Torque-Speed Characteristics of Three Phase Squirrel Cage Induction Motor

Aim

To obtain the torque-speed characteristics (T-N_r) of a three phase squirrel cage induction motor using

1. Variable voltage control
2. Variable voltage variable frequency (V/F) control

Theory

An induction motor compared to a dc motor has some major advantages such as - Absence of brushes, commutator segments, rugged construction, being cheap, lesser maintenance requirements and smaller size for the same power output. Due to these advantages induction machines have become more popular in industrial applications. For any motor load application, it is imperative to know the torque speed characteristic of the motor. Consider a three phase squirrel cage induction motor whose stator has three windings displaced in space by 120°. When they are excited with currents that are displaced in time by 120°, a rotating magnetic field rotating at a speed called synchronous speed N_s is set up. The synchronous speed, N_s is given by (1).

$$N_s = \frac{120f}{P} \tag{1}$$

where, f is the frequency of the currents and P is the number of poles. If the rotor of the induction motor rotates at a speed, N_r, then the slip, s is defined by (2).

$$s = \frac{N_s - N_r}{N_s} \tag{2}$$

The torque developed by the induction motor is given by (3).

$$T = \frac{3}{\omega_s}\frac{{I_2}^2 R_2}{s} = \frac{3}{\omega_s}\frac{{V_s}^2 R_2/s}{(R_1 + R_2/s)^2 + (X_1 + X_2)^2} \tag{3}$$

where ω_s is the synchronous speed in rps, V_s is the voltage applied to the stator, I_2, R_2, X_2 are the rotor current, resistance and reactance referred to stator respectively. R_1, X_1 are the stator resistance and reactance respectively. If (3) is plotted, we get the T-N_r characteristics as shown in Fig. 1. The maximum torque developed, T_m and the slip,s_m at which T_m occurs is given by (4).

$$\begin{aligned} T_m &= \frac{3}{2\omega_s}\frac{{V_s}^2}{R_1 \pm \sqrt{{R_1}^2 \pm (X_1 + X_2)^2}} \\ s_m &= \frac{R_2}{\sqrt{{R_1}^2 + (X_1 + X_2)^2}} \end{aligned} \tag{4}$$

T-N_r characteristics with variable stator voltage

If voltage applied to the stator of the induction motor is varied, developed torque will vary with a relation $T \propto {V_s}^2$. The maximum torque developed, T_m is also proportional to square of the applied voltage as in (4), but s_m is independent of applied voltage. So, if the T-N_r characteristics is plotted for different voltages, we get the characteristics as shown in Fig. 2.

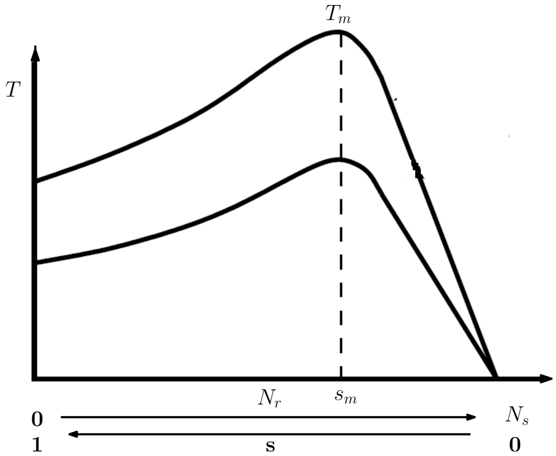


Figure 1: T-N_r characteristics of a three phase induction motor

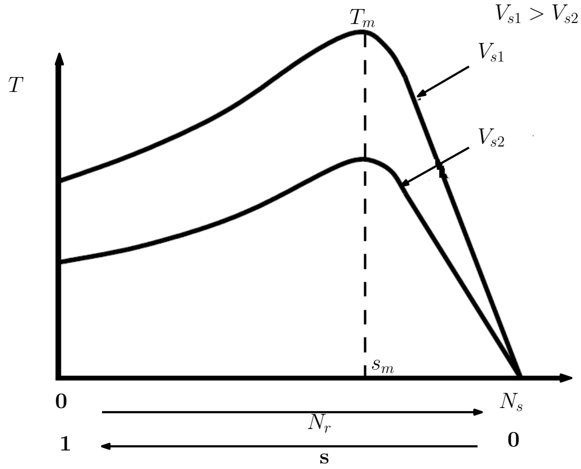


Figure 2: T-N_r characteristics of a three phase induction motor with variable voltage control

T-N_r characteristics with V/f control

If the motor is operated with a variable voltage- variable frequency source, we can implement constant V/f control of the induction motor, where the operating flux ϕ is kept constant.

$$E = 4.44 K_c \phi f N_{st} \tag{5}$$

$$\phi \propto \frac{E}{f} \tag{6}$$

where K_c is the machine constant, E is the induced voltage in the stator, ϕ is the rated flux in the air-gap, N_{st} is the number of turns in the stator. Assuming $V_s = E$, if the V/f ratio is kept constant, ϕ will also be constant. If $V_s = KV_{srated}$ and $f = Kf_{rated}$, then the slip will be as follows.

$$s = \frac{K\omega_s - \omega_r}{K\omega_s} \tag{7}$$

$$sK = \frac{K\omega_s - \omega_r}{\omega_s} \tag{8}$$

where the term sK is the slip speed, that is the drop in motor speed from no load speed ($K\omega_s$). The expression for the developed torque with V/f control will be given by (9).

$$T = \frac{3}{K\omega_s}\frac{{I_2}^2 R_2}{s} = \frac{3}{\omega_s}\frac{{V_s}^2 R_2/sK}{(R_2/Ks)^2 + {X_2}^2} \tag{9}$$

The maximum torque developed, T_m and the slip at which T_m occurs,s_m are given by (10).

$$\begin{aligned} T_m &= \frac{3}{2\omega_s}\frac{V_s^2}{X_2} \\ s_m &= \frac{R_2}{KX_2} \end{aligned} \tag{10}$$

So with V/f control, the maximum torque developed is independent of K, but s_m is inversely proportional to K. From (9), for any given torque,T, the drop in motor speed from no load speed, (sK) will be same for any value of K. Thus , with V/f control, the T-N_r characteristics for different values of K will be parallel to each other as shown in Fig.3.

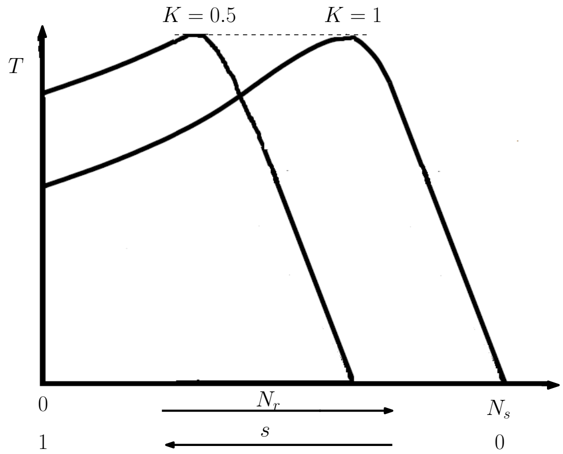


Figure 3: T-N_r characteristics of a three phase induction motor with V/f control

The starting torque (for s=1), T_{st} is given by (11). Thus, $T_{st} \propto 1/K$.

$$T_{st} = \frac{3}{\omega_s}\frac{{V_s}^2 R_2/K}{(R_2/K)^2 + {X_2}^2} \tag{11}$$

Procedure:

Variable voltage control:

A. Connect the circuit as shown in figure 4. In this experiment the motor is loaded with a mechanical system.

B. Initially no load is applied to the motor. Set the output of the autotransformer to zero and switch on the three phase supply.

C. Vary the voltage applied to the stator using autotransformer. Increase the voltage to half the rated value. Increase the load slowly to get different torque and speed points to get the T-N_r characteristics at half the rated voltage. Make sure that the motor is not loaded above its rated current.

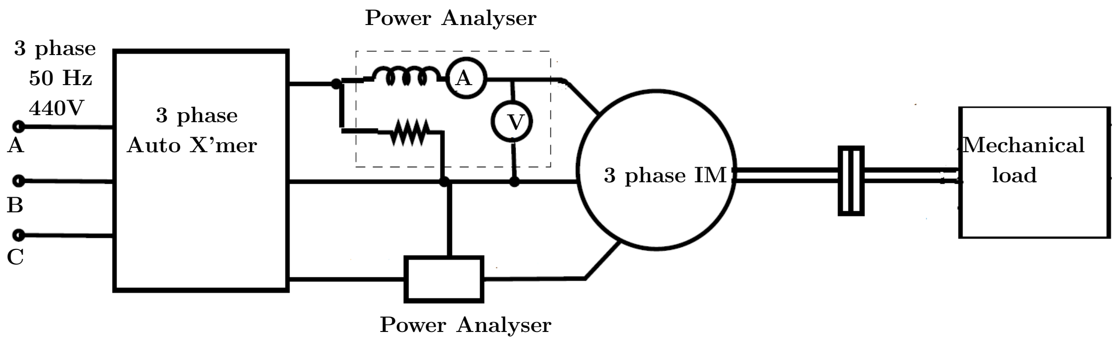


Figure 4: Circuit diagram for variable voltage control

D. Now reduce the load to zero and repeat the same steps[A-C] with rated voltage applied to the stator.

E. Bring the load to zero. Then bring the autotransformer to zero position and switch off the supply.

V/f control:

A. Connect the circuit as shown in figure 5.

B. Initially no load is applied to the motor. Switch on the variable frequency drive. Set the speed at half the synchronous speed. Press the RUN button in VFD.

C. Increase the load slowly to get different torque and speed points to get the T-N_r characteristics at K=0.5.

D. Now set the speed in VFD as the synchronous speed of the motor and repeat the same steps[A-C] to obtain the characteristics at K=1.

E. Bring the load to zero. Then turn off the VFD and switch off the supply.

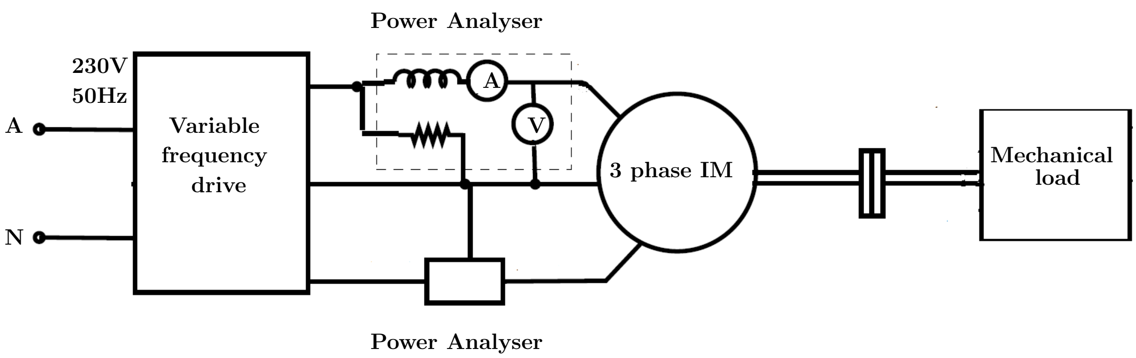


Figure 5: Circuit diagram for V/f control

The cut section of a squirrel cage induction motor is shown in Fig.6. Separate view of the stator and rotor of an induction motor is shown in Fig.7.

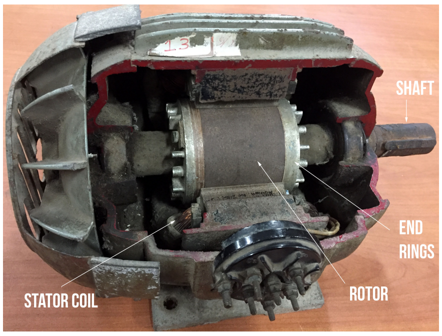
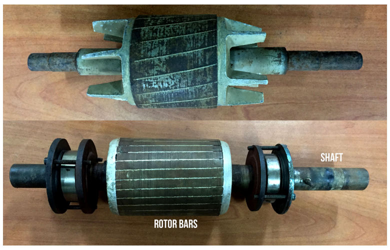


Figure 6: Cut section of an Induction motor

(a)



(b)

Figure 7: a) Stator b) Rotor

References

[1] G. K. Dubey. *Fundamentals of Electrical Drives,* Alpha Science International Ltd., 2001.

This document is prepared by *Neethu S.* (Research Scholar, 2014 batch).