Ministry of Higher Education and Scientific Research

Al-Mustaqbal University

College of Engineering Technology

Medical Instrumentation Techniques Engineering Department

Electrical Machines

Second Class

Lectures 3 and 4

Testing in Transformers

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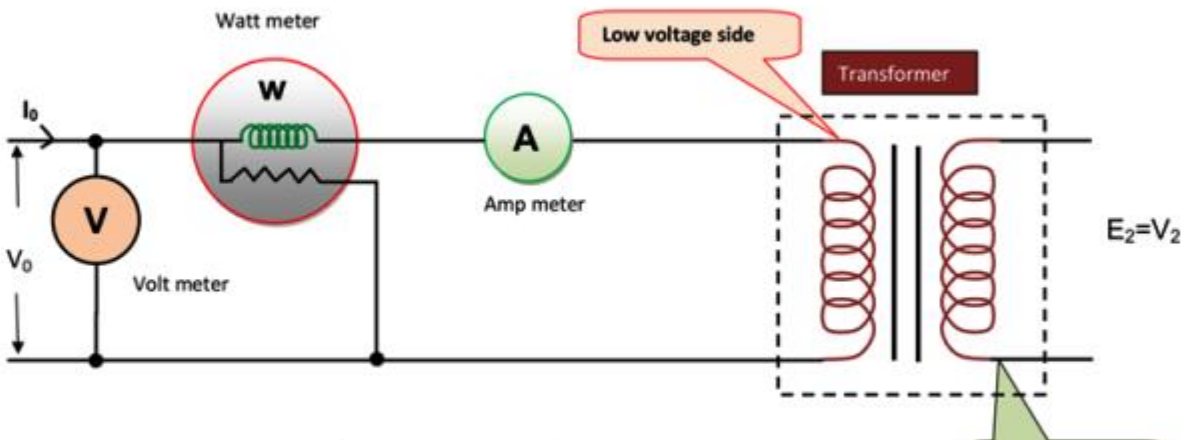

Open-circuit test of Transformer

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1. Introduction

All the transformers are tested before placing them in the field. By performing these tests, we can determine the parameters of a transformer to compute its performance characteristics (like voltage regulation and efficiency etc.). Large transformers cannot be tested by direct loading because of the following reasons:

(i) It is almost impossible to arrange such a large load required for direct loading.

(ii) While performing test by direct loading, there is huge power wastage.

(iii) It is very inconvenient to handle the power equipment.

1.1 Types of Transformer Tests

Tests of transformer done at the manufacturer's premises –

- Type tests.
- Routine tests.
- Special tests.

Tests of transformer done at the consumer's site

- Pre-commissioning tests.
- Periodic tests.
- Emergency tests.

1.1.1 Type Tests of Transformer

The type tests of a transformer are performed at the manufacturer's premises to prove the design expectations and consumer's specifications. The type tests are performed in a prototype unit, not in all manufactured units and these tests confirm the basic and main design criteria of the transformer.

Following transformer tests are included in the type tests –

- Transformation ratio test.
- Winding resistance test of transformer.
- Measurement of core losses and no-load current through open-circuit test.
- Measurement of short circuit impedance and copper losses through short-circuit test.
- Transformer vector group test.
- Measurement of insulation resistance.
- Dielectric test of transformer.
- On-load tap-changer test.
- Temperature rise test.
- Vacuum test of tank and radiators.

1.1.2 Routine Tests of Transformer

The routine tests of a transformer are performed to confirm the operational performance of the transformer and being performed on every units manufactured.

Following tests are included in the routine tests –

- Winding resistance test of transformer
- Transformation ratio test
- Measurement of core losses and no-load current through open-circuit test
- Measurement of short circuit impedance and copper losses through short-circuit test
- Transformer vector group test
- Dielectric test of transformer
- On-load tap-changer test
- Oil pressure to check against the leakages of joints and gaskets.

1.1.3 Special Tests of Transformer

The special tests of transformer are performed depending upon customer's requirements to gathering the information which is useful during the operation and maintenance of the transformer.

The special tests of transformer include the following tests −

- Dielectric test of transformer
- Short-circuit test
- Measurement of acoustic noise level
- Measurement of no-load current harmonics
- Measurement of zero-sequence impedance of the 3-phase transformer
- Measurement of power drawn by cooling fans and oil pumps
- Tests on accessories e.g. buchholz relay, oil preservator, temperature indicators, pressure relief devices etc.

To furnish the required information open circuit and short circuit tests are conducted conveniently without actually loading the transformer. The other important tests which are conducted on a transformer are polarity test voltage ratio test and Back-to-back test.

2. Polarity test

Polarity test is performed to determine the terminals with same instantaneous polarity of the two windings when terminals are not being marked. The relative polarities of the primary and secondary terminals are required to be known for

(i) interconnecting two or more transformers in parallel.

(ii) connecting three single-phase transformers while doing poly-phase transformation of power.

(iii) connecting windings of the same transformer in parallel or series.

For determining the relative polarity of the two windings of a transformer, the two winding are connected in series and a voltmeter is connected across them as shown in Fig. 1. One of the winding (preferably HV winding) is excited from a suitable AC voltage (less than rated value). If the polarities of the windings are as marked on the diagram, then the windings will have a subtractive polarity and the voltmeter will read the difference of E1 and E2 (i.e., E1 – E2). If the voltmeter reads E1 + E2 the polarity marking of one of the windings must be reversed.

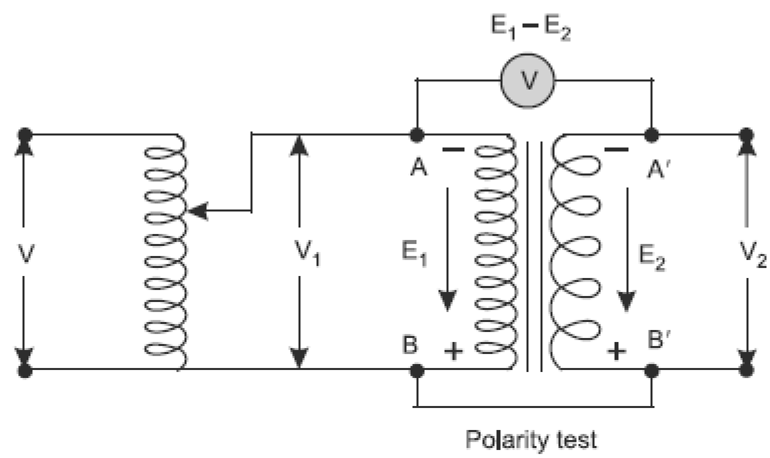


Fig 1. Block diagram for Polarity test.

3. Open circuit test

This test is carried out at rated voltage to determine the no-load loss or core loss or iron loss. It is also used to determine no-load current I_0 which is helpful in finding the no-load parameters i.e., exciting resistance R_0 and exciting reactance X_0 of the transformer.

Usually, this test is performed on low voltage side of the transformer, i.e., all the measuring instruments such as voltmeter (V), wattmeter (W) and ammeter (A) are connected in low-voltage side (say primary). The primary winding is then connected to the normal rated voltage V_1 and frequency as given on the name plate of the transformer. The secondary side is kept open or connected to a voltmeter V′ as shown in Fig. 2.

Since the secondary (high voltage winding) is open circuited, the current drawn by the primary is called no-load current I_0 measured by the ammeter A. The value of no-load current I_0

is very small usually 2 to 10% of the rated full-load current. Thus, the copper loss in the primary is negligibly small and no copper loss occurs in the secondary as it is open. Therefore, wattmeter reading W_0 only represents the core or iron losses for all practical purposes. These core losses are constant at all loads. The voltmeter V′ if connected on the secondary side measures the secondary induced voltage V_2.

The ratio of voltmeter readings, V_2/V_1 gives the transformation ratio of the transformer

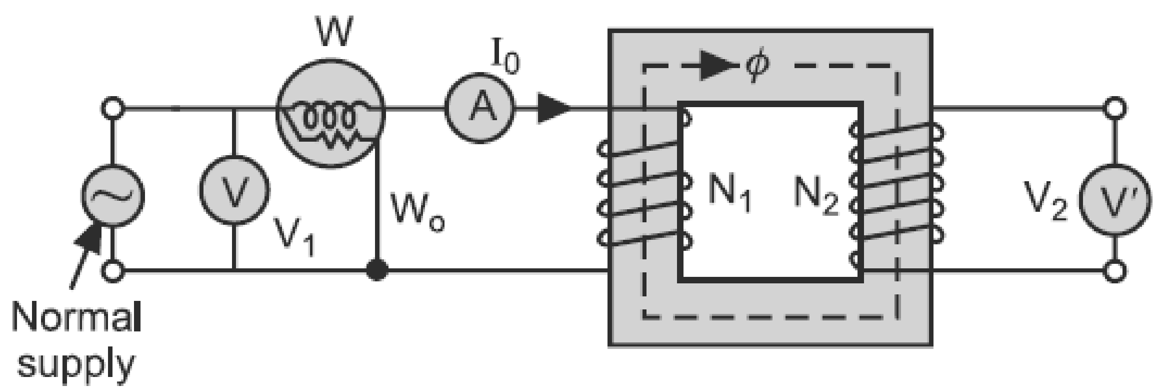


Fig 2. Open circuit test

The Iron losses measured by this test are used to determine transformer efficiency and parameters of exciting circuit of a transformer shown in Fig. 3

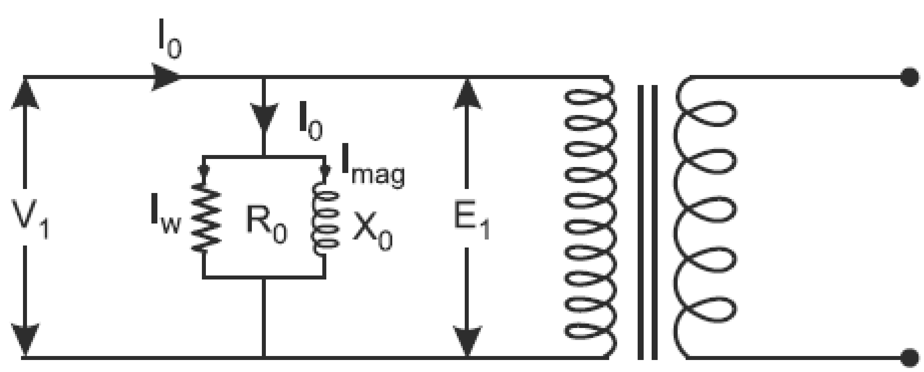


Fig 3. Equivalent circuit of transformer at open test.

In table below, a set of equation can be derived by performing this test (if the test is performed at the primary side).

Parameter Description	Symbols (test on primary)	Symbols (test on secondary)
Voltmeter reading	V_1	V_2
Ammeter reading	I_0	I_0'
Wattmeter reading or iron losses	$W_0 = V_1 I_0 \cos\phi_0$	$W_0 = V_2 I_0' \cos\phi_0$
Working component	$I_w = \frac{W_0}{V_1}$	$I_w' = \frac{W_0}{V_2}$
Magnetizing component	$I_\mu = \sqrt{{I_0}^2 - {I_w}^2}$	$I_\mu' = \sqrt{{I_0'}^2 - {I_w'}^2}$
Exciting resistance	$R_0 = \frac{V_1}{I_w}$	$R_0' = \frac{V_2}{I_w'}$
Exciting reactance	$X_0 = \frac{V_1}{I_\mu}$	$X_0' = \frac{V_2}{I_\mu'}$

4. Short circuit test

This test is carried out to determine the following:

(i) Copper losses at full load (or at any desired load). These losses are required for the calculations of efficiency of the transformer.

(ii) Equivalent impedance (Z_{01} or Z_{02}), resistance (R_{01} or R_{02}) and leakage reactance (X_{01} or X_{02}) of the transformer referred to the winding in which the measuring instruments are connected. Knowing equivalent resistance and reactance, the voltage drop in the transformer can be calculated and hence regulation of transformer is determined.

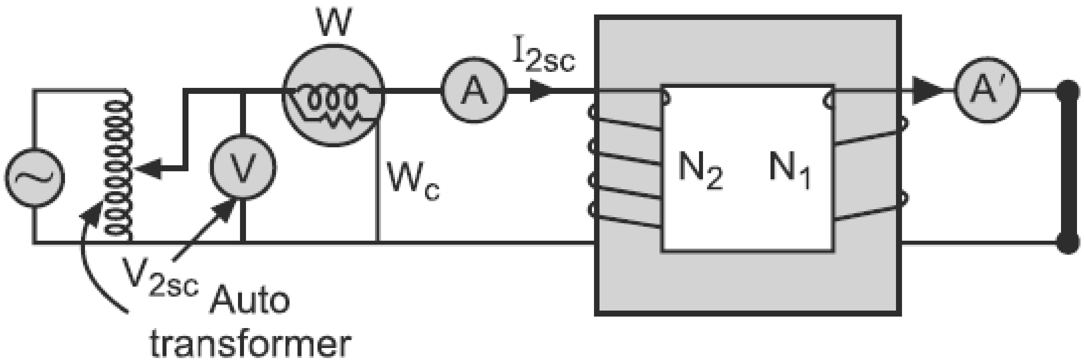


Fig 4. Short circuit test

This test is usually carried out on the high-voltage side of the transformer i.e., a wattmeter W, voltmeter V and an ammeter A are connected in high-voltage* winding (say secondary). The other winding (primary) is then short circuited by a thick strip or by connecting an ammeter A′ across the terminals as shown in Fig. 4. A low voltage at normal frequency is applied to the high voltage winding with the help of on autotransformer so that full-load current flows in both the windings, measured by ammeters A and A′. Low voltage is essential, failing which an excessive current will flow in both the windings which may damage them.

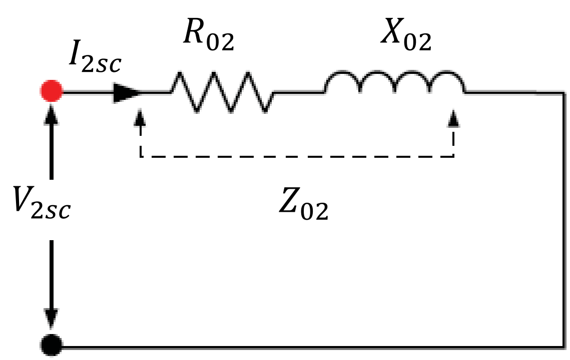


Fig 5. Equivalent circuit of transformer at Short circuit test (Secondary side)).

The iron losses are negligibly small due to low value of flux as these losses are approximately proportional to the square of the flux. Hence, wattmeter reading W_c only represents the copper losses in the transformer windings for all practical purposes. The applied voltage V_{2sc}

is measured by the voltmeter V which circulates the current I_{2sc} (usually full load current) in the impedance Z_{02} of the transformer to the side in which instruments are connected as shown in Fig. 5.

In table below, a set of equation can be derived by performing this test.

Parameter Description	Symbols (test on secondary)	Symbols (test on primary)
Voltmeter reading	V_{2sc}	V_{1sc}
Ammeter reading (first ammeter)	I_{2sc}	I_{1sc}
Wattmeter reading	$W_c = I_{2sc}^2 R_{02}$	$W_c = I_{1sc}^2 R_{01}$
Equivalent resistance referred to secondary	$R_{02} = \frac{W_c}{I_{2sc}^2}$	$R_{01} = \frac{W_c}{I_{1sc}^2}$
Equivalent impedance referred to secondary	$Z_{02} = \frac{V_{2sc}}{I_{2sc}}$	$Z_{01} = \frac{V_{1sc}}{I_{1sc}}$
Equivalent reactance referred to secondary	$X_{02} = \sqrt{{Z_{02}}^2 - {R_{02}}^2}$	$X_{01} = \sqrt{{Z_{01}}^2 - {R_{01}}^2}$

Examples 1: A 15 kVA, 440/230 V, 50 Hz, single phase transformer gave the following test results:

Open Circuit (LV side) 250 V, 1.8A, 95 W.

Short Circuit Test (HV side) 80 V, 12.0 A, 380 W.

Compute the parameters of the equivalent circuit referred to LV side.

Solution

Transformer rating = 15 kVA; E_1 = 440 V; E_2 = 230 V; f = 50 Hz

Open circuit test (LV side); V_2= 250 V; I_0'= 1.8 A; W_0= 95 W

Short circuit test (HV side); V_{1sc} = 80 V; I_{1sc}= 12 A; W_c = 380 W

From **open circuit test** performed on LV side;

$$I'_w = \frac{W_0}{V_2} = \frac{95}{250} = 0.38 \text{ A}$$

$$I'_\mu = \sqrt{{I'_0}^2 - {I'_w}^2} = \sqrt{(1.8)^2 - (0.38)^2} = 1.75943 \text{ A}$$

$$R'_0 = \frac{V_2}{I'_w} = \frac{250}{0.38} = 658\ \Omega$$

$$X'_0 = \frac{V_2}{I'_\mu} = \frac{250}{1.75943} = 142\ \Omega$$

From **short circuit test** performed on HV side;

$$Z_{01} = \frac{V_{1sc}}{I_{1sc}} = \frac{80}{12} = 6.667\ \Omega$$

$$R_{01} = \frac{W_c}{I_{1sc}^2} = \frac{380}{(12)^2} = 2.639\ \Omega$$

$$X_{01} = \sqrt{{Z_{01}}^2 - {R_{01}}^2} = \sqrt{(6.667\ )^2 - (2.639)^2} = 6.122\ \Omega$$

$$k = \frac{230}{440} = 0.5227$$

Transformer resistance and reactance referred to LV (secondary) side;

$$R_{02} = R_{01} \times k^2 = 2.639 \times (0.5227)^2 = 0.7211\ \Omega$$

$$X_{02} = X_{02} \times k^2 = 6.122 \times (0.5227)^2 = 2.673\ \Omega$$

Examples 2: Open-circuit and short-circuit tests on a 4 kVA, 200/400 V, 50 Hz, one-phase transformer gave the following test:

O.C. test: 200 V, 1 A, 100 W (on L.V. side)

S.C. test: 15 V, 10 A, 85 W (with primary short-circuited)

Draw the equivalent circuit referred to primary:

Solution

Transformer rating = 4 kVA; E_1 = 200 V; E_2 = 400 V

Open circuit test (LV side); V_1= 200 V; I_0= 1 A; W_0= 100 W

Short circuit test (HV side); V_{2sc} = 15 V; I_{2sc}= 10 A; W_c = 100 W

From **open circuit test** performed on LV side;

$$I_w = \frac{W_0}{V_1} = \frac{100}{200} = 0.5 \text{ A}$$

$$I_\mu = \sqrt{{I_0}^2 - {I_w}^2} = \sqrt{(1)^2 - (0.5)^2} = 0.866 \text{ A}$$

$$R_0 = \frac{V_1}{I_w} = \frac{200}{0.5} = 400\ \Omega$$

$$X_0 = \frac{V_1}{I_\mu} = \frac{200}{0.866} = 231\ \Omega$$

From **short circuit test** performed on HV side;

$$Z_{02} = \frac{V_{2sc}}{I_{2sc}} = \frac{15}{10} = 1.5\ \Omega$$

$$R_{02} = \frac{W_c}{I_{2sc}^2} = \frac{85}{(10)^2} = 0.85\ \Omega$$

$$X_{02} = \sqrt{{Z_{02}}^2 - {R_{02}}^2} = \sqrt{(1.5)^2 - (0.85)^2} = 1.236\ \Omega$$

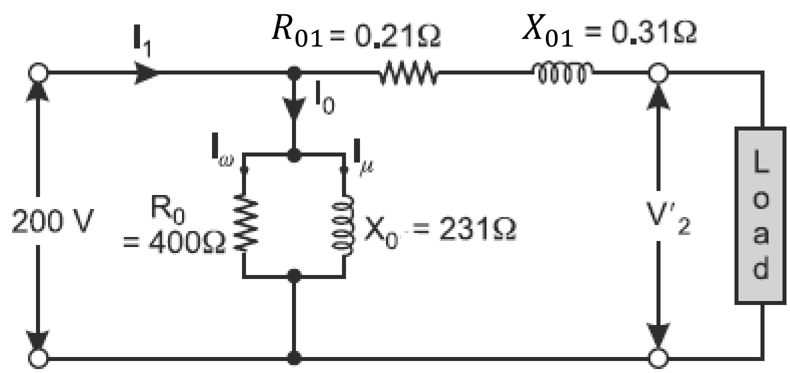
$$k = \frac{400}{200} = 2$$

Transformer resistance and reactance referred to primary side;

$$R_{01} = \frac{R_{02}}{k^2} = \frac{0.85}{(2)^2} = 0.21\ \Omega$$

$$X_{01} = \frac{X_{02}}{k^2} = \frac{1.236}{(2)^2} = 0.31\ \Omega$$

The equivalent circuit referred to primary side is shown below



5. Back-to-back Test

The open-circuit test and short circuit test are performed to determine the equivalent circuit parameter. With the help of these tests, we cannot find the temperature rise in a transformer. Because the open-circuit test is examined only core loss and short-circuit test is examined only copper loss. However, the transformer is not subjected concurrently to both losses. Hence, the alternative is Sumpner's test.

The solution to this problem is the Sumpner's test. The Sumpner's test is performed to determine the transformer efficiency, voltage regulation, and heating effect of the transformer under loading conditions. The Sumpner's test is also known as the back-to-back test as this test consists of two identical transformers connected back-to-back.

In Sumpner's test, actual loading conditions are simulated without connecting actual load. For a small transformer, it is convenient to connect full-load. But it is difficult to connect full-load in the case of large transformers. Therefore, this test helps to find the important parameters of the transformer. And the Sumpner's test gives more accurate results compared to open-circuit and short-circuit tests.

To perform the Sumpner's test, two single-phase transformers with identical ratings are required. The experimental circuit diagram of the Sumpner's test is shown in the figure below.

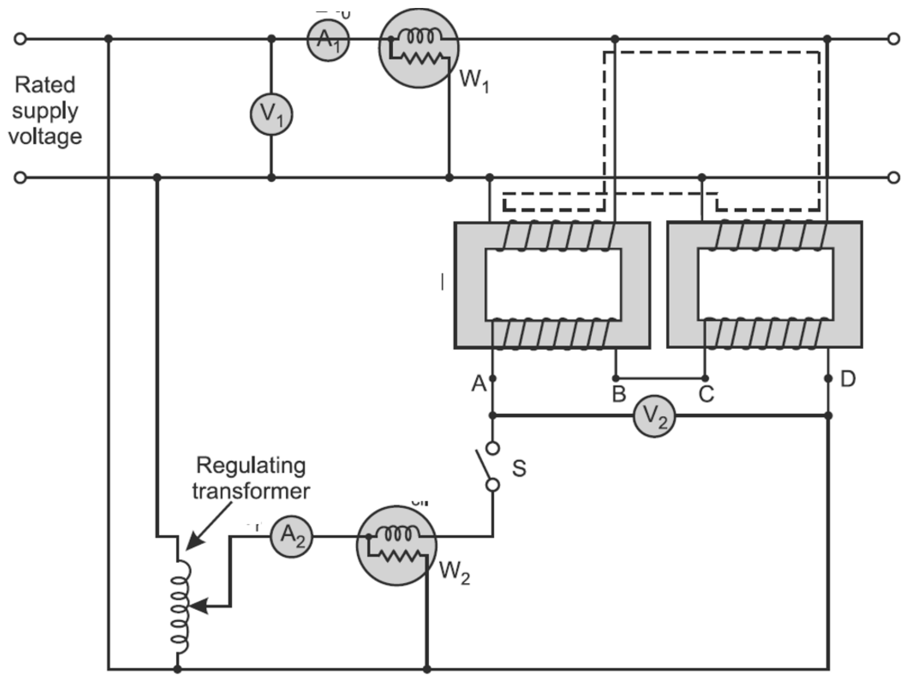


Fig 6. Experimental circuit diagram of the Sumpner's test.