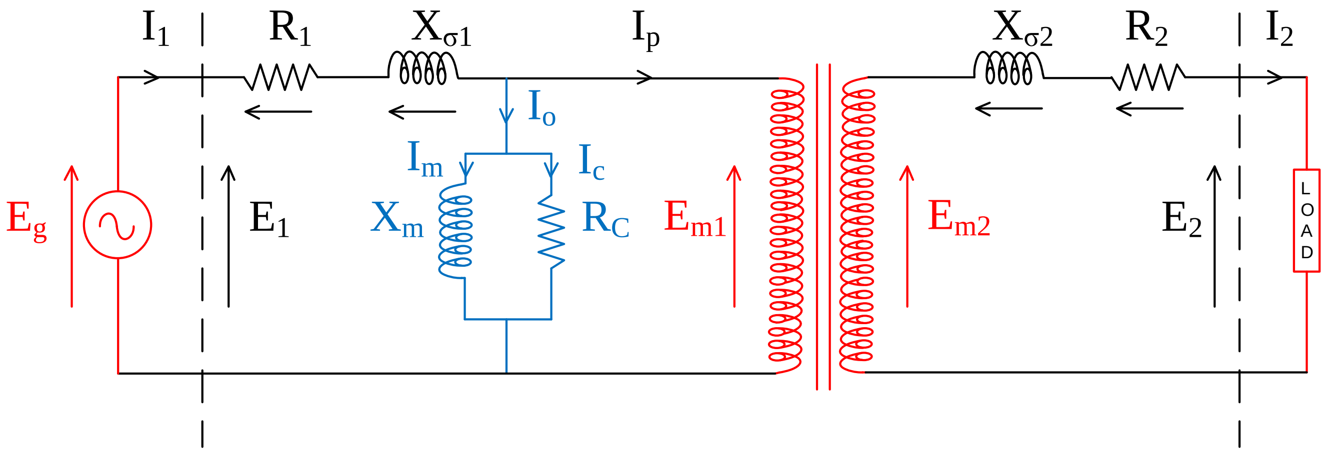
Lecture-26

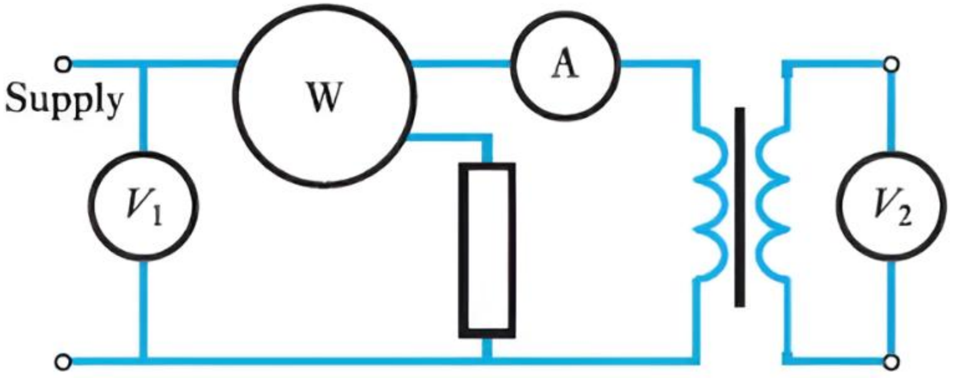
On

INTRODUCTION TO ELECTRICAL ENGINEERING (ESO203)

- Open circuit test.
- Short circuit test.
- Voltage Regulation.
- Auto Transformer.

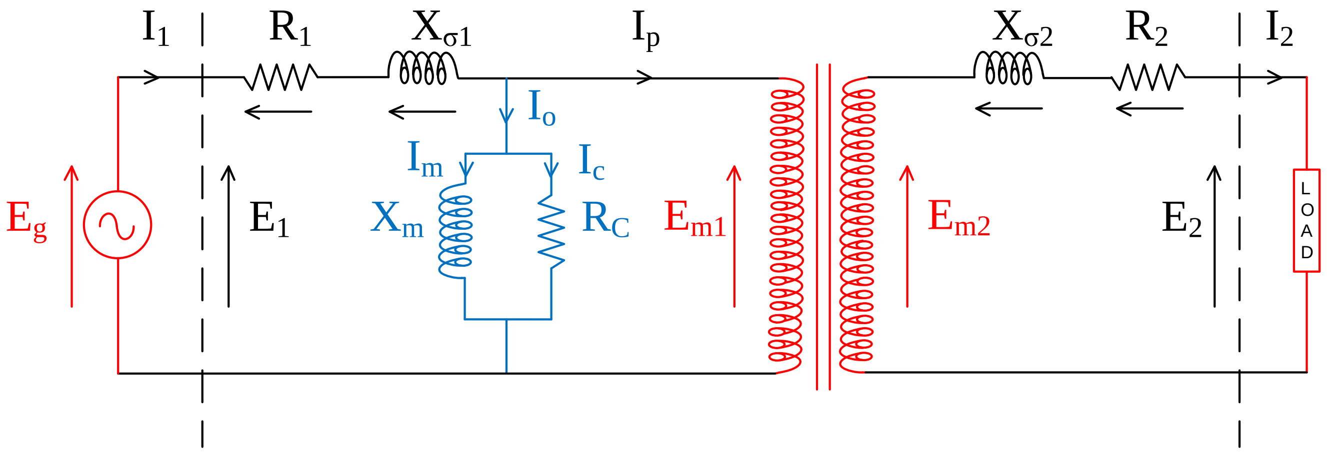
Open Circuit Test

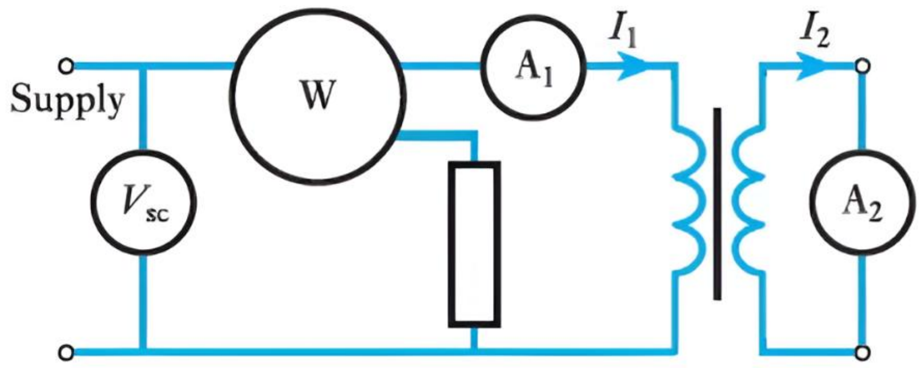




- Primary supplied at rated voltage and frequency.
- The primary current on no load is usually less than 3 to 5 percent of the full-load current.
- Wattmeter reading ≅ the core loss of the transformer.

Short Circuit Test

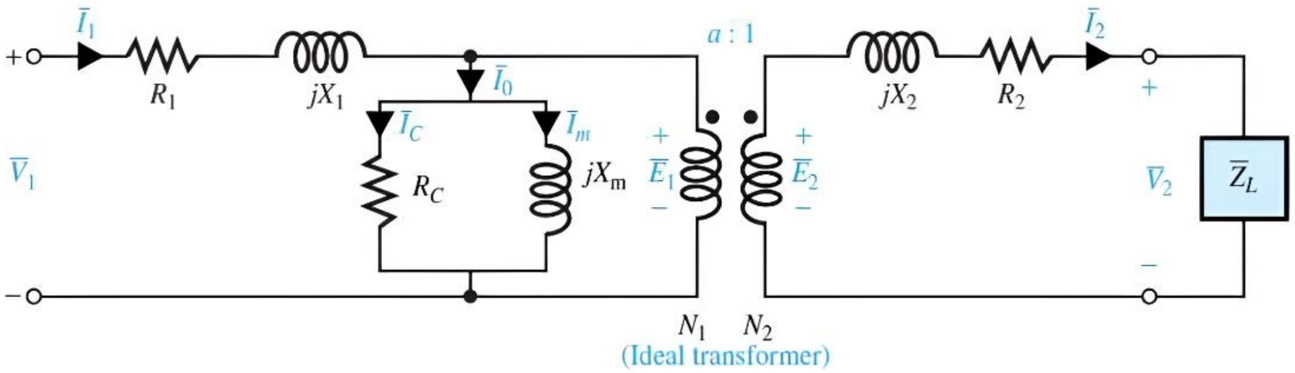




- The primary supplied with a low voltage sufficient to circulate full-load currents in the primary and secondary circuits.
- The core loss is negligibly small, since the applied voltage and therefore the flux are only about one-twentieth to one-thirtieth of the rated voltage and flux.
- Wattmeter reading ≅ the copper loss of the transformer.

Transformer Equivalent Circuit (Cont…)

❑ Non-ideal Transformer:



$I_1 R_1$ = Voltage drop due to primary resistance

$I_1 X_1$ = Voltage drop due to primary leakage reactance

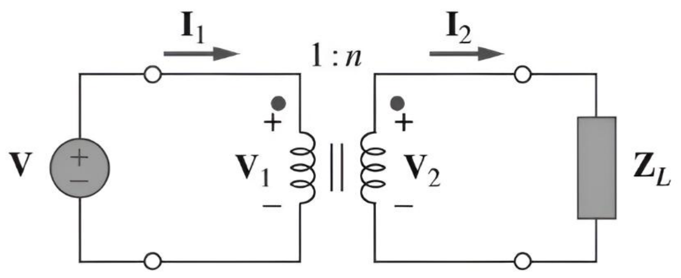
$I_1 Z_1$ = Voltage drop due to primary impedance

$V_1 = E_1 + I_1 Z_1$ = Supply voltage

Recall

- The input impedance as seen by the source is given by,

$$\boldsymbol{Z}_{in} = \frac{\boldsymbol{V}_1}{\boldsymbol{I}_1} = \frac{1}{n^2}\frac{\boldsymbol{V}_2}{\boldsymbol{I}_2}$$



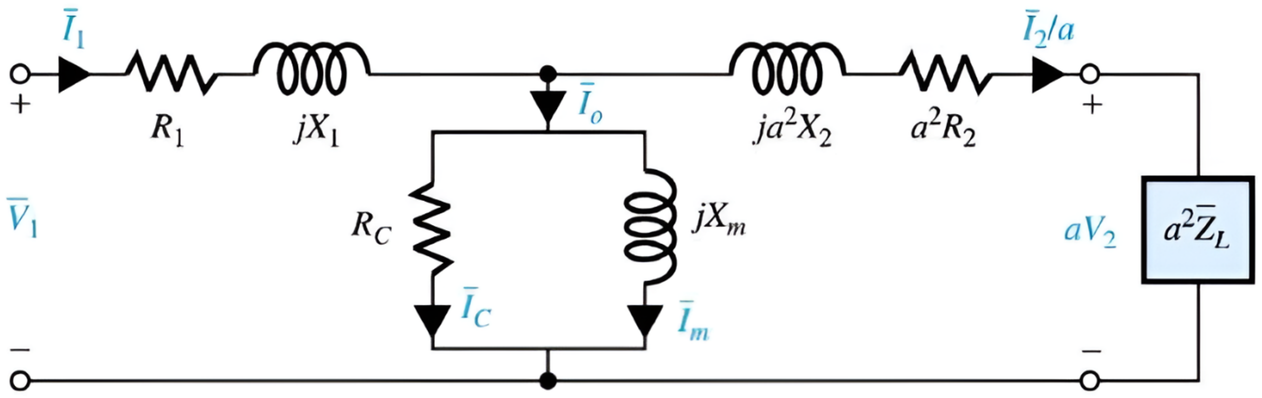
- But $\frac{\boldsymbol{V}_2}{\boldsymbol{I}_2} = \boldsymbol{Z}_L$ so that,

$$\boldsymbol{Z}_{in} = \frac{1}{n^2}\boldsymbol{Z}_L$$

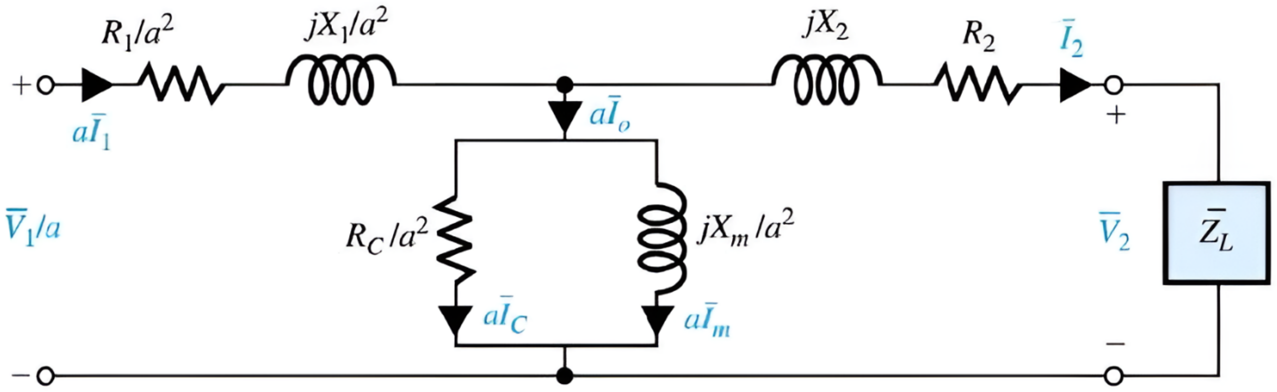
- The input impedance is also called the reflected impedance, since it appears as if the load impedance is reflected (referred) to the primary side.

- This ability of the transformer to transform a given impedance into another impedance provides us a means of impedance matching to ensure maximum power transfer.

Transformer Equivalent Circuit (Cont…)

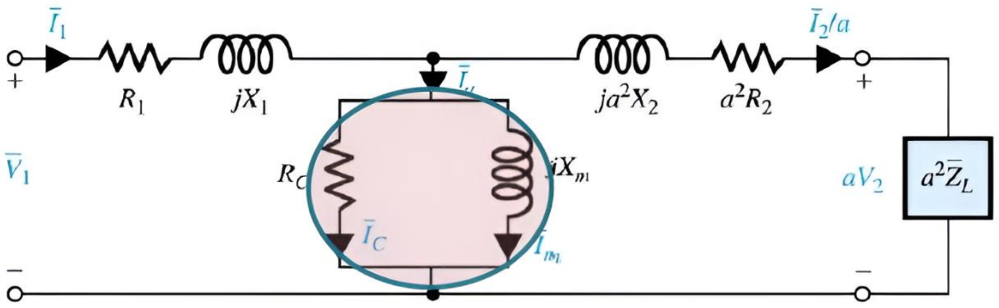


equivalent circuit referred to primary



equivalent circuit referred to secondary

Transformer Equivalent Circuit (Cont…)



equivalent circuit referred to primary

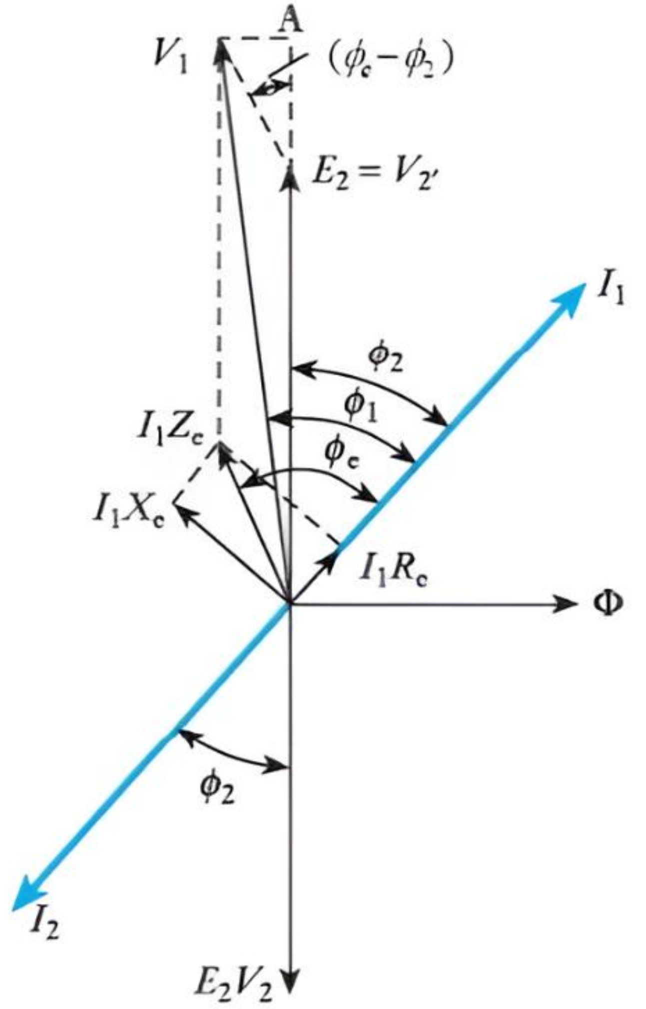
$$I_1^2R_{2'} = I_2^2R_2 \Rightarrow R_{2'} = R_2\left(\frac{I_2}{I_1}\right)^2 \cong R_2\left(\frac{V_1}{V_2}\right)^2$$

$$R_e = R_1 + R_{2'} = R_1 + R_2\left(\frac{V_1}{V_2}\right)^2$$

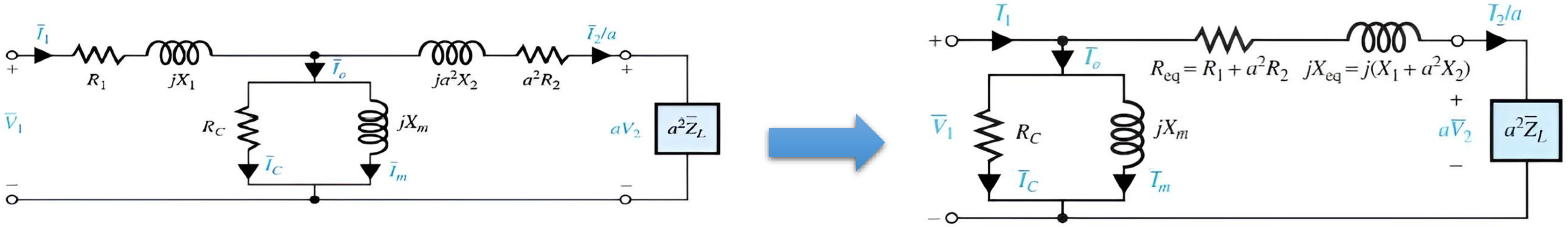
$$X_{2'} = X_2\left(\frac{N_1}{N_2}\right)^2 \cong X_2\left(\frac{V_1}{V_2}\right)^2$$

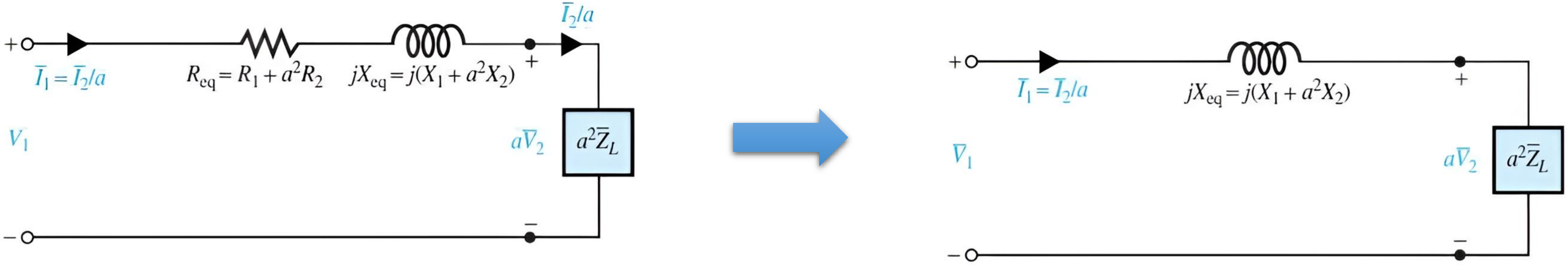
$$Z_e = \sqrt{R_e^2 + X_e^2}$$

$$R_e = Z_e cos\phi_e \qquad X_e = Z_e sin\phi_e$$



Transformer Equivalent Circuit (Cont…)



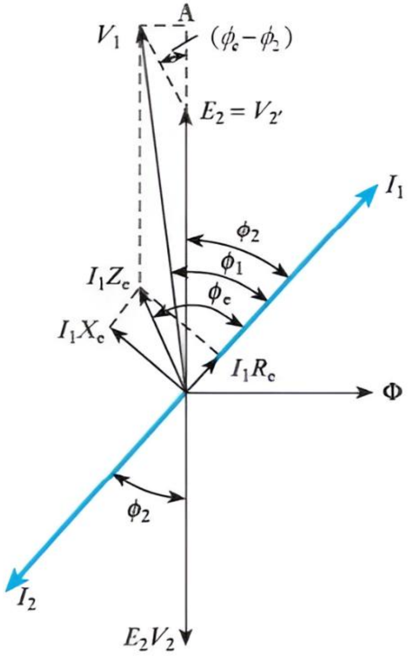


Voltage Regulation

- The voltage regulation of a transformer is defined as the variation of the secondary voltage between no load and full load, expressed as either a per-unit or a percentage of the no-load voltage, assuming primary voltage constant.

$$Voltage\ Regulation = \frac{No\ load\ voltage - Full\ load\ voltage}{No\ load\ volatge}$$

$$= \frac{V_1\frac{N_2}{N_1} - V_2}{V_1\frac{N_2}{N_1}} = \frac{V_1 - V_2\frac{N_1}{N_2}}{V_1}\ per\ unit = \frac{V_1 - V_2\frac{N_1}{N_2}}{V_1} \times 100\%\ \text{percent}$$



$$V_1^2 = \{V_{2'} + I_1Z_e\cos(\phi_e - \phi_2)\}^2 + \{I_1Z_e\sin(\phi_e - \phi_2)\}^2$$ Very small

$$V_1 \cong V_{2'} + I_1Z_e\cos(\phi_e - \phi_2)$$

Per-unit Voltage Regulation = $\frac{I_1Z_e\cos(\phi_e - \phi_2)}{V_1}$

$$Z_e\cos(\phi_e - \phi_2) = Z_e(cos\phi_e\cos\phi_2 + sin\phi_e sin\phi_2) = R_e cos\phi_2 + R_e sin\phi_2$$

❑ Example:

- A 100 kVA transformer has 400 turns on the primary and 80 turns on the secondary. The primary and secondary resistances are 0.3 Ω and 0.01 Ω respectively, and the corresponding leakage reactances are 1.1 Ω and 0.035 Ω respectively. The supply voltage is 2200 V. Calculate:

a) the equivalent impedance referred to the primary circuit;

b) the voltage regulation and the secondary terminal voltage for full load having a power factor of (i) 0.8 lagging

❑ Solution:

$$R_e = 0.3 + 0.01\left(\frac{400}{80}\right)^2 = 0.55\Omega$$

$$X_e = 1.1 + 0.035\left(\frac{400}{80}\right)^2 = 1.975\Omega$$

$$Z_e = \sqrt{0.55^2 + 1.975^2} = 2.05\Omega$$

Voltage Regulation (Cont…)

- (b) (i) Since $cos\phi_2$=0.8, therefore $sin\phi_2 = 0.6$

  Full-load primary current $\cong \frac{100\times1000}{2200} = 45.45\ A$

- Voltage regulation for power factor 0.8 lagging is,

$$\frac{45.45 \times (0.55 \times 0.8 + 1.975 \times 0.6)}{2200} = 0.0336\, per\ unit = 3.36\%$$

Voltage Regulation (Cont…)

❑ Efficiency:

1. Core losses due to hysteresis and eddy currents
2. Copper losses in primary and secondary winding

- Since the maximum value of the flux in a normal transformer does not vary by more than about 2 per cent between no load and full load, it is usual to assume the core loss constant at all loads.

- Total losses in transformer = $P_c + I_1^2 R_1 + I_2^2 R_2$

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

$$\text{Efficiency} = \frac{I_2 V_2 \times p.f.}{I_2 V_2 \times p.f. + P_c + I_1^2 R_1 + I_2^2 R_2}$$

- Energy efficiency → All-day efficiency $\quad \eta_{AD} = \frac{Energy\ output\ over\ 24\ hours}{Energy\ input\ over\ 24\ hours} \times 100$

❑ Maximum Efficiency:

- Equivalent resistance of the primary and secondary windings referred to the secondary circuit

$$R_{2e} = R_1 \left(\frac{N_2}{N_1}\right)^2 + R_2$$

$$\text{Efficiency} = \frac{I_2 V_2 \times p.f.}{I_2 V_2 \times p.f. + P_c + I_2^2 R_{2e}}$$

$$\frac{d}{dI_2}\left(V_2 \times p.f. + \frac{P_c}{I_2} + I_2 R_{2e}\right) = 0 \Rightarrow -\frac{P_c}{I_2^2} + R_{2e} = 0$$

$$\Rightarrow P_c = I_2^2 R_{2e}$$

❑Efficiency from OC and SC test:

$$\text{Efficiency on full load} = \frac{full-load\ S \times p.f.}{(full-load\ S \times p.f.) + P_{oc} + P_{sc}}$$

$$\text{Total loss on full load} = P_{oc} + P_{sc}$$

$$\text{For any load equal to } n \times full\ load,$$

$$\eta = \frac{n \times full - load\ S \times p.f.}{n \times (full - load\ S \times p.f.) + P_{oc} + n^2 P_{sc}}$$

Voltage Regulation (Cont…)

- Voltage regulation from SC test:

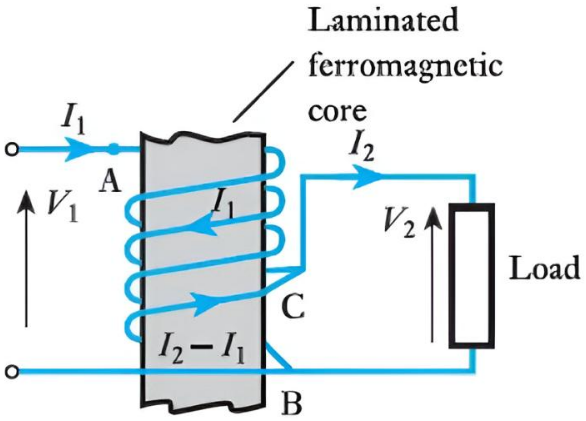
$$cos\phi_e = power\ factor\ on\ short - circuit\ test$$

$$= \frac{P_{sc}}{I_1 V_{sc}}$$

$$Per\ unit\ voltage\ regulation = \frac{V_{sc}\cos(\phi_e - \phi_2)}{V_1}$$

Auto Transformer

❑ Auto Transformer:



An auto-transformer is a transformer having a part of its winding common to the primary and secondary circuits

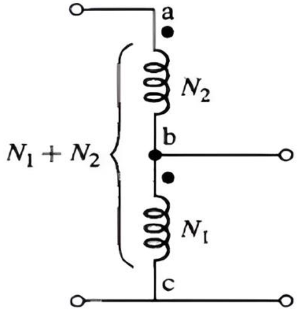
I_1 and I_2 = primary and secondary currents respectively

N_1 = No. of turns between A and B

N_2 = No. of turns between B and C

n = ratio of the smaller voltage to larger voltage

$$n = \frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1}$$



Effective turns ratio

$$V_{L_{rated}} = V_{1_{rated}}$$

$$V_{H_{rated}} = V_{1_{rated}} + V_{2_{rated}} = \frac{N_1 + N_2}{N_1} V_{L_{rated}}$$


THANKS
FOR YOUR
ATTENTION