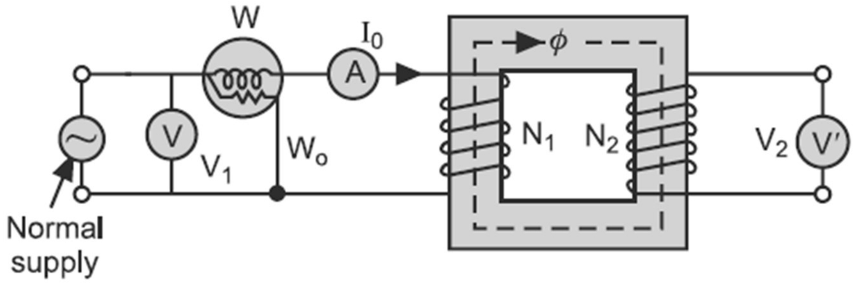


Fig 2. Open circuit test

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

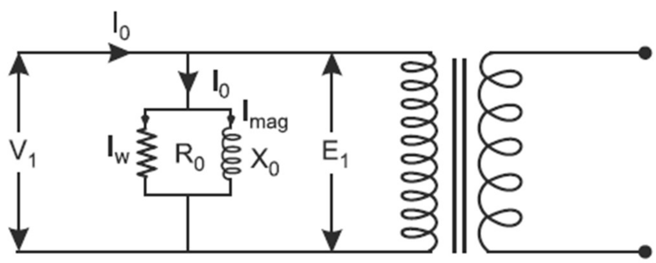


Fig 3. Equivalent circuit of transformer at open test.

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.

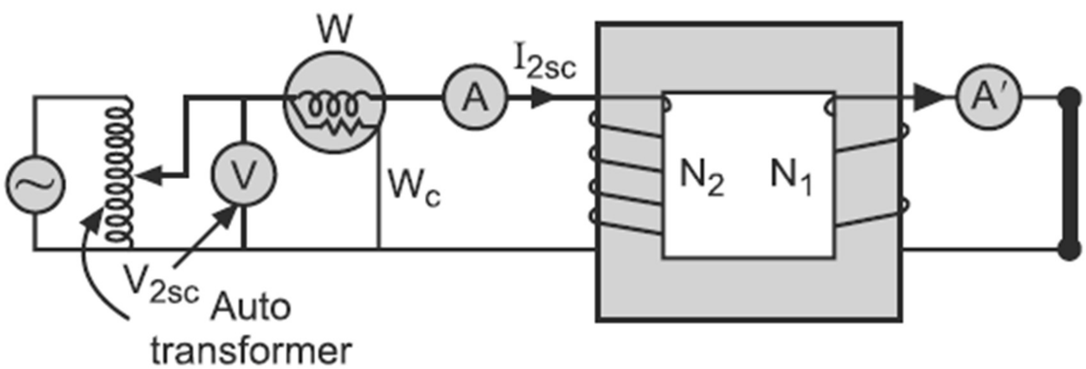


Fig 4. Short circuit test

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.

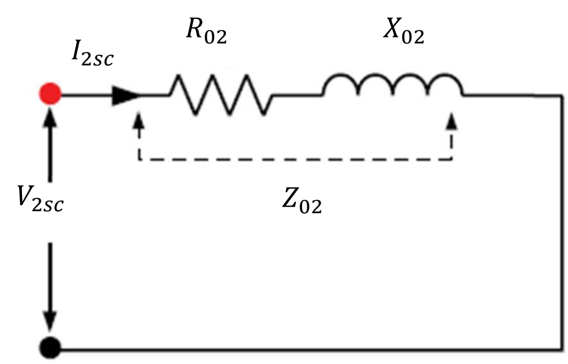


Fig 5. Equivalent circuit of transformer at Short circuit test (Secondary side)).

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_{1s} = 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= 250 V; I_0= 1.8 A; W_0= 95 W

Short circuit test (HV side); V_{2sc} = 80 V; I_{2sc}= 12 A; W_c = 380 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;

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

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

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

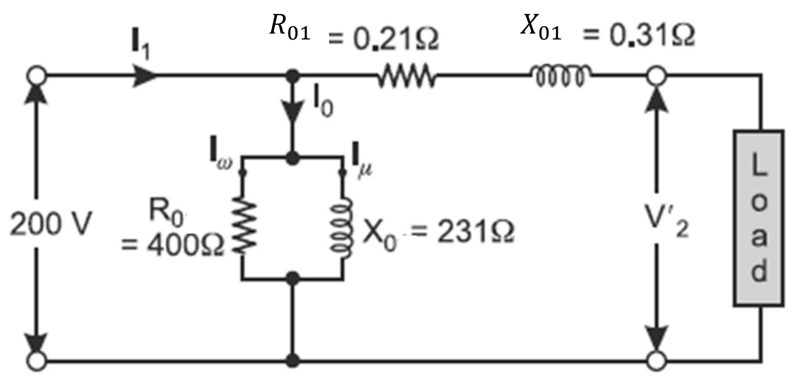
$$k = \frac{400}{200} = 2$$

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.

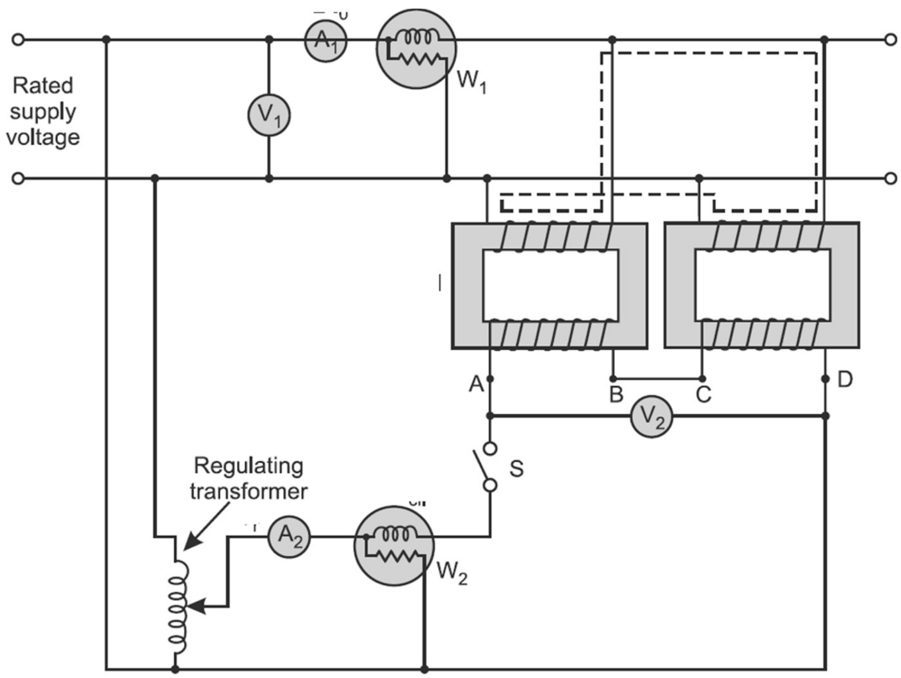


Fig 6. Experimental circuit diagram of the Sumpner's test.