

Module 8

Three-phase Induction Motor

Lesson

33

Different Types of Starters for Induction Motor (IM)

Instructional Objectives

- Need of using starters for Induction motor
- Two (Star-Delta and Auto-transformer) types of starters used for Squirrel cage Induction motor
- Starter using additional resistance in rotor circuit, for Wound rotor (Slip-ring) Induction motor

Introduction

In the previous, i.e. fourth, lesson of this module, the expression of gross torque developed, as a function of slip (speed), in IM has been derived first. The sketches of the different torque-slip (speed) characteristics, with the variations in input (stator) voltage and rotor resistance, are presented, along with the explanation of their features. Lastly, the expression of maximum torque developed and also the slip, where it occurs, have been derived. In this lesson, starting with the need for using starters in IM to reduce the starting current, first two (Star-Delta and Auto-transformer) types of starters used for Squirrel cage IM and then, the starter using additional resistance in rotor circuit, for Wound rotor (Slip-ring) IM, are presented along with the starting current drawn from the input (supply) voltage, and also the starting torque developed using the above starters.

Keywords: Direct-on-Line (DOL) starter, Star-delta starter, auto-transformer starter, rotor resistance starter, starting current, starting torque, starters for squirrel cage and wound rotor induction motor, need for starters.

Direct-on-Line (DOL) Starters

Induction motors can be started Direct-on-Line (DOL), which means that the rated voltage is supplied to the stator, with the rotor terminals short-circuited in a wound rotor (slip-ring) motor. For the cage rotor, the rotor bars are short circuited via two end rings. Neglecting stator impedance, the starting current in the stator windings is (see lesson 32) is

$$(I_1)_{st} = \frac{E_r'}{\sqrt{(r_2')^2 + (x_2')^2}}$$

where,

$$(I_1)_{st} = (I_2')_{st} = (I_2)_{st} / a = \text{Starting current in the motor (stator)}$$

$$a = T_s' / T_r' = \text{Effective turns ratio between stator and rotor windings}$$

$$E_s = E_r' = a E_r = \text{Input voltage per phase to the motor (stator)}$$

$$E_r = \text{Induced emf per phase in the rotor winding}$$

$$r_2' = a^2 r_2 = \text{Rotor resistance in terms of stator winding}$$

$$x_2' = a^2 x_2 = \text{Rotor reactance at standstill in terms of stator winding}$$

The input voltage per phase to the stator is equal to the induced emf per phase in the stator winding, as the stator impedance is neglected (also shown in the last lesson (#32)).

In the formula for starting current, no load current is neglected. It may be noted that the starting current is quite high, about 4-6 times the current at full load, may be higher, depending on the rating of IM, as compared to no load current.

The starting torque is $((T_0)_{st} \propto [(I_1)_{st}]^2)$, which shows that, as the starting current increases, the starting torque also increases. This results in higher accelerating torque (minus the load torque and the torque component of the losses), with the motor reaching rated or near rated speed quickly.

Need for Starters in IM

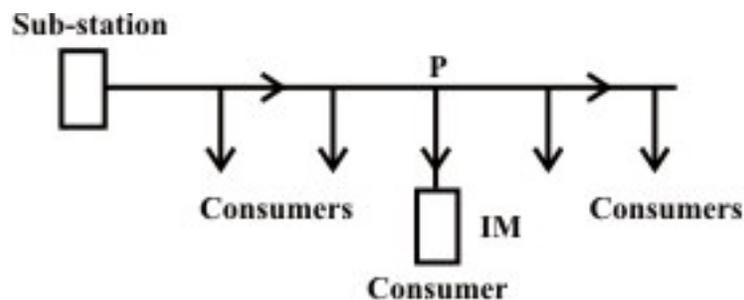


Fig. 33.1: The distribution line fed from substation for supply to various consumers.

The main problem in starting induction motors having large or medium size lies mainly in the requirement of high starting current, when started direct-on-line (DOL). Assume that the distribution line is starting from a substation (Fig. 33.1), where the supply voltage is constant. The line feeds a no. of consumers, of which one consumer has an induction motor with a DOL starter, drawing a high current from the line, which is higher than the current for which this line is designed. This will cause a drop (dip) in the voltage, all along the line, both for the consumers between the substation and this consumer, and those, who are in the line after this consumer. This drop in the voltage is more than the drop permitted, i.e. higher than the limit as per ISS, because the current drawn is more than the current for which the line is designed. Only for the current lower the current for which the line is designed, the drop in voltage is lower the limit. So, the supply authorities set a limit on the rating or size of IM, which can be started DOL. Any motor exceeding the specified rating, is not permitted to be started DOL, for which a starter is to be used to reduce the current drawn at starting.

Starters for Cage IM

The starting current in IM is proportional to the input voltage per phase (V_s) to the motor (stator), i.e. $(I_1)_{st} \propto E_s$, where, $|V_s| \approx |E_s|$, as the voltage drop in the stator impedance is small compared to the input voltage, or $|V_s| = |E_s|$, if the stator impedance is neglected. This has been shown earlier. So, in a (squirrel) cage induction motor, the

starter is used only to decrease the input voltage to the motor so as to decrease the starting current. As described later, this also results in decrease of starting torque.

Star-Delta Starter

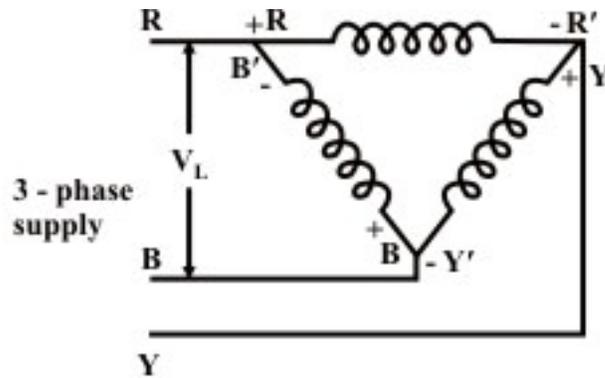


Fig. 33.2(a): Delta-connected stator winding of IM at run

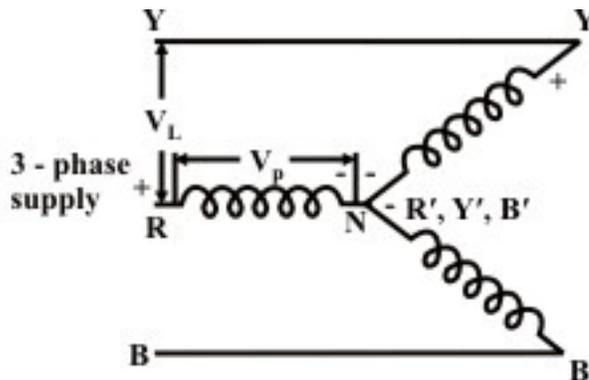


Fig. 33.2(b): same winding of IM, reconnected as star at start.

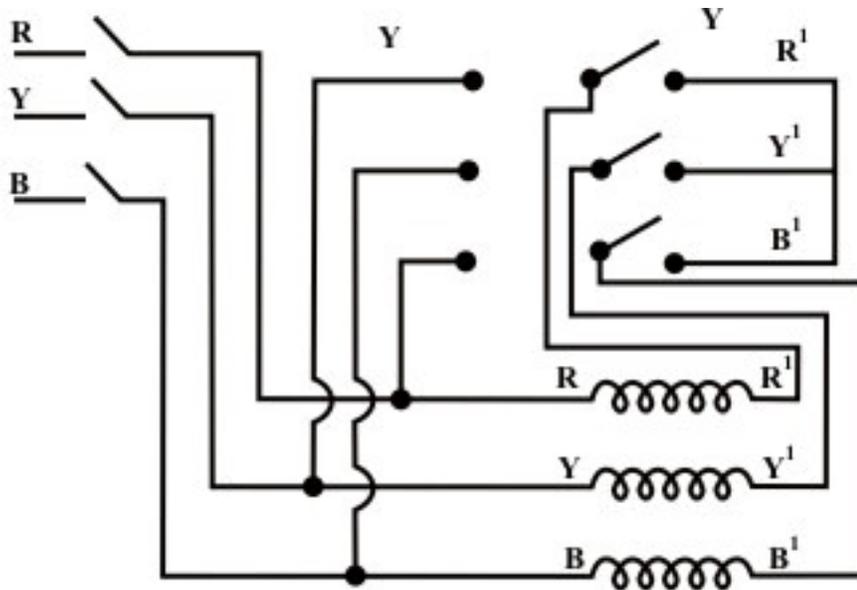
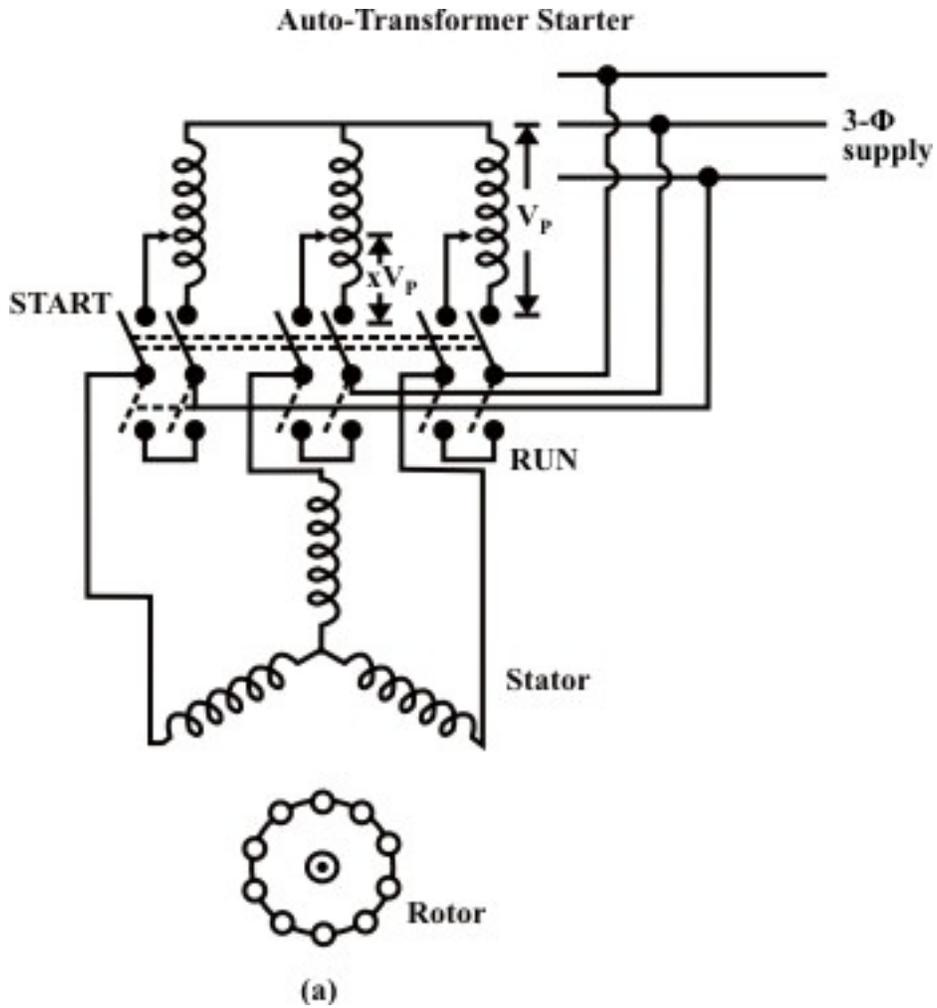


Fig. 33.2(c): T.P.D.T. switch used to first start the motor with the windings connected in star and then switch for delta connection in run position(star-delta starter).

This type is used for the induction motor, the stator winding of which is nominally delta-connected (Fig. 33.2a). If the above winding is reconnected as star (Fig. 33.2b), the voltage per phase supplied to each winding is reduced by $1/\sqrt{3}$ (0.577). This is a simple starter, which can be easily reconfigured as shown in Fig. 33.2c. As the voltage per phase in delta connection is V_s , the phase current in each stator winding is (V_s / Z_s) , where Z_s is the impedance of the motor per phase at standstill or start (stator impedance and rotor impedance referred to the stator, at standstill). The line current or the input current to the motor is $[(I_1)_{st} = (\sqrt{3} \cdot V_s) / Z_s]$, which is the current, if the motor is started direct-on-line (DOL). Now, if the stator winding is connected as star, the phase or line current drawn from supply at start (standstill) is $[(V_s / Z_s) / \sqrt{3}]$, which is $(1/3 = (1/\sqrt{3})^2)$ of the starting current, if DOL starter is used. The voltage per phase in each stator winding is now $(V_s / \sqrt{3})$. So, the starting current using star-delta starter is reduced by 33.3%. As for starting torque, being proportional to the square of the current in each of the stator windings in two different connections as shown earlier, is also reduced by $(1/3 = (1/\sqrt{3})^2)$, as the ratio of the two currents is $(1/\sqrt{3})$, same as that (ratio) of the voltages applied to each winding as shown earlier. So, the starting torque is reduced by 33.3%, which is a disadvantage of the use of this starter. The load torque and the loss torque, must be lower than the starting torque, if the motor is to be started using this starter. The advantage is that, no extra component, except that shown in Fig. 33.2c, need be used, thus making it simple. As shown later, this is an auto-transformer starter with the voltage ratio as 57.7%. Alternatively, the starting current in the second case with the stator winding reconnected as star, can be found by using star-delta conversion as given in lesson #18, with the impedance per phase after converting to delta, found as $(3 \cdot Z_s)$,

and the starting current now being reduced to $(1/3)$ of the starting current obtained using DOL starter, with the stator winding connected in delta.

Auto-transformer Starter



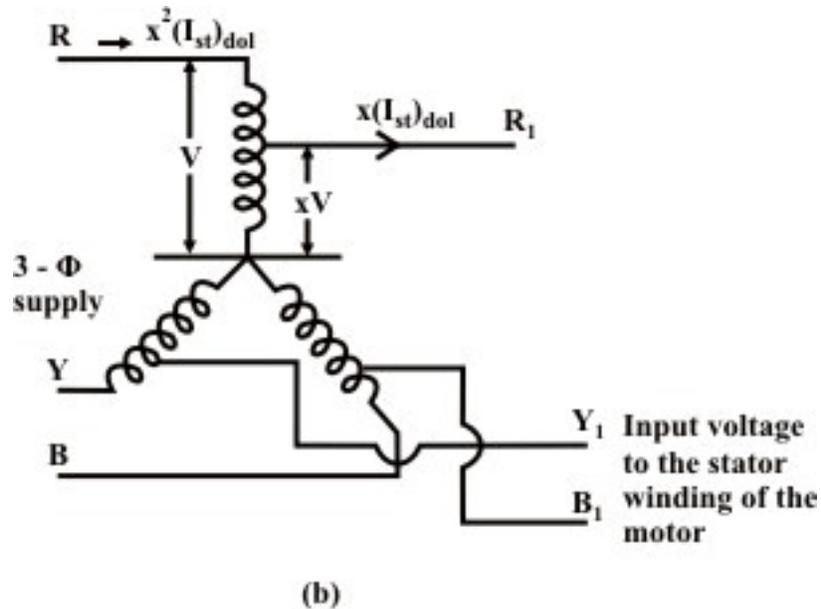


Fig. 33.3: Auto-transformer starter for IM

An auto-transformer, whose output is fed to the stator and input is from the supply (Fig. 33.3), is used to start the induction motor. The input voltage of IM is $x \cdot V_s$, which is the output voltage of the auto-transformer, the input voltage being V_s . The output voltage/input voltage ratio is x , the value of which lies between 0.0 and 1.0 ($0.0 < x < 1.0$). Let $(I_1)_{st}$ be the starting current, when the motor is started using DOL starter, i.e. applying rated input voltage. The input current of IM, which is the output current of auto-transformer, is $x \cdot (I_1)_{st}$, when this starter is used with input voltage as $x \cdot V_s$. The input current of auto-transformer, which is the starting current drawn from the supply, is $x^2 \cdot (I_1)_{st}$, obtained by equating input and output volt-amperes, neglecting losses and assuming nearly same power factor on both sides. As discussed earlier, the starting torque, being proportional to the square of the input current to IM in two cases, with and without auto-transformer (i.e. direct), is also reduced by x^2 , as the ratio of the two currents is x , same as that (ratio) of the voltages applied to the motor as shown earlier. So, the starting torque is reduced by the same ratio as that of the starting current. If the ratio is $x = 0.8$ (80%), both starting current and torque are

$x^2 = (0.8)^2 = 0.64$ (64%) times the values of starting current and torque with DOL starting, which is nearly 2 times the values obtained using star-delta starter. So, the disadvantage is that starting current is increased, with the result that lower rated motor can now be started, as the current drawn from the supply is to be kept within limits, while the advantage is that the starting torque is now doubled, such that the motor can start against higher load torque. The star-delta starter can be considered equivalent to an auto-transformer starter with the ratio, $x = 0.577$ (57.7%). If $x = 0.7$ (70%), both starting current and torque are $x^2 = (0.7)^2 = 0.49 \approx 0.5$ (50%) times the values of starting current and torque with DOL starting, which is nearly 1.5 times the values obtained using star-delta starter. By varying the value of the voltage ratio x of the auto-transformer, the

values of the starting current and torque can be changed. But additional cost of auto-transformer with intermittent rating is to be incurred for this purpose.

Rotor Resistance Starters for Slip-ring (wound rotor) IM

In a slip-ring (wound rotor) induction motor, resistance can be inserted in the rotor circuit via slip rings (Fig. 33.4), so as to increase the starting torque. The starting current in the rotor winding is

$$(I_2)_{st} = \frac{E_r}{\sqrt{(r_2 + R_{ext})^2 + (x_2)^2}}$$

where R_{ext} = Additional resistance per phase in the rotor circuit.

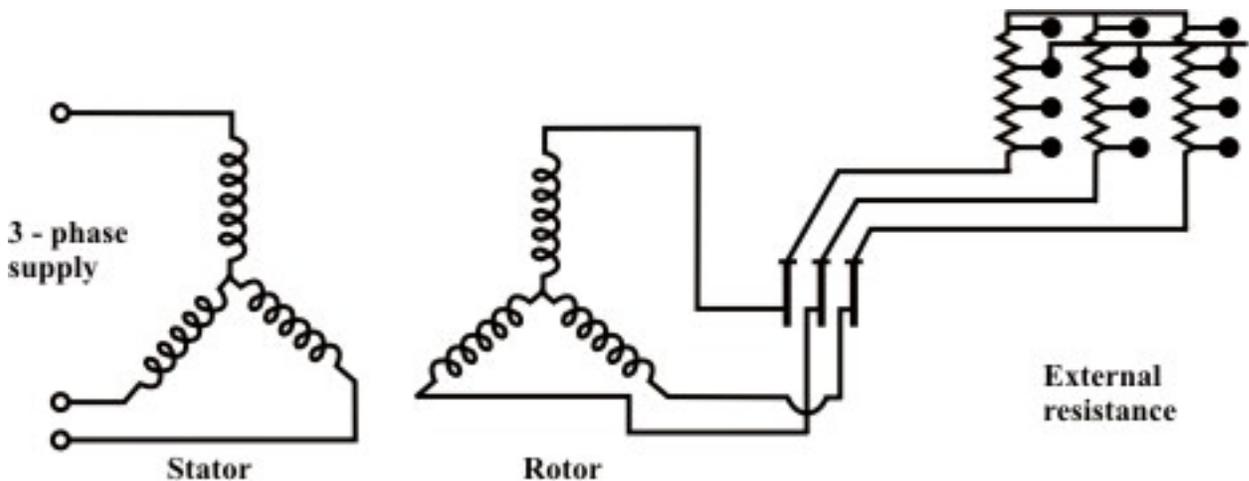


Fig. 33.4: Rotor resistance starter for IM

The input (stator) current is proportional to the rotor current as shown earlier. The starting current (input) reduces, as resistance is inserted in the rotor circuit. But the starting torque, $[(T_0)_{st} = 3 \cdot [(I_2)_{st}]^2 \cdot (r_2 + R_{ext})]$ increases, as the total resistance in the rotor circuit is increased. Though the starting current decreases, the total resistance increases, thus resulting in increase of starting torque as shown in Fig. 32.2b, and also obtained by using the expression given earlier, for increasing values of the resistance in the rotor circuit. If the additional resistance is used only for starting, being rated for intermittent duty, the resistance is to be decreased in steps, as the motor speed increases. Finally, the external resistance is to be completely cut out, i.e. to be made equal to zero (0.0), thus leaving the slip-rings short-circuited. Here, also the additional cost of the external resistance with intermittent rating is to be incurred, which results in decrease of starting current, along with increase of starting torque, both being advantageous. Also it may be noted that the cost of a slip-ring induction is higher than that of IM with cage rotor, having same power rating. So, in both cases, additional cost is to be incurred to obtain the above advantages. This is only used in case higher starting torque is needed to start IM with high load torque. It may be observed from Fig. 32.2b that the starting torque increases till it reaches maximum value, i.e. $((T_0)_{st} < (T_0)_m)$, as the external resistance in the rotor circuit is increased, the range of total resistance being $[r_2 < (r_2 + R_{ext}) < x_2]$.

The range of external resistance is between zero (0.0) and $(x_2 - r_2)$. The starting torque is equal to the maximum value, i.e. $((T_0)_{st} = (T_0)_m)$, if the external resistance inserted is equal to $(x_2 - r_2)$. But, if the external resistance in the rotor circuit is increased further, i.e. $[R_{ext} > (x_2 - r_2)]$, the starting torque decreases $((T_0)_{st} < (T_0)_m)$. This is, because the starting current decreases at a faster rate, even if the total resistance in the rotor circuit is increased.

In this lesson – the fifth one of this module, the direct-on-line (DOL) starter used for IM, along with the need for other types of starters, has been described first. Then, two types of starters – star-delta and auto-transformer, for cage type IM, are presented. Lastly, the rotor resistance starter for slip-ring (wound rotor) IM is briefly described. In the next (sixth and last) lesson of this module, the various types of single phase induction motors, along with the starting methods, will be presented.