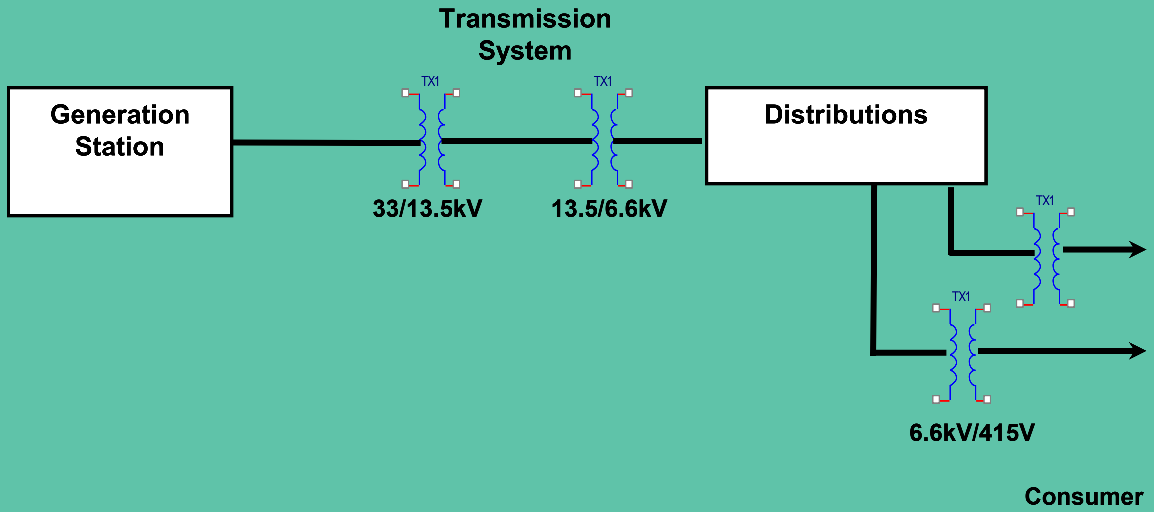
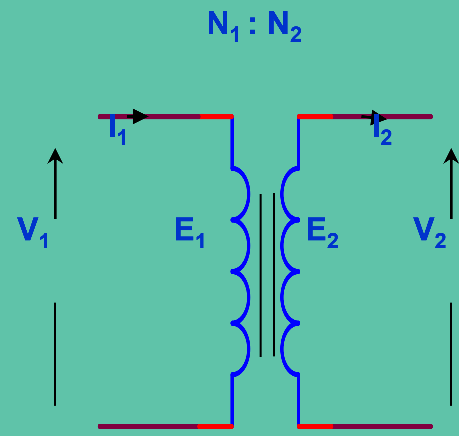
Introduction

- A transformer is a static machines.
- The word 'transformer' comes form the word 'transform'.
- Transformer is not an energy conversion device, but is a device that changes AC electrical power at one voltage level into AC electrical power at another voltage level through the action of magnetic field, without a change in frequency.
- It can be either to step-up or step down.



Ideal Transformer

- An ideal transformer is a transformer which has no loses, i.e. it's winding has no ohmic resistance, no magnetic leakage, and therefore no $I^2 R$ and core loses.
- However, it is impossible to realize such a transformer in practice.
- Yet, the approximate characteristic of ideal transformer will be used in characterized the practical transformer.

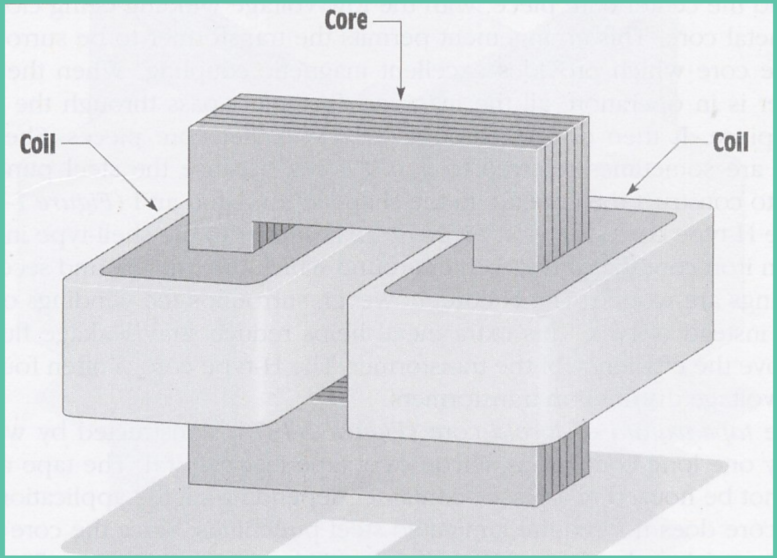


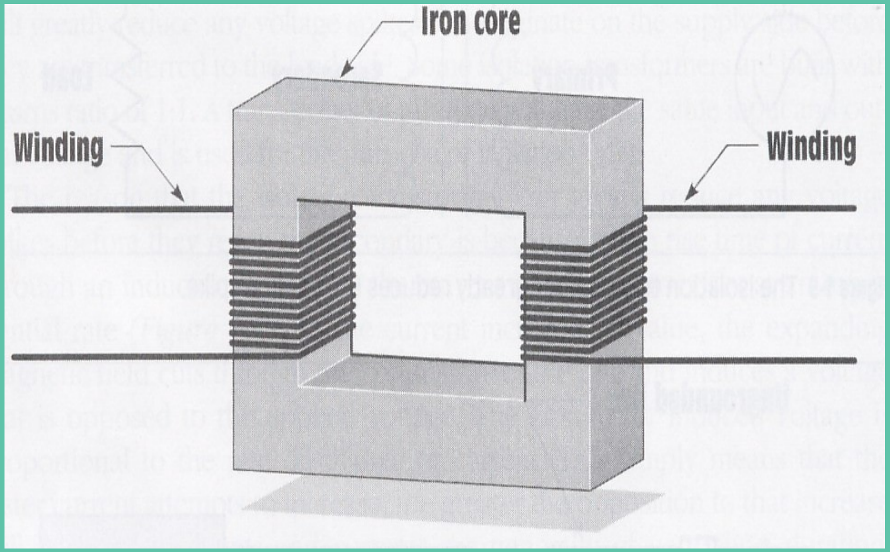
V_1 – Primary Voltage
V_2 – Secondary Voltage
E_1 – Primary induced Voltage
E_2 – secondary induced Voltage
$N_1:N_2$ – Transformer ratio

Transformer Construction

- Two types of iron-core construction:
  a) Core - type construction
  b) Shell - type construction

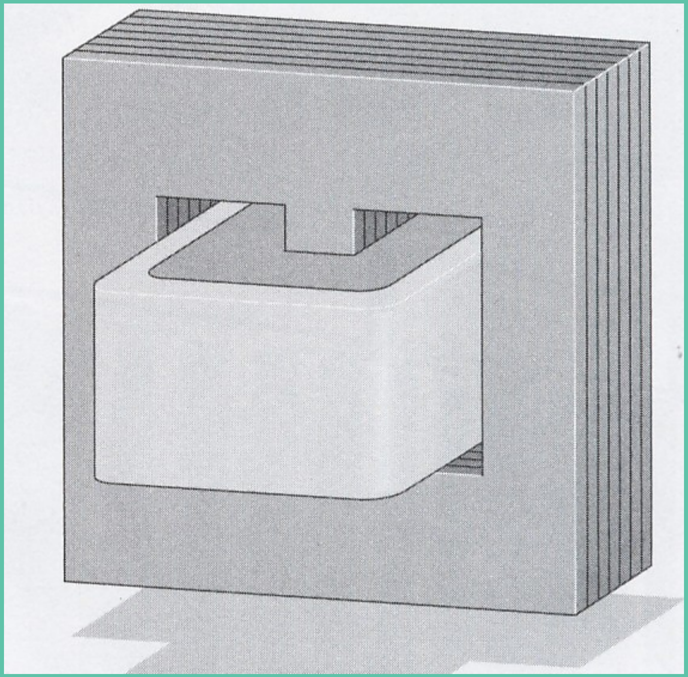
- <u>Core - type construction</u>

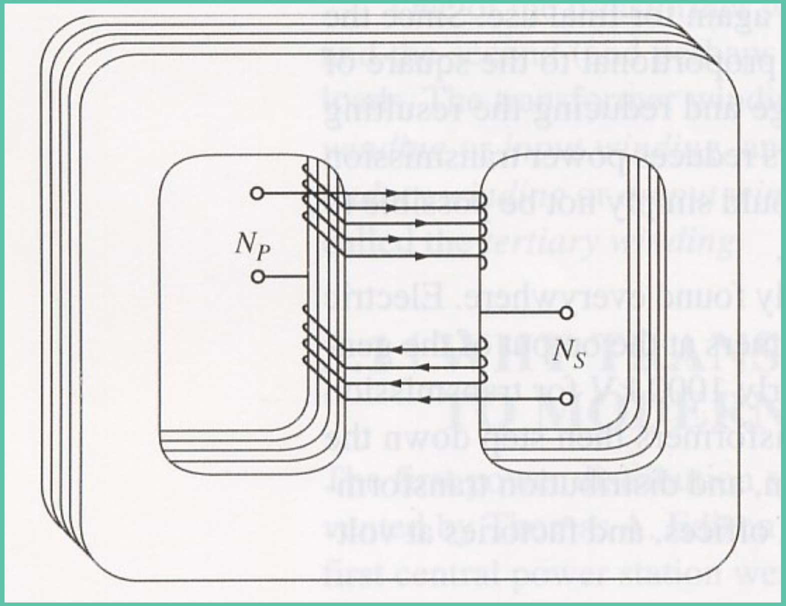




Transformer Construction

- <u>Shell - type construction</u>





Transformer Equation

- Faraday's Law states that,
  - If the flux passes through a coil of wire, a voltage will be induced in the turns of wire. This voltage is directly proportional to the rate of change in the flux with respect of time.

$$V_{ind} = Emf_{ind} = -\frac{d\Phi(t)}{dt}$$

Lenz's Law

If we have N turns of wire,

$$V_{ind} = Emf_{ind} = -N\frac{d\Phi(t)}{dt}$$

Transformer Equation

- For an ac sources,
  - Let $V(t) = V_m \sin\omega t$

    $i(t) = i_m \sin\omega t$

  Since the flux is a sinusoidal function;

Then:

Therefore: $\Phi(t) = \Phi_m \sin\omega t$

$$V_{ind} = Emf_{ind} = -N \frac{d\Phi_m \sin\omega t}{dt}$$

Thus:

$$= -N\omega\Phi_m \cos\omega t$$

$$V_{ind} = Emf_{ind(\max)} = N\omega\Phi_m = 2\pi f N\Phi_m$$

$$Emf_{ind(rms)} = \frac{N\omega\Phi_m}{\sqrt{2}} = \frac{2\pi f N\Phi_m}{\sqrt{2}} = 4.44 fN\Phi_m$$

Transformer Equation

- For an ideal transformer

$$E_1 == 4.44 f N_1 \Phi_m$$
$$E_2 == 4.44 f N_2 \Phi_m$$

………………… (i)

- In the equilibrium condition, both the input power will be equaled to the output power, and this condition is said to ideal condition of a transformer.

$$Input\ power = output\ power$$
$$V_1 I_1 \cos\theta = V_2 I_2 \cos\theta$$
$$\therefore \frac{V_1}{V_2} = \frac{I_2}{I_1}$$

- From the ideal transformer circuit, note that,

$$E_1 = V_1\ and\ E_2 = V_2$$

- Hence, substitute in (i)

Transformer Equation

$$Therefore, \quad \frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1} = a$$

Where, ‘a’ is the Voltage Transformation Ratio; which will determine whether the transformer is going to be step-up or step-down

For a >1 ⟶ $E_1 > E_2$

For a <1 ⟶ $E_1 < E_2$

Transformer Rating

- Transformer rating is normally written in terms of Apparent Power.
- Apparent power is actually the product of its rated current and rated voltage.

$$VA = V_1 I_1 = V_2 I_2$$

- Where,
  - I_1 and I_2 = rated current on primary and secondary winding.
  - V_1 and V_2 = rated voltage on primary and secondary winding.

- Rated currents are actually the full load currents in transformer

Example

1. 1.5kVA single phase transformer has rated voltage of 144/240 V. Finds its full load current.

Solution

$$I_{1FL} = \frac{1500}{144} = \underline{\underline{10.45A}}$$

$$I_{2FL} = \frac{1500}{240} = \underline{\underline{6A}}$$

Example

2. A single phase transformer has 400 primary and 1000 secondary turns. The net cross-sectional area of the core is $60m^2$. If the primary winding is connected to a 50Hz supply at 520V, calculate:
   a) The induced voltage in the secondary winding
   b) The peak value of flux density in the core

Solution

$N_1=400$ $V_1=520V$ $A=60m^2$

$N_2=1000$ $V_2=?$

Example 2 (Cont)

a) Know that,

$$a = \frac{N_1}{N_2} = \frac{V_1}{V_2}$$

$$\frac{400}{1000} = \frac{520}{V_2}$$

$$V_2 = \underline{\underline{1300V}}$$

b) Emf,

$$E = 4.44 fN\Phi_m$$

$$= 4.44 fN\left[B_m \times A\right]$$

$$known, E_1 = 520V \text{ , } E_2 = 1300V$$

$$E = 4.44 fN\left[B_m \times A\right]$$

$$520 = 4.44(50)(400)(B_m)(60)$$

$$B_m = \underline{\underline{0.976Wb / m^2}}$$

Example

3. A 25kVA transformer has 500 turns on the primary and 50 turns on the secondary winding. The primary is connected to 3000V, 50Hz supply. Find:
   a) Full load primary current
   b) The induced voltage in the secondary winding
   c) The maximum flux in the core

Solution

VA = 25kVA

N_1=500 V_1=3000V

N_2=50 V_2=?

Example 3 (Cont.)

a) Know that,

$$VA = V \times I$$

$$I_{1FL} = \frac{VA}{V_1} = \frac{25 \times 10^3}{3000} = \underline{\underline{8.33A}}$$

b) Induced voltage,

$$a = \frac{N_1}{N_2} = \frac{I_2}{I_1}$$

$$I_2 = 500\left(\frac{8.33}{50}\right) = 83.3A$$

$$E_2 = E_1 \frac{I_1}{I_2} = 3000\left(\frac{8.33}{83.3}\right) = \underline{\underline{300V}}$$

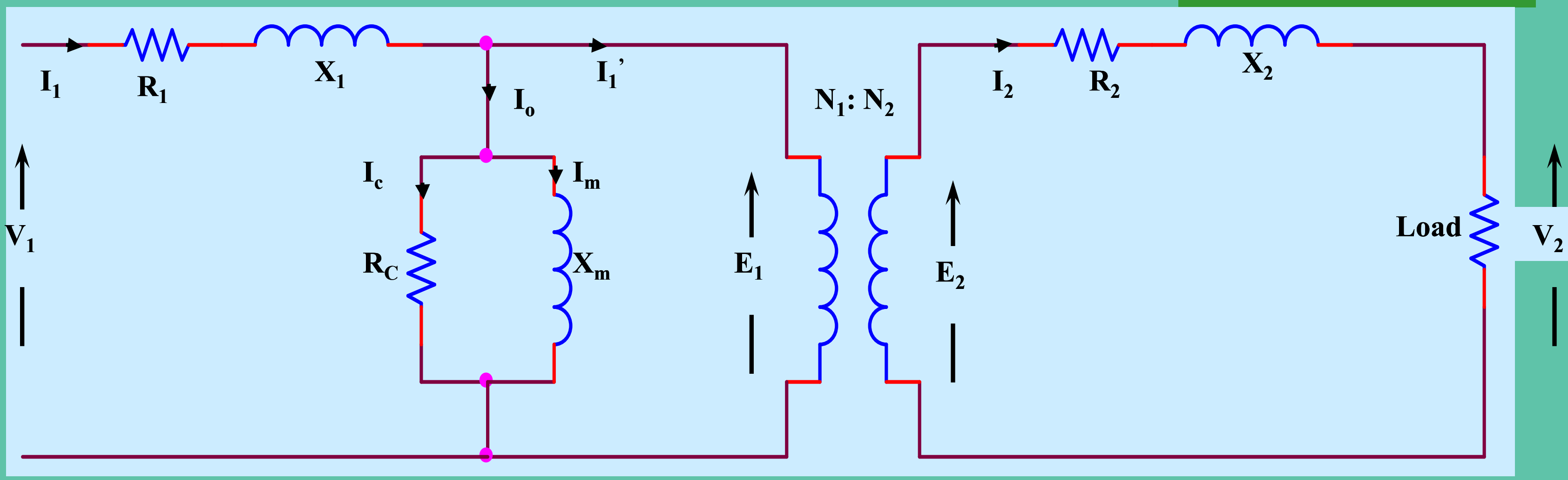
c) Max flux

$$E = 4.44 fN\Phi$$

$$300 = 4.44(50)(50)\Phi$$

$$\Phi = \underline{\underline{27mWb}}$$

Practical Transformer (Equivalent Circuit)

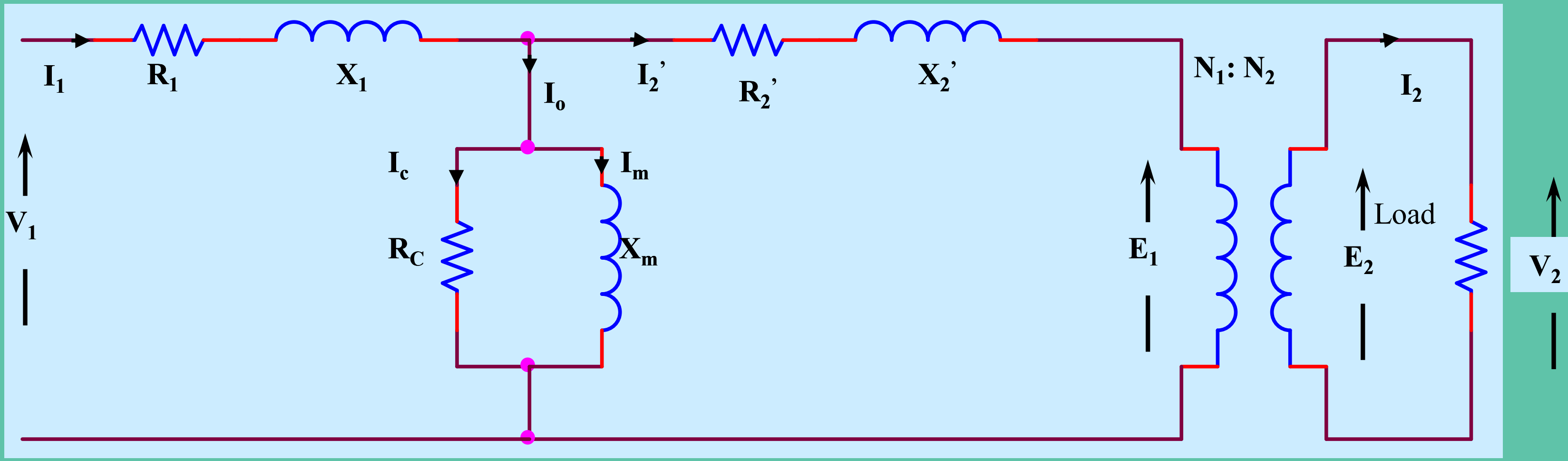


V_1 = primary supply voltage
V_2 = 2nd terminal (load) voltage
E_1 = primary winding voltage
E_2 = 2nd winding voltage
I_1 = primary supply current
I_2 = 2nd winding current
I_1' = primary winding current
I_o = no load current

I_c = core current
I_m = magnetism current
R_1= primary winding resistance
R_2= 2nd winding resistance
X_1= primary winding leakage reactance
X_2= 2nd winding leakage reactance
R_c= core resistance
X_m= magnetism reactance

Single Phase Transformer (Referred to Primary)

- Actual Method



$$R_2' = \left(\frac{N_1}{N_2}\right)^2 R_2 \quad OR \quad R_2' = a^2 R_2$$

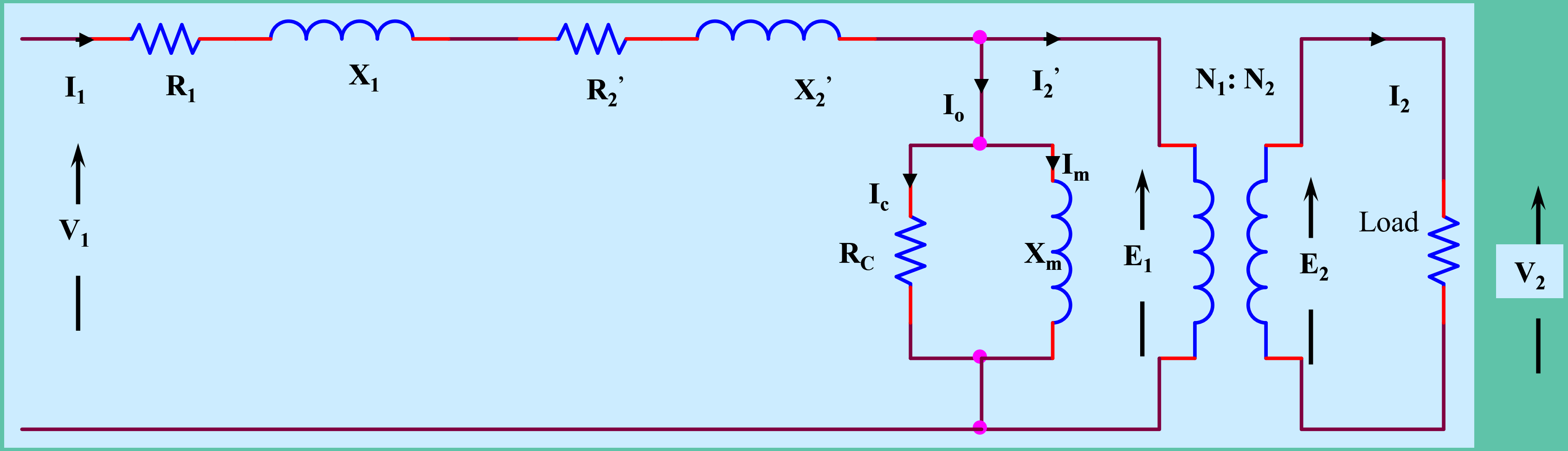
$$X_2' = \left(\frac{N_1}{N_2}\right)^2 X_2 \quad OR \quad X_2' = a^2 X_2$$

$$E_1 = V_2' = \left(\frac{N_1}{N_2}\right) V_2 \quad OR \quad V_2' = aV_2$$

$$I_2' = \frac{I_2}{a}$$

Single Phase Transformer (Referred to Primary)

- Approximate Method



$$R_2' = \left(\frac{N_1}{N_2}\right)^2 R_2 \quad OR \quad R_2' = a^2 R_2$$

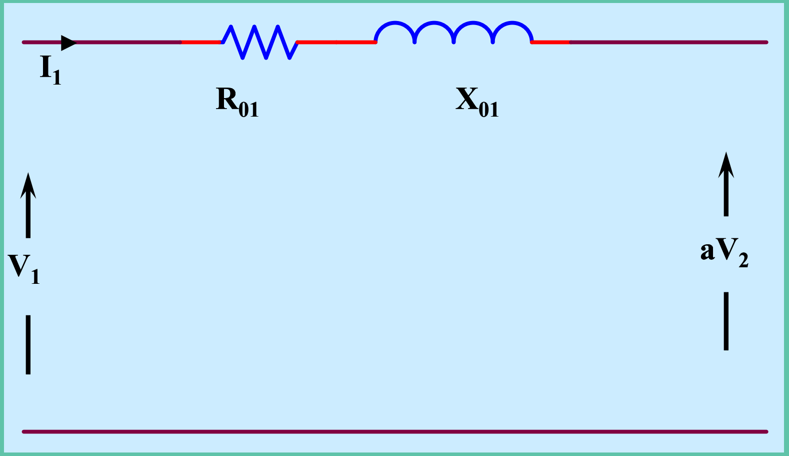
$$X_2' = \left(\frac{N_1}{N_2}\right)^2 X_2 \quad OR \quad X_2' = a^2 X_2$$

$$E_1 = V_2' = \left(\frac{N_1}{N_2}\right) V_2 \quad OR \quad V_2' = aV_2$$

$$I_2' = \frac{I_2}{a}$$

Single Phase Transformer (Referred to Primary)

- Approximate Method



In some application, the excitation branch has a small current compared to load current, thus it may be neglected without causing serious error.

$$R_2' = \left(\frac{N_1}{N_2}\right)^2 R_2 \quad OR \quad R_2' = a^2 R_2$$

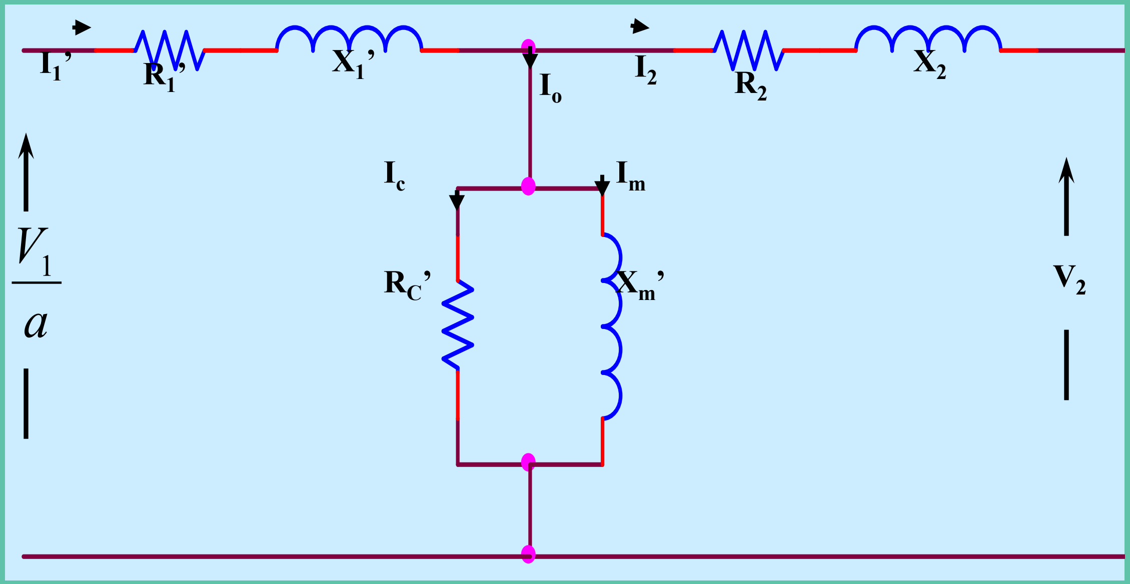
$$V_2' = \left(\frac{N_1}{N_2}\right) V_2 \quad OR \quad V_2' = aV_2$$

$$X_2' = \left(\frac{N_1}{N_2}\right)^2 X_2 \quad OR \quad X_2' = a^2 X_2$$

$$R_{01} = R_1 + R_2'$$
$$X_{01} = X_1 + X_2'$$

Single Phase Transformer (Referred to Secondary)

- Actual Method



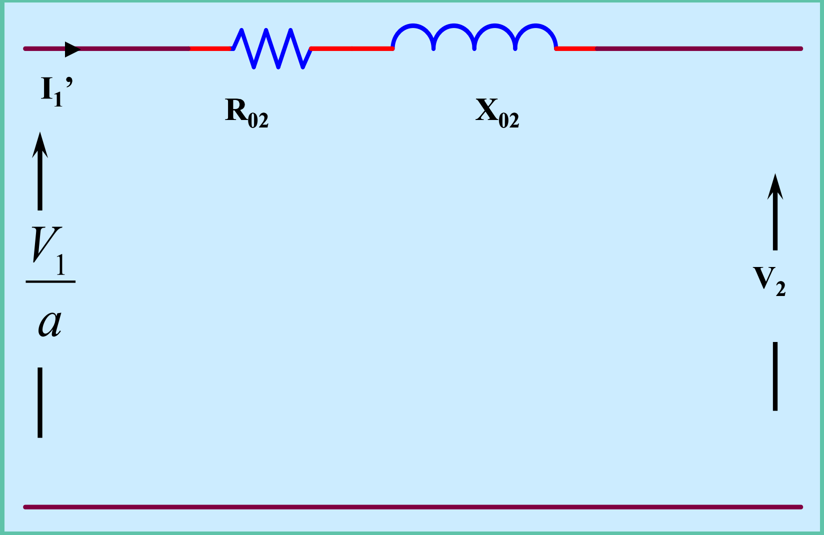
$$R_1' = \left(\frac{N_2}{N_1}\right)^2 R_1 \quad OR \quad R_1' = \frac{R_1}{a^2}$$

$$X_1' = \left(\frac{N_2}{N_1}\right)^2 X_1 \quad OR \quad X_1' = \frac{X_1}{a^2}$$

$$V_1' = \left(\frac{N_2}{N_1}\right) V_1 \quad OR \quad V_1' = \frac{V_1}{a}$$

Single Phase Transformer (Referred to Secondary)

- Approximate Method



Neglect the excitation branch

$$R_{02} = R_1' + R_2$$
$$X_{02} = X_1' + X_2$$

$$R_1' = \left(\frac{N_2}{N_1}\right)^2 R_1 \quad OR \quad R_1' = \frac{R_1}{a^2}$$

$$X_1' = \left(\frac{N_2}{N_1}\right)^2 X_1 \quad OR \quad X_1' = \frac{X_1}{a^2}$$

$$V_1' = \left(\frac{N_2}{N_1}\right) V_1 \quad OR \quad V_1' = \frac{V_1}{a}$$

$$I_1' = aI_1$$

Example

4. For the parameters obtained from the test of 20kVA 2600/245 V single phase transformer, refer all the parameters to the high voltage side if all the parameters are obtained at lower voltage side.

   $R_c = 3.3\Omega$, $X_m = j1.5\Omega$, $R_2 = 7.5\Omega$, $X_2 = j12.4\Omega$

   Solution

   Given

   $R_c = 3.3\Omega$, $X_m = j1.5\Omega$,

   $R_2 = 7.5\Omega$, $X_2 = j12.4\Omega$

Example 4 (Cont)

i) Refer to H.V side (primary)

$$a = \frac{E_1}{E_2} = \frac{V_1}{V_2} = \frac{2600}{245} = \underline{\underline{10.61}}$$

$R_2' = (10.61)^2\ (7.5) = \underline{844.65\Omega}$,

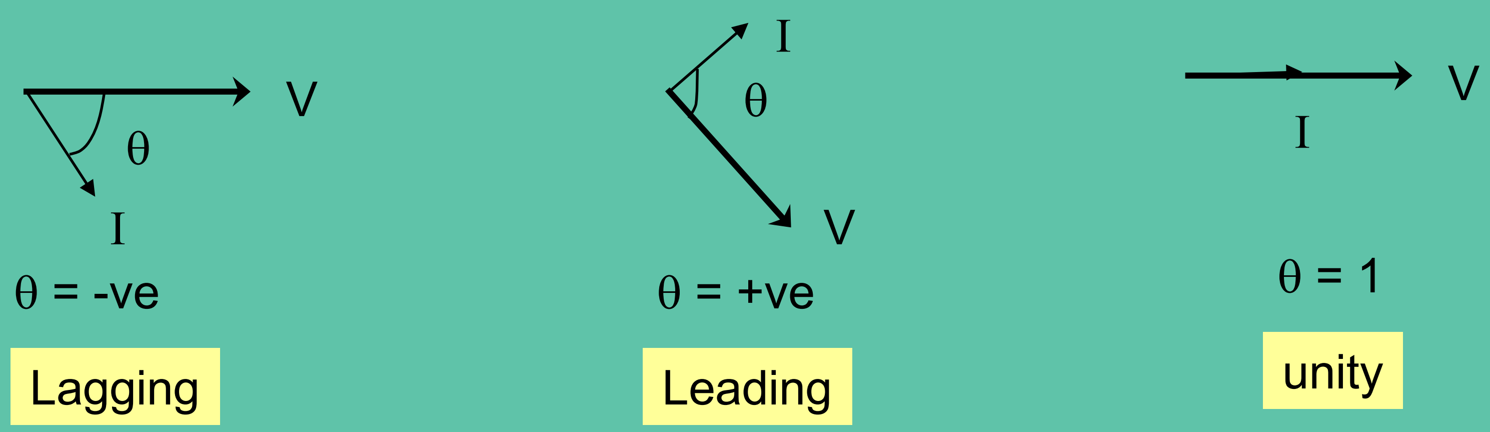
$X_2' = j(10.61)^2\ (12.4) = \underline{1.396k\Omega}$

$R_c' = (10.61)^2\ (3.3) = \underline{371.6\Omega}$,

$X_m' = j(10.61)^2\ (1.5) = \underline{j168.9\ \Omega}$

Power Factor

- Power factor = angle between Current and voltage, cos θ



- Power factor always lagging for real transformer.

Example

5. A 10 kVA single phase transformer 2000/440V has primary resistance and reactance of 5.5Ω and 12Ω respectively, while the resistance and reactance of secondary winding is 0.2Ω and 0.45 Ω respectively. Calculate:
   i. The parameter referred to high voltage side and draw the equivalent circuit
   ii. The approximate value of secondary voltage at full load of 0.8 lagging power factor, when primary supply is 2000V.

Example 5 (Cont)

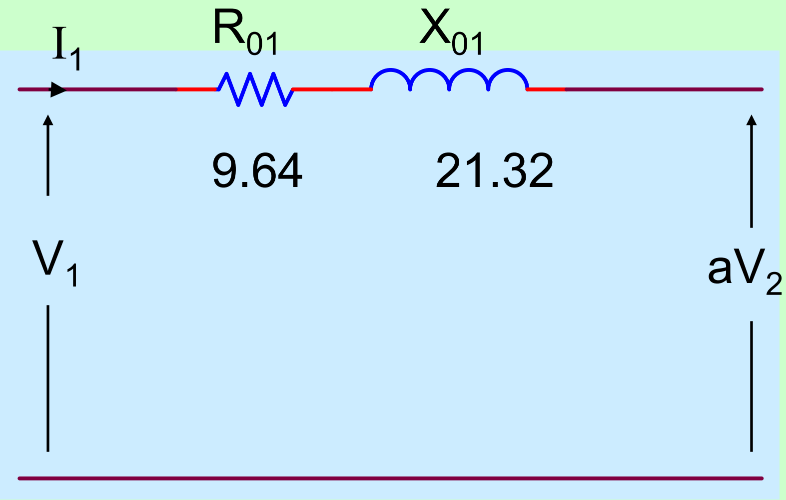
Solution

R_1=5.5 Ω, X_1=j12 Ω

R_2=0.2 Ω, X_2=j0.45 Ω

i) Refer to H.V side (primary)

$$a = \frac{E_1}{E_2} = \frac{V_1}{V_2} = \frac{2000}{440} = \underline{\underline{4.55}}$$



R_2'=$(4.55)^2$ (0.2) = 4.14Ω,

X_2'=j$(4.55)^2$0.45 = j9.32 Ω

Therefore,

R_{01}=R_1+R_2'=5.5 + 4.13 = 9.64 Ω

X_{01}=X_1+X_2'=j12 + j9. 32 = j21.32 Ω

Example 5 (Cont.)

Solution

ii) Secondary voltage

p.f = 0.8

Cos θ = 0.8

θ = 36.87°

Full load, → $I_{FL_1} = \frac{10\times10^3 VA}{2000V} = 5A$

From eqn. cct,

$$V_1\angle 0^o = (R_{01} + jX_{01})(I_1\angle -\theta^o) + aV_2$$

$$2000\angle 0^o = (9.64 + j21.32)(5\angle -36.87^o) + (4.55)V_2$$

$$V_2 = 422.6\angle 0.8^o$$

Transformer Losses

- Generally, there are two types of losses;
  1. Iron losses :- occur in core parameters
  2. Copper losses :- occur in winding resistance

i. Iron Losses

$$P_{iron} = P_c = (I_c)^2 R_c = P_{open circuit}$$

ii. Copper Losses

$$P_{copper} = P_{cu} = (I_1)^2 R_1 + (I_2)^2 R_2 = P_{short circuit}$$

$$or\ if\ \ referred, P_{cu} = (I_1)^2 R_{01} = (I_2)^2 R_{02}$$

Transformer Efficiency

- To check the performance of the device, by comparing the output with respect to the input.
- The higher the efficiency, the better the system.

$$Efficiency\ ,\eta = \frac{Output\ Power}{Input\ Power} \times 100\%$$

$$= \frac{P_{out}}{P_{out} + P_{losses}} \times 100\%$$

$$= \frac{V_2 I_2 \cos\theta}{V_2 I_2 \cos\theta + P_c + P_{cu}} \times 100\%$$

$$\eta_{(fullload)} = \frac{VA\cos\theta}{VA\cos\theta + P_c + P_{cu}} \times 100\%$$

$$\eta_{(load\ n)} = \frac{nVA\cos\theta}{nVA\cos\theta + P_c + n^2 P_{cu}} \times 100\%$$

Where, if ½ load, hence n = ½ ,
¼ load, n= ¼ ,
90% of full load, n =0.9

Where $P_{cu} = P_{sc}$
$P_c = P_{oc}$

Voltage Regulation

- The purpose of voltage regulation is basically to determine the percentage of voltage drop between no load and full load.
- Voltage Regulation can be determine based on 3 methods:
  a) Basic Defination
  b) Short – circuit Test
  c) Equivalent Circuit

Voltage Regulation (Basic Defination)

- In this method, all parameter are being referred to primary or secondary side.
- Can be represented in either
  - <u>Down – voltage Regulation</u>

$$V.R = \frac{V_{NL} - V_{FL}}{V_{NL}} \times 100\%$$

  - <u>Up – Voltage Regulation</u>

$$V.R = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$

Voltage Regulation (Short – circuit Test)

- In this method, direct formula can be used.

$$V.R = \frac{V_{sc}\cos\left(\theta_{sc} \mp \theta_{p.f}\right)}{V_1} \times 100\%$$

⟸ If referred to primary side

$$V.R = \frac{V_{sc}\cos\left(\theta_{sc} \mp \theta_{p.f}\right)}{V_2} \times 100\%$$

⟸ If referred to secondary side

Note that:

'–' is for Lagging power factor
'+' is for Leading power factor
I_{sc} must equal to I_{FL}

Voltage Regulation (Equivalent Circuit)

- In this method, the parameters must be referred to primary or secondary

$$V.R = \frac{I_1\left[R_{01}\cos\theta_{p.f} \pm X_{01}\sin\theta_{p.f}\right]}{V_1}\times 100\%$$

← If referred to primary side

$$V.R = \frac{I_2\left[R_{02}\cos\theta_{p.f} \pm X_{02}\sin\theta_{p.f}\right]}{V_2}\times 100\%$$

← If referred to secondary side

Note that:

'+' is for Lagging power factor

'–' is for Leading power factor

j terms ~0

Example

6. In example 5, determine the Voltage regulation by using down – voltage regulation and equivalent circuit.

Solution

Down – voltage Regulation

Know that, V_{2FL}=422.6V

V_{2NL}=440V

Therefore,

$$V.R = \frac{V_{NL} - V_{FL}}{V_{NL}} \times 100\%$$

$$= \frac{440 - 422.6}{440} \times 100\%$$

$$= \underline{\underline{3.95\%}}$$

Example 6 (Cont.)

<u>Equivalent Circuit</u>

I_1=5A R_{01}=9.64Ω X_{01} = 21.32Ω V_1=2000V, 0.8 lagging p.f

$$V.R = \frac{I_1\left[R_{01}\cos\theta_{p.f} \pm X_{01}\sin\theta_{p.f}\right]}{V_1}\times 100\%$$

$$= \frac{5\left[9.64(0.8)+21.32(0.6)\right]}{2000}\times 100\%$$

$$= \underline{\underline{5.12\%}}$$

Example

7. A short circuit test was performed at the secondary side of 10kVA, 240/100V transformer. Determine the voltage regulation at 0.8 lagging power factor if

V_{sc} =18V

I_{sc} =100

P_{sc}=240W

Solution

Check:

$$I_{FL_2} = \frac{VA}{V} = \frac{10000}{100} = 100A$$

$$I_{FL_2} = I_{sc},$$

Hence, we can use short-circuit method

$$V.R = \frac{V_{sc}\cos\left(\theta_{sc} \mp \theta_{p.f}\right)}{V_2} \times 100\%$$

Example 7 (Cont.)

$$V.R = \frac{V_{sc}\cos\left(\theta_{sc} \mp \theta_{p.f}\right)}{V_2} \times 100\%$$

$$Given\ p.f = 0.8$$

$$Hence, \theta_{p.f} = \cos^{-1} 0.8 = \underline{\underline{36.87^o}}$$

$$Know\ that,$$

$$P_{sc} = V_{sc} I_{sc} \cos\theta_{sc}$$

$$\theta_{sc} = \cos^{-1}\left(\frac{P_{sc}}{V_{sc} I_{sc}}\right)$$

$$= \cos^{-1}\left(\frac{240}{(18)(100)}\right) = \underline{\underline{82.34^o}}$$

$$V.R = \frac{18\cos\left(82.34^o - 36.87^o\right)}{100} \times 100\%$$

$$= \underline{\underline{12.62\%}}$$

Example

8. The following data were obtained in test on 20kVA 2400/240V, 60Hz transformer.

   V_{sc} =72V

   I_{sc} =8.33A

   P_{sc}=268W

   P_{oc}=170W

   The measuring instrument are connected in the primary side for short circuit test. Determine the voltage regulation for 0.8 lagging p.f. (use all 3 methods), full load efficiency and half load efficiency.

Example 8 (Cont.)

$$V.R = \frac{V_{sc}\cos\left(\theta_{sc} \mp \theta_{p.f}\right)}{V_2} \times 100\%$$

$$Given\ p.f = 0.8$$

$$Hence, \theta_{p.f} = \cos^{-1} 0.8 = \underline{\underline{36.87^o}}$$

$$Know\ that,$$

$$P_{sc} = V_{sc} I_{sc} \cos\theta_{sc}$$

$$\theta_{sc} = \cos^{-1}\left(\frac{P_{sc}}{V_{sc} I_{sc}}\right)$$

$$= \cos^{-1}\left(\frac{268}{(72)(8.33)}\right) = \underline{\underline{63.4^o}}$$

$$Z_{sc} = \frac{V_{sc}}{I_{sc}} = \frac{72}{8.33} = \underline{\underline{8.64\Omega}}$$

$$\therefore Z_{sc} = 8.64\angle 63.4^o = \underline{\underline{3.86 + j7.72}} = R_{01} + jX_{01}\ because\ connected\ to\ primary\ side.$$

Example 8 (Cont.)

1. *Short Circuit method*, $V.R = \dfrac{V_{sc}\cos\left(\theta_{sc} \mp \theta_{p.f}\right)}{V_1} \times 100\%$

$$V.R = \frac{72\cos\left(63.4^o - 36.87^o\right)}{2400} \times 100\% = \underline{\underline{2.68\%}}$$

2. *Equivalent circuit*, $V.R = \dfrac{I_1\left[R_{01}\cos\theta_{p.f} \pm X_{01}\sin\theta_{p.f}\right]}{V_1} \times 100\%$

$$\frac{\frac{20000}{2400}\left[3.86(0.8) + 7.72(0.6)\right]}{2400} \times 100\% = \underline{\underline{2.68\%}}$$

Example 8 (Cont.)

3. *Basic Defination*,

$$V_1 = I_1 Z_{01} + aV_2$$

$$2400\angle 0^o = \left(\frac{20000}{2400}\angle -36.87^o\right)\left(8.64\angle 63.4^o\right) + \left(\frac{2400}{240}\right)V_2$$

$$V_2 = \underline{\underline{233.58\angle 0.79^o\ V}}$$

$$V.R = \frac{V_{NL} - V_{FL}}{V_{NL}} \times 100\%$$

$$= \frac{240 - 233.58}{240} \times 100\%$$

$$= \underline{\underline{2.68\%}}$$

Example 8 (Cont.)

$$\eta_{(full\,load)} = \frac{(1)(20000)(0.8)}{(1)(20000)(0.8)+170+(1)^2(268)} \times 100\% = 97.34\%$$

$$\eta_{(half\,load)} = \frac{(0.5)(20000)(0.8)}{(0.5)(20000)(0.8)+170+(0.5)^2(268)} \times 100\% = 97.12\%$$

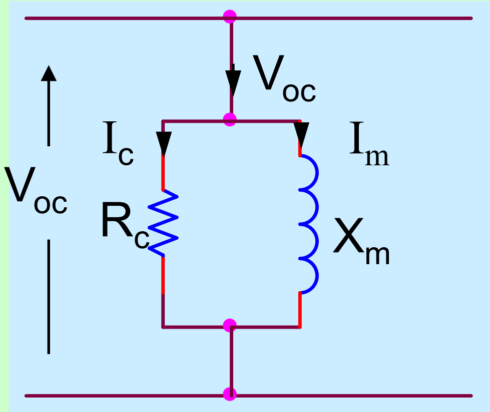
Measurement on Transformer

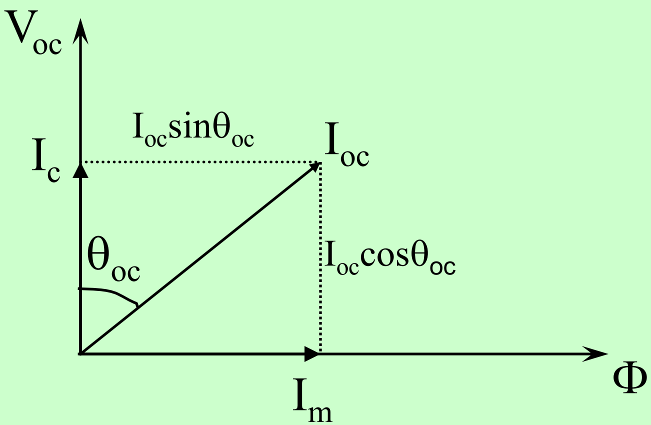
- There are two test conducted on transformer.
  i. **Open Circuit Test**
  ii. **Short Circuit test**

- The test is conducted to determine the parameter of the transformer.
- Open circuit test is conducted to determine magnetism parameter, R_c and X_m.
- Short circuit test is conducted to determine the copper parameter depending where the test is performed. If performed at primary, hence the parameters are R_{01} and X_{01} and vice-versa.

Open-Circuit Test

- Measurement are at high voltage side
- From a given test parameters,





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

$$\theta_{oc} = \cos^{-1}\left(\frac{P_{oc}}{V_{oc} I_{oc}}\right)$$

Hence,

$$I_c = I_{oc} \cos\theta_{oc}$$

$$I_m = I_{oc} \sin\theta_{oc}$$

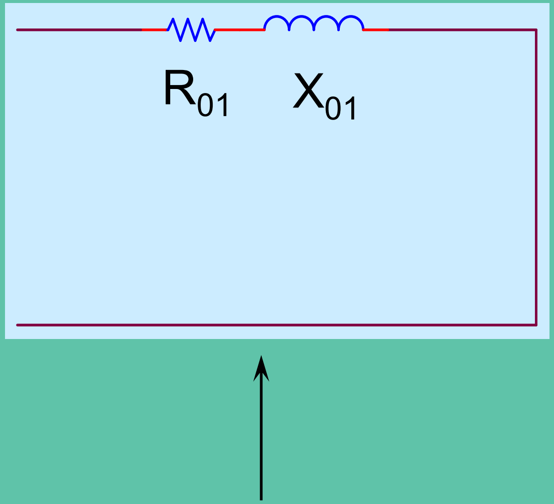
Then, R_c *and* X_m,

$$R_c = \frac{V_{oc}}{I_c}, \quad X_m = \frac{V_{oc}}{I_m}$$

Note:
If the question asked parameters referred to Low voltage side, the parameters (R_c and X_m) obtained need to be referred to low voltage side

Short-Circuit Test

- Measurement are at low voltage side
- If the given test parameters are taken on primary side, R_{01} and X_{01} will be obtained. Or else, vice-versa.



For a case referred to Primary side

$$P_{sc} = V_{sc} I_{sc} \cos \theta_{sc}$$

$$\theta_{sc} = \cos^{-1}\left(\frac{P_{sc}}{V_{sc} I_{sc}}\right)$$

Hence,

$$Z_{01} = \frac{V_{sc}}{I_{sc}} \angle \theta_{sc}$$

$$Z_{01} = R_{01} + jX_{01}$$

Example

9. Given the test on 500kVA 2300/208V are as follows:

$P_{oc} = 3800W$ | $P_{sc} = 6200W$
$V_{oc} = 208V$ | $V_{sc} = 95V$
$I_{oc} = 52.5A$ | $I_{sc} = 217.4A$

Determine the transformer parameters and draw equivalent circuit referred to high voltage side. Also calculate appropriate value of V_2 at full load, the full load efficiency, half load efficiency and voltage regulation, when power factor is 0.866 lagging.

[1392Ω, 517.2Ω, 0.13Ω, 0.44Ω, 202V, 97.74%, 97.59%, 3.04%]

Example 9 (Cont)

From Open Circuit Test,

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

$$\theta_{oc} = \cos^{-1}\left(\frac{3800}{(52.5)(208)}\right) = \underline{\underline{69.6^{o}}}$$

$$I_c = I_{oc} \cos\theta_{oc}$$

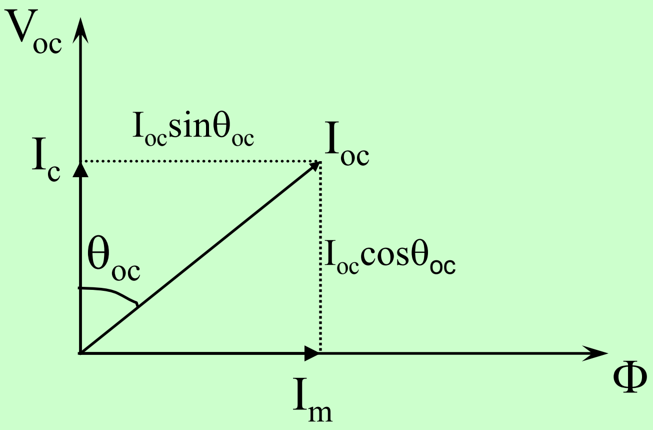
$$= 52.5 \cos 69.6^{o}$$

$$= \underline{\underline{18.26 A}}$$

$$I_m = I_{oc} \sin\theta_{oc}$$

$$= 52.5 \sin 69.6^{o}$$

$$= \underline{\underline{49.2 A}}$$



Example 9 (Cont)

Since V_{oc}=208V

$\therefore$ all reading are taken on the secondary side

$$R_c = \frac{V_{oc}}{I_c} = \frac{208}{18.26} = \underline{\underline{11.39\Omega}}$$

$$X_m = \frac{V_{oc}}{I_m} = \frac{208}{49.21} = \underline{\underline{4.23\Omega}}$$

Parameters referred to high voltage side,

$$R_c' = R_c\left(\frac{E_1}{E_2}\right)^2 = 11.39\left(\frac{2300}{208}\right)^2 = \underline{\underline{1392\Omega}}$$

$$X_m' = X_m\left(\frac{E_1}{E_2}\right)^2 = 4.23\left(\frac{2300}{208}\right)^2 = \underline{\underline{517.21\Omega}}$$

Example 9 (Cont)

From Short Circuit Test,

First, check the I_{sc}

$$I_{FL_1} = \frac{VA}{V_1} = \frac{500 \times 10^3}{2300} = \underline{\underline{217.4A}}$$

Since $I_{FL1} = I_{sc}$, $\therefore$ all reading are actually taken on the primary side

$$P_{sc} = V_{sc} I_{sc} \cos\theta_{sc}$$

$$\theta_{sc} = \cos^{-1}\left(\frac{6200}{(95)(217.4)}\right) = \underline{\underline{72.53^o}}$$

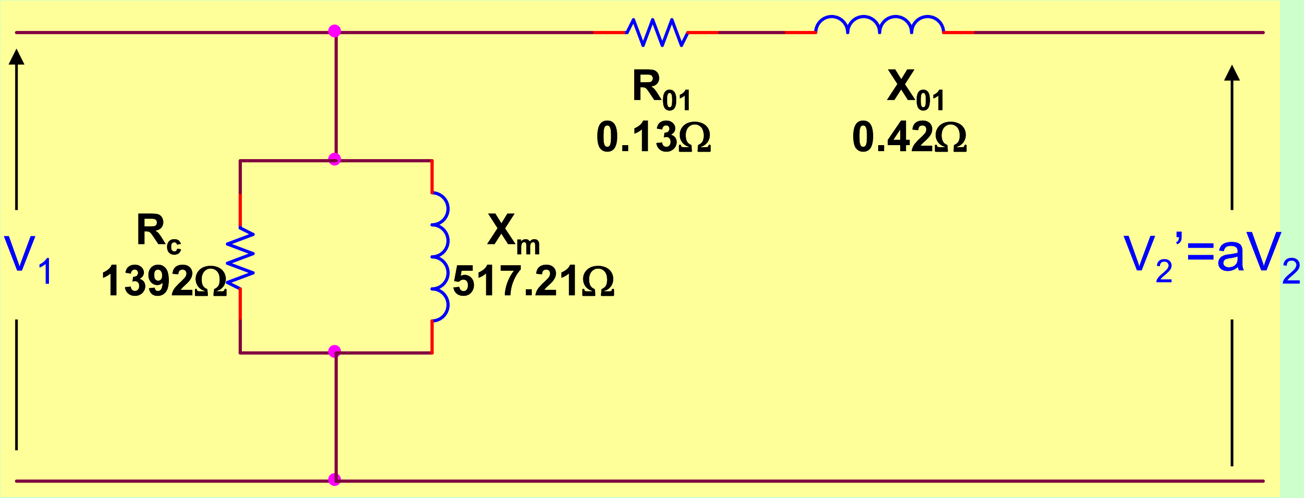
$$Z_{01} = \left(\frac{V_{sc}}{I_{sc}}\right)\angle\theta_{sc}$$

$$= \left(\frac{95}{217.4}\right)\angle 72.53^o = 0.44\angle 72.53^o$$

$$= \underline{\underline{0.13 + j0.42\Omega}}$$

Example 9 (Cont)

Equivalent circuit referred to high voltage side,



Example 9 (Cont)

Efficiency,η

$$\eta_{FL} = \left[\frac{VA\cos\theta}{VA\cos\theta + P_{sc} + P_{oc}}\right]\times 100\%$$

$$= \left[\frac{(500\times 10^3)(0.866)}{(500\times 10^3)(0.866) + 6200 + 3800}\right]\times 100\%$$

$$= \underline{\underline{97.74\%}}$$

$$\eta_{\frac{1}{2}L} = \left[\frac{nVA\cos\theta}{nVA\cos\theta + n^2 P_{sc} + P_{oc}}\right]\times 100\%$$

$$= \left[\frac{(0.5)(500\times 10^3)(0.866)}{(0.5)(500\times 10^3)(0.866) + (6200)(0.5)^2 + 3800}\right]\times 100\%$$

$$= \underline{\underline{97.59\%}}$$

Example 9 (Cont)

Voltage Regulation,

$$V.R = \left[\frac{V_{sc} \cos\left[\theta_{sc} - \theta_{pf}\right]}{E_1} \right] \times 100\%$$

$$= \left[\frac{(95)\cos\left[72.53 - 30\right]}{2300} \right] \times 100\%$$

$$= \underline{\underline{3.04\%}}$$