



## Torque of three phase induction motor

Torque of three phase induction motor :  $T \propto E_r I_r \cos \theta_2$  ,  $E_r \propto \phi$

$T \propto \phi I_r \cos \theta_2$

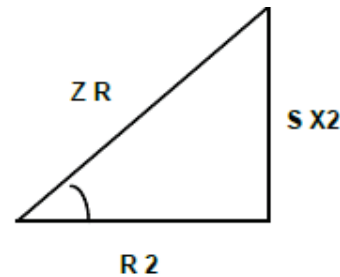
Where

$$E_r = \text{rotor e.m.f / phase}$$

$$I_r = \text{rotor current / phase}$$

$$E_r = S E_2$$

$$I_r = \frac{E_r}{Z_r} = \frac{S E_2}{\sqrt{R_2^2 + (S X_2)^2}}$$



From figure above

$$\cos \theta_2 = \frac{R_2}{\sqrt{R_2^2 + (S X_2)^2}}$$

$$T \propto \frac{S \phi E_2 R_2}{R_2^2 + (S X_2)^2} = \frac{K \phi S E_2 R_2}{R_2^2 + (S X_2)^2}$$

But  $E_2 \propto \phi$

$$T = \frac{K S E_2^2 R_2}{R_2^2 + (S X_2)^2}$$

At standstill when  $S = 1$  , obviously

$$T = \frac{K E_2^2 R_2}{R_2^2 + X_2^2}$$

Condition for maximum torque :

The torque of a rotor under running condition is

$$T = \frac{K \phi S E_2 R_2}{R_2^2 + (S X_2)^2}$$



The condition for maximum torque may be obtained by differentiating the above equation with respect to slip (S) and then putting it equal to zero.

Hence, torque under running conditions is maximum at that value of the slip (S) which makes rotor reactance per phase equal to rotor resistance per phase.

$$T_{\max} = \frac{K \Phi S E_2}{2R_2}$$

Relation between torque and slip :

A family of torque/slip curves is shown in figure below, for a range of  $S = 0 - 1$  We have seen above that

$$T = \frac{K \Phi S E_2 R_2}{R_2^2 + (SX_2)^2}$$

It is clear that when  $S = 0$ ,  $T = 0$ . Hence the curve starts from point 0. At normal speeds, close to synchronism the term  $(SX_2)$  is small and hence negligible w.r.t  $R_2$ .

$$T \propto \frac{S}{R_2}$$

If  $R_2$  is constant, then  $T \propto S$

Hence, for low values of slips, the torque /slip curve is approximately a straight line.

As slip increase ( for increasing load on the motor ) the torque also increases and become maximum when  $S = R_2/X_2$ .

As the slip further increases ( i.e. motor speed falls ) with further increase in motor load,  $R_2$  becomes negligible as compared to  $(SX_2)$ , therefore



$$T \propto \frac{1}{(S X_2)^2}$$

Hence , the torque/slip curve is a rectangular hyperbola . So ,we see that beyond the point of maximum torque , any further increase in motor load results in decrease of torque developed by the motor . The result is that the motor slows down and eventually stops . The circuit – breaker will be tripped and open the circuit . In fact , the stable operation of motor lies between the values of  $S = 0$  and that corresponding to maximum torque The operating range is shown shaded in the next figure.

