SUBJECT- ELECTRICAL MACHINE-1

EE 4^{TH} SEM

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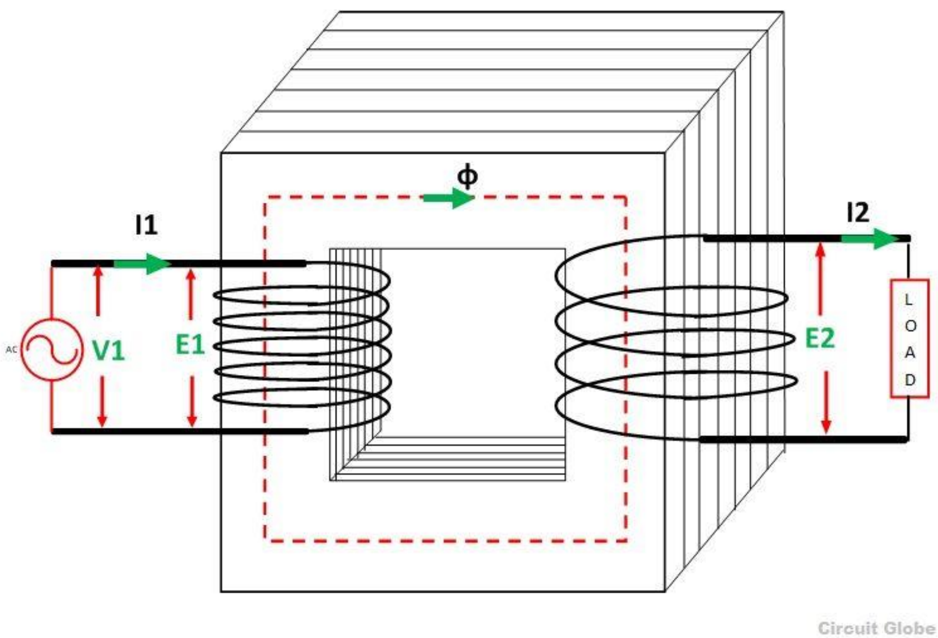
TOPIC NAME TRANSFORMERS AND IT'S TYPES, & EMF EQUATION

TRANSFORMER Electrical transformer is a static electrical machine which transforms electrical power from one circuit to another circuit, without changing the frequency. Transformer can increase or decrease the voltage with corresponding decrease or increase in current.

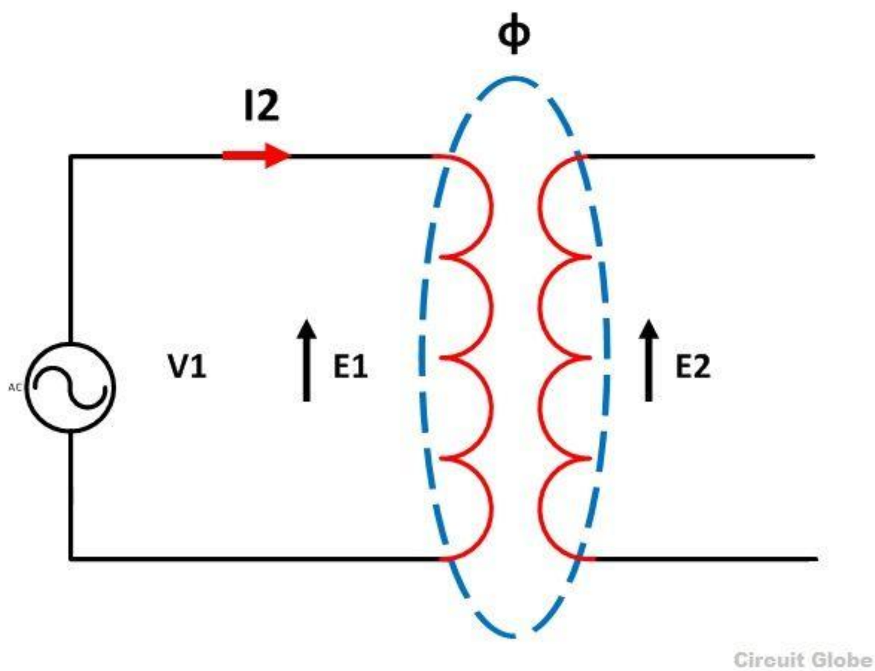
Working principle of transformer

The basic principle on which the transformer works is Faraday's Law of Electromagnetic Induction or mutual induction between the two coils. The working of the transformer is explained below. The transformer 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 to which load is connected is called secondary winding as shown in the figure below. It works on the alternating current only because an alternating flux is required for mutual induction between the two windings.



When the AC supply is given to the primary winding with a voltage of V_1, an alternating flux ϕ sets up in the core of the transformer, which links with the secondary winding and as a result of it, an emf is induced in it called Mutually Induced emf. The direction of this induced emf is opposite to the applied voltage V_1, this is because of the Lenz's law shown in the figure below:



Physically, there is no electrical connection between the two windings, but they are magnetically connected. Therefore, the electrical power is transferred from the primary circuit to the secondary circuit through mutual inductance.

Transformer on DC supply

As discussed above, the transformer works on AC supply, and it cannot work not DC supply. If the rated DC voltage is applied across the primary winding, a constant magnitude flux will set up in the core of the transformer and hence there will not be any self-induced emf generation, as for the linkage of flux with the secondary winding there must be an alternating flux required and not a constant flux.
According to Ohm's Law

$$\text{Primary Current} = \frac{\text{DC applied voltage}}{\text{Resistance of primary winding}}$$

The resistance of the primary winding is very low, and the primary current is high. So this current is much higher than the rated full load primary winding current. Hence, as a result, the amount of heat produced will be greater and therefore, eddy current loss (I^2R) loss will be more.
Because of this, the insulations of the primary windings will get burnt, and the transformer will get damaged.

Turn Ratio

It is defined as the ratio of primary to secondary turns.

$$\text{Turn ratio} = \frac{N_1}{N_2}$$

If $N_2 > N_1$ the transformer is called Step-up transformer
If $N_2 < N_1$ the transformer is called Step down transformer

Transformation Ratio

The transformation ratio is defined as the ratio of the secondary voltage to the primary voltage. It is denoted by K.

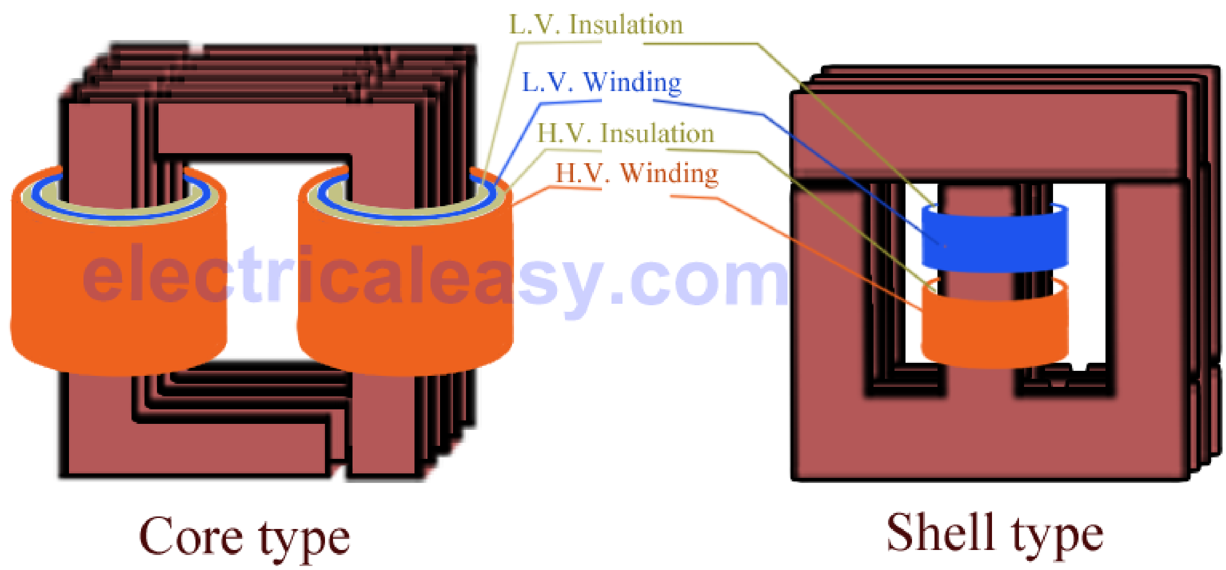
$$K = \frac{E_2}{E_1} = \frac{N_2}{N_1}$$

As ($E_2 \propto N_2$ and $E_1 \propto N_1$)

Types of transformers

Transformers can be classified on different basis, like types of construction, types of cooling etc.

(A) On the basis of construction, transformers can be classified into two types as; (i) Core type transformer and (ii) Shell type transformer, which are described below.



(i) ***Core type transformer***
In core type transformer, windings are cylindrical former wound, mounted on the core limbs as shown in the figure above. The cylindrical coils have different layers and each layer is insulated from each other. Materials like paper, cloth or mica can be used for insulation. Low voltage windings are placed nearer to the core, as they are easier to insulate.

(ii) ***Shell type transformer***
The coils are former wound and mounted in layers stacked with insulation between them. A shell type transformer may have simple rectangular form (as shown in above fig), or it may have a distributed form.

On the basis of their purpose

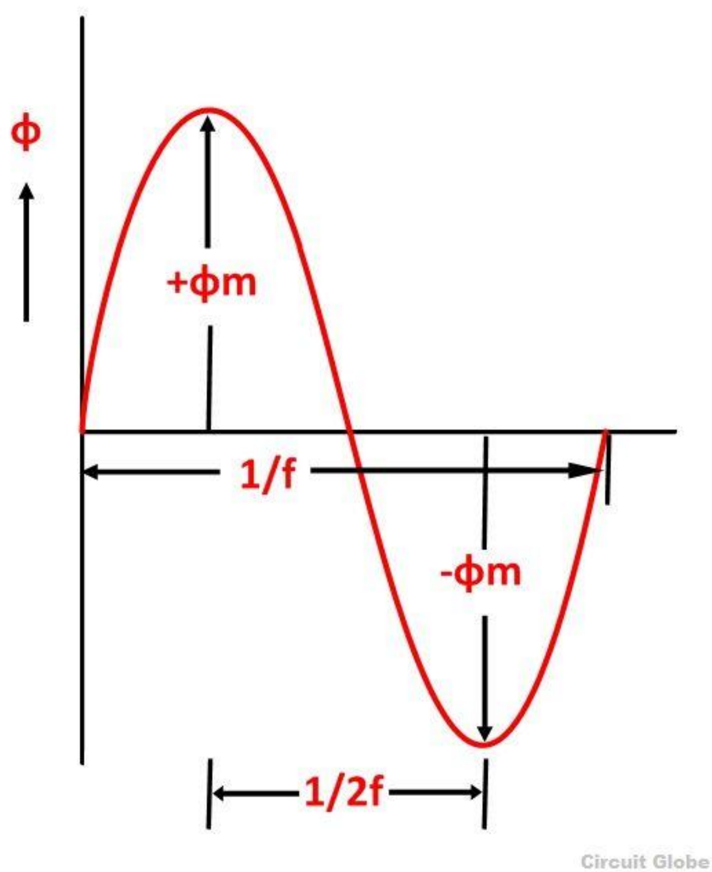
- **Step up transformer:** Voltage increases (with subsequent decrease in current) at secondary.
- **Step down transformer:** Voltage decreases (with subsequent increase in current) at secondary.
- Instrument transformer: Used in relay and protection purpose in different instruments in industries
    - **Current transformer (CT)**
    - **Potential transformer (PT)**

EMF Equation of a Transformer

When a sinusoidal voltage is applied to the primary winding of a transformer, alternating flux ϕ_m sets up in the iron core of the transformer. This sinusoidal flux links with both primary and secondary winding. The function of flux is a sine function.
The rate of change of flux with respect to time is derived mathematically.
The derivation of the EMF Equation of the transformer is shown below. Let

- ϕ_m be the maximum value of flux in Weber
- f be the supply frequency in Hz
- N_1 is the number of turns in the primary winding
- N_2 is the number of turns in the secondary winding

Φ is the flux per turn in Weber



As shown in the above figure that the flux changes from + ϕ_m to – ϕ_m in half a cycle of 1/2f seconds.
By Faraday's Law

Let E_1 be the emf induced in the primary winding

$$E_1 = -\frac{d\psi}{dt} \dots\dots\dots(1)$$

Where $\Psi = N_1\phi$

$$\text{Therefore, } E_1 = -N_1 \frac{d\varphi}{dt} \dots\dots\dots(2)$$

Since ϕ is due to AC supply $\phi = \phi_m$ Sinwt

$$E_1 = -N_1 \frac{d}{dt} (\varphi_m \, \mathrm{Sinwt})$$

$$E_1 = -N_1 \, w\varphi_m \, \mathrm{Coswt}$$

$$E_1 = N_1 w\varphi_m \, \mathrm{Sin}(wt - \pi/2) \dots\dots\dots.(3)$$

$$E_1 max = N_1 w\varphi_m \dots\dots\dots.(4)$$

But $w = 2\pi f$

$$E_1 max = 2\pi f N_1 \varphi_m \dots\dots\dots.(5)$$

Root mean square RMS value is

$$E_1 = \frac{E_{1max}}{\sqrt{2}} \dots\dots\dots..(6)$$

Putting the value of E_1max in equation (6) we get

$$E_1 = \sqrt{2}\pi f N_1 \varphi_m \dots\dots..(7)$$

Putting the value of $\pi = 3.14$ in the equation (7) we will get the value of E_1 as

$$E_1 = 4.44 f N_1 \varphi_m \dots\dots\dots(8)$$

Similarly

$$E_2 = \sqrt{2}\pi f N_2 \varphi_m$$

Or

$$E_2 = 4.44 f N_2 \varphi_m \dots\dots\dots (9)$$

Now, equating the equation (8) and (9) we get

$$\frac{E_2}{E_1} = \frac{4.44 f N_2 \varphi_m}{4.44 f N_1 \varphi_m}$$

Or

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

The above equation is called the turn ratio where K is known as the transformation ratio.
The equation (8) and (9) can also be written as shown below using the relation
($\phi m = B_m \times A_i$) where A_i is the iron area and B_m is the maximum value of flux density.

$$E_1 = 4.44 N_1 f B_m A_i \text{ Volts} \quad \text{and} \quad E_2 = 4.44 N_2 f B_m A_i \text{ Volts}$$

$$\frac{\text{R.M.S value}}{\text{Average value}} = \text{Form factor} = 1.11$$

For a sinusoidal wave
Here 1.11 is the form factor.