resistive heating losses in the core of the transformer. They are proportional to the square of voltage applied.

(iii) Hysteresis Losses-: These are associated with the magnetization and demagnetization of the core. i.e. rearrangement of domains in the core during each half-cycle. They are a complex, non-linear function of the voltage applied.

(iv) Leakage Flux-: The fluxes ϕ_{LS} and ϕ_{LP} which escape the core and pass through only one of transformer windings are leakage fluxes. They produce a leakage inductance in the primary and secondary coils.



Q.17 What components compose the excitation current of a transformer? How are they modelled in the transformer's equivalent circuit?

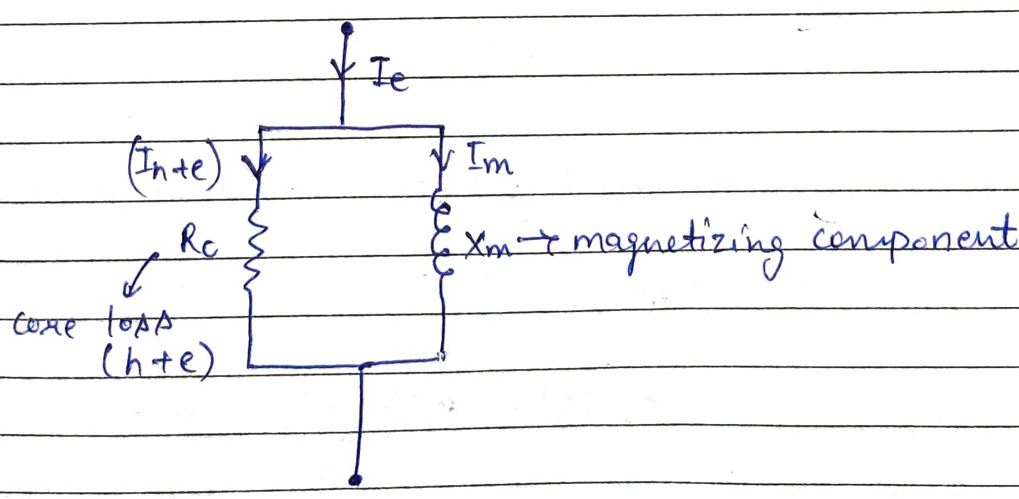
The excitation current in a real transformer has two component

(i) the core loss current ($I_h + I_e$) i.e. hysteresis current and eddy current.

(ii) Magnetising current (I_M):

The core loss is a real-power component and is revealed as resistive heating component.

The magnetizing current (I_m) furnishes the magnetomotive force (mmf) to get over the magnetic reluctance and is represented as inductive component.



Modelling in equivalent circuit

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Q.18. What is the leakage flux in a transformer? Why is it modelled in a transformer equivalent circuit as inductor?

The flux is present in the primary coil of the transformer, not all flux produced in the primary coil passes through the secondary coil. Some of the flux leaves the iron core and passes through ~~that goes~~ air instead. The portion of the flux that goes through one of the transformer coils but not the other one is called leakage flux.

$$\phi_P = \phi_m + \phi_{LP}$$
$$\phi_S = \phi_m + \phi_{LS}$$

$$e_{LP}(t) = N_P \frac{d\phi_P}{dt} \quad \text{—(I)}$$

$$\phi_{LP} \propto I_P$$

$$\phi_{LP} = \rho N_P I_P \quad (\rho - \text{permeance})$$

Substitute in (I),

$$e_{LP}(t) = \rho N_P^2 \frac{dI_P}{dt} \quad \text{—(II)}$$

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$$V = \frac{L\,dI}{dt} \quad \text{--- (iii)}$$

Comparing eq (2) & eq (3)

$$\boxed{L_p = \rho N_p^2}$$

Leakage Inductance in primary

Similarly, $e_{Ls}(t) = \rho N_s^2 \frac{dI_s}{dt}$

$$\boxed{L_s = \rho N_s^2} \rightarrow \text{Leakage Inductance in Secondary}$$

Hence, we see that leakage flux can be modelled as inductors with inductance L_p in primary and L_s in secondary.