Electrical Technology

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Transformer tests

- The performance of a transformer can be calculated on the basis of its equivalent circuit which contains the 4 main parameters:

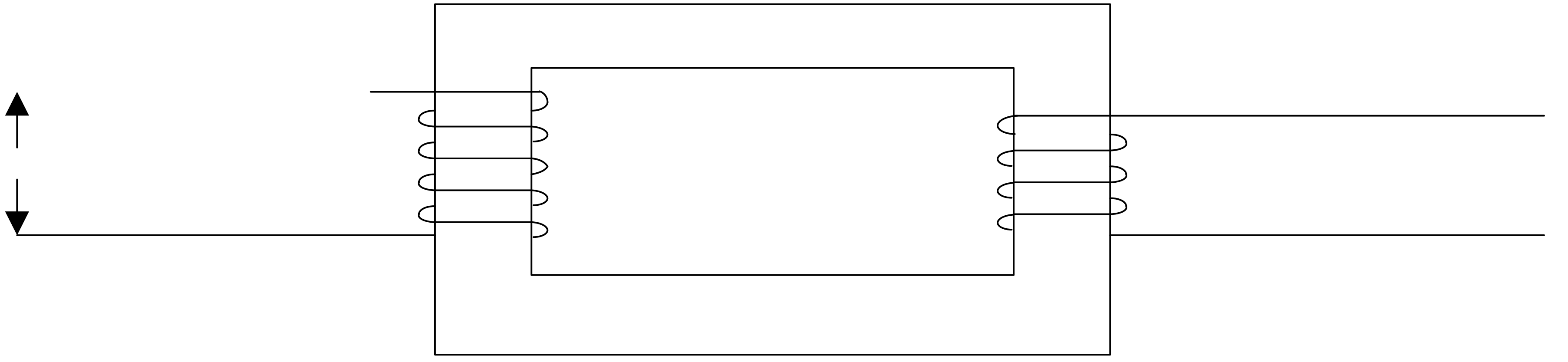
  1. Equivalent resistance R_{01}(or R_{02})
  2. Equivalent leakage reactance X_{01} (or X_{02})
  3. Core loss resistance R_0
  4. Magnetizing reactance X_0

- These parameters are determined from the following tests:

  a) Open circuit test

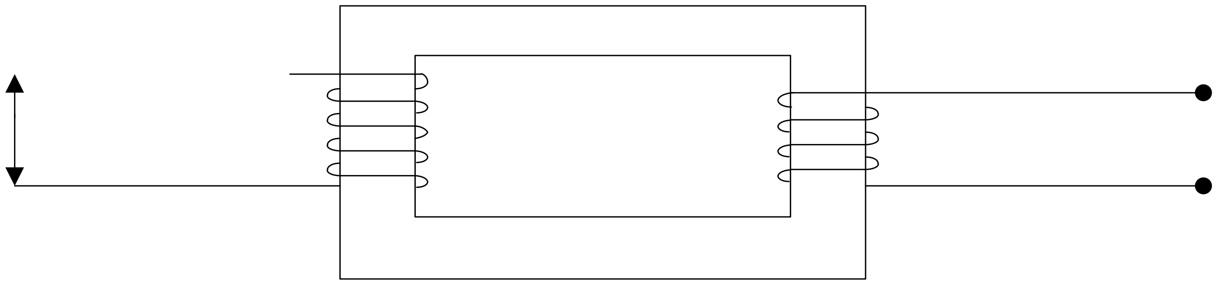
  b) Short circuit test

Open circuit test



Short Circuit test

- This test is conducted to determine:
  1. Full-load copper loss
  2. Equivalent resistance & reactance referred to metering side.

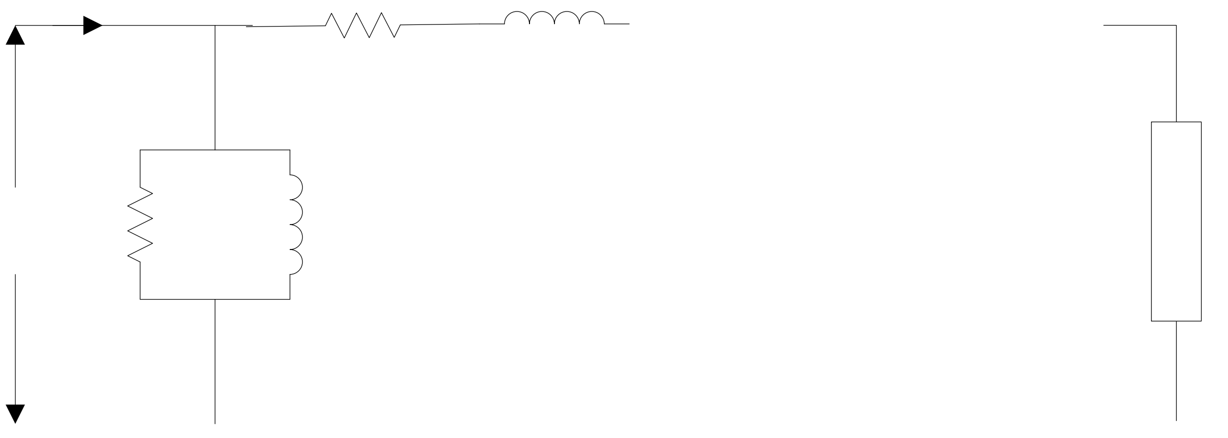


Regulation of a transformer

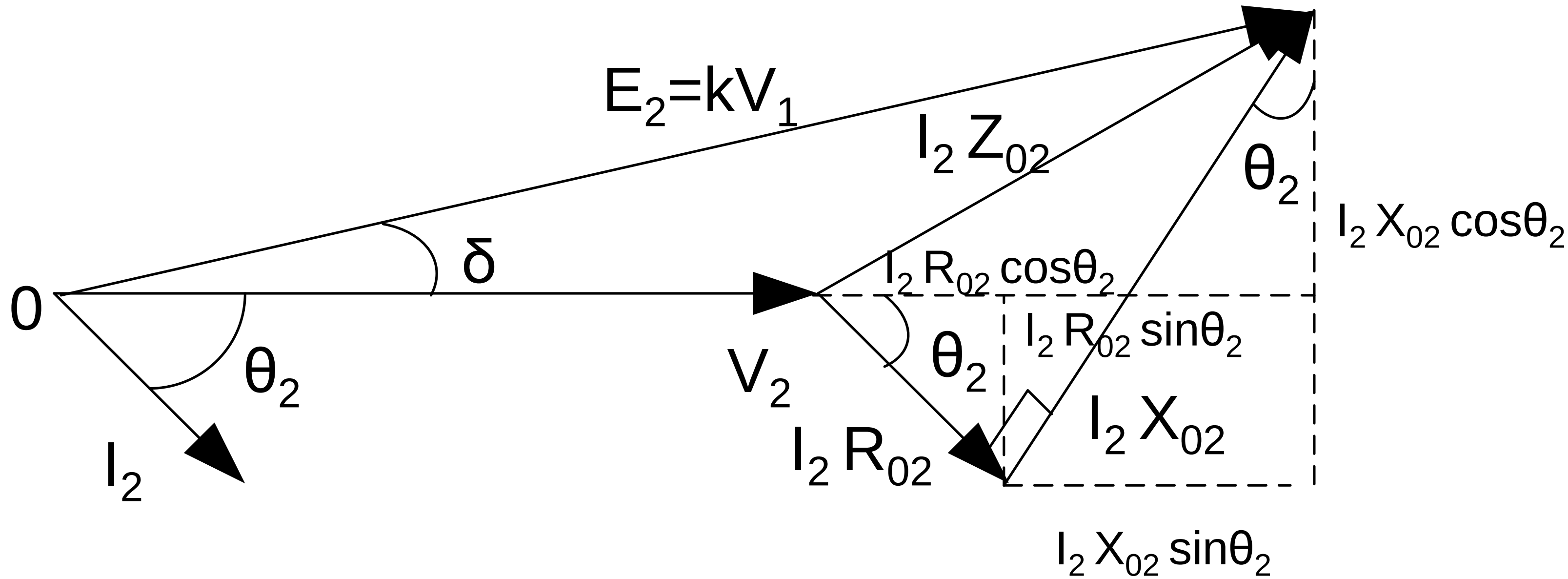
- Voltage regulation is defined as: *"the change in secondary voltage when rated load at a specified power is removed".*

- Let, E_2 = sec. terminal voltage at no load
  V_2 = sec. terminal voltage at full load

Then, % regulation = $$\frac{E_2 - V_2}{V_2} \times 100$$



Regulation expressed in terms of secondary values



$$E_2^{\,2} = \left(V_2 + I_2R_{02}\cos\theta_2 + I_2X_{02}\sin\theta_2\right)^2 + \left(I_2X_{02}\cos\theta_2 - I_2R_{02}\sin\theta_2\right)^2$$

$$= V_2^{\,2} + I_2^{\,2}R_{02}^{\,2}\cos^2\theta_2 + I_2^{\,2}X_{02}^{\,2}\sin^2\theta_2 + 2V_2I_2R_{02}\cos\theta_2$$

$$+ 2I_2^{\,2}R_{02}X_{02}\sin\theta_2\cos\theta_2 + 2V_2I_2X_{02}\sin\theta_2 + I_2^{\,2}X_{02}^{\,2}\cos^2\theta_2 + I_2^{\,2}R_{02}^{\,2}\sin^2\theta_2$$

$$- 2I_2^{\,2}R_{02}X_{02}\sin\theta_2\cos\theta_2$$

$$= V_2^{\,2} + I_2^{\,2}R_{02}^{\,2} + I_2^{\,2}X_{02}^{\,2} + 2V_2I_2R_{02}\cos\theta_2 + 2V_2I_2X_{02}\sin\theta_2$$

$$E_2 = \sqrt{V_2^{\,2} + I_2^{\,2}R_{02}^{\,2} + I_2^{\,2}X_{02}^{\,2} + 2V_2I_2R_{02}\cos\theta_2 + 2V_2I_2X_{02}\sin\theta_2}$$

Efficiency of a transformer

- Losses in a transformer –

1. Core or Iron loss = Hystersis loss + Eddy Current loss (from OC test)
2. Copper loss = $I^2{}_1 R_1 + I^2{}_2 R_2 = I^2{}_1 R_{01} = I^2{}_2 R_{02}$

   (from SC test)

$$Efficiency = \frac{Output}{Input} = \frac{Output}{Output + Losses}$$

$$= \frac{Output}{Output + Iron\ loss + Cu\ loss}$$

Condition for maximum efficiency

- Cu loss = $I_1^{\ 2} R_{01}$ Iron loss = $W_h + W_e = W_i$

  considering primary side

  Primary input = $V_1 I_1 \cos\phi_1$

$$\eta = \frac{V_1 I_1 \cos\phi_1 - losses}{V_1 I_1 \cos\phi_1}$$

$$= \frac{V_1 I_1 \cos\phi_1 - I_1^{\ 2} R_{01} - W_i}{V_1 I_1 \cos\phi_1}$$

$$= 1 - \frac{I_1 R_{01}}{V_1 \cos\phi_1} - \frac{W_i}{V_1 I_1 \cos\phi_1}$$

Differentiating both sides w.r.t I_1, we get

$$\frac{d\eta}{dI_1} = 0 - \frac{R_{01}}{V_1\cos\varphi_1} + \frac{W_i}{V_1 I^2{}_1 \cos\varphi_1}$$

For η to be maximum, $\frac{d\eta}{dI_1} = 0$

$$0 = 0 - \frac{R_{01}}{V_1\cos\varphi_1} + \frac{W_i}{V_1 I^2{}_1 \cos\varphi_1}$$

$$\Rightarrow \frac{R_{01}}{V_1\cos\varphi_1} = \frac{W_i}{V_1 I^2{}_1 \cos\varphi_1}$$

$$\Rightarrow I^2{}_1 R_{01} = W_i$$

$$\text{Cu loss} = \text{Iron loss}$$

The current corresponding to maximum efficiency is:

$$I_1 = \sqrt{\frac{W_i}{R_{01}}}$$

$$I_2 = \frac{I_1}{k} = \sqrt{\frac{W_i}{R_{02}}}$$

Efficiency of Transformer at any load

$$\eta = \frac{\mathrm{x} \times \text{Full Load kVA} \times \text{p.f}}{\mathrm{x} \times \text{Full Load kVA} \times \text{p.f} + \text{Iron Loss} + \mathrm{x}^2 \times \text{Full Load Copper Loss}} \times 100\%$$

$$\mathrm{x} = \text{Ratio of Actual to Full Load kVA}$$

Ex: A 2300/208 V, 500kVA, 60Hz transformer has the following data:

Test	V	A	W	Side used
O.C	208	85	1800	L.V
S.C	95	217.4	8200	H.V

Calculate efficiency of the transformer at 0.8 pf lagging & 1/4th rated load.

Solution

$$\eta = \frac{x \times \text{Full Load kVA} \times \text{p.f}}{x \times \text{Full Load kVA} \times \text{p.f} + \text{Iron Loss} + x^2 \times \text{Full Load Copper Loss}} \times 100\%$$

$$\eta = \frac{\frac{1}{4} \times 500 \times 0.8}{(\frac{1}{4} \times 500 \times 0.8) + (\frac{1}{4})^2 \times 8.2 + 1.8}$$

$$= 97.74\%$$