EXPERIMENT 1 | THE SINGLE PHASE TRANSFORMER

OBJECTIVES

- To understand the basic working principle of a transformer.
- To obtain the equivalent circuit parameters from OC and SC tests, and to estimate efficiency & regulation at various loads.

THEORY

Transformers are arguably the most universally applied pieces of electrical equipment. As such, they range in size from miniature units weighing ounces to huge units weighing tons. All transformers, however, exhibit the same basic properties.

When mutual induction is permitted between two coils or windings, a change in current flowing through one coil induces a voltage upon the other coil. All transformers have a primary winding and one or more secondary windings. The electromagnetic coupling between the primary and secondary windings allows electrical energy to be transferred from the primary winding to the secondary winding. Electrical current entering the primary winding appears as an electromotive force (emf) at the secondary. Connecting the secondary winding to a load allows the energy to be transferred to the load. Since there is no electrical connection between primary and secondary windings (only a magnetic connection), the source and load can be electrically isolated from each other by means of a transformer.

When a transformer is energized and loaded, AC current flowing in its windings creates an alternating magnetic field in its iron core. A small portion of the current, called the magnetizing current, is dedicated to the magnetic circuit in the creation of the magnetic field. Losses associated with the magnetizing current are reactive power (VARs). In addition, there are real power losses (Watts) in the transformer, associated with the inherent resistance in the
windings (copper losses) and with eddy currents and hysteresis in the core (iron losses). For these reasons, the total power delivered to the primary side of the transformer is always larger than the total power available at the secondary side. Even so, it is still reasonable to say that energy is conserved in the transformer and that the real, reactive and apparent power applied to the primary of almost any transformer equals the real, reactive and apparent power available at the secondary.

When the voltage applied to the primary winding is raised above rated value, the iron core begins to saturate, which leads to a rapid increase in the magnitude of the magnetizing current. Saturation of the core also distorts the sinusoidal voltage and current waveforms. The resulting harmonics can lead to mechanical resonances which, in large transformers, can be damaging. Transformers are also very susceptible to damage from short circuit currents.

**APPARATUS:**

- Power Supply Module
- Transformer Module  550 VA, 1ϕ Transformer
- AC Ammeter (0-10A)
- AC Voltmeter (0-1000V)
- Wattmeter  2KW

**PROCEDURE**

**CAUTION!** – High voltages are present in this Experiment. DO NOT make any connections with the power supply ON. Get in the habit of turning OFF the power supply after every measurement.

- Examine the construction of the Transformer Module, its terminals and Input/output voltages.
- List the rated voltage between each of the identified connection terminals, and list the rated current for connections.
- Find the turn ratio between the windings.
Open Circuit Test

The main aim of this test is to determine the Iron losses & No-load current of the T/F which are helpful in finding $R_o$ & $X_o$. In this test generally supply will be given to primary and secondary kept open. Since secondary is opened a small current (magnetizing current will flow and it will be 5 to 10% of full load current. The wattmeter connected in primary will give directly the Iron losses (core losses).

Figure 1: Connection Diagram for Open Circuit Test.
Short Circuit Test:

The main aim of this test is to determine the full load copper losses which is helpful in finding the magnitude of the total effective winding resistance, leakage reactance, efficiency and regulation of the Transformer.

Generally low voltage side will be short circuited and supply will be given to high voltage side & it will be of 5-10% of the rated voltage. The wattmeter connected in primary will give directly the full load copper losses of the Transformer.

![Connection Diagram for Short Circuit Test](image)

Figure 2: Connection Diagram for Short Circuit Test.

**PROCEDURE**

(a) Open Circuit Test:

- Connect the circuit diagram as shown in the Figure 1.
- Gradually increase the voltage using the auto-transformer till the voltmeter reads 220V.
- Record the voltmeter, ammeter and wattmeter readings. The ammeter indicates the no-load current and wattmeter indicates the iron losses.
- Switch off the supply and set the auto-transformer at zero position.
Open Circuit Test Readings

<table>
<thead>
<tr>
<th>$V_{oc}$ (Volt)</th>
<th>$I_{oc}$ (Amp)</th>
<th>$W_{oc}$ (Watt)</th>
<th>$I_C$</th>
<th>$I_M$</th>
<th>$\cos \theta$</th>
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- Find the values of the equivalent core loss resistance $R_c$ and magnetizing reactance $X_m$.
- Calculate $\cos \theta$, the angle $\theta$, $I_c$ and $I_m$, from the test results recorded. Then construct the phasor diagram.
- Plot the no-load current $I_{oc}$, magnetizing current $I_M$ and core loss $W_{oc}$ and no-load power factor $\cos \theta$, against the applied voltage $V_{oc}$ on the same graph paper.

(b) Short Circuit Test:

- Connect the circuit diagram as shown in the Figure 2.
- Gradually increase the voltage using the auto-transformer till the ammeter reads the rated current of the transformer on HV side.
- Record the voltmeter, ammeter and wattmeter readings. The ammeter indicates $I_{sc}$, voltmeter indicates $V_{sc}$ and wattmeter indicates $W_{sc}$ copper losses of the transformer at full load condition.
- Switch off the supply and set the auto-transformer at zero position.

Short Circuit Test Readings

<table>
<thead>
<tr>
<th>$V_{sc}$ (Volt)</th>
<th>$I_{sc}$ (Amp)</th>
<th>$W_{sc}$ (Watt)</th>
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- Compute the equivalent circuit parameter $R_s$ and $X_s$ at the rated high voltage winding current.
- Draw the equivalent circuit of the transformer in the form having all impedances on the primary side of the ideal transformer. Mark in the values calculated in this practical and include all the calculated parameters.
Notes:

1. It may seem that it would be far simpler to measure the winding resistance with an ohm meter, and the leakage reactance may seem rather uncertain from your measurements. But consider the situation with a very large transformer.

2. Large transformers have thick conductors in order to pass large currents without excessive heating. The resistance is often too low to measure with an ordinary ohmmeter and in any case may differ between AC and DC values, so it is better determined by the ammeter and electrodynamic wattmeter method using AC.

3. You may have found the reactance uncertain because its calculation involved a small difference between two large quantities. But in a large transformer, the reactance is usually much larger than the resistance and, in this case, the errors of the measurement matter far less.

LOAD TEST:

The load on a large power transformer in a sub-station will vary from a very small value in the early hours of the morning to a very high value during the heavy peaks of maximum industrial and commercial activity. The transformer secondary voltage will vary somewhat with the load, and because motors, incandescent lamps, and heating devices are all quite sensitive to voltage changes, transformer regulation is of considerable importance. The secondary voltage also depends upon whether the power factor of the load is leading, lagging, or unity. Therefore, it should be known how the transformer will behave (its voltage regulation) when connected to a capacitive, an inductive, or a resistive load.
This test is performed to determine the efficiency and regulation of a transformer at different load conditions. Usually, this test is performed for low, power, rating of transformers. This test gives accurate results as compared to the above tests. In this test, measurements are taken on HV side and LV side at different load conditions.

PROCEDURE:

- Make the connections as the circuit diagram in Figure 3.
- Keep the switch on secondary side open so that load is zero to measure no load voltage. Also keep knob of auto transformer at zero output voltage position.
- Now increase the voltage through auto transformer until the voltage at secondary winding at its rated value.
- Adjust the switches on the Resistive Load module to successively increase the loading factor.
- For each resistance value, record the readings from Wattmeter, Voltmeter, & Ammeter.
- Switch off the AC-Supply.

Figure 3: Connection Diagram for Load Test.
OBSERVATION TABLE (Load Test):

<table>
<thead>
<tr>
<th>Loading Factor %</th>
<th>$W_{\text{prim}}$ (Watts)</th>
<th>$V_{\text{prim}}$ (volts)</th>
<th>$I_{\text{prim}}$ (Amp)</th>
<th>$I_{\text{sec}}$ (Amp)</th>
<th>Output Power</th>
<th>Efficiency</th>
<th>Regulation</th>
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- Fill the table with your measurements and calculate the efficiency and regulation of the transformer.
- Plot the output power versus the regulation and the efficiency.

FORMULAS:

Open Circuit Test

The apparent power taken by the primary on no load is:

$$S = V_1 I_o$$

And the power input is: $P_1 = S \cos \phi$

Hence:

$$\cos \phi = P_1 / (V_1 I_o)$$

And:

$$I_c = I_o \cos \phi \text{ (Core loss component in phase with the applied voltage)}$$

$$I_m = I_o \sin \phi \text{ (Magnetizing component in quadrature with applied voltage)}$$

Short Circuit Test

$$W_1 = I_1^2 R'_1$$

So that: $R'_1 = W_1 / I_1^2 = \ldots$

Also the total impedance is:

$$Z = \sqrt{R'_1^2 + X'_1^2}$$

So that $X'_1$ can be calculated as:

$$X'_1 = \sqrt{Z^2 - R'_1^2}$$