Unit V [Transformer & Three Phase Induction Motor]

Sinchitha. C

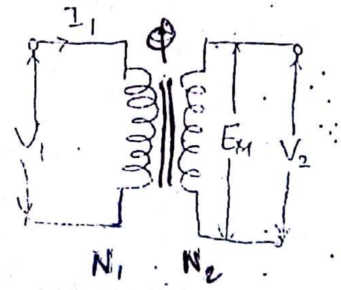
G sec

⇐: TRANSFORMERS :⇒

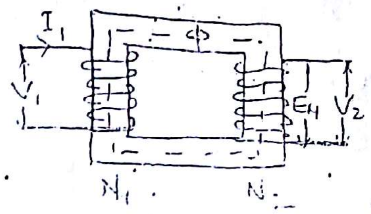
Definition ⇒ Transformer is a static electrical machine, which transfers electrical energy from one circuit to another circuit without change in frequency.

Working Principle ⇒

Transformer works on the principle of mutual induction and is explained below.



(1)



(2)

Above fig (1) shows symbolical representation of transformer where V_1 is the voltage applied to primary winding with N_1 no. of turns, then varying current I_1 flows through N_1 turns, produces its own magnetic field around it causing establishment of varying flux ϕ_1. This varying flux linking with both N_1 turns of primary and also links secondary N_2 turns. When ϕ_1 links secondary turns N_2 causes change in flux linkages ($N_2\phi_1$) thus emf is induced in secondary turns N_2. Hence electrical energy in primary winding is transferred to secondary winding without change in frequency. Therefore emf is available in secondary winding due to variation of current I_1 in primary winding thus mutual induction between two coils. The mutual induced emf in secondary winding is given by

$$\boxed{E_M = M \cdot \frac{dI_1}{dt}}$$

where M is mutual induction between primary & secondary windings

Classification of Transformers :→

Transformers can be classified based on many factors and they are as follows.

1> **Based on Constructional details**

a> Core type transformers

b> shell type transformers

2> **Based on Secondary output Voltage**

a> Step up transformer

b> Step down transformer

3> **Based on rating**

a> Power Transformers

b> Distribution Transformers

4> **Based on measurement**

a> Potential Transformers

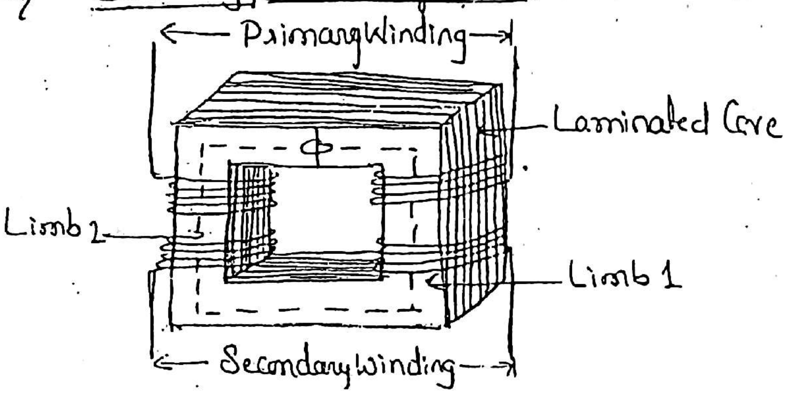
b> Current Transformers

5> **Application based**

Welding Transformers.

Constructional Details :→

a> **Core type Transformer :→**

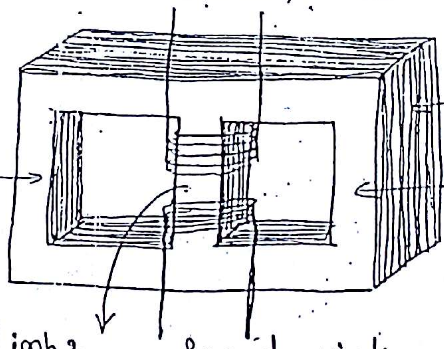


-Any transformer has got two very important parts of it they are
1> Core 2> Windings.

In Core type transformer, * Core is of rectangular shape with two limbs.
* Core is made from high grade silicon steel to minimise hysterisis losses.
* Core is made using laminations to minimise the eddy current losses.
* It has single magnetic circuit.
* Here the windings surrounds the core.
* The windings are made of copper material and windings used are of cylinderical.
* In this type of transformer, primary is split into two windings and winding is done on both limbs of core. Similarly secondary winding is also split into two windings and winding is done on both limbs of core. This arrangement is done to minimise the leakage of flux and to have better flux linking.

* As windings are exposed outside the core and are also split into two, the natural cooling is more effective.

b> Shell type

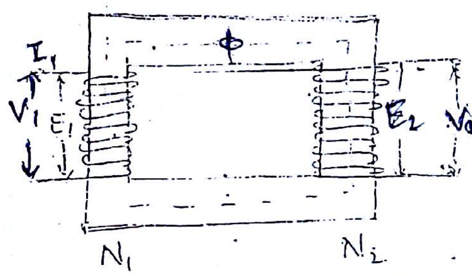


* Core is made from high grade silicon steel to minimise hysterisis losses and winding is made of copper material.
* Core is made of laminations to minimise eddy current losses.
* Here core is having double magnetic circuit and three limbs.
* Here core surrounds windings since winding is done on central limb of the two side limbs of core surrounds the winding therefore natural cooling is not effective.
* Winding type is sandwitched winding, where high voltage windings are sandwitched between two low voltage windings.

Comparision of Core type and Shell type Transformers :-

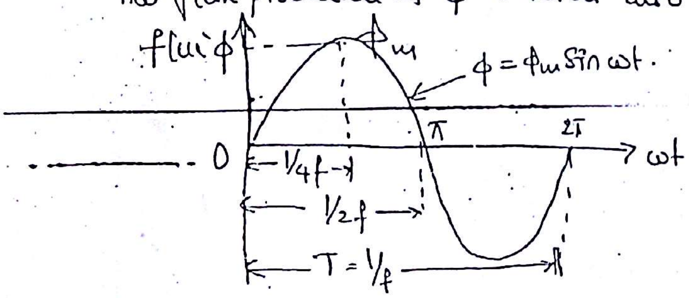
Core type	Shell type
* Winding surrounds the Core	* Core surrounds the winding
* Has single ~~magnetic~~ Circuit	* Has Double magnetic Circuit
* Core has two limbs	* Core has three limbs
* Cylindrical windings are used	* Sandwitched windings are used.
* Natural Cooling is effective	* Natural Cooling is not effective
* Prefered for low voltage transformers	* Prefered for high voltage transformers

EMF Equation of a Transformer :-



Let ϕ be the flux in wb
ϕ_m be the maximum flux in wb
N_1 be the no of turns on primary
N_2 be the no. of turns on secondary
f be the frequency of the supply in Hz
E_1 be the RMS value of primary induced emf
E_2 be the RMS value of secondary induced emf.

As it is known, when input voltage V_1 is applied to primary, then alternating current I_1 flows through N_1 turns and produces its own magnetic field around it. The flux produced is ϕ which is also alternating in nature and hence shown below.



Now from faradays law of electromagnetic induction, average emf induced per each turn is proportional to average rate of change of flux.

$$\therefore \text{Avg. emf per turn} = \frac{d\phi}{dt}$$

If we consider a quarter cycle of flux wave, the change in flux is given as $(\phi_m - 0)$ and time taken to have this change in flux is $1/4f$ sec.

Avg. emf induced per turn = $\dfrac{\text{change in flux}}{\text{Time required for change of flux}}$

$= \dfrac{\phi_m - 0}{1/4f}$

$= 4f\phi_m$

Now RMS value of emf induced per turn $= 1.11 \times 4f\phi_m$

$= 4.44 f\phi_m$ ($\because$ Form factor $= \frac{RMS}{Avg}$)

Since in primary winding N_1 turns are there, hence RMS value of emf induced in N_1 turns $= 4.44 f\phi_m N_1$ volts.

$\therefore$ $\boxed{E_1 = 4.44 f\phi_m N_1 \text{ volts}}$

Similarly emf induced in secondary N_2 turns $= 4.44 f\phi_m N_2$

$\boxed{E_2 = 4.44 f\phi_m N_2 \text{ volts}}$

Ratio of Transformer :→

We have, $E_1 = 4.44 f\phi_m N_1$ & $E_2 = 4.44 f\phi_m N_2$ ...... ϕ B = $\frac{\phi}{A}$

Taking E_2/E_1, then

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

$\therefore$ $\boxed{\dfrac{E_2}{E_1} = \dfrac{N_2}{N_1} = K}$ where K is voltage transformation ratio.

1) If $N_2 > N_1$ i.e $K > 1$ then $E_2 > E_1$ then transformer is called as step up transformer.

2) If $N_1 > N_2$ i.e $K < 1$ then $E_1 > E_2$ then transformer is called as step down transformer.

3) If $N_1 = N_2$ i.e $K = 1$, then $E_2 = E_1$ then transformer is called as isolation transformer or unit transformer.

Scanned by CamScanner

Current Ratio :→

$V_1 I_1$ = Input VA , $V_2 I_2$ = output VA

For ideal transformer,

$$V_1 I_1 = V_2 I_2$$

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

Rating of Transformer :→

$$\text{KVA rating of Transformer} := \frac{V_1 I_1}{1000} = \frac{V_2 I_2}{1000}$$

$$\therefore I_{1\,full\,load} = \frac{\text{KVA rating} \times 1000}{V_1}$$

$$\therefore I_{2\,full\,load} = \frac{\text{KVA rating} \times 1000}{V_2}$$

Losses in a Transformer :→

Losses in transformer can be classified as i) Iron losses 2) Copper losses.

1) Iron losses (core losses or Constant losses) :→

Iron losses can be classified as a) Hysterisis losses b) Eddy current losses

a) Hysterisis losses :→

Due to alternating ~~flux~~ setup in the magnetic core of transformer, the core undergoes a cycle of magnetization and de-magnetization which is called as hysterisis effect. Due to this hysterisis effect, there is loss of energy in this process called as hysterisis loss.

It is given by $W_{Hysterisis} = K_h \cdot B_m^{1.67} f V$ watts

where K_h hysterisis constant depends on material.

B_m maximum flux density

f frequency

V volume of the core.

Scanned by CamScanner

To minimise the hysteresis losses, the core is made of material having silicon content with low hysteresis loop.

b) Eddy Current losses :→

During mutual induction process, the alternating flux links both N_1 and N_2 of primary and secondary winding and also links core thus producing emf inducement in the core, as core is a closed path the current starts circulating in the core called as eddy current and this eddy current produces eddy current losses which is given as

$$\boxed{W_{eddy} = K_e B_m^2 f^2 t^2 \text{ Watts / unit Volume}}$$

In the form of Eddy emf

where K_e eddy current constant

t thickness of core

B_m maximum flux density

f frequency

The eddy current losses can be minimised by manufacturing laminated core. The laminated core gives less area, which in turn increases the resistance and decreases the eddy current, hence minimises the Eddy current losses.

2> Copper losses :→

The Copper losses are due to the power wasted in the form of I^2R losses due to resistance of primary and secondary windings. The Copper loss depends on the magnitude of the current flowing through windings.

$$\boxed{\text{Total Copper loss} = I_1^2 R_1 + I_2^2 R_2}$$

If the current through the windings is full load current, we get Copper loss at full load.

★ Why Copper losses are called variable losses? and Iron losses are called Constant losses?

Iron losses as Constant losses :→

As the flux in the core is almost constant as supply voltage V_1 at rated frequency f is always constant. Hence flux density B_m in the core and hence both hysteresis and eddy current losses are constant at all loads. Hence Iron losses are called as constant losses.

<u>Copper losses as Variable losses</u> :⇒

Since Copper losses are depending on the magnitude of current flowing in secondary winding, and magnitude of current varies as the load on transformer varies. Hence Copper losses varies. At full load current Copper losses are full load Copper losses, at half load, Copper losses are half load Copper losses. Thus copper losses are variable losses.

Voltage Regulation of Transformer :⇒

When transformer is connected to load, it is observed that voltage drops across the secondary impedances thus the secondary terminal voltage drops from its no load value (E_2) to load value (V_2) as load and the current increases.

<u>Definition</u>:- Voltage regulation of transformer is defined as the change in secondary output terminal voltage from no load to full load.

Let $E_2 \rightarrow$ Secondary terminal voltage on no load
$V_2 \rightarrow$ Secondary terminal voltage on given load.

then % voltage regulation is given by

$$\boxed{\%\text{ Voltage regulation} = \frac{E_2 - V_2}{E_2} \times 100}$$

<u>Its importance</u>:⇒

* If regulation is low, then it indicates that voltage drop across secondary winding is less
* If regulation is low then transformer is said to be well performing

Scanned by CamScanner

Efficiency of Transformer :→

η is generally given as output by input.

$$\therefore \eta = \frac{\text{Output}}{\text{Input}} \times 100$$

$$\eta = \frac{\text{Power output}}{\text{Power input}} \times 100$$

Power output = Power input ~~+~~ losses (Total)

$\therefore$ Power input = Power output + Total losses

= Power output + $P_i + P_{cu}$.

$$\eta = \frac{\text{Power output}}{\text{Power output} + P_i + P_{cu}}$$

Now power output = $V_2 I_2 \cos\phi$ (where $\cos\phi$ is load power factor)

$$\therefore \eta = \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + P_i + I_2^2 R_2} \quad (\text{where } P_{cu} = I_2^2 R_2)$$

But $V_2 I_2$ is VA rating of transformer.

$$\therefore \eta = \frac{(\text{VA rating}) \times \cos\phi}{(\text{VA rating}) \times \cos\phi + P_i + I_2^2 R_2}$$

$$\boxed{\eta_{\text{at full load}} = \frac{(\text{VA rating}) \times \cos\phi}{(\text{VA rating}) \times \cos\phi + P_i + P_{cu \text{ at full load}}}}$$

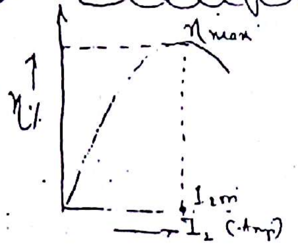
From the η equation the only variable parameter with load is I_2 hence η at fractional load is given by

$$\boxed{\eta_{\text{at fractional load}} = \frac{x\,(\text{VA rating}) \times \cos\phi}{x\,(\text{VA rating}) \times \cos\phi + P_i + x^2 (I_2^2 R_2)}}$$

Where x is load put on Transformer, for ex; if transformer is 50% loaded then $x = 0.5$ & η equation becomes

$$\eta_{\text{at 50\% of full load}} = \frac{0.5\,(\text{VA rating}) \times \cos\phi}{\ldots}$$

Imp — Condition for maximum efficiency :-



For a given constant input voltage & rated frequency transformer efficiency varies with load.
As load increases, η increases and at certain load current, it achives a maximum efficiency.
After this increase in load or load current decreases the efficiency and is shown in graph.

Efficiency is a function of load; i.e load current I_2, $\cos\phi$ & V_2 are assumed constant, so for maximum efficiency the condition is obtained by

$$\frac{d\eta}{dI_2} = 0,$$

$$\therefore \eta = \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + P_i + I_2^2 R_2}$$

$$\therefore \frac{d\eta}{dI_2} = \frac{d}{dI_2}\left[\frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + P_i + I_2^2 R_2}\right]$$

$$(V_2\cos\phi)\, I_2\, (V_2\cos\phi + 2 I_2 R_2)$$

$$(V_2 I_2 \cos\phi + P_i + I_2^2 R_2)\frac{d}{dI_2}(V_2 I_2 \cos\phi) - \cancel{V_2 I_2 \cos\phi \frac{d}{dI_2}(\ldots)}$$

$$\therefore (V_2 I_2 \cos\phi + P_i + I_2^2 R_2)(V_2\cos\phi) = (V_2\cos\phi) I_2 (V_2\cos\phi + 2 I_2 R_2) = I_2 V_2 \cos\phi + 2 I_2^2 R_2$$

$$V_2 I_2 \cos\phi + P_i + I_2^2 R_2 = V_2 I_2 \cos\phi + 2 I_2^2 R_2$$

$$P_i = 2 I_2^2 R_2 - I_2^2 R_2$$

$$\therefore P_i = I_2^2 R_2$$

$$\therefore \boxed{P_i = P_{cu}} \quad \text{or} \quad \boxed{P_{cu} = P_i}$$

Thus Condition for maximum efficiency is

$\boxed{\text{Copper loss} = \text{Iron losses}}$

Load Current I_{2m} at maximum efficiency :-

$$I_2^2 R_2 = P_i \qquad \text{as } I_2 = I_{2m}$$

$$\therefore I_{2m}^2 R_2 = P_i$$

$$\therefore I_{2m}^2 = \frac{P_i}{R_2}$$

$$\therefore I_{2m} = \sqrt{\frac{P_i}{R_2}}$$

dividing I_{2fL} on both sides.

$$\frac{I_{2m}}{I_{2fL}} = \frac{1}{I_{2fL}}\sqrt{\frac{P_i}{R_2}} \Rightarrow \frac{I_{2m}}{I_{2fL}} = \sqrt{\frac{P_i}{I_{2fL}^2 R_2}} \Rightarrow \boxed{I_{2m} = I_{2fL}\sqrt{\frac{P_i}{P_{cu}}}}$$

5.5 KVA load supplied at Maximum efficiency :⇒

For constant $i_{\ldots}$ ∴ the KVA supplied is function of load current

$$\therefore KVA \text{ at } \eta_{max} = I_{2m}V_2 = V_2 (I_2)_{FL} \times \sqrt{\frac{P_i}{P_{cu \text{ at } FL}}}$$

$$\boxed{KVA \text{ at } \eta_{max} = (KVA \text{ rating}) \times \sqrt{\frac{P_i}{P_{cu \text{ at } FL}}}}$$

→ 3ϕ Induction Motor ←

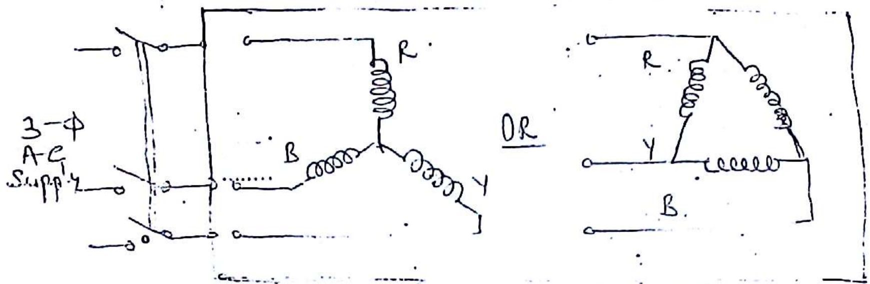
Definition: → Three phase induction motor is a rotating machine which works on the principle of rotating field.

Rotating Magnetic field :→

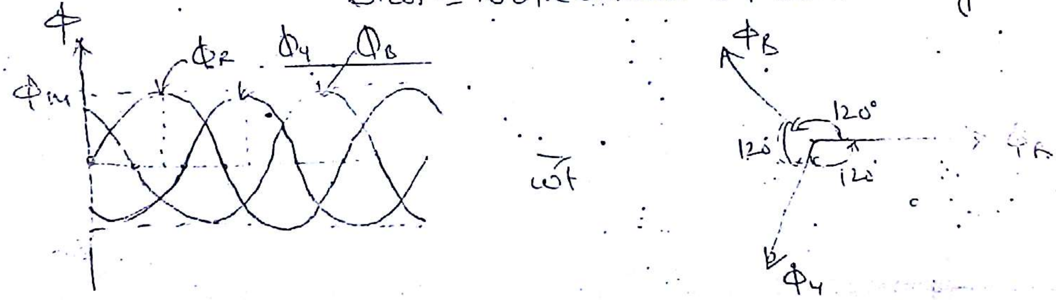
It is defined as the field or flux having constant Amplitude but whose axis is continuously rotating in a plane with certain speed.

In 3-ϕ Induction motor such a rotating magnetic field is produced by supplying currents to a set of stationary windings, with the help of 3-ϕ AC supply.

Production of Rotating Magnetic field :→



Star or Delta Connected 3-ϕ statorwinding.



* The stator of 3-ϕ Induction motor consists of 3-ϕ stator windings which are connected either in Star or Delta connection.

These windings are supplied with 3-ϕ AC supply, then perphase voltage across each phase of stator is V_R, V_Y and V_B and corresponding currents are I_R, I_Y and I_B, the fluxes produced by these currents are ϕ_R, ϕ_Y and ϕ_B and are shown both in waveforms and phasors above.

Then the instantaneous values of the fluxes are given by

$$\phi_R = \phi_m \sin\theta$$

$$\phi_Y = \phi_m \sin(\theta - 120°)$$

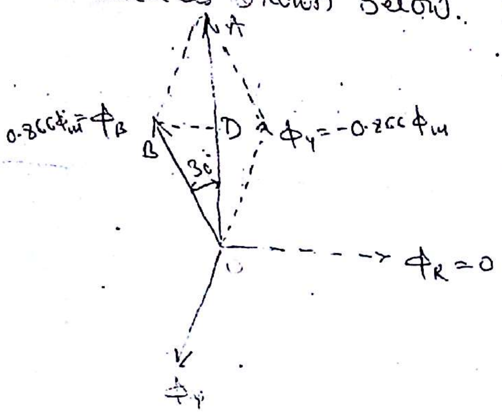
$$\phi_B = \phi_m \sin(\theta - 240°)$$

The resultant flux ϕ_T' of the three fluxes ϕ_R ϕ_Y and ϕ_B is found at different instances such as $\theta = 0, 60, 120$ and 240.

Case 1) when $\theta = 0$

$$\phi_R = \phi_m \sin 0 = 0$$
$$\phi_Y = \phi_m \sin(0-120) = -0.866\,\phi_m$$
$$\phi_B = \phi_m \sin(0-240) = +0.866\,\phi_m$$

The resultant ϕ_T is obtained by the phasor addition of ϕ_Y & ϕ_B and is shown below.



BD is drawn perpendicular from B on ϕ_T. It bisects ϕ_T.

$\therefore OD = DA = \phi_T/2$

In Δ^{le} OBD, $\cos 30 = \frac{OD}{OB}$

$$\frac{\sqrt{3}}{2} = \frac{\phi_T/2}{0.866\,\phi_m}$$

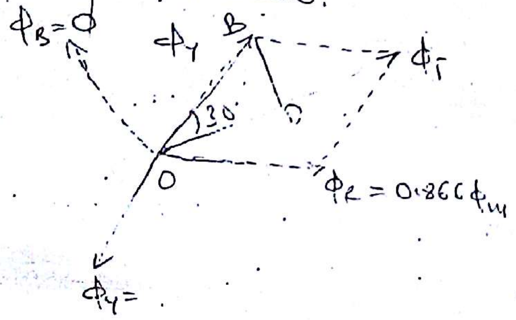
$$\therefore \phi_T = \sqrt{3} \times 0.866\,\phi_m$$

$$\boxed{\therefore \phi_T = 1.5\,\phi_m}$$

Case 2) when $\theta = 60$

$$\phi_R = \phi_m \sin 60 = +0.866\,\phi_m$$
$$\phi_Y = \phi_m \sin(60-120) = -0.866\,\phi_m$$
$$\phi_B = \phi_m \sin(60-240) = 0$$

Now resultant ϕ_T is obtained by the phasor addition of ϕ_R & ϕ_Y and is shown below.



BD is drawn perpendicular from B on ϕ_T. It bisects ϕ_T.

$\therefore OD = DA = \phi_T/2$

In Δ^{le} OBD, $\cos 30 = \frac{OD}{OB}$

$$\frac{\sqrt{3}}{2} = \frac{\phi_T/2}{0.866\,\phi_m}$$

$$\therefore \phi_T = \sqrt{3} \times 0.866\,\phi_m$$

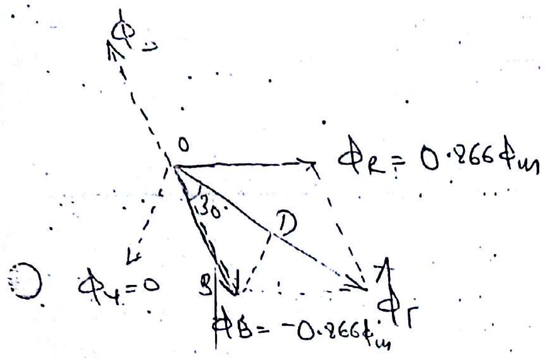
$$\boxed{\phi_T = 1.5\,\phi_m}$$

$\phi_R = \phi_m \sin 120° = +0.866\phi_m$

$\phi_Y = \phi_m \sin(120-120°) = 0$

$\phi_B = \phi_m \sin(120°-240°) = -0.866\phi_m$

Now resultant ϕ_T is obtained by the phasor addition of ϕ_R & ϕ_B and is shown below.



BD is drawn perpendicular from B on ϕ_m. It bisects ϕ_T.

$\therefore OD = DA = \phi_T/2$

In Δ^{le} OBD: $\cos 30 = \frac{OD}{OB}$

$$\frac{\sqrt{3}}{\cancel{2}} = \frac{\phi_T/\cancel{2}}{0.866\phi_m}$$

$\therefore \phi_T = \sqrt{3} \times 0.866\phi_m$

$\boxed{\phi_T = 1.5\phi_m}$

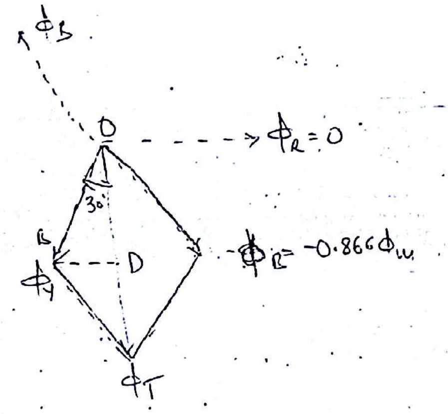
Case : 4> $\theta = 180°$

$\phi_R = \phi_m \sin 180° = 0$

$\phi_Y = \phi_m \sin(180-120°) = +0.866\phi_m$

$\phi_B = \phi_m \sin(180°-240°) = -0.866\phi_m$

Now the resultant ϕ_T is obtained by the phasor addition of ϕ_Y & ϕ_B and is shown below.



BD is drawn perpendicular on ϕ_T from B so that it bisects ϕ_T.

$\therefore OD = DA = \phi_T/2$

In Δ^{le} OBD $\cos 30° = \frac{OD}{OB}$

$$\frac{\sqrt{3}}{\cancel{2}} = \frac{\phi_T/\cancel{2}}{0.866\phi_m}$$

$\phi_T = \sqrt{3} \times 0.866\phi_m$

$\boxed{\phi_T = 1.5\phi_m}$

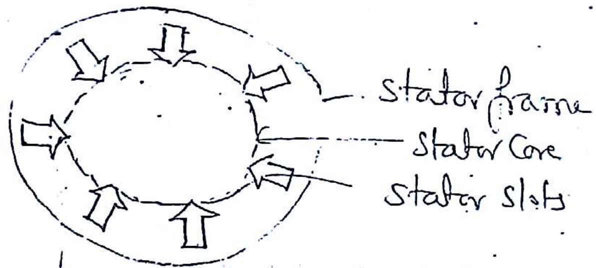
From the above four different cases, it is clear that resultant flux with constant magnitude $1.5\phi_T$ rotates with certain speed. The speed is found out to be N_s synchronous speed. Thus rotating magnetic field. Speed of rotating magnetic field is $N_s = \frac{120f}{P}$.

Constructional Details of 3-φ induction Motor :→

3-φ Induction motor has two important parts and they are
i> Stator ii> Rotor

1> Stator :→

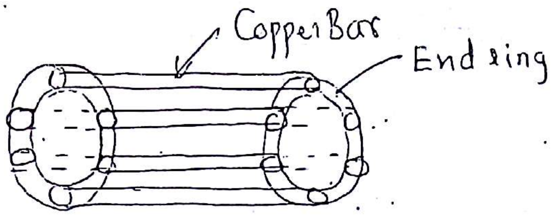
* Stator is the stationary part of the motor.
* Stator has laminated construction made up of stampings which are 0.4 mm to 0.5 mm thick.
* Stator stampings are sloted at its periphery to carry the stator windings.
* Stampings are insulated from each other.
* The number of stampings are stamped together to build the Stator Core.
* The builtup stator core is then fitted in a casted or fabricated [illegible] [illegible].
* The choice of material and laminated construction of core minimises [illegible] losses.
* The stator has got 3-φ windings wound for definite no. of poles.



2> Rotor :→

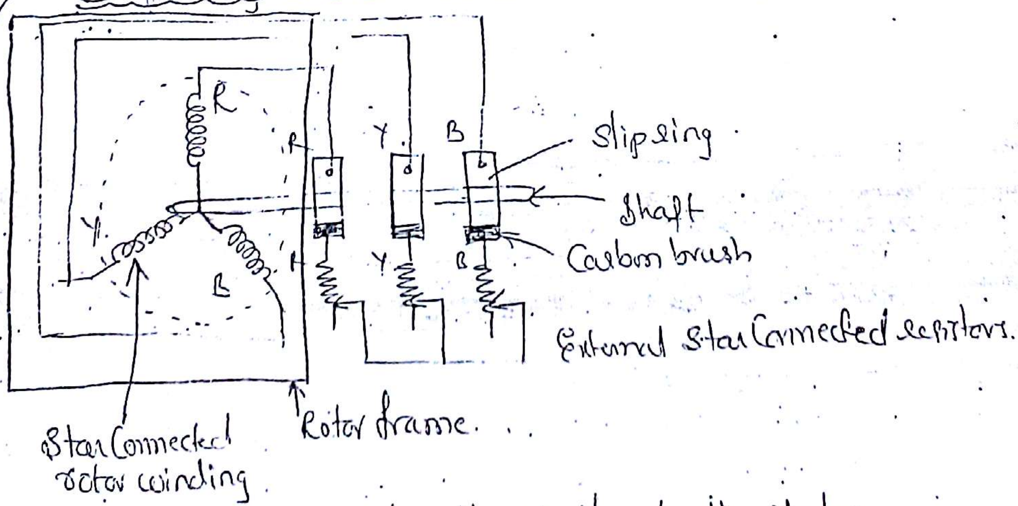
There are two types of rotors available for 3-φ Induction motor and they are
a> Squirrel Cage Type rotor
b> Slip ring type rotor.

a) Squirrel Cage Type Rotor :→ T1.



* The rotating part of the motor is called as Rotor
* The rotor core is cylindrical and slotted on its periphery.
* The rotor consists of uninsulated copper or aluminium bars acting as rotor conductors.
* The copper bars are permanently shorted at each end with the help of conducting copper ring called endring.
* The copper bars are usually brazed to the end rings to provide good mechanical strength.
* The entire structure looks like a cage forming a closed electrical circuit. so the rotor is called squirrel cage rotor.
* As bars are permanently shorted to each other through end ring, the entire rotor resistance is very very small, hence this rotor is also called as short circuited rotor.
* It does not provide any option to add external resistance to it.

b) Slip ring rotor or Wound Rotor :→



* This type of rotor is exactly similar to the stator
* The rotor carries a three phase star or delta connected winding.
* The rotor is laminated and slotted at the periphery.
* The rotor winding connected either star or delta is permanently connected to slip rings to provide option of adding external resistance

rotor.

* addition of external resistance helps in better speed control and also provides high starting torque.

* As this rotor uses rotor conductors, which offer more resistance in comparision with bars hence losses are more and efficiency is less.

Comparision of Squirrel Cage and Wound Rotor :-

Slipring rotor or wound rotor	Squirrel Cage Rotor
1. Rotor consists of three phase winding similar to the stator winding	Rotor consists of bars which are shorted at the end rings.
2. Construction is complicated.	Construction is simple
3. Sliprings and brushes are present to add external resistances.	Slipring and brushes are absent, as not possible to add external resistances
4. Resistances can be added externally	Resistances can not be added externally
5. The construction is delicate hence needs frequent maintainance	The construction is simple hence maintainance free.
6. The rotors are costly	The rotors are cheap.
7. High starting torque can be obtained	Moderate starting torque can ~~be added~~ obtained
8. Speed control by rotor resistance is possible	Speed control by rotor resistance is not possible.
9. Rotor copper losses are high hence efficiency is less	Rotor copper losses are less and efficiency is high.
10. Used for lifts, cranes elevators and compressors etc.	Used for drilling, lathe machines, fans, blowers, water pumps etc.

Working P...
3-ϕ Induct...
When ...

Working Principle :⇒ T2

3-φ Induction motor works on the principle of rotating magnetic field.

When 3-φ AC supply is given to 3-φ stator windings, the voltage across each phase would be V_R V_Y and V_B, then I_R I_Y and I_B be the currents flowing in each phase. The current carrying conductor produces its magnetic field. Then ϕ_R ϕ_Y and ϕ_B be the fluxes established in each phase R, Y and B correspondingly. This produces a rotating magnetic field with constant magnitude of 1.5 times ϕ_m and also rotates with synchronous speed $N_s = \frac{120f}{P}$.

Now the stator flux (rotating magnetic field) rotates around the rotor, where rotor conductors are stationary hence there exist a relative motion between stator flux and stationary rotor conductors. The result is rotor conductors cut the rotating stator flux, an emf will be induced in the rotor. The rotor is a closed circuit, [illegible] will circulate the current through the rotor called rotor current.

The rotor current carried by the rotor conductor produce their own flux around them thus producing a rotor flux. Now their exist two fluxes stator flux and rotor flux, the interaction between the fluxes causes a force exerts on the rotor conductors causing the rotor to rotate thus the Induction motor rotates.

Slip :→

Slip of an induction motor can be defined as difference between the synchronous speed (N_s) and actual speed of rotor i.e motor (N) expressed as a fraction of synchronous speed (N_s). This is also called as absolute slip or fractional slip.

$$\boxed{\% S = \frac{N_s - N}{N_s} \times 100}$$ (Percentage slip)

$$\boxed{S = \frac{N_s - N}{N_s}}$$ (Absolute slip)

The actual speed of motor in terms of slip is given by

$$\boxed{N = N_s(1-s)}$$

At start when rotor is at rest hence i.e. $N = 0$ then

$$s = \frac{N_s - 0}{N_s}$$

$$\boxed{s = 1}$$

It is the maximum value of slip possible in an Induction motor.

If $N = N_s$ then

$$s = \frac{N_s - N_s}{N_s}$$

$$\boxed{s = 0}$$

The above condition is not possible in an induction motor. Practically induction motor operates in the range of slip 0.01 to 0.05 i.e. 1% to 5%.

Effect of slip on the rotor frequency :-

In 3-ϕ Induction motor, the rotating field speed is given by

$$N_s = \frac{120f}{P}$$

$f \rightarrow$ supply frequency in Hz.

At start when $N = 0$, $s = 1$, and stationary rotor has maximum relative motion with respect to rotating magnetic field. Hence maximum emf is induced in rotor at start. The frequency of this induced emf at start is same as that of supply frequency.

Hence frequency f -- the relative speed is N_s

$$f \rightarrow N_s \longrightarrow (1)$$

Once the motor starts rotating the relative motion between rotor conductors and rotating magnetic field reduces and becomes equal to $N_s - N$, at this speed the frequency of the rotor induced emf also decreases as emf induced decreases.

$$\text{Hence } f_r \rightarrow N_s - N \longrightarrow (2)$$

Dividing (2) by (1)

$$\therefore \frac{f_r}{f} = \frac{N_s - N}{N_s}$$

$$\therefore \frac{f_r}{f} = s$$

$$\therefore \boxed{f_r = sf}$$

during motor running the frequency of the rotor induced emf is slip times the frequency of supply.

Effect of Slip on rotor induced emf :→

We know at stand still condition of rotor, $N = 0$ hence $s = 1$

Relative speed is maximum and emf gets induced in the rotor is also maximum.

Let $E_2 \rightarrow$ Rotor induced emf per phase on standstill

As motor gains speed relative motion decreases hence rotor induced emf reduces and the proportional to relative speed $N_s - N$.

$$E_2 \propto N_s \longrightarrow (1) \qquad E_{2r} \propto N_s - N \longrightarrow (2)$$

Dividing (2) ÷ (1),

$$\frac{E_{2r}}{E_2} = \frac{N_s - N}{N_s}$$

$$\therefore \frac{E_{2r}}{E_2} = s$$

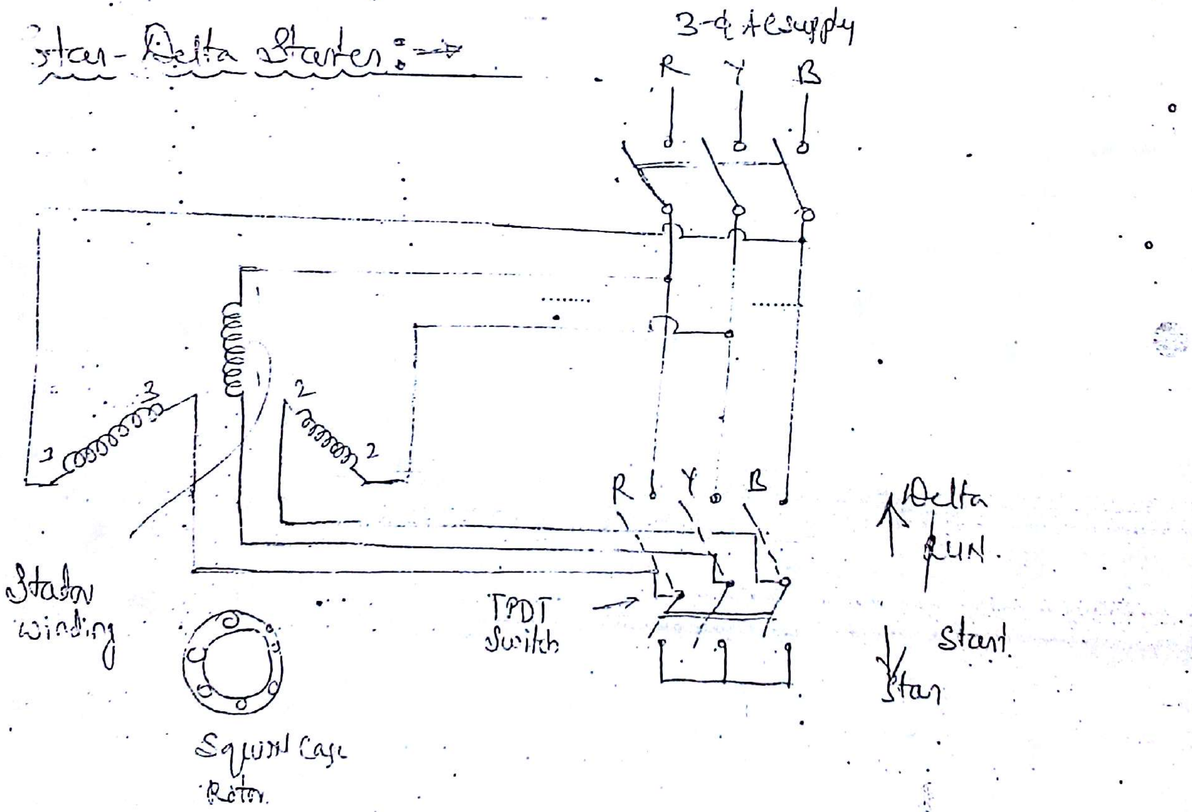
$$\therefore \boxed{E_{2r} = s E_2}$$

Scanned by CamScanner

Necessity of Starter in Induction Motor :→

In 3-ϕ Induction motor, the magnitude of rotor induced emf is maximum, as the relative motion is maximum during starting of the motor. As rotor conductors are short circuited in most of the motors, due to squirrel cage construction. The rotor induced emf circulates very high current through rotor at the starting. Thus the rotor current is high at start, consequently stator draws the current which is of the order of 5 to 8 times the full load current at starting. Due to such a high current at starting, there is possibility of damage of the motor winding. Similarly due to sudden inrush of current, other appliances connected to the same line may be subjected to voltage spikes which may affect their working.
To avoid such effects it is necessary to limit current drawn by the motor at starting. Hence starter is necessary for an Induction motor.

Star-Delta Starter :→



* This is the cheapest starter of all other starters.
It uses a Tripple pole double throw switch which connects the stator winding in star during starting and then in delta while normal running.
* The arrangement is shown in the fig above.
* Initially when switch is in START position, the stator winding gets connected in star. Hence

$$\boxed{V_{ph} = \frac{V_L}{\sqrt{3}}}$$

* The voltage across each phase gets reduced by factor $1/\sqrt{3}$. Due to this, starting current also gets reduced by factor $1/\sqrt{3}$. When motor picks speed, then switch is thrown in the RUN position. Hence winding gets connected in delta.

$$\boxed{V_{ph} = V_L = \text{rated Voltage}}$$

* Each phase of the winding gets rated voltage. The operation of switch can be automatic by using ~~relays~~ which ensures the motor will not start with switch in RUN position.
* The limitations of this starter are that it is suitable for normal delta connected motors.

Advantages of Induction Motor :-

* Cost is low compared to other types of motors
* Maintainance is less as robust and rugged
* Simple in construction
* Efficiency is high
* Power factor is better
* The starting torque can be controlled in slip ring type.

Limitations of Induction Motor :⇒

* The starting torque is low and cannot be adjusted in squirrel cage type motor.
* The speed control is difficult.
* Various parameters like speed, power factor, efficiency etc vary as load varies.

Applications :⇒

1) Squirrel Cage type of motors

* Driving fans.
* water pumps
* Blowers
* Grinders
* Lathe machines
* Printing machines

2) Slip ring induction motor

* Lifts
* Hoists
* Elevators
* Cranes
* Compressors.

squirrel cage

Three phase induction motor

Theory

1. Explain with a neat diagram construction of (i) squirrel cage Induction motor (ii) slip-ring(phase wound) Induction motor.
   Mention the merits and demerits of each type and mention their applications
2. Explain the principle of operation of three phase Induction motor.
3. Define the term slip with respect to induction motor.
4. Can an induction motor run at synchronous speed? Explain.
5. Derive the expression for rotor induced emf
6. Explain the need for a starter in three phase induction motor.
   With a neat diagram, explain the working of star delta starter for three phase induction motor

Numericals

1. A three -phase induction motor is wound for four poles and is supplied from a 50Hz [illegible]. Calculate: (i) the synchronous speed; (ii) the speed of the rotor when the slipis 4 per cent; (iii) [illegible] frequency when the speed of the rotor is 600 r/min.

2. The frequency of emf in the stator of a 4 pole induction motor is 50Hz, and that in the rotor is 1Hz. What is the slip and speed?

3. In a 6 pole, 50Hz, 3-ϕ Induction Motor running on full load the rotor emf makes 90complete cycles/minute, find the slip and full-load speed.

4. A 6 pole 3-ϕ Induction Motor [illegible]0 rpm from a 50Hz supply. Find the [illegible] of complete cycles of the rotor [illegible].

5. A 6-pole induction motor is supplied by a 10 pole alternator which is driven at 600 rpm. If the induction motor is running at 970 rpm, determine its percentage slip.

6. A 12 pole 3ϕ alternator is driven by a 440V, 3-phase 6 pole Induction Motor runningat a slip of 3%. Find frequency of EMF generated by the alternator.

7. A 6-pole alternator is driven at 1200 rpm (i) What is the frequency of the generatede.m.f ? (ii) If this alternator supplies power to a 10 pole induction motor, find its speed when slip is 3%

8. A 12 pole 3ϕ alternator is coupled to an engine running at 500 rpm. It supplies an Induction Motor which has a full load speed of 1440 rpm. Find the percentage slipand the number of poles of the motor.