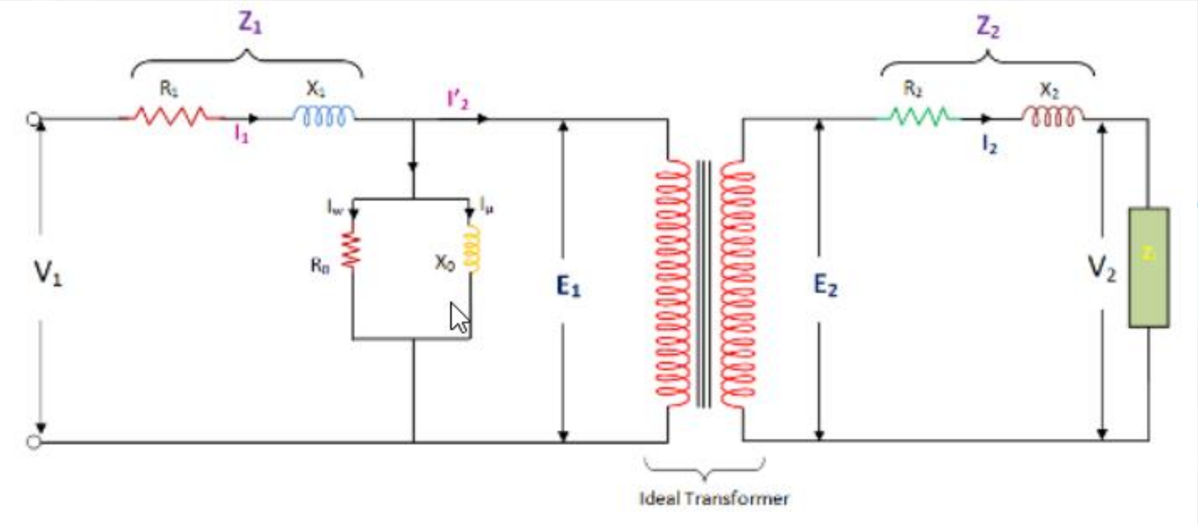
Transformer Parameters

Lecture Two

- Transformer equivalent circuit
- Transformer Tests:
  - ❑Open circuit test (O.C)
  - ❑Short circuit test (S.C)



$$Z_L = \frac{V_s}{I_s}$$

$$E_p = 4.44 f N_p \phi_{max}$$
$$E_s = 4.44 f N_s \phi_{max}$$

$$\Downarrow$$

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} = a$$

Turns ratio

$$P_{in} = P_{out} = V_p I_p = V_s I_s$$
$$\frac{I_p}{I_s} = \frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{1}{a}$$

Equivalent circuit of Transformer

Generalized transformer equivalent circuit can either be obtained by referring all parameters to primary side or by secondary side and omitting the ideal transformer notation. The generalized form of equivalent circuit of transformer is shown below.

Nonideal transformer

leakage flux is present at both primary and secondary sides .

This leakage gives rise to leakage reactances x_1 and x_2

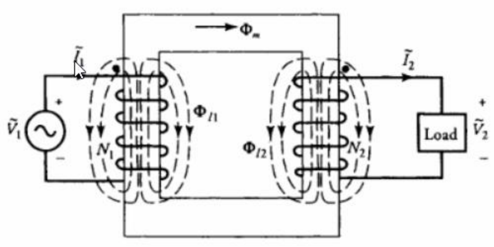
r_1 and r_2 are the primary and secondary winding resistances .

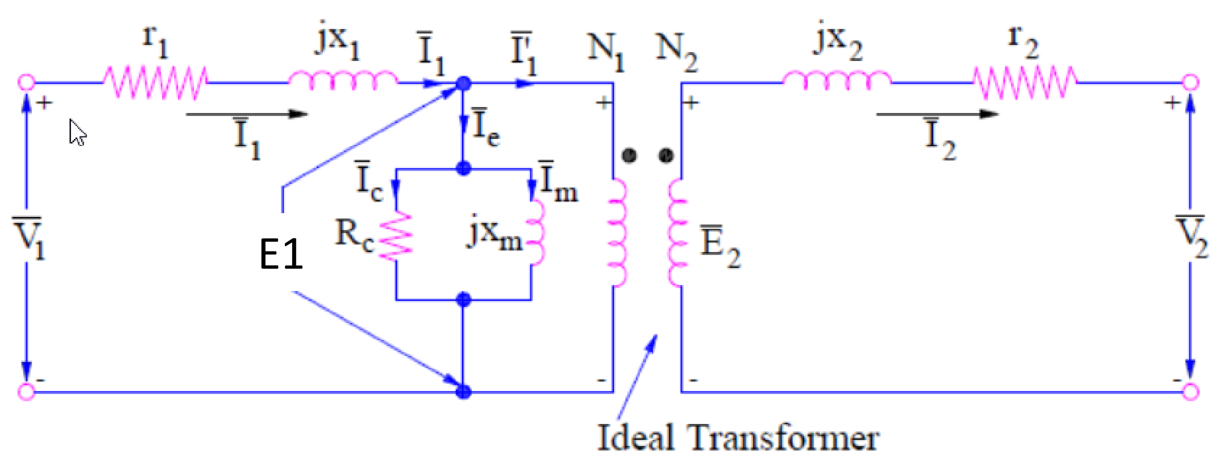
These resistances causes voltage drop as , I_1R_1 and I_2R_2

copper loss $I_1^2R_1$ and $I_2^2R_2$.

Permeability of the core can not be infinite , hence some magnetizing current is needed .

Mutual flux also causes core loss in iron parts of the transformer .





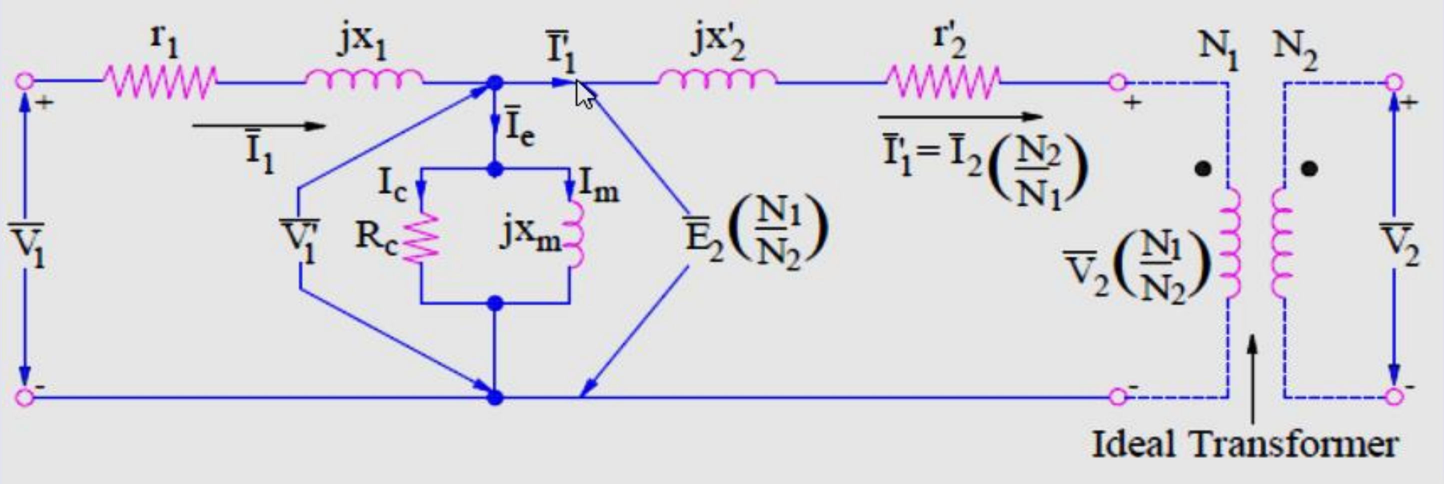
Generalized Transformer Equivalent Circuit

The no load current I_0 is divided into, pure inductance X_m (taking magnetizing components I_m) and non induction resistance R_c (taking working component I_c) which are connected into parallel across the primary.

The value of E_1 can be obtained by subtracting I_1Z_1 from V_1.

The value of R_c and X_m can be calculated as, $R_c = E_1 / I_c$ and $X_m = E_1 / I_m$.

Equivalent Circuit when all the quantities are referred to Primary side



Secondary resistance drop when referred to primary side must be multiplied with **(N_1/N_2).**

Secondary Resistance drop **I_2r_2** referred to Primary

$= (I_2r_2)(N_1/N_2)$ But **$I_2 = I_1\,(N_1/N_2)$**

Secondary resistance drop **I_2r_2** referred to Primary

$= I_1\,[(N_1/N_2)^2 r_2] = I_1 r_2'$

where **$r_2' = (N_1/N_2)^2\, r_2$**

This resistance **r_2'** is called the *secondary resistance referred to* primary *side*.

$r_{e1} = r_1 + r_2'$ the total resistance of primary circuit

r_{e1} the equivalent resistance of transformer referred to primary side.

Similarly,

The secondary leakage reactance drop when referred to primary side

$= (I_2x_2)(N_1/N_2) = I_1\,[(N_1/N_2)^2 x_2] = I_1 x_2'$

where **$x_2' = (N_1/N_2)^2 x_2$**

This reactance **x_2'** is called the *secondary reactance referred to primary side*.

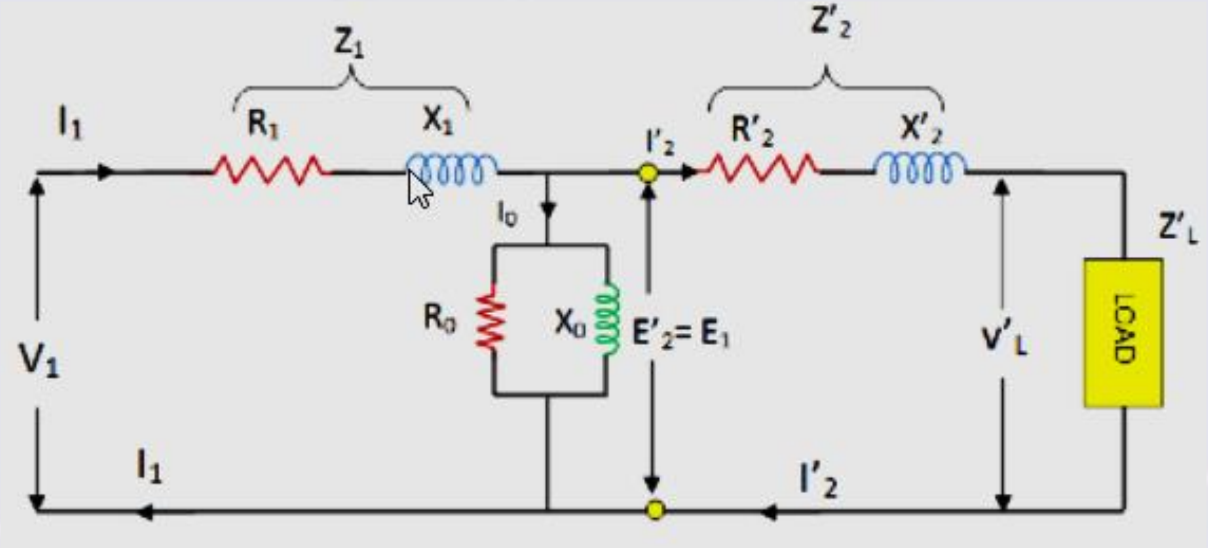
the total resistance of primary circuit **$x_{e1} = x_1 + x_2'$**

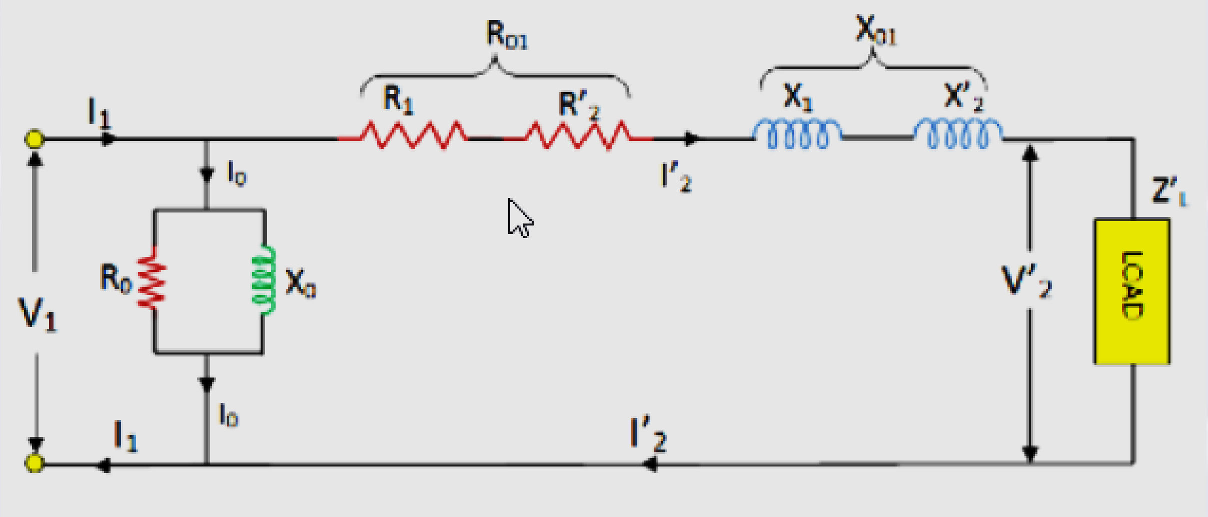
x_{e1} the equivalent reactance of transformer referred to primary side.

Thus, the total leakage impedance of transformer referred to primary side is given as

$z_{e1} = r_{e1} + jx_{e1}$

Equivalent Circuit when all the quantities are referred to Primary side





Equivalent Circuit when all the quantities are referred to secondary side

The total leakage impedance of transformer referred to secondary side is given as

$z_{e2} = r_{e2} + jx_{e2}$

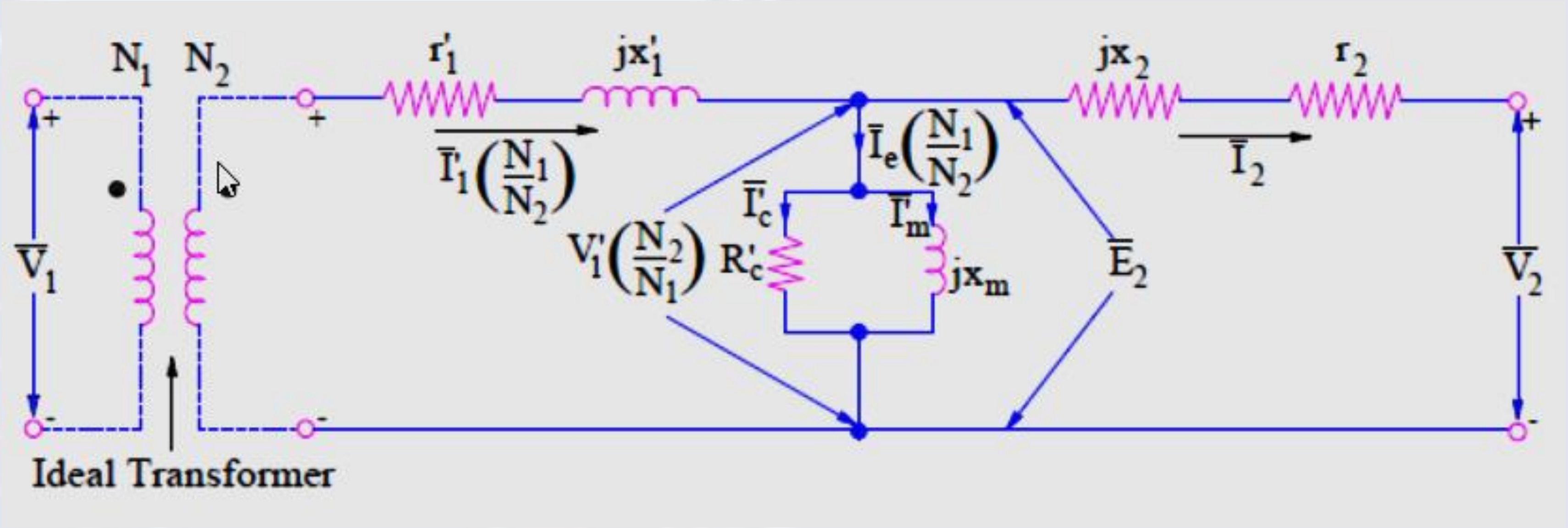
Where

$r_{e2} = r_2 + r_1'$

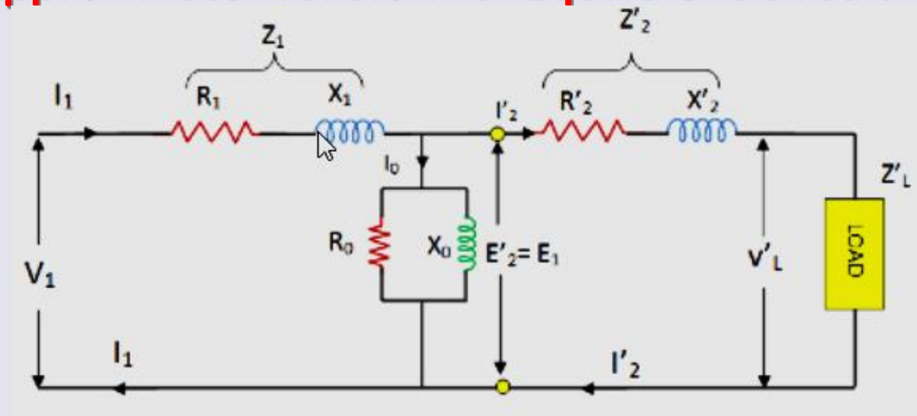
$x_{e2} = x_2 + x_1'$

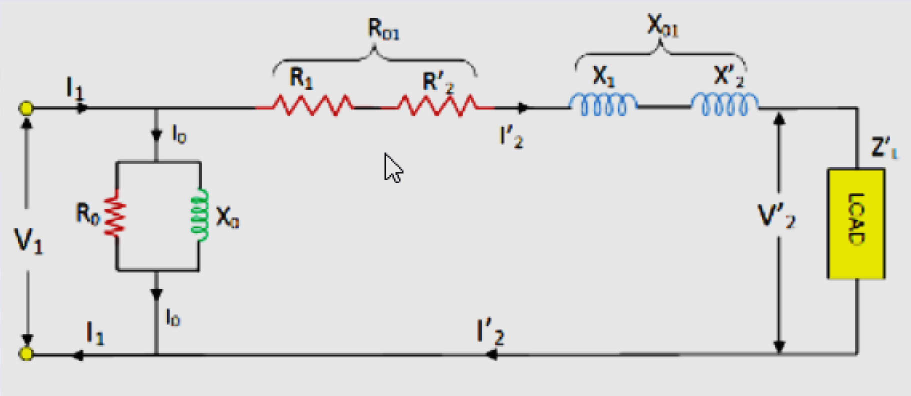
$r_1' = (N_2/N_1)^2 r_1$

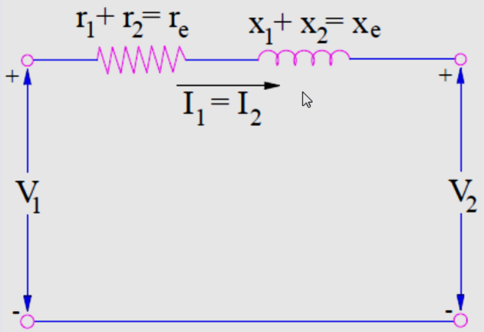
$x_1' = (N_2/N_1)^2 x_1$



Approximate Transformer Equivalent Circuit







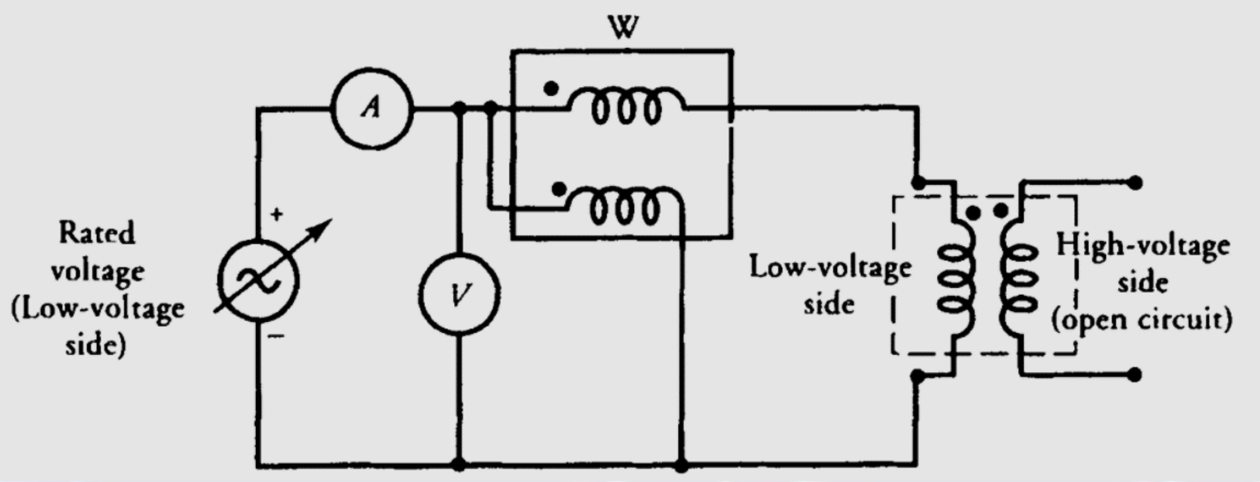
The approximate equivalent circuit of transformer is obtained from the generalized equivalent circuit by moving the shunt branch to either primary side or secondary side. When the shunt branch is moved to primary side, the excitation current I_e don't flow through the primary leakage impedance.

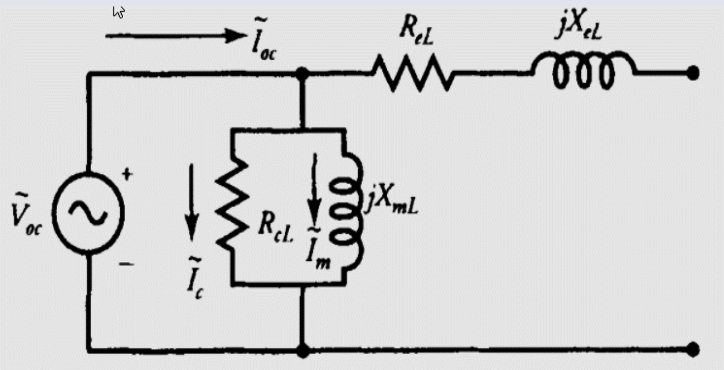
Similarly, when the shunt branch is moved to secondary side, the excitation current does flow through the secondary leakage impedance. But in actual or exact transformer equivalent circuit, it does not flow through the secondary leakage impedance. Thus this approximate circuit includes the voltage drop in secondary leakage impedance due to exciting current I_e.

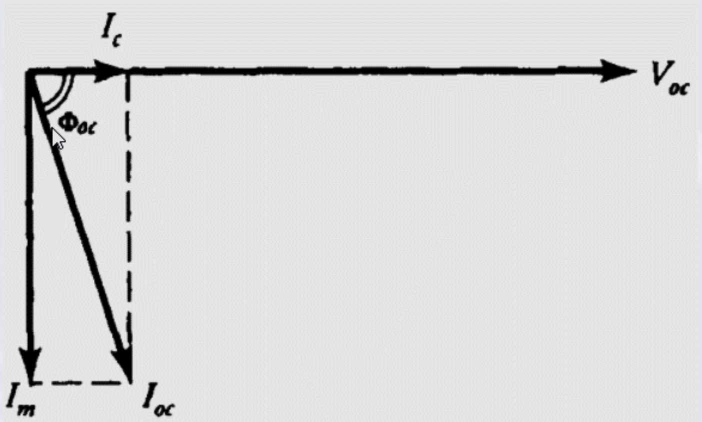
Determination of Transformer Parameters

The equivalent circuit parameters of a transformer can be determined by performing two tests: the open-circuit test and the short-circuit test.

Open-Circuit or No load Test







the wattmeter measures the core loss in the transformer

$$R_{cL} = \frac{V_{oc}}{I_c} = \frac{V_{oc}^2}{P_{oc}}$$

$$X_{mL} = \frac{V_{oc}}{I_m} = \frac{V_{oc}^2}{Q_{oc}}$$

$$I_c = I_{oc} \cos(\phi_{oc})$$

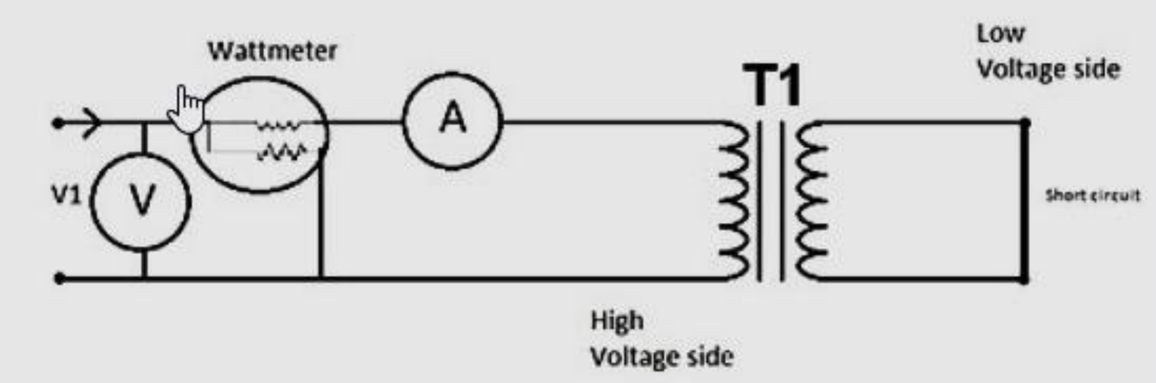
$$I_m = I_{oc} \sin(\phi_{oc})$$

power-factor angle $\phi_{oc} = \cos^{-1}\left[\frac{P_{oc}}{S_{oc}}\right]$

Determination of Transformer Parameters

Short-Circuit Test

The test is implemented on the high-voltage (HV) side of the transformer where the low-voltage (LV) side is short circuited



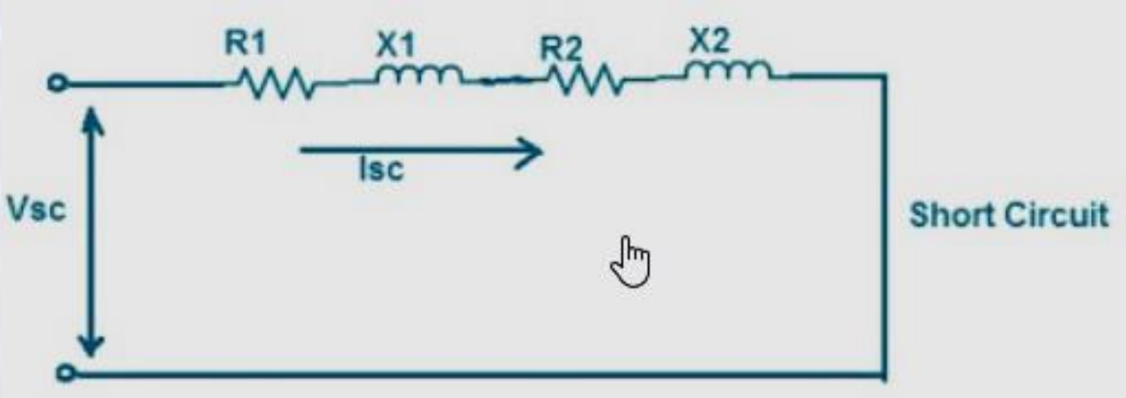
$Z_{eH} = R1+R2 +j(X1+X2)$

$Z_{eH} = V_{sc} / I_{sc}$

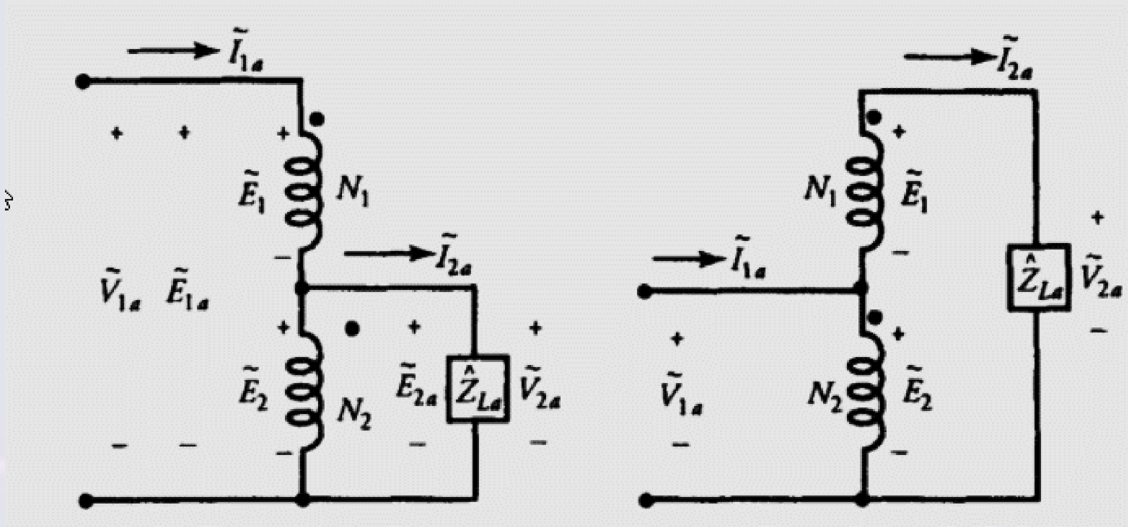
$R_{eH} = R_2R+_{1'}$

$R_{eH} = P_{sc} / I_{sc}^2$

$X_{eH} = \sqrt{Z_{eH}{}^2 - R_{eH}{}^2}$



Autotransformers



Advantages
1.Cheaper
2.Efficient
3.exciting current is low
4.Better voltage regulation

Disadvantages
1. short-circuit current is large
2. No isolation exists between the primary and secondary windings

Per-Unit Computations

An electric system has four quantities of interest: voltage, current, apparent power, and impedance. If we select base values of any two of them, the base values of the remaining two can be calculated. If S, is the apparent base power and Vb is the base voltage, then the base current and base impedance are

$$\text{Quantity, pu} = \frac{\text{actual quantity}}{\text{its base value}}$$

$$I_b = \frac{S_b}{V_b}$$

$$Z_b = \frac{V_b}{I_b}$$