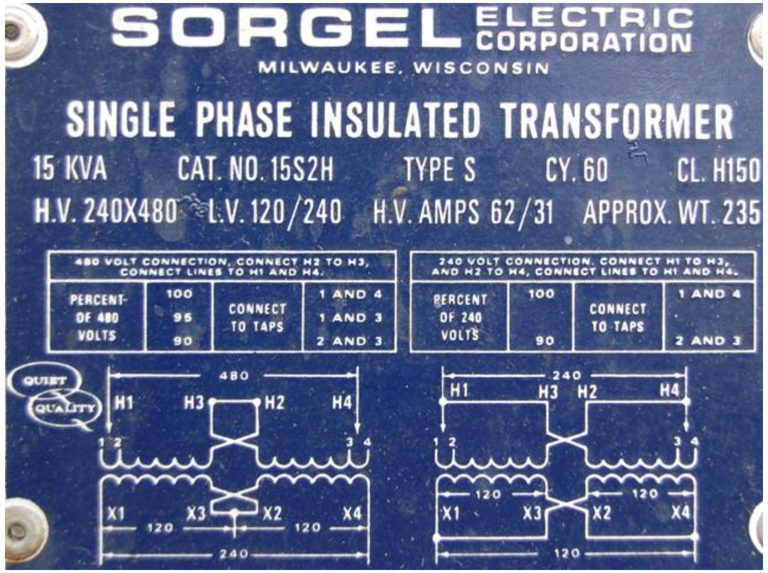
Electrical Machines II

Week 3: Transformer Tests and voltage regulation

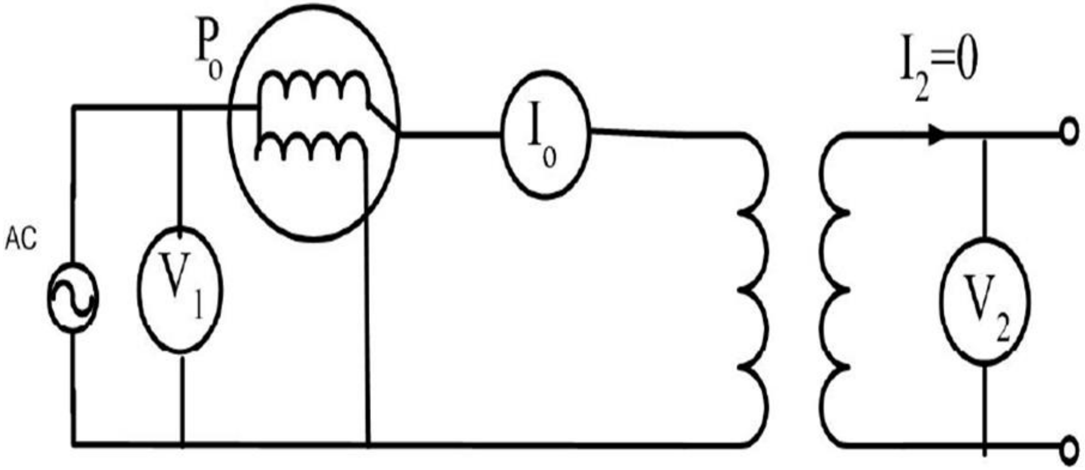
Determination of Equivalent Circuit Parameters

- All the circuit parameters can be easily determined by performing three tests,
  - a no-load test (or open circuit test)
  - short circuit test
  - D.C. test



No information what so ever about the equivalent circuit parameters

1-Open circuit (no load) test

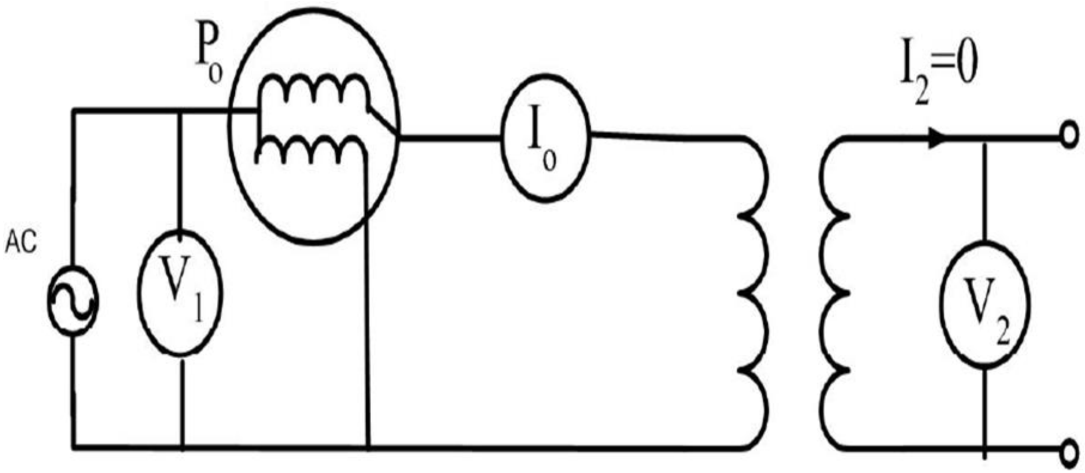


- Transformer's secondary winding is open-circuited
- Primary winding is connected to a full-rated line voltage. All the input current must be flowing through the excitation branch of the transformer.
- The series elements R_p and X_p are too small in comparison to R_C and X_M to cause a significant voltage drop, so essentially all the input voltage is dropped across the excitation branch.
- Input voltage, input current, and input power to the transformer are measured.

Measured values	Symbol
Open circuit voltage	V_{oc}
Open circuit current	I_{oc}
Open circuit power	P_{oc}

Calculated values	Symbol
Core loss resistance	R_c
Magnetizing reactance	X_M

1-Open circuit (no load) test

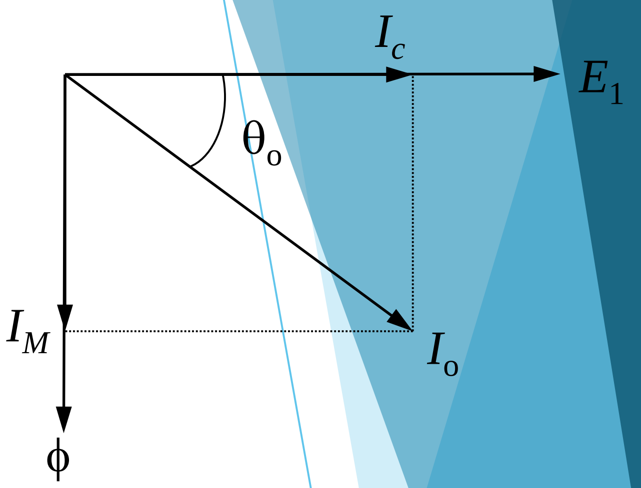


Measured values	Symbol
Open circuit voltage	V_{oc}
Open circuit current	I_{oc}
Open circuit power	P_{oc}

Calculated values	Symbol
Core loss resistance	R_c
Magnetizing reactance	X_M

Although it does not matter which side of the transformer is excited, it is **safer** to conduct the test on the **low-voltage side.** Another justification for performing the test on the low-voltage side is the availability of the low-voltage source in any test facility.

1-Open circuit (no load) test



Circuit Parameters: Open-Circuit Test

The open circuit power (no load power) is given by:

$$P_{oc} = V_{oc} I_{oc} \cos\phi_{oc}$$

The open-circuit power factor and power factor angle can be determined:

$$PF_{oc} = \cos\phi_{oc} = \frac{P_{oc}}{V_{oc} I_{oc}} \quad or,\ \phi_{oc} = \cos^{-1}\left[\frac{P_{oc}}{V_{oc} I_{oc}}\right]$$

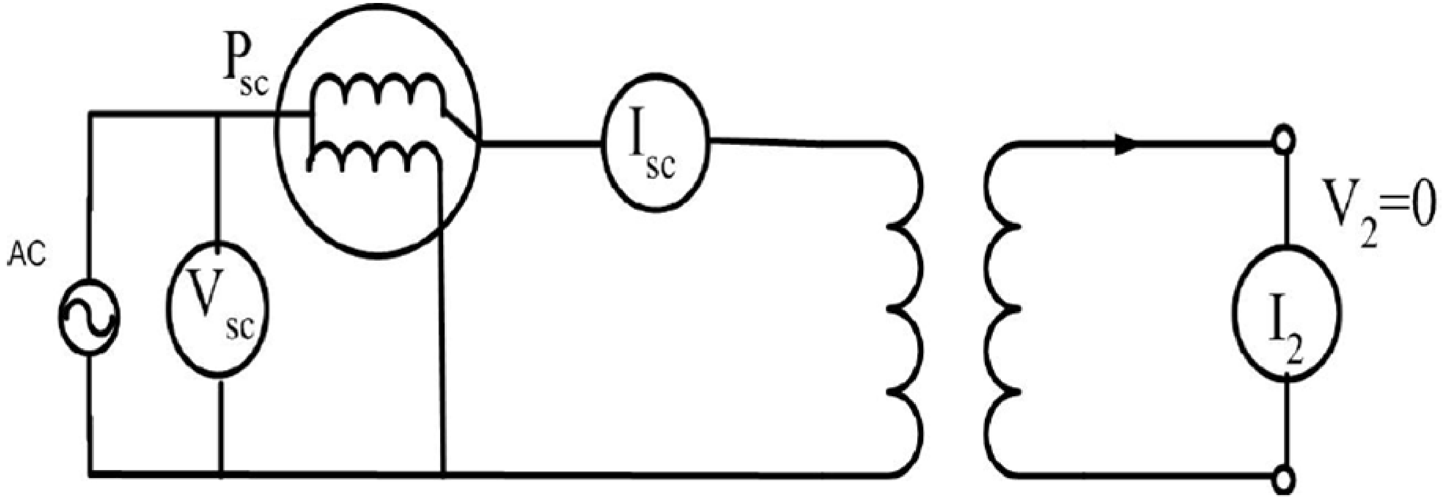
Since the no load current I_{oc} will correspond to the magnetic branch current which constitutes two current components, I_M and I_c

$$\because I_M = I_{oc}\cos\phi_{oc}, \because I_c = I_{oc}\sin\phi_{oc}$$

Then one can easily determine X_M and R_c:

$$\therefore X_M = \frac{V_{oc}}{I_M}, \therefore R_c = \frac{V_{oc}}{I_c}$$

2-Short circuit test

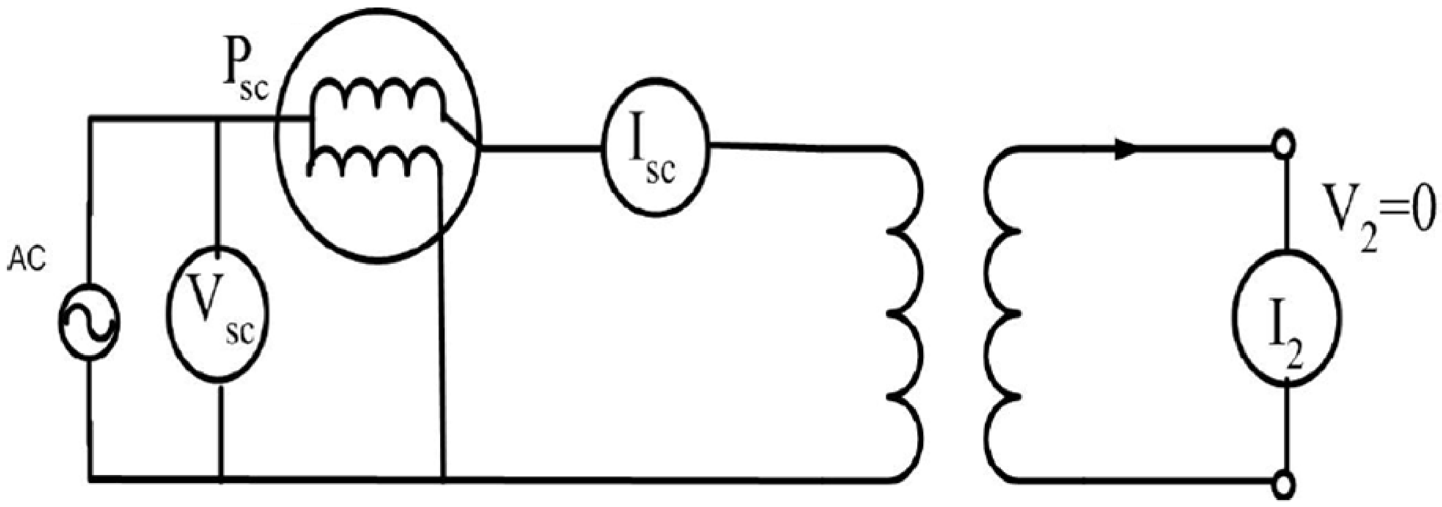


Measured values	Symbol
short circuit voltage	V_{sc}
short circuit current	I_{sc}
short circuit power	P_{sc}

Calculated values	Symbol
winding resistances	R_{eq}
leakage reactances	X_{eq}

- Transformer's secondary winding is short-circuited
- Primary winding is connected to a fairly low-voltage source.
- The input voltage is adjusted until the current in the short-circuited windings is equal to its rated value.
- Input voltage, input current, and input power to the transformer are measured.
- Excitation current is negligible, since the input voltage is very low. Thus, the voltage drop in the excitation branch can be ignored. All the voltage drop can be attributed to the series elements in the circuit.

2-Short circuit test



Measured values	Symbol
short circuit voltage	V_{sc}
short circuit current	I_{sc}
short circuit power	P_{sc}

Calculated values	Symbol
winding resistances	R_{eq}
leakage reactances	X_{eq}

The low power input at the rated current implies that **the applied voltage is a small fraction of the rated voltage. Therefore, extreme care must be exercised in performing this test.**

Once again, it does not really matter on which side this test is performed. However, the measurement of the rated current suggests that, for safety purposes, the test be performed on the high-voltage side.

2-Short circuit test

Circuit Parameters: Short-Circuit Test

The short-circuit power and current can be related as:

$$P_{sc} = I_{sc}^{\ 2} R_{sc}$$

$$\therefore R_{sc} = R_{eq} = \frac{P_{sc}}{I_{sc}^{\ 2}}$$

Since the series impedance (equivalent impedance) can be given by:

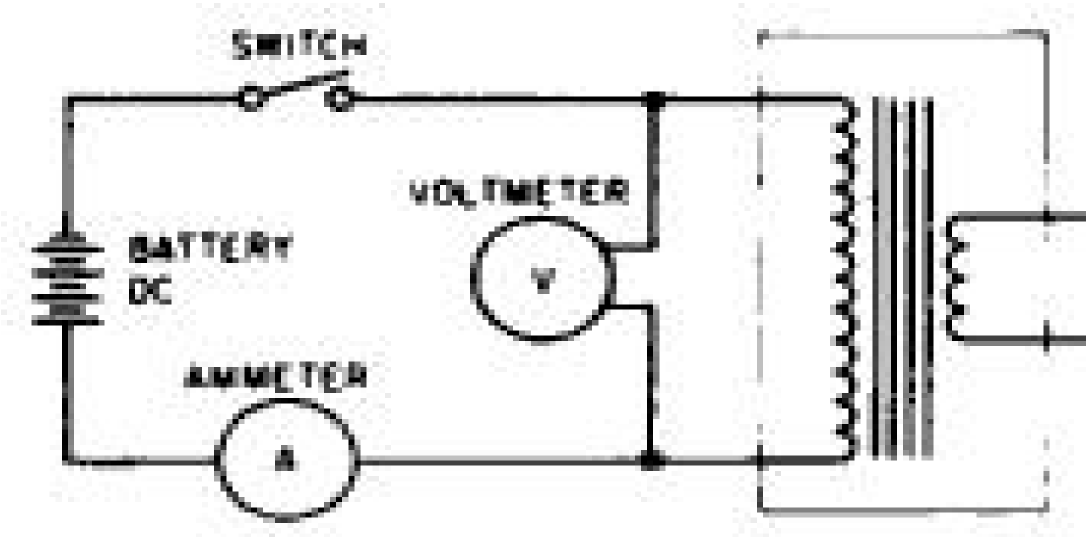
$$|Z_{sc}| = \sqrt{R_{eq}^{\ 2} + X_{eq}^{\ 2}}$$

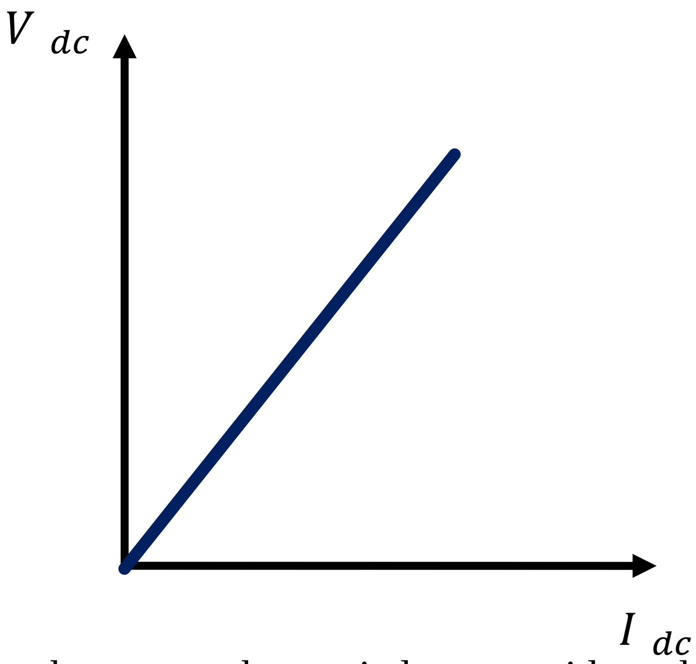
$$|Z_{sc}| = \frac{V_{sc}}{I_{sc}}$$

It is possible to determine the equivalent leakage transformer reactance since the resistive part is already known

Take care where have you performed the test

3-D.C. test





This test is carried out to measure the resistance of each winding, thus the test can be carried on one side and the other side is concluded with the help of the short circuit test

To determine the primary winding resistance, the secondary winding is open circuited and the primary winding is excited with dc source. The dc voltage is varied till the primary current reaches rated current. Each time the voltage is increased, the corresponding primary current reading is recorded.

The resistance of each winding is obtained from the Ohms Law:

$$R_{dc} = R_1 = \frac{\Delta V_{dc}}{\Delta I_{dc}}$$

Measured values	Symbol
Dc voltage	V_{dc}
Dc current	I_{dc}

Transformer Voltage regulation

Because a real transformer has series impedance within it, the output voltage of a transformer varies with the load even if the input voltage remains constant. The voltage regulation of a transformer is the change in the magnitude of the secondary terminal voltage from no-load to full-load.

$$\%Voltage\ Regulation = \frac{V_s[no-load]-V_s[full-load]}{V_s[full-load]}\times 100$$

$$\approx \frac{V_p[no-load]-V_p[full-load]}{V_p[full-load]}\times 100$$

Referred to the primary side