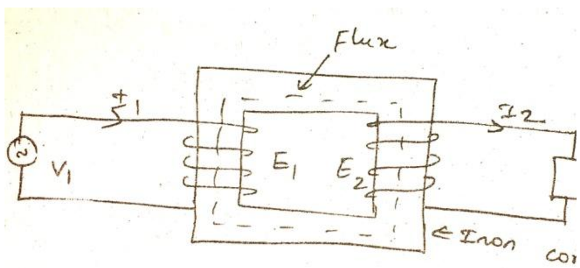
Transformers:

One of the main advantages of AC generation over DC generation is that the alternating voltage can be increased or reduced, as per our requirement, very easily. This job is done by a transformer. When the voltage is increased, it is called a step-up transformer. When the voltage is reduced, it becomes a step-down transformer.

Working Principle:

Transformer is a static device which changes the alternating voltage from one level to another.



It consists of a magnetic core and two distinct windings wound over the core. The two windings form two independent electrical circuits whereas the core forms a magnetic circuit which is common to both the windings. The basic principle of a transformer is the mutual induction b/w two circuits linked by a common magnetic circuit.

If one winding is connected to AC supply, an alternating flux is established in the core. Most of this flux links with the other winding. This produces a mutually induced emf in that winding. If the circuit of the second winding is closed; a current flows in it and therefore electrical energy is transferred from the first winding to the second. Here the input and output frequency are the same.

The first winding which is connected to AC supply is called the primary winding whereas the other winding is which energy in transformed is called the secondary winding.

Classification:

On the basis of:

i) Duty they perform:

1. Power transformers - for transmission & Distribution purposes
2. Current transformers - instrument transformer
3. Potential transformers - instrument transformer

ii) Construction:

1. Core type transformer
2. Shell type transformer
3. Berry type transformer

iii) Voltage output:

1. Step down transformer
2. Step-up
3. Auto transformer

iv) Application:

1. Welding transformer
2. Furnace transformer

v) Cooling:

1. Duct type transformer

2. Oil immersed

a) Self cooled b) Forced air cooled

c) Water cooled d) Forced oil cooled

vi) Input supply:

1. Single phase transformer
2. Three phase transformer

Three phase transformer

a) Star-Star

b) Star-Detlta

c) Delta-Delta

d) Delta-Star

e) Open-Delta

f) Scott connection

EMF equation of a transformer:

$E_1 = 4.44\ f\ B_M\ A\ N_1$ volts

$E_2 = 4.44\ f\ B_M\ A\ N_2$ volts

where

N_1 = Number of primary turns

N_2 = Number of secondary turns

ϕ_m= Maximum value of flux in the core in Wb

B_m = Maximum value of flux density in the core Wb/m^2

A = Area of the core in m^2

f = Frequency of the AC supply in Hz

V_1 = Supply voltage across primary in volts

V_2 = Terminal voltage across secondary in volts

I_1 = Full load primary current in amperes

I_2 = Full load secondary current in amperes

E_1 = Emf induced in the primary in volts

E_2 = Emf induced in the secondary in volts

Transformation Ratio (K)

$V_1 = E_1$;

$V_2 = E_2$;

$\therefore \frac{V_2}{V_1} = \frac{I_1}{I_2}$

$\frac{E_2}{E_1} = \frac{I_1}{I_2}$

From the above relations, we have

$\frac{E_2}{E_1} = \frac{N_2}{N_1}$

$\therefore \frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = K$

Where K is called transformation ratio.

If, $N_2 > N_1$, i.e. $K > 1$, transformer is a stop-up X^r.

If $N_2 < N_1$ i.e., $K < 1$, step-down transformer

Voltage ratio = $\frac{E_2}{E_1}$ = K

Current ration = $\frac{I_2}{I_1} = \frac{1}{K}$

Ideal transformer:

It has the following properties.

1. No winding resistance i.e. purely inductive.
2. No magnitude leakage flux.
3. No I^2R loss i.e. no copper loss.
4. No core

Practical Transformer on No-load:

$I_w = I_o \cos \phi_o$ Watt full component

$I_\mu = I_o \sin \phi_o$ = Watt less component

$I_o = \sqrt{I_w^2 + I_\mu^2}$

- I_o is very small as to the full load py current.
- As I_o is very small, the no-load primary Cu loss is negligible.

  ∴ This no load input power is practically equal to the iron or core loss of the transformer.

Transformer on load:

i) The flux passing through core is same as that no load i.e. flux is constant at no-load as well as loaded condition. That is why transformer is also called a constant flux apparatus.

ii) The total primary current (I_1) will be vector sum of I_o and I_2^1.

Shifting Impedances in a Transformer

Referred to primary:

$R_{01} = R_1 + R_2^1 = R_1 + \frac{R_2}{K^2}$

$X_{01} = X_1 + X_2^1 = X_1 + \frac{X_2}{K^2}$

$Z_{01} = \sqrt{R_{01}^2 + X_{01}^2}$

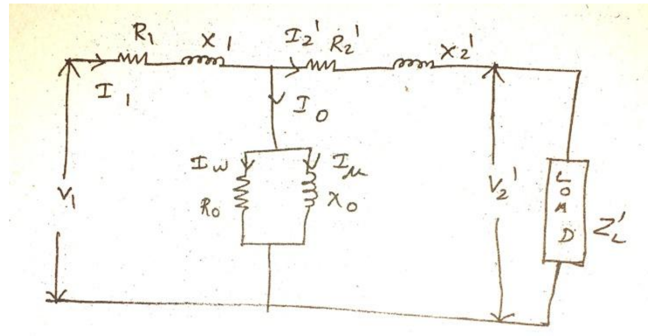
Referred to secondary:

$R_{02} = R_2 + R_1^1 = R_2 + R_1$

$X_{02} = X_2 + X_1 = X_2 + K^2 X_1$

$Z_{02} = \sqrt{R_{02}^2 + X_{02}^2}$

Equivalent circuit of a transformer referred to primary:



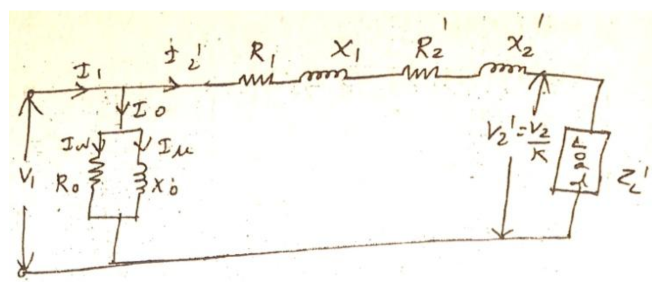
$R_2^1 = \frac{R_2}{K_2}; X_2^1 = \frac{X_2}{K_2}$

$I_2^1 = KI_2; Z_L^1 = \frac{Z_L}{K^2}$

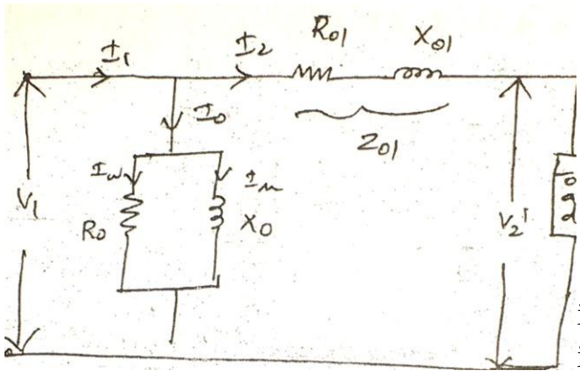
$V_2^1 = \frac{V_2}{K}; R_0 = \frac{V_1}{I_w}; X_0 = \frac{V_2}{I_\mu}$

Approximate Equivalent circuit:

The no-load current I_0 is only 1-3% of rated primary current. So I_2^1 practically equal to I_1. Due to this, equivalent circuit can be simplified by transferring the exciting branch (R_0 & X_0) to the left position of the circuit. This circuit is known as approximate equivalent circuit of the transformer.



Referred to primary:

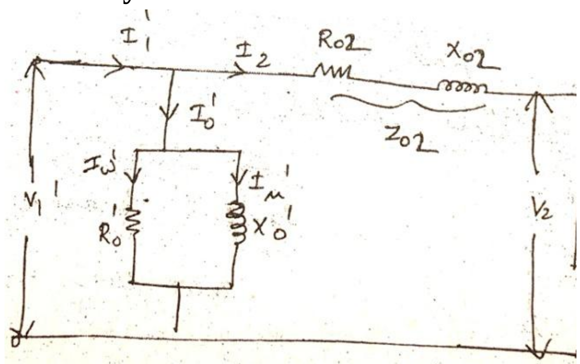


$R_{01} = R_1 + R_2^1$

$X_{01} = X_1 + X_2^1$

$Z_{01} = \sqrt{R_{01}^2 + X_{01}^2}$

Equation Circuit referred to secondary:



$R_{02} = R_1^1 + R_2 = R_1K^2+R_2$

$X_{02}= X_1^1 + X_2 =X_1K^2+X_2$

$Z_{02} = \sqrt{R_{02}^2 + X_{02}^2}$

Transformer tests :

1. Open circuit test or No load test.
2. Short circuit test or Impendance test .

By using these two tests we can find:

1. Circuit constants (R_0,X_0,R_{01},x_{01},R,02 and $x_{,02}$)
2. Core loss and full load copper loss.
3. Predetermine the efficiency and voltage regulation

Open Circuit test :

Used to find :

i) No-Load loss (or) loss

ii) No –Load Current i_0 Which is helpful in finding out R_0 and X_0

Iron losses p_i= Wattmeter reading = w_0

No load Power factor $\cos\emptyset = W_0/V_0 I_0$

$\emptyset_0=\cos^{-1}(W_0/V_0 I_0)$

No –Load Wattiful component ,$I_w=I_0 \cos\emptyset_0 = W_0/V_0$

No-load magnetising component,

$I\mu=I_0\sin \emptyset_0 =\sqrt{I^2 + I^2}$

No-Load resistance $=v_1^2/w_0$

No –Load reactance

$X_0=v_1/I_w=v_1/\sqrt{I^2 + I^2}$

Short circuit test:

Useful to find:

i) Full –load copper loss.

ii) Equivalent resistance and reactance referred to metering side .

Full load copper loss P_{cu}=wattmeter

Reading =W_s

$P_{cu}=I^2{}_1R_1+ I^2{}_1R_2= I^2{}_1R_{01}$

$R_{01}=P_{cu}/I^2{}_1$

R=Total resistances of transformer referred to primary.

Toatl impedance refeered to primary .

$Z_{01}=V_{sc}/I_1$

Total leakage reactance referred to primary

$X_{01}=\sqrt{z^2+R^2}$

Short circuit powerful cos θ =$P_{cu}/v_{sc}I_1$

Losses in a Transformer:

1.Core or Iron loss:

Iron loss is caused by the alternating flux in the core and consists of hysteresis and eddy current loss. The core flux in a transformer remaining practically constant for all loads and so the core loss is practically the same at all loads.

Hysteresis loss $W_h=nB^{1.6}{}_{max}$ fv watts

Eddy current loss W_e=P $B^2{}_{max}$ f^2 v^2 watts

Hysteresis loss can be minimized by using steel of high silicon content for the core and eddy current loss can be minimized by using very thin laminations,

Copper Loss:

This loss is due to ohmic resisrance of the trandformer windings.

Total Coppwr loass= $I^2{}_1R_1+ I^2{}_1R_2$

Theses losses vary as the square of the load current .For example copper loss at half the full load is one fourth of that at full load.

Efficiency (η) of a Transformer:

$$\eta = \frac{\text{Output power}}{\text{Input power}}$$

$$\eta = \frac{\text{O/P Power}}{\text{O/P Power} + \text{losses}}$$

$$= \frac{\text{O/P Power}}{\text{O/P Power} + \text{Iron Losses} + \text{Copper Losses}}$$

o/p power = V_2 I_2 cos ϕ

$$\eta = \frac{nV_2 I_2 \cos\phi}{nV_2 I_2 \cos\phi + P_i + n^2 P_{cu}}$$

At full load, n = 1

At half load, n = $\frac{1}{2}$

Condition for maximum efficiency:

Iron loss = Copper loss (or) constant loss = Variable loss

Voltage regulation of a Transformer:

% Regulation = $\frac{(\text{V}_2 \text{ on noload}) - (\text{V}_2 \text{ when loaded})}{\text{V}_2 \text{ on no-load}} \times 100$

For lagging p.f_1

$\% \text{ regulation} = \frac{\text{Voltage drop}}{V_1} \times 100$

For leading power factor,

$\% \text{ regulation} = \frac{I_1 R_{01} \cos\phi - I_1 X_{01} \sin\phi}{V_1} \times 100$

For unity power factor

$\% \text{ reg} = \frac{I_1 R_{01}}{V_1} \times 100$

All day efficiency or energy efficiency:

$\eta_{all\ day} = \frac{K_{wh}\ O/P\ in\ 24\ hours}{K_{wh}\ i/p\ in\ 24\ hours}$

Why transformer rating is in KVA?

Copper logs depends on current and iron loss depend upon voltage. Hence the total loss in a transformer depends upon volt-ampere (VA) only and not on the phase angle b/w voltage and current i.e. it is independent of load power factor.

That is why the rating of a transformer is given in KvA and not in Kw.