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Basics of Electrical and Electronics Engineering

ECE101B

Unit IV - Single Phase Transformer

Topics:

- Working principle
- Construction
- Types
- Equivalent circuit
- Losses
- Efficiency
- Regulation

Single Phase Transformer

A static device which transfers electrical energy from one ac circuit to another with the desired change in voltage or current and without any change in frequency

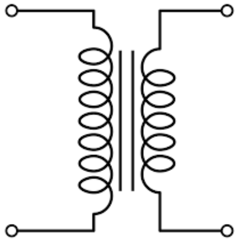
- AC device
- Voltage/current can be amplified or reduced

Step-up and step-down transformer

- Step-up: Step up to higher voltages for the transmission lines.
- Step-down: To step the voltage down to values suitable for motors, lamps, heaters, etc.

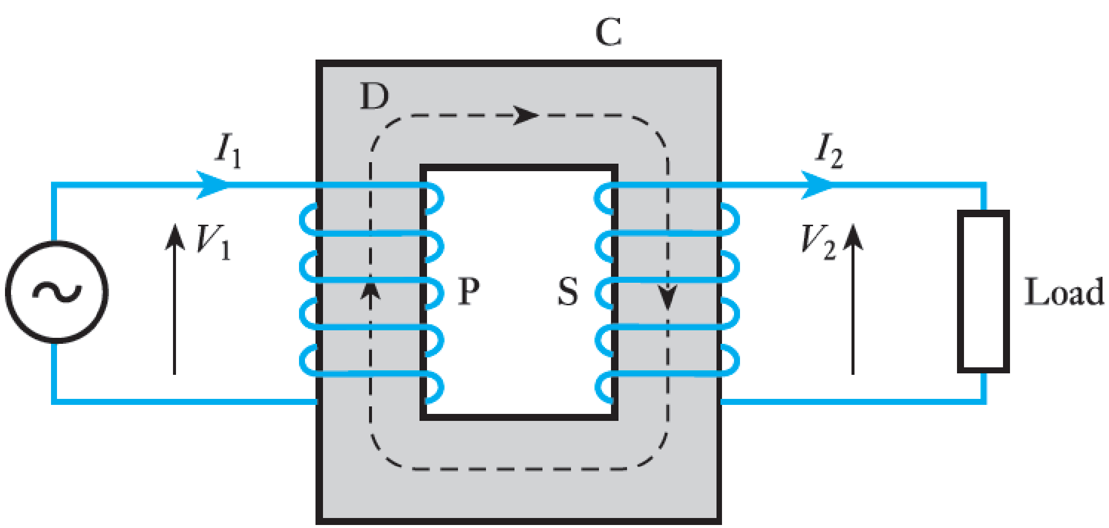
Single phase transformer and three phase transformer

- Symbol of Transformer -



Working Principal of Single Phase Transformer

- A steel core C consists of laminated sheets, about 0.35–0.7 mm thick, insulated from one another.
- Coil P is connected to the supply and is therefore termed the *primary*; coil S is connected to the load and is termed the *secondary*.
- The magnetic flux forms the connecting link between the primary and secondary circuits



Working Principal of Single Phase Transformer

- An alternating voltage applied to P circulates an alternating current through P and this current produces an alternating flux in the steel core
- If the whole of the flux produced by P passes through S, the e.m.f. induced in each turn is the same for P and S.
- Hence, if N1 and N2 are the number of turns on P and S respectively,

$$\frac{\text{Total e.m.f. induced in S}}{\text{Total e.m.f. induced in P}} = \frac{N_2}{N_1}$$

$$\frac{V_2}{V_1} \simeq \frac{N_2}{N_1}$$

Primary and secondary power factors are nearly equal,

$$I_1 V_1 \simeq I_2 V_2$$

so that

Current ratio is given by:

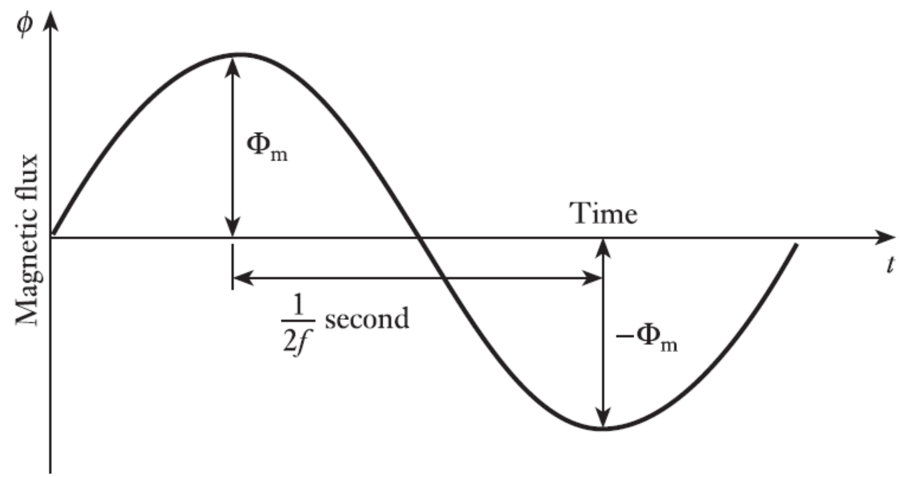
$$\frac{I_1}{I_2} \simeq \frac{V_2}{V_1}$$

$$\frac{I_1}{I_2} \simeq \frac{N_2}{N_1} \simeq \frac{V_2}{V_1}$$

EMF equation of a transformer

- The maximum value of the flux to be Φm webers and the frequency to be f hertz. From Fig. 34.3, the flux has to change from +Φm to −Φm in half a cycle, namely 1/2f in seconds.

Fig. 34.3 Waveform of flux variation



$$\therefore \qquad \text{Average rate of change of flux} = 2\Phi_m \div \frac{1}{2f}$$

$$= 4f\,\Phi_m \text{ webers per second}$$

and average e.m.f. induced per turn is

$$4f\,\Phi_m \text{ volts}$$

EMF equation of a transformer

But for a sinusoidal wave the r.m.s. or effective value is 1.11 times the average value,

$\therefore$ RMS value of e.m.f. induced per turn $= 1.11 \times 4f\,\Phi_m$

Hence, r.m.s. value of e.m.f. induced in primary is

$$\boxed{E_1 = 4.44 N_1 f \Phi_m} \quad \text{volts} \qquad [34.4]$$

and r.m.s. value of e.m.f. induced in secondary is

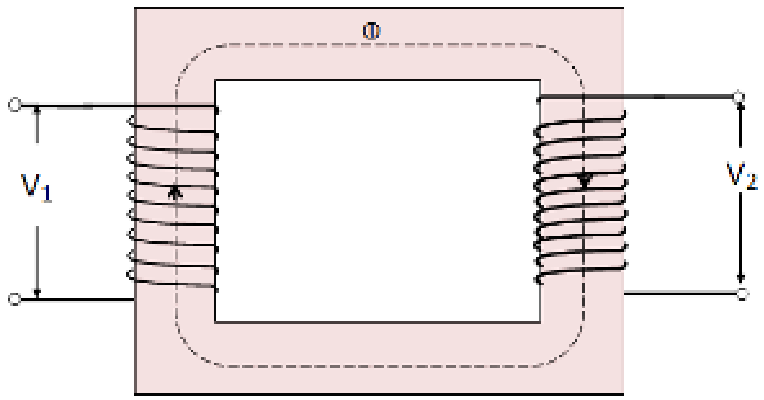
$$\boxed{E_2 = 4.44 N_2 f \Phi_m} \quad \text{volts} \qquad [34.5]$$

Construction of Single Phase Transformer

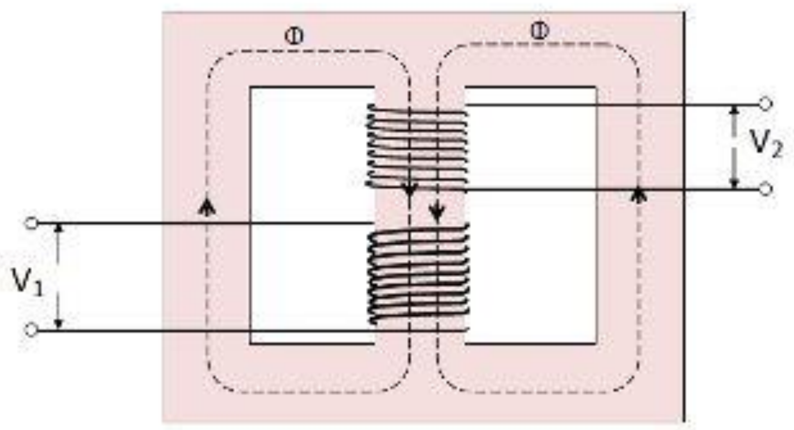
- A simple two-winding transformer construction consists of each winding being wound on a separate soft iron limb or core which provides the necessary magnetic circuit
- This magnetic circuit, know more commonly as the “transformer core” is designed to provide a path for the magnetic field to flow around, which is necessary for induction of the voltage between the two windings.
- The core is designed to reduce “eddy currents”, cause heating and energy losses within the core decreasing the transformers efficiency.
- To reduce these unwanted power losses, transformer core is constructed from thin steel laminations.

Construction of Single Phase Transformer

- The two most common and basic designs of transformer construction are the **Closed-core Transformer and the Shell-core Transformer.**
- In the "closed-core" type (core form) transformer, the primary and secondary windings are wound outside and surround the core ring.
- In the "shell type" (shell form) transformer, the primary and secondary windings pass inside the steel magnetic circuit (core) which forms a shell around the windings as shown below.



Core Type Transformer

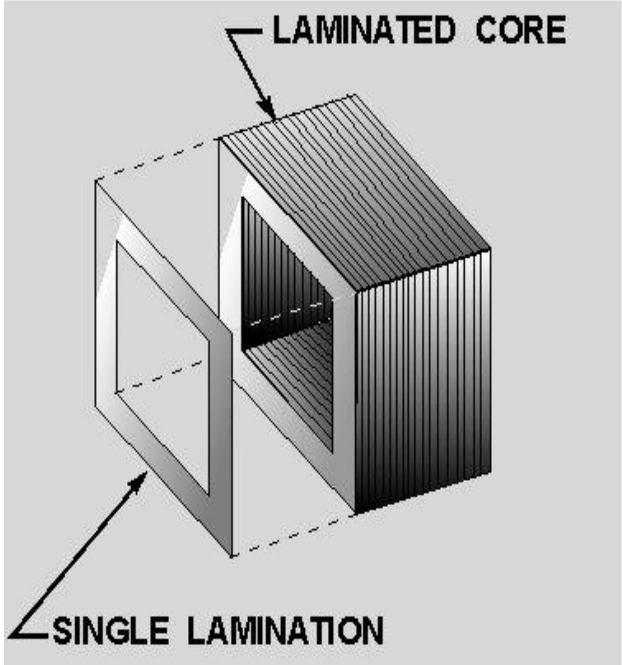


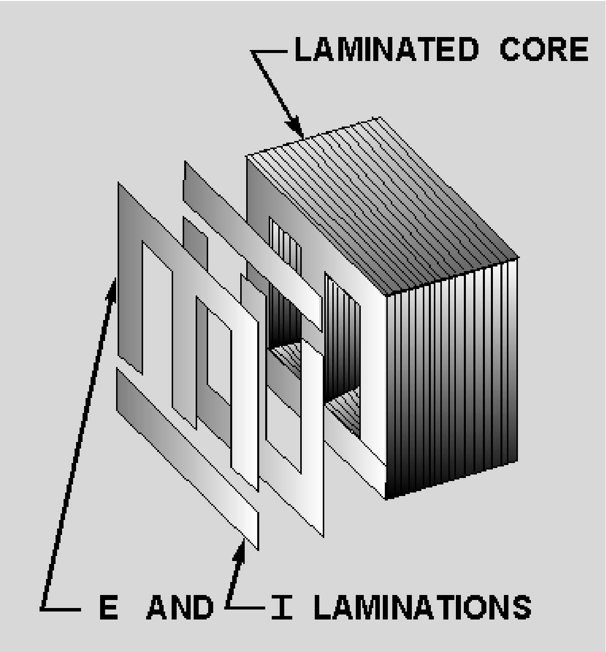
Shell Type Transformer

Construction of Single Phase Transformer

Core Construction:

- The central iron core is constructed from of a highly permeable material made from thin silicon steel laminations
- These thin laminations are assembled together to provide the required magnetic path with the minimum of magnetic losses
- Typically 0.35 to 0.7 mm thick

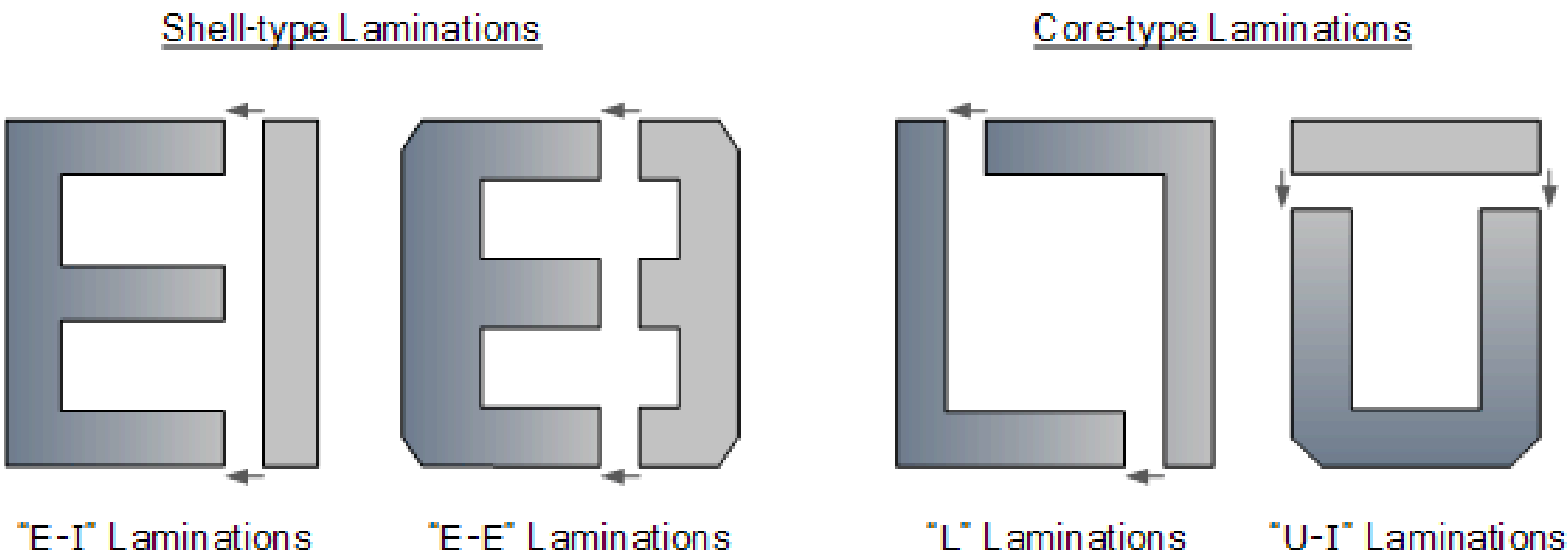


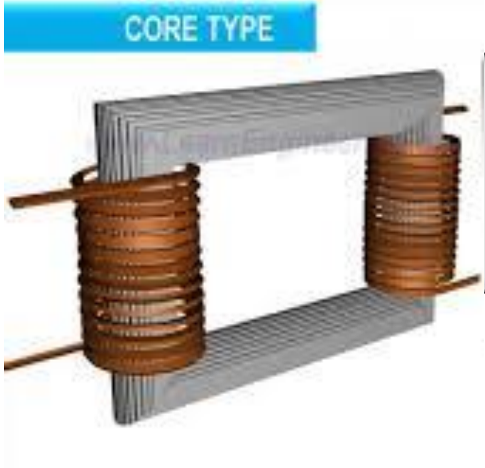


Construction of Single Phase Transformer

Laminations:

- the individual laminations are stamped out from larger steel sheets and formed into strips of thin steel resembling the letters “E”s, “L”s, “U”s and “I”s as shown below





Comparison

	Core		**Shell**
1.	Winding encircles the core	1.	Core encircles most of the windings
2.	Single magnetic circuit	2.	Double magnetic circuit
3.	Core has two limbs	3.	Core has three limbs
4.	Cylindrical coils are used	4.	Sandwich type coils are used
5.	Windings are distributed on two limbs hence natural cooling is effective	5.	Windings are surrounded by the core hence no natural cooling
6.	Coils can be easily removed for maintenance	6.	Coils cannot be removed easily
7.	For low voltage transformers	7.	For high voltage transformers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Types of Transformer

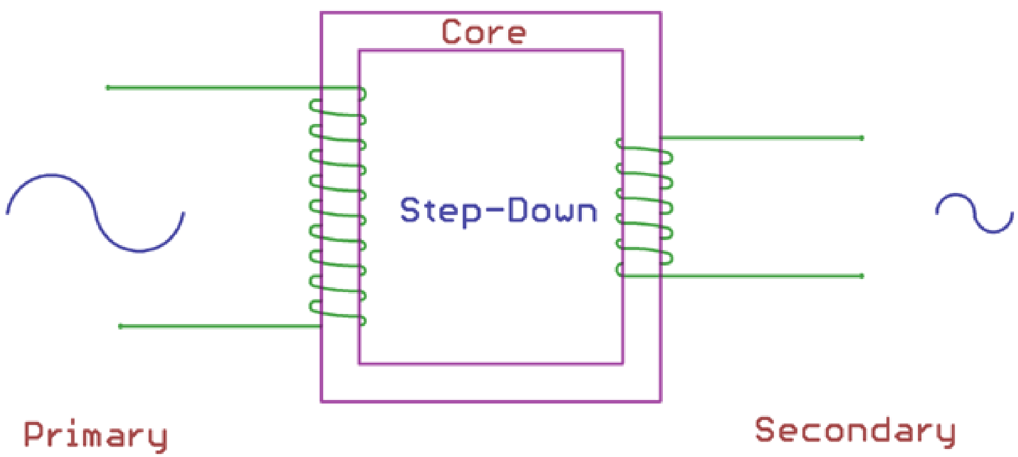
Transformer Types based on Voltage Level:

- Depending on the voltage level of the primary side and secondary side, the transformer has three categories.
  - ✓ Step Down
  - ✓ Step Up
  - ✓ Isolation Transformer.

Types of Transformer

1. Step-Down Transformer:

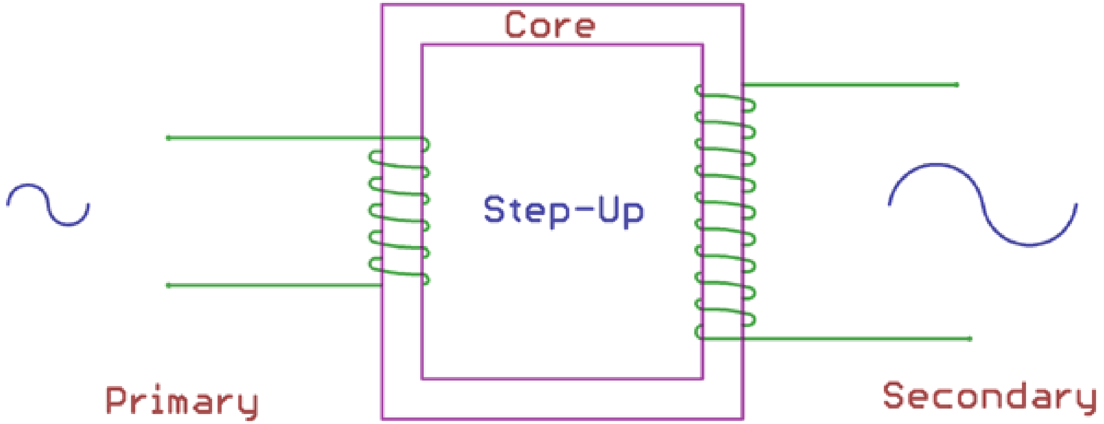
- A step-down transformer converts the primary voltage level to a lower voltage across the secondary output.
- This is achieved by the ratio of primary and secondary windings.
- For step-down transformers the number of windings is higher across the primary side than the secondary side. Therefore, the overall winding ratio of primary and secondary always remains more than 1.



Types of Transformer

2. Step-Up Transformer:

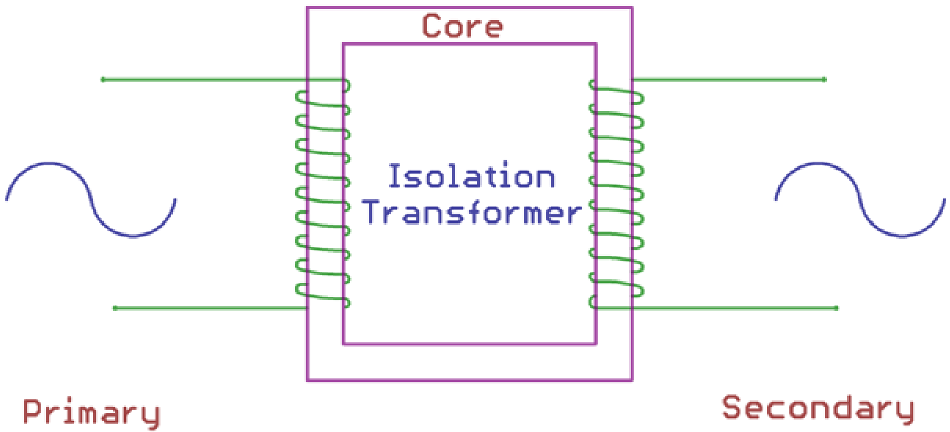
- Step Up transformer is exactly opposite of the step-down transformer.
- Step up transformer increase the low primary voltage to a high secondary voltage.
- Again it is achieved by the ratio of primary and secondary winding ratio.
- For the Step Up transformer, the ratio of the primary winding and the Secondary winding remains less than 1. That means the number turns in secondary winding is higher than the primary winding.



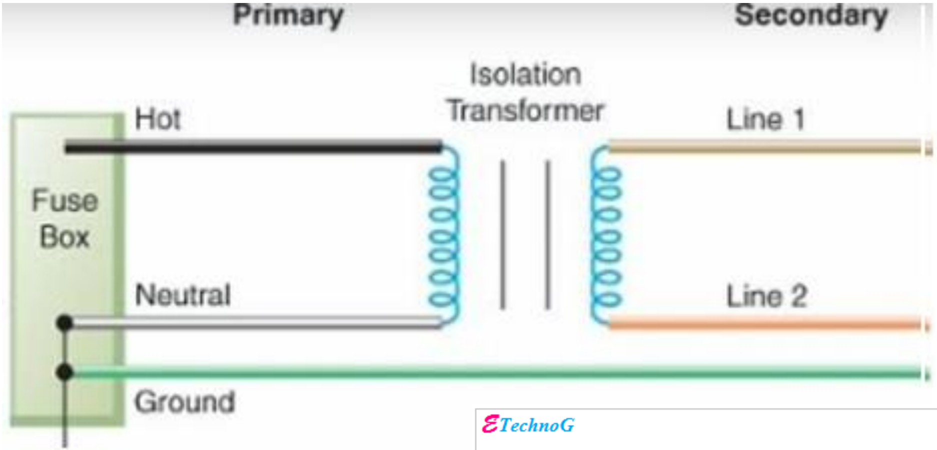
Types of Transformer

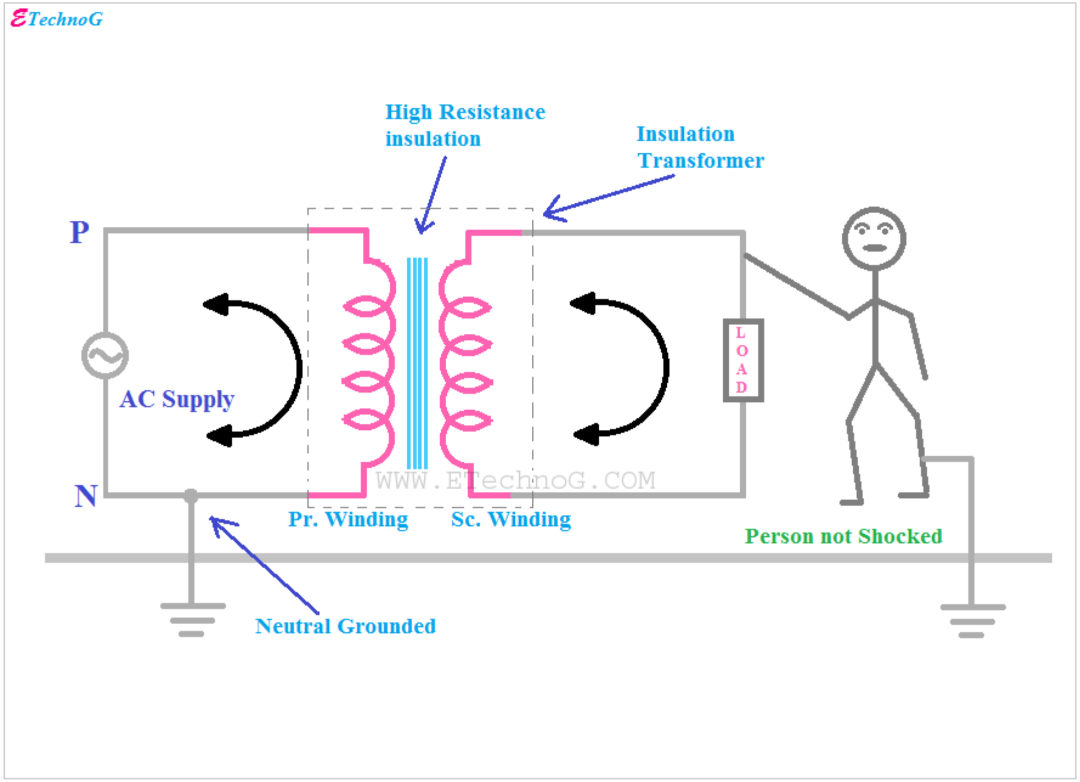
3. Isolation Transformer:

- Isolation transformer does not convert any voltage levels. The Primary voltage and the secondary voltage of an isolation transformer always remain the same.
- This is because the primary and the secondary winding ratio is always equal to the 1.
- That means the number of turns in primary and secondary winding is same in isolation transformer.
- The transformer does not have any electrical connections between primary and secondary, it is also used as an isolation barrier where the conduction happens only with the magnetic flux. It is used for safety purpose and to cancel noise transfer from primary to secondary or vice-versa.



Isolation transformers block transmission of the DC component in signals from one circuit to the other, but allow AC components in signals to pass





How transformer Works

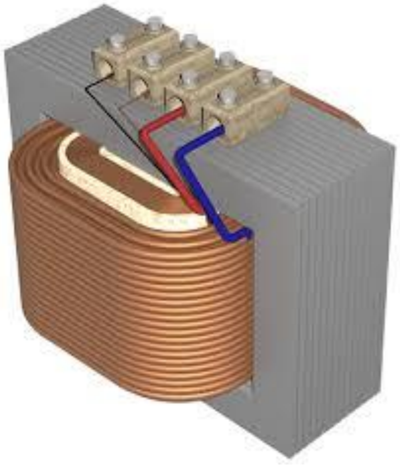
Types of Transformer

Transformer Types based on Core material:

- ✓ Iron Core Transformer
- ✓ Ferrite Core Transformer
- ✓ Air-core Transformer

1. Iron Core Transformer:

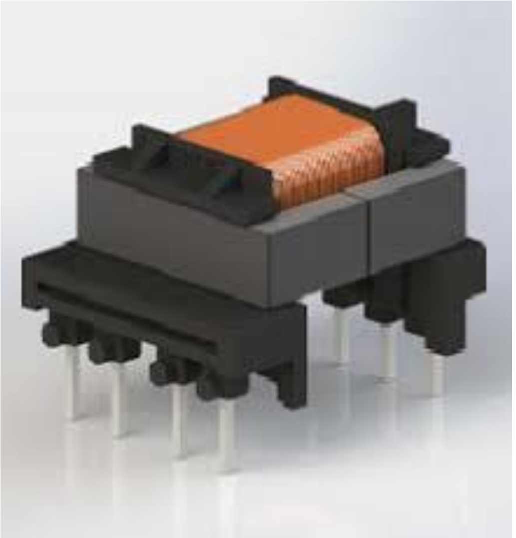
- Iron core transformer uses multiple soft iron plates as the core material.
- Due to the excellent magnetic properties of iron, the flux linkage of the iron core transformer is very high. Thus, the efficiency of the iron core transformer is also high.



Types of Transformer

2. Ferrite Core Transformer:

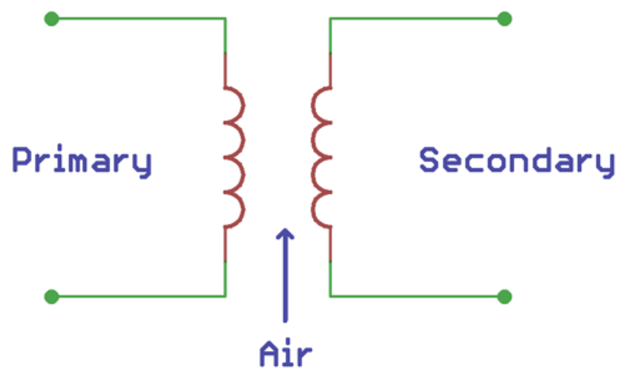
- A ferrite core transformer uses a ferrite core due to high magnetic permeability.
- This type of transformer offers very low losses in the high-frequency application.
- Due to this, ferrite core transformers are used in high-frequency application such as in switch mode power supply (SMPS), RF related applications, etc.



Types of Transformer

4. Air Core transformer:

- Air Core transformer does not use any physical magnetic core as the core material. The flux linkage of the air-core transformer is made entirely using the air.
- In air core transformer, the primary coil is supplied with alternating current which produces an electromagnetic field around it. When a secondary coil is placed inside the magnetic field, the secondary coil is induced with a magnetic field which further is used to power the load.
- However, air core transformer produces low mutual inductance compared to physical core material such as iron or ferrite core.



Types of Transformer

Transformer Types based on usage:

- ✓ Power transformers
- ✓ Measurement Transformers
- ✓ Distribution Transformers

1. Power transformers :

- The Power transformers are used in high power transfer applications for both step-up and step-down applications, where the operating voltages are more than 33KV.
- These are usually big in size depending upon the power handling capacity and its application.
- These transformers are available in three phase or single phase type.
- As these transformers are bulky, they are placed in large open area.

Types of Transformer

2. Measurement Transformers:

- The Measurement transformers are used for measuring high voltage and high currents.
- These are mostly helpful in isolating the circuits from them.
- These are mainly of two types, Current transformers and Voltage transformers.

Types of Transformer

3. Distribution Transformers:

- The Distribution transformers are used for distribution of electrical energy at end-user level.
- The operating voltages are around 33KV for industrial purposes and 440v-220v for domestic purposes.

Types of Transformer

Transformer Types based on supply used:

- ✓ Single phase transformer
- ✓ Three phase transformer

1. Single phase transformer

A normal transformer is a single phase transformer. It has a primary and a secondary winding and it is operated to either decrease or increase the secondary voltage.

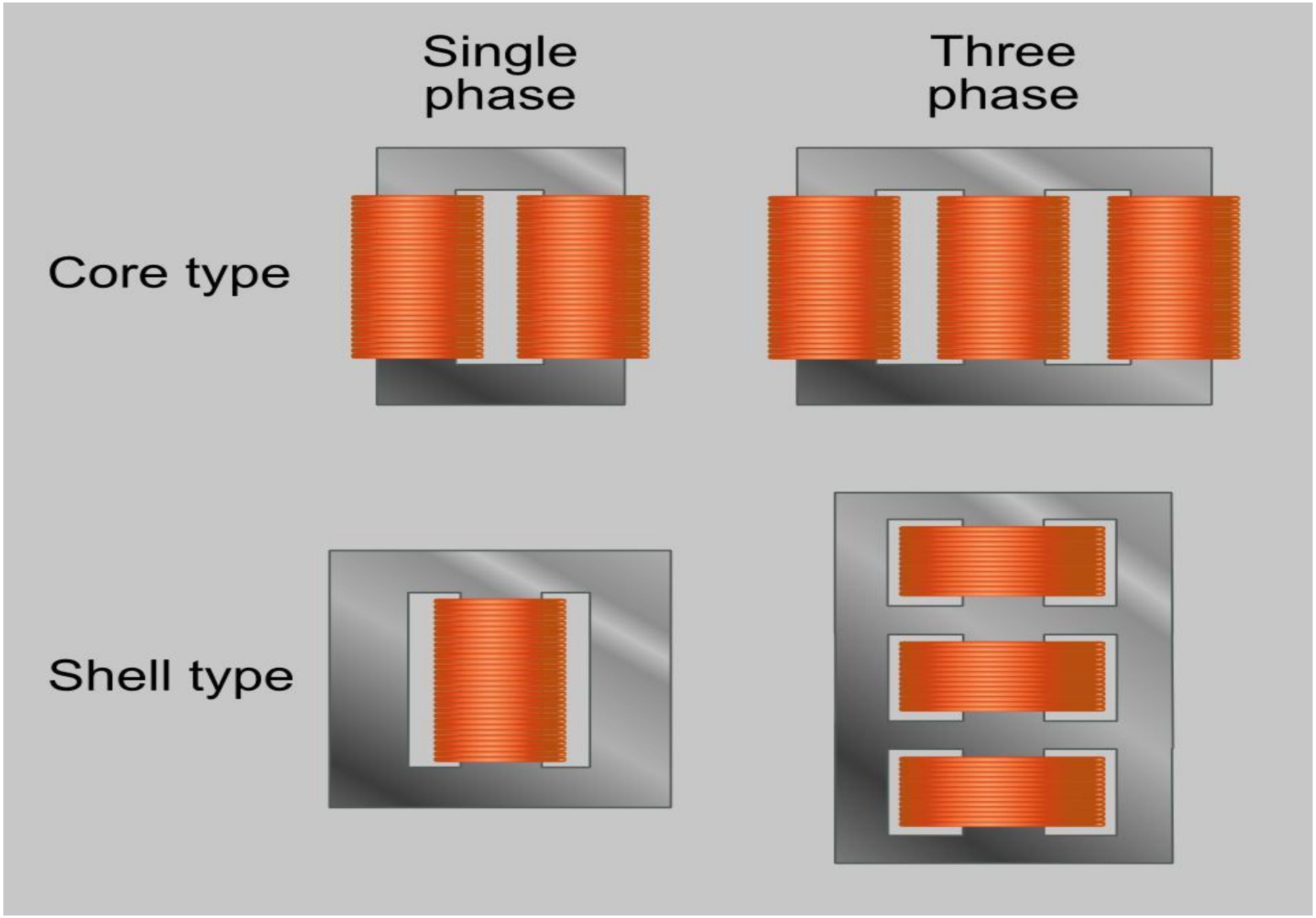
2. Three phase transformer

For a three phase transformer, three primary windings are connected together and three secondary windings are connected together.

Another classification of these transformers is Core and Shell type.

- In Shell type, the windings are positioned on a single leg surrounded by the core.
- In Core type, they are wounded on different legs.

Types of Transformer



Voltage regulation of a transformer

- The voltage regulation of a transformer is defined as the variation of the secondary voltage between no load and full load, expressed as either a per-unit or a percentage of the no-load voltage, the primary voltage being assumed constant, i.e.

$$\text{Voltage regulation} = \frac{\text{no-load voltage} - \text{full-load voltage}}{\text{no-load voltage}}$$

If V_1 is primary applied voltage

Secondary voltage on no load = $V_1 \times \frac{N_2}{N_1}$

since the voltage drop in the primary winding due to the no-load current is negligible.

If V_2 is secondary terminal voltage on full load,

Voltage regulation of a transformer

$$\text{Voltage regulation} = \frac{V_1 \frac{N_2}{N_1} - V_2}{V_1 \frac{N_2}{N_1}}$$

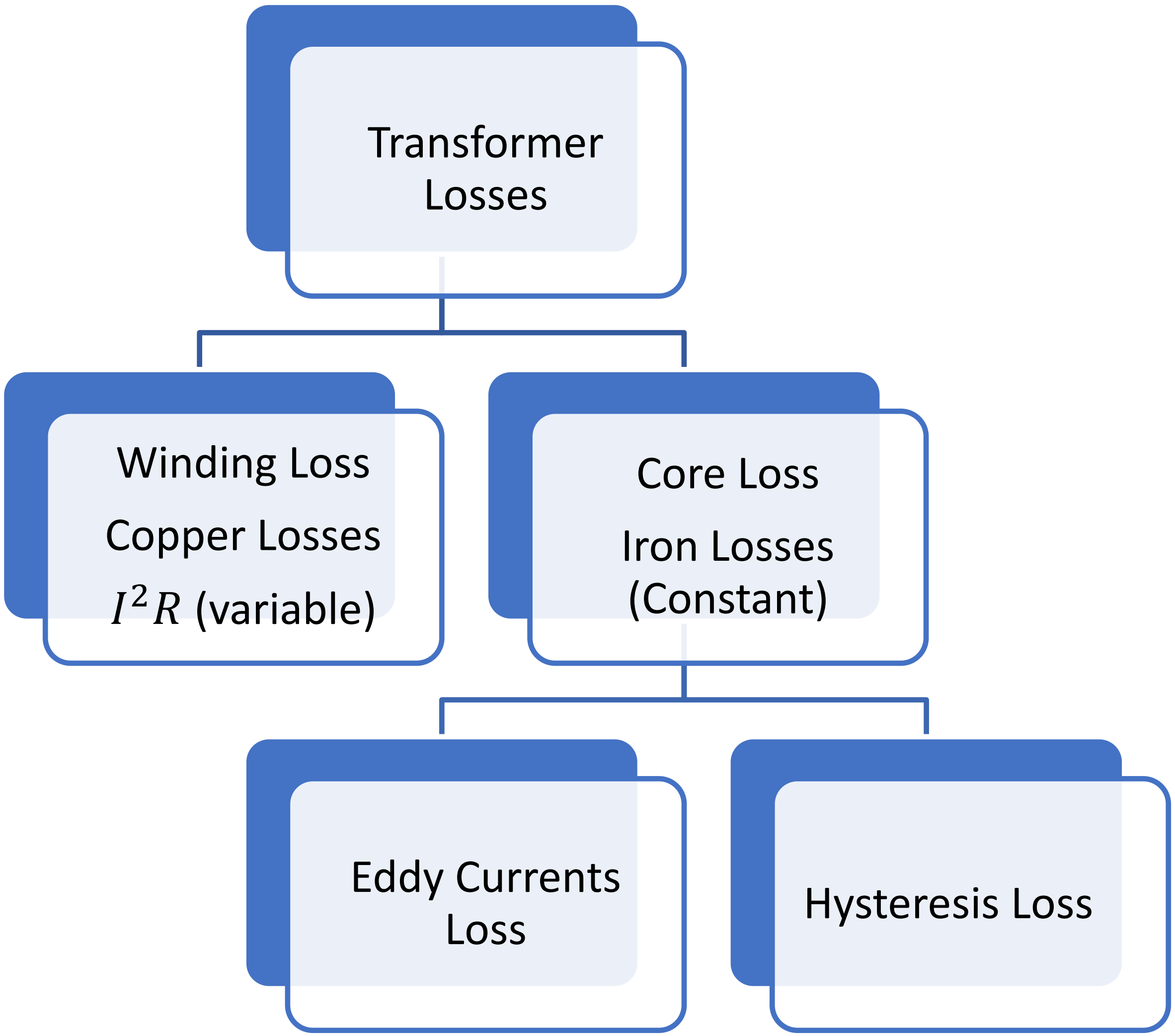
$$= \frac{V_1 - V_2 \frac{N_1}{N_2}}{V_1} \text{ per unit}$$

$$= \frac{V_1 - V_2 \frac{N_1}{N_2}}{V_1} \times 100 \text{ per cent}$$

$$\therefore \qquad \text{Per-unit voltage regulation} = \frac{V_1 - V_{2'}}{V_1}$$

Where, $V_{2'} = V_2 \, (N_1/N_2)$

Transformer losses

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Transformer losses

Copper Losses:

- Due to resistance of the windings
- Power loss is proportional to the square of the currents and ultimately heat up the windings
- Total copper loss = ${I_1}^2 R_1 + {I_2}^2 R_2$

  Where, R_1&R_2 are the primary and secondary resistances
- Material with good conductivity is used to reduce these losses, eg. copper

Transformer losses

Eddy Currents Loss:

- The varying flux in the core induces e.m.f.s and hence currents in the core material. These losses are called eddy-current losses

$$P_e = K_e {B_m}^2 f^2 t^2 v \quad watts$$

Where, t – thickness of laminations
Ke – constant
f - frequency in Hz
Bm – max flux density in tesla
v – volume of magnetic material in cubic meters

- These losses are reduced by thin laminations of silicon steel

Transformer losses

Hysteresis Loss:

- The larger the loop the greater the energy required to create the magnetic field
- This requirement of supplying energy to magnetize the core is known as the hysteresis loss.

$$P_h = K_h B_m^{1.6} f v \quad watts$$

f - frequency in Hz

Bm – max flux density in tesla

v – volume of magnetic material in cubic meters

Kh- constant

- These losses are : nearly constant, independent of current

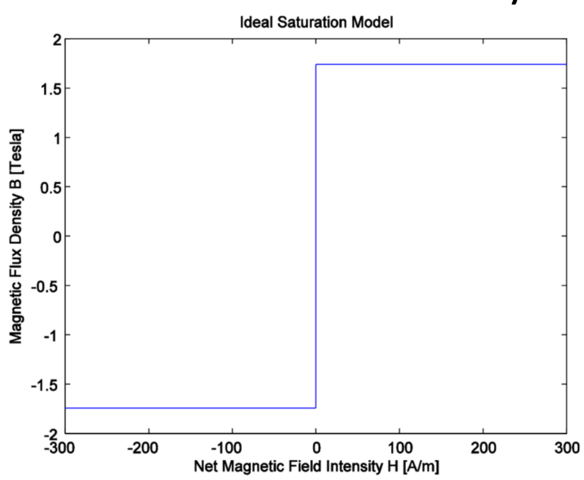

Fig. Ideal BH curve

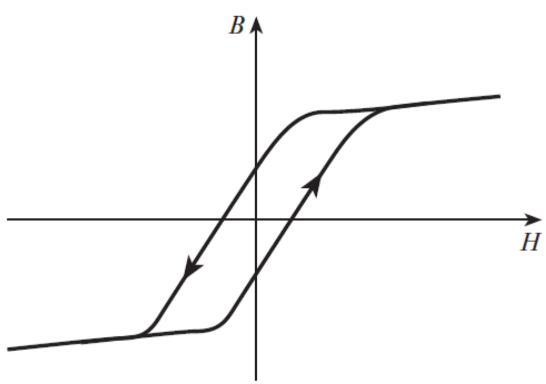

Fig. Hysteresis loop

Efficiency of a transformer

The losses which occur in a transformer on load can be divided into two groups:

1. I^2R losses in primary and secondary windings, namely $I_1^2\ R_1 + I_2^2\ R_2$
2. Core losses due to hysteresis and eddy currents.

If,

P_C = total core loss,

Then,

Total losses in transformer = $P_C + I_1^2\ R_1 + I_2^2\ R_2$

Efficiency of a transformer is given by:

$$\text{Efficiency} = \frac{\text{output power}}{\text{input power}} = \frac{\text{input power} - \text{losses}}{\text{input power}}$$

$$\boxed{\eta = 1 - \frac{\text{losses}}{\text{input power}}}$$