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SINGLE PHASE TRANSFORMER

OBJECTIVE

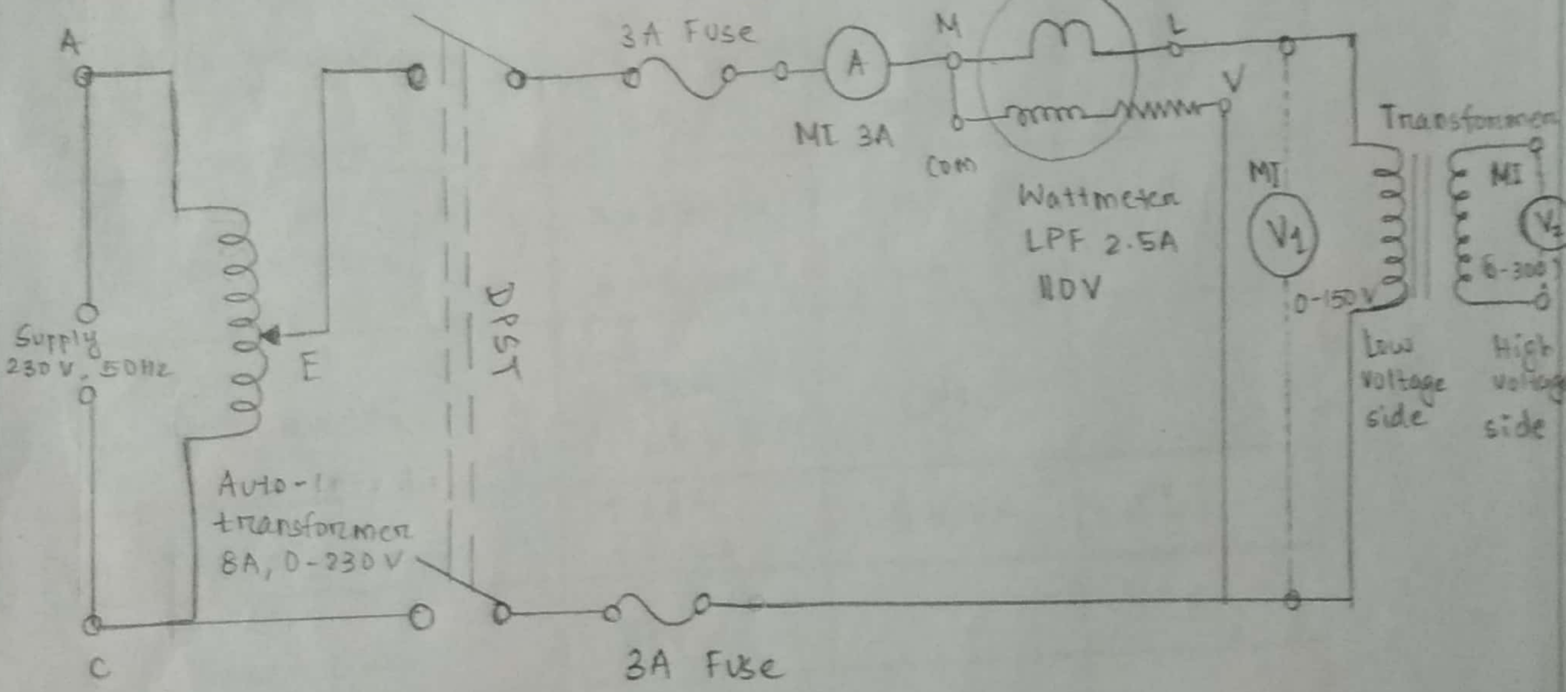
To determine the efficiency and regulation of a single phase transformer by conducting:

(a) Open Circuit Test

(b) Short circuit Test

I. OPEN CIRCUIT TEST

CIRCUIT DIAGRAM



Circuit diagram for Open circuit test of a transformer

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APPARATUS REQUIRED

Sl. No.	Apparatus Name	Range	Specification	Quantity
1	Auto transformer	8A 0-230V, 50Hz		1
2	Ammeter	3 A	MI	1
3	Voltmeter	0 - 150 V 0 - 300 V	MI MI	1 1
4	Wattmeter	2.5 A 110 V (LPF)	LPF	1
5	Transformer	220 V 13.6 A	3 KVA	1
6	Fuse wire	3A		2
7	Switch		DPST	1

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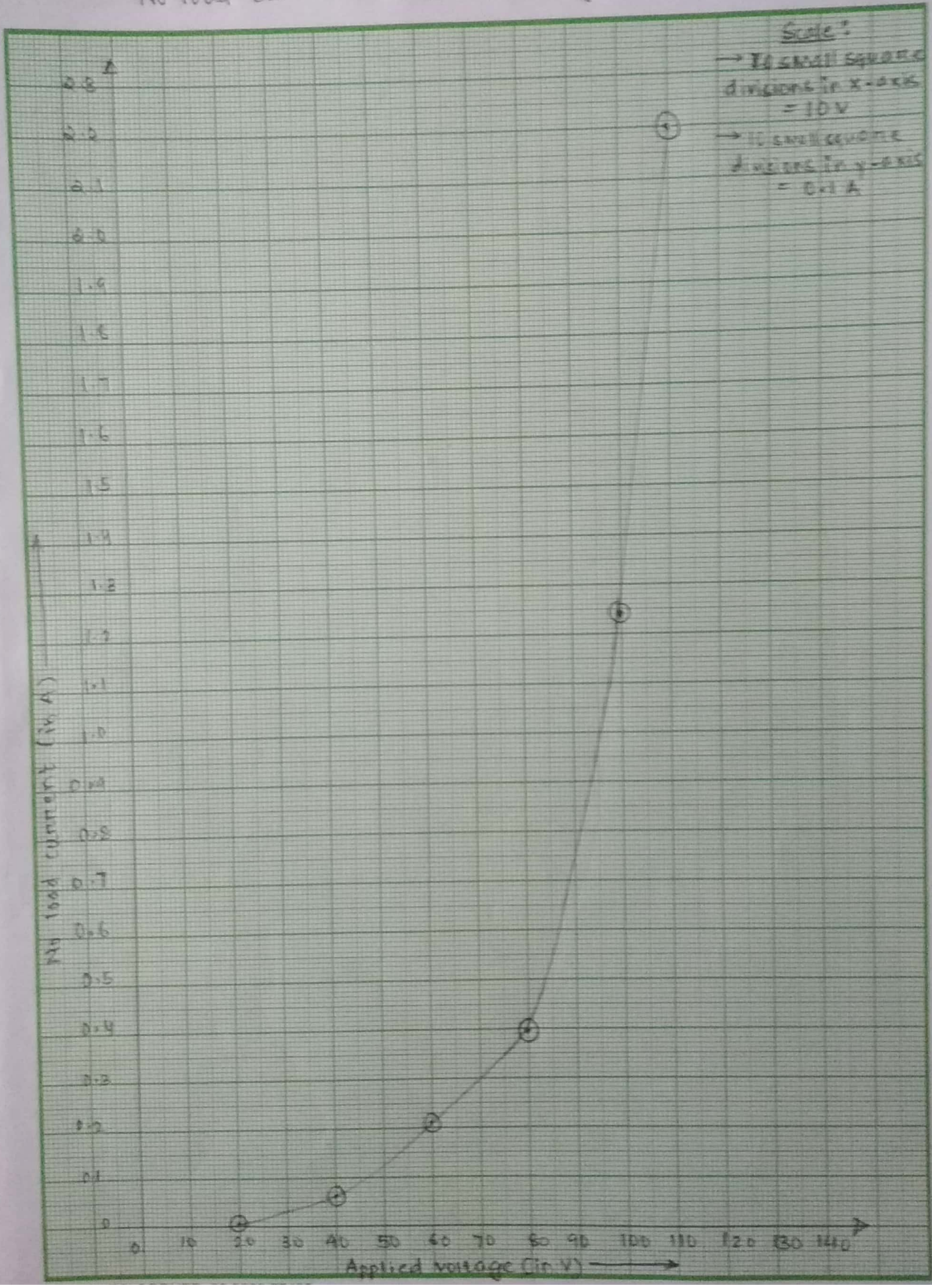
OBSERVATION TABLE

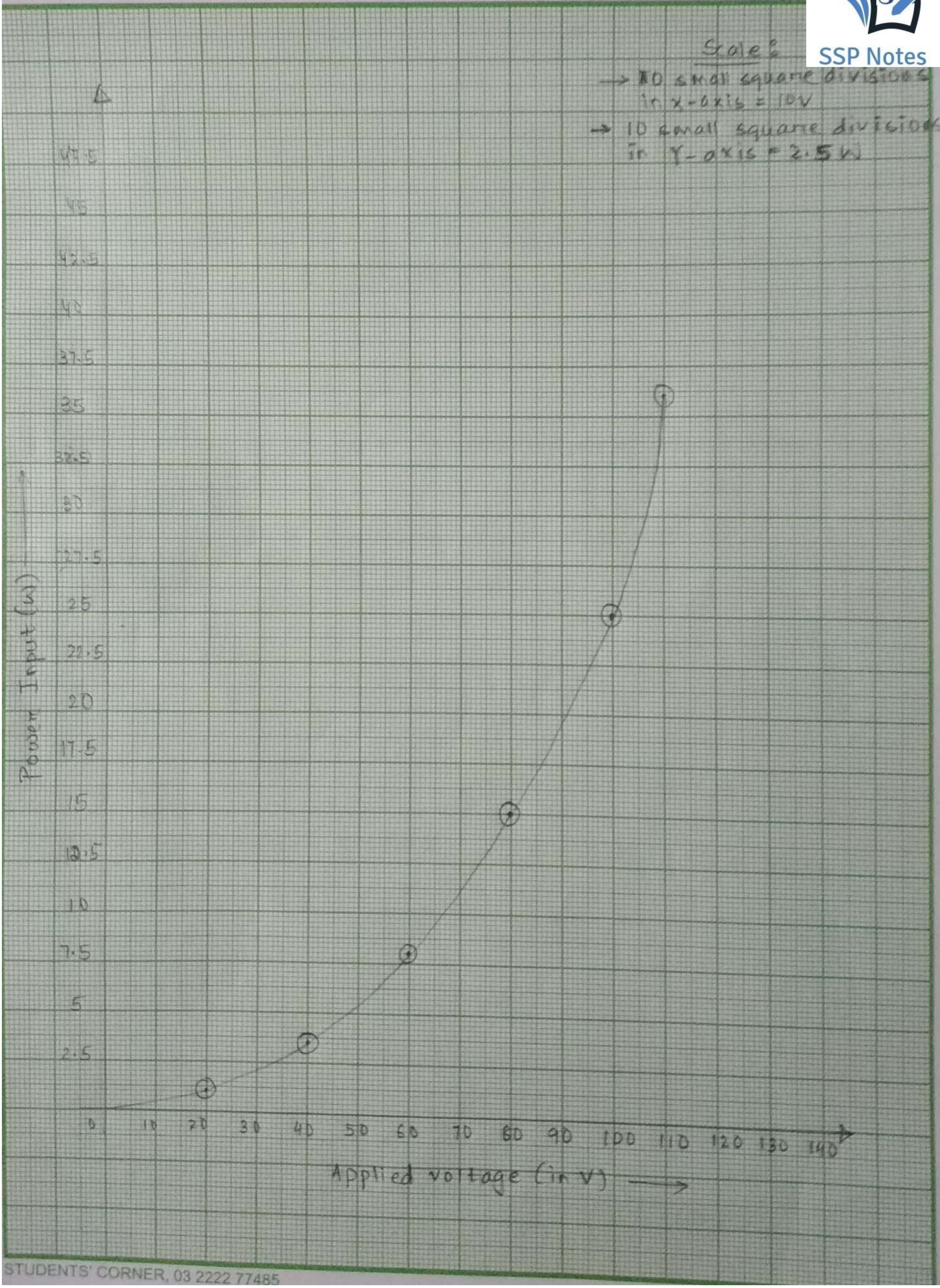
I. OPEN CIRCUIT TEST

Sl. No.	Primary voltage (V_1) L.V. side (V)	Primary current I_1 (I) (A)	Input power P_1 (W)	Secondary voltage V_2 H.V. side (V)
1	20	0	0.5 × 2 = 1	29
2	40	0.06	1.75 × 2 = 3.5	75
3	60	0.21	4 × 2 = 8	113
4	80	0.39	7.5 × 2 = 15	155
5	100	1.24	12.5 × 2 = 25	194
6	110	2.2	18 × 2 = 36	217

No load current vs Applied voltage

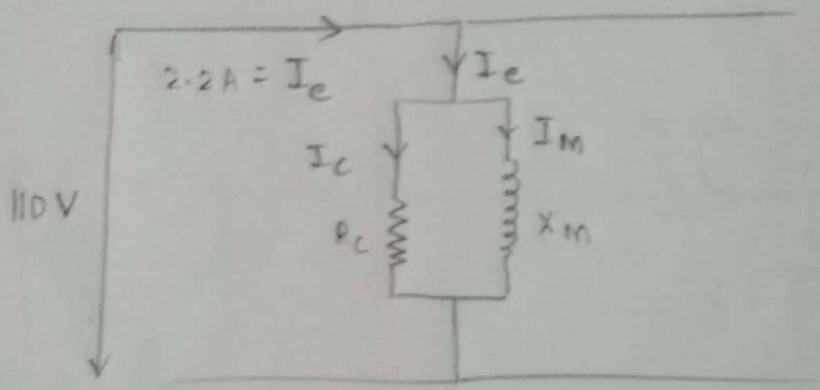


Power Input vs Applied Voltage



RESULTS :

Equivalent transformer for open circuit test is -



Here $V = 110\ V$, $I = 2.2\ A$, $P = 36\ W$

$$\cos\phi = \frac{P}{VI} = \frac{36}{2.2 \times 110} = 0.15 \Rightarrow \sin\phi = 0.98$$

$$I_c = I_0 \cos\phi$$

$$= (2.2)(0.15) = 0.33\ A$$

$$I_M = \sqrt{I_0^2 - I_c^2} = 2.18\ A$$

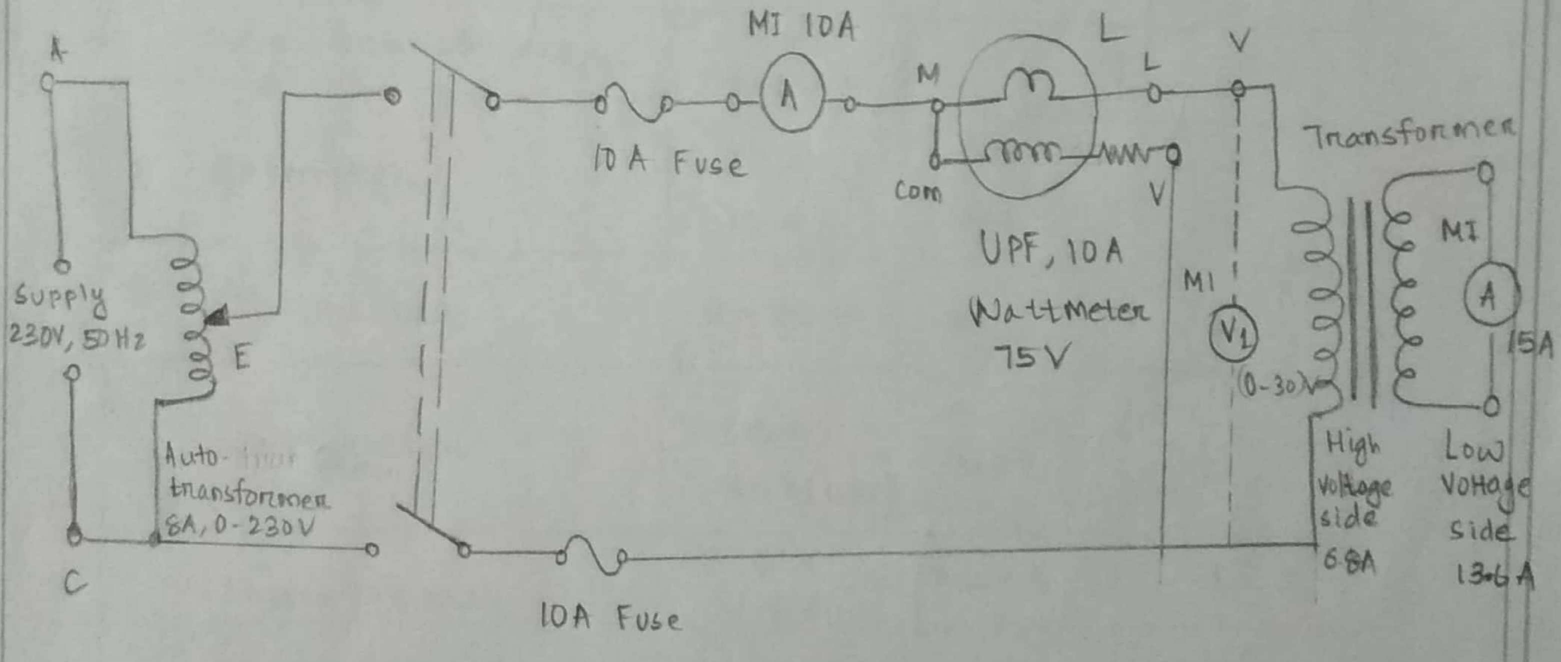
$$R_c = \frac{V}{I_c} = \frac{110}{0.33} = 333.33\ \Omega$$

$$X_M = \frac{V}{I_M} = \frac{110}{2.18} = 50.46\ \Omega$$

SSP Notes

II. SHORT CIRCUIT TEST

CIRCUIT DIAGRAM



Circuit diagram for short circuit test of a transformer

APPARATUS REQUIRED

Sl. No.	Apparatus Name	Range	Specification	Quantity
1	Auto-transformer	8A 0-230 V		1
2	Ammeter	10 A 15 A	MI MI	1 1
3	Voltmeter	0 - 30 V	MI	1
4	Wattmeter	10 A 75 V(UPF)	UPF	1
5	Transformer	220 V 13.6 A	3KVA	1
6	Fuse wire	10 A		2
7	Switch		DPST	1

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OBSERVATION TABLE

II. SHORT CIRCUIT TEST

Sl No.	Primary Voltage V_1 H.V. side (V)	Primary Current I_1 (I) (A)	Input Power P_1 (W)	Secondary Current I_2 L.V. side (A)
1	2	1.4	4	3.4
2	3.8	3.4	10	6.8
3	5.9	5	22	10.2
4	8	6.8	40	13.6

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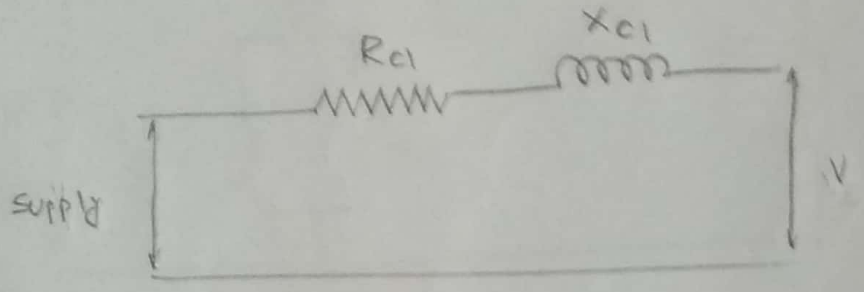
RESULTS:

Equivalent transformer circuit for short circuit test -



Now, $P = 40\ W$, $V = 8\ V$, $I = 6.8\ A$

$$P = I^2 R_{c1}$$

$$\Rightarrow 40 = (6.8)^2 R_{c1}$$

$$\Rightarrow R_{c1} = 0.86\ \Omega$$

Also $Z = \dfrac{V}{I} = \dfrac{8}{6.8} = 1.18\ \Omega$

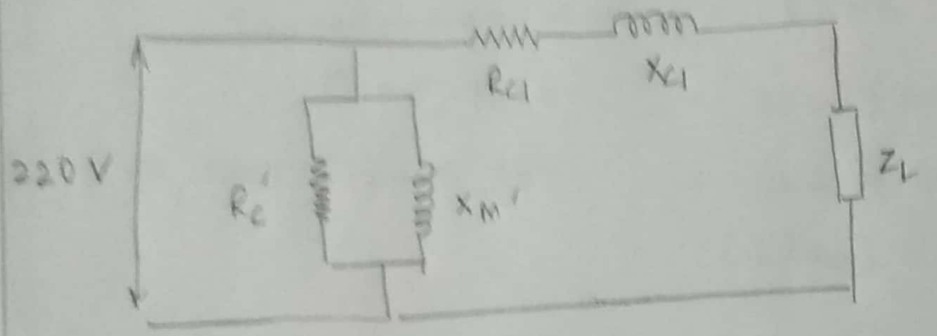
Now $X_{c1} = \sqrt{Z^2 - R_{c1}^2} = \sqrt{(1.18)^2 - (0.86)^2}$

$$\Rightarrow X_{c1} = 0.81\ \Omega$$

Transformer ratio $= \dfrac{217}{110} = 1.97 \approx 2$

P.R.E.

1) Equivalent circuit of transformer referred to H.V side –



$R_{c1} = 0.86\,\Omega$

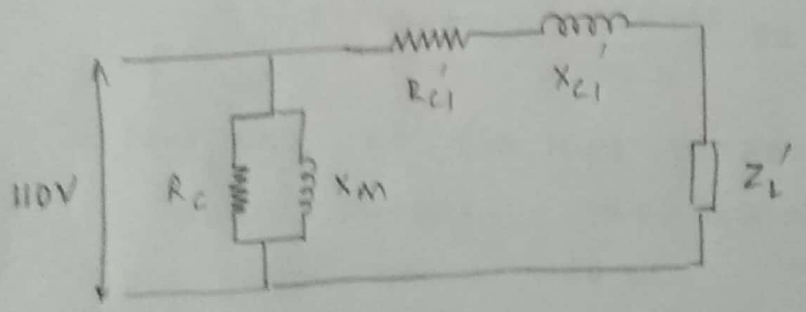
$X_{c1} = 0.81\,\Omega$

$a = \frac{220}{110} = 2$

$R_c' = R_c \times a^2$
$= 4R_c = 1333.32\,\Omega$

$X_m' = X_M \cdot a^2 = 50.46 \times 4 = 201.84\,\Omega$

Equivalent circuit of transformer referred to L.V. side –



$R_c = 333.33\,\Omega$

$X_M = 50.46\,\Omega$

$R_{c1}' = R_{c1}/a^2 = 0.86/4 = 0.215\,\Omega$

$X_{c1}' = X_{c1}/a^2 = 0.81/4 = 0.202\,\Omega$

11) Efficiency Calculation (at UPF)

Transformer rating = 3 kVA

Core loss = 36W (from open circuit test)

Full load Copper loss = 40W (from short circuit test) ($I^2 R_{e1}$)

a) For 25% of full load current -

Power output = $(0.25)(3 \times 10^3) = 750$ W

Core loss = 36 W

Copper loss = $(0.25)^2 (40) = 2.5$ W

η = efficiency = $\frac{750 \times 100}{788.5} = 95.12\%$

b) For 50% of full load current -

Power output = $(0.5)(3 \times 10^3) = 1500$ W

Core loss = 36 W

Copper loss = $(0.5)^2 (40) = 10$ W

η = efficiency = $\frac{1500}{1546} \times 100 = 97.02\%$

c) For 75% of full load current -

Power output $= (0.75)(3 \times 10^3) = 2250 W$

Core loss $= 36 W$

Copper loss $= (0.75)^2(40) = 22.5 W$

η = efficiency $= \frac{2250}{2308.5} \times 100 = 97.46\%$

d) For 100% of full load current -

Power output = 3000 W

Core loss = 36 W

Copper loss = 40 W

η = efficiency $= \frac{3000}{3076} \times 100 = 97.53\%$

iii) Full load voltage regulation -

a) power factor = 1 b) Power factor = 0.8 (lag)

c) Power factor = 0.8 (lead)

$V_1 = 220\ V$

$R_{C_1} = 0.86\ \Omega$

$X_{C_1} = 0.81\ \Omega$

$I_1 = 6.8\ A$

$$\text{voltage regulation} = \frac{I_1}{V_1}\left\{R_{C_1}\cos\phi \pm X_{C_1}\sin\phi\right\}$$

a) power factor = 1

$\Rightarrow \cos\phi = 1$ and $\sin\phi = 0$

$$\text{voltage regulation} = \frac{6.8}{220}(0.86) = 0.0266$$

$= 2.66\%$

b) power factor = 0.8 (lag)

$\Rightarrow \cos\phi = 0.8$ and $\sin\phi = +0.6$

$$\text{voltage regulation} = \frac{6.8}{220}\left\{0.86 \times 0.8 + 0.81 \times 0.6\right\}$$

$= 0.0363 = 3.63\%$

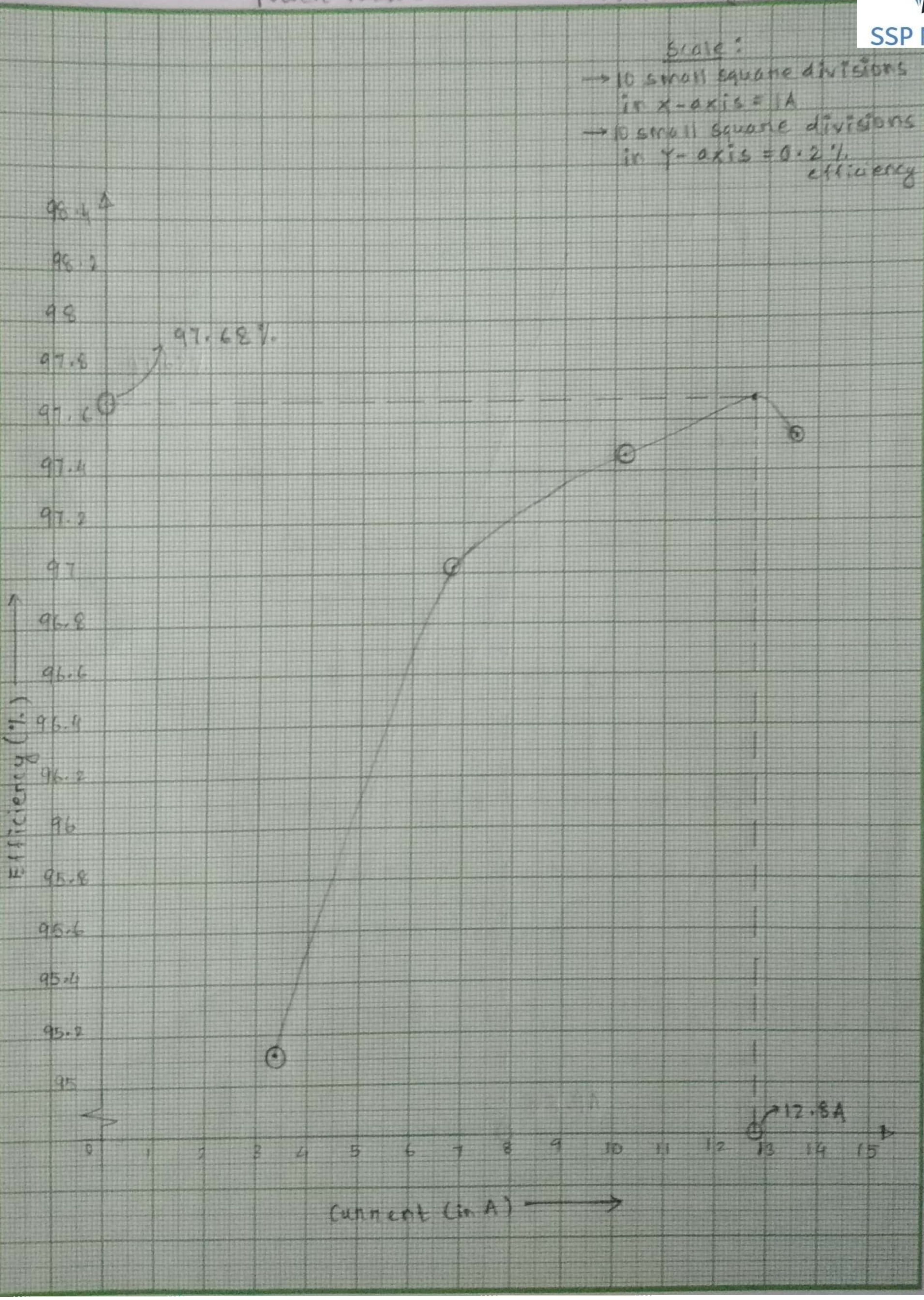
c) power factor = 0.8 (lead)

$\Rightarrow \cos\phi = 0.8$ and $\sin\phi = -0.6$

$$\text{voltage regulation} = \frac{6.8}{220}\left\{0.86 \times 0.8 - 0.81 \times 0.6\right\}$$

$= 0.0062 = 0.62\%$

Efficiency at unity power factor vs Load current at rated voltage



From graph, we can see that maximum efficiency is attained when load current is 12.8 A, i.e., 94.12 % of full load current

Maximum efficiency (theoretically) –

copper loss = core loss

$x^2 (40) = 36$

$x^2 = 0.9 \Rightarrow x = 0.9487$

$\equiv 94.87\%$

$\eta_{max.} = 97.68\%$ (from graph)

Also power output = $(0.9487)(3000) = 2846.1$ W

Core loss = copper loss = 36 W

$$\eta_{Max.} (\text{theoretical}) = \frac{2846.1}{2846.1 + 72} \times 100 = 97.533\%$$

So maximum theoretical efficiency = 97.533 %.

The results are within experimental errors

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DISCUSSION

Q1. Why is OC test carried out by energising LV side?

Ans - We can carry out O.C. test in either L.V or H.V. side, but if we carry out by energising H.V. side, we must provide high voltage, but low voltage is required for the same, if we carry out by energising LV side. Further current flowing in HV side is very small; thus we require precise instruments. Thus OC test is carried out by energicing LV side

Q2. Why is SC test carried by energising HV side?

Here also we can carry out by energising either LV or HV side, but -

i) Short circuit test is performed at rated current. As the rated current on high voltage side is much less than low voltage side, so the rated high voltage side current is easily achieved compared to low voltage side.

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2) If we short circuit high voltage side, voltage of HV side essentially falls to zero and since VI = constant, so HV side current will be very high and will burn the winding.

Q3. When is the efficiency maximum for a transformer

Ans - If the core loss is equal to copper loss then efficiency is maximum in a transformer.

$$\eta = \frac{\text{Power output}}{\text{Output power + Loss}}$$

$$= \frac{x P_{f.l.}}{x P_{f.l.} + W_c + x^2 W_{cu}}$$

$$= \frac{P_{f.l.}}{P_{f.l.} + \frac{W_c}{x} + x W_{cu}}$$

$P_{f.l.}$ = full load power

W_c = core loss

W_{cu} = full load copper loss

$x = \frac{I_2}{I_2 (\text{full load})}$

For maximum η ;

$$\frac{d\eta}{dx} = 0 \Rightarrow \frac{W_c}{x} = x W_{cu} \Rightarrow W_c = x^2 W_{cu}$$

$\Rightarrow \boxed{\text{core loss = copper loss}}$

Q4.). Why does no-load losses arise in a transformer?

Ans - When there is no load, then losses in transformer occur due to I_c and R_c ; i.e. core loss, which comprises of hysteresis and eddy current losses. A very small amount of power is also lost due to the resistance of conducting wires used to make circuit connection in primary side.