Unit-3

Looses and Other Transformer

Recap POLL

- For Core material selection ,the Reluctance of the material should be

A)High

B)Low

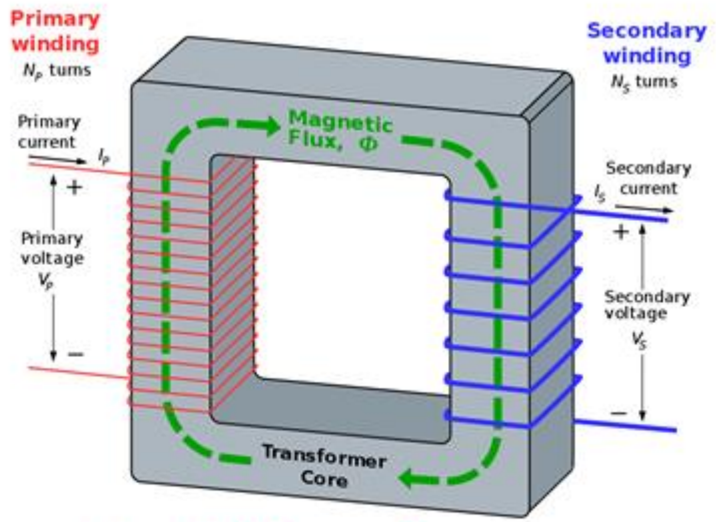
C)Infinite

D)None of the above

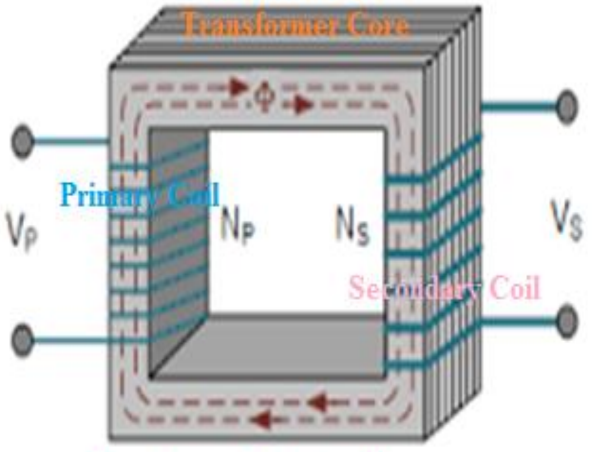
Characteristics/Conditions for an Ideal Transformer

1. Resistance of primary as well as secondary winding of an ideal transformer is **zero**. That is, both the coils are purely inductive in nature.
2. Leakage flux is a part of magnetic flux which does not get linked with secondary winding. In an ideal transformer, it is assumed that entire amount of flux get linked with secondary winding (that is, no leakage flux).
3. An ideal transformer does not have any losses like hysteresis loss, eddy current loss etc. So, the output power of an ideal transformer is exactly equal to the input power. Hence, 100% efficiency.
4. Higher the permeability, lesser the mmf required for flux establishment. That means, if permeability is high, less magnetizing current is required to magnetize the transformer core.

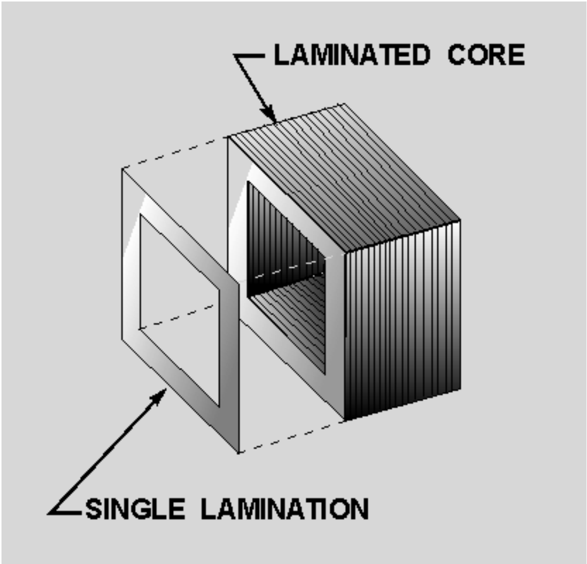
Transformer Construction

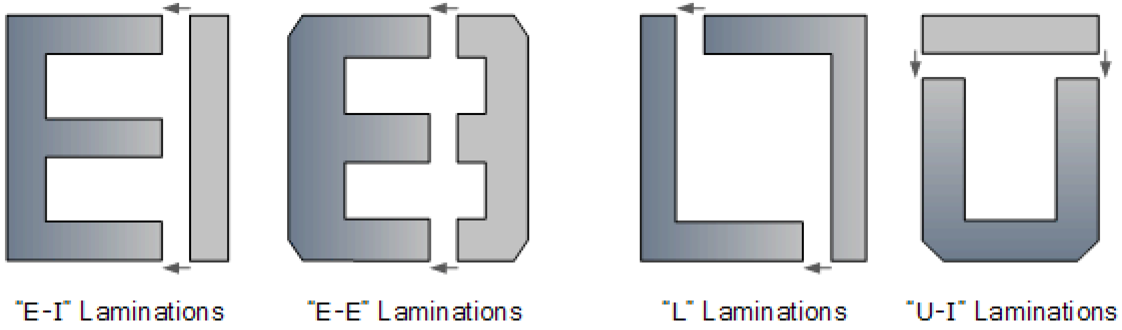


Inside Transformer



Transformer Construction





Losses in a Transformer

Major Losses

1. Copper Loss or I2R Loss
2. Iron Loss or Core Loss

Minor Losses

1. Magnetostriction Losses
2. Dielectric Losses
3. Stray Losses

Major Losses in a Transformer

Copper Loss or I^2R Loss:

- These losses occur due to ohmic resistance of the transformer windings.
- If I_1 and I_2 are the primary and the secondary current. R1 and R2 are the resistance of primary and secondary winding, then the copper losses occurring in the primary and secondary winding will be $I_1^2 R_1$ and $I_2^2 R_2$ respectively.
- As the both primary & secondary currents depend upon load of transformer, copper loss in transformer vary with load.

Major Losses in a Transformer

Iron Loss or Core Loss

Iron losses are caused by the alternating flux in the core of the transformer as this loss occurs in the core it is also known as Core loss. Iron loss is further divided into two types:

❖Eddy current loss.

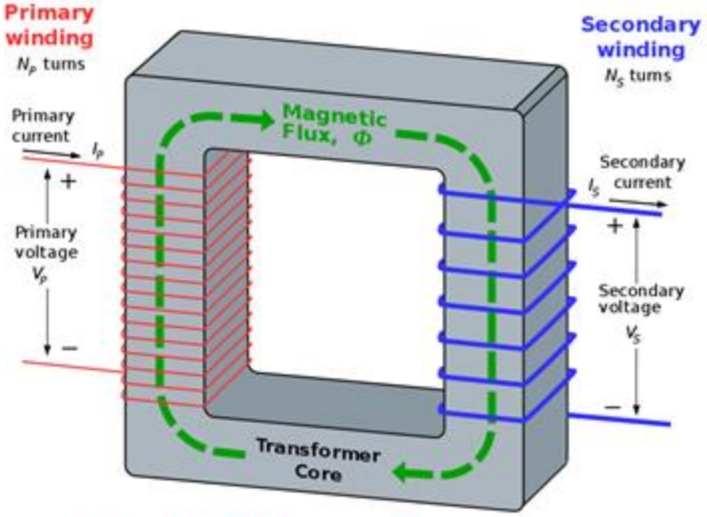
❖Hysteresis loss.

- Hysteresis loss and eddy current loss, both depend upon magnetic properties of the materials used to construct the core of transformer and its design. So these losses in transformer are fixed and do not depend upon the load current.

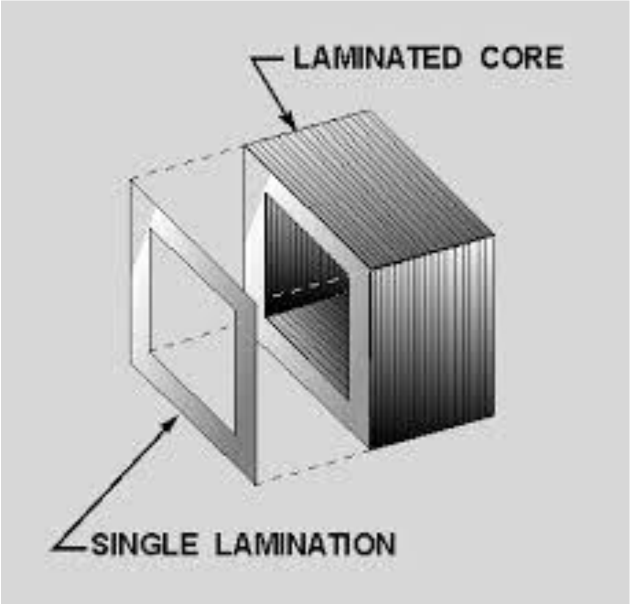
Eddy Current Loss

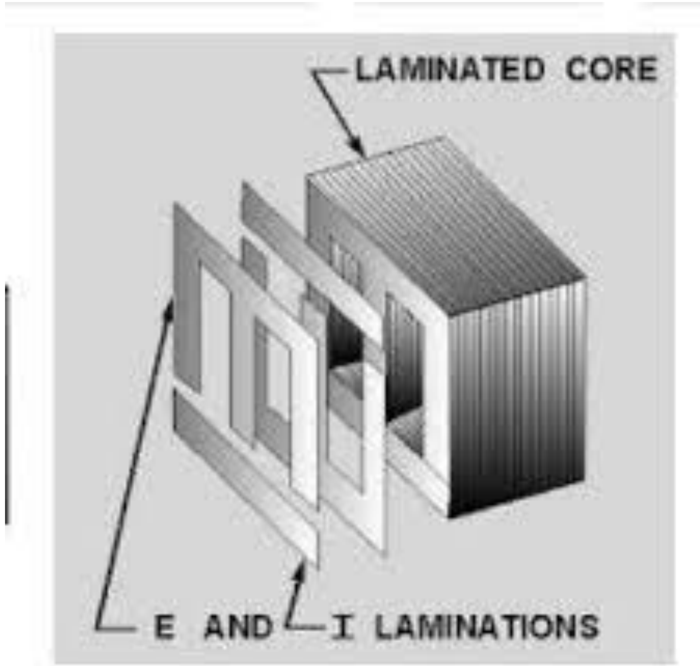
- In transformer, we supply alternating current in the primary, this alternating current produces alternating magnetizing flux in the core and as this flux links with secondary winding, there will be induced voltage in secondary, resulting current to flow through the load connected with it.
- Some of the alternating fluxes of transformer; may also link with other conducting parts like steel core or iron body of transformer etc. As alternating flux links with these parts of transformer, there would be a locally induced emf.
- Due to these emfs, there would be currents which will circulate locally at that parts of the transformer. These circulating current will not contribute in output of the transformer and **dissipated as heat**. This type of energy loss is called eddy current loss of transformer.

Explanation Slide



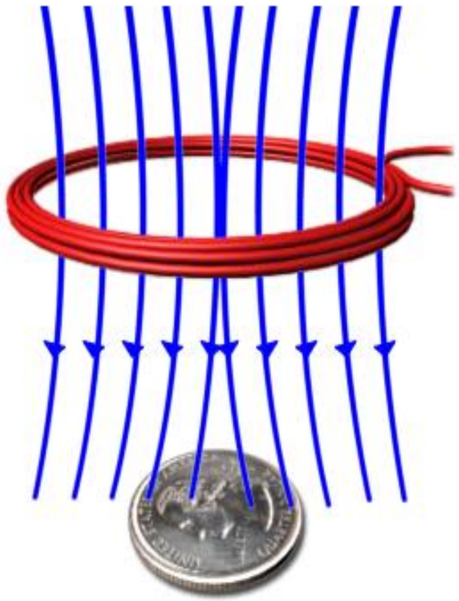
Inside Transformer

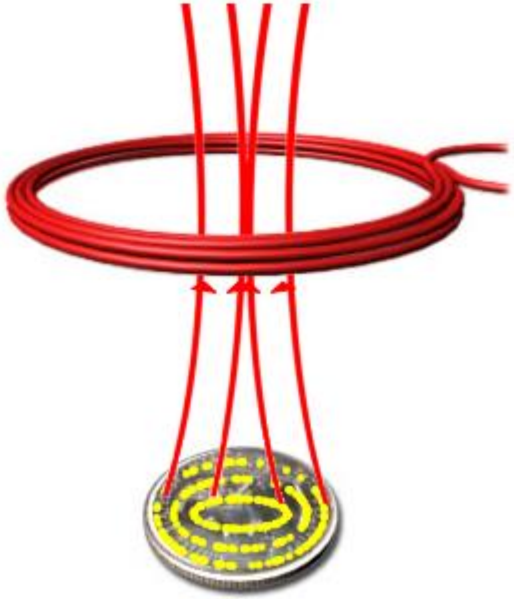




Example Metal detector

- The operation of metal detectors is based upon the principles of electromagnetic induction. Metal detectors contain one or more inductor coils that are used to interact with metallic elements on the ground. The single-coil detector illustrated is a simplified version of one used in a real metal detector.
- A pulsing current is applied to the coil, which then induces a magnetic field shown in blue. When the magnetic field of the coil moves across metal, such as the coin in this illustration, the field induces electric currents (called eddy currents) in the coin. The eddy currents induce their own magnetic field, shown in red, **which generates an opposite current in the coil**, which induces a signal indicating the presence of metal.





Quick QUIZ (POLL)

- How the eddy current are related to frequency:

A)Proportional to f

B)Proportional to f^2

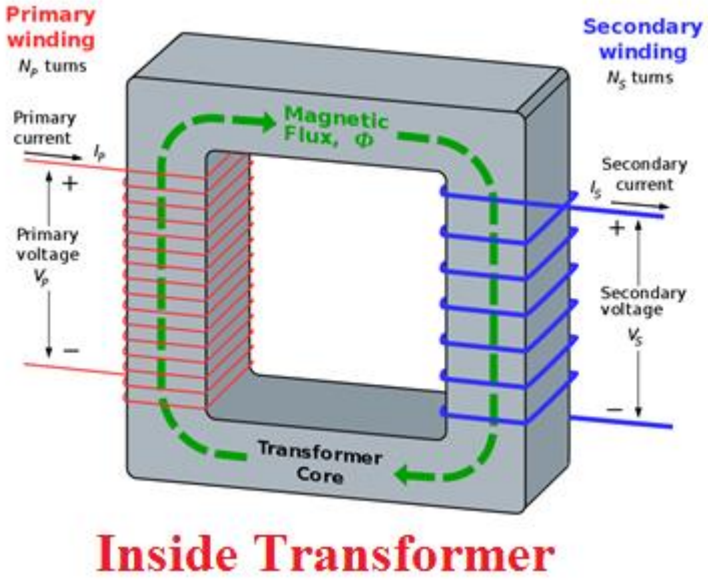
C)Inversely Proportional to f

D)Inversely Proportional to f^2

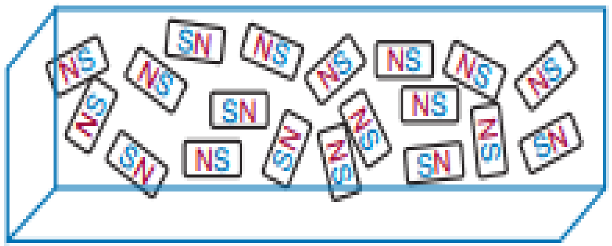
Hysteresis Loss

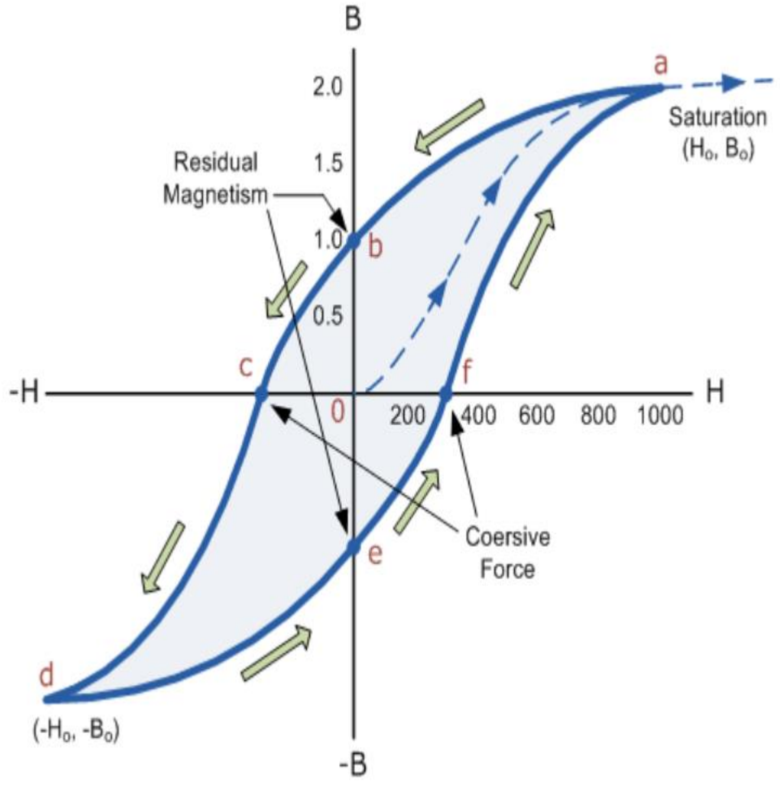
- The core of the transformer is made up of a steel which is a good ferromagnetic material.
- Whenever a magnetic flux is passed through , it behaves as a magnet.
- The randomly directed domains align themselves.
- However, once an external mmf is removed, maximum numbers of domains again come to random positions, but some of them still remain in their changed position.
- Because of these unchanged domains, the substance becomes slightly magnetized permanently. To neutralize this magnetism, some opposite mmf is required to be applied.
- The magnetomotive force or mmf applied in the transformer core is alternating. For every cycle due to this domain reversal, there will be extra work done. For this reason, there will be a consumption of electrical energy which is known as **Hysteresis loss of transformer**.

Explanation Slide



The domains in unmagnetized material are randomly arranged with no overall magnetic effect.





Major Losses in a Transformer

Iron Loss or Core Loss

Hysteresis loss in transformer is denoted as,

$$W_h = K_h f (B_m)^{1.6} \quad watts$$

Eddy current loss in transformer is denoted as,

$$W_e = K_e f^2 K_f^2 B_m^2 \; watts$$

Where, K_h = Hysteresis constant.

K_e = Eddy current constant.

K_f = form constant.

QUICK QUIZ (POLL)

Which of the following losses remain constant in a transformer?

A. Eddy current loss

B. Hysteresis loss

C. Copper loss

D. Both A and B

Minor Losses in a Transformer

Minor Losses

1. **Magnetostriction Losses**: change in the size/shape/length/dimension of the core, once an alternating magnetic flux passes through it. Results in the heating and creates a *buzzing sound*.

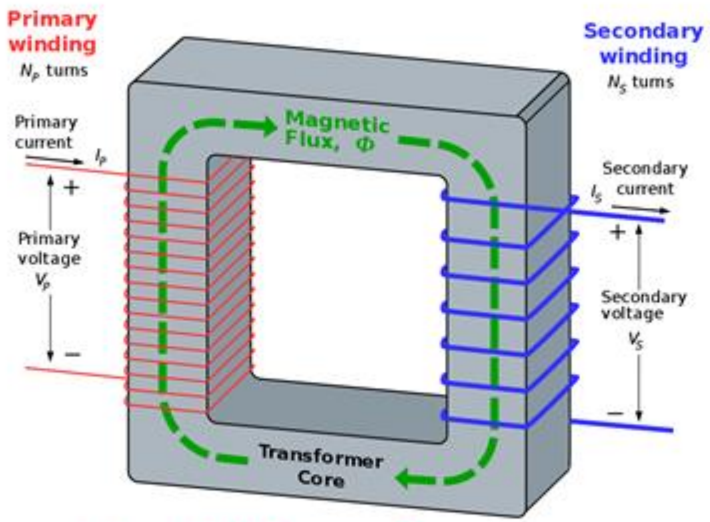
2. **Dielectric losses** are caused by the insulating material and insulation such as transformer oil. It rarely occurs as compared to the core and copper losses.

   If the transformer oil or insulation capacity gets deteriorated, the dielectric loss increases.

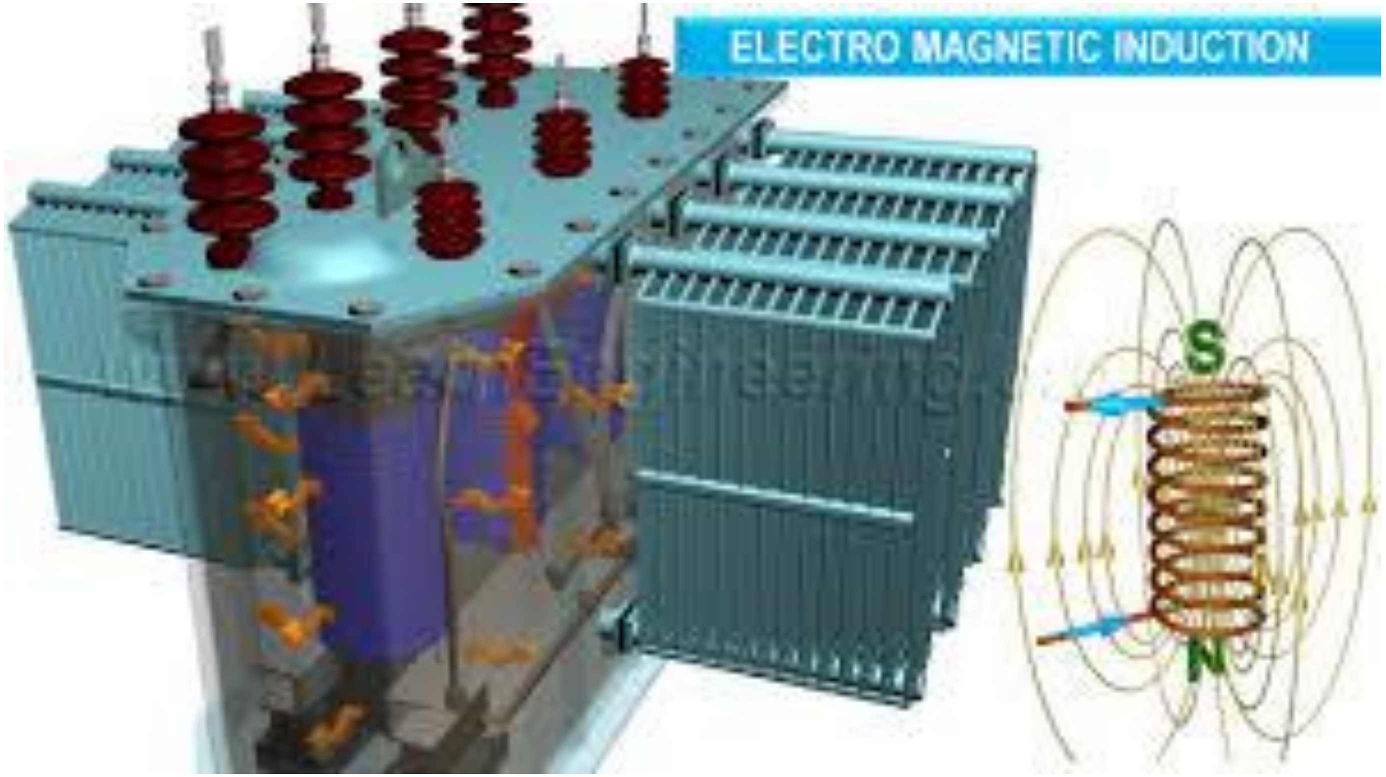
- **How to minimize Dielectric loss in transformer?**
- by using oil testing
- by maintaining insulation capacity and quality

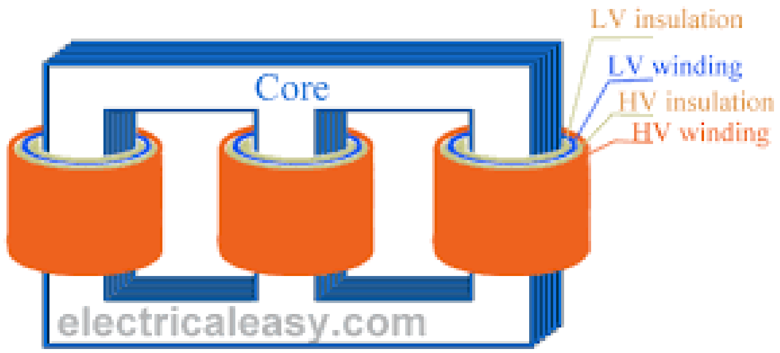
3**. Stray Losses**: Caused due to the leakage flux that intercepts the near by conducting material, such as transformer's support structure. It will again give rise to eddy currents causing the loss of power.

Explanation Slide



Inside Transformer





Core type three phase transformer

Efficiency of a Transformer

- The efficiency of a transformer is defined as:

$$\eta = \frac{\text{Power output}}{\text{Power input}} = \frac{\text{Power output}}{\text{Power output} + \text{Power losses}} = \frac{P_o}{P_o + P_l}$$

Power Losses

An ideal transformer would have no power losses, and would be 100% efficient. In practical transformers, power is dissipated in the windings, core, and surrounding structures. Large-size transformers used in power transmission are designed to be more efficient ($\eta > 98\%$). But, small transformers, such as those used in power adapters for charging mobile phones, may be no more than 85% efficient. There are some losses which are quite predominant, and some are quite insginificant.

Condition for maximum Efficiency

- $Efficiency = \frac{output}{input} = \frac{output}{output+losses} = \frac{input-losses}{input} = 1 - \frac{losses}{input}$

$$\text{efficiency} = 1 - \frac{\text{losses}}{\text{input}} = 1 - \frac{I_1^2R_1 + W_i}{V_1I_1\cos\Phi_1}$$

$$\eta = 1 - \frac{I_1R_1}{V_1\cos\Phi_1} - \frac{W_i}{V_1I_1\cos\Phi_1}$$

differentiating above equation with respect to I_1

$$\frac{d\eta}{dI_1} = 0 - \frac{R_1}{V_1\cos\Phi_1} + \frac{W_i}{V_1I_1^2\cos\Phi_1}$$

η will be maximum at $\frac{d\eta}{dI_1} = 0$

Hence efficiency η will be maximum at

$$\frac{R_1}{V_1\cos\Phi_1} = \frac{W_i}{V_1I_1^2\cos\Phi_1}$$

$$\frac{I_1^2R_1}{V_1I_1^2\cos\Phi_1} = \frac{W_i}{V_1I_1^2\cos\Phi_1}$$

$$I_1^2R_1 = W_i$$

Thus, the efficiency at a given terminal voltage would be maximum when the variable losses (copper losses) are equal to the constant losses (iron losses).

All Day Efficiency

Definition: All day efficiency means the power consumed by the transformer throughout the day. It is defined as the **ratio of output power to the input power** in kWh or wh of the transformer over 24 hours. Mathematically, it is represented as

$$\text{All day efficiency, } \eta_{\text{all day}} = \frac{\text{output in kWh}}{\text{input in kWh}} \quad (\text{for 24 hours})$$

$$\eta = \frac{\text{output power}}{\text{input power}} = \frac{\text{output power}}{\text{output power} + \text{losses}}$$

Need for All Day Efficiency

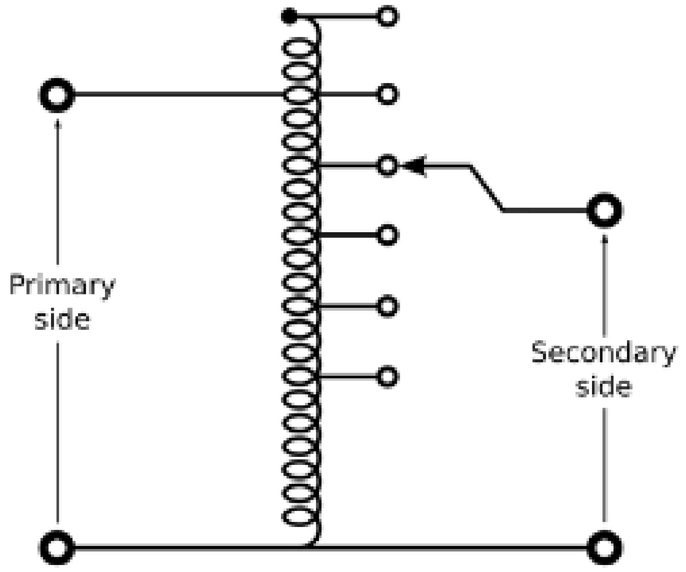
- Some transformer efficiency cannot be judged by simple commercial efficiency as the load on certain transformer fluctuate throughout the day.
- For example, the distribution transformers are energized for 24 hours, but they deliver very light loads for the major portion of the day, and they do not supply rated or full load, and most of the time the distribution transformer has 50 to 75% load on it.
- As we know, there are various losses in the transformer such as iron and copper loss. The iron loss takes place at the core of the transformer. Thus, the iron or core loss occurs for the whole day in the distribution transformer.
- The second type of loss known as a copper loss and it takes place in the windings of the transformer and is also known as the **variable loss**. It occurs only when the transformers are in the loaded condition.
- Hence, the performance of such transformers cannot be judged by the commercial or ordinary efficiency, but the efficiency is calculated or judged by All Day Efficiency also known as operational efficiency or energy efficiency which is computed by the energy consumed for 24 hours.

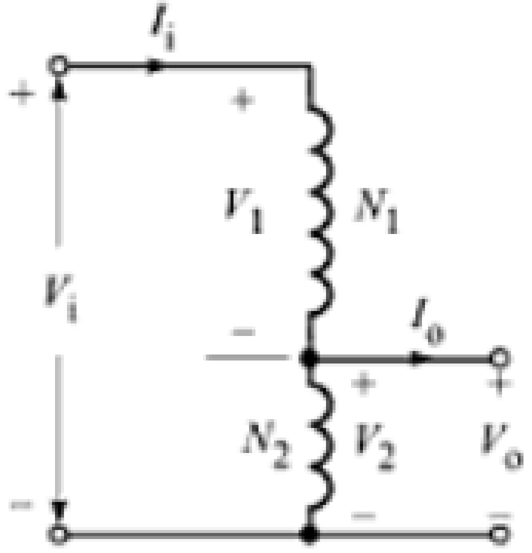
SOME SPECIAL TRANSFORMERS

Auto Transformer
Current Transformer
Potential Transformer

Autotransformer

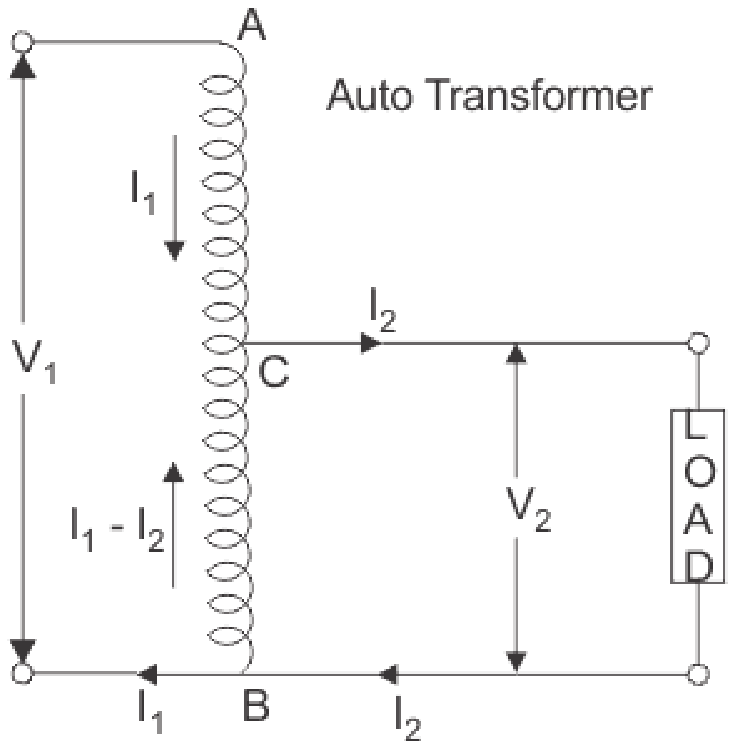
- An Auto-transformer is an electrical transformer with only one winding.
- In an auto transformer, one single winding is used as primary winding as well as secondary winding. But in two windings transformer two different windings are used for primary and secondary purpose.





Autotransformer

The winding AB of total turns N_1 is considered as primary winding. This winding is tapped from point 'C' and the portion BC is considered as secondary. Let's assume the number of turns in between points 'B' and 'C' is N_2.



If V_1 voltage is applied across the winding i.e. in between 'A' and 'C'.

$$So\ voltage\ per\ turn\ in\ this\ winding\ is\ \frac{V_1}{N_1}$$

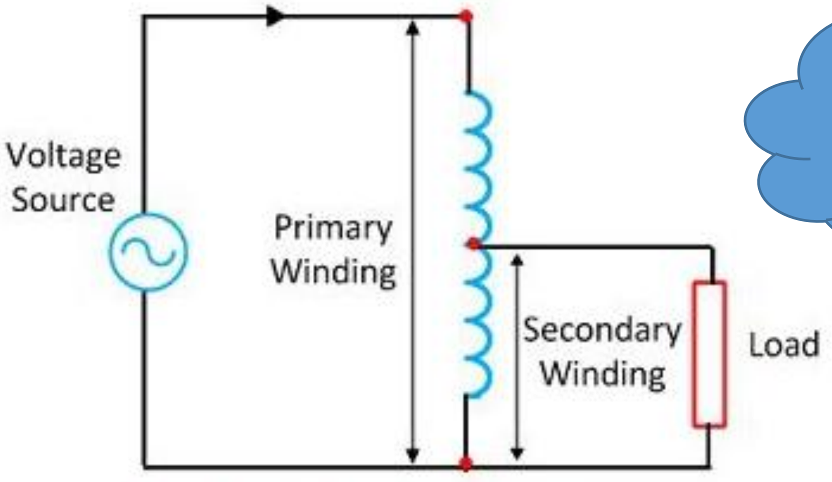
Hence, the voltage across the portion BC of the winding, will be,

$$\frac{V_1}{N_1} X N_2\ and\ from\ the\ figure\ above,\ this\ voltage\ is\ V_2$$

$$Hence,\ \frac{V_1}{N_1} X N_2 = V_2$$

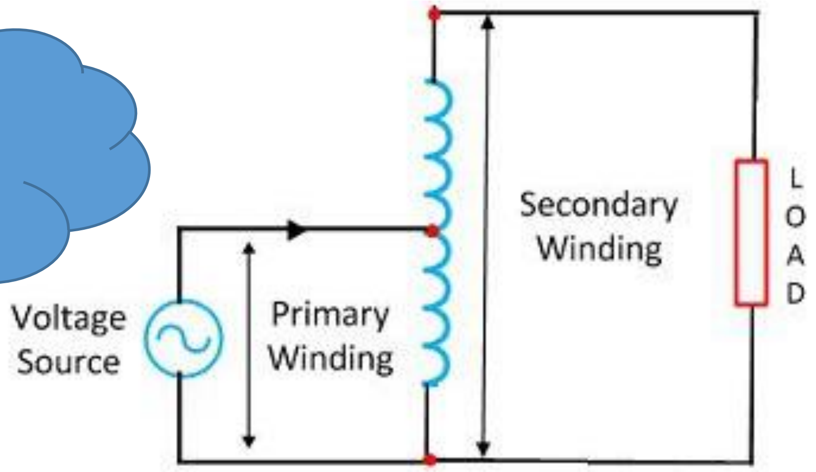
$$\Rightarrow \frac{V_2}{V_1} = \frac{N_2}{N_1} = Constant = K$$

Step Up and Step Down in Autotransformer



Stepdown Autotransformer

Current and voltage in Autotransformer



Step-up Autotransformer

Variable Autotransformer

This type of Variable Autotransformer is generally used in laboratories and science labs in schools and colleges and is known more commonly as the Variac.

Advantages of Autotransformer

- smaller in size and cheaper.
- Less copper losses, therefore more efficient.
- Better voltage regulation

Disadvantages

- No isolation between the primary and the secondary winding.
- The leakage flux between the primary and secondary windings is small and hence the impedance is low. This results into severe short circuit currents under fault conditions.
- Wire Break (N2) ,then full AC Voltage reach to load and damage the load

QUICK QUIZ (POLL)

An auto transformer steps down voltage from V1 to V2 ,If an open circuit develops in the common winding ,the voltage across the load may become

A)V1

B)V1-V2

C)V1+V2

D)V2

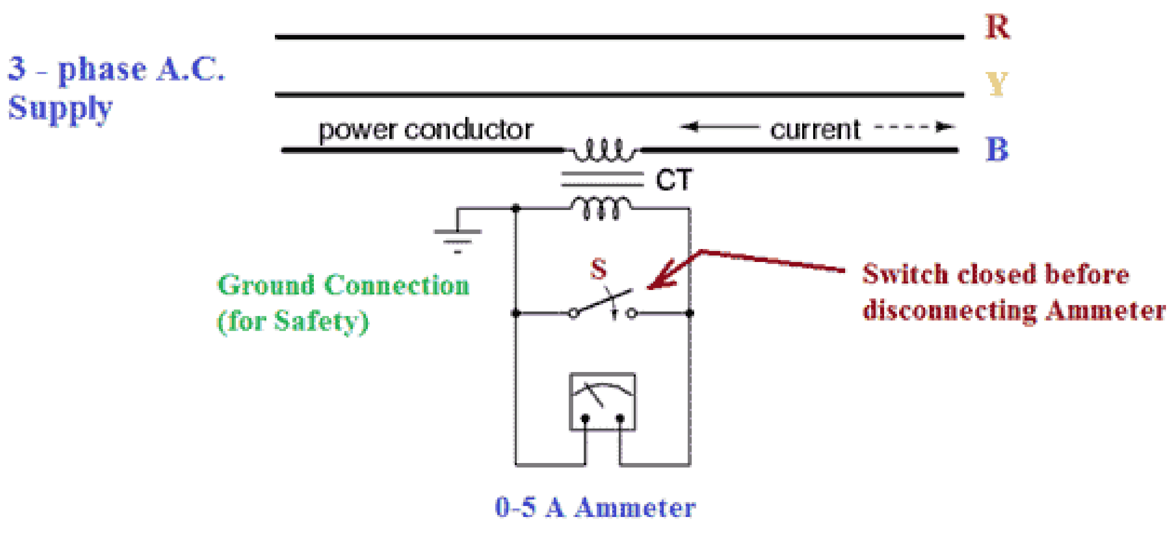
Instrument Transformers

- It is a type of transformer that is used for its high accuracy and isolation to decrease any voltage or current levels for measurement purposes.
- The problem with high voltage measurement is that they are quite hazardous. So the effective way is to introduce an instrument transformer to decrease the voltages or current before connecting any measurement device.
- There are two types of instrument transformer

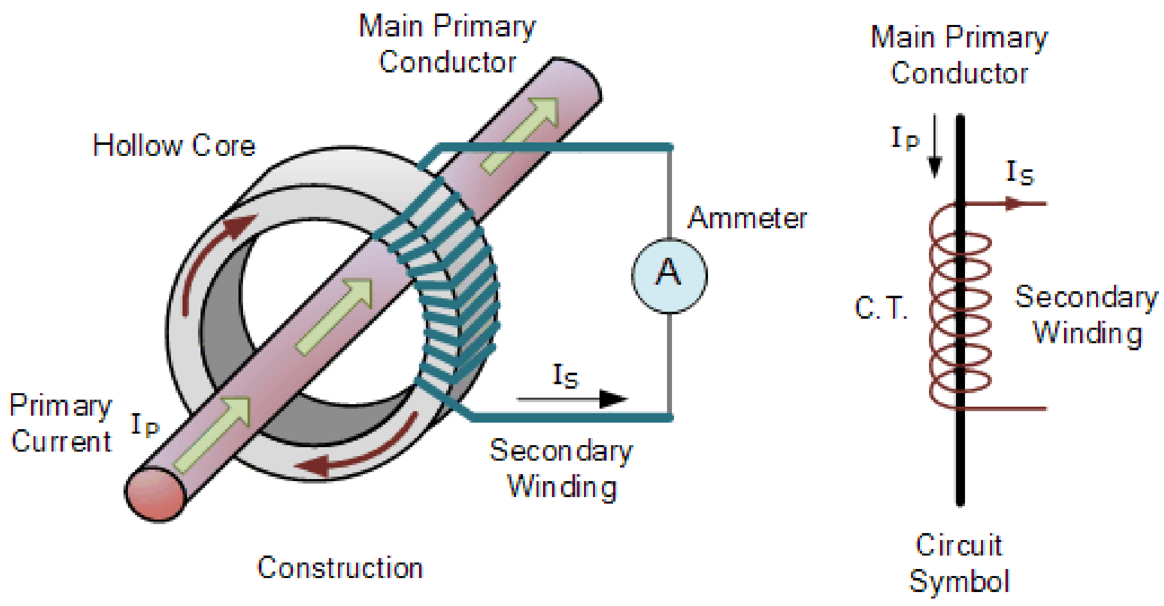
1. Current transformer (CT)
2. Potential Transformer (PT)

Current Transformer

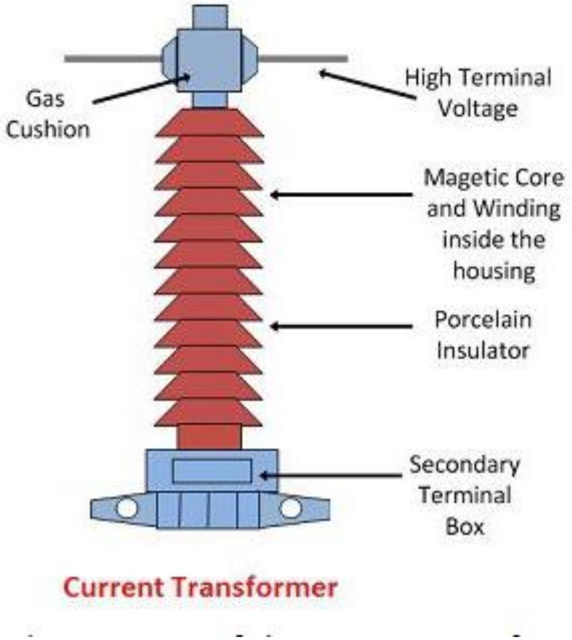
- Current transformer is used to step down the current of power system to a lower level to make it feasible to be measured by small rating Ammeter (i.e. 5A ammeter). A typical connection diagram of a current transformer is shown in figure below.



Current Transformer (C.T.)

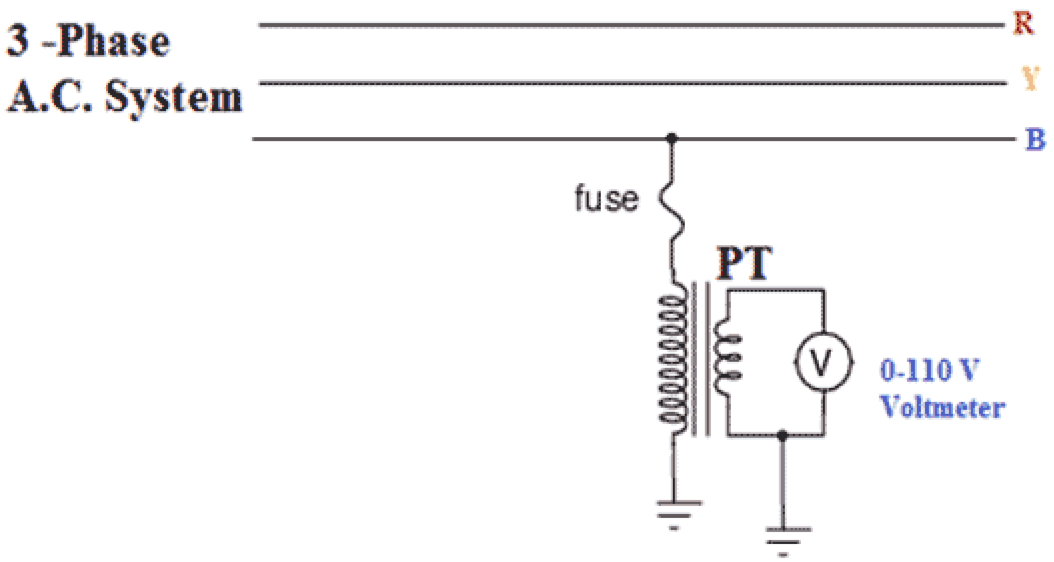


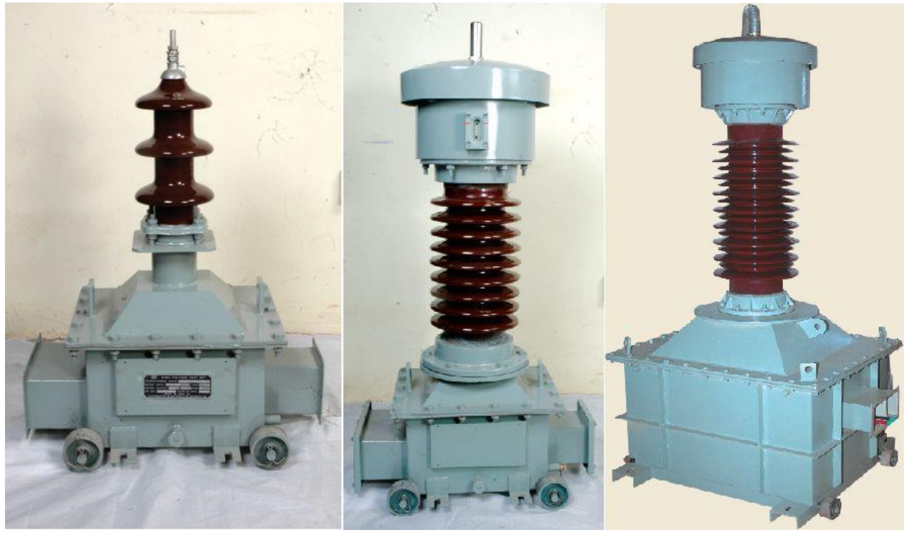
Current Transformer



Potential Transformer

- Potential transformer is used to step down the voltage of power system to a lower level to make is feasible to be measured by small rating voltmeter i.e. 110 – 120 V voltmeter. A typical connection diagram of a potential transformer is showing figure below.





Potential Transformer