Electric Motors
BEE401

Module-3
Performance of Three-Phase Induction Motor

-Presented By
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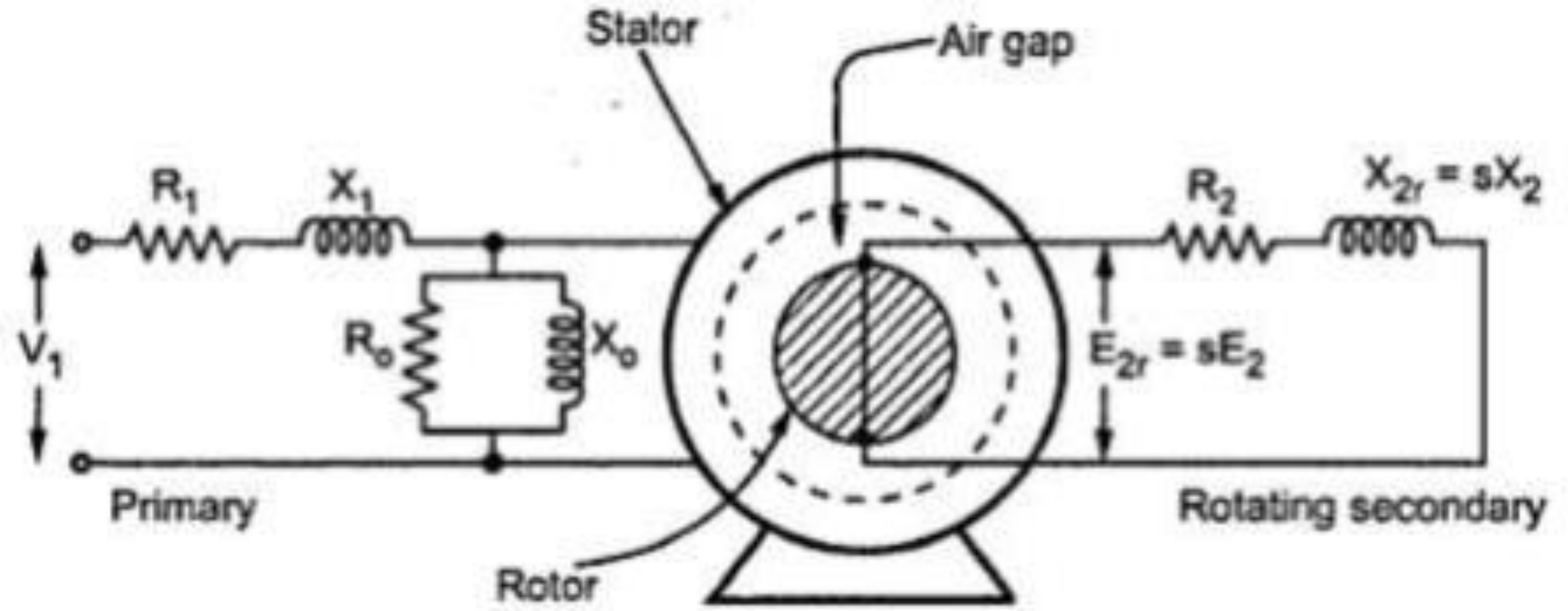
ATMECE

Module-3

Performance of three-phase Induction Motor: Phasor diagram of induction motor on no-load and on load, equivalent circuit, losses, efficiency, No-load, and blocked rotor tests. Performance of the motor from the circle diagram and equivalent circuit. Cogging and crawling. High torque rotors-double cage and deep rotor bars. Equivalent circuit and performance evaluation of double cage induction motor. Induction motor working as induction generator; standalone operation and grid-connected operation.

Equivalent circuit of Three-Phase Induction Motor:



Induction motor as a transformer

E_1 = Induced voltage in stator per phase

E_2 = Rotor induced e.m.f. per phase on standstill

k = Rotor turns / Stator turns

$k = E_2 / E_1$

E_{2r} = Rotor induced e.m.f. in running condition per phase

R_2 = Rotor resistance per phase

X_{2r} = Rotor reactance per phase in running condition

R_1 = Stator resistance per phase

X_1 = Stator reactance per phase

When induction motor is on no load, it draws a current from the supply to produce the flux in air gap and to supply iron losses.

1. I_c = Active component which supplies no load losses
2. I_m = Magnetizing component which sets up flux in core and air gap

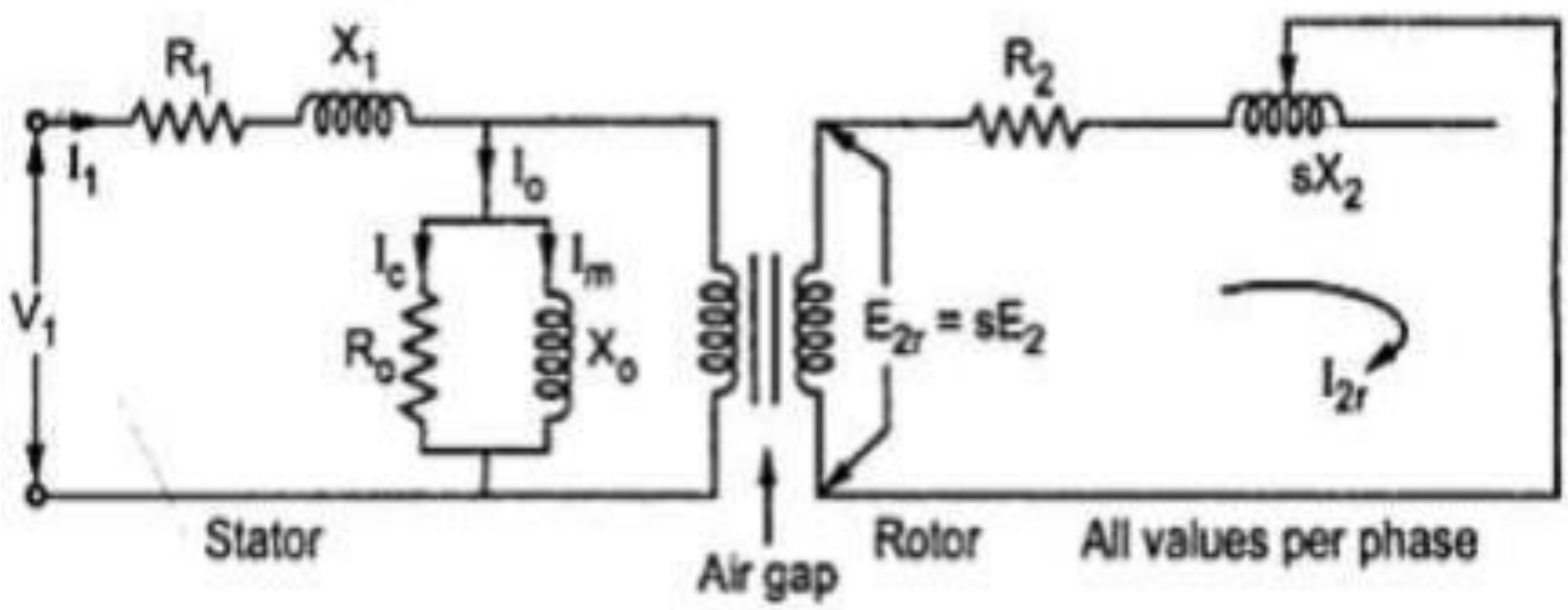
These two currents give us the elements of an exciting branch as,

R_o = Representing no load losses = V_1 / I_c

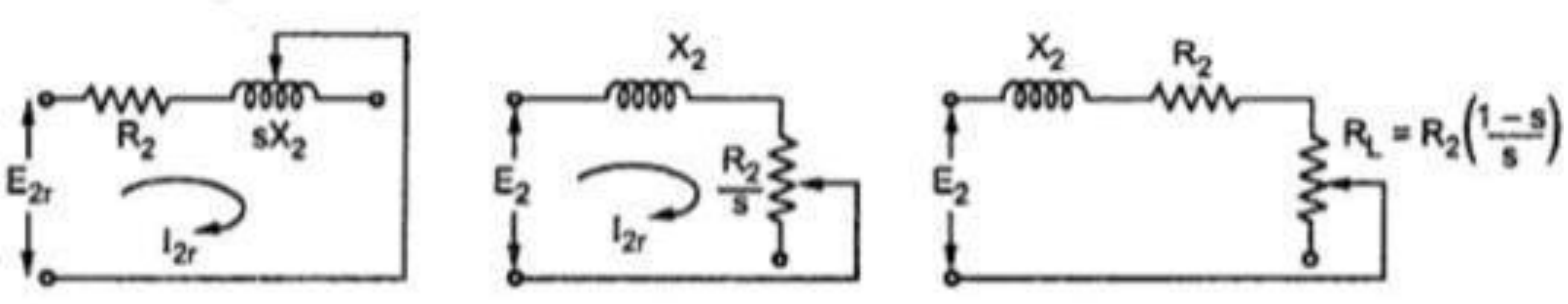
and X_o = Representing flux set up = V_1 / I_m

Thus, $\bar{I}_o = \bar{I}_c + \bar{I}_m$

Basic equivalent circuit:



Rotor equivalent circuit



(a) (b) (c)

Equivalent circuit referred to stator:

Transfer all the rotor parameters to stator,

$$k = E_2/E_1 = \text{Transformation ratio}$$

$$E_2' = E_2/\,k$$

The rotor current has its reflected component on the stator side which is I_{2r}'.

$$I_{2r}' = k\, I_{2r} = (k\ s\ E_2\ )/\sqrt{(R_2^2 + (s\ X_2)^2)}$$

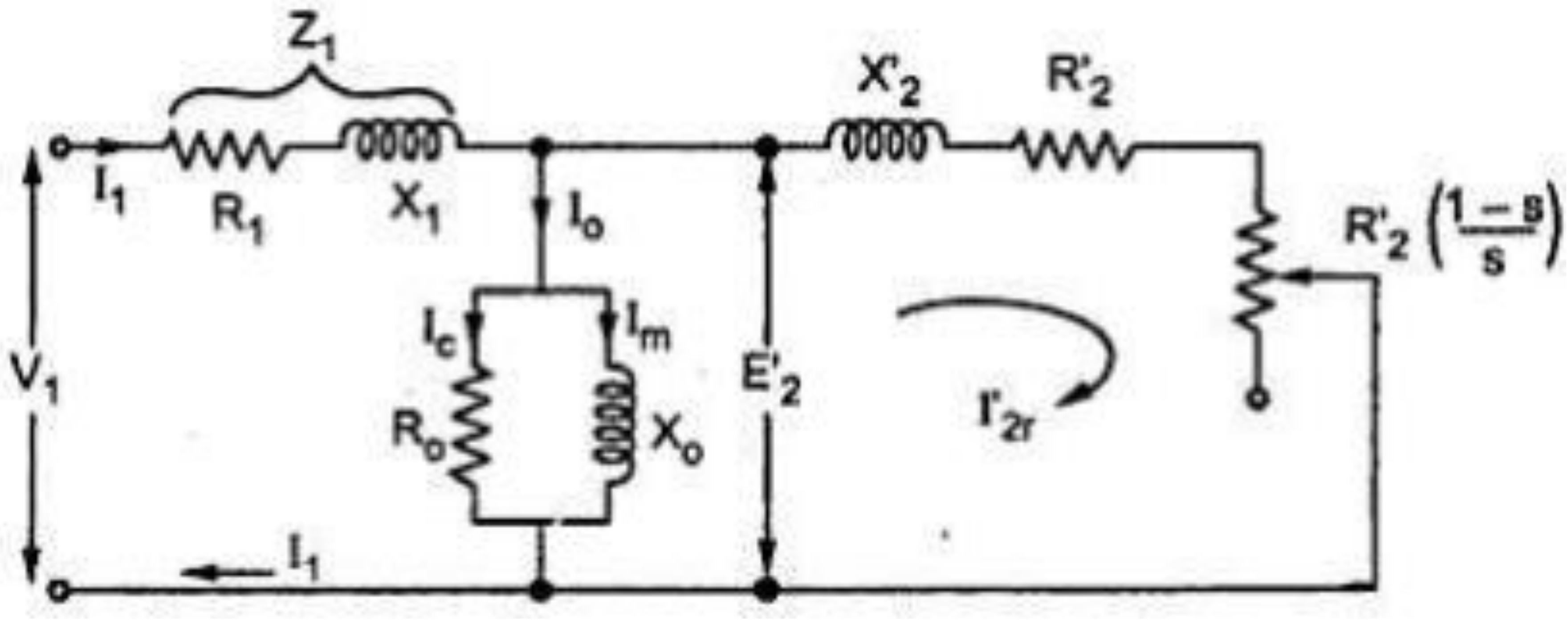
$$X_2' = X_2/K^2 = \text{Reflected rotor reactance}$$

$$R_2' = R_2/K^2 = \text{Reflected rotor resistance}$$

$$R_L' = R_L/K^2 = (R_2/K^2)(1\text{-}s\ /\ s)$$

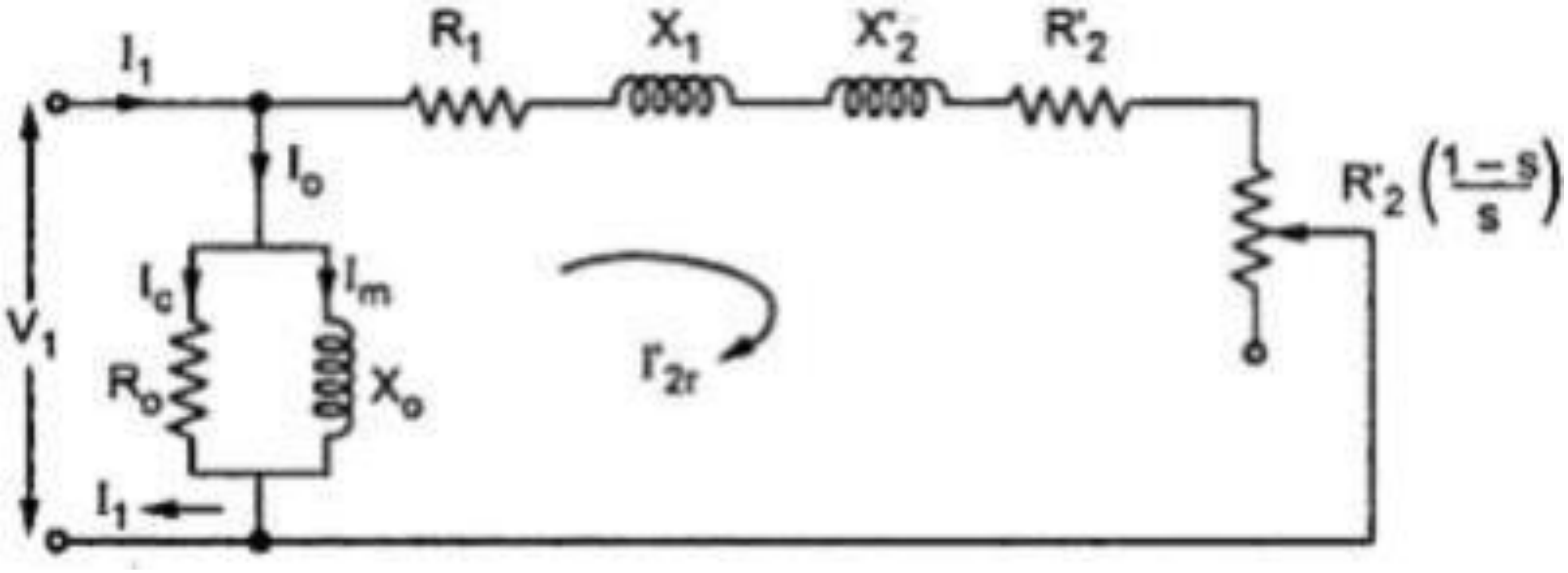
$$= R_2'\ (1\text{-}s\ /\ s)$$

Thus R_L' is reflected mechanical load on stator.



Equivalent circuit referred to stator

Approximate Equivalent Circuit:



Now the resistance R_1 and R_2' while reactance X_1 and X_2' can be combined. So we get,

R_{1e} = Equivalent resistance referred to stator = $R_1 + R_2'$

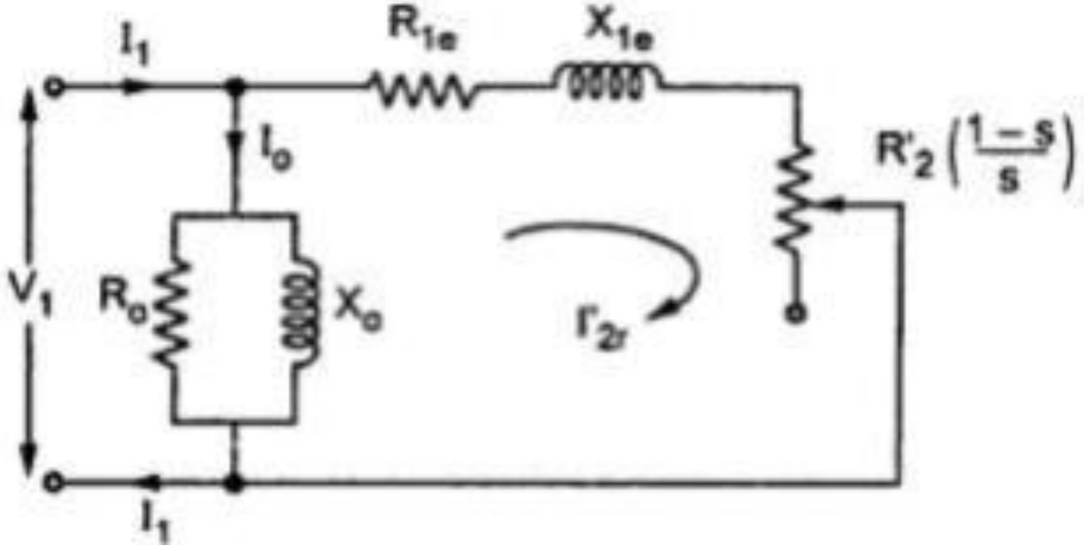
X_{1e} = Equivalent reactance referred to stator = $X_1 + X_2'$

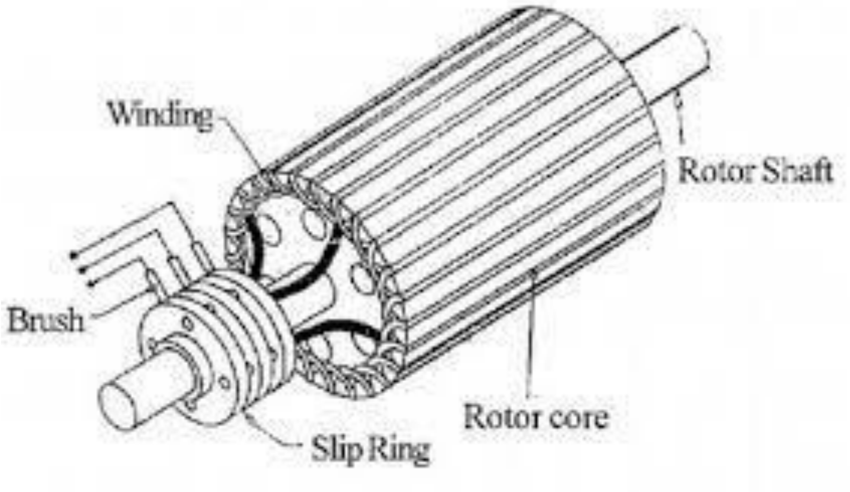
$$R_{1e} = R_1 + (R_2/K^2)$$

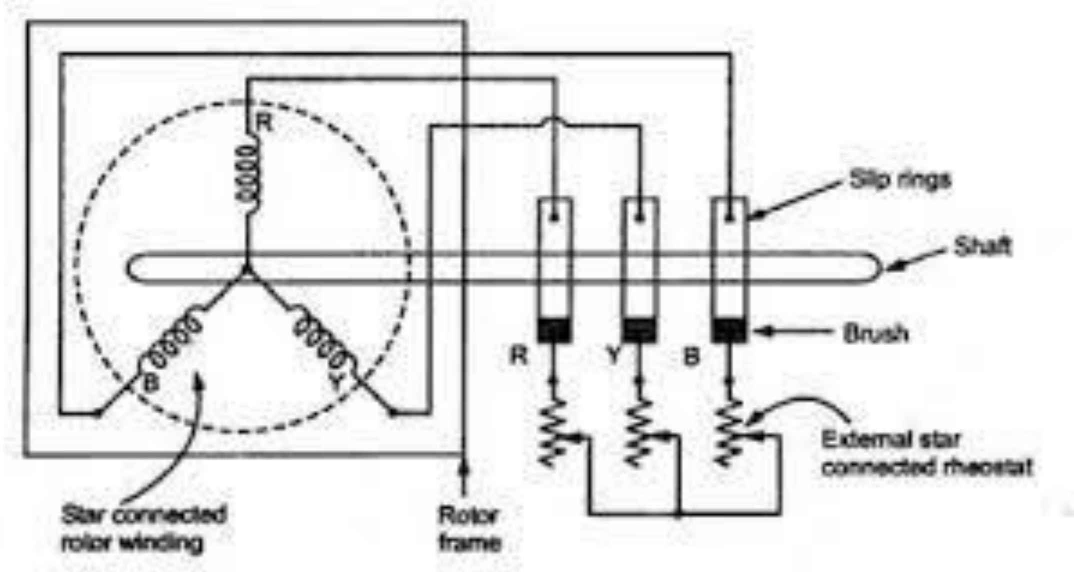
and $$X_{1e} = X_1 + (X_2/K^2)$$

While $\bar{I}_1 = \bar{I}_o + \bar{I}_{2r}'$ .... phasor diagram

and $\bar{I}_o = \bar{I}_c + \bar{I}_m$




Winding
Rotor Shaft
Brush
Rotor core
Slip Ring


R
Slip rings
Shaft
Brush
R
Y
B
B
Y
External star connected rheostat
Star connected rotor winding
Rotor frame


HIGH STARTING TORQUE
LOW STARTING TORQUE
SLIP RING ROTOR
SQUIRREL CAGE ROTOR

What is the need?

Conventional Squirrel Cage motors suffer from the disadvantages of low starting torque because of low rotor resistance.
The starting torque can be increased by using the bar material of higher resistivity.
However high rotor resistance reduces the full-load speed, increases rotor ohmic loss and lower efficiency.
Therefore in order to achieve high starting torque without effecting the efficiency, the rotor resistance is made higher at the time of starting & low under normal operating conditions.

In wound rotor induction motors these conditions are met by connecting external resistance in the rotor circuit at the time of starting & resistances are cut out in steps as the motor attains its normal speed.

In squirrel cage motor this is not feasible as the conductors are short-circuited by end rings.

In order to attain the above desired conditions following types of rotors are used:-

Deep bar rotor

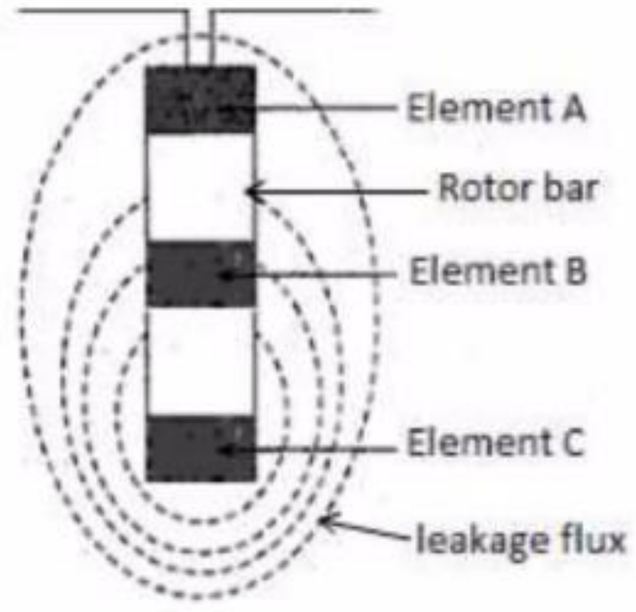
Double cage rotor

Deep-Bar Rotor

The figure below shows a cage rotor with deep and narrow bars. A bar may be assumed to be made up of a number of narrow layers connected in parallel.

It is seen that the topmost layer element 'A' is linked with minimum leakage flux and therefore its leakage inductance is minimum.

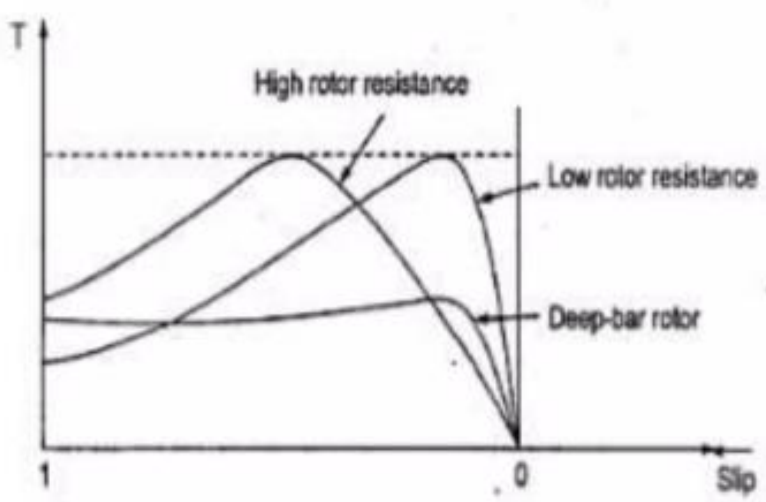
On the other hand, the bottom layer 'C' links maximum flux, therefore its leakage inductance is maximum.



Deep-bar rotor and leakage flux pattern

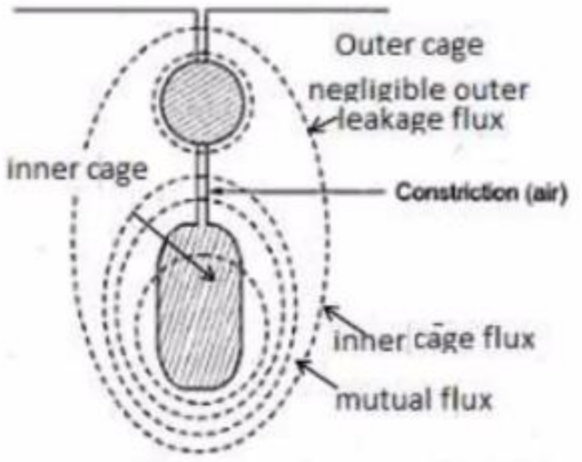
- At starting the rotor frequency is equal to the supply frequency. The bottom layer element 'C' offers more impedance to the current flow the upper layer 'A'.
- Therefore the maximum current flows through the top layer and minimum through the bottom layer. This unequal current distribution causes the effective rotor resistance to increase.
- With a high rotor resistance at starting condition, the starting torque is relatively high & starting current is low as desired.
- Now under normal operating conditions, the slip and the rotor frequency are very small. The reactance of all the layers are small compared to their resistances.
- The impedances of all the layers are nearly equal, so current flows through all the parts of the bar equally.
- The resulting large cross-section area makes rotor resistance small, resulting in good efficiency at low slips.

- The slip-torque curve for the deep-bar rotor is shown below along with the deep-bar stator. Torque/Slip Curve Deep-Bar rotor.



Double-Cage Rotors

- An induction motor with two rotor windings or cages is used for obtaining high starting torque at a low current.
- The stator of a double cage induction motor is similar to that of an ordinary induction motor. In a double cage rotor there are two layers of bars as shown
- The outer cage bars have a smaller cross-sectional area than the inner bars and are made of high resistivity materials like brass etc.

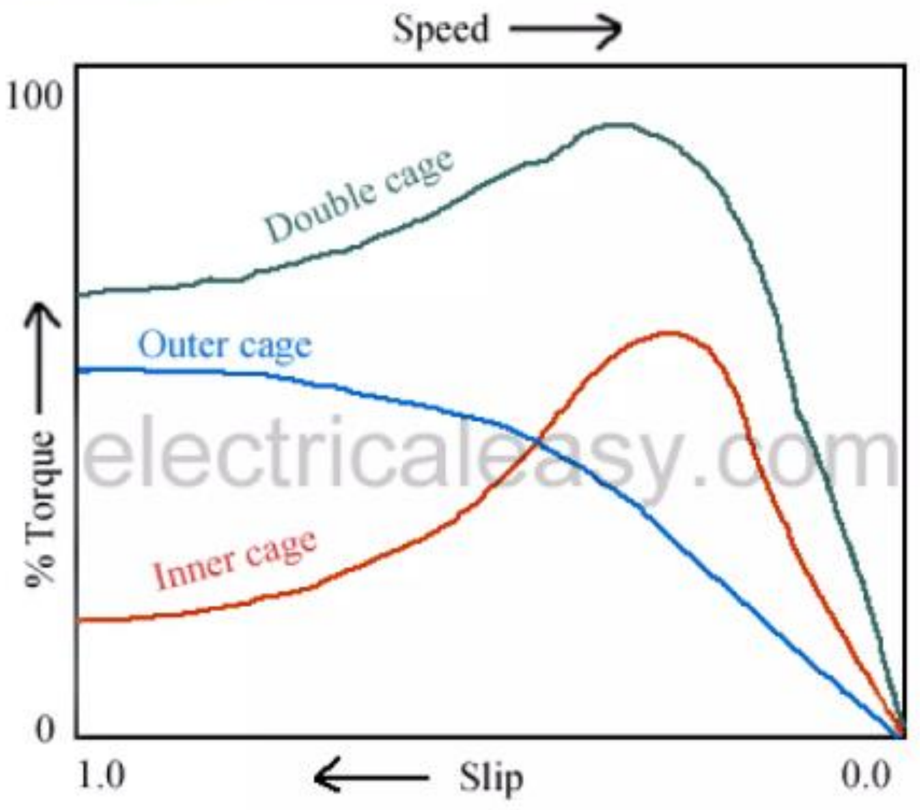


Slot-leakage flux pattern for double-cage rotor

- The inner cage bars are made up of low-resistance material like copper. Thus the resistance of the outer cage is greater than that of the inner cage.
- There is a slit between the top and bottom slot. This increases permeance for leakage flux around the inner cage bars.
- Thus the leakage flux linking the inner cage winding is much larger than that of the outer cage. The inner cage winding, therefore has a greater self-inductance.
- At starting voltage induced in the rotor is the same as the supply frequency. Hence the leakage reactance of the inner cage winding is much larger than that of the outer cage.
- Therefore most of the starting current is flowing in the outer cage winding which offers low impedance to current flow.
- The high resistance outer cage winding, therefore, develops high starting torque.
- As the rotor speed increases, the frequency of rotor emf decreases.

- At normal speed, the leakage reactance of both windings becomes negligibly small.
- The rotor current division between the two cages is governed mainly by their resistances.
- Since the resistance of the outer cage is about 5 to 6 times that of the inner cage, most of the rotor current flows through the inner cage.
- Hence under normal operating speed, torque is developed mainly by low resistance inner cage.

Torque–slip charecteristic of double–cage rotor




thank you