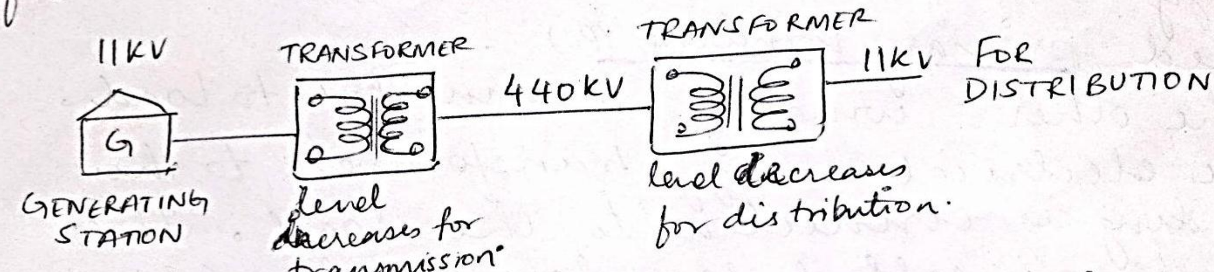
TRANSFORMERS

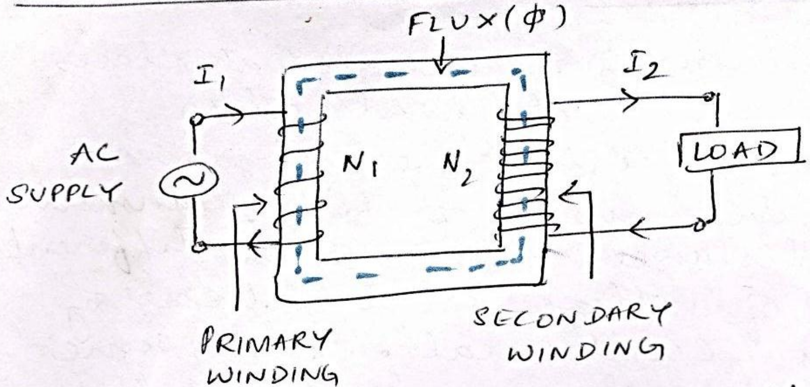
INTRODUCTION: electrical energy is generated at places where it is easier to get water head, oil or coal for hydroelectric, diesel or thermal power stations respectively. Then energy is to be transmitted at considerable distances for use in different places. Transmission of voltage electrical energy at high voltages is economical. Hence, some means are required for stepping up the voltage at generating stations and stepping down the same at the places where it is used. The machine used for this purpose is called a Transformer.

In our country, the electrical energy is usually generated at 6.6 or 11 or 33 KV, stepped up to 132, 220, 400 or 765 KV with the help of step-up transformers for transmission and then stepped down to 66 KV or 33 KV and then to 11 KV at distribution transformers, stepping down the voltage further to 400/230 V for the consumers.



"A transformer is a static electrical device which transfers electrical device, which transfers electrical power from one electrical circuit to the other, which are magnetically coupled together without any change in the frequency and power."

WORKING PRINCIPLE



→ The transformer works on the principle of mutual induction which states that when two coils are inductively coupled and if current in one coil is changed uniformly then an emf gets induced in the other coil.

→ In its elementary form, a transformer consists of two inductive coils which are electrically separated but linked through a common magnetic circuit. The two coils have high mutual inductance.

→ One of the two coils is connected to a source of alternating voltage. This coil in which electrical energy is fed with the help of source is called primary winding (P).

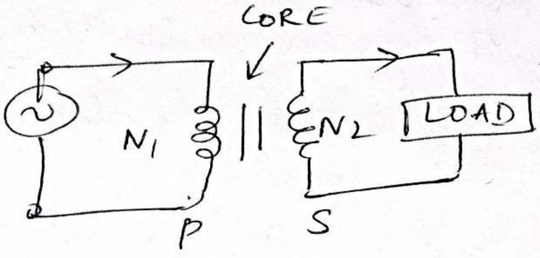
→ The other winding is connected to load. The electrical energy transformed to this winding is connected to the load. The winding is called secondary winding (S).

→ Primary winding has N_1 turns and the secondary winding has N_2 turns.

→ When primary winding is excited by an alternating Vg, it circulates an alternating current. This current produces an alternating flux (ϕ) which completes its path through the common magnetic core (as shown dotted). This alternating flux links the secondary winding.

→ As the flux is alternating, according to Faraday's law of electromagnetic induction, mutually induced emf gets developed in the secondary winding. A self induced emf also gets induced in the primary winding.

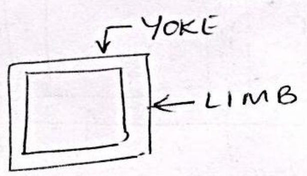
→ Symbolic Representation of a transformer :



→ The two parallel lines in between two windings represents the common magnetic core.

→ ∴ Though there is no electrical contact between the two windings, an electrical energy gets transferred from primary to the secondary.

CONSTRUCTION



→ There are two basic parts of a transformer: i) Magnetic core. ii) Winding or coils

→ vertical portion of the core on which coils are wound is called limb. Horizontal portion is called YOKE.

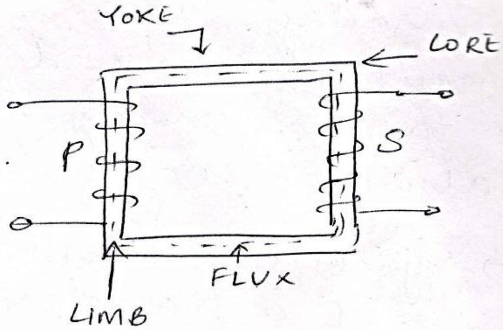
→ Core is made up of laminations to minimize eddy current losses. These laminations are insulated from each other using insulation like varnish.

→ The coils are made up of copper or other conducting material.

→ The core provides the low reluctance path to the flux produced by the primary while the windings carry the currents necessary for the functioning of the transformer

TYPES OF SINGLE PHASE TRANSFORMERS

1. CORE TYPE TRANSFORMER :-



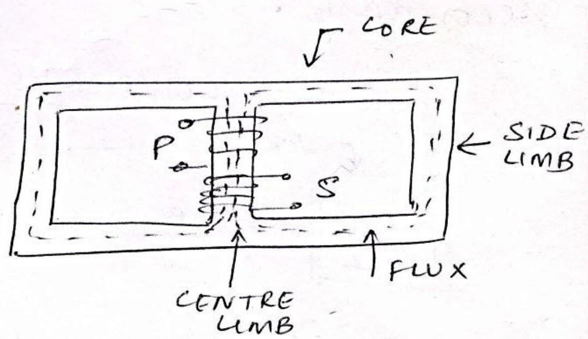
→ It has a single magnetic circuit. The core is rectangular having two limbs. The winding encircles the core

→ Both the coils are placed on both the limbs.

→ As the windings are uniformly distributed over the two limbs, the natural cooling is more effective.

→ The coils can be easily removed by removing the laminations of the top yoke for maintenance.

2. SHELL TYPE TRANSFORMER :-



→ It has a double magnetic circuit. The core has three limbs.

→ Both windings are placed on the central limb.

→ The core encircles most part of the windings, natural cooling doesnt exist.

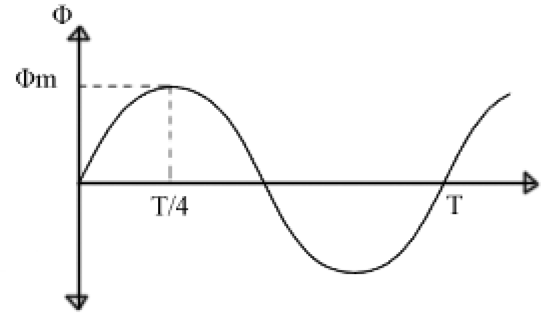
→ Generally for very high voltage transformers, the shell type construction is preferred.

→ For removing any winding for maintenance, large number of lamination are required to be removed.

EMF Equation of a Transformer

In a transformer, source of alternating current is applied to the primary winding. Due to this, the current in the primary winding (called as magnetizing current) produces alternating flux in the core of transformer. This alternating flux gets linked with the secondary winding, and because of the phenomenon of mutual induction an emf gets induced in the secondary winding. Magnitude of this induced emf can be found by using the following **EMF equation of the transformer**.

Let,
N_1 =Number of turns in primary winding
N_2 = Number of turns in secondary winding
Φ_m = Maximum flux in the core (in Wb) = (B_m x A)
f = frequency of the AC supply (in Hz)



As, shown in the fig., the flux rises sinusoidally to its maximum value Φ_m from 0. It reaches to the maximum value in one quarter of the cycle i.e in T/4 sec (where, T is time period of the sin wave of the supply = 1/f).
Therefore,

Average rate of change of flux = $\Phi_m /_{(T/4)}$ = $\Phi_m /_{(1/4f)}$

Therefore,
average rate of change of flux = 4f Φ_m .... (Wb/s).
Now,
Induced emf per turn = rate of change of flux per turn

Therefore, average emf per turn = 4f Φ_m ....(Volts).
Now, we know, Form factor = RMS value / average value =1.11 for sine wave

Therefore, RMS value of emf per turn = Form factor * average emf per turn.

Therefore, RMS value of emf per turn = 1.11 x 4f Φ_m = 4.44f Φ_m.

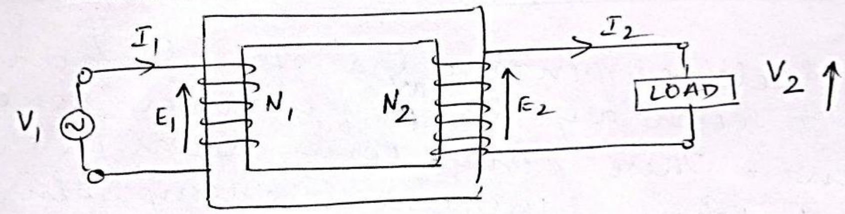
RMS value of induced emf in whole primary winding (E_1) = RMS value of emf per turn X Number of turns in primary winding

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

Similarly, RMS induced emf in secondary winding (E_2) can be given as

$$E_2 = 4.44f\ N_2\ \Phi_m.$$

RATIOS OF A TRANSFORMER



1. VOLTAGE RATIO :

$E_1 = 4.44 f \Phi_m N_1$

$E_2 = 4.44 f \Phi_m N_2$

Taking ratio of the two equations :-

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

Ratio of secondary induced emf to primary induced emf is known as voltage transformation ratio denoted as K

$$\therefore \boxed{E_2 = KE_1 \quad \text{where } K = \frac{N_2}{N_1}}$$

→ If $N_2 > N_1$ i.e $K > 1$ we get $E_2 > E_1$ then the transformer is called step-up transformer.

→ If $N_2 < N_1$ i.e $K < 1$ we get $E_2 < E_1$ then the transformer is called step-down transformer

→ If $N_2 = N_1$ i.e $K = 1$ we get $E_1 = E_2$ then the transformer is called 1:1 or isolation transformer.

2. CURRENT RATIO :

For an ideal transformer, there are no losses.

∴ input VA = output V.A

$V_1 I_1 = V_2 I_2$

$\frac{V_1}{V_2} = \frac{E_1}{E_2}$ for an ideal transformer

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

VOLT-AMPERE RATING [VA]

→ when electrical power is transferred from primary winding to secondary there are a few power losses in between. These power losses appear in the form of heat which increase the temperature of the device.

→ The copper loss (I^2R) in the transformer depends on the current 'I' through the winding.

→ The iron or core loss depends on the voltage 'V'.

→ None of these losses depend on the power factor of the load. Hence losses decide the rating of the transformer.

→ Hence, as losses depend on V and I only, the rating of the transformer is specified as a product of these 2 parameters only called VA rating.

→ The VA rating is expressed in KVA. KVA of primary and secondary remains same.

$$\text{KVA rating of a transformer} = \frac{V_1 I_1}{1000} = \frac{V_2 I_2}{1000}.$$

FULL-LOAD CURRENTS

We can obtain the full-load currents of primary and secondary I_1 & I_2 from the KVA rating of the transformer. [This is the safe maximum current limit which the transformer may carry keeping temperature rise below its limiting value]

$$I_1 \text{ full-load} = \frac{\text{KVA rating} \times 1000}{V_1}$$

$$I_2 \text{ full load} = \frac{\text{KVA rating} \times 1000}{V_2}$$

Flux in the core of a transformer

For a transformer,

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

$$\Phi_m \propto \frac{E1}{f}$$

The primary voltage and frequency remain constant. Hence, for a transformer, the flux in the core remains constant and independent of the load.

DC SUPPLY FOR A TRANSFORMER

→ The transformer works on the principle of mutual induction, for which current in one coil must change uniformly. If d.c supply is given, the current will not change due to constant supply and transformer will not work.

→ Practically winding resistance is very small. For dc supply, the inductive reactance is zero as dc has no frequency. ∴ Total impedance is very low. Thus, the winding will draw very high current if dc supply is given to it. This may cause the burning of windings and may cause permanent damage of the transformer.

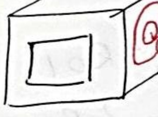
∴ D.C Supply should not be connected to the transformers.

Losses in a transformer

As the transformer is a static apparatus and doesnt contain any rotating parts, there are no mechanical losses. The losses that occur in a transformer are:-

(i) IRON LOSS (Wi): This loss is also called as the 'CORE LOSS' and it occurs in the iron portion i.e the core of the transformer. These are of two types:-
(i) Eddy current loss (ii) Hysteresis loss.

Eddy current loss (We) occurs due to the flow of eddy currents in the laminations of the core. These eddy currents are induced in the laminations because the alternating flux produced by the primary winding links them. These eddy currents flow in a circular path and cause power loss in the core and heats up the core of the transformer.



$$\boxed{W_e = \beta B_m^2 f^2 t^2 V^2 \text{ watts}}$$

$B_m \rightarrow$ Maximum flux density in the core (Wb/m^2)
$f \rightarrow$ Frequency (Hz)
$t \rightarrow$ thickness of lamination (m)
$V \rightarrow$ Volume of the core (m^3)
$\beta \rightarrow$ Constant whose value depends on the quality of the magnetic material used for core.

To Reduce eddy current losses, the core is made of thin laminations of high permeability magnetic material such as silicon steel and they are insulated from one another by coating them with varnish.

The Hysteresis loss (Wh) occurs because the core of the transformer is subjected to cycles of magnetization.

$$\boxed{W_h = \eta B_m^{1.6} f V \text{ watts}}$$

$\eta \rightarrow$ constant whose value depends on the quality of the magnetic material used for making the core.

$$\boxed{W_i = W_e + W_h}$$

We observe that the iron loss depends upon B_m and frequency. All the other quantities like the thickness of laminations, volume of the core are constants. We also know that the flux in the core of the transformer is almost constant as long as supply voltage V_1 is always constant.

$\therefore$ Iron / Core losses in the transformer are considered to be constant losses

(ii) COPPER LOSS (W_{cu}) : These losses occur due to the power consumed by the resistances R_1 & R_2 of the primary and secondary windings.

Total copper loss $(W_{cu}) = I_1^2 R_1 + I_2^2 R_2$

$$= I_1^2 (R_1 + R_2') = I_1^2 R_{01}$$

$$\text{or} = I_2^2 (R_2 + R_1') = I_2^2 R_{02}$$

We observe that $(W_{cu}) \propto I_2^2$. At full load, I_{2FL} flows through the windings, hence we obtain full-load copper loss $(W_{cu})_{FL}$. Similarly copper losses at half load will be lesser than $(W_{cu})_{FL}$. Hence W_{cu} is termed as variable losses.

$$\boxed{\text{TOTAL LOSS IN A TRANSFORMER} = W_i + W_{cu}}$$