Lecture 7

Losses & Efficiency of Three Phase Induction Motor

Electrical AC Machines for Third Class

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Losses & Efficiency of Three Phase Induction Motor

Losses in Three Phase Induction Motor :

Power losses in 3phase induction motor are that portion of the input power that becomes heat rather than driving the load .

These losses can be divided into two categories:

1) Fixed Loses:

Fixed losses are assumed to be constant at all conditions of motor loading from no load to full load.

These losses are included:

I. Magnetic core losses (hysteresis and eddy current).

II. Mechanical friction losses (bearing friction, brush friction, and air friction or windage).

2) Variable Losses:

Variable losses are increased as the load (torque) on the motor is increased, and thus the current drawn by the motor is increased. These losses are included:

I. The power lost in the resistance of the motor windings and are often called copper losses, or I^2R losses, which included the stator and rotor windings copper losses.

II. Stray load losses such as minor variations in fixed losses with load and speed and other small miscellaneous losses.

Losses & Efficiency of Three Phase Induction Motor

1 Stator copper Losses

The stator copper loss is a function of the current flowing in the stator winding and the stator winding resistance.

Stator Losses = $\mathbf{I^2 R_1}$ Where **I** = Stator Current, $\mathbf{R_1}$ = Stator Resistance

The stator losses are a function of the stator winding resistance and directly proportional to square of stator currents, thus stator losses are inversely proportional to square of efficiency and power factor.

For a given motor, the winding resistance is inversely proportional to the weight of copper conductors used in the stator winding. Therefore, stator losses could also be reduced by using additional conductor material in the stator winding.

2 Rotor Losses

Rotor losses consist of copper and iron losses. During normal operation of induction motors, since the slip is very small, the magnetic reversals in the rotor core are only in the order of one or two per second. The iron losses caused by this are very small and hence can be neglected , so :

Rotor losses = Copper losses = input power to rotor - output power of rotor

$$= T\,W_1 - T\,W_2 = T\,(W_1 - W_2)$$

Where: **T** = Torque, $\mathbf{W_1}$ = Angular velocity of RMF, $\mathbf{W_2}$ = Angular velocity of rotor

But slip (**S**) is given by: $S = (W_1 - W_2) / W_1 = T\,(W_1 - W_2) / T\,W_1$ = Rotor losses / input power to rotor

So, **Rotor losses = S x input power to rotor**

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3 **Magnetic Core (Iron) Losses:**

Magnetic core losses consist of the eddy current and hysteresis losses.

Hysteresis loss is increased linearly with an increase in frequency, while the eddy current loss is increased as the square of the frequency. This can be expressed by the following equation:

Iron Loss = $h f + e f^2$

where (h) is the coefficient of the hysteresis loss ,(e) is the coefficient of the eddy current loss , and (f) is the supply frequency .

Iron losses could be reduced by:

1) Increasing the length of magnetic structure and thus decreasing flux density.
2) Using thinner laminations in the magnetic structure.
3) Using silicon grades of electrical steel. In general higher the silicon content (up to 4%), the lesser shall be the magnetic losses.

4 **Friction and Windage (Rotational) Losses:**

These are power losses due to friction of the bearings, air friction (windage) caused by the motion of the moving parts through the surrounding medium. The friction loss is relatively fixed for a given design. Most of the windage losses are associated with ventilation fans that required for heat dissipation due to other losses such as windings loss, core loss etc. As these heat producing losses are reduced, it is possible to reduce the ventilation and thus the windage losses can be reduced.

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5 These are the residual losses in the motor that are difficult to determine by calculation or measurement. Some of the influencing factors are winding design , ratio of air gap length to rotor slot openings, air gap flux density etc.

By careful design, some of the elements contributing to stray losses can be minimized. An arbitrary figure of 0.5% of the input power has been used for stray load losses ,and appears in IEC specifications.

In a very general sense, the average loss distribution for NEMA - Design B Motors is tabulated below:

Motor Component Loss	**Total Loss %**
Stator copper Losses	37%
Rotor copper Losses	18%
Magnetic Core Losses	20%
Friction and Windage Losses	9%
Stray Load Losses	16%

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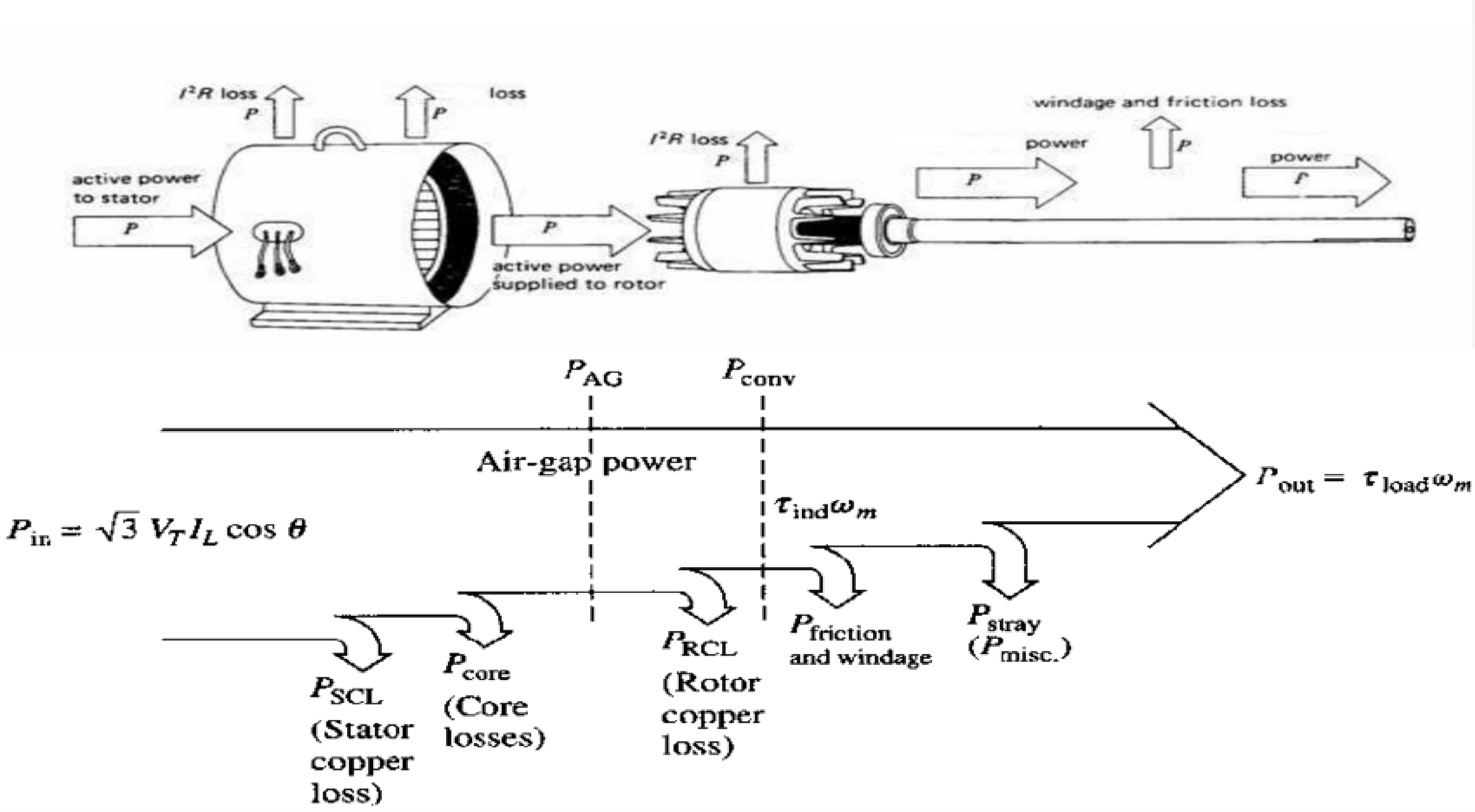
Power Flow in a Three Phase Induction Motor :



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Motor Efficiency and Power Factor :

Motor efficiency is the ratio of the output of the motor to the electrical input power, usually expressed in percent of the input power.

Efficiency = Output (Watts) / Input (Watts)
= 746 x HP / (V x I x PF)
= (Input - Losses) / Input
= Output / (Output + losses)

Where, HP is the output horse power, PF is the input power factor

Normally, Large three phase induction motors are more efficient than smaller size motors. Large induction motor efficiency can be as high as 95% at full load, however 90% is more common.

Efficiency for a lightly load or no-loaded induction motor is poor because most of the current is involved with maintaining magnetizing flux.

Power factor is the ratio between the KW and the KVA drawn by the motor, where the KW is the motor active (or real) power and the KVA is the motor apparent(or total) power. Induction motors present a lagging (inductive) power factor to the power line. The power factor in large fully loaded high speed motors can be as favourable as 90%. The power factor for small low speed motors can be as low as 50%.

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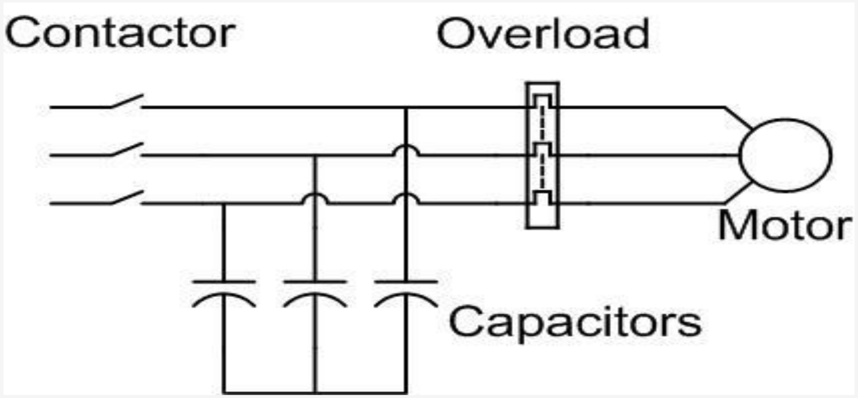
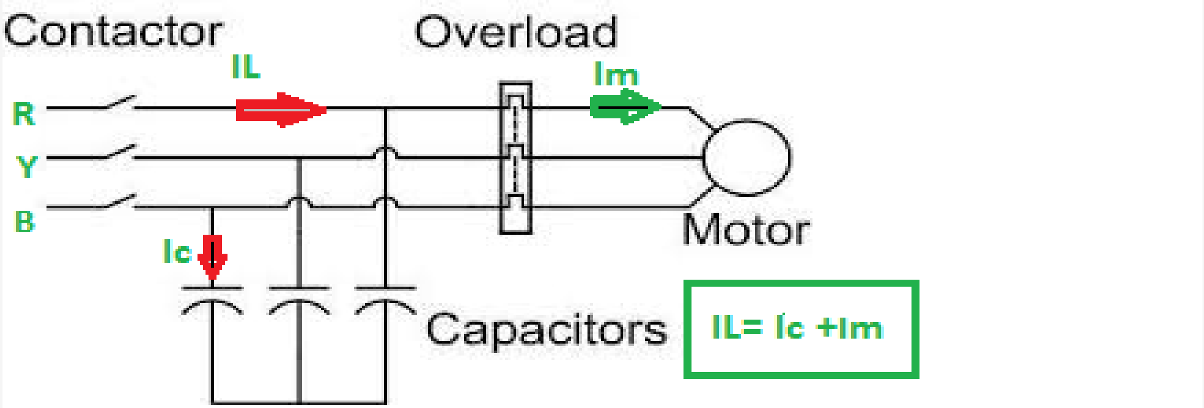
At starting, the power factor can be in the range of 10% to 25% , rising as the rotor achieves speed. Power factor (PF) varies considerably with the motor mechanical load. An unloaded motor is analogous to a transformer with no resistive load on the secondary. Little resistance is reflected from the secondary (rotor) to the primary (stator). Thus the power line sees a reactive load, as low as 10% PF. As the rotor is loaded an increasing resistive component is reflected from rotor to stator, increasing the power factor.

A poor power factor due to an inductive load can be improved by generating an amount of reactive power (normally by using capacitors). These capacitors is used to deliver the required reactive power that the motor needs to establish the magnetic flux which means no more reactive power is supplied from the power line to the motor and thus improving the overall power factor. This technique is called power factor correction (PFC), the circuit layout of connected capacitors is shown in the figures below.





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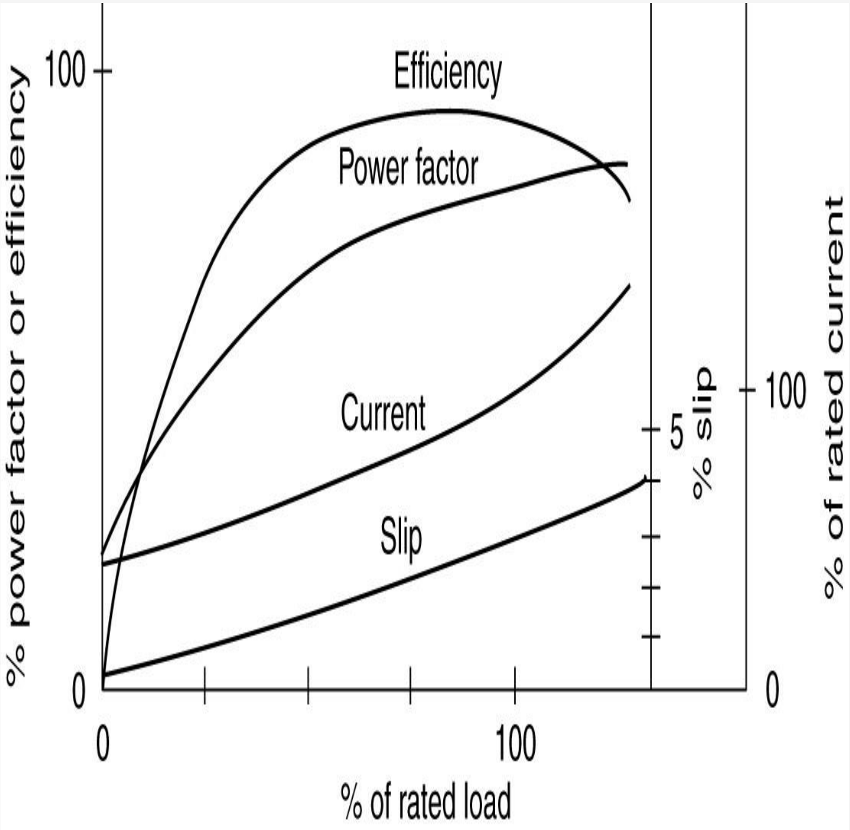
Performance of Three Phase Induction Motor:

The shown figure is the representative performance curves for typical three phase Induction Motor. Which illustrates how efficiency may vary with percent applied load. Maximum efficiency appears at the load when the variable losses are equal to the constant losses. The power factor is increased as applied load increasing. The motor drown current is rising as the load is increased with 100% from its rated value at full load. The slip is starting from the value of unity and ends down with nearly 3% at full load.



Related Questions in Sheet No. 2

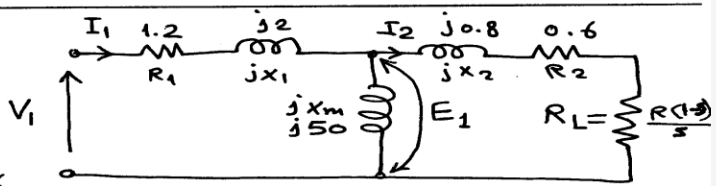
Losses & Efficiency of Three Phase Induction Motor

Solved Example on induction motor losses & efficency

A certain 30 hP, 4 Pole, 440V, 60 Hz, Δ connected 3ϕIM has ($R_1 = 1.2\,\Omega$, $R_2 = 0.6\,\Omega$, $x_1 = 2\,\Omega$, $x_2 = 0.8\,\Omega$, and $x_m = 50\,\Omega$), the machine operates at 1746 r.p.m under load, and has rotational losses of 900W.

Find Stator & Rotor losses, motor efficiency ?

Solution:



$$N_s = \frac{120f}{P} = \frac{120 * 60}{4}$$

$$N_s = 1800\,rpm$$

$$s = \frac{N_s - N_r}{N_s} = \frac{1800 - 1746}{1800} = 0.02$$

$$Z_T = R_1 + jx_1 + \frac{jx_m(R_2 + R_L + jx_2)}{jx_m + R_2 + R_L + jx_2} = 1.2 + j2 + \frac{j50(0.6 + 29.4 + j0.8)}{j50 + 0.6 + 29.4 + j0.8}$$

$$Z_T = 22.75 + j15.51 = 27.53\angle 34.29^\circ$$

$$\text{Power factor (PF)} = \cos(34.29^\circ) = 0.8262 \text{ lagging}$$

$$I_1 = \frac{V_1}{Z_T} = \frac{V_1}{Z_T} = \frac{440\angle 0^\circ}{27.53\angle 34.29^\circ} = 15.98\angle -34.29^\circ$$

For Δ connected $I_{line} = \sqrt{3}\, I_{ph} = \sqrt{3} * 15.98 = 27.68$ Amp

$$P_{in} = 3V_1 I_1 \cos\phi = 3 * 440 * 15.98 * \cos(-34.29) = 17.43\,kW$$

$$E_1 = V_1 - I_1(R_1 + jx_1) = 440\angle 0^\circ - 15.98\angle -34.29^\circ (1.2 + j2)$$

$$E_1 = 406.46\angle -2.196^\circ$$

$$I_2 = \frac{E_1}{jx_2 + R_2 + R_L} = \frac{406.46\angle -2.196^\circ}{j0.8 + 0.6 + 29.4} = 13.54\angle -3.727^\circ$$

Stator copper loss $P_{cu1} = 3I_1^2 R_1 = 3(15.98)^2 * 1.2 = 919.3\,W$

Rotor copper loss $P_{cu2} = 3I_2^2 R_2 = 3(13.54)^2 * 0.6 = 330\,W$

$$P_{dev} = 3R_L I_2^2 = 3 * 29.4 * (13.54)^2 = 16.17\,kW$$

$$P_{out} = P_{dev} - P_{rot} = 16.17 - 0.9 = 15.27\,kW$$

$$\eta = \frac{P_{out}}{P_{in}} * 100\% = \frac{15.27}{17.43} * 100\% = 87.61\%$$