Single-phase Transformer

Single-phase Transformer Construction

Losses and Test

Acknowledgement: *The materials presented in this lecture has been taken from open source, reference books etc. This can be used only for student welfare and academic purpose.*

Recap

- Transformer definition and its need
- Constructional details
- Its classifications and applications
- Its cooling
- Induced EMF in secondary and primary winding

Lecture-5 Objectives

- Losses in the transformer
- Equivalent circuit of the transformer
- Testing of the transformer
- Example

Losses in a Transformer

- The power losses in a transformer are of two types, namely;
  - ❑ Core or Iron losses
  - ❑ Copper losses

Core or Iron losses (P_i)

- This loss consists of hysteresis and eddy current loss and occur in the transformer core due to the alternating flux.
- These losses can be determined by open-circuit test.

$$\text{Hysteresis loss, } P_h = K_h\, B_{max}^{16}\, f\, v \quad \text{watts}$$

$$\text{Eddy current loss, } P_e = K_e\, B_{max}^{2}\, f^2\, t^2 v \quad \text{watts}$$

- Both the above losses depend on B_m and frequency which are constant.
- Hence, core or iron losses are practically the same at all loads.

Copper losses (P_C)

- These losses occur in both the primary and secondary windings due to their ohmic resistance.
- These losses can be determined by short-circuit test.

$$P_C = I_1^2 R_1 + I_2^2 R_2 = I_1^2 R_{01} = I_2^2 R_{02}$$

- Copper losses vary as the square of load current.
- Copper losses account for about 90% of the total losses.

Summary

Core loss

- ✓It is the Constant loss
- ✓Does not change even as the load current changes
- ✓Proportional to supply voltage and frequency

Copper loss or I^2R loss

- ✓It is a variable loss
- ✓Also called as I^2R loss
- ✓Proportional to square of the load current
- ✓Occurs in the winding resistances
- ✓It is dissipated as heat

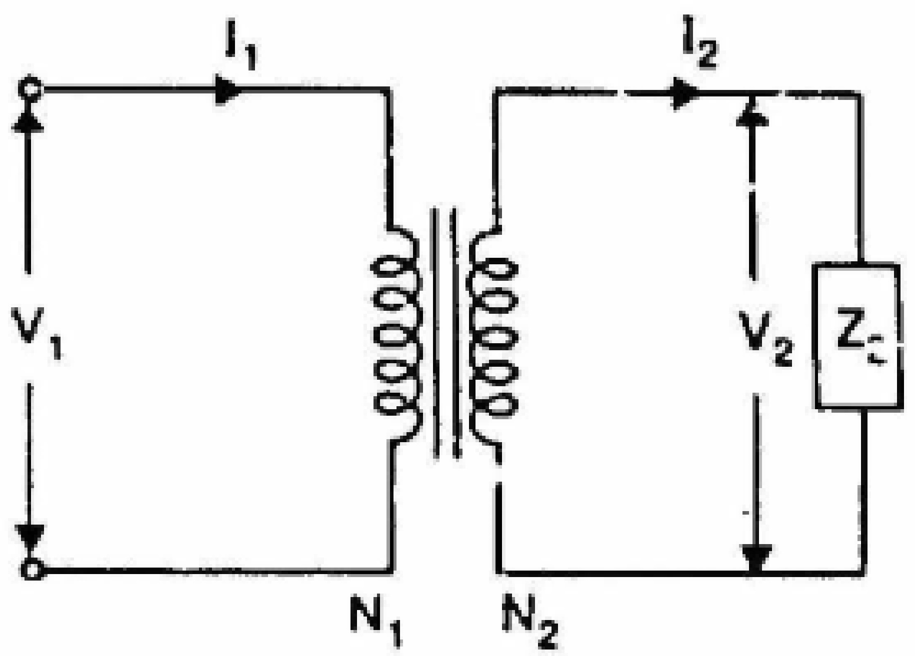
Impedance Ratio

$$Z_2 = \frac{V_2}{I_2} \qquad Z_1 = \frac{V_1}{I_1}$$

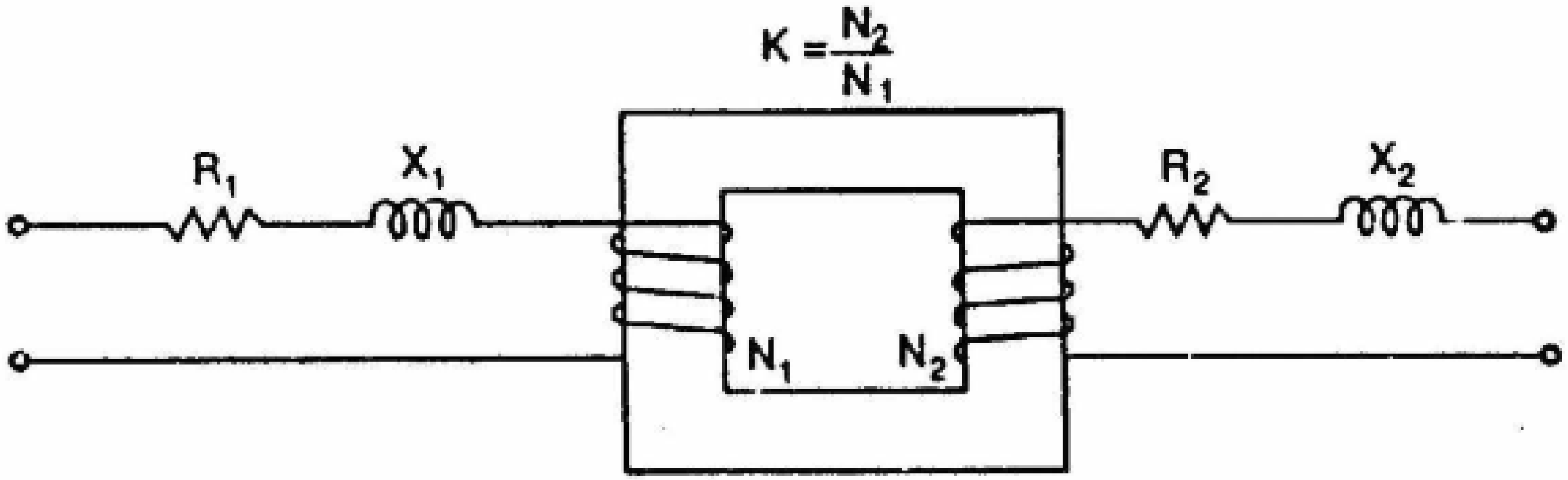
$$\therefore \quad \frac{Z_2}{Z_1} = \left(\frac{V_2}{V_1}\right) \times \left(\frac{I_1}{I_2}\right)$$

$$\frac{Z_2}{Z_1} = K^2$$

Similarly, $\frac{R_2}{R_1} = K^2$ $\quad \frac{X_2}{X_1} = K^2$

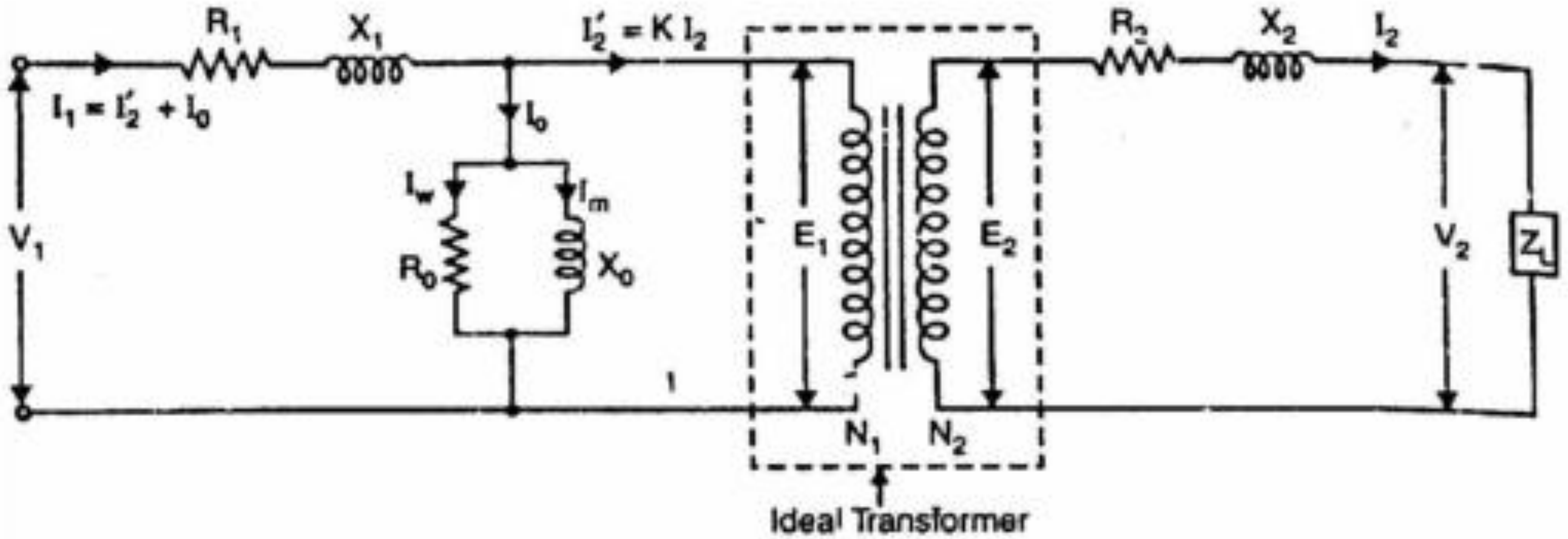


Shifting Impedances

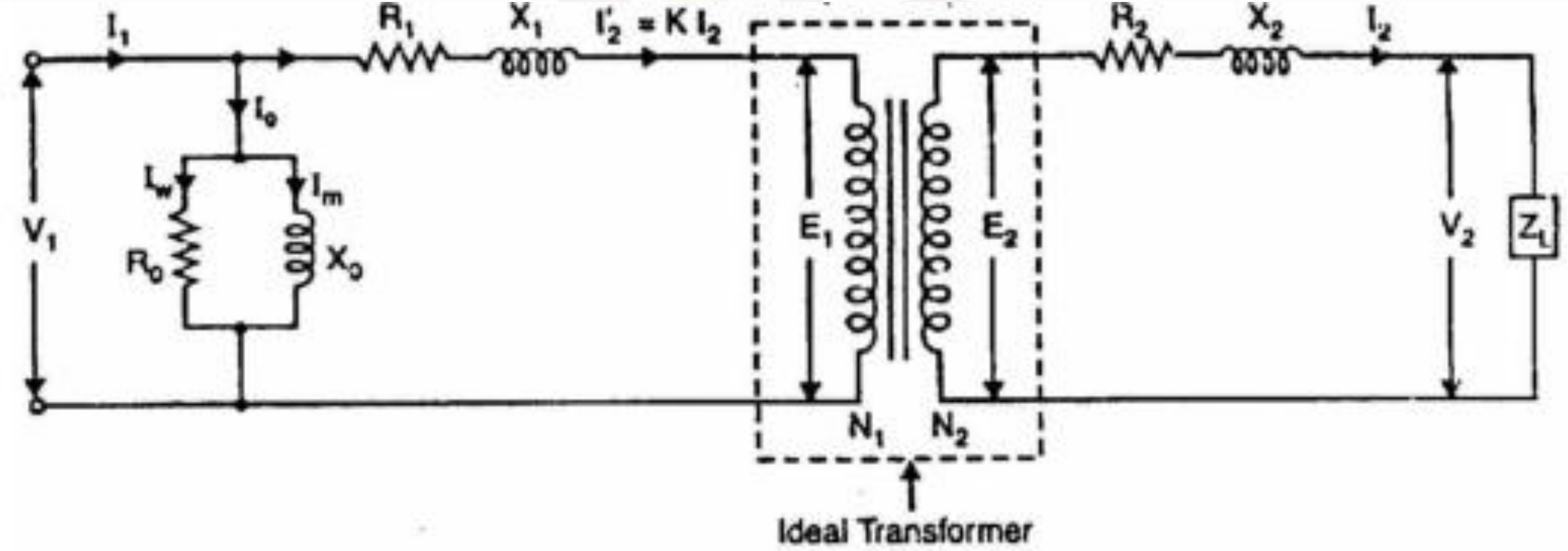


- When transferring resistance or reactance from primary to secondary, multiply it by K^2.
- When transferring resistance or reactance from secondary to primary, divide it by K^2.

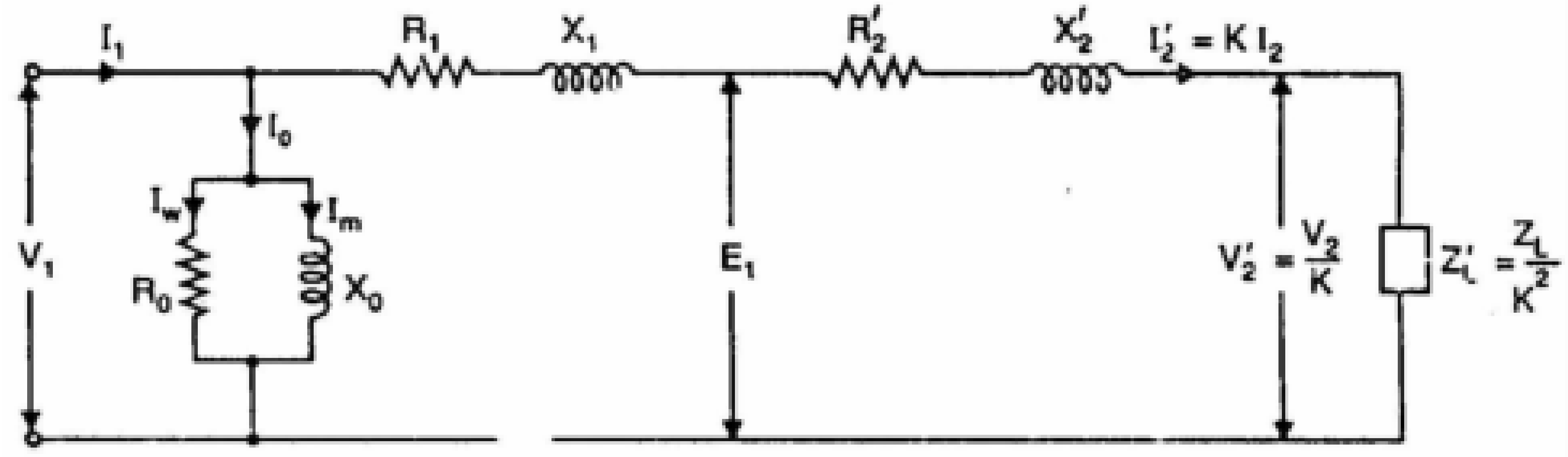
Equivalent Circuit of a Transformer



Simplified Equivalent Circuit of a Transformer

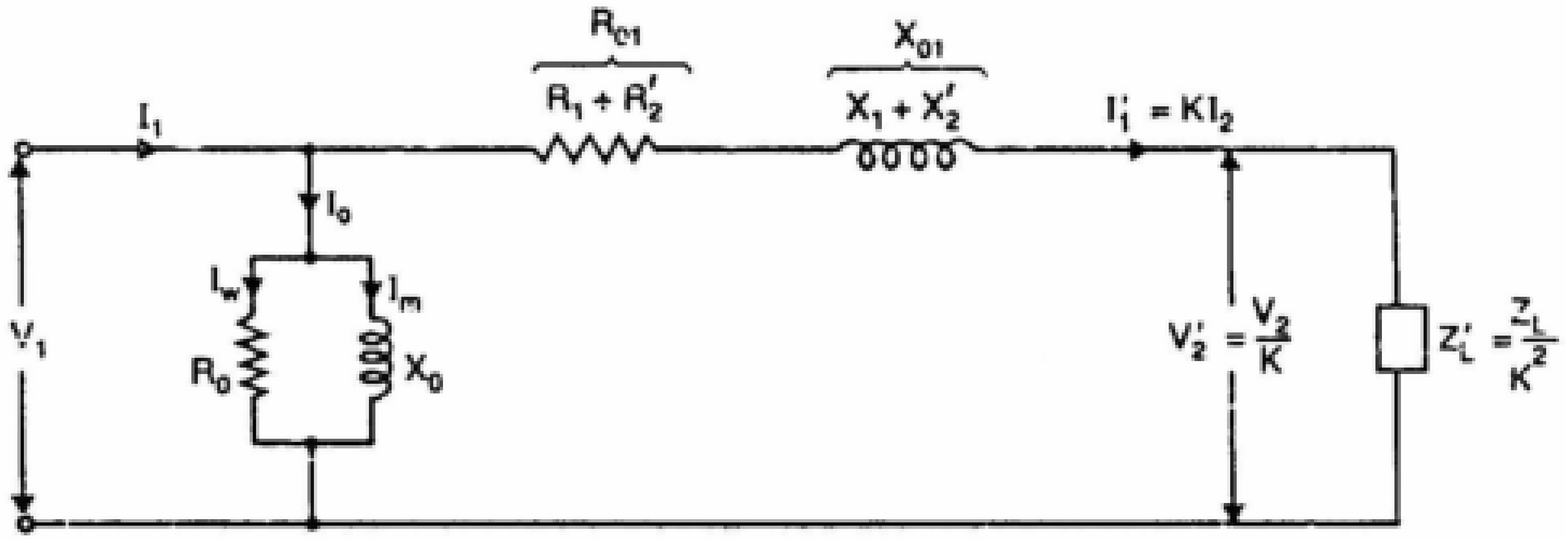


Equivalent Circuit Referred to Primary Side



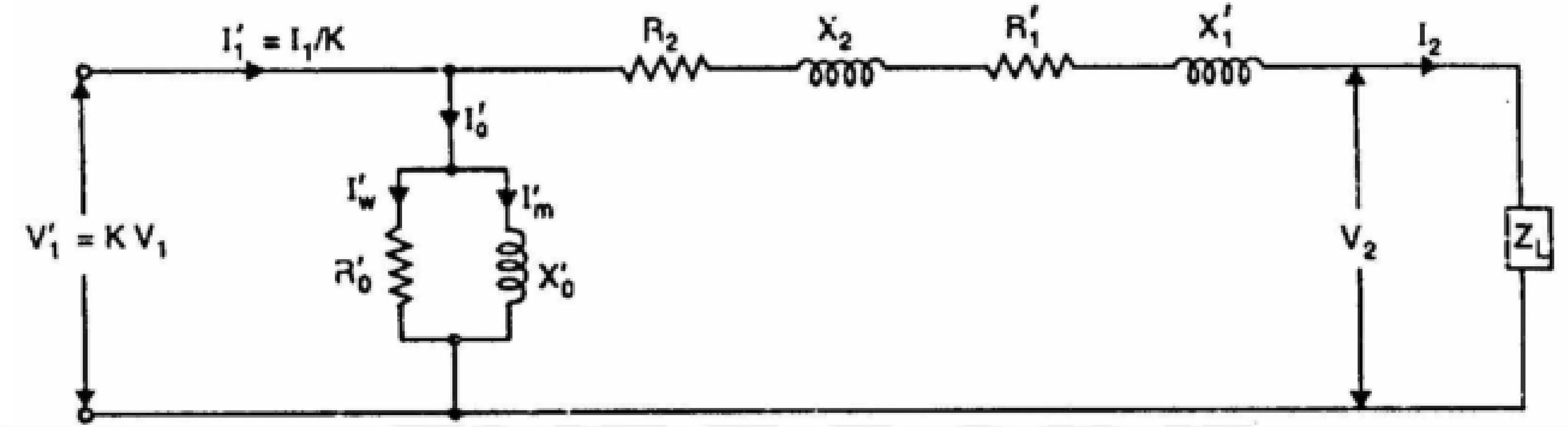
$$R'_2 = \frac{R_2}{K^2}; \quad X'_2 = \frac{X_2}{K^2}; \quad Z'_L = \frac{Z_L}{K^2}; \quad V'_2 = \frac{V_2}{K}; \quad I'_2 = K\, I_2$$

Equivalent Circuit Referred to Primary Side



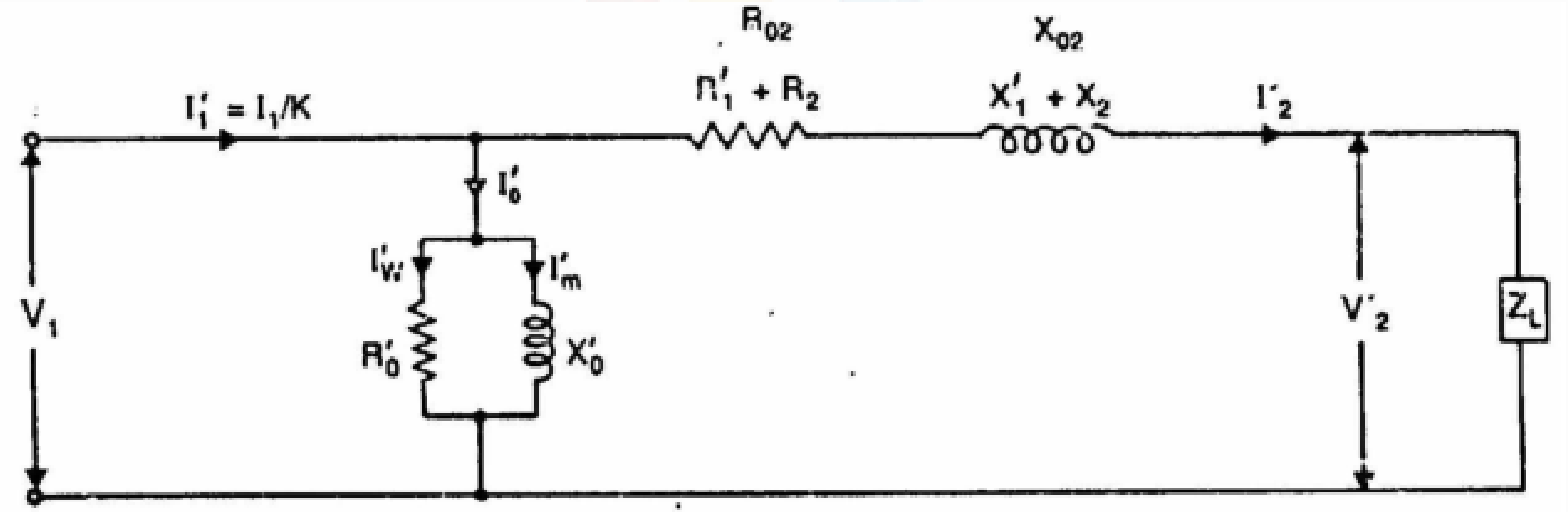
$$R_{01} = R_1 + R'_2 \;; \qquad X_{01} = X_1 + X'_2$$

Equivalent Circuit Referred to Secondary Side



$R'_1 = K^2 R_1;$ $X'_1 = K^2 X_1;$ $V'_2 = K\ V_1;\ I'_1 = \frac{I_1}{K}$

Equivalent Circuit Referred to Secondary Side



$$R_{02} = R_2 + R'_1 ; \qquad X_{02} = X_2 + X'_1$$

Testing of Transformers

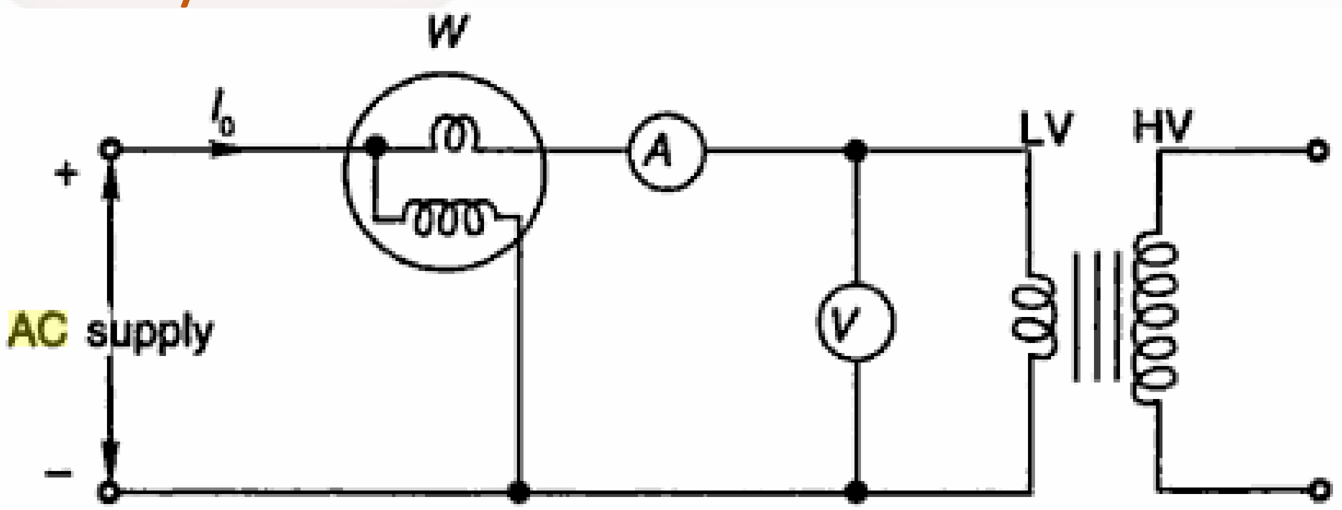
- The circuit constants, efficiency and voltage regulation of a transformer can be determined by two simple tests.

  (i) Open-circuit test

  (ii) Short-circuit lest

Open Circuit Test

- This test is conducted to determine R_0 & X_0
- Rated voltage is applied on LV side & HV side is kept open.
- At no load, current taken by the transformer is 3-5% of full load current. So I^2R loss is negligible.
- Therefore power consumed by the transformer on no load is considered as core loss.



Single-phase Transformer Losses and Test

Data observed from the test

- Supply voltage = V_0 volts
- No load current = I_0 amps
- Iron losses = W_0 watts

$$W_0 = V_0 I_0 \cos\Phi_0$$

$$\cos\Phi_0 = W_0/(V_0 I_0)$$

$$I_W = I_0 \cos\Phi_0$$

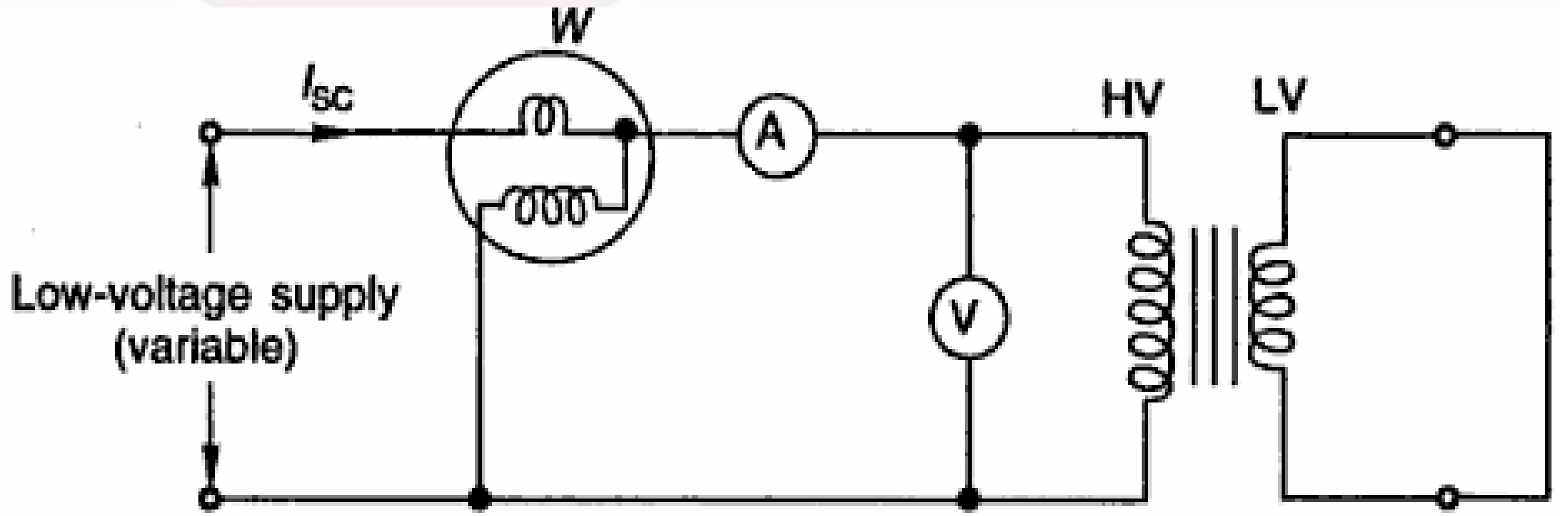
$$I_m = I_0 \sin\Phi_0$$

$$R_0 = V_1/I_W$$

$$X_0 = V_1/I_m$$

Short Circuit Test

- This test is conducted to determine R_{02} & X_{02}
- LV side of the Tfr is short circuited & the test is conducted on HV side.
- A low voltage is applied on the HV side to circulate the rated current on both the windings.
- Power drawn during this test is considered as copper loss.



Single-phase Transformer Losses and Test

Data observed from the test

- Applied voltage = V_{SC} volts
- Short circuit current = I_{SC} amps
- Copper losses = W_{SC} watts

$$W_{SC} = I_{SC}^2 R_{02}$$

$$R_{02} = W_{SC}/I_{SC}^2$$

$$Z_{02} = V_{SC}/I_{SC}$$

$$X_{02} = [Z_{02}^2 - R_{02}^2]^{1/2}$$

Obtain the equivalent circuit of a 200 / 400 V, 50 Hz, 1 phase transformer from the following test data:

O.C. test: 200 V, 0.7 A, 70 W – on L.V side.

S.C. test: 15 V, 10 A, 85 W – on H.V side.

Calculate the secondary voltage when delivering 5 kW at 0.8 p.f lagging, the primary voltage being 200 V.

From OC Test

$$P_0 = V_0 I_0 \cos\phi_0$$

$$\cos\phi_0 = \frac{P_0}{V_0 I_0} = \frac{70}{200 \times 0.7}$$

$$\cos\phi_0 = 0.5$$

$$\sin\phi_0 = 0.866$$

$$I_w = I_0 \cos\phi_0 = 0.7 \times 0.5 = 0.35A$$

$$I_m = I_0 \sin\phi_0 = 0.7 \times 0.866 = 0.606A$$

$$R_0 = \frac{V_0}{I_w} = \frac{70}{0.35} = 200\ \Omega$$

$$X_0 = \frac{V_0}{I_m} = \frac{70}{0.606} = 115.5\ \Omega$$

From SC Test

$$P_{sc} = I_{sc}^2 R_{02}$$

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

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

$$X_{02} = \sqrt{({Z_{02}}^2 - {R_{02}}^2)}$$

$$X_{02} = \sqrt{(1.5^2 - 0.85^2)}$$

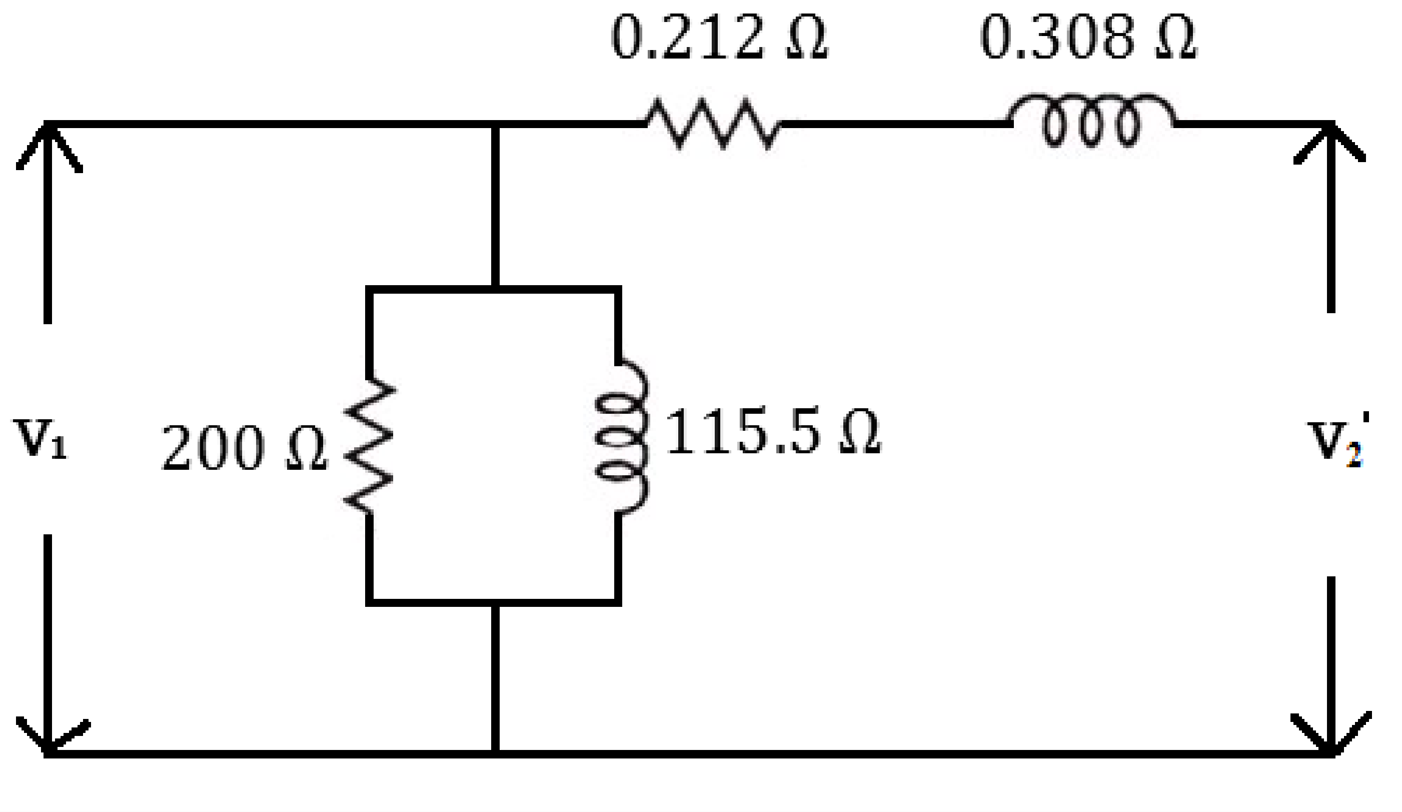
$$X_{02} = 1.235\ \Omega$$

Equivalent Circuit Referred to Primary Side

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

$$R_{01} = \frac{0.85}{2^2} = 0.212\ \Omega$$

$$X_{01} = \frac{1.235}{2^2} = 0.308\ \Omega$$

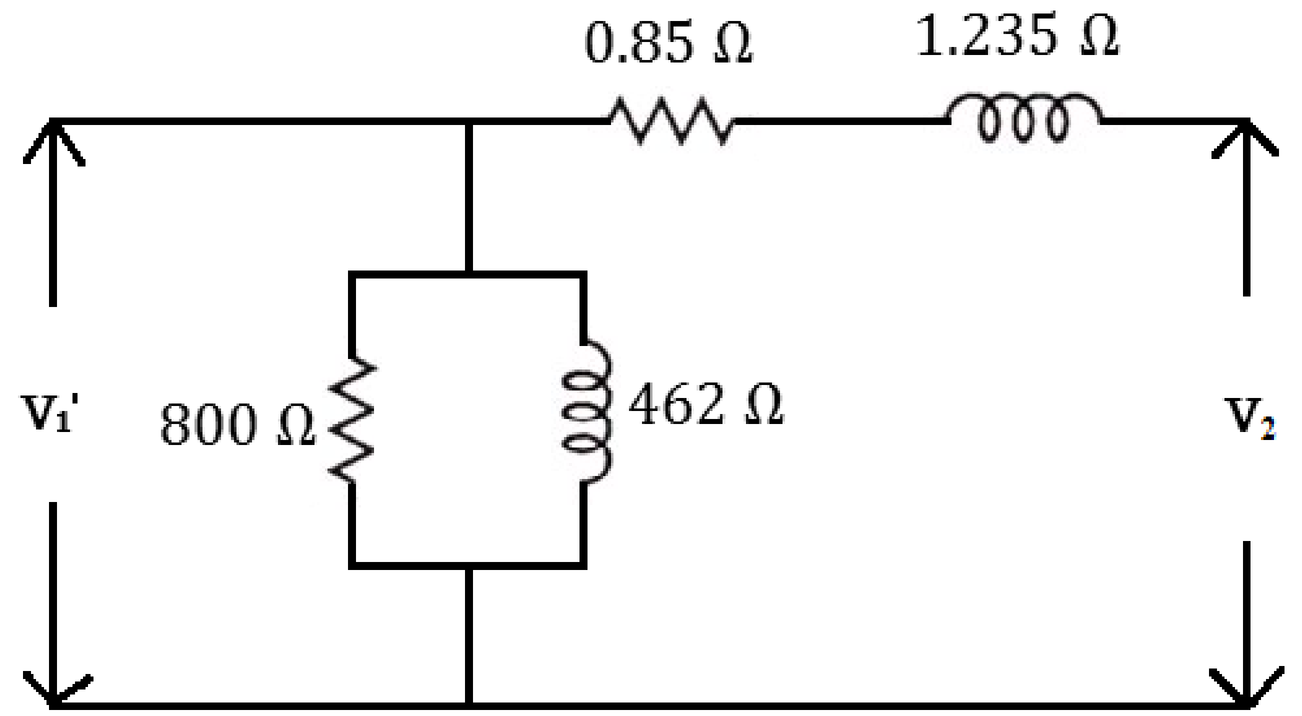


Equivalent Circuit Referred to Secondary Side

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

$$R_0' = 200 \times 2^2 = 800\ \Omega$$

$$X_0' = 115.5 \times 2^2 = 462\ \Omega$$



Single-phase Transformer Losses and Test

- Load kVA corresponding to 5 kW is,

$$= \frac{5000}{0.8} = 6250\, VA$$

- Load current I_2 while delivering 6250 VA is,

$$= \frac{6250}{400} = 15.625\, A$$

- Total voltage drop in secondary when it carries 15.625 A is,

$$= I_2(R_{02} \cos \phi_2 + X_{02} \sin \phi_2)$$

$$= 15.625(0.85 \times 0.8 + 1.235 \times 0.6)$$

$$= 22.20\, V$$

- Hence the secondary voltage is,

$$V_2 = 400 - 22.2 = 377.8\, V$$

Summary

- Losses in the transformer
- Equivalent circuit of the transformer
- Testing of the transformer
- Example