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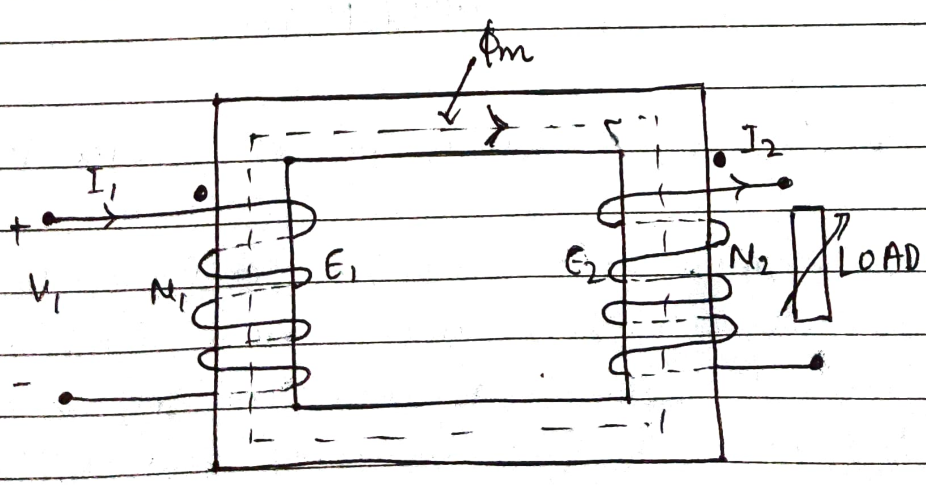
EE160: Experiment 7

Objective :- To determine the efficiency and regulation of a single phase transformer by conducting (a) Open Circuit Test and (b) Short Circuit Test.

Theory :- The physical basis of the transformer is mutual induction between two circuits linked by a common magnetic field. Transformer is required to pass electrical energy from one circuit to another, via the medium of the pulsating magnetic field, as efficiently and economically possible. This could be achieved using either iron or steel which serves as a good permeable path for mutual magnetic flux.

Basics of Transformer



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1.

Let an alternating voltage V be applied to primary coil of N_1 turns linking a suitable iron core. A current flows in the coil, establishing a flux ϕ in the core. The flux induces an electromotive force (emf) e_1 in the coil to counter balance the applied voltage V_1. This emf is

$$e_1 = N_1 \frac{d\phi_p}{dt}$$

Assuming sinusoidal time variation of the flux,

$$\phi_p = \phi_m \sin(\omega t)$$

Then,

$$e_1 = N_1 \omega \phi_m \cos(\omega t)$$

The rms value of this voltage is given by

$$E_1 = 4.44 f N_1 \phi_m$$

(where f is frequency of source V_1)

Now if there is a secondary coil of N_2 turns, wound on the same core, then by mutual induction an emf e_2 is developed therein. The rms value of this voltage is given by,

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$$E_2 = 4.44 f N_2 \phi'_m$$

where ϕ'_m is the maximum value of the sinusoidal flux linking the secondary coil (ϕ_s). If it is assumed that $\phi_p = \phi_s$, then the primary and secondary emf bear the ratio,

$$\frac{e_1}{e_2} = \frac{E_1}{E_2} = \frac{N_1}{N_2}$$

Note-: In actual practice, $\phi_p = \phi_s$, since some of the flux paths linking the primary coil do not link the secondary coil and similarly some of the flux paths linking the secondary coil do not link the primary coil. The fluxes which do not link both the coils are called "Leakage fluxes" of the primary and secondary coil.

Although, iron is highly permeable, it is not possible to generate a magnetic flux in it without the application of a small (magneto-motive force)

$$P_h = K_h B_{max}^x f$$

$$P_e = k_e B_{max}^2 f^2$$

$$P_c = P_h + P_e$$

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where P_h, P_e and P_c are hysteresis, eddy current and core losses respectively. K_h and K_e are constants which depend on the magnetic material, and B_{max} is maximum flux density in the core.

Mathematical Expressions for Voltage and Current in a Transformer

$I_p \Rightarrow$ current in primary
$I_s \Rightarrow$ current in secondary
$N_p \Rightarrow$ No. of turns on primary
$N_s \Rightarrow$ No. of turns on secondary

$a \Rightarrow$ turn ratio of transformer

$$a = \frac{N_p}{N_s}$$

$$\boxed{\frac{\overline{V_p}}{\overline{V_s}} = \frac{N_p}{N_s} = a}$$

$$\boxed{\frac{\overline{I_p}}{\overline{I_s}} = \frac{N_s}{N_p} = \frac{1}{a}}$$

Real power in primary,

$$P_{in} = V_p I_p \cos\phi_p$$

Real power in secondary

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

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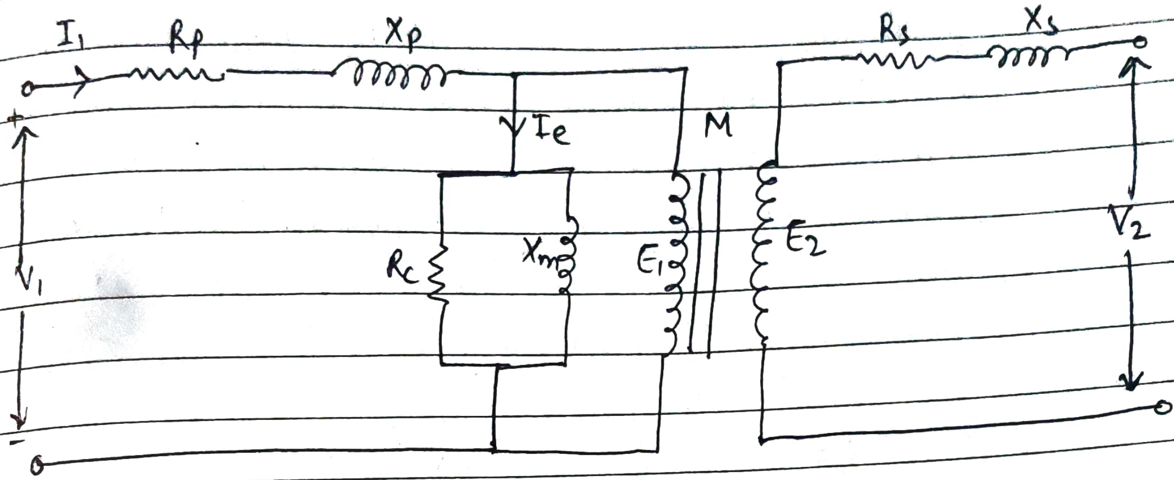
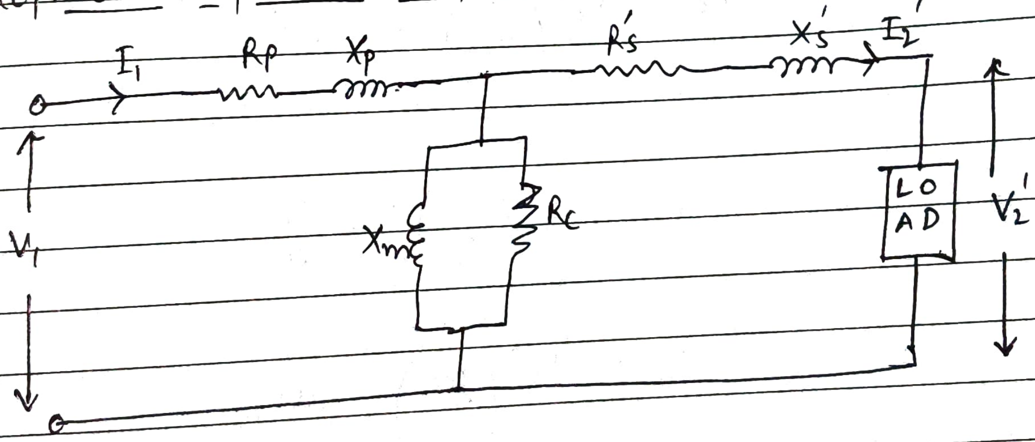
Ideally, $P_{in} = P_{out}$

Equivalent Circuit of a Practical Transformer



Development of a transformer's Equivalent Circuit



The practical transformer has coils of finite resistance. Though this resistance is distributed uniformly, it can be concieved as concentrated. Also, all the flux produced by the primary current cannot be confined into a desired path completely as an electric current. On account of the leakage flux, both the windings have a voltage drop which is due to leakage reactance.

The transformer shown in figure 1 can be resolved into an equivalent circuit as shown in figure 2. in which the resistance and leakage reactance of primary and secondary are represented by lumped R_p, X_p, R_s, X_s. This equivalent circuit can be simplified by referring all quantities in the secondary side of the transformer to primary and is shown in figure 2.

$$R_s' = R_s\left(\frac{N_1}{N_2}\right)^2 = R_s a^2$$

$$X_s' = X_s\left(\frac{N_1}{N_2}\right)^2 = X_s a^2$$

$$I_2' = I_2\left(\frac{N_2}{N_1}\right) = \frac{I_2}{a}$$

$$V_2' = V_2\left(\frac{N_1}{N_2}\right) = aV_2$$

Mathematical Expressions for

(a) **Open-Circuit Test**

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

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$I_c = I_{oc} \cos\phi$, $I_m = I_{oc} \sin\phi$

$R_c = \dfrac{V_{oc}}{I_c}$, $X_m = \dfrac{V_{oc}}{I_m}$

(b) Short Circuit Test

$$Z_{sc} = \frac{V_{sc}}{I_{sc}}$$

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

$$R_{eq} = R_p + R_s' = Z_{sc} \cdot \cos\theta$$

$$X_{eq} = X_p + X_s' = Z_{sc} \cdot \sin\theta$$

Procedure -:

(a) Open- Circuit Test

- Increase the voltage of the autotransformer, starting from zero, by increasing the turn ratio, to rated value and observe the no load current, input power and the primary and secondary voltages.

- Corresponding to each set of values, simulate and fill the table.

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(b) Short Circuit Test

- Increase the voltage in setup slowly (by increasing turn ratio) and observe short circuit current, Input power, primary voltage and secondary current corresponding to each value.

- Simulate to get the value of Re and Xe.
- Click on 'Fill Table'.

Simulation Results

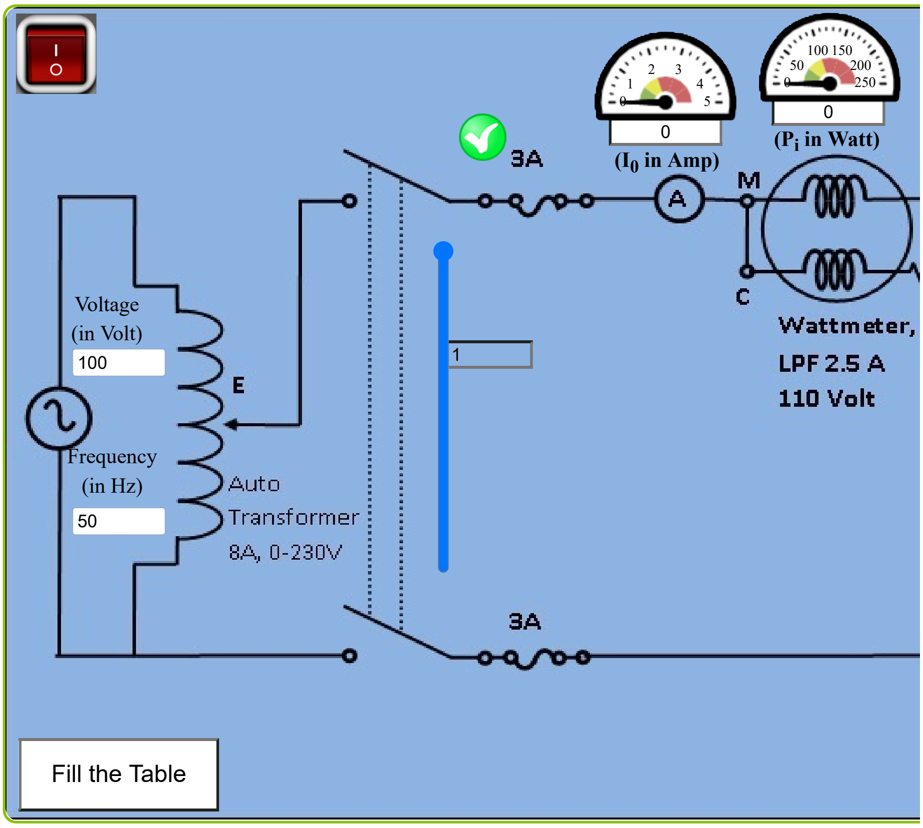
Tests on Single Phase Transformer

OPEN CIRCUIT TEST | SHORT CIRCUIT TEST | LOAD CIRCUIT TEST

Procedure:

1. Set the input voltage at 50Hz frequency to the autotransformer input.
2. Switch on the supply, keeping output voltage at auto-transformer at zero (by setting turns ratio of autotransfomer at zero).
3. Increase the voltage in set up (by increasing the turns ratio of the auto-transformer)to rated value and observe the no load current, input power and the primary and secondary voltages corresponding to each value of the applied voltage.
4. Now click on **"simulate"** to get the value of the shunt parameters (R_o and X_m) of the transformer.
5. Click on **"fill the Table"** tab to tabulate the primary voltage(V_1),no load current or primary current(I_0), input power(P_i) and secondary voltage(V_2)corresponding to each value of the applied voltage in Observation table.
6. Then change the input voltage to take another observation.

N.B.: Click on the fuse indicator to repair it, if it got fused.



Observation Table

Serial no. of Observation	Primary Voltage V_1 (L.V. Side)	Primary Current I_0 (Amp)	Input Power P_i (Watt)	Secondary Volatge V_2 (H.V.Side)
1st	0.0000	0.0000	0.0000	0.0000
2nd	10.600	0.11094	0.18015	21.730
3rd	35.900	0.37573	2.0664	73.595
4th	72.800	0.76193	8.4973	149.24
5th	100.00	1.0466	16.033	205.00

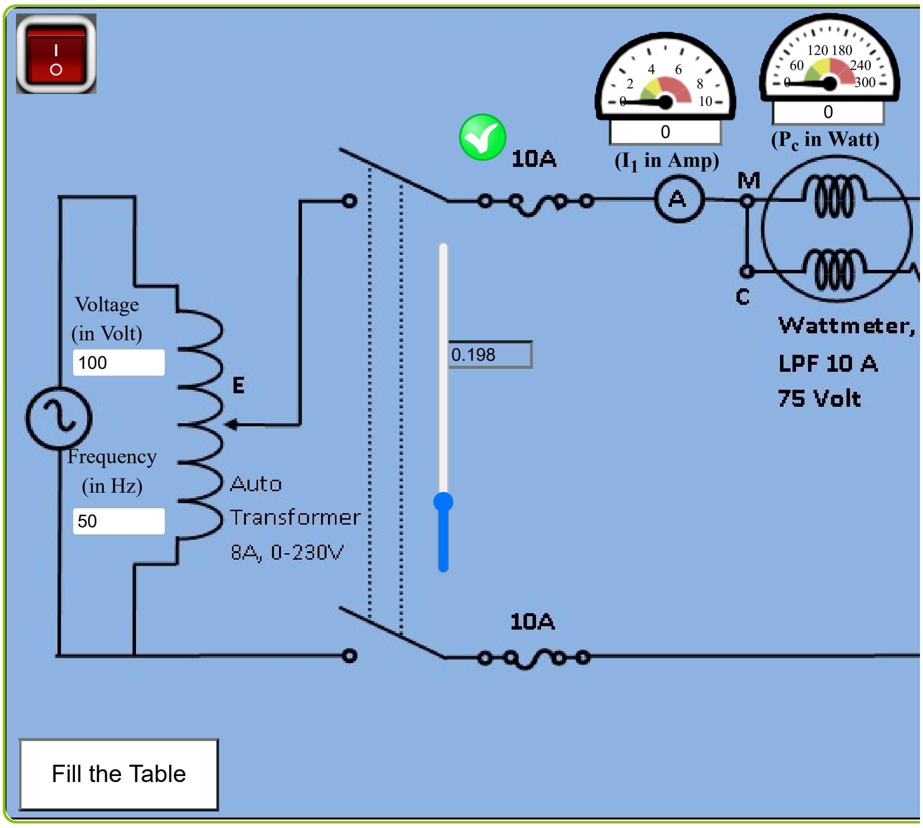
Tests on Single Phase Transformer

OPEN CIRCUIT TEST | SHORT CIRCUIT TEST | LOAD CIRCUIT TEST

Procedure:

1. Set the input voltage at 50Hz frequency to the autotransformer input.
2. Switch on the supply, keeping output voltage at auto-transformer at zero (by setting turns ratio of autotransfomer at zero).
3. Increase the voltage in set up slowly (by increasing the turns ratio of the auto-transformer)to rated value and observe the Short circuit current, input power, primary voltage and secondary cuttent corresponding to each value of the applied voltage.
4. Now click on **"simulate"** to get the value of the shunt parameters (R_e and X_e) of the transformer.
5. Click on **"fill the Table"** tab to tabulate the primary voltage(V_1),no load current or primary current(I_1), input power(P_i) and secondary current(I_2)corresponding to each value of the applied voltage in Observation table.
6. Adjust the output voltage of the auto-transformer to get secondary short circuit current of 25%, 59%, 75%, 100% of the rated current..

   N.B.: Click on the fuse indicator to repair it, if it got fused.



Observation Table

Serial no. of Observation	Primary Voltage V_1 (H.V. Side)	Primary Current I_1 (Amp)	Input Power P_c (Watt)	Secondary Current I_2 (L.V.Side)
1st	0	0	0	0
2nd	6.80000000C	2.885765124	9.360267758	5.771530249
3rd	13	5.516903914	34.21032117	11.03380782
4th	16.1	6.832473309	52.47134527	13.66494661
5th	19.8	8.402669039	79.35984800	16.80533807

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Conclusion:

- Open-circuit or no load test gives the core losses of a transformer and shunt parameters of equivalent circuit.
- Short circuit test gives the copper losses and losses due to leakage flux.
- Together, they are helpful in finding the efficiency and regulation of transformer,

$$\text{Efficiency } \eta = \frac{\text{Power output (in kW)}}{\text{Power output (kW)} + \text{copper losses} + \text{core losses}}$$

$$\text{output power (in kW)} = S \cos\phi$$

$$\text{Regulation} = \frac{V_{s_1,NL} - V_{s_1,FL}}{V_{s_1,FL}} \times 100\%.$$

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Quiz

Performance

Tests on Single Phase Transformer

THEORY (#) PROCEDURE (#) OPERATING ENVIRONMENT (#) SIMULATOR (#) QUIZ (#) REFERENCE (#)

Quiz

Test Your Knowledge!!

✓ 1. The emf per turn for a single phase, 2310/220 V, 50Hz transformer is approximately 13V. Calculate a) the number of primary and secondary turns and b) the net cross sectional area of the core for a maximum flux density of 1.4T

- (a) N_1=189, N_2=18 (b) A_i=393cm^2
- (a) N_1=180, N_2=17 (b) A_i=350cm^2
- (a) N_1=189, N_2=18 (b) A_i=350cm^2
- (a) N_1=180, N_2=17 (b) A_i=393cm^2

✓ 2. A single phase 50 Hz transformer has the three windings : a 220V primary, a 600V secondary and a center trapped 11-0-11 V tertiary. For a net core area of 75 cm^2 , calculate the number of turns in the three windings. The maximum value of flux density of 1.2T

- N_1=120, N_2=240
- N_1=140, N_2=380
- N_1=120, N_2=327
- N_1=210, N_2=327

✓ 3. A 2200/220 V, 50 Hz, single phase transformer has exciting current of 0.6Amp and a core loss of 361 Watts, When its h.v side is energized at rated voltage. Calculate the two components of the exciting current.

- I_c=0.264A, I_m=0.577A
- I_c=0.264A, I_m=0.777A
- I_c=0.164A, I_m=0.777A
- I_c=0.164A, I_m=0.577A

✓ 4. An ideal transformer has three windings : 100 turns on the primary winding p, 160 turns on secondary windings s and 60 turns on tertiary windings T. Winding s feeds 10A to a resistive load whereas a pure capacitance load across winding T takes 20A. Calculate the current in the primary winding and its power factor in case transformer magnetizing current is neglected.

- Primary winding current is=15A and power factor=0.4 lagging
- Primary winding current is=17A and power factor=0.6 lagging
- Primary winding current is=20A and power factor=0.8 lagging
- Primary winding current is=25A and power factor=0.8 lagging

✓ 5. A 10KVA, 2500/250V, single phase transformer has resistances and leakage reactances as follows: r_1 =4.8Ω, r_2=0.048Ω, x_1=11.2Ω, x_2=0.112Ω, 1 and 2 denote high voltage and low voltage winding respectively. With the primary voltage held constant at 2500V, calculate the secondary terminal voltage when, a) the l.v. side is connected to a load impedance of (5+j3.5Ω) b) the transformer delivers its rated current at 0.8 p.f lagging on the l.v. side

- ○ (a) Secondary terminal voltage=142V (b) the rated current on L.V. side is=300A
- ◉ (a) Secondary terminal voltage=242V (b) the rated current on L.V. side is=40A
- ○ (a) Secondary terminal voltage=342V (b) the rated current on L.V. side is=60A
- ○ (a) Secondary terminal voltage=442V (b) the rated current on L.V. side is=50A

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