Basic Electrical Engineering

Module – 04: AC Machines

Transformer

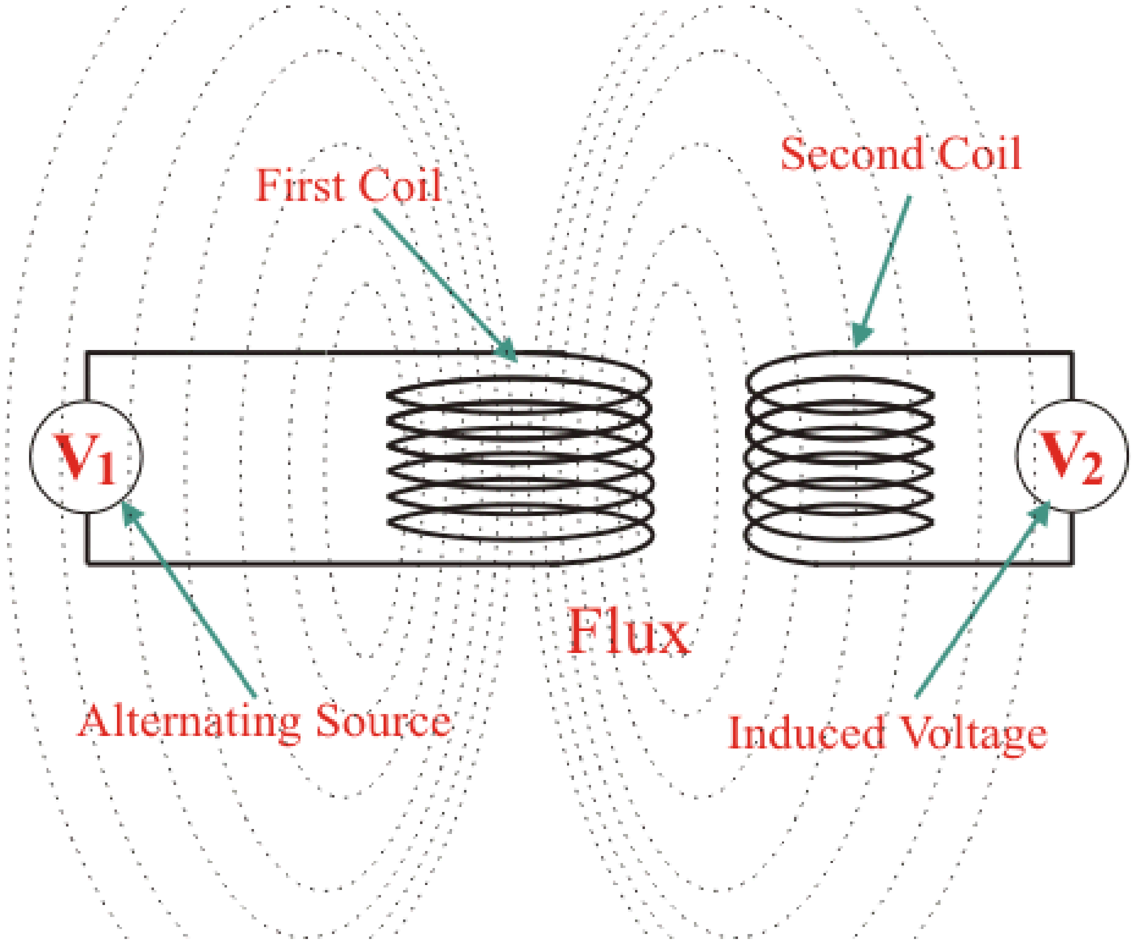
Transformers

Introduction

- A transformer is a static machine used for transforming power from one circuit to another without changing frequency.
- It can raise or lower the voltage or current in an ac circuit.
- It can isolate circuits from each other.
- The transformer enables us to transmit electrical energy over great distances.
- Since, there is no rotating or moving part, so a transformer is a static device.
- Transformer operates on an ac supply.
- A transformer works on the principle of mutual induction.

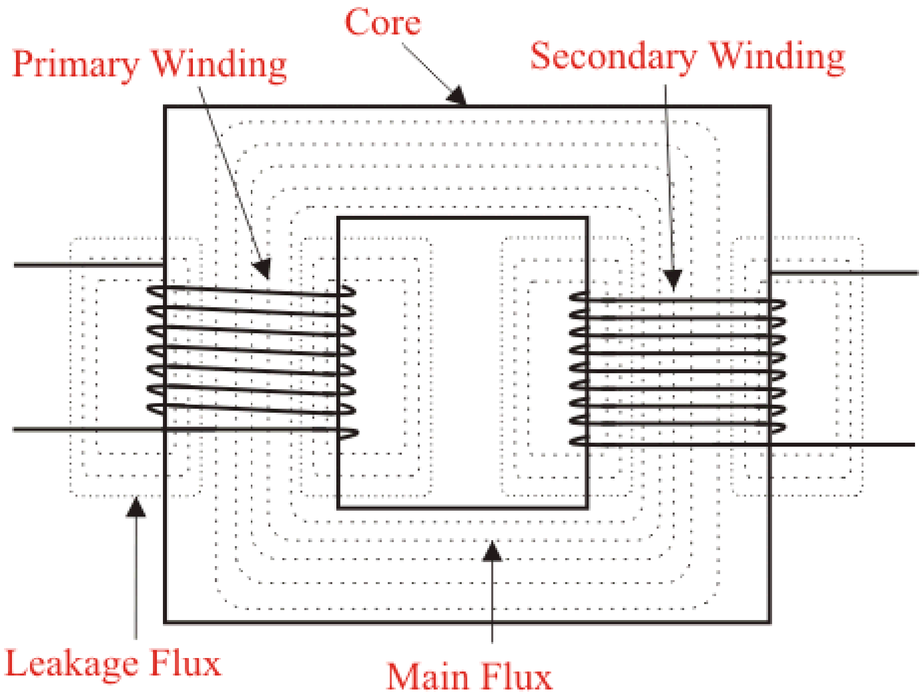
Mutual induction

- The alternating current through the winding produces a continually changing and alternating flux that surrounds the winding.
- If another winding is brought close to this winding, some portion of this alternating flux will link with the second winding.
- As this flux is continually changing in its amplitude and direction, there must be a changing flux linkage in the second winding or coil.
- According to Faraday's law of electromagnetic induction, there will be an EMF induced in the second winding.
- If the circuit of this secondary winding is closed, then a current will flow through it.

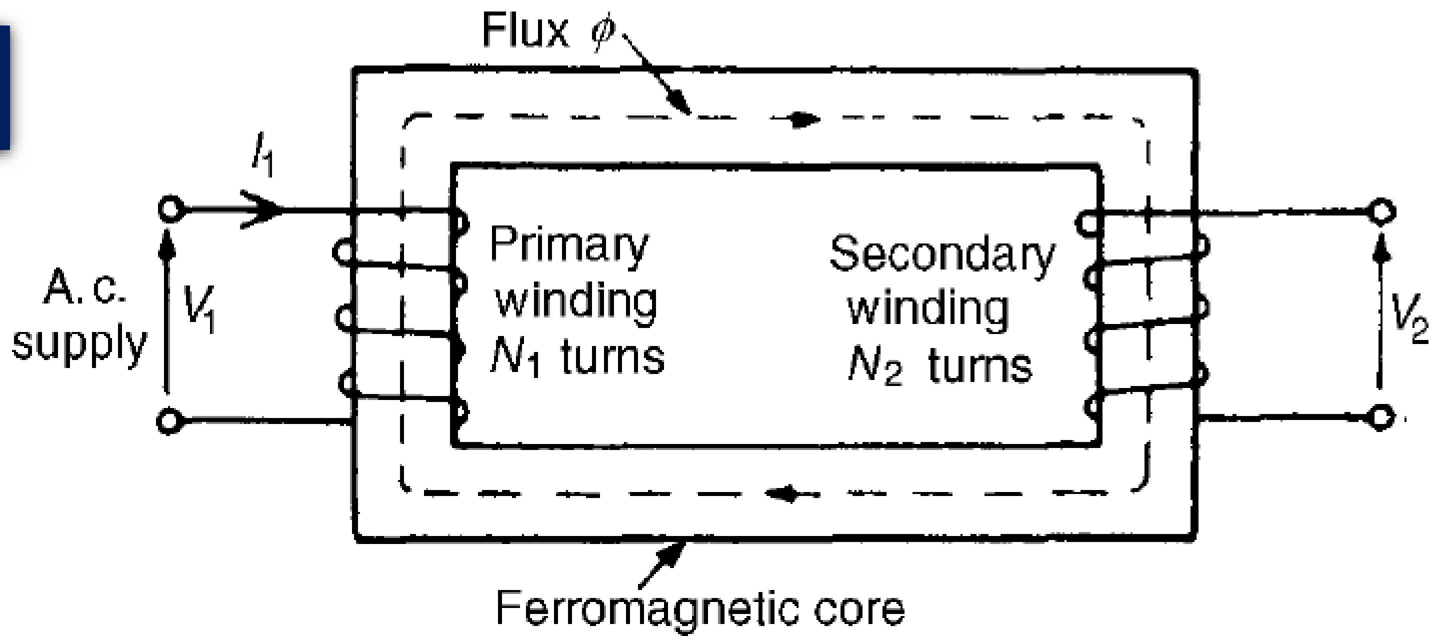


Transformers

- The winding which receives electrical power from the source is known as the ‘primary winding’.
- The winding which gives the desired output voltage due to mutual induction is commonly known as the ‘secondary winding’.
- A transformer that increases voltage between the primary to secondary windings is defined as a step-up transformer.
- A transformer that decreases voltage between the primary to secondary windings is defined as a step-down transformer.
- Whether the transformer increases or decreases the voltage level depends on the relative number of turns between the primary and secondary side of the transformer.
- The purpose of the transformer core is to provide a low reluctance path, through which the maximum amount of flux produced by the primary winding is passed through and linked with the secondary winding.



Principle of Operation



- When the secondary is open-circuit and an alternating voltage V_1 is applied to the primary winding, a small current called the no-load current I_0 flows, which sets up a magnetic flux in the core.
- This alternating flux links with both primary and secondary windings and induces in them e.m.f.'s of $E1$ and $E2$

The induced e.m.f. *E* in a coil of *N* turns is given by

$$E = -N\frac{d\varphi}{dt}$$

Transformers

Principle of Operation

❖ In an ideal transformer, the rate of change of flux is the same for both primary and secondary and thus

$$E_1 = -N_1 \frac{d\varphi}{dt} \qquad E_2 = -N_2 \frac{d\varphi}{dt}$$

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

i.e. the induced e.m.f. per turn is constant

❖ Assuming no losses, $\boldsymbol{E_1} = \boldsymbol{V_1}$ ***and*** $\boldsymbol{E_2} = \boldsymbol{V_2}$. Hence

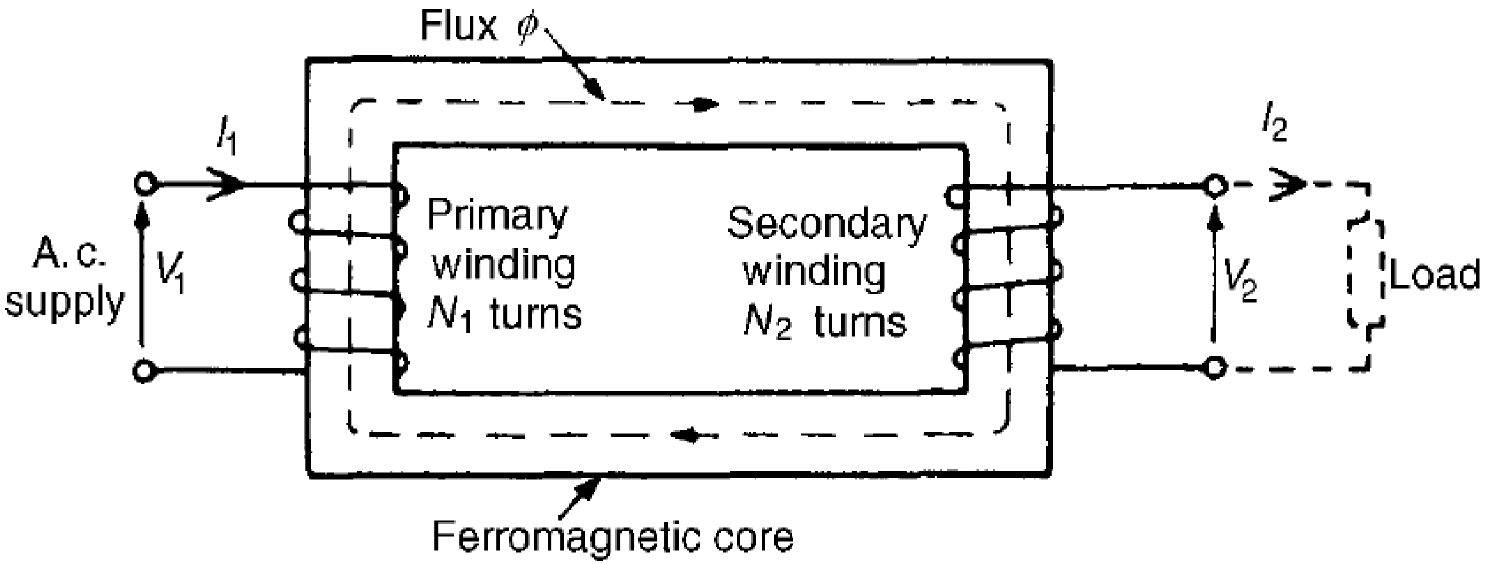
$$\boldsymbol{\frac{V_2}{V_1} = \frac{N_2}{N_1}}$$

❖ V_2/V_1 is called the voltage ratio and N_2/N_1 the turns ratio, or the 'transformation ratio' of the transformer.

❖ If N_2 is less than N_1 then V_2 is less than V_1 and the device is termed as step down transformer.

❖ If N_2 is greater then N_1 then V_2 is greater than V_1 and the device is termed as step-up transformer.

Principle of Operation



- When a load is connected across the secondary winding, a current I_2 flows. In an ideal transformer losses are neglected and a transformer is considered to be 100% efficient.

input power = output power

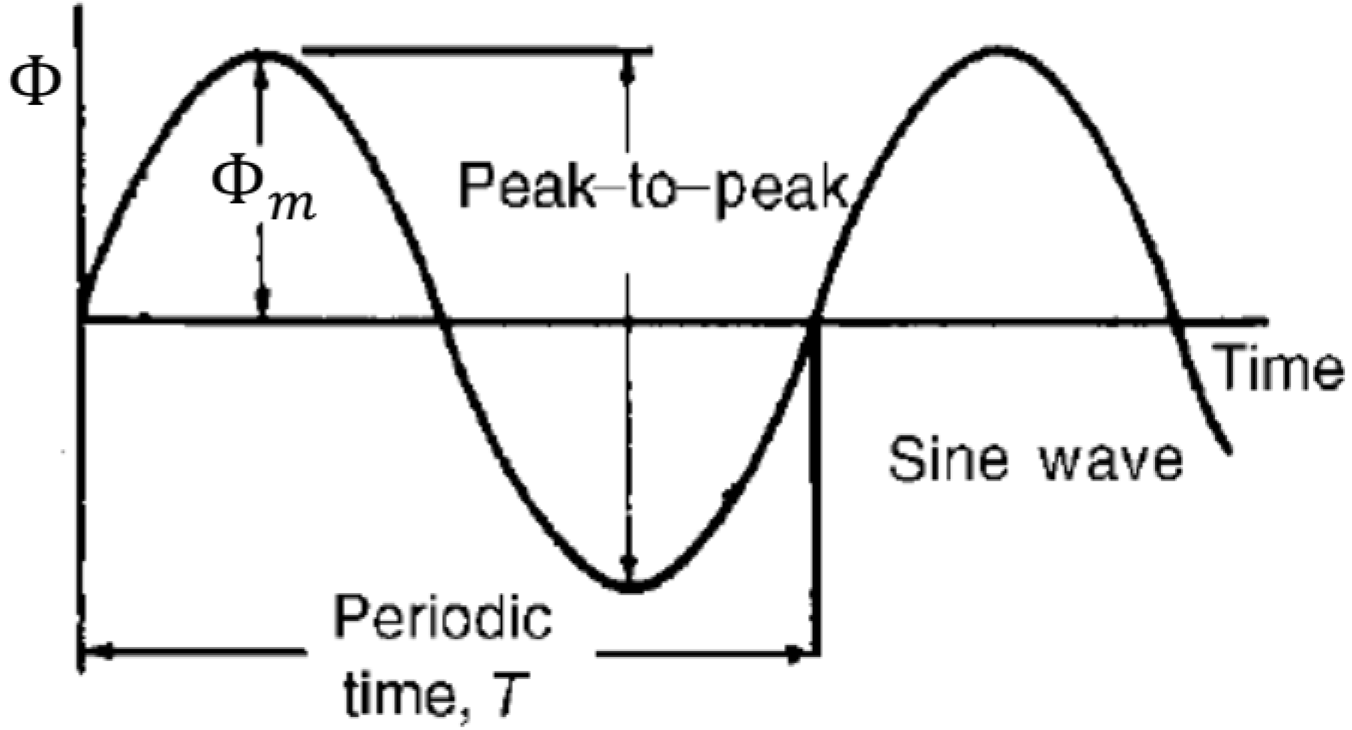
$$V_1 I_1 = V_2 I_2$$

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

$$\boxed{\frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}}$$

E.m.f. equation of a transformer

The magnetic flux Φ set up in the core of a transformer when an alternating voltage is applied to its primary winding is also alternating and is sinusoidal.



Let Φ_m be the maximum value of the flux. The time for 1 cycle of the alternating flux is the periodic time T, where $T = 1/f$ seconds and f is the frequency of the supply.

E.m.f. equation of a transformer

The flux rises sinusoidally from zero to its maximum value in $\frac{1}{4}$ cycle, and the time for $\frac{1}{4}$ cycle is 1/4f seconds.

Hence the average rate of change of flux $= \dfrac{\Phi_m}{(1/4f)} = 4f\Phi_m$ Wb/s, and since 1 Wb/s = 1 volt, the average e.m.f. induced in each turn = $4f\Phi_m$ volts.

As the flux Φ varies sinusoidally, a sinusoidal e.m.f. will be induced in each turn of both primary and secondary windings. For a sine wave,

$$\boxed{\text{Form factor} = \frac{\text{rms value}}{\text{average value}}}$$

The values of form factor give an indication of the shape of waveforms.

E.m.f. equation of a transformer

$$\text{Hence } rms\ value = \ form\ factor\ *\ average\ value$$

$$= 1.11 * average\ value$$

$$\text{Thus rms e.m.f. induced in each turn} = \ 1.11\ * 4f\Phi_m \text{ volts}$$

$$= 4.44f\Phi_m \text{ volts}$$

Therefore, rms value of e.m.f. induced in primary,

$$E_1 = 4.44f\Phi_m N_1 \text{volts}$$

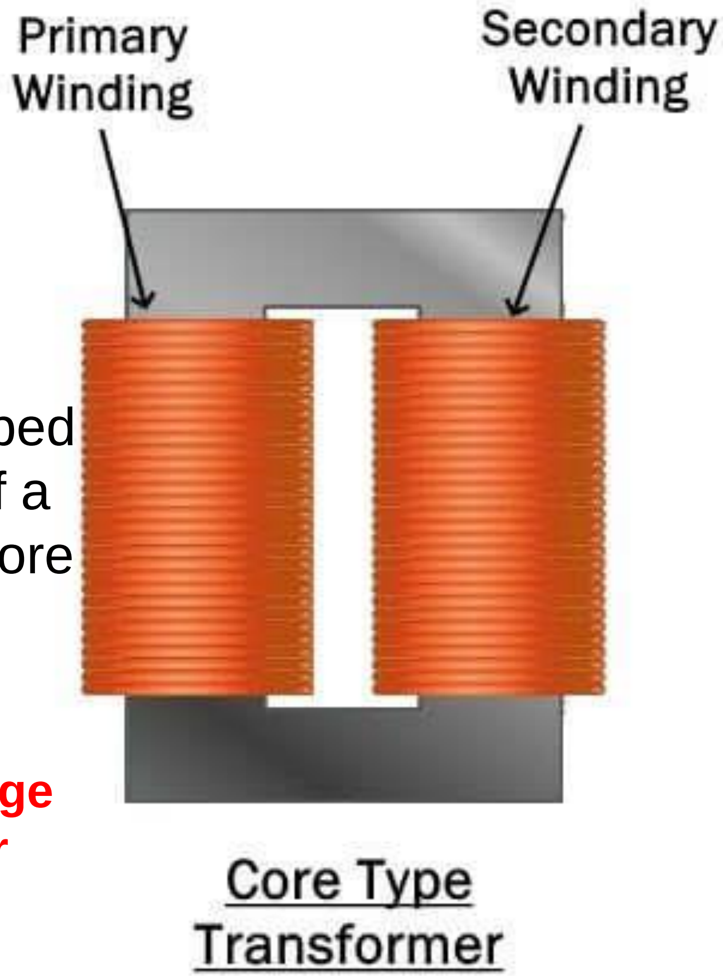
and rms value of e.m.f. induced in secondary,

$$E_2 = 4.44f\Phi_m N_2 \text{volts}$$

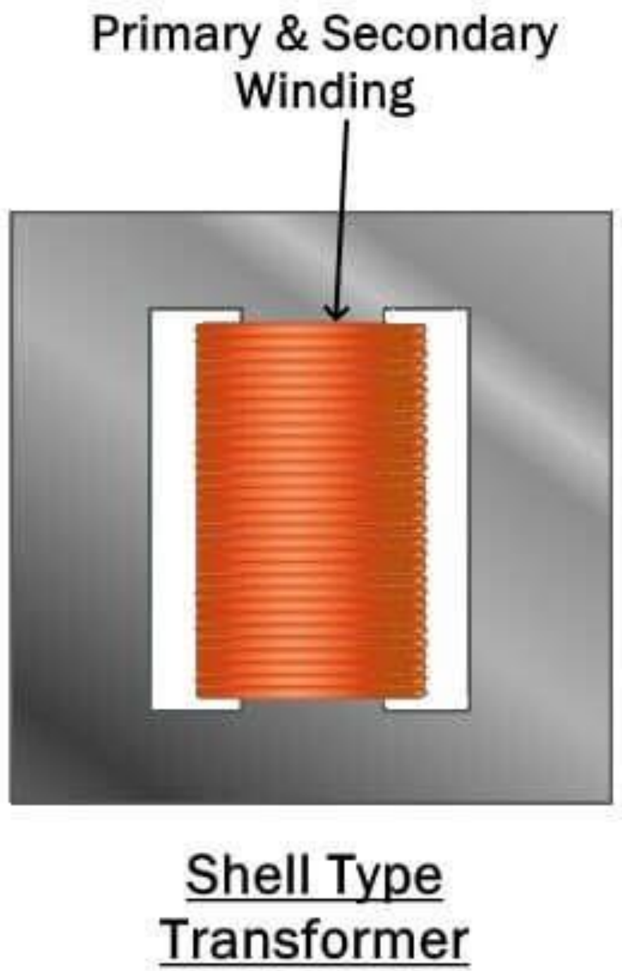
$$\boxed{\frac{E_2}{E_1} = \frac{N_2}{N_1}}$$

Type of Transformer

Windings are wrapped around two side of a laminated square core



For Low Voltage Transformer



Windings are wrapped around the center leg of the laminated core

For High Voltage Transformer

Losses in transformer

- ❖ In any electrical machine, 'loss' can be defined as the difference between input power and output power.
- ❖ An electrical transformer is an static device. Hence mechanical losses (like windage or friction losses) are absent in it.
- ❖ A transformer only consists of electrical losses (iron losses and copper losses).

Transformer Losses

- **Iron or Core Loss**
  - **Hysteresis loss**
  - **Eddy current loss**
- **Copper Loss**

❖ Copper loss is due to ohmic resistance of the transformer windings.

❖ Copper loss for the primary winding is $I_1^2R_1$ and for secondary winding is $I_2^2R_2$.

❖ Where, I_1 and I_2 are current in primary and secondary winding respectively, R_1 and R_2 are the resistances of primary and secondary winding respectively.

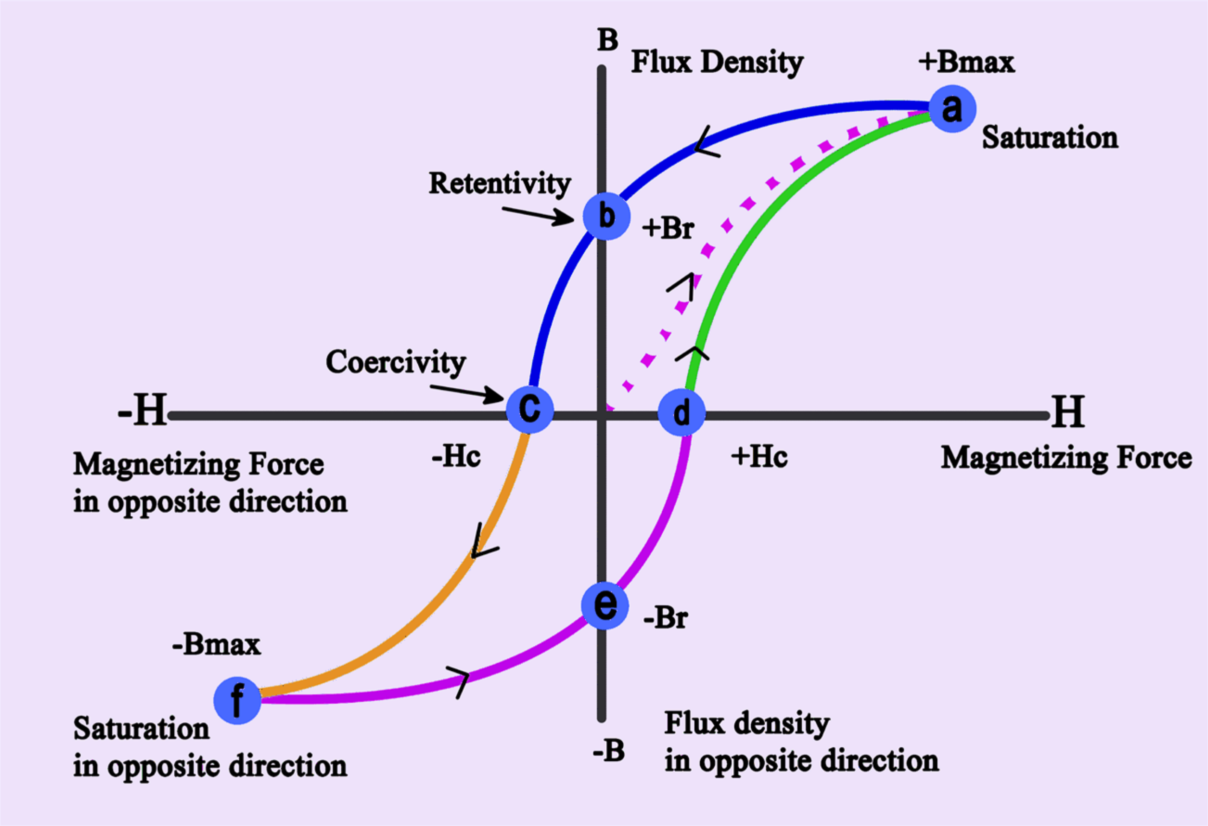
❖ Copper loss in transformer varies with the load.

Losses in transformer

Core losses or Iron losses

- Eddy current loss and hysteresis loss depend upon the magnetic properties of the material used for the construction of core. Hence these losses are also known as core losses or iron losses.

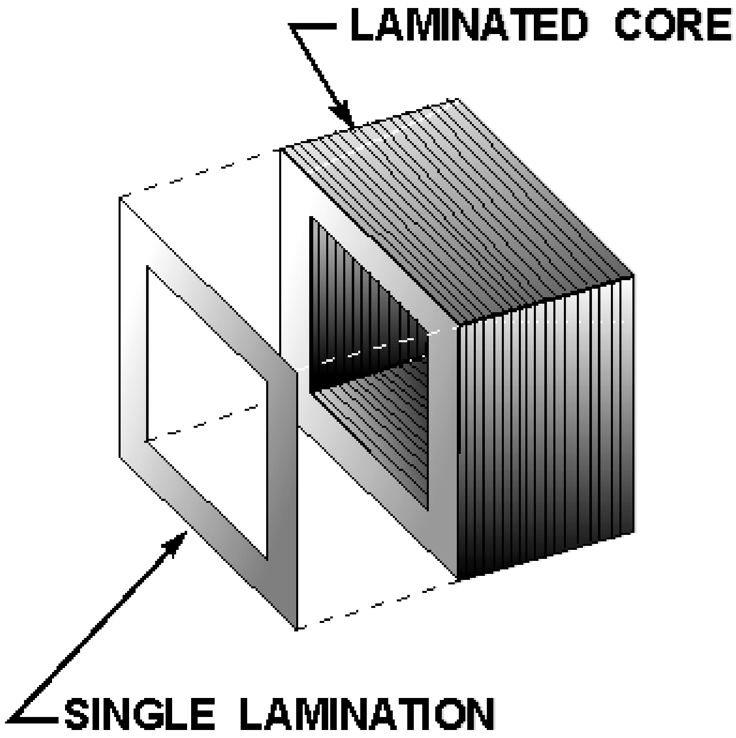
- **Hysteresis loss in transformer:**
  - Hysteresis loss is due to reversal of magnetization in the transformer core.
  - This loss depends upon the volume and grade of the iron, frequency of magnetic reversals and value of flux density.
  - The loss is proportional to the area of the hysteresis loop and thus low loss nickel iron alloys are used for the core since their hysteresis loops have small areas



Losses in transformer

Core losses or Iron losses

- Eddy current loss and hysteresis loss depend upon the magnetic properties of the material used for the construction of core. Hence these losses are also known as core losses or iron losses.
- **Eddy current loss in transformer:**
  - Eddy current loss is due to e.m.f. being induced not only in the transformer windings but also in the core.
  - These induced e.m.f.'s set up circulating currents, called eddy currents.
  - Owing to the low resistance of the core, eddy currents can be quite considerable and can cause a large power loss and excessive heating of the core.
  - Eddy current losses can be reduced by increasing the resistivity of the core material or, more usually, by laminating the core



Efficiency of Transformer

- **Efficiency of a transformer** can be defined as the output power divided by the input power.

$$\textbf{Transformer Efficiency, }\eta = \frac{Output}{Input}$$

- Transformers are the most highly efficient electrical devices. Most of the transformers have full load efficiency between 95% to 98.5% .
- As a transformer being highly efficient, output and input are having nearly same value, and hence it is impractical to measure the efficiency of transformer by using output / input.
- A better method to find efficiency of a transformer is using,

$$\textbf{Transformer Efficiency, }\eta = \frac{Input\ Power - Losses}{Input\ Power}$$

Thank You !