Lecture 4

Starting and Speed Control of Three Phase Induction Motor

1. Introduction:

Referring to the equivalent circuit of three phase induction motor. At starting the slip is unity and the motor impedance is quite small with rated applied voltage, thus the motor current is excessive due to the small motor impedance. This abnormal condition must be brought within normal limits using **starting methods**. The starters are used to start the motors in safe mode and to protect it from over withdrawn current. For small size motors, there is no need to use any starting method since smaller motors have higher per unit impedances and the starting period is rather short. Induction motors are practically a constant speed motor which account about 90 percent of the electrical drives used in industry. The inherent features of induction motors make them very attractive for drive applications. **They are rugged, economically viable to manufacture and have no sliding contacts to wear.** The difficulty with using induction motors lies in the servomechanisms and variable speed drives which they are **hard to control** since their torque-speed characteristics is multi-regional and nonlinear. However, with the modern power electronics and digital control schemes used to maintaining the required speed with variable applied load, induction machines are seeing increasing use in drives applications.

2. Starting Methods of Three-Phase Induction Motor:

The standard methods for starting of squirrel cage and wound rotor Induction motors are as follows:

I. **Direct on-Line Starting:** This method involves direct switching of three-phase stator on to the supply mains as in figure 1.

The motor draws low power factor starting current with (5-7) times of full load current (FLC). Due to this large current there is a considerable voltage drop in the power utility which causes undesirable dip in supply voltage thereby affecting the operation of other equipment connected to the power utility as well.

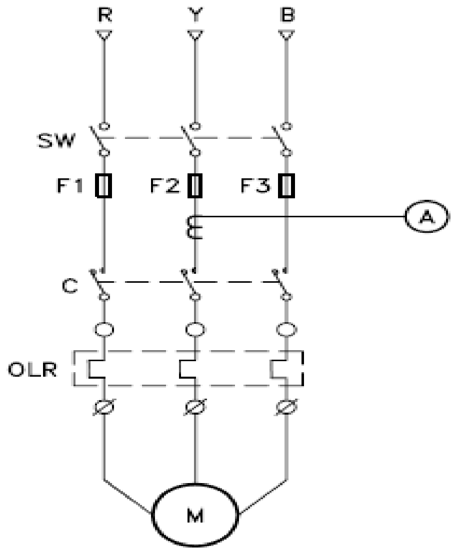


Figure 1 Power Circuit for DOL Starting

II. **Autotransformer Starting:** This method of starting is illustrated in figure 2, a fraction of ‘x’ (where x is always less than unity) of the supply voltage is applied to the stator terminals at the time of starting by means of an Autotransformer. This reduces the starting current of the motor. After the motor has accelerated close to its operating speed, the Autotransformer is disconnected, and full line voltage is applied to the stator windings by connecting it to the supply mains

$\mathbf{I_{AT} = x^2 \; I_{DOL}}$

$\mathbf{I_{DOL}}$ = Per phase starting current on direct switching to full voltage.

$\mathbf{I_{AT}}$ = Per phase starting current by means of Autotransformer. Thus, the ratio of motor starting torque with direct on-line to the starting torque with an Autotransformer will be:

$$\frac{Starting\ Torque\ with\ Auto-transformer}{Starting\ Torque\ with\ Direct\ Switching} = \mathbf{x^2}$$

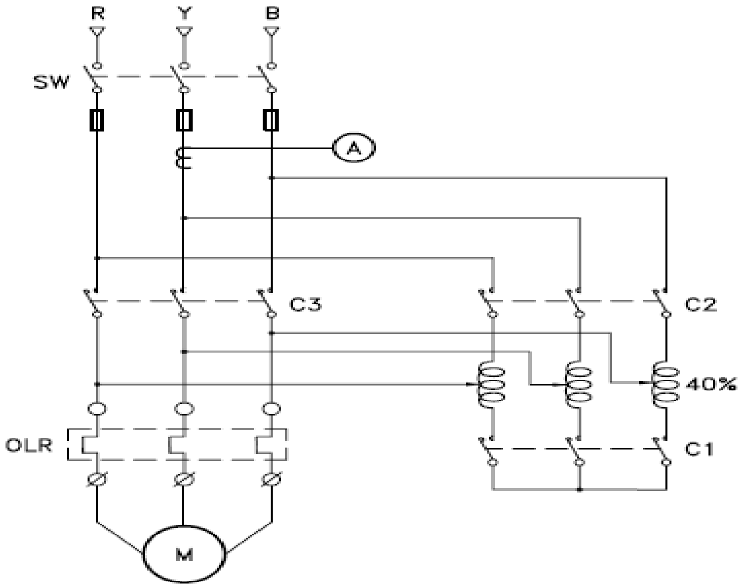


Figure 2 Power Circuit for Autotransformer Starting

III. **Star-Delta Starting:** This method may be adopted only for those motors which are designed to operate normally in delta. The six terminals from the stator winding must be available as shown in the figure 3 below. The terminals have been marked as a1, a2 for 'R' phase, b1, b2 for 'Y' phase and c1, c2 for 'B' phase. The terminals are connected to a TPDT (triple pole double throw) switch. During motor starting, the TPDT switch is in position 1, and hence the stator winding gets connected in star. Once the motor has accelerated to its steady state speed, the TPDT switch changes over to position 2. Now, the stator winding gets connected in delta. Hence, the motor has started in star connection thereby reducing the starting current and then switched to delta connection for its normal operation.

$$\mathbf{I_{Y\text{-}D} = \frac{1}{3}\, I_{DOL}}$$

$\mathbf{I_{Y\text{-}D}}$ = Starting line current with star-delta starter.

$\mathbf{I_{DOL}}$ = Starting line current with direct switching in delta.

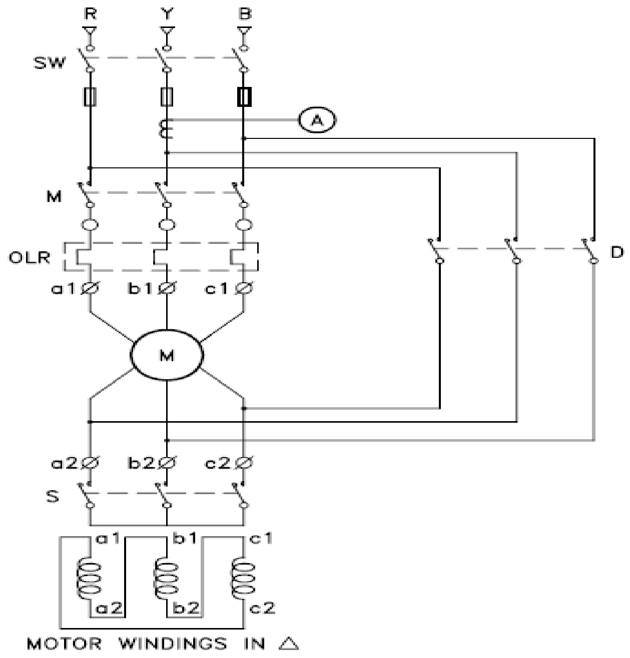


Figure 3 power Circuit for Star-Delta Starting

It is evident from the above that the starting torque available during DOL starting is also reduced to one-third in case of star-delta starting.

IV. **The Stator Resistance (or Inductance) Starting:** A suitable resistance (or inductance) is added in series with the stator and the motor is started with reduced current. As the motor speeds up, this resistance (or inductance) is gradually cut-off and finally the rated voltage is applied to the motor, and the motor achieves full speed.

V. **Rotor–Rheostat Starting:** A suitable resistance is added (at starting) to the wound rotor windings via slip rings and then it is gradually cut, as the motor speeds up. Finally, when the rotor achieves full speed, the added resistance is fully cut-off.

VI. **Electronic Soft Starting:** It is based upon the controlled rectifier or 'Thyristor'. By applying a firing pulses to the Thyristor, it switches from 'off' to 'on' until the current stops flowing through it, which occurs every half cycle of an AC supply. By controlling electronically, the Thyristor turn on point (firing angle), it is possible to regulate the energy passing through it. Figure 4 showing the effect of the firing angle of the Thyristor on the output voltage. By starting with a large delay angle and gradually reducing it, the motor terminal voltage is increased from a low value to full voltage, giving a smooth, step less starting. Electronic soft starting has a simple, reliable and cost effective piece of equipment.

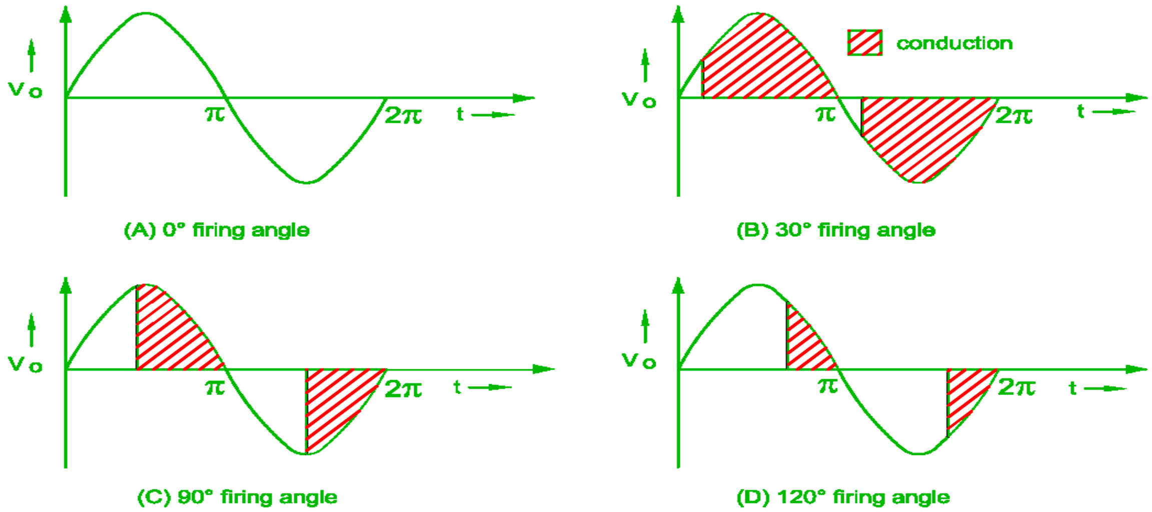


Figure 4 Effect of Firing Angle on Output Voltage

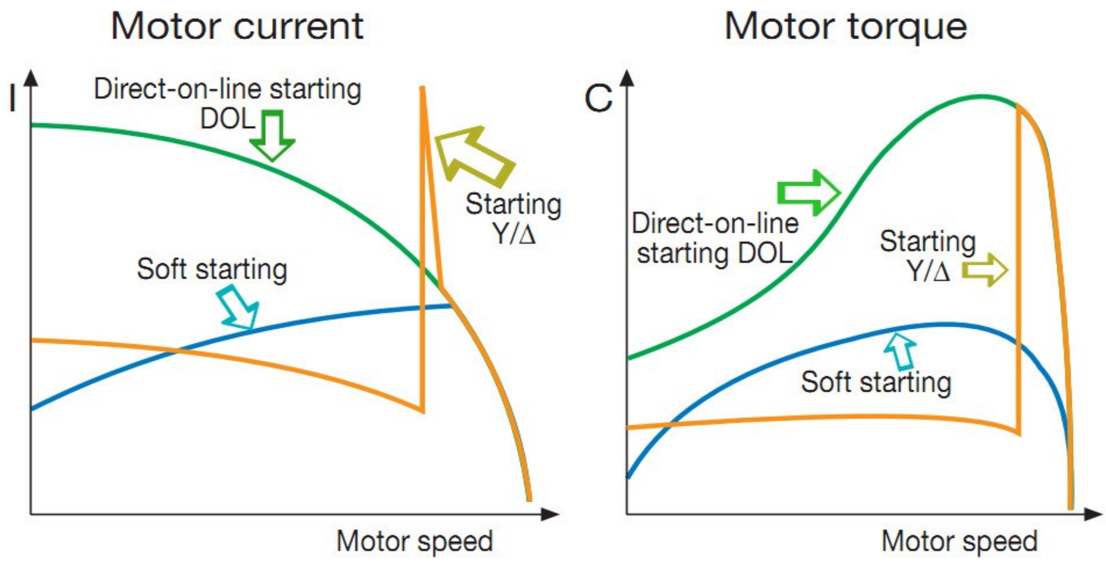
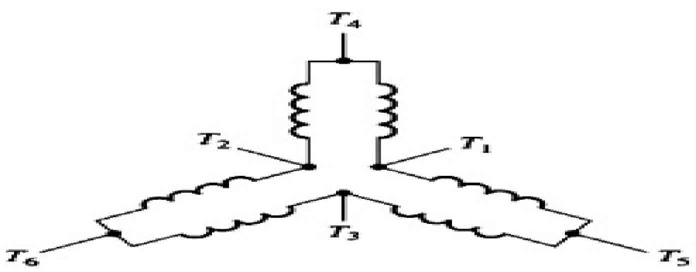


Figure 5 Comparison Between DOL, Y-Δ, and Soft Starting Methods

3. Speed Control of Three Phase Induction Motor:

As mentioned earlier that the synchronous speed N_s = (120 x f)/ P, hence it is evident that either by changing the number of poles (P) or the frequency (f), the synchronous speed can be varied. Accordingly, the slip and the rotor speed (N_r) shall vary as well. There are many different methods adopted for speed control of Induction motors. Some of standard methods for speed control are as below:

I. **Pole Changing:** It is obvious that for a given frequency, the synchronous speed is inversely proportional to the number of poles. Hence by changing the number of poles different speeds can be achieved for a motor. However, provision for changing the number of poles (as shown in figure 6), has to be incorporated during manufacturing stage and such motors are called ''pole changing motors'' or ''multi-speed motors''. Changing the stator poles is sufficient as the same number of poles will be induced on the roto bars. But in case of wound rotor motors pole changing needs to be adopted for both the stator and rotor which makes it complicated and expensive. Hence the method is adopted only for squirrel cage motors.



Speed	Lines			
	L_1	L_2	L_3	
Low	T_1	T_2	T_3	T_4, T_5, T_6 open
High	T_4	T_5	T_6	T_1 - T_2 - T_3 together

Figure 6 Pole Changing For Speed Control with Constant Torque

II. **Stator Voltage Control:** Since torque is proportional to the square of the voltage, when the voltage is reduced to decrease the speed, for the same current, the torque gets reduced as well (as in Fig-7). Hence this method is suitable for applications where torque demand reduces with speed like in case of some fan drives.

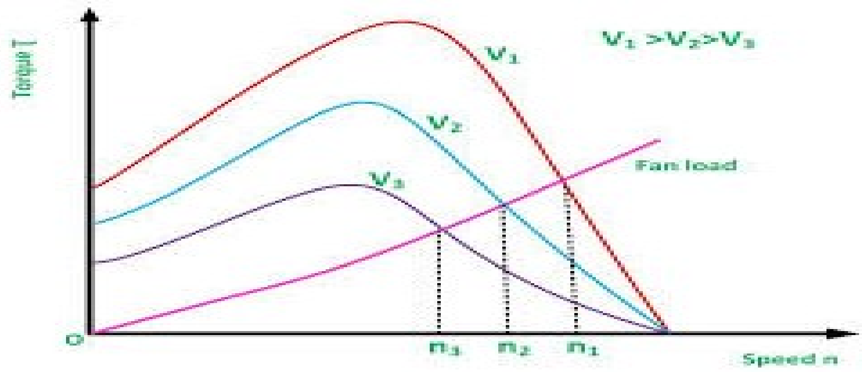


Figure 7 Stator Voltage Control

III. **Voltage / Frequency Control:** The motor speed can be controlled by varying the synchronous speed via changing the supply frequency. As the e.m.f equation indicate that the voltage induced in the stator is proportional to the product of the supply frequency and the flux. That means, Φ α (V / f) (Neglecting the voltage drop in the stator winding). Hence, if the voltage and frequency are varied simultaneously in the same proportion, the flux will remain constant. However, the voltage can't be increases beyond the rated voltage which shall occur at rated frequency. Beyond this point only frequency can be increased to increase the speed, keeping voltage constant at rated value. As in Figure 8, the operating region before the rated voltage/ frequency point is called a 'Constant-Torque' operating region while the region after that point is called a 'Constant-Power' operating region.

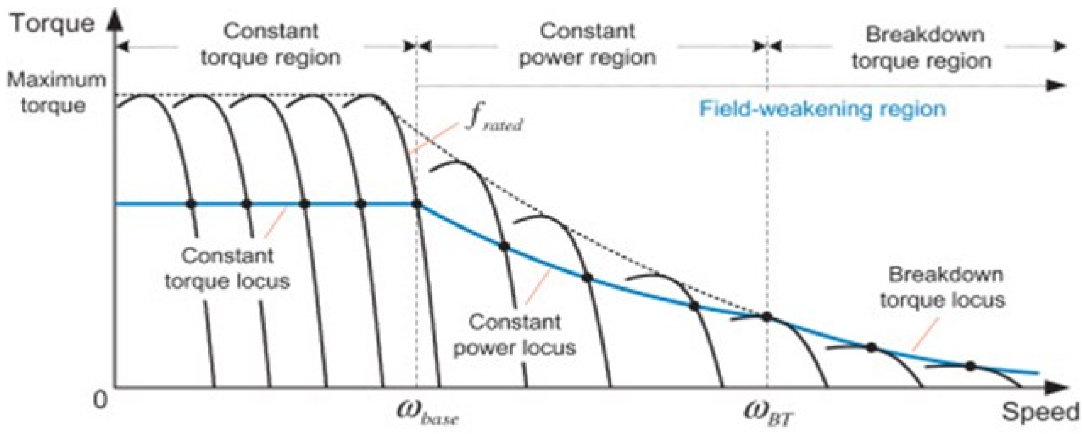


Figure 7 Constant V/F Control

IV. Rotor Resistance Control: This method can be specifically adopted in slip ring (Wound Rotor) induction motors. The max. torque is independent of rotor resistance (only the speed at which the max. torque occur is affected). For the same torque, speed falls with increase in rotor resistance. The advantage of this control is that the torque capability remains same even at low speeds. Because of its low cost and high torque capability it is used for speed control of 'cranes'. However, it has a disadvantage of having a low efficiency due to additional losses in the external resistors connected to the rotor circuit.

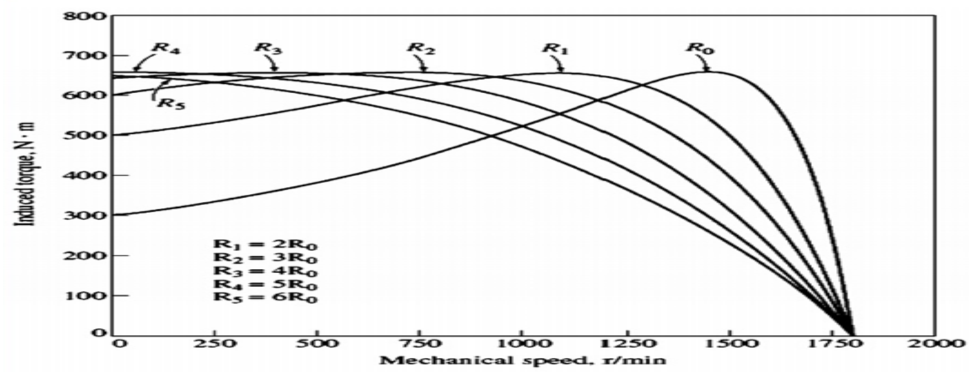


Figure 8 Rotor Resistance Control