Module 4

Transformers: Necessity of transformer. Principle of operation. Type and construction of single phase transformers. EMF equation. Losses, variation of losses with respect to load. Efficiency and simple numerical.

Three Phase Induction Motors: Concept of rotating magnetic field, principle of operation. Construction and features of motor, types - squirrel cage & wound rotor. Slip and its significance. Simple numerical.

## Transformers

A transformer is a static device which transfers the electrical power from one electrical circuit to the other without any change in frequency. A transformer works on the principle of mutual induction.

While transferring electrical power from one circuit to other, it changes the current and voltage level. The power transferred will almost remain constant except for the losses in the transformer. Since there is no rotating part in the transformer, it does not have friction losses and efficiency of the transformer is high.

Step up Transformer: If the secondary voltage is higher than the primary voltage, it is called step up transformer. $V_2 > V_1$

Step down Transformer: If the secondary voltage is less than the primary voltage, then it is called as the step down transformer. $V_2 < V_1$

Necessity of Transformer.

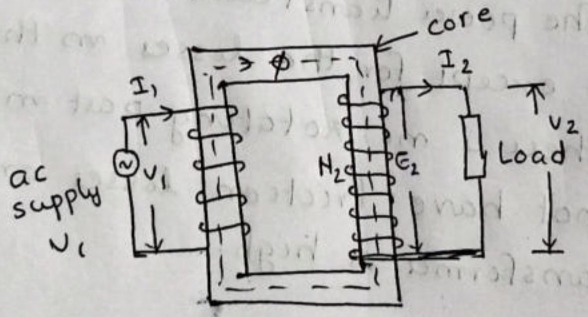
Transformers can change the ac voltage

level It can step up or step down voltage & current. So ~~in~~ applications in which ac current, voltage level has to be changed, transformers are used.

Electrical Power is generated, transmitted and distributed in the form of ac. Transformers are used for stepping up or stepping down of the voltage during power transmission & distribution system.

## Principle of Operation of transformer.

Transformers work on the principle of mutual Electromagnetic induction between two coils. Transformers consists of two windings or coils which are electrically separated, but magnetically ~~connected~~ coupled. The general arrangement of a transformer is shown in fig.




The winding which is connected to the supply is called primary winding. The winding which is connected to the load is called as the secondary winding. When alternating voltage is supplied to the primary winding, alternating current flows. and an alternating flux is set up in the core. This alternating flux links not only with the primary winding, but also with the secondary. Thus the varying flux links with primary and secondary winding. This produces a self induced emf $E_1$ in the primary and mutually induced emf $E_2$ in the secondary winding. Assuming ideal transformer

~~But~~ $$E_1 = -N_1 \frac{d\phi}{dt}$$

$$E_2 = -N_2 \frac{d\phi}{dt}$$

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = k \quad \text{———} (1)$$

k is the transformation ratio, which is defined as the ratio of secondary voltage to the primary voltage.

The Power transferred from primary winding to secondary winding is same.

$$E_2 I_2 = E_1 I_1$$

$$\therefore \frac{E_2}{E_1} = \frac{I_1}{I_2} = k \quad \text{———} (2)$$

From (1) & (2)

$$\boxed{\frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = k}$$

$k \rightarrow$ Transformation ~~rat~~ ratio

~~Com~~

$\frac{N_2}{N_1} \rightarrow$ Transformation Ratio

$\frac{N_1}{N_2}$ – Turns Ratio

# Construction of Transformer

The construction of a single phase transformer is discussed below.

A transformer mainly consists of

(i) Primary winding

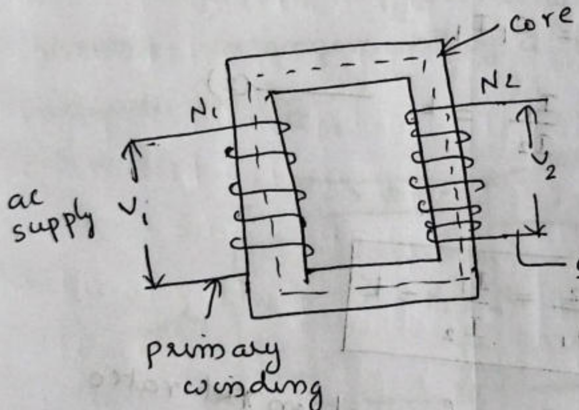
(ii) Secondary winding

(iii) Laminated core

(iv) Metal casing or metal frame.

## Primary winding.

The winding which is connected to the supply is called as the primary winding. Its main function is to produce alternating flux when alternating supply is given. It is made up of number of turns of Cu conductors insulated by varnish, paper or oxide film.




## Secondary winding

The winding which is ~~the~~ connected to the load is called the secondary winding. Its function is to get mutually induced emf in it. It is made up of a number of turns of copper conductors insulated by varnish, paper or oxide film.

## Transformer Core

The core of the transformer core is

constructed by ~~a~~ silicon steel laminations. Usually 2 to 4% of Silicon & 98 to 96% of steel is used. They are normally 0.3mm to 0.6mm thick laminations and are insulated by varnish, enamel or oxide film.

The purpose of laminating the core is to reduce the eddy current ~~and~~ losses. & thus to prevent overheating of transformer.

Functions of the core are (1) to provide an easy magnetic path to the flux & (2) to support the windings.

## Metal Tank or Metal Casing

Steel metal frame or metal tanks are used for large power transformers & metal casings are used in small transformers. Its function is to protect transformer winding, support transformer core and to house the transformer cooling oil.

## Types of Transformers

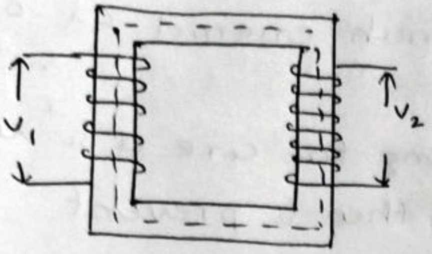
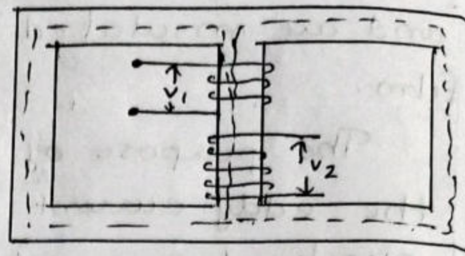
Based on the construction, the transformers are classified into two

(1) Core type transformer.

(2) Shell type transformer.

In core type transformer, the winding encircles the core. In shell type transformer the core encircles the winding.

The difference between the core type and shell type transformers are listed below.

| | Core Type Transformer | Shell Type Transformer |
|---|---|---|
| (1) |   | (1)   |
| (2) | The winding encircles the core | (2) The core encircles the winding |
| (3) | It has single magnetic circuit | (3) It has double magnetic circuit. |
| (4) | It has two limbs | (4) It has three limbs. |
| (5) | This construction is preferred for ~~low~~ High voltage ~~low~~ High power transformers. | (5) The construction is preferred for ~~high~~ low voltage ~~high~~ Low power operation |
| (6) | The coils can be easily removed for maintenance. | (6) Removing the coils for maintenance is difficult |
| (7) | Many number of turns are required & efficiency is less comparitively | (7) Less number of turns are sufficient & efficiency is high comparitively. |
| (8) | Natural cooling is effective | (8) Natural cooling is not effective |

Based on the o/p voltage obtained the transformers are classified into:

(1) step up transformer &

(2) Step down transformer.

When $N_2 > N_1$, $E_2 > E_1$ → step up transformer

When $N_2 < N_1$ $E_2 < E_1$ → Step down transformer

$N_1$ → No. of turns in the primary

$N_2$ → No. of turns in the secondary

$E_1$ → emf induced in the primary

$E_2$ → emf induced in the secondary

## EMF Equation of a Transformer.

Consider a transformer having

$N_1 \rightarrow$ No. of turns in the primary

$N_2 \rightarrow$ No. of turns in the secondary

$E_1 \rightarrow$ emf induced in the primary

$E_2 \rightarrow$ emf induced in the secondary

$\phi_m \rightarrow$ maximum flux produced in Wb

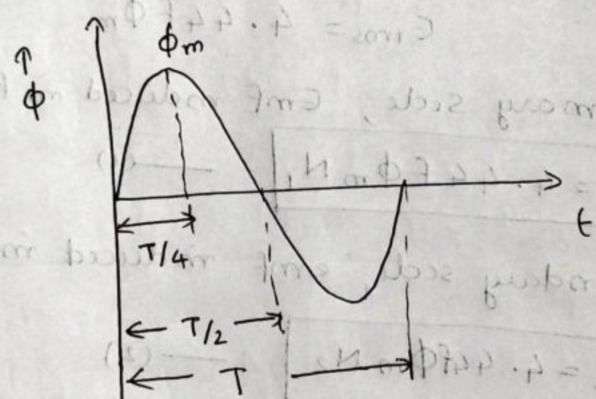
$\phi_m = B_m A$

where $B_m \rightarrow$ maximum flux density in $Wb/m^2$ or Tesla

$A \rightarrow$ Area of cross section in $m^2$

$f \rightarrow$ frequency in Hz.

When the primary is supplied with alternating voltage, alternating flux is produced as shown in fig.




It is clear that the flux changes from 0 to its maximum value $\phi_m$ in $T/4$ seconds.

From Faraday's law of electromagnetic induction Average value of emf induced is proportional to the ~~average~~ rate of change of flux.

$$\text{Average emf induced / turn} = \frac{\text{Change in flux}}{\text{Time required}}$$

$$= \frac{d\phi}{dt}$$

Change in flux $= \phi_m - 0 = \phi_m$

Time taken $= T/4$

We know that $T = \frac{1}{f}$ $\qquad T/4 = \frac{1}{4f}$.

∴ Average emf induced per turn

$$= \frac{\text{flux change}}{\text{Time taken}}$$

$$= \frac{\phi_m}{1/4f} = 4f\phi_m \text{ volts.}$$

For a sinusoidal wave

$$\text{form factor} = \frac{\text{RMS Value}}{\text{Average Value}} = 1.11$$

∴ $E_{rms} = 1.11 \times$ Average value of emf induced/turn

$$E_{rms} = 1.11 \times 4f\phi_m$$

$$E_{rms} = 4.44 f\phi_m.$$

∴ The rms value of induced emf/turn

$$E_{rms} = 4.44 f\phi_m$$

For primary side, Emf induced in the primary

$$\boxed{E_1 = 4.44 f\phi_m N_1} \quad \text{——} (1)$$

For secondary side, emf induced in the secondary

$$\boxed{E_2 = 4.44 f\phi_m N_2} \quad \text{——} (2)$$

This can be written as

$$E_1 = 4.44 f B_m A N_1 \qquad (\because \phi_m = B_m A)$$

$$E_2 = 4.44 f B_m A N_2$$

From (1) & (2)

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

if $N_2 > N_1$, ~~then~~ ie $k > 1$, $E_2 > E_1$ step up

$N_2 < N_1$ ie $k < 1$, $E_2 < E_1$ step down.

# Losses in Transformer

Losses in Transformer

- core loss (constant loss or iron loss)
  - Eddy current loss
  - Hysteresis loss
- Winding loss. (copper loss or variable loss)

The losses in the transformer are Core loss & copper loss.

(1) Core loss (Iron loss or Constant loss) ($W_{core}$)

This loss occurs at the core of the transformer. It includes hysteresis and eddy current losses. Iron loss is a constant loss.

Hysteresis loss ($W_h$)

The core of the transformer is subjected to alternating flux. Therefore power is required for the continuous reversal of molecular magnets in the core. This power is lost in the form of heat & is known as hysteresis losses.

$$\boxed{W_h = K_h B_m^{1.6} f V} \text{ watts}$$

$B_m \rightarrow$ Maximum flux density in $Wb/m^2$

$f \rightarrow$ frequency in Hz

$V \rightarrow$ volume of the laminations in $m^3$.

$K_h \rightarrow$ constant

Eddy Current Losses. ($W_e$)

The core is subjected to alternating flux, emf is induced in the core. The core being a closed path of conducting material, eddy currents circulate in the core. This current causes heat in the core & causes power loss which is known as eddy current loss.

$$W_e = K_e B_m^2 f^2 t^2 V$$

$k_e \rightarrow$ constant

$B_m \rightarrow$ Maximum flux density in $Wb/m^2$ or Tesla

$f \rightarrow$ frequency in Hz

$t \rightarrow$ thickness of the lamination in m

$V \rightarrow$ volume of the core in $m^3$.

Both hysteresis losses & eddy current losses depend on the maximum flux density, supply frequency & thickness & volume of the transformer. Since flux in the core is constant, maximum flux density is constant. Also supply frequency, thickness & volume ~~of~~ of the laminations constant. So core loss is constant.

<u>Cu loss. (Variable losses)</u> $W_{cu}$.

The Copper loss (cu loss) occur due to the resistance in primary & secondary windings.

Let $R_1 \rightarrow$ Primary resistance

$R_2 \rightarrow$ secondary resistance

$I_1 \rightarrow$ Primary current

$I_2 \rightarrow$ secondary current.

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

$$W_{cu} = I_2^2 R_{02}$$

$R_{02} \rightarrow$ Equivalent resistance of the winding referred to secondary.

$$W_{cu} \propto I_2^2$$

Cu loss Varies with respect to $I_2$

## Efficiency of a Transformer ($\eta$)

Efficiency of the transformer is the ratio of output power to the input power.

$$\eta = \frac{\text{output Power}}{\text{Input Power}}$$

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

$$\eta = \frac{\text{output Power}}{\text{output Power} + \text{Losses}}$$

Here output Power $= V_2 I_2 \cos\theta_2$

i/p Power = o/p Power + losses

$= V_2 I_2 \cos\theta_2 + W_{core} + W_{cu}$

If $x$ is the fraction of load, then $I_2$ should be taken as $xI_2$.

$$\therefore \boxed{\eta = \frac{x V_2 I_2 \cos\theta_2}{x V_2 I_2 \cos\theta + W_{core} + x^2 W_{cu}}}$$

This can be written as

$$\boxed{\eta = \frac{x\, VA \cos\theta}{x\, VA \cos\theta + W_{core} + x^2 W_{cu}}}$$

$x \to$ fraction of load

At full load $x = 1$

At half ~~the~~ full load $x = 0.5$

at $3/4^{th}$ load $x = 0.75$

at 60% load $x = 0.6$ & so on.

## Condition for Maximum Efficiency

At maximum efficiency, $\frac{d\eta}{dx} = 0$

$$\eta = \frac{x\, VA \cos\theta}{x\, VA \cos\theta + W_{core} + x^2 W_{cu}}$$

$$\frac{d\eta}{dx} = 0 \qquad \frac{d(u/v)}{dx} = \frac{v\frac{du}{dx} - u\frac{dv}{dx}}{v^2}$$

$(x V_A \cos\theta + W_{core} + x^2 W_{cu}) (V_A \cos\theta)$
$$- x V_A \cos\theta \left[V_A \cos\theta + 0 + 2x W_{cu}\right] = 0$$

$$x V_A \cos\theta + W_{core} + x^2 W_{cu} - x V_A \cos\theta - 2x^2 W_{cu} = 0$$

$$W_{core} - x^2 W_{cu} = 0$$

$$\therefore \boxed{W_{core} = x^2 W_{cu}}$$

This is the condition for maximum efficiency

At maximum efficiency,

$$\boxed{\text{Core loss} = \text{Copper Loss}}$$

At full load

$$\boxed{W_{core} = W_{cu}}$$

The Load at which maximum efficiency occurs.

At max. $\eta$.

$$x^2 W_{cu} = W_{core}$$

$$\boxed{x = \sqrt{\frac{W_{core}}{W_{cu}}}}$$

## Voltage Regulation of a Transformer

The change in the secondary terminal voltage from no load to full load with respect to no load voltage is called as the voltage regulation of the transformer

$$\% \text{ voltage Regulation} = \frac{V_{NL} - V_{FL}}{V_{NL}} \times 100$$

~~As regulation~~

Problems

1. Find the number of turns in the primary and secondary side of a 440/230V, 50Hz, 1$\phi$ transformer if the net area of cross section of the core is $30 cm^2$ & the flux density is $1 Wb/m^2$.

Solution

$A = 30 cm^2$
$= 30 \times 10^{-4} m^2$

$E_1 = 4.44 f \phi_m N_1$

$\phi_m = B_m A = 1 \times 30 \times 10^{-4}$

$E_1 = 4.44 \times 50 \times 30 \times 10^{-4} \times N_1$

$440 = 4.44 \times 50 \times 30 \times 10^{-4} N_1$

$N_1 = \dfrac{440}{4.44 \times 50 \times 30 \times 10^{-4}}$

$N_1 = 660.67 =$
$\approx \underline{\underline{662}}$ turns.

$\dfrac{E_2}{E_1} = \dfrac{N_2}{N_1}$ $\quad \dfrac{230}{440} = \dfrac{N_2}{662}$

$N_2 = \dfrac{230}{440} \times 662$

$= \underline{346}$ turns

OR $E_2 = 4.44 \times 50 \times 30 \times 10^{-4} N_2$

$N_2 = \dfrac{E_2}{4.44 \times 50 \times 30 \times 10^{-4}} = 346$ turns

(2) A single phase, 20kVA transformer has 1000 primary turns & 2500 secondary turns. The net cross sectional area of the core is $100 cm^2$. When the primary winding is connected ~~with~~ to 500V, 50Hz supply. Calculate (i) The maximum value of flux density in the core
(ii) the voltage induced in the secondary winding
(iii) The primary & secondary full load current

solution

20kVA , $N_1 = 1000$

$N_2 = 2500$

$A = 100\ cm^2 = 100 \times 10^{-4}\ m^2$

$V_1 = E_1 = 500V \quad f = 50Hz$

(i) $E_1 = 4.44 f B_m A N_1$

$$B_m = \frac{E_1}{4.44 \times f A N_1}$$

$$= \frac{500}{4.44 \times 50 \times 100 \times 10^{-4} \times 1000}$$

$$= \underline{\underline{0.225}}\ Wb/m^2$$

(ii) $\frac{E_2}{E_1} = \frac{N_2}{N_1}$

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

$$= 500 \times \frac{2500}{1000} = \underline{\underline{1250V}}$$

(iii) $I_1 = \frac{kVA \times 10^3}{V_1} = \frac{20 \times 10^3}{500} = 40A$

$$I_2 = \frac{kVA \times 10^3}{V_2} = \frac{20 \times 10^3}{1250} = \underline{\underline{16A}}$$

3) A 5000kVA transformer has $N_1 : N_2 = 300:20$. The primary winding is connected to a 2200V, 50Hz supply. Calculate

(i) Secondary voltage on no load

(ii) Approximate value of primary & secondary currents on full load.

(iii) The maximum value of flux.

(i) $\frac{E_2}{E_1} = \frac{N_2}{N_1}$

KVA = 5000 kVA

$N_1 = 300$

$N_2 = 20$

$E_1 = 2200$

$f = 50 Hz$

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

$= 2200 \times \frac{20}{300}$

$= \underline{\underline{146.67 V}}$

(ii) $I_1 = \frac{kVA \times 10^3}{V_1} = \frac{5000 \times 10^3}{2200} = 227.27 A$

$I_2 = \frac{kVA \times 10^3}{V_2} = \frac{5000 \times 10^3}{146.67} = \underline{\underline{3409.01 A}}$

(iii) $E_1 = 4.44 f \phi_m \times N_1$

$\phi_m = \frac{E_1}{4.44 f N_1} = \frac{2200}{4.44 \times 50 \times 300}$

$\phi_m = \underline{\underline{0.033 Wb}}$

4. A single phase transformer has 400 turns in primary & 1000 turns in secondary. The net cross sectional area of the core is 60 cm². The primary winding is connected to a 500V, 50Hz supply. Find.

(i) Peak value of flux density

(ii) emf induced in the secondary winding

Soln

$N_1 = 400$ $N_2 = 1000$ $A = 60 cm^2 = 60 \times 10^{-4} m^2$

$E_1 = 500V$ $f = 50 Hz$

(i) $E_1 = 4.44 f B_m A N_1$

$B_m = \frac{E_1}{4.44 f A N_1} = \frac{500}{4.44 \times 50 \times 60 \times 10^{-4} \times 400}$

$= \underline{\underline{0.938 Wb/m^2}}$

$\frac{E_2}{E_1} = \frac{N_2}{N_1}$ $E_2 = E_1 \times \frac{N_2}{N_1} = \frac{500 \times 1000}{400}$

 $= \underline{\underline{1250V}}$

5. Find the number of turns on the high voltage side of 415V/240V, 50Hz. single phase transformer. If the area of cross section of the core is 25cm$^2$ & max. flux density is 1.3 Wb/m$^2$.

Solution

$E_1 = 415V \quad E_2 = 240V \quad f = 50Hz$

$B_m = 1.3\ Wb/m^2 \quad A = 25\ cm^2$
$= 25 \times 10^{-4}\ m^2$

$E_1 = 4.44 f \phi_m N_1$

$E_1 = 4.44 f B_m A N_1$

$$N_1 = \frac{E_1}{4.44 f B_m A} = \frac{415}{4.44 \times 50 \times 1.3 \times 25 \times 10^{-4}}$$

$= 575.19$

$= \underline{576}$

Here high voltage side is of 415 V. i.e Primary.

So.. number of turns in the high voltage side, $N_1 = \underline{576}$ turns.

6. A single phase 10kVA, 1100/220V transformer has core loss, 300W at rated voltage & copper loss 400W at full load. Find the efficiency of the transformer feeding to a load of 8kVA at 0.8pf lagging

$kVA = 10\ kVA \quad E_1 = 1100V \quad E_2 = 220V$

$\cos\theta = 0.8$

$W_{core} = 300W$

$W_{cu} = 400W.$

Loading factor $x = \frac{\text{Load kVA}}{\text{Actual kVA}} = \frac{8}{10} = \underline{0.8}$

$\therefore\ x = \underline{\underline{0.8}}$

Efficiency, $\eta = \dfrac{x\, kVA \times 10^3 \cos\theta}{x\, kVA \times 10^3 \cos\theta + W_{core} + x^2 W_{cu}} \times 100\ \%$

$= \dfrac{0.8 \times 10 \times 10^3 \times 0.8}{0.8 \times 10 \times 10^3 \times 0.8 + 300 + (0.8)^2 \times 400} \times 100\%$

$= \underline{\underline{92\%}}$

7. In a 25kVA, 2000/200V single phase transformer the iron & full load copper loss are 350W & 400W respectively. Calculate the efficiency ($\eta$) at unity power factor on (i) full load (ii) half full load.

<u>solution</u>

25kVA $\quad V_1 = 2000V \quad V_2 = 200V \quad W_{core} = 350W$

$W_{cu} = 400W$

unity Power factor (upf) $\Rightarrow \cos\theta = 1$

(i) $\eta$ = Full load ie $x = 1$

$\eta = \dfrac{x\, kVA \times 10^3 \cos\theta}{x \times kVA \times 10^3 \cos\theta + W_{core} + x^2 W_{cu}}$

$= \dfrac{1 \times 25 \times 10^3 \times 1}{1 \times 25 \times 10^3 \times 1 + 350 \times (1)^2 \times 400}$

$= 97.09\%$

(2) At half full load upf.

$x = 0.5 \quad \cos\theta = 1$

$\eta = \dfrac{x\, kVA \times 10^3 \times \cos\theta}{x\, kVA \times 10^3 \cos\theta + W_{core} + x^2 W_{cu}}$

$= \dfrac{0.5 \times 25 \times 10^3 \times 1}{0.5 \times 25 \times 10^3 \times 1 + 350 + (0.5)^2 \times 400}$

$= \underline{\underline{96.52\%}}$

8. In a ~~500~~ 50kVA 11kV/400V, 1φ transformer, the iron & copper losses are 500W & 600W respectively. Under rated conditions Calculate (i) η at upf at full load (ii) The load for maximum efficiency (iii) Copper loss at this load.

**Solution**

50kVA $V_1 = 11kV$ $V_2 = 400V$

$W_{core} = 500W$ $W_{cu} = 600W$.

(i) At upf full load $\cos\theta = 1$, $x = 1$

$$\eta = \frac{x\, kVA \times 10^3 \cos\theta}{x\, kVA \times 10^3 \cos\theta + W_{core} + x^2 W_{cu}}$$

$$= \frac{1 \times 50 \times 10^3 \times 1}{1 \times 50 \times 10^3 \times 1 + 500 + (1)^2 \times 600} \times 100$$

$$= 97.85\%$$

(ii) At max. η

$$W_{core} = x^2 W_{cu}$$

$$x = \sqrt{\frac{W_{core}}{W_{cu}}} = \sqrt{\frac{500}{600}} = 0.913$$

(iii) Copper loss at the load of max. η

$$W_{cu\,(at\ max\ \eta)} = x^2 W_{cu}$$

$$= (0.913)^2 \times 600$$

$$= 500W$$

or at this load.

~~Wcu~~ Copper loss = Core loss

ie $W_{cu} = 500$

19. The maximum efficiency at full load unity power factor of a single phase, 25 kVA, 500/1000 V 50 Hz transformer is 98%. Determine its efficiency at (i) 75% load, 0.9 pf & (ii) 50% load 0.8 pf & (iii) 25% load 0.6 pf

solution

25 kVA $\quad V_1 = 500\,V \quad V_2 = 1000\,V$

$f = 50\,Hz \quad$ maximum efficiency = 98%

WKT At max $\eta$ $\quad W_{core} = x^2 W_{cu}$

$$\eta = \frac{x\,kVA \times 10^3 \cos\theta}{x\,kVA \times 10^3 \cos\theta + W_{core} + x^2 W_{cu}}$$

It can be written as

$$\eta = \frac{x\,kVA \times 10^3 \cos\theta}{x\,kVA \times 10^3 + W_{core} + W_{core}}$$

$$\eta = \frac{x\,kVA \times 10^3 \cos\theta}{x\,kVA \times 10^3 \times \cos\theta + 2W_{core}}$$

FL $\therefore x = 1$

upf $\therefore \cos\theta = 1$

$$0.98 = \frac{1 \times 25 \times 10^3 \times 1}{1 \times 25 \times 10^3 \times 1 + 2W_{core}}$$

$2W_{core} = 510.2$

$W_{core} = 255.1\,W$

(i) 75% load 0.9 pf $\quad x = 0.75 \quad \cos\theta = 0.9$

$$\eta = \frac{x\,kVA \times 10^3 \cos\theta}{x\,kVA \times 10^3 \cos\theta + W_{core} + x^2 W_{cu}}$$

$$= \frac{0.75 \times 25 \times 10^3 \times 0.9}{0.75 \times 25 \times 10^3 \times 0.9 + 255.1 + (0.9)^2\,255.1} \times 100$$

$= 97.69\%$

(ii) ~~at~~ half load, 0.8 pf

$x = 0.5 \quad \cos\theta = 0.8$

$$\eta = \frac{x\,kVA \times 10^3 \cos\theta}{x \times kVA \times 10^3 \cos\theta + W_{core} + x^2 W_{cu}}$$

$$= \frac{0.5 \times 25 \times 10^3 \times 0.8}{0.5 \times 25 \times 10^3 \times 0.8 + 255.1 + (0.5)^2 255.1} \times 100$$

$= 96.91\%$

(iii) $1/4^{th}$ load $\cos\theta = 0.6$

$x = 0.25 \quad \cos\theta = 0.6$

$$\eta = \frac{x\,kVA \times 10^3 \cos\theta}{x\,kVA \times 10^3 \cos\theta + W_{core} + x^2 W_{cu}} \times 100$$

$$= \frac{0.25 \times 25 \times 10^3 \times 0.6}{0.25 \times 25 \times 10^3 \times 0.6 + 255.1 + (0.25)^2\, 255.1}$$

$= \underline{\underline{93.26\%}}$

18. A 600 kVA transformer has an efficiency of 92% both at full load unity pf & half load 0.9 pf. Determine its efficiency at 75% load & 0.9 pf

**Solution**

600 kVA

At full load, upf $\quad x = 1 \quad \cos\theta = 1$

$\eta = 92\%$

$$\eta = \frac{x\,kVA \times 10^3 \times \cos\theta}{x\,kVA \times 10^3 \times \cos\theta + W_{iout} + x^2 W_{cu}}$$

$$0.92 = \frac{1 \times 600 \times 10^3 \times 1}{1 \times 600 \times 10^3 \times 1 + W_{iout} + (1)^2 W_{cu}}$$

$W_{core} + W_{cu} = 52.17\,kW \quad \text{—— (1)}$

Case 2

At half load 0.9 pf

$x = 0.5 \quad \cos\theta = 0.9$

$$\eta = \frac{x\, kVA \times 10^3 \cos\theta}{x\, kVA \times 10^3 \cos\theta + W_{core} + x^2 W_{cu}}$$

$$0.92 = \frac{0.5 \times 600 \times 10^3 \times 0.9}{0.5 \times 600 \times 10^3 \times 0.9 + W_{core} + (0.5)^2 W_{cu}}$$

$W_{core} + 0.25 W_{cu} = 23.48\, kW$ —— (2)

$\therefore \quad W_{core} + W_{cu} = 52.17\, kW$ —— (1)

$W_{core} + 0.25 W_{cu} = 23.48\, kW$ —— (2)

(1) − (2) $\quad 0.75 W_{cu} = 28.69\, kW$

$W_{cu} = 38.25\, kW$

$W_{core} = \underline{13.92\, kW}$

11. A transformer is rated ~~at full loa~~ at 100 kVA. At full load its copper loss is 1200 W & it core loss is 960 kW. Calculate (i) the $\eta$ at full load & upf
(ii) $\eta$ at half load ~~load~~ & 0.8 pf
(iii) Load kVA at which maximum efficiency will occur.

Solution

100 kVA $\quad W_{core} = 960\, W \quad W_{cu} = 1200\, W$

(i) At FL upf $\quad x = 1 \quad \cos\theta = 1$

~~$\eta = 1 \times 100 \times$~~

$$\eta = \frac{x\, kVA \times 10^3 \times \cos\theta}{x\, kVA \times 10^3 \cos\theta + W_{core} + x^2 W_{cu}}$$

$$= \frac{1 \times 100 \times 10^3 \times 1}{1 \times 100 \times 10^3 \times 1 + 960 + (1)^2\, 1200} \times 100$$

$\% \eta = \underline{97.89\, \%}$

(ii) $x = 1/2 \qquad \cos\theta = 0.8$

$$\eta = \frac{x \times kVA \times 10^3 \times \cos\theta}{x \times kVA \times 10^3 \cos\theta + W_{core} + x^2 W_{cu}}$$

$$\eta = 96.95\%$$

(iii) $W_i = x^2 W_{cu}$

$$x = \sqrt{\frac{W_i}{W_{cu}}} = \sqrt{\frac{960}{1200}} = 0.894$$

Load kAA = $x \times$ Actual kVA

$= 0.894 \times 100$ kVA

$= \underline{89.44 \text{ kVA}}$



former working at 0.8

B. Three Phase Induction Motor

Concept of Rotating magnetic field, principle of operation. Constructional features of motors. Types - Squirrel cage & wound rotor. Slip & its significance. Simple numericals.

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## Introduction

The three phase induction is the most widely used ac motor. It has a stator and rotor. The stator winding is connected to the three phase ($3\phi$) supply. The rotor winding is not connected to the supply. The power is transferred from stator to the rotor only by mutual induction. For this reason, it is called as induction motor. Here stator acts like primary & rotor as secondary. So it is called as rotating transformer as the power is transferred from stator to rotor by mutual induction.

## Advantages of Induction motor.

(1) It has simple and rugged construction

(2) It is relatively cheap.

(3) It requires less maintenance.

(4) ~~Fairly good Power factor~~ Reliable.

(5) It has high efficiency.

## Disadvantages

(1) Speed control is difficult

(2) Poor starting torque & high inrush current (about 4 to 8 times rated current)

(3) They operate under lagging power factor.

## Rotating Magnetic Field

The rotating magnetic field is defined as the field or flux having constant amplitude but whose axis is continuously rotating in a plane with a certain speed called synchronous speed.

The three phase induction motor consist of a $3\phi$ winding as its stator. The $3\phi$ stator windings are connected in star or delta. ~~& displaced from each other by 120°~~.
The three phase stator winding are supplied from a $3\phi$ balanced supply. $3\phi$ currents displaced at 120° flows through the windings. Hence three magnetic flux are produced which are sinusoidal & displaced by 120°. The resultant of these magnetic field is constant in magnitude, but continuously changes its direction. So the field is called rotating magnetic field.

The speed of rotation of stator magnetic field is called Synchronous speed ($N_s$)

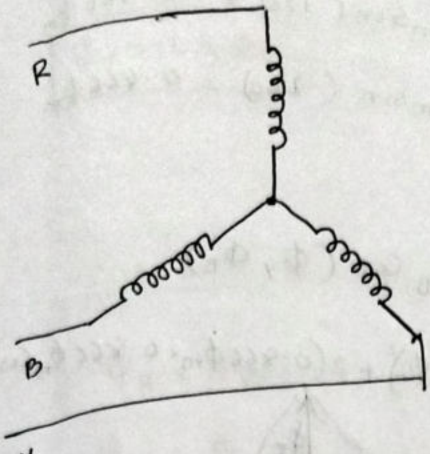
The Synchronous speed can be calculated as

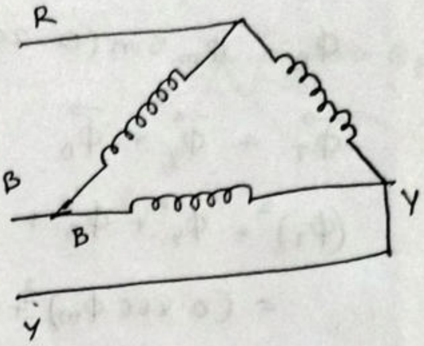
$$N_s = \frac{120f}{P}$$

$f \rightarrow$ Frequency

$P \rightarrow$ No. of poles.

Consider 3$\phi$ stator winding connected in star or delta with 3$\phi$ supply.



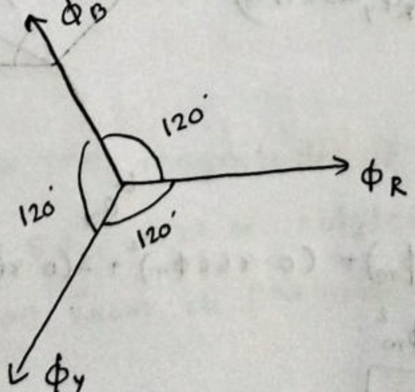

If the phase sequence of the winding is RYB, then the mathematical equation for instantaneous values of the 3 fluxes $\phi_R$, $\phi_Y$ & $\phi_B$ can be written as

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

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

$$\phi_B = \phi_m \sin(\theta - 240) = \phi_m \sin(\theta + 120)$$

The vector representation of the three fluxes are shown.




The resultant flux at any instant is given by the vector sum of the individual fluxes

$$\vec{\phi_T} = \vec{\phi_R} + \vec{\phi_Y} + \vec{\phi_B}$$

Consider 4 cases with intervals $\theta = 0°$, $\theta = 60°$, $\theta = 120°$, $\theta = 180°$

case (i)

When $\theta = 0°$

$\phi_R = \phi_m \sin\theta = \phi_m \sin 0 = 0$

$\phi_Y = \phi_m \sin(\theta - 120) = \phi_m \sin(-120) = -0.866\phi_m$

$\phi_B = \phi_m \sin(\theta - 240) = \phi_m \sin(-240) = 0.866\phi_m$

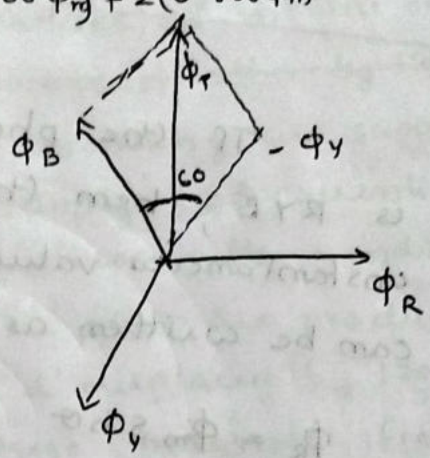
$\vec{\phi_T} = \vec{\phi_Y} + \vec{\phi_B}$

$(\phi_T)^2 = \phi_Y^2 + \phi_B^2 + 2\phi_R\phi_B \cos(\phi_Y \phi_B)$

$= (0.866\phi_m)^2 + (0.866\phi_m)^2 + 2(0.866\phi_m \times 0.866\phi_m \cos 60)$

$\phi_T^2 = 2.25\phi_m^2$

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




## Case (2)

When $\theta = 60°$

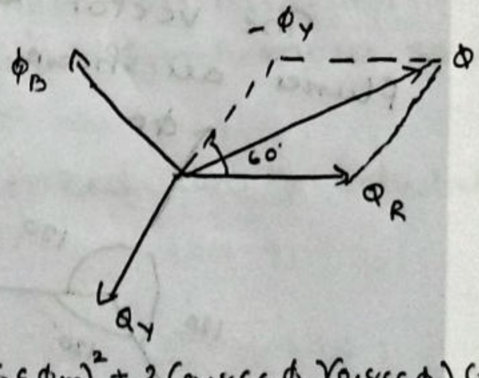
$\phi_R = \phi_m \sin\theta = \phi_m \sin 60 = 0.866\phi_m$

$\phi_Y = \phi_m \sin(\theta - 120) = \phi_m \sin(60 - 120) = -0.866\phi_m$

$\phi_B = \phi_m \sin(\theta - 240) = \phi_m \sin(60 - 240) = 0$

$\overline{\phi_T} = \overline{\phi_R} + \overline{\phi_Y}$

$\phi_T^2 = \phi_R^2 + \phi_Y^2 + 2\phi_R\phi_Y \cos(\phi_R \phi_Y)$




$\phi_T^2 = (0.866\phi_m)^2 + (0.866\phi_m)^2 + 2(0.866\phi_m)(0.866\phi_m)\cos 60°$

$\phi_T^2 = 2.25\phi_m^2$

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

case (iii) $\theta = 120°$

$\phi_R = \phi_m \sin\theta = \phi_m \sin 120 = 0.866\phi_m$

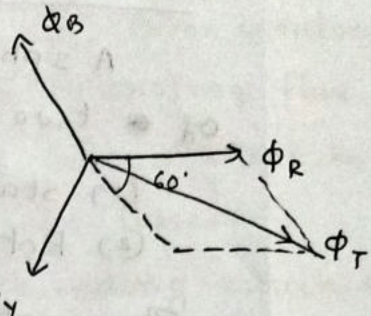
$\phi_Y = \phi_m \sin(\theta - 120) = \phi_m \sin(120 - 120) = 0$

$\phi_B = \phi_m \sin(\theta - 240) = -0.866\phi_m$

$\bar{\phi}_T = \bar{\phi}_R + \bar{\phi}_B$

$\phi_T^2 = \phi_R^2 + \phi_B^2 + 2\phi_R\phi_B \cos 60$

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




<u>case (iv)</u> $\theta = 180°$

$\phi_R = \phi_m \sin\theta = \phi_m \sin 180 = 0$

$\phi_Y = \phi_m \sin(\theta - 120) = \sin 60 = 0.866\phi_m$

$\phi_B = \phi_m \sin(\theta - 240) = \sin(-60) = -0.866\phi_m$

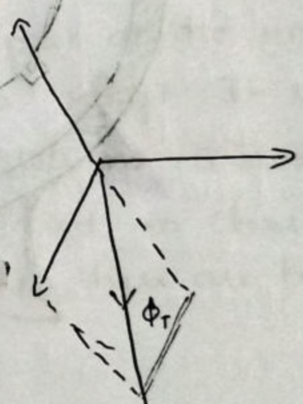
$\vec{\phi}_T = \vec{\phi}_Y + \phi_B$

$\phi_T^2 = \phi_Y^2 + \phi_B^2 + 2\phi_Y\phi_B \cos 60$

$\phi_T^2 = (0.866\phi_m)^2 + (0.866\phi_m)^2 + 2(0.866\phi_m)(0.866\phi_m)\cos 60$

$\phi_T^2 = 2.25\phi_m^2$

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



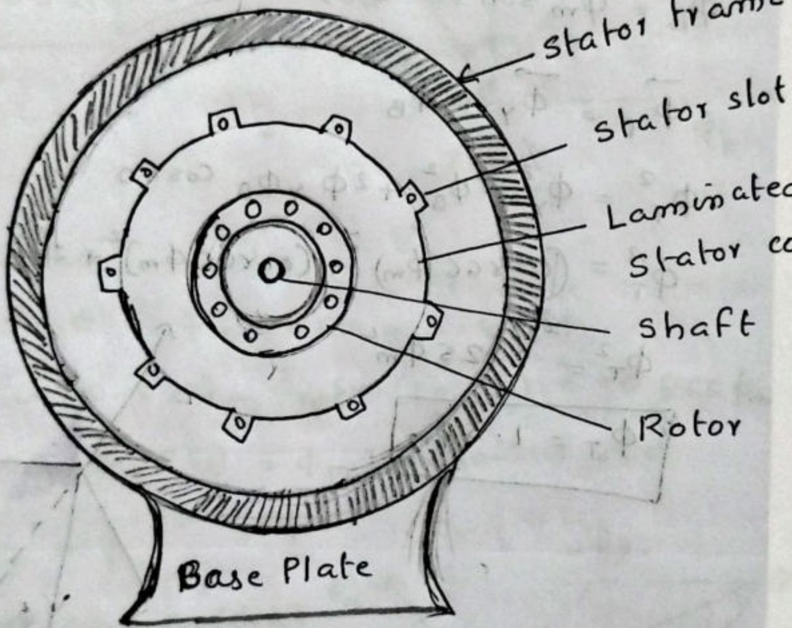

Hence the magnitude of the resultant flux $\phi_T = 1.5\phi_m$ & it is rotated through in clockwise direction from its previous position.

## Construction of 3$\phi$ Induction Motor

A 3 phase induction motor consists of two main parts namely

(1) Stator
(2) Rotor

The rotor is separated from the stator by a small air gap which ranges from 0.4 mm to 4 mm depending on the power of motor.




### Stator

The main parts of stator are

(i) Stator frame
(ii) Stator core

### Stator Frame

It is the outer body of the motor. The functions of the stator frame are

(i) to support the stator core & winding
(ii) to protect the inner parts of the machine.

stator core.

It is a hollow cylindrical core having slots on its inner periphery to carry stator winding since the stator core carries alternating flux it is made of laminations of silicon steel to reduce eddy current & hysteresis losses.

The stator core carries 3$\phi$ winding which is supplied from 3$\phi$ supply & can be connected in star / Delta

The stator of the motor is wound for definite number of poles as per the requirement of speed $\left(N_s = \frac{120f}{P}\right)$. Greater the number of poles, lesser the speed.

The airgap between stator & rotor is ~~known~~ kept as small as possible.

Rotor

It is the rotating part of the motor. The rotor is mounted on a shaft. It is a hollow laminated core having slots on its outer periphery. The rotor windings are placed in these slots. Based on the construction, there are two types of rotors.

1. Squirrel Cage Induction Motor
2. Slip Ring Induction Motor (Phase Wound Induction Motor)

1. Squirrel Cage Induction Motor

- Squirrel cage induction motors rotor consists of cylindrical laminated core with parallel slots for carrying rotor conductors.
- The rotor conductors are heavy bars of

copper or Aluminium. At both ends of the rotor, the rotor conductors are all short-circuited by the continuous end rings of similar material to that of rotor conductors.

- The rotor conductors & their end rings form a complete closed circuit, resembling a squirrel cage. So it is called as squirrel cage induction motor.

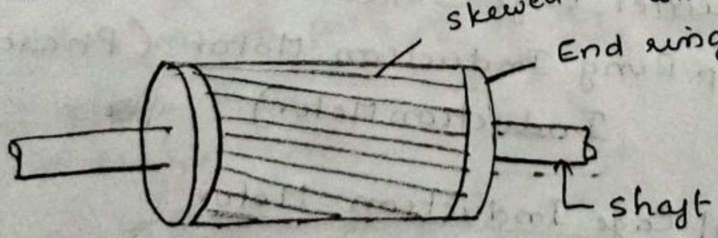
- Since the rotor winding is permanently short circuited, there is no possibility of adding any external resistance in the rotor circuit.

- Almost 90% of the induction motors are produced with squirrel cage rotor because of its simple, robust & almost indestructible construction.

- The slots on the rotor are always not parallel to the motor shaft. But are usually skewed in order to (1) obtain a uniform torque.

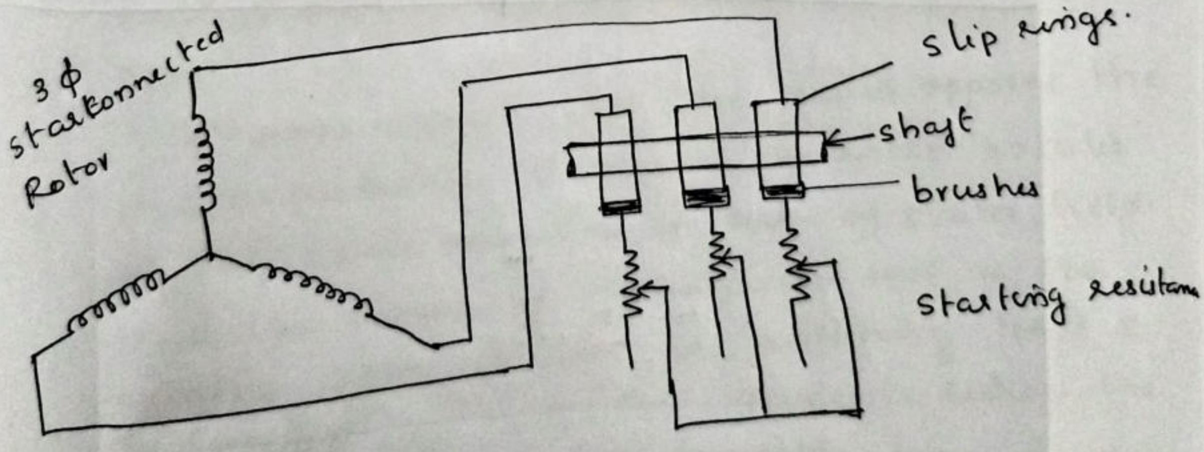
(2) To reduce the magnetic locking of stator & rotor

(3) To reduce the magnetic humming noise while running.



## (2) Phase wound or slip ring Rotor.

- It consists of a laminated cylindrical core having uniform slots on it's outer periphery.
- The rotor is wound for the same number of poles as that of stator & rotor winding is similar to stator.
- The rotor winding may be star or delta. But star connection is prefered.
- The three finishing terminals are connected together to form star point & open ends of the stator windings are brought out and are connected to 3 insulated slip rings mounted on the shaft with brushes resting on them.
- The brushes are further externally connected to $3\phi$ star connected rheostat for the purpose of starting & speed control.
- At the time of starting, the external resistance is included in the rotor circuit & the resistance is gradually cut out as the rotor picks up load.



## Comparison of Squirrel Cage & Slip ring Rotor

| Squirrel Cage Rotor | Slip Ring Rotor |
| --- | --- |
| (1) Rotor consists of heavy bars of copper or Aluminium which are shorted at the ends. | (1) Rotor consists of 3 $\phi$ winding similar to the stator winding. |
| (2) Construction is simple. | (2) Construction is complicated. |
| (3) External Resistance cannot be added. | (3) External Resistance can be added. |
| (4) Slip Rings & brushes are absent. | (4) Slip Rings & brushes are present. |
| (5) Moderate starting torque. | (5) High starting torque. |
| (6) Rotor Copper losses are less & so high efficiency. | (6) Rotor Copper losses are more & hence low efficiency. |
| (7) Used for lathes, water pumps, printing machine etc. | (7) Used for lifts, elevators & cranes etc. |

## Principle of Operation of 3$\phi$ Induction Motor

When a 3$\phi$ supply is given to the stator of a 3$\phi$ induction motor, a rotating magnetic field of constant magnitude & synchronous speed ($N_s = \frac{120f}{P}$) is set up.

~~The stationary rotor~~ conductors ~~at the rotating magnetic field~~

The rotating magnetic passes through the air gap and cuts the rotor conductors which are stationary.

Thus due to electromagnetic induction, an emf is induced in the motor conductors

As the motor conductors are short circuited a current passes through the rotor conductors. Hence a field is set up around Rotor Conductors.

The current carrying rotor conductors are placed in the magnetic field produced by rotor. ~~Hence a field is set up around rotor conductors~~. Both field interact each other. Therefore the rotor conductors experiences a force & a torque is produced.

Due to this torque, the rotor starts rotating in the same direction as that of the stator field.

As per Lenz's Law the result opposes the cause producing it. Hence the rotor rotates in the same direction as that of stator field. Here the cause of the induced emf is the relative speed between the rotating field & the stationary rotor conductors. Hence to reduce the cause the rotor rotates in the same direction of the stator field.

The speed of the rotor gradually increases & tries to catch the speed of the rotating field. But it fails to attain to attain the synchronous speed. ~~If it~~ If it reaches the synchronous speed, the relative speed ($N_s - N$) becomes zero & there would be no induced emf & no current in the rotor conductors. No rotor field & hence no torque. Hence the machine comes to standstill. Thus the induction motor never runs at synchronous speed.

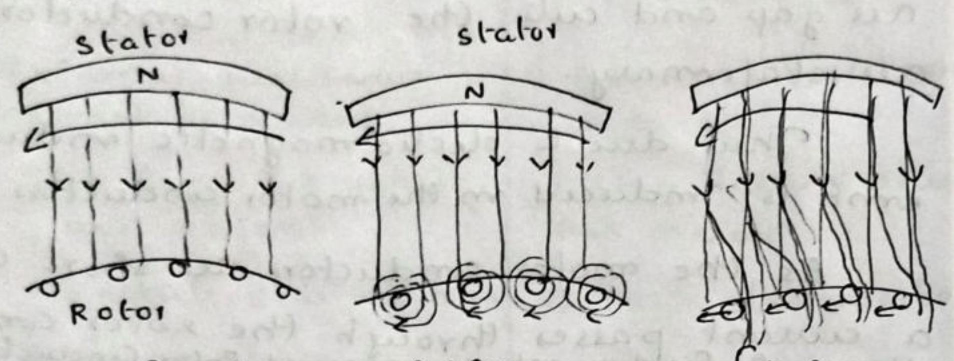



fig (a) fig (b) fig c

## Slip of an Induction Motor & its importance

The slip of an induction motor is defined as the ratio of the difference between the synchronous speed $N_s$ of the magnetic field to the actual speed of rotor $N$ to the synchronous speed $N_s$

$$\text{Slip, } s = \frac{N_s - N}{N_s}$$

$$\% s = \frac{N_s - N}{N_s} \times 100$$

Without slip, (ie the difference in $N_s$ & $N$, the induction motor will not work. ie If $N_s = N$, then there would be no relative speed between stator field & rotor. Hence no emf & rotor current induced & no torque would be produced.

to drive the rotor. The friction & windage losses immedeately causes the rotor to slow down. Hence the rotor speed is always less than synchronous speed.

## Frequency of the Rotor emf & Current

At start when $N = 0$, $s = \frac{N_s - N}{N_s} = 1$

ie when the rotor is stationary, the rotor conductors are being cut by the rotating flux at synchronous speed. $N_s = \frac{120f}{P}$

Hence maximum emf is induced in the rotor at start & the frequency of the rotor current is same as supply frequency.

$$N_s = \frac{120f}{P} \quad \text{——— (1)}$$

But the rotor starts revolving with speed N, the rate at which the rotor conductor is being cut by the rotating flux depends on the relative speed between the rotor & stator rotating flux called slip speed $(N_s - N)$

$$N_s - N = \frac{120 f_r}{P} \quad \text{——— (2)}$$

$f_r \rightarrow$ Rotor frequency.

(2)/(1)

$$\frac{N_s - N}{N_s} = \frac{120 f_r}{P} \Big/ \frac{120 f}{P}$$

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

$$s = \frac{f_r}{f} \qquad \boxed{f_r = sf}$$

~~Hence~~ where $s \rightarrow$ slip

$f_r \rightarrow$ rotor frequency

$f \rightarrow$ supply frequency.

## Application of Induction Motors

Squirrel cage Induction motors having moderate starting torque & constant speed characteristics. Hence used for driving water pumps, lathe machines, printing machine, drilling machine

Slip ring induction motors having starting torque, & hence used for elevator, lifts & cranes & compressors.

Problems

(1) A 3 phase induction motor is wound for four poles & is supplied from 50Hz supply calculate
(i) synchronous speed
(ii) Speed of the rotor when slip is 4%
(iii) Rotor frequency when the speed of the rotor is 1450 rpm

Jun-16 - 14ELE25

Solution:

$P = 4, \; f = 50Hz$

(i) $N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = \underline{1500 \text{ rpm}}$

(ii) $S = \frac{N_s - N}{N_s}$

$0.04 = \frac{1500 - N}{1500} \Rightarrow 60 = 1500 - N$

$N = \underline{1440 \text{ rpm}}$

(iii) $S = \frac{N_s - N}{N_s} = \frac{1500 - 1450}{1500} = 0.033\%$

$f_r = sf = 0.033 \times 50 = \underline{1.67Hz}$

(2) A 3-phase, 6 pole 50Hz induction motor has a slip of 1% at no load & 3% at full load. Determine (i) Synchronous speed (ii) No load speed (iii) full load speed (iv) frequency of rotor current at standstill (v) frequency of rotor current at full load.

Dec-13 [10ELE15]
Dec-15 [15ELE15
Jun-12 [10ELE
JUN-18 [17

Solution: $P = 6, \; f = 50Hz,$

no load slip = 1%. full load slip = 3%

classmate
Date ______
Page ______

(i) $N_S = \frac{120f}{P} = \frac{120 \times 50}{6} = \underline{1000\ rpm}$

(ii) at no load slip = 1%.

$$S = \frac{N_S - N}{N_S}$$

$$0.01 = \frac{1000 - N}{1000} \Rightarrow \underline{N = 990\ rpm}$$

(iii) full load speed

$S = 3\%$.

$$S = \frac{N_S - N}{N_S} \Rightarrow 0.03 = \frac{1000 - N}{1000} \Rightarrow N = \underline{970\ rpm.}$$

(iv) At stand still, $f_r = sf = \underline{50\,Hz}$

(v) At full load, $f_r = sf = 0.03 \times 50 = \underline{1.5\,Hz}$

③ If a 6 pole induction motor supplied from a 3 phase, 50 Hz supply has a rotor frequency 2.3 Hz, calculate the (i) percentage slip (ii) The speed of the motor

Dec-15 [15EE15]

Solution

$P = 6$, $f = 50\,Hz$, $f_r = 2.3\,Hz$.

(i) $f_r = sf$

$S = f_r/f = 2.3/50 = 0.046 \Rightarrow \boxed{S = 4.6\%}$

(ii) $N_S = 120f/P = \frac{120 \times 50}{6} = 1000\ rpm$

$$S = \frac{N_S - N}{N_S} \Rightarrow 0.046 = \frac{1000 - N}{1000} \Rightarrow \boxed{N = 954\ rpm}$$

④ A 4 pole, $3\phi$, induction motor is supplied from 50 Hz supply. Find its synchronous speed. On full load its speed is observed to be 1410 rpm. Calculate its full load slip.

Dec-15 [14EE15]

Solution: $P = 4$, $f = 50\,Hz$.

(i) $N_S = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500\ rpm.$

(ii) $S = \frac{N_S - N}{N_S} = \frac{1500 - 1410}{1500} = 0.06 \Rightarrow \boxed{S = 6\%}$

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(5) The frequency of the emf in the stator of a 4 pole induction motor is 50 Hz & in the rotor is 1.5 Hz. What is the slip & at what speed is the motor running Jun-15 [14ELE25]

Solution:

$P=4$, $f=50\,Hz$, $f_r=1.5\,Hz$, $N_s = 120f/P = \frac{120\times 50}{4} = 1500\,rpm$

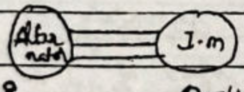
(i) $f_r = sf \Rightarrow s = f_r/f = \frac{1.5}{50} = 0.03 \Rightarrow \boxed{s = 3\%}$

(ii) $s = \frac{N_s - N}{N_s} \Rightarrow 0.03 = \frac{1500 - N}{1500}$

$\Rightarrow \boxed{N = 1455\,rpm}$

(6) An 8 pole alternator runs at 750 rpm & supplies power to a 4-pole Induction motor. The frequency of rotor current is 1.5 Hz. Determine the speed of the motor Jan-15 [14ELE15]

Solution:




$P=8$ $\quad P=4$ pole.

$N_s = 750\,rpm$

For alternator

(i) $f = \frac{PN_s}{120} = \frac{8\times 750}{120} = 50\,Hz$

For I.M

$f=50\,Hz$, $P=4$, $f_r = 1.5\,Hz$, $N_s = \frac{120f}{P} = \frac{120\times 50}{4} = 1500\,rpm$

(i) $s = f_r/f = \frac{1.5}{50} = 0.03$

$\Rightarrow \boxed{s = 3\%}$

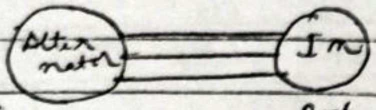
(ii) $s = \frac{N_s - N}{N_s} \Rightarrow 0.03 = \frac{1500 - N}{1500} \Rightarrow \boxed{N = 1455\,rpm}$

classmate
Date
Page

(7) An 8 pole alternator runs at 750 rpm & supplies power to a 6 pole induction motor which runs at 970 rpm. What is the slip of the induction motor.

Dec-14 [14ELE15]
Jan-16 [14ELE16]

Solution:




$P=8,\quad N_S=750\ rpm$ $\qquad$ $P=6,\quad N=970\ rpm$

For alternator:

$P=8,\ N_S=750\ rpm$

$$f=\frac{PN_S}{120}=\frac{8\times750}{120}=50\ Hz.$$

For I.M.

$P=6,\ N=970\ rpm,\ f=50\ Hz$

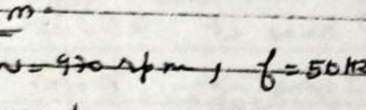
(i) $$N_S=\frac{120f}{P}=\frac{120\times50}{6}=1000\ rpm$$

(ii) $$S=\frac{N_S-N}{N_S}\Rightarrow S=\frac{1000-970}{1000}=0.03\Rightarrow \boxed{S=3\%}$$

(8) A 3-phase I.M with 4 pole is supplied from an alternator having 6 poles & running at 1000 rpm. Calculate: (i) The synchronous speed of I.M Dec-15/14ELE15
(ii) Its speed when slip is 0.04
(iii) Frequency of the rotor emf when the speed is 600 rpm

JUN-18 [17ELE25]

Solution:




$P=6$ poles, $N_S=1000\ rpm$ $\qquad$ $P=4$

For alternator: $$f=\frac{PN_S}{120}=\frac{6\times1000}{120}=50\ Hz$$

For I.M:

$f=50\ Hz,\ P=4$

(i) $$N_S=\frac{120f}{P}=\frac{120\times50}{4}=\underline{1500\ rpm}$$

(ii) $N = ?$ $\quad s = 0.04$

$$S = \frac{N_s - N}{N_s}$$

$$0.04 = \frac{1500 - N}{1500} \Rightarrow \underline{N = 1440 \text{ rpm}}$$

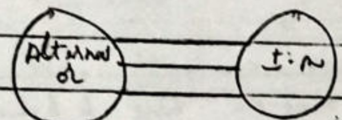
(iii) $f_r = ?$ $\quad N = 600$ rpm

$$S = \frac{N_s - N}{N_s} = \frac{1500 - 600}{1500} = \underline{0.6}$$

$$f_r = sf \Rightarrow f_r = S \times 50 = 0.6 \times 50 \Rightarrow \boxed{f_r = 30\text{Hz}}$$

(9) A 3 phase, 12 pole alternator is driven by an engine running at 500 rpm. The alternator supplies an induction motor which has a full load speed of 1455 rpm. Find the slip & the number of poles of the motor. Dec-14 [10ELE15]

Solution:




$P = 12$, $N_s = 500$ rpm $\qquad N = 1455$ rpm

For alternator

$$f = \frac{PN_s}{120} = \frac{12 \times 500}{120} = 50\text{Hz}$$

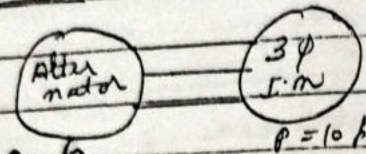
For I.M

$f = 50$Hz, $N = 1455$ rpm

(10) A 10 pole induction motor is supplied by a 6-pole alternator which is driven at 1200 rpm. If the motor runs at a slip of 3%. What is its speed?

Jan-14 [10ELE25]

Solution:




P = 10 pole.

P = 6

Ns = 1200 rpm

for alternator:

P = 6, Ns = 1200 rpm

$f = \frac{PN_s}{120} = 60\,Hz$

for I.M

$f = 60\,Hz,\ P = 10\,pole,\ S = 3\%,\ N_s = \frac{120f}{P} = \frac{120 \times 60}{10} = 720\ rpm.$

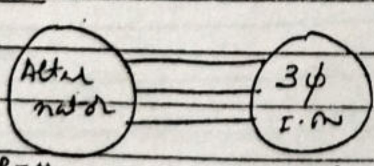
$S = \frac{N_s - N}{N_s} \Rightarrow 0.03 = \frac{720 - N}{720} \Rightarrow N = 698.4\ rpm$

$\boxed{N = 698\ rpm}$

(11) A 3-phase Induction motor has 6 poles & runs at 960 rpm on full load. It is supplied from an alternator having 4 poles & running at 1500 rpm. Calculate the full load slip & the frequency of the rotor currents of the induction motor

Jan-12 [06ELE25]

Solution:




P = 4

Ns = 1500 rpm

P = 6

N = 960 rpm

for alternator:

$f = \frac{PN_s}{120} = 50\,Hz$

for I.M:

P = 6, N = 960 rpm, f = 50 Hz

(i) $N_s = 120f/P = 1000\ rpm$

(ii) $S = \frac{N_S - N}{N_S} \Rightarrow S = \frac{1000 - 960}{1000}$

$\Rightarrow S = 0.04 \Rightarrow \boxed{S = 4\%}$

(iii) $f_r = sf$

$f_r = 0.04 \times 50$

$\boxed{f_r = 2 Hz}$

(12) A 6 pole induction motor is supplied from a 50Hz supply has an emf in the rotor of frequency 2.5Hz. Determine (i) slip (ii) The speed of the motor. Jun-13 [06 Marks]

Solution:

$P = 6$, $f = 50Hz$, $f_r = 2.5Hz$

(i) $s = f_r/f = 2.5/50 = 0.05$

$\boxed{S = 5\%}$

(ii) $N_S = \frac{120 f}{P} = \frac{120 \times 50}{6} = 1000$ rpm

(iii) $s = \frac{N_S - N}{N_S}$

$0.05 = \frac{1000 - N}{1000}$

$\boxed{N = 950 \text{ rpm}}$