Open Circuit (OC) and Short Circuit (SC) Tests on Single Phase Transformer

1 Aim

To obtain the equivalent circuit parameters from OC and SC tests, and to estimate efficiency & regulation at various loads.

2 Theory

Equivalent circuit of transformer and simplified form of the circuit are shown in Fig. 1 and Fig. 2 respectively. Various performance parameters of transformers can be calculated if we know values of parameters in equivalent circuit. These parameters can be easily determined by performing tests that involve little power consumption. Two tests - no-load test (or open circuit test) and short circuit test will provide information for determining the parameters of the equivalent circuit.

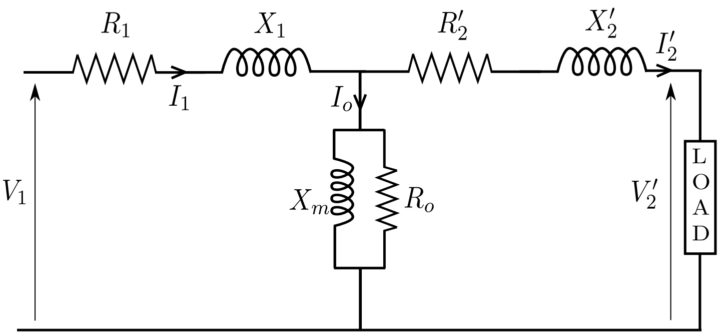


Figure 1: Equivalent circuit of a transformer

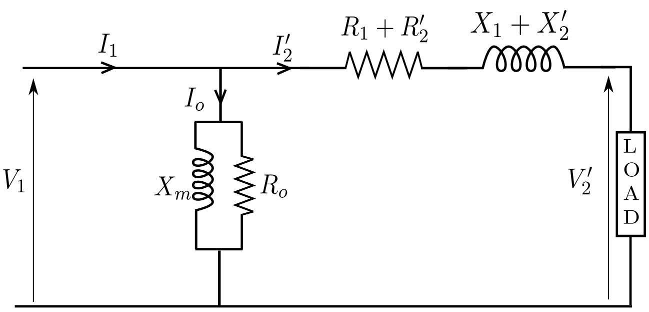


Figure 2: Simplified equivalent circuit of a transformer

2.1 Open circuit (OC) test

The shunt branch parameters are determined by performing this test. Since, the core loss and the magnetizing current depend on applied voltage only and are practically unaltered by the load current (*why*?). Hence to get these parameters, rated voltage is applied to one of the windings keeping the other winding open (generally HV winding is kept open and rated voltage is applied to LV winding - (*why*?). The circuit diagram to conduct this test is shown in Fig. 3. The secondary terminals are open

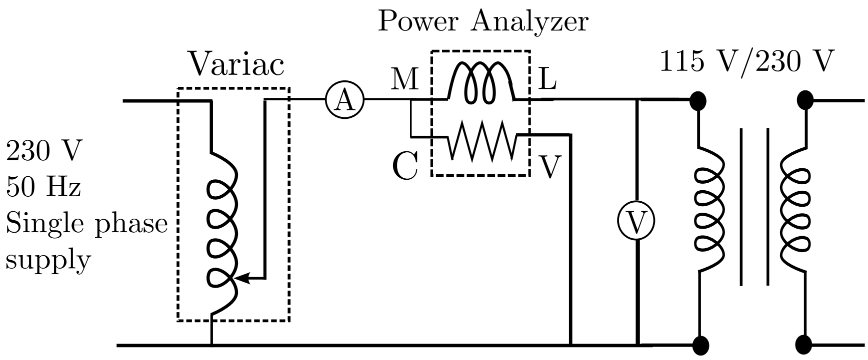
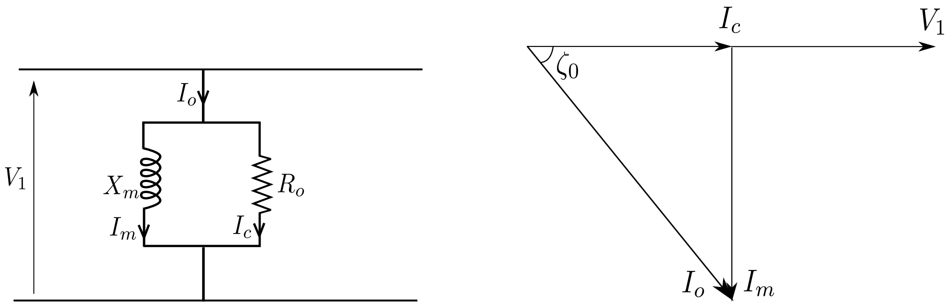


Figure 3: Connection diagram for OC test of a transformer



(a) Equivalent circuit for no load

(b) Phasor diagram on no-load

Figure 4: Equivalent circuit and phasor diagram for OC test

("no load" is connected across the secondary), hence the current drawn from the source is called as *no load current*.

On no-load, the approximate equivalent circuit shown in Fig. 2 can be further reduced and is shown in Fig. 4. Under no-load condition, load resistance is not present in Fig. 1. Hence power input to the transformer is equal to the sum of losses in the primary winding resistance R_1 and core loss. But, no load current is very small ($< 10\%$) as compared to full load current the loss in winding resistance is neglected. Thus, on no load the power drawn from the source is dissipated as heat in the core. If I_o and P_i are the current and input power drawn by the transformer at rated voltage V_1 respectively, then

$$\cos \zeta_o = \frac{P_i}{V_1.I_0} \tag{1}$$

From Fig. 4,

$$I_c = I_0 \cos \zeta_o, \qquad I_m = I_0 \sin \zeta_o, \tag{2}$$

$$\therefore R_0 = V_1/I_c, \qquad X_m = V_1/I_m \tag{3}$$

2.2 Short circuit (SC) test

Consider the circuit shown in Fig. 2. Suppose the input voltage is reduced to a small fraction of rated value and secondary terminals are short-circuited. A current will circulate in the secondary winding. Since a small fraction of rated voltage is applied to the primary winding, the flux in the core and hence the core loss is very small. Hence, the power input on short circuit is dissipated as heat in the winding.

The circuit diagram to conduct this test is shown in Fig. 6. In this test, the LV terminals of the transformer are short circuited. The primary voltage is gradually applied till the rated current flows in the winding. Since, the applied voltage is very small (may be of the order of $5-8\%$), the magnetizing branch can now be eliminated from the equivalent circuit. The modified equivalent circuit is shown in Fig. 5. If V_{sc} is the applied voltage to circulate the rated current (I_2') on short circuit, and P_c is the power input to the transformer then,

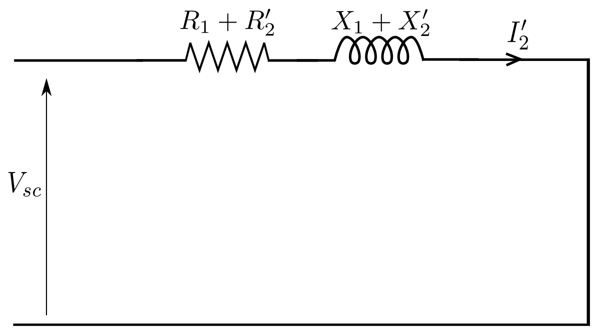


Figure 5: Equivalent circuit on SC test

$$Z_{sc} = \frac{V_{sc}}{I_2'} \qquad \cos\theta = \frac{P_c}{V_{sc}.I_2'} \tag{4}$$

$$\therefore (R_1 + R_2') = Z_{sc}\cos\theta, \qquad (X_1 + X_2') = Z_{sc}\sin\theta \tag{5}$$

3 Pre-lab Questions

1. A 100 kVA, 240 V: 8 kV, 50 Hz single phase transformer has following parameters

$$R_1 = 7\ \Omega \qquad X_1 = 45\ \Omega$$
$$R_2 = 3.6\ \Omega \qquad X_2 = 40\ \Omega$$
$$R_0 = 245.3\ \Omega \qquad X_m = 120\ \Omega$$

   Assume that the transformer is supplying its rated kVA at its low voltage terminals. Calculate the load current. Also calculate the magnetizing current as a fraction of load current.

2. Why HV winding, and not LV winding, is kept open during OC test?

4 Procedure

Note down the name plate readings and determine the rated currents for both the windings.

4.1 No-Load Test:

1. Connect the circuit as shown in Fig. 3
2. Apply voltage to the LV side in steps upto the rated voltage and for each case record primary current and power drawn from the source. Also, observe the current waveform on the power analyzer.
3. Also, observe the waveform on DSO (Digital Storage Oscilloscope). Save ("record") signals of the voltage and the current in form of a data file.
4. Increase the applied voltage by 10% and repeat the above step.
5. Reduce the output voltage of the variac to zero and switch-off the supply.

4.2 Short-Circuit Test:

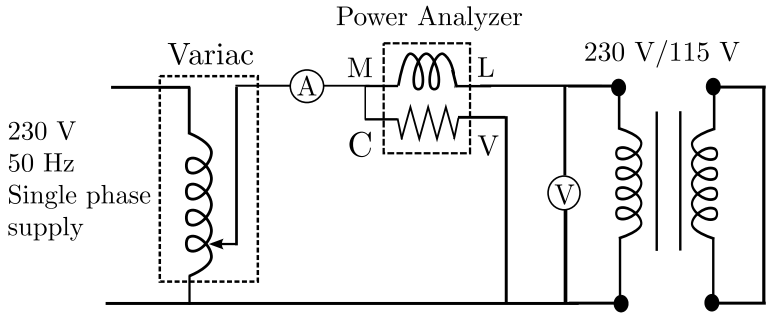


Figure 6: Connection diagram for short circuit test

1. Connect the circuit as shown in Fig. 6. Set the autotransformer output to zero. **It is extremely important to note that a low voltage is to be applied to the primary winding.**
2. Adjust the output of the autotransformer such that rated current flows through the windings. Record the applied voltage, current and input power.
3. Reduce the output voltage of the autotransformer to zero and put off the supply.

5 Report

1. Determine the equivalent circuit parameters from the test results.
2. Using equivalent circuit parameters compute the following:
   - regulation at 25%, 75% and full load for powerfactor = 1, 0.6 lag and 0.6 lead.
   - efficiency at 25%, 50%, 75% and full load for powerfactor = 1, 0.8 lag, and 0.6 lead.
3. Plot the variation of
   - Efficiency with load VA for each power factor
   - Regulation with powerfactor.
4. Plot the recorded data of voltage and current using appropriate tool e.g. gnuplot, MATLAB. Using this data, calculate the power dissipated and power factor. Note that in theory, $\int vidt = P$. However, in practice, we get discrete time samples as voltage and current signals. Hence, to calculate power we need to do numerical integration (i.e. summation) to get power disssipated.

6 Post-lab Questions

1. Which winding (LV or HV) should be kept open while conducting OC test? Justify your answer.
2. Assume that the given transformer has the following name plate ratings:
   40 kVA, 440 V/11 kV, 50 Hz.
   What do these numbers imply?

3. Comment on the nature of the current waveform drawn from the source during OC test for (i) 50%, (ii) 100% and (iii) 110% of the rated voltage.
4. Can the regulation be negative? What does it signify?
5. Assume that you have been given a transformer manufactured in the US (The supply voltage and frequency are 110 V and 60 Hz respectively). What voltage will you apply if this transformer is to be used in this country? Justify your answer.
6. What is the reason for high no load current at lower-than-rated voltage for the no load test on high frequency transformer which was demonstrated to you by the TAs ?
7. Assume that you have been given two transformers of identical VA, and voltage ratings. But one of them is a 10 kHz transformer and another is a 100 Hz transformer. Just by inspection, how would you identify which one is the high frequency transformer? Justify your answer.
8. What is an 'impedance matching' transformer? Name one instrument of everyday use, in which this transformer being used.

This experiment/chapter is prepared by *Makarand M Kane* (Research Scholar, 2015 batch)