TRANSFORMERS

Prepared by

CH.VENKATA KRISHNA REDDY

ASST.PROF

EEE Dept

CBIT

Electrical Machines

Electrical Machine is a rotating or non rotating Device Which converts

i) Mechanical energy to Electrical Energy

(Ex: Generators)

or

ii)Electrical Energy to Mechanical energy

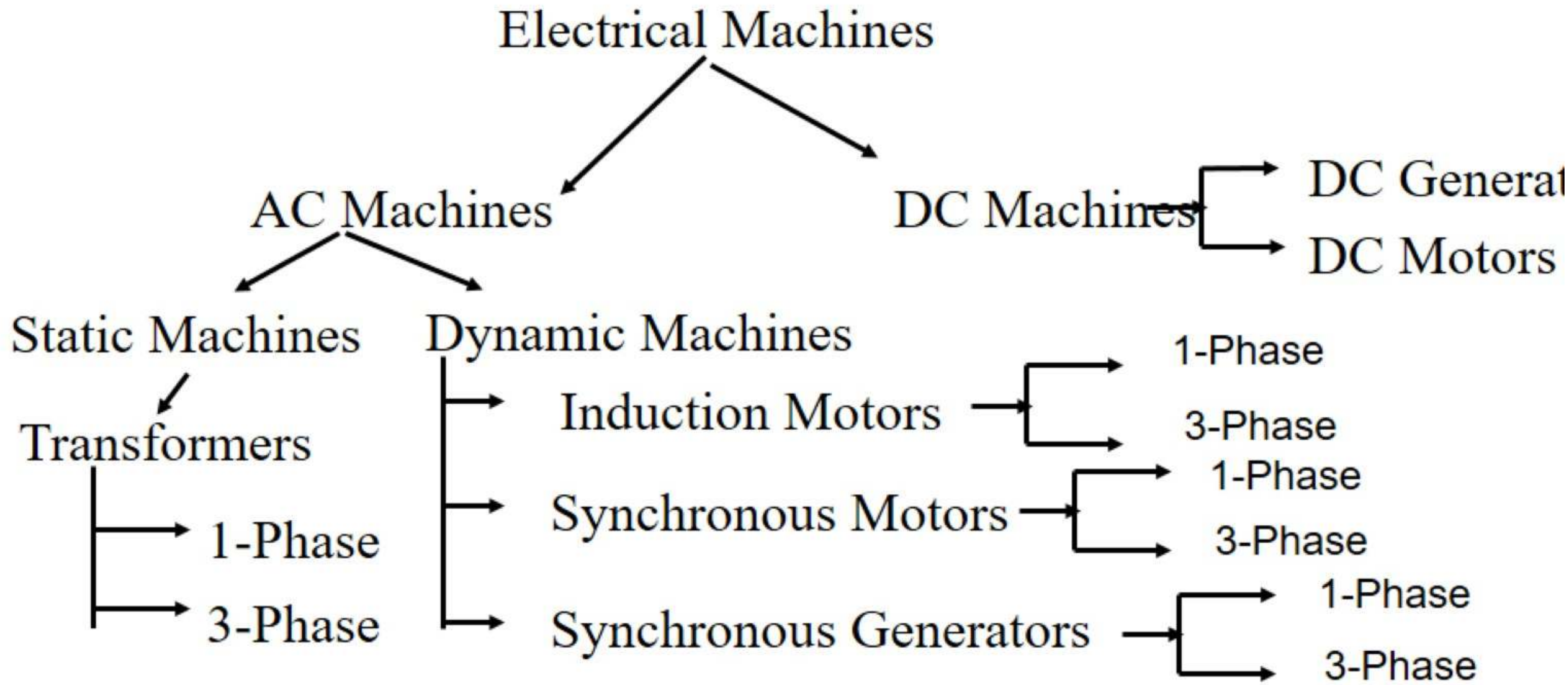
(Ex: Motors)

or

iii) Electrical Energy to electrical Energy

(Ex: Transformers)

Classification of Electrical Machines



Definition:

- A Transformer is a STATIC AC Electrical Machine that changes ac electric power from one circuit to another circuit through the process of electromagnetic induction with a desired change in voltage and current without changing frequency using Mutual induction Principle.
- *Recall:*

  i) Electromagnetic Induction

  It is the process in which an electromotive force (emf) is induced in a closed circuit due to changes in the magnetic field around the circuit.

• *Recall:*

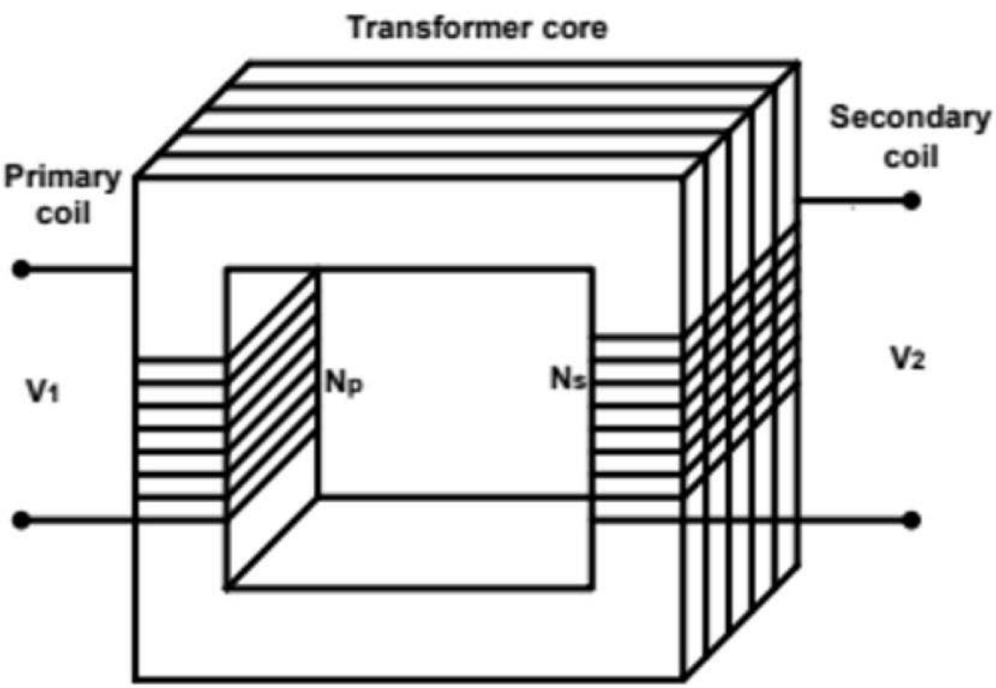
ii) Mutual induction

Principle of mutual induction states that when two coils are inductively coupled and if current in one coil is changed uniformly then an emf gets induced in the other coil. This induced emf can derive current when the closed path is provided in second coil.

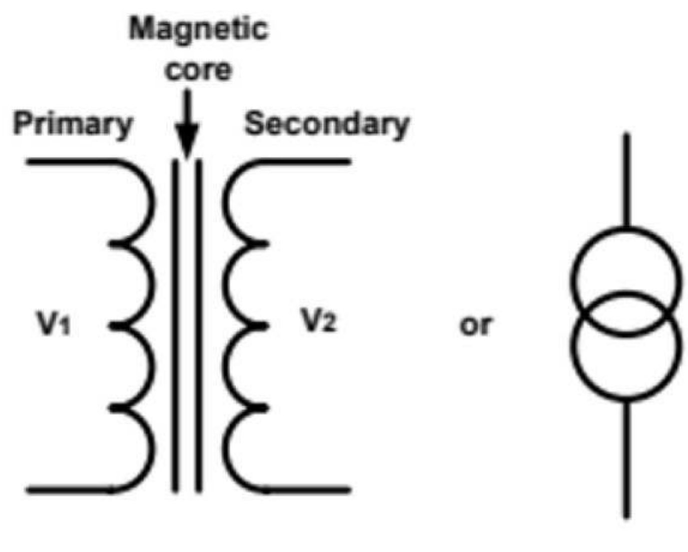
Construction:

- The main parts of a transformer are

  1. Windings or coils
     i) Primary Winding
     ii)Secondary Winding
  2. Magnetic Core



Transformer with core and winding



Transformer symbol

1. Winding

Material used is copper.

i) Primary Winding

- The winding which is connected to **source** is called Primary winding.
- Windings will have both resistance and inductance.
- But Windings will have more inductance and less Resistance. i.e generally windings are more inductive.

ii) Secondary Winding

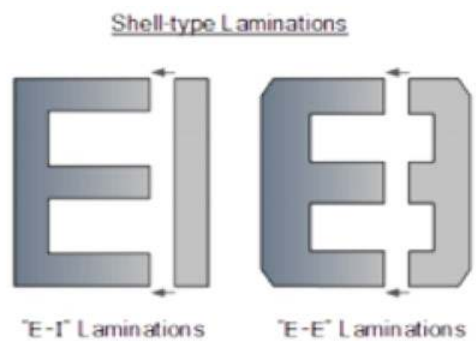
- The winding which is connected to **load** is called Secondary winding
- Windings will have both resistance and inductance.
- But Windings will have more inductance and less Resistance. i.e generally windings are more inductive.

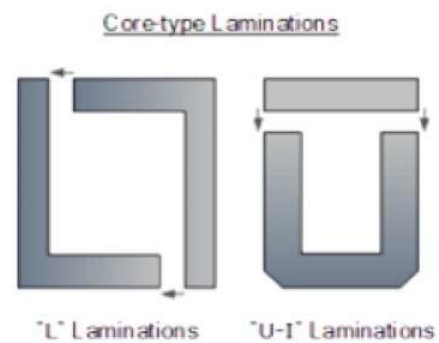
- **Construction: Magnetic Core:**

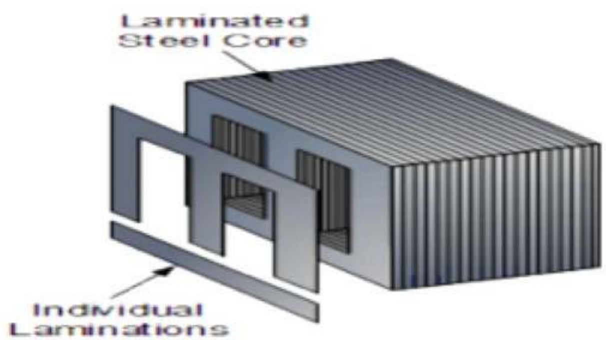
- Material used are i) Iron ii) High grade silicon steel

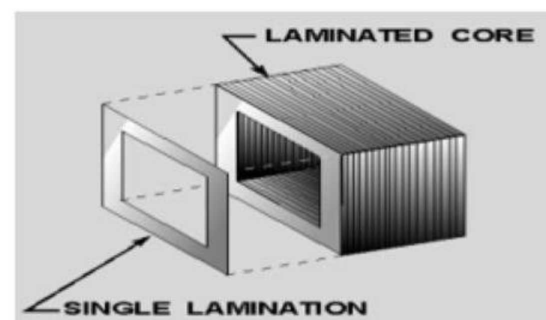
(To reduce Hysteresis loss)

- The magnetic core of a transformer is made up of stacks of thin laminations (0.35mm – 0.5mm thichkness) of cold-rolled grain oriented silicon steel sheets lightly insulated with varnish. Silicon steel has the desirable properties of low cost, low core loss and high permeability at high flux





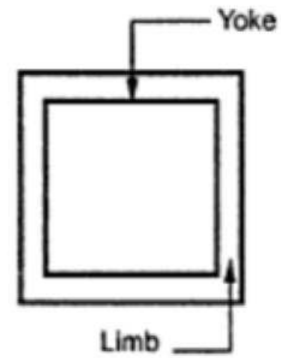




- **Construction:**
- **Magnetic Core:**

- Core consist of two Parts i) Limb

  ii) Yoke



i) Limb: The vertical portion on which coils are wound is called Limb

ii) Yoke: Top and Bottom horizontal portion is called yoke

- Size /Shape of the core is either i) Square (or) ii) Rectangle
- Core is made of laminations. Since core is laminated we can reduce eddy current loss. These laminations are insulated from each other by using insulation like varnish or paper etc. These laminations are overlapped one over the other and staged at ends to avoid air gaps.

- Types of core:

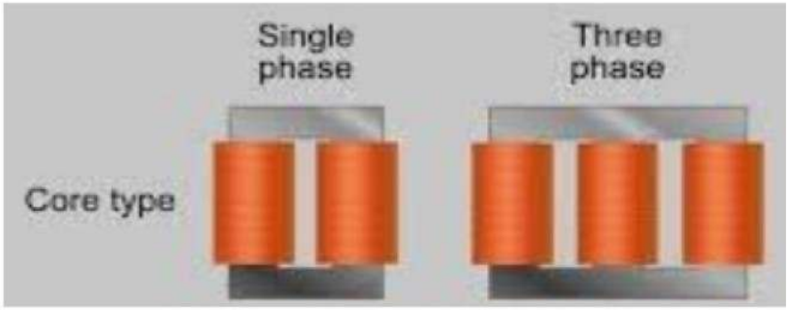
  The two types of construction differ in their relative arrangement of copper conductor and the iron cores.

  i) Coe type

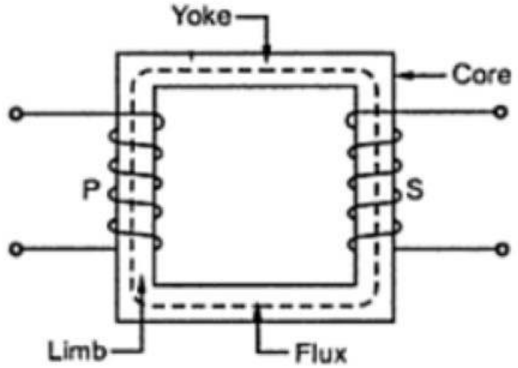
  ii) Shell type

• Construction: Magnetic Core:

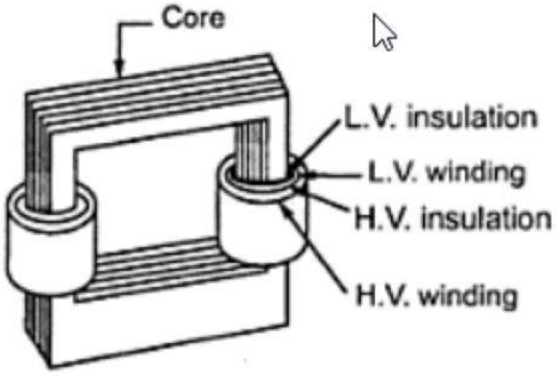
i) Core type :



- Generally core is of rectangular in shape.
- It has single Magnetic circuit
- Core will have two limbs
- Winding encircles the core
- The coils used are of cylindrical type
- Both coils are place on both limbs
- The low voltage coil is placed inside near the core
- High voltage coil is placed (surrounds) over the low voltage coil
- Windings are distributed uniformly over two limbs, Hence natural cooling is more effective.
- During maintenance, coils can be easily removed by removing laminations of the top yoke.
- Preferred for low voltage applications



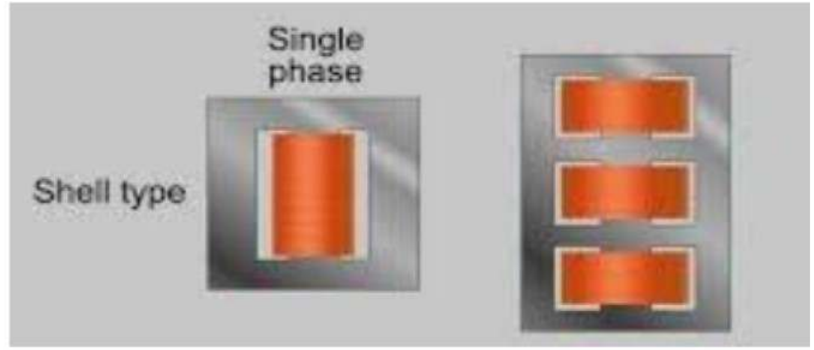
(a) Representation

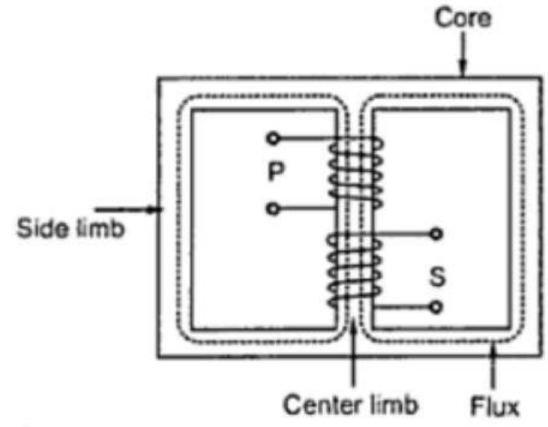


(b) Construction

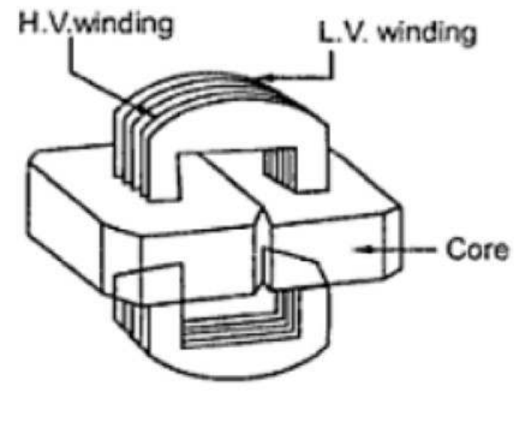
- **Construction:**
- **Magnetic Core:**
- **Shell type:**

- It has double Magnetic circuit
- Core will have three limbs
- Both windings are placed on central limb
- Core encircles the winding
- The coils used are of multi layer disc type or sandwich type
- Each high voltage coil is in between two low voltage coils and low voltage coils are nearest to top and bottom of the yokes.
- As the windings are surrounded by the core, natural cooling does not exist.
- Preferred for high voltage applications





(a) Representation



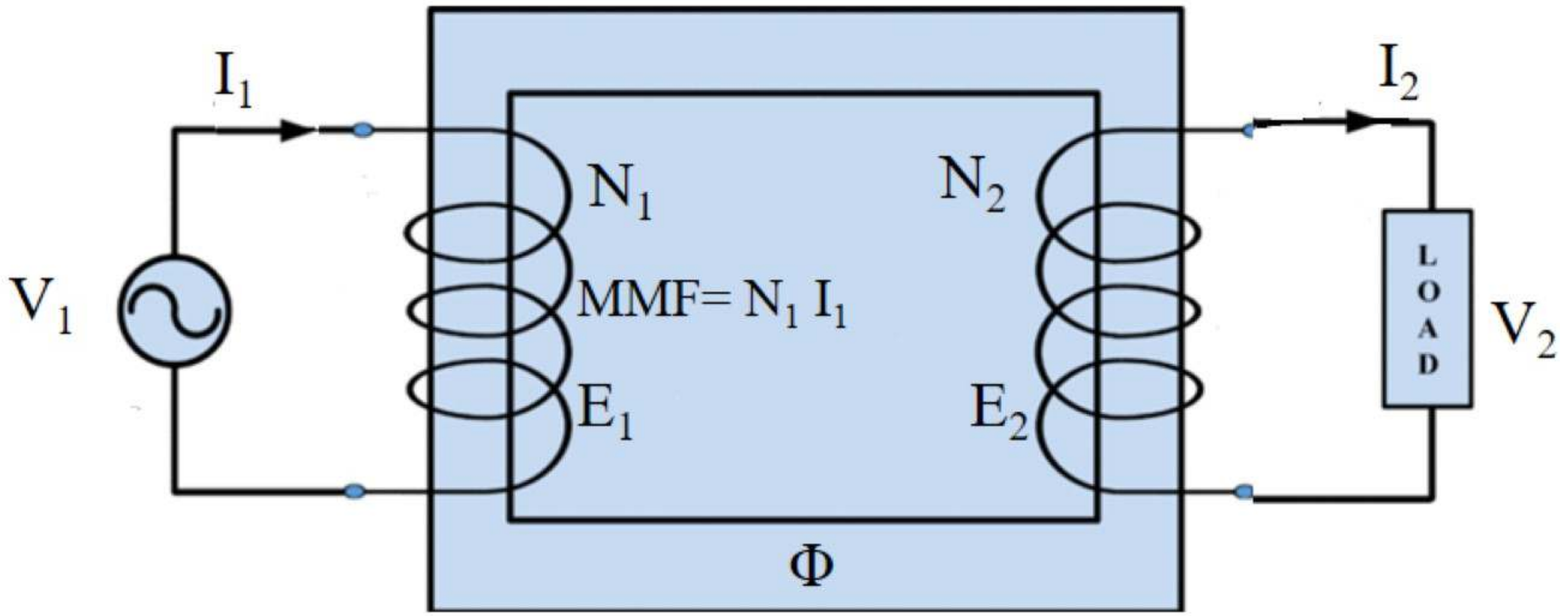
(b) Construction

Core Type		Shell Type
1.	The winding encircles the core.	The core encircles most part of the winding.
2.	It has single magnetic circuit.	It has a double magnetic circuit.
3.	The core has two limbs.	The core has three limbs.
4.	The cylindrical coils are used.	The multilayer disc or sandwich type coils are used.
5.	The windings are uniformly distributed on two limbs hence natural cooling is effective.	The natural cooling does not exist as the windings are surrounded by the core.
6.	The coils can be easily removed from maintenance point of view.	The coils can not be removed easily.
7.	Preferred for low voltage transformers.	Preferred for high voltage transformers.

- There is no electrical contact between primary winding , secondary windings and core.
- These three components are insulated with each other using insulation as paper or mica to avoid short circuit.

• Principle

AC supply is given to primary winding, current passes in the primary winding and this current is called primary current 'I_1'.This primary current 'I_1' induces MMF 'N_1I_1' on primary winding and this force set up the flux 'Φ' in the core of the transformer. According to electromagnetic induction EMF will induce in the primary coil. This induced EMF is called Self induced EMF. This self induced EMF will oppose supply voltage (Based on application of Lenz's Law).This self induced EMF is also known as Back EMF of primary. The flux available in the core will also links secondary coil. Hence due to mutual induction EMF will setup in secondary coil. If the load is connected to secondary coil current will flow. If the second coil (secondary circuit) is closed, a current flows in it and so electric energy is transferred (entirely magnetically) from the first coil to the second coil.



- **Principle:**
- If $N_1 > N_2$

  $E_1 > E_2$ $(E = N\, d\phi/dt)$

  $V_1 > V_2$ ……Known as Step down transformer

  Here

  primary coil = High voltage winding (LV)

  Secondary coil = Low voltage winding (HV)
- If $N_1 < N_2$

  $E_1 < E_2$ $(E = N\, d\phi/dt)$

  $V_1 < V_2$ ……..Known as Step up transformer

  Here

  primary coil = Low voltage winding (LV)

  Secondary coil = High voltage winding (HV)

Finally, We can say that

- Primary winding can be used as either LV winding or HV winding
- Secondary winding can be used as either LV winding or HV winding

Transformer on DC Supply:

Transformer Classification:

- Based on number of windings
  - Conventional transformer: two windings
  - Autotransformer: one winding

- Based on number of phases
  - Single-phase transformer
  - Three-phase transformer

- Based on voltage level at which the winding is operated
  - Step-up transformer: primary winding is a low voltage (LV) winding
  - Step-down transformer : primary winding is a high voltage (HV) winding
- Based on the type of core
  - Core type Transformer
  - Shell type Transformer

• EMF Equation:

• Consider that an alternating voltage ' V_1 ' of frequency ' f ' is applied to the primary winding. The sinusoidal flux ' Φ ' produced by the primary can be represented as:

$$\phi = \phi_m \sin\omega t$$

The instantaneous e.m.f. e_1 induced in the primary is

$$\begin{aligned} e_1 &= -N_1 \frac{d\phi}{dt} = -N_1 \frac{d}{dt}(\phi_m \sin\omega t) \\ &= -\omega N_1 \phi_m \cos\omega t = -2\pi f N_1 \phi_m \cos\omega t \\ &= 2\pi f N_1 \phi_m \sin(\omega t - 90^\circ) \qquad \text{(i)} \end{aligned}$$

It is clear from the above equation that maximum value of induced e.m.f. in the primary is

$$E_{m1} = 2\pi f N_1 \phi_m$$

The r.m.s. value E^ of the primary e.m.f. is

$$E_1 = \frac{E_{m1}}{\sqrt{2}} = \frac{2\pi f N_1 \phi_m}{\sqrt{2}}$$

or $E_1 = 4.44 f N_1 \phi_m$

Similarly $E_2 = 4.44 f N_2 \phi_m$

In an ideal transformer, $E_1 = V_1$ and $E_2 = V_2$.

From e.q 1,
E_1 lags the flux ϕ by 90^0
Similarly
E_2 lags the flux ϕ by 90^0

- **Example**: The primary winding of a single phase transformer is connected to a 220 V, 50 Hz supply. The secondary winding has 2000 turns. If the maximum value of the core flux is 0.003 wb, determine i) the number of turns on the primary winding ii) the secondary induced voltage

Solution:

$$E_1 = 220\,V, f = 50\,Hz$$

$$N_2 = 2000, \varphi_m = 0.003\,wb$$

$$i)\ E_1 = 4.44 f \varphi_m N_1$$

$$N_1 = \frac{E_1}{4.44 f \varphi_m} = \frac{220}{4.44 \times 50 \times 0.003} = 330$$

$$ii)\ E_2 = 4.44 f \varphi_m N_2 = 4.44 \times 50 \times 0.003 \times 2000 = 1332$$

Ideal Transformer:

A TRANSFORMER is said to be an ideal transformer if it posses all the following properties

1.Winding resistance is zero. i.e. Primary and secondary winding resistance are zero, hence no voltage drop.

2. Zero leakage flux .i.e. same amount of flux links both primary and secondary.

3. Losses are Zero.

   i.e. efficiency is 100%

   i.e input power = output power

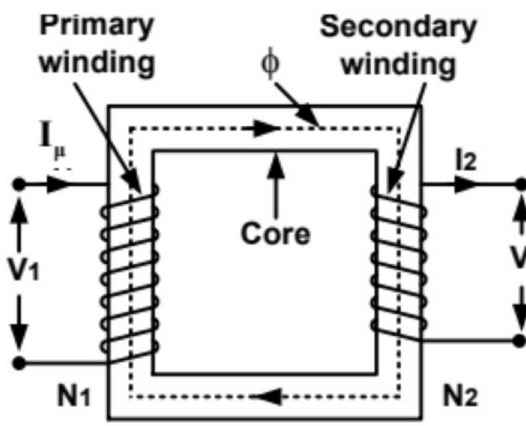
   i.e $V_1I_1=V_2I_2$

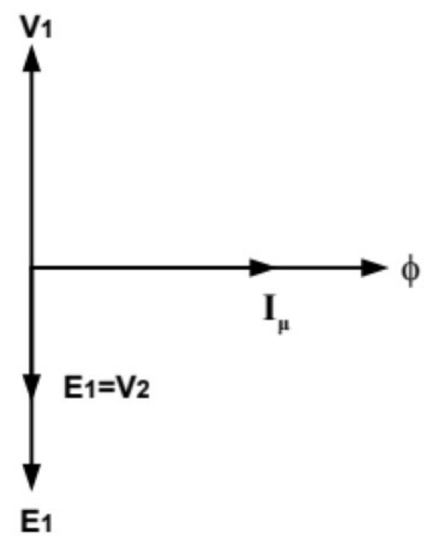
4. Zero magnetizing current. i.e.permeability of the core is infinite so that it requires zero mmf to create flux in the core.

Ideal Transformer on No-Load:

Although every winding is desired to be purely inductive but it has some resistance in it which causes voltage drop and loss in it. In such ideal transformer model, the windings are also considered ideal that means resistance of the winding is zero.

- Now if an alternating source voltage V_1 is applied in the primary winding of that ideal transformer, there will be a counter self emf E_1 induced in the primary winding which is purely 180 degree in phase opposition with supply voltage V_1.
- For developing counter emf E_1 across the primary winding, it draws current from the source to produce required magnetizing flux.
- As the primary winding is purely inductive, that current 90^o lags from the supply voltage. This current is called magnetizing current of transformer $I\mu$.
- This alternating current $I\mu$ produces an alternating magnetizing flux Φ which is proportional to that current and hence in phase with it.
- As this flux is also linked with secondary winding through the core of transformer, there will be another emf E_2 induced in the secondary winding, this is mutually induced emf.
- As the secondary is placed on the same core where the primary winding is placed, the emf induced in the secondary winding of transformer, E_2 is in the phase with primary emf E_1 and in phase opposition with source voltage V_1.





• Transformation Ratio (K):

The emf equation of a transformer is

$$E_1 = 4.44\ f\ N_1\ \phi_m$$

Hence

$$E_2 = 4.44\ f\ N_2\ \phi_m$$

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} \qquad \therefore \quad \frac{E_2}{E_1} = \frac{N_2}{N_1} = K$$

(i) $E_1 = V_1$ and $E_2 = V_2$ as there is no voltage drop in the windings.

$$\therefore \quad \frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{N_2}{N_1} = K$$

(ii) there are no losses. Therefore, volt-amperes input to the primary are equal to the output volt-amperes i.e.

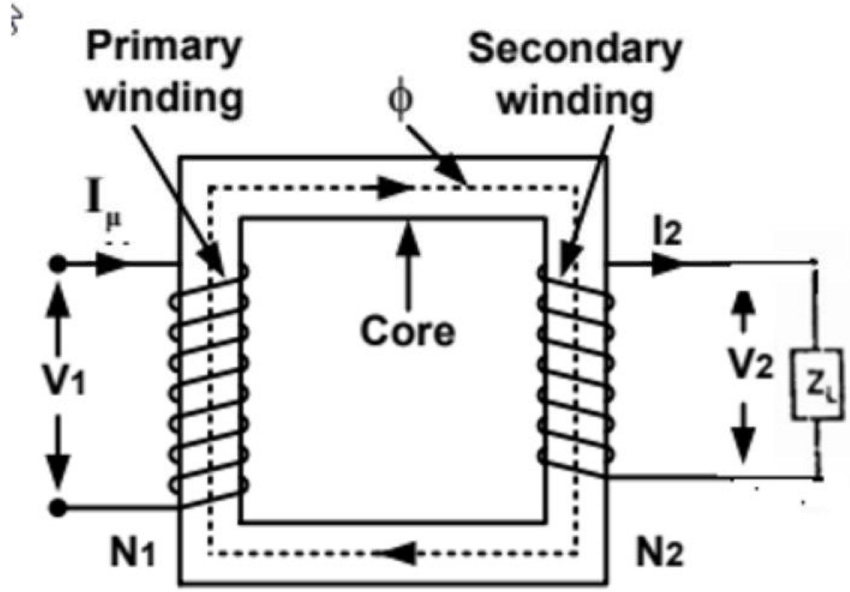
$$V_1 I_1 = V_2 I_2$$

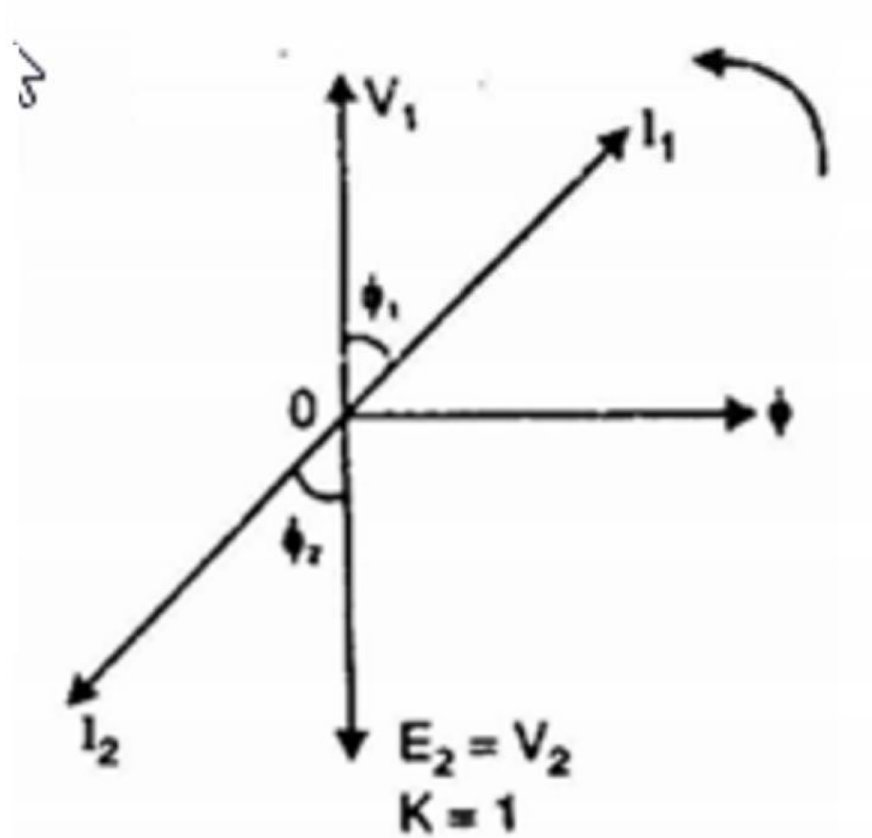
or $$\frac{I_2}{I_1} = \frac{V_1}{V_2} = \frac{1}{K}$$

Hence, currents are in the inverse ratio of voltage transformation ratio. This simply means that if we raise the voltage, there is a corresponding decrease of current.

• Ideal Transformer on Load:

Consider the load Z_L is connected to secondary winding, then according to transformer principle, I_2 current will flow in the winding which makes voltage drop V_2 across the load.

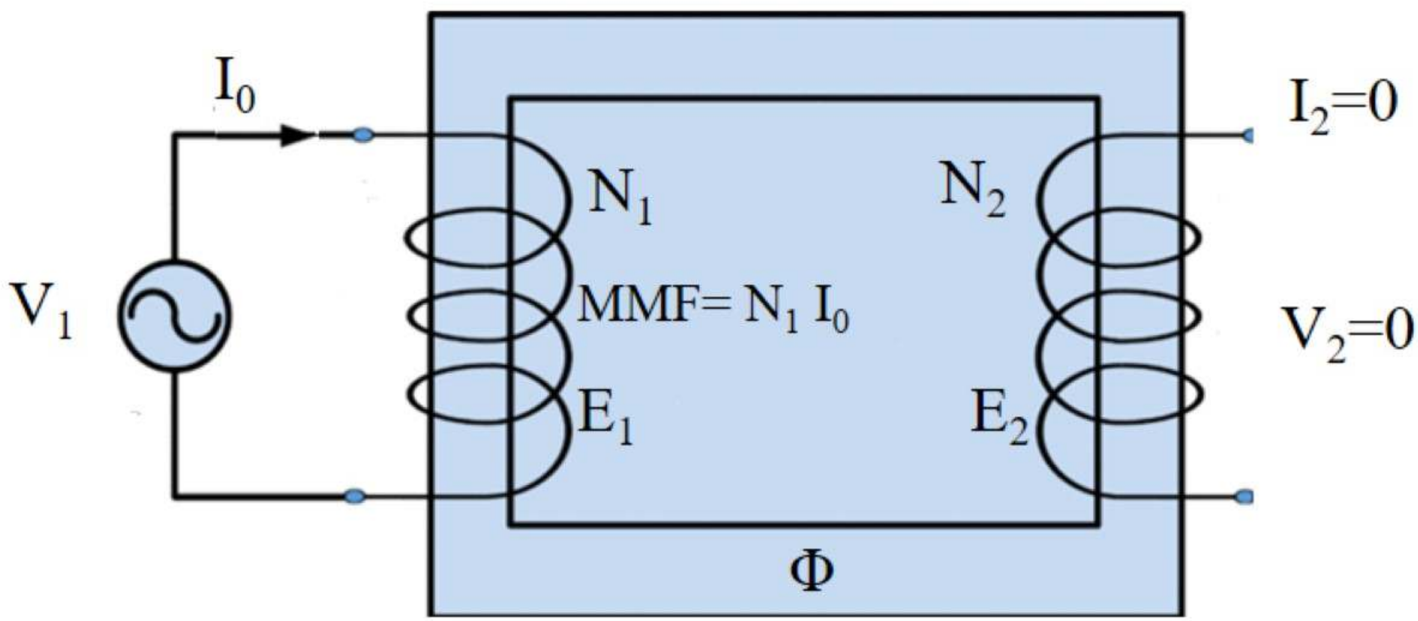




Transformer on No-Load(1/4):

When the transformer is operating at no load, the secondary winding is open-circuited, which means there is no load on the secondary side of the transformer and, therefore, current in the secondary will be zero. While primary winding carries a small current 'I_0' called no-load primary current which is 3 to 5% of the rated primary current.

This No-Load primary current is responsible for supplying the iron losses (hysteresis and eddy current losses) in the core and a very small amount of copper losses in the primary winding.

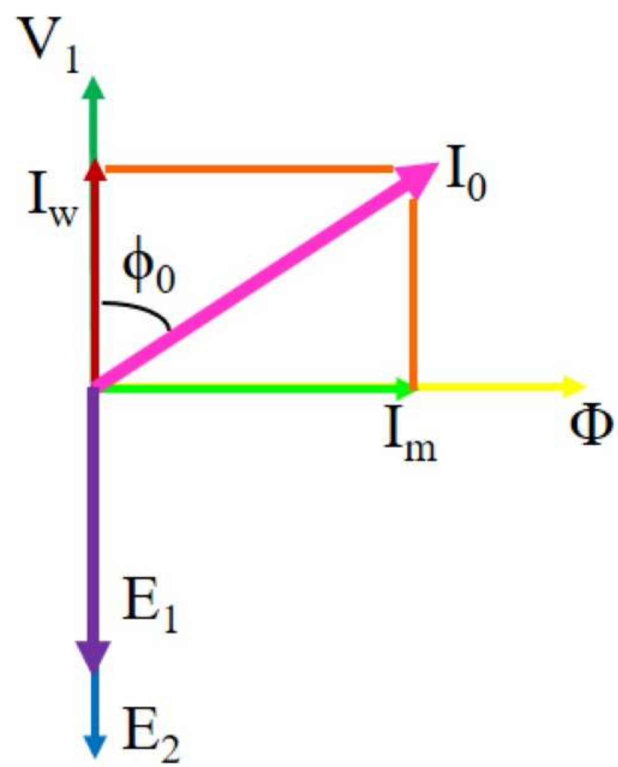


Transformer on No-Load(2/4):

- Hence this No-Load primary current is made up with two components. i.e I_w and I_m
- The component I_m is called magnetizing component and it magnetize the core and is in phase with Φ (since $I_m \alpha \Phi$). It is also called reactive component or wattles component of No-load current.
- The another component I_w is called working component or active component or wattful component and is in phase with supply voltage.
- No load current I_0 is small. So drops in R_1 and X_1 on primary side are very small(Neglect). At no load $V_1 = E_1$.
- No load primary copper loss ($I_0^2 R_1$) is very small(Neglect). So, no load primary input power is equal to iron loss.

Transformer on No-Load(3/4):

- Consider Φ phasor as reference phasor(Since flux Φ in the core is same for both windings)
- Since E_1 and E_2 are induced EMFs by the same flux and they will be in phase with each other. E_2 differs from magnitude of E_1. E_1 and E_2 are lag behind Φ by 90^0.
- If the voltage drops in primary winding are neglected, E_1 will be equal and opposite to the applied voltage V_1.
- I_m is in phase with Φ
- I_w is in phase with V_1.
- The phasor sum of I_m and I_w is I_0
- Hence ϕ_0 is the angle between V_1 and I_m and is Known as no-load power factor angle and corresponding power factor is cos ϕ_0



- **Transformer on No-Load(4/4):**

$$I_w = I_0 \cos\varphi_0 \,, I_m = I_0 \sin\varphi_0 \,, I_0 = \sqrt{{I_m}^2 + {I_w}^2}$$

$$\text{No load power factor}, \cos\varphi_0 = \frac{I_w}{I_0}$$

$$\text{No load input power (active power)} = V_1 I_0 \cos\varphi_0$$

$$\text{No load reactive power} = V_1 I_0 \sin\varphi_0$$