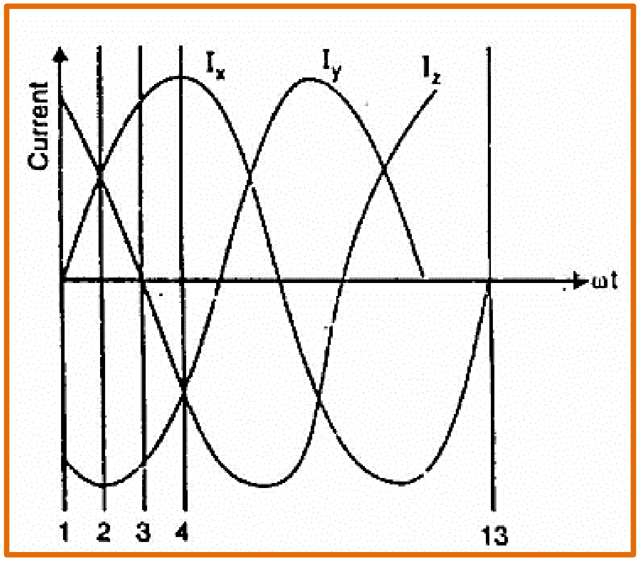
Speed of Rotating Magnetic Field

- Referring to Fig. 7 during the time period (from no. 1 to no. 4), the current I_x represents ¼ cycle. In this period of the current cycle, the rotating field rotates 90^o. So, for that 2-pole induction motor; *one cycle of the current make one revolution of the field*. But, for a 4-pole induction motor, ***two*** *cycles of the current make one revolution of the field.*



- What the relation between cycle of the current and number of revolution of the motor?

Cycles of current = (P/2) × Revolutions of field

Cycles of current/sec = (P/2) × Revolutions of field/sec

$$f = (P/2) \times (N_s/60)$$

- Finally:

$$f = \frac{P}{2} \times \frac{N_s}{60} \quad \rightarrow \quad \therefore N_s = \frac{120 f}{P}$$

Where;

f : supply frequency (Hz)

P : number of stator poles

N_s : speed of the stator magnetic field (rpm)

[*Named as:* synchronous speed]

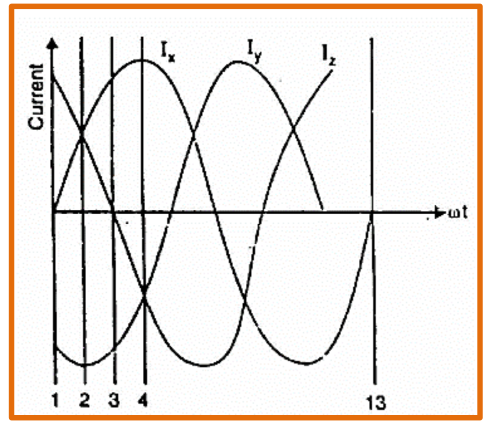
Why the speed of the 3-phase induction motor is named as a Synchronous Speed?

- The speed of the rotating magnetic field of the stator in the 3-phase induction motor is the same as the speed of the alternator that is supplying power to the motor if the two machines (motor and alternator) have the same number of poles. Hence the magnetic flux in the stator is said to rotate at synchronous speed (N_s).

<u>Watch Video</u>: How does an Induction Motor work? (4:05 min)

- For example, for a 6-pole, 50 Hz, 3-phase induction motor, $N_s = 120 * 50/6 = 1000$ rpm. It means that the flux rotates around the stator at a speed of 1000 rpm.

How Can You Change Motor Direction of Rotation?



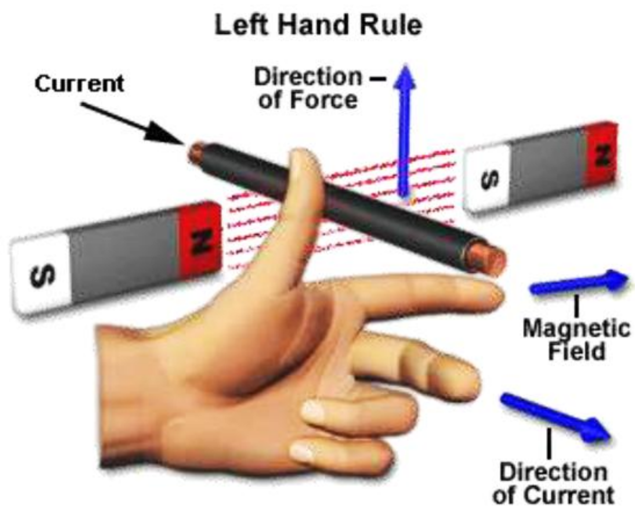
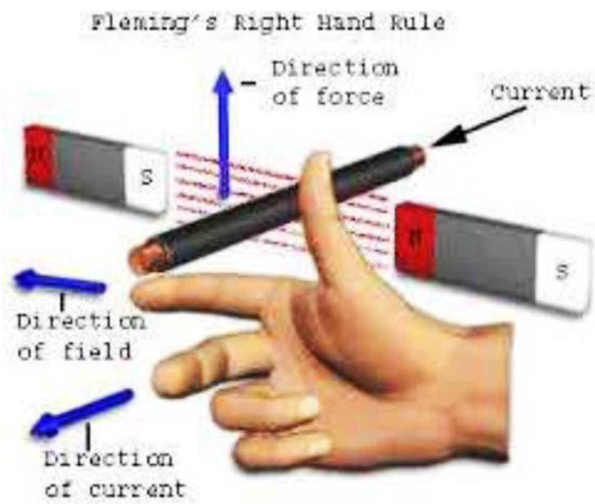
- For the stator number of poles (P) and the speed of the magnetic field (N_s) remain unchanged. Thus it is necessary only to change the phase sequence in order to change the direction of rotation of the magnetic field (*i.e.*, in order to change the motor direction of rotation). For a three-phase supply, this can be done by interchanging any two of the three lines.
- Referring to Fig. 7: the phase sequence of the 3-phase voltage applied to the stator winding is X-Y-Z, so (as shown in Fig 9) the field rotates in clockwise.

Hence, the motor rotates in the clockwise direction

- Referring to Fig. 7: if this sequence is changed to X-Z-Y, it is observed that the direction of rotation of the field is reversed *i.e.*, the field rotates counterclockwise

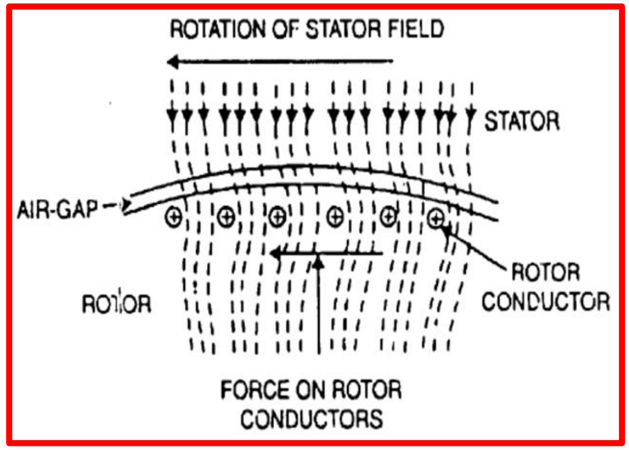
Hence, the motor rotates in the counterclockwise direction

Fleming's Right and Left Hand Rules

(Fleming's **Left** hand rule) Motor Rule When a conductor carrying current placed in a magnetic field between two poles, then, the field of conductor current and the field of poles are interact to produce motion of the conductor.	(Fleming's **Right** hand rule) Generator Rule When a conductor moves by a certain speed between two poles cutting the magnetic field of the poles, then, EMF is produced across conductor terminals.
 	

Principle of Operation of 3-Phase Induction Motor

- Consider a portion of 3-phase induction motor as shown in Fig. 10. The operation of the motor can be explained as follows:



▲Fig. 10: portion of 3-ph IM

i- When the 3-phase stator winding is energized from a 3-phase supply, a rotating magnetic field is set up which rotates round the stator at synchronous speed ($N_s = 120f/P$).

ii- The rotating flux of stator passes through the air gap and cuts the rotor conductors (which as yet, are stationary). Due to the relative speed (i.e., a motion found) between the rotating flux and the stationary rotor, electromotive forces (EMF: is an induced voltage) are induced in the rotor conductors. Since the rotor circuit is short-circuited; the current flows in the rotor conductors outward the pageهنا: قاعدة فلمنج لليد اليمنى ولكن الفيض هو المتحرك والموصل هو الثابت.

iii- But really there is an interaction between *the stator flux* and *the flux produced from current-carrying rotor conductors*. Consequently, the sum of the mechanical forces on all rotor conductors produces a torque which tends to ***move the rotor*** in the same direction as the stator field.

Slip

- We have seen: the rotor rapidly accelerates in the direction of the stator field.
- In practice, the rotor can never reach the speed of the stator flux. If it did, there would be no relative speed between the stator field and rotor conductors, no induced rotor currents and, therefore, no torque to drive the rotor. The friction and windage would immediately cause the rotor to slow down.
- Hence, the rotor speed (N) is always less than the stator field speed (N_s). This difference in speed depends upon load on the motor.

Slip …

- The difference between the synchronous speed (N_s) and the actual rotor speed (N) is called a slip. It is usually expressed as a percentage of synchronous speed i.e.,

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

i- The relative speed (N_s – N) is sometimes called ***slip speed***.

$$n_{slip} = N_s - N$$

ii- Rotor (or Motor) speed is $N = (1\text{-}s)N_s$.

iii- When the rotor is stationary (*i.e.*, N=0), slip, s =1= 100 %.

iv- In an induction motor, the change in slip from no-load to full-load is hardly 0.1% to 3% so that it is essentially a constant-speed motor.

Note that: the value of the slip is: $s \leq 1$ such that

s=1 in case of motor is standstill but

s<1 in all other running conditions.

Rotor Current Frequency

- When the rotor is stationary, the rotor current frequency (*f'*) is the same as the supply frequency (*f*).
- But when the rotor starts to rotate, then the rotor current frequency depend upon the relative speed (slip speed).
- For the supply frequency: $f = \frac{N_s P}{120}$ 1
- For the rotor current frequency: $f^{\backslash} = \frac{(N_s - N)P}{120}$ 2

Dividing equation 2 by equation 1: $\frac{f^{\backslash}}{f} = \frac{(N_s - N)}{N_s} = s$

$$\therefore\ f^{\backslash} = s\,f$$

Example 1: A 4-pole, 3-phase induction motor operates from a supply whose frequency is 50Hz. Calculate:

(i) Speed at which the magnetic field of stator is rotating.
(ii) Speed of the rotor when the slip is 0.04.
(iii) Frequency of the rotor current when the slip is 0.03.
(iv) Frequency of the rotor current when the motor is standstill.

Answer

[Ans.: 1500rpm – 1440rpm – 1.5Hz – 50Hz]

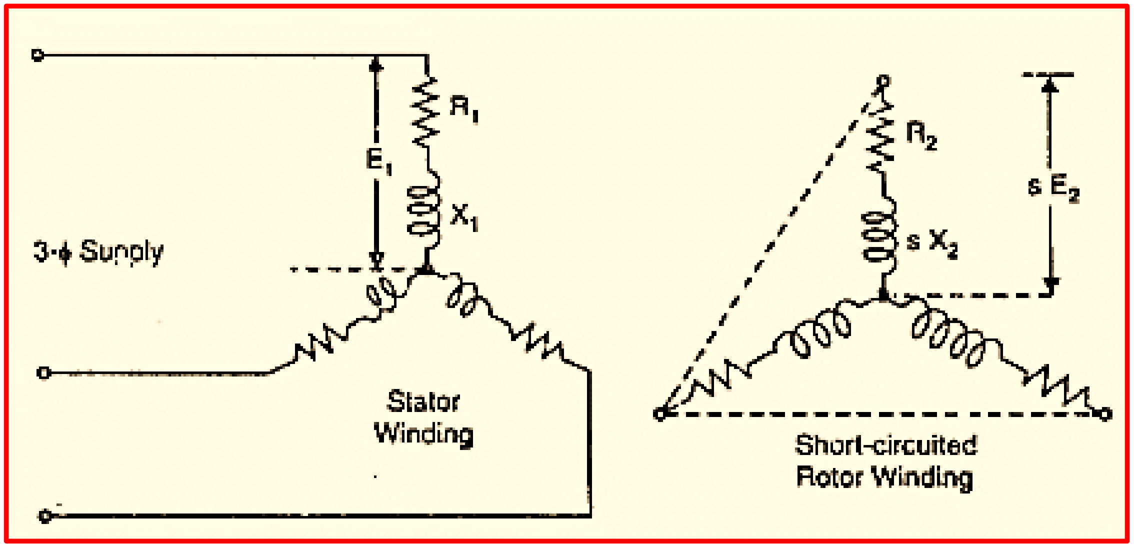
Example 2: A 3-phase induction motor is wound for 4 poles and is supplied from 50Hz source. Calculate:

(i) The synchronous speed.
(ii) The rotor speed when the slip is 4%.
(iii) Rotor current frequency when the rotor runs at 600rpm.

Answer

[Ans.: 1500rpm – 1440rpm – 30Hz]

Effect of Slip on the Rotor Circuit



- When the rotor is stationary, $s=1$. Under these conditions, the per phase rotor e.m.f. E_2 has a frequency equal to that of supply frequency f. At any slip s, the relative speed between stator field and the rotor is decreased. Consequently, the rotor e.m.f. and frequency are reduced proportionally to sE_s and sf respectively. At the same time, per phase rotor reactance X_2, its value depend on the frequency and so it is reduced to sX_2.

Effect of Slip on the Rotor Circuit …

- For example; consider a 6-pole, 3-phase, 50 Hz induction motor. It has synchronous speed $N_s = 120f/P = 120\times50/6 = 1000$ rpm.
  - At standstill, the speed of the stator flux is 1000 rpm and the rotor e.m.f./phase = E_2 (say).
  - If the full-load speed of the motor is 960 rpm, then,

$$\%slip = \%s = \frac{N_s - N}{N_s}\times100 = \frac{1000-960}{1000}\times100 = 4\% \quad\rightarrow\quad \therefore s = 0.04$$

(i) The relative speed between stator flux and the rotor is now only 40 rpm. Consequently, rotor e.m.f./phase is reduced to:

$$E_2\times\frac{40}{1000} = 0.04E_2 \quad\rightarrow\quad sE_2$$

(ii) The rotor frequency is also reduced in the same ratio to:

$$f\times\frac{40}{1000} = 50\times0.04 \quad\rightarrow\quad sf$$

(iii) The per phase rotor reactance X_2 is also reduced to:

$$X_2\times\frac{40}{1000} = 0.04\,X_2 \quad\rightarrow\quad sX_2$$

Effect of Slip on the Rotor Circuit …

- ***Finally***: at any slip *s*,

  Rotor e.m.f/phase = sE_2

  Rotor reactance/phase = sX_2

  Rotor frequency = sf

Where: E_2, X_2 and f are the corresponding values at standstill.