**Subject** : Basic electrical engineering

**Question** : Explain the slip-torque characteristics of 3 phase induction motor.

**Answer** :

As the induction motor is loaded from no load to full load its speed decreases. Hence, slip increases. Due to the increased load, motor has to produce more torque to satisfy the load demand. The torque ultimately depends on slip as explained earlier. The behaviour of motor can be easily judged by sketching a curve obtained by plotting torque produced against the slip of induction motor. The curve obtained by plotting torque against slip from s = 1 (at start) to s =0 (at synchronous speed) is called torque-slip characteristics of the induction motor.

The torque equation of induction motor is,

$$\boxed{T \propto \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2}}$$

For a constant supply voltage, $E_2$ is also constant. So, we get torque equation as,

$$\boxed{T \propto \frac{sR_2}{R_2^2 + (sX_2)^2}}$$

Now, to judge the nature of torque–slip characteristics, let us divide the slip range (s=0 to s=1) into two parts and analyse them independently.

i. **Low slip region:**

In low slip region's' is very small. Due to this, the term $(sX_2)^2$ is so small as compared to $R_2^2$ that it can be neglected.

$$\therefore \quad \boxed{T \propto \frac{sR_2}{R_2^2} \propto s} \qquad \text{...As } R_2 \text{ is constant}$$

Hence, in low slip region torque is directly proportional to slip. So, as load increases, speed decreases thereby, increasing the slip. This increases the torque which satisfies the load demand.

Hence, the graph is a straight line in nature.

At $N = N_s, s = 0$ and hence T=0. As no torque is generated at $N = N_s$, motor stops if it tries to achieve the synchronous speed. Torque increase linearly in this region of low slip values.

**ii. High slip region:**

In this region, slip is high i.e. slip value is approaching to 1. Here, it can be assumed that the term $R_2^2$ is very small as compared to $(sX_2)^2$. Hence, neglecting $R_2^2$ from the denominator, we get

$$\boxed{T \propto \frac{sR_2}{(sX_2)^2} \propto \frac{1}{s}}$$

where, $R_2$ and $X_2$ are constants.

So, in high slip region torque is inversely proportional to the slip. Hence, its nature is like rectangular hyperbola.

Now, when the load increases load demand increases but speed decreases. As speed decreases, slip increases. In high slip region as $T \propto 1/s$, torque decreases as slip increases. But torque must increase to satisfy the load demand. As torque decreases, due to extra loading effect, speed further decreases and slip further increases. Again torque decreases as $T \propto 1/s$ hence same load acts as an extra load due to reduction in the torque produced. Hence, speed drops further. Eventually, motor comes to standstill condition. The motor cannot continue to rotate at any point in this high slip region. Hence, this region is called unstable region of operation.

***So, torque - slip characteristics has two parts,***

1. Straight line called stable region of operation.
2. Rectangular hyperbola called unstable region of operation.

Now, the obvious question is, upto which value of slip; the torque-slip characteristic represents stable operation?

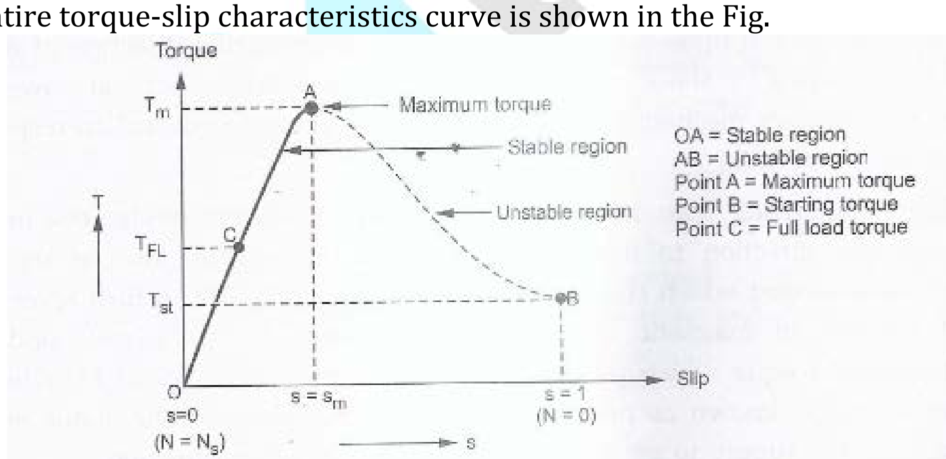
In low slip region, as load increases, slip increases and the torque also increases linearly. Every motor has its own limit to produce a torque. The maximum torque that the motor can produce as load increases is $T_m$ which occurs at $s = s_m$. So, linear behaviour continues till $s = s_m$.

If load is increased beyond this limit, motor slip acts dominantly pushing motor into high slip region. Due to unstable conditions, motor comes to standstill condition at such a load. Hence, $T_m$ i.e. maximum torque which motor can produce is also called breakdown torque or pull out torque.

So ranges s = 0 to $s = s_m$ is called low slip region, known as stable region of operation. Motor always operates at a point in this region. And range $s = s_m$ to s = 1 is called high slip region which is rectangular hyperbola, called unstable region of operation. Motor cannot continue to rotate at any point in this region.

At s = 1, N = 0 i.e. at start, motor produces a torque called starting torque denoted as $T_{st}$.

The entire torque-slip characteristics curve is shown in the Fig.




**Torque –slip characteristics**