Steady- State Performance of a 1-Phase Transformer

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Contents

1 Single Phase Transformer

1.1 Aim

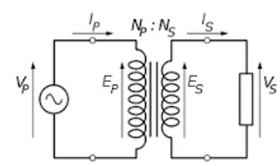
Obtain equivalent circuit parameters by conducting open-circuit, short-circuit and resistance measurement tests.

1.2 Apparatus Required

1. 1-Phase Transformer of identical ratings
2. 1-Phase Auto-transformer
3. Low Power-factor Wattmeter
4. AC Ammeter
5. AC Voltmeter

1.3 Theory

A single phase transformer consists of two magnetically coupled windings that are capable of transforming the voltage and current of an alternating supply to different values. Two windings, one referred to as the input or primary winding and the other as the output or secondary winding, are placed on a silicon steel-stamped core. The core provides a path with low reluctance for the magnetic flux that connects the two windings.



If we assume the pulsating flux Φ to have a sinusoidal waveform $\Phi_m \text{Cos}\omega$ t, where ω is the supply frequency in radians per second, the induced primary voltage is given by:

$$E_1 = -N_1 \frac{d\Phi_m}{dt} \tag{1}$$

where N_1 is the number of primary turns.

Thus the primary RMS induced voltage E_1 is proportional to the primary turns N_1 and lags behind the flux by 90°. Since the flux Φ_m also links with the secondary turns and is in phase with E_1.

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} \tag{2}$$

Now, E_1 opposes the applied voltage say V_I and is nearly equal to V_I if the primary resistance and leakage reactance is very small.

Now with the primary resistance and leakage inductance neglected, we have:

$$E_1 = V_1 \tag{3}$$

$$E_2 = V_2 \tag{4}$$

Since $E_2/E_1 = N_2/N_1$, we can say that $V_2/V_1 = N_2/N_1$. Thus approximately the output voltage bears the same ratio to the input voltage, which secondary turns bear to the primary turns.

Until now, the secondary has been deemed open circuit. Current I_2 will flow through the load and secondary winding if it is loaded. This current reduces the magnetic flux Φ_m in accordance with Lenz's law. This reduces the E_1 induced emf. Now, the current from the primary source rushes to cancel out the effect of the secondary current and establish flux Φ_m equilibrium. The mutual flux has therefore transferred power from the primary to the secondary winding. Now, ignoring losses, it is possible to state that output power equals input power.Thus:

$$I_2 E_2 = I_1 E_1 \tag{5}$$

$$\frac{I_2}{I_1} = \frac{E_1}{E_2} = \frac{N_1}{N_2} \tag{6}$$

Therefore the current ratio is equal to the inverse of the voltage turns ratio. This situation in the phasor diagram where I_2 is shown to balance the effect of I_2 and the total input current on load become I_1. The phasor diagram can now be modified to include the effect of resistance and leakage reactances of the windings.

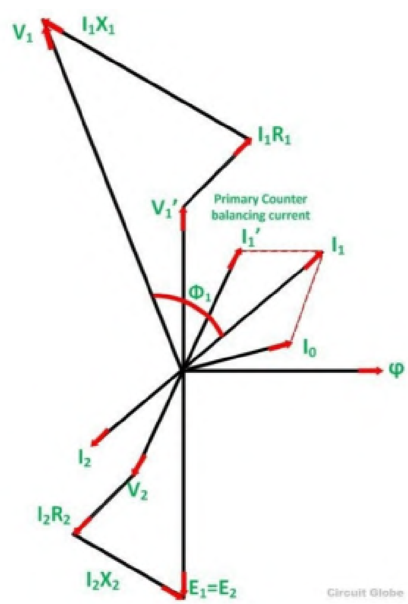


Figure 1: Full-load phasor diagram

It is seen that the open circuit test on transformer is used to determine core losses in transformer and parameters of shunt branch of the equivalent circuit of transformer.

It is seen that the short circuit test on transformer is used to determine copper loss in transformer at full load and parameters of approximate equivalent circuit of transformer.

1.4 Breadboard Setup

Figure 2: Open Circuit Test

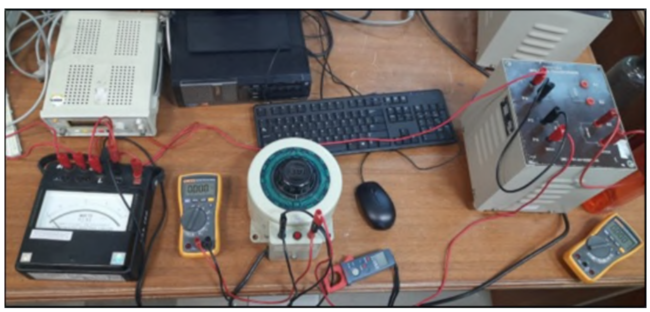


Figure 3: Short Circuit Test

1.5 Observations

Open Circuit Test

V_{Input}(V)	Current(A)	Power(W)	V_{Output}(V)
28.29	0.11	1	54.54
47.45	0.15	2.2	92.1
68	0.19	4.2	133
86.8	0.24	6.8	170.9
107.4	0.33	9.7	210.5
120	0.4	11.7	235.5

Short Circuit Test

V_{Input}(V)	Current(A)	Power(W)
10.21	2.96	15
13.18	3.77	30
16.8	4.79	65

1.6 Calculations

1.6.1 Open Circuit Test

V_0(V)	I_0(A)	W_0(W)	V_{Out}(V)	$\cos\Phi_0$	$\sin\Phi_0$	I_W	I_μ	R_0	X_0
28.29	0.11	1.0	54.54	0.321	0.897	0.035	0.097	808.28	291.65
47.45	0.15	2.2	92.1	0.309	0.904	0.046	0.136	1031.52	348.90
68.00	0.19	4.2	133.0	0.325	0.890	0.062	0.169	1096.77	402.37
86.8	0.24	6.8	170.9	0.326	0.894	0.078	0.215	1112.82	403.72
107.4	0.33	9.7	210.5	0.273	0.925	0.090	0.305	1193.33	352.13
120.00	0.4	11.7	235.5	0.243	0.941	0.097	0.376	1237.11	319.14

Hence,

- $I_W = I_0 \cos\Phi_0 = 0.068$A
- $I_\mu = I_0 \sin\Phi_0 = 0.216$A
- $R_0 = \frac{V_0}{I_W} = 1079.97\Omega$
- $X_0 = \frac{V_0}{I_\mu} = 352.99\Omega$

1.6.2 Short Circuit Test

V_{SC}(V)	I_{SC}(A)	W_{SC}(W)	$Z_2(\Omega)$	$R_2(\Omega)$	$X_2(\Omega)$
10.21	2.96	15	3.449	1.712	2.994
13.18	3.77	30	3.496	2.111	2.787
16.8	4.79	65	3.507	2.851	2.042

Hence,

- $Z_2 = \frac{V_{SC}}{I_{SC}} = 3.484\Omega$
- $R_2 = \frac{W_{SC}}{I_{SC}^2} = 2.225\Omega$
- $X_2 = \sqrt{Z_2^2 - R_2^2} = 2.681\Omega$
- $R_1 = R_2 \times (\frac{N_1}{N_2}) = 2.225\Omega$
- $X_1 = X_2 \times (\frac{N_1}{N_2})^2 = 2.681\Omega$

2 Sources Of Error

- Resistance of wires not taken into account, and also giving rise to inconsistency due to increase in resistance due to heating.
- Change in the connections while circuit is closed.
- Loose Connections.
- Scale of multi-meter not appropriate for measurements

3 Precautions

- Make the connections neat and tight.
- Wear proper shoes and use insulated tools.
- Don't leave the switch on for long continuous periods of time.

4 Concluding Remarks

From the above experiment, we have been able to calculate the various circuit parameters of a real transformer using the open circuit and the short circuit tests.

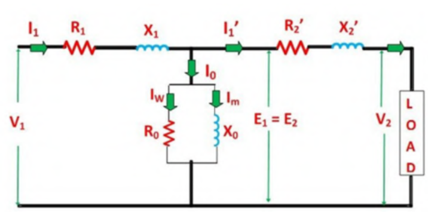


Figure 4: Exact Equivalent Circuit

For the given transformer, we calculated the absolute parameters as follows:

1. R_0=1079.97Ω
2. X_0=352.99Ω
3. R_1=2.225Ω
4. R_2=2.225Ω
5. X_1=2.681Ω
6. X_2=2.681Ω