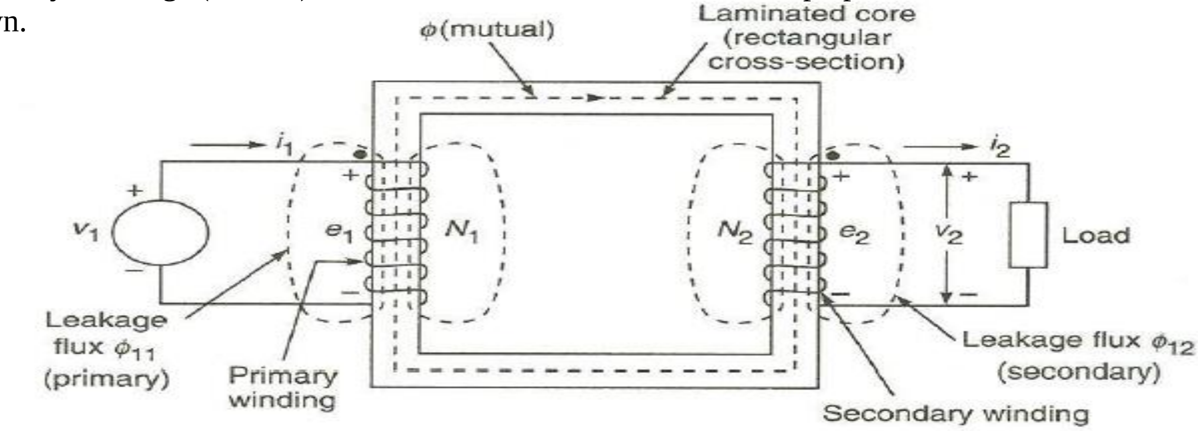
UNIT- 2nd :- Transformer

Transformer is a static piece of apparatus that transfer electric energy from one circuit to another circuit keeping power and frequency constant.

Working Principle of a transformer:-

The basic principle of a transformer is electromagnetic induction. It consists of two separate windings placed over the laminated silicon steel core. The winding to which ac supply is connected is called primary winding and the winding to which load is connected is called a secondary winding. When ac supply of voltage v_1 is connected to primary winding, an alternating flux is set up in the core. This alternating flux when links with secondary winding, an emf is induced in it and is called mutually induced emf. The direction of this induced emf is opposite to the applied voltage v_1. The same alternating flux also links with the primary winding and produces self-induced emf e_1. Although there is no electrical connection between primary and secondary winding, but electrical power is transferred from primary circuit to the secondary circuit through mutual flux. The induced emf in the primary and secondary winding depends upon the rate of change of flux linkages (i.e. $N\, d\phi/dt$). The rate of change of flux ($d\phi/dt$) is same for both primary and secondary. Therefore, the induced emf in the primary is proportional to number of turns of the primary winding ($e_1 \propto N_1$) and in the secondary it is proportional to the number of turns of the secondary windings ($e_2 \propto N_2$). In case $N_2 > N_1$ the transformer is step up and in case $N_2 < N_1$ the transformer is step down.



Construction of 1ϕ Transformer :-

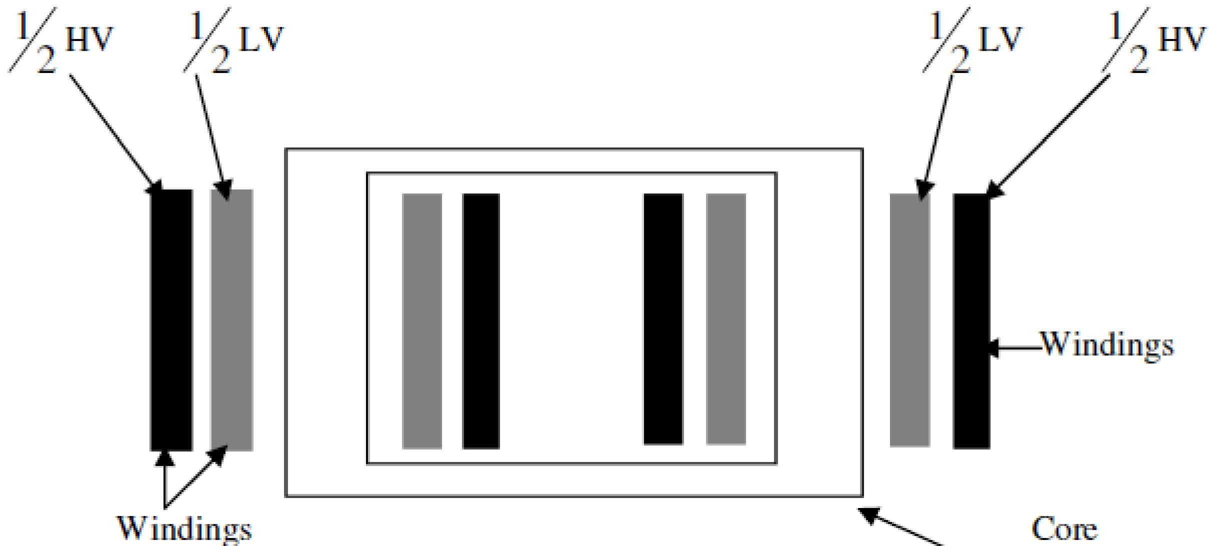
The Transformer either 1ϕ or 3ϕ , mainly consist of following

1) **Magnetic circuit :-** It consist of Limbs(core) , yokes and clamping structures that provide the flux path
2) **Electric Circuit :-** It consist of low voltage and High voltage winding.
3) **Dielectric circuit :-** It consist of insulation in different forms and used at different places of the transformer such as between core to LV winding and LV to HV winding.
4) **Tank & Accessories**

- **Magnetic circuit :-** Magnetic circuit of transformer consist of cores and yokes.This circuit provides the path to flow of Magnetic flux.The magnetic frame i.e. Core and Yokes are made up of laminated electro-technic steel consisiting of 3 to 4% silicon. Silicon content in the steel increases its resistivity to eddy current and thereby reduces eddy current losses. The steel get brittle if silicon content is increased beyond 4% .To reduce eddy current losses further the thickness of the lamination should be 0.3 to 0.5 mm. Various laminations are insulated from each other by a very thin coat of varnish.

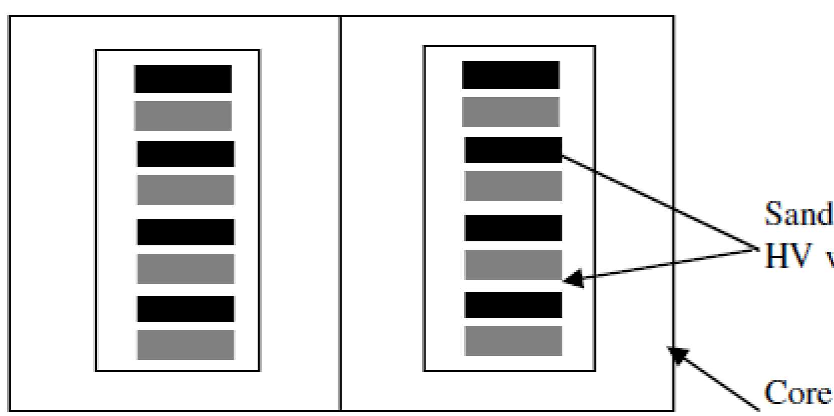
Depending on the Magnetic circuit transformers are

1) **Core Type Transformer :-** core type of construction, the LV and HV coils are interleaved to reduce the leakage flux. Half of LV and half HV are wound on each limb of the core type transformer. For economical insulation, the LV coils are placed next to the core and HV coils are placed on the outside



CORE TYPE

2) **Shell Type Transformer :-** In the shell type transformer reduced leakage flux is obtained by sandwiching the LV and HV coils. The LV coils are sandwiched between the sections of the HV coil. Both the coils are placed on the central limb of the core.



SHELL TYPE

Electric Circuit :- Electric circuit of Transformer mainly consist of Primary & Secondary winding Usually made of Copper and may be made by aluminium as well.Although Aluminium is cheaper but the difference in cost is counterbalance by high cost of extras required. Small transformer with aluminium winding will be cheaper whereas the large transformer with copper winding will be cheaper.

Dielectric circuit:- The dielectric consist of insulation used at different places in the transformer to insulate the conducting parts. All the conducting part & magnetic part should be well insulated from each other. Core & low voltage winding(LV) and Low & High voltage (LV & HV) winding , are insulated by cylinder of paper , bakelite or press board.

Tank & Accessories:-

The assembled transformer with magnetic frame & winding is housed in proper tank, that contains transformer oil, use for cooling various parts of transformer. Small transformer are air cooled & lower fire over the transformer whereas the large transformer are oil cooled .Oval or circular tubes are also attached with the body of tank for circulation of oil.

Some accessories are

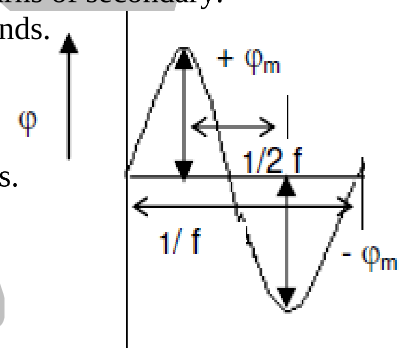
Breather:- A breather mounted on transformer tank contains calcium chloride or silica gel, which has tendency to extract moisture from air and oil as well.

Bushings:- Transformers are connected to high-voltage lines. Extreme care is required to prevent flashover from the high-voltage connection to earthed bank. Bushings are used to insulate and bring out terminals of the winding from the container to the external circuit. For transformers upto 33 kV, this is achieved by using bushings of porceling around the conductor at the point of entry. For transformers above 33 kV, either oil-filled or capacitor-type bushings are used.

EMF Equation of Transformer :-

When a sinusoidal voltage is applied to the primary winding of a transformer, a sinusoidal flux as shown in the fig. is set up in the iron core which links with the primary and secondary winding. Let ϕ_m = maximum value of flux in wb, f = supply frequency in Hz. N_1= No. of turns of the primary and N_2 = No. of turns of secondary.

As shown in the fig. the flux changes from + ϕ_m to - ϕ_m in half a cycle ie. 1/2f seconds.



Average rate of change of flux = $\dfrac{\emptyset_m - (-\emptyset_m)}{1/_2 f}$ = 4 ϕ_m f wb/s

Now, the rate of change of flux per turn is the average induced emf per turn in volts.

Therefore, average induced emf / turn = 4 ϕ_m f volts.

For a sinusoidal wave, R.M.S. value / Average value = Form factor = 1.11

Therefore, R.M.S. value of emf induced / turn, E = 1.11 X 4 ϕ_m f volts.

Therefore, R.M.S. value of emf induced in primary,

E_1 = (emf induced/ turn) X No. of primary turns. = 4.44 f ϕ_m N_1 volts. = 4.44 N_1 f B_m A_i

Similarly R.M.S. value of emf induced in secondary,

E_2 = (emf induced/ turn) X No. of secondary turns. = 4.44 f ϕ_m N_2 volts. = 4.44 N_2 f B_m A_i

Transformer Ratio :-

- Transformer ratio is defined as the ratio Secondary emf to primary winding emf.
- Transformer is also the ratio number of turn in secondary coil to no. of turn in primary coil.
- $$K = \frac{E_S}{E_P} = \frac{N_S}{N_P} = \frac{I_P}{I_S}$$
- For Ideal transformer Ep Ip = Es Is or Vp Ip = Vs Is (Vp ≈Ep & Vs ≈Es)
- If K >1 ; Step Up transformer (Ns > Np)
- If K<1 ; Step Down transformer (Ns < Np)
- If K = 1 ; Uni-ratio Transformer

- The number of turn in each winding is always a whole number.Each winding in core type transformer is accommodated on both the limbs ,half number of turn of each winding on one limb. Hence the no. of tuen in each winding is even.

Q.1) A 1ϕ Transformer has 350 primary and 1050 secondary turns. The area of the cross section of the core is 55cm^2**.** If primary winding is supplied with 400 V,50Hz supply.Calculate emf induced in the secondary winding. Also find the maximum flux density.

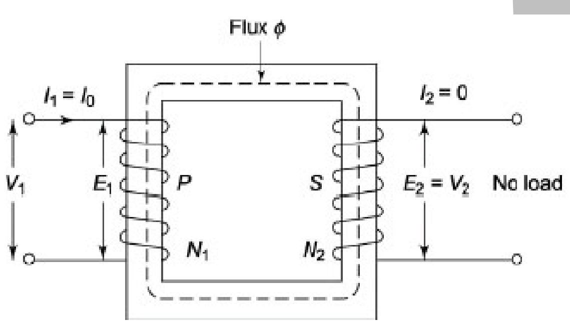
(**Ans.** :- 1200v , 0.93 Tesla or Wb/m^2)

Q.2) The required no load voltage ratio in a 1ϕ , 50 Hz , core type Transformer is 6600 / 500. Find the number of turns in each winding , if the flux is to be 0.06 Wb.

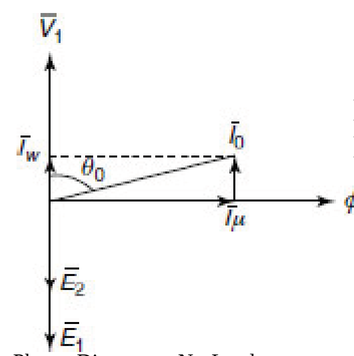
(Ans. :- Ns = 38 not 37.5 , Np = 500 not 501.6**)**

Transformer at no Load Condition

- When the transformer is at no load condition very small current i.e. 2 to 5% of rated current called no load current flows through the primary winding. No load current has 2 components magnetizing component (I_μ) and working component (I_w).
- Magnetizing component (I_μ) is responsible to set flux ϕ_0 in the high permeability core and hence as shown in Phasor diagram, I_m is in phase with the flux
- working component (I_w) the power to losses occur in transformer and in the phasor diagram it is in phase with the applied voltage**.**



Equivalent Circuit of Transformer at No-load



Phasor Diagram at No-Load

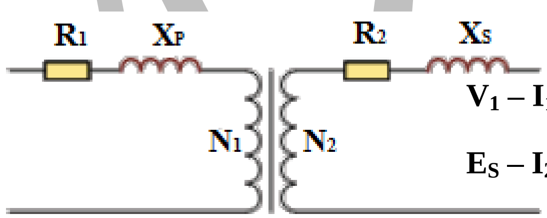
$I_w = I_0 \cos \phi_0$

$I_\mu = I_0 \sin \phi_0$

$$I_0 = \sqrt{I_w^2 + I_\mu^2}$$

$$\theta_0 = \tan^{-1}\left(\frac{I_\mu}{I_w}\right)$$

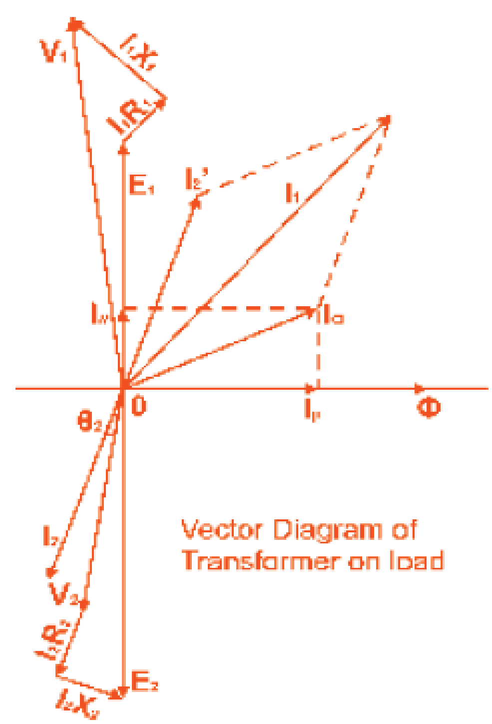
Transformer on Load Condition



Actual Transformer

$V_1 - I_1R_1 - I_1X_P = E_P$ 1)

$E_S - I_2 R_2 - I_2 X_2 = V_2$ 2)



- When the transformer is at no load , very small current I_0 flow through the primary coil . MMF N_1 I_0 set the flux ϕ_0 in the core.
- If this flux is linked with primary winding EMF E_1 is induced and if it is linked with the secondary winding the EMF E_2 is induced .
- When the transformer is loaded the current I_2 starts flowing through the secondary winding of the transformer. MMF N_2 I_2 sets the flux ϕ_s which opposes the main flux ϕ_0 and consequently weakens it.
- But transformer is a constant flux device, so to maintain its flux constant it draws some additional current I_p from the source. The magnitude of I_p is such that N_1 I_p is equal to N_2 I_2 . The direction of I_p opposite to that of the direction of I_2 .