DEE-SEM-4 PART-3.

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Starting Induction Motor.

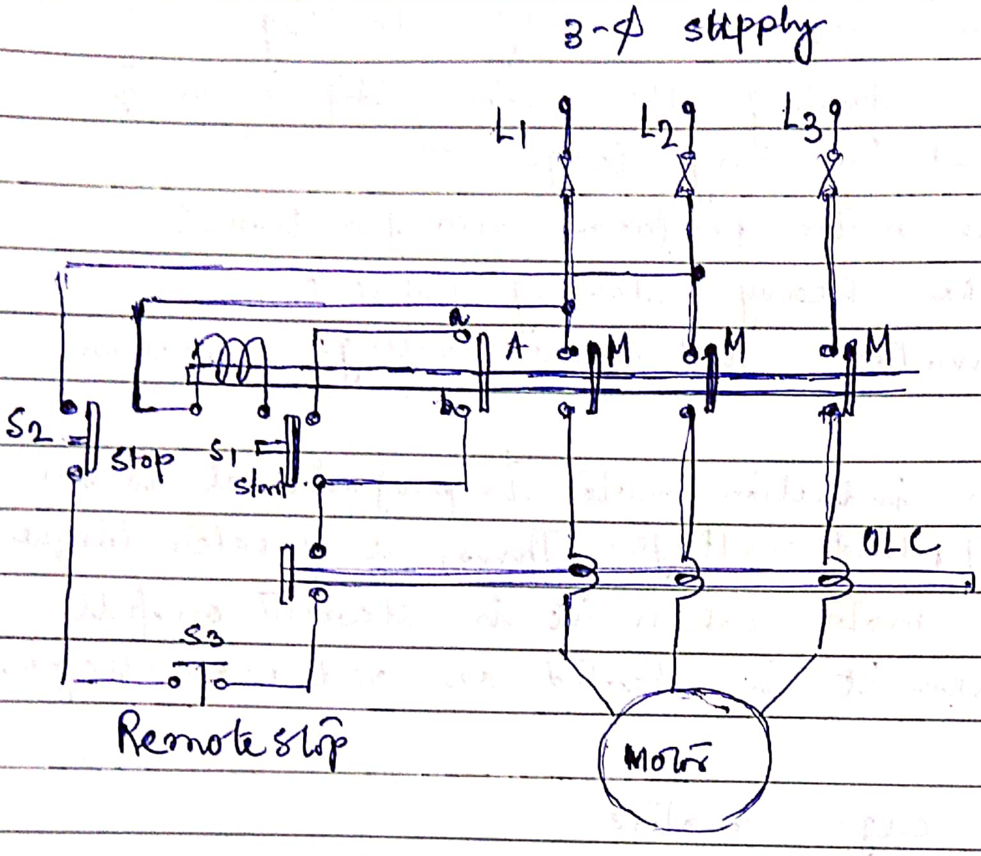
A 3-ϕ induction motor is self-starting. At the time of starting the motor slip is unity and starting current is very large. -
The starter of the motor performs two functions:
1. To reduce the heavy starting current
2. To provide overload and under-voltage protection.

The torque of an induction motor is proportional to the square of the applied voltage. Thus, a greater torque is exerted by a motor when it is started on full voltage than when it is started on reduced voltage.

Starting of cage motors

The following are the commonly used starters for cage motors:
1. Direct on line starter
2. Starr- Delta Starter
3. Auto-transformer starter.

Direct On-line Starter.



On pressing the start push button S_1, the contactor coil C is energised from two line conductors L_1 & L_2. The three main contacts M and the auxiliary contact A close and terminals a & b are short-circuited. The motor is thus connected to supply. When the pressure on S_1 is ~~...~~ released, it moves back under spring action. Even then coil C remains energised through ab. Thus, the main contacts M remain closed the motor continues to get supply.

When stop push-button S_2 is pressed, the supply through the contactor coil C is dis-connected. Since the coil C is is de-energised, the main contacts M and auxiliary Contact A are opened. The supply to motor is disconnected.

Under-voltage protection:

When the voltage falls below a certain value, or in the event of failure of supply during motor operation, the coil C is de-energised. The motor is then disconnected from the supply.

Overload protection:

In case of an overload on the motor, one or all over load coils (OLC) are energised. The normally closed contact D is opened and contactor coil C is de-energised to disconnect the supply to the motor.

Fuses are provided in the circuit for short-ckt protection.

Direct-on-line starting is a simple and cheap method. The starting current may be as large as 10 time the full load current & starting torque is full-load torque. Such a large starting current produces excessive voltage drop in the line supplying motor. Small motors upto 5 KW rating may be started by DOL starters to avoid supply voltage fluctuations.

Relation between starting & full load torque. (DOL starter)

Rotor input $= \frac{2\pi N_s T}{60} = KT$

$\because N_s =$ Synchronous speed & $K = \frac{2\pi N_s}{60}$.

But rotor copper loss $= S \times$ rotor input

$\therefore \; 3 (I_2)^2 \times R_2 = S \times KT$

or $T \propto \frac{(I_2)^2}{S}$ or $T \propto \frac{(I_1)^2}{S}$. $(\because I_2 \propto I_1)$

I_{st} be the starting current, then starting torque

$T_{st} \propto I_{st}^2$ $(\because S = 1$, at starting$)$

Similarly if I_f is the full load current & corresponding full load torque is T_f then,

$T_f \propto \frac{I_f^2}{S_f}$

$\therefore \; \frac{T_{st}}{T_f} \propto \left(\frac{I_{st}}{I_f}\right)^2 \cdot S_f$.

Let, $I_{st} = 5 I_f$ & $S_f = 0.04$

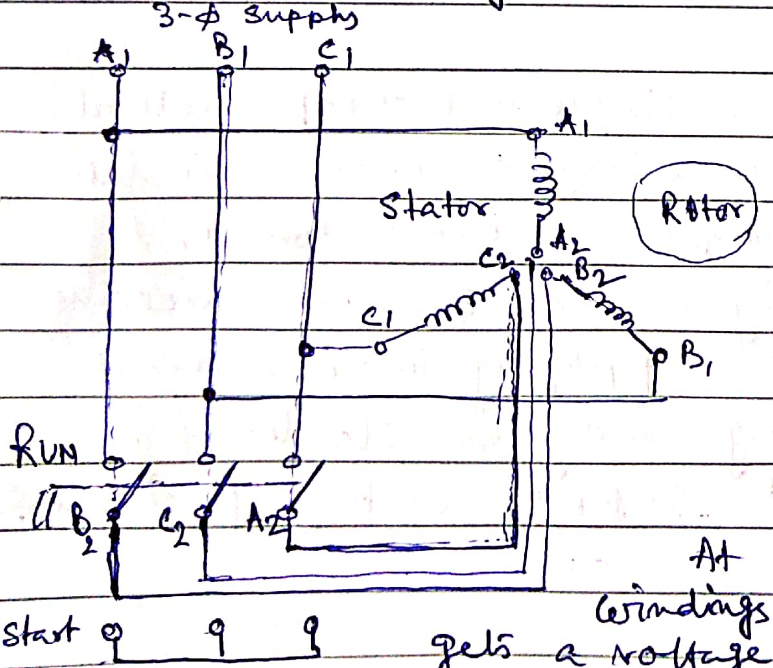
$\therefore \; \frac{T_{st}}{T_f} = 5^2 \times .04 = 1$

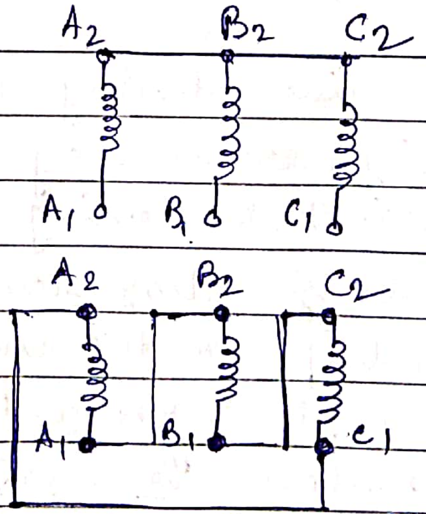
* Though starting current is five times the full load current, the starting torque is equal to full load torque. So in spite of high starting current starting torque is quite low. Such a high starting current causes a relatively large voltage drop in the cables. ~~and thereby~~ Long time flowing current may cause over heat the motor & damage the insulation.

Star-Delta Starter.

[Use upto 25 KW but unsuitable for voltage more than 3KV due to excessive number of stator turns required for delta-running]

This is a very common type of starter and extensively used, compared to the other types of starters. A star-delta starter is used for cage motor designed to run normally on delta-connected stator winding. When switch S is in START position, the stator windings are connected in STAR. When the motor picks up speed, say 80% of its rated value, the changeover switch S thrown quickly to RUN position which connects the stator windings in DELTA. By connecting the stator windings, first in star and then in delta, the line current drawn by the motor at starting is reduced to one-third as compared to starting current with the windings connected in delta.





starting torque is 50% of full load torque

At the time of starting, when stator windings are star connected, each stator phase gets a voltage $V_L/\sqrt{3}$. Since the torque developed by an induction motor is proportional to the square of the applied voltage, star-delta starting reduces the starting torque to 1/3 that obtainable by direct-delta starting.

Relation between Starting & full-load Torques: (Star-delta starter)

As starting stator winding is connected in star phase voltage $= \frac{1}{\sqrt{3}}$ of normal voltage (V_L)

starting current per phase, $I_S = \frac{1}{\sqrt{3}} I_{SC}$

$\therefore$ the line current $= \frac{1}{\sqrt{3}} \cdot I_S = \left(\frac{1}{\sqrt{3}}\right)^2 \cdot I_{SC} = \frac{1}{3} I_{SC}$

$\therefore$ starting torque is $\frac{1}{3}$ of short ckt value

$$\therefore \frac{T_{st}}{T_f} = \frac{1}{3}\left(\frac{I_{sc}}{I_f}\right)^2 \cdot S_f$$

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V_L = Line voltage

$I_{st\,YP}$ = Starting current per phase with stator windings connected in star

$I_{st\,YL}$ = starting line current with stator windings connected in star

For star connection, line current = Phase current

$\therefore I_{st\,YL} = I_{st\,YP}$

If, V_P = Phase voltage

$I_{st\,\Delta P}$ = starting current per phase with stator windings connected in delta.

$I_{st\,\Delta L}$ = starting line current ~~per phase~~ with stator windings connected in delta.

Z_{e10} = standstill equivalent impedance per phase of the motor referred to stator.

$I_{stYP} = \frac{V_P}{Z_{e10}} = \frac{V_L}{\sqrt{3} \cdot Z_{e10}}$ ✓

$I_{st\Delta P} = \frac{V_P}{Z_{e10}} = \frac{V_L}{Z_{e10}}$

for delta connection, line current $= \sqrt{3}$ Phase current

$\therefore I_{st\Delta L} = \sqrt{3}\, I_{st\Delta P} = \sqrt{3} \cdot \frac{V_P}{Z_{e10}} = \sqrt{3}\, \frac{V_L}{Z_{e10}}$ ✓

~~Stada~~ $\therefore \frac{I_{stYP}}{I_{st\Delta L}} = \frac{V_L / \sqrt{3} \cdot Z_{e10}}{\sqrt{3}\, V_L / Z_{e10}} = \frac{1}{3}$,

Thus, with star-delta starter, the starting current from the main supply is 1/3 of that with direct switching in delta.

Also,

$$\frac{\text{Starting torque with star-delta starting}}{\text{Starting torque with direct switching in delta}} = \frac{\left(\frac{V_L}{\sqrt{3}}\right)^2}{V_L^2} = \frac{1}{3}$$

$$\frac{\text{Starting torque with star-delta starting}}{\text{full-load torque with stator winding in delta}} = \frac{(I_{stYP})^2 \cdot \frac{R_2}{1}}{2\pi n_s} \div \frac{I_{fL\Delta P}^2 \cdot R_2}{2\pi n_s \cdot S_{fL}}$$

$$= \left(\frac{I_{stYP}}{I_{fL\Delta P}}\right)^2 \cdot S_{fL}$$

$I_{fL\Delta P}$ = full-load phase current with winding in delta

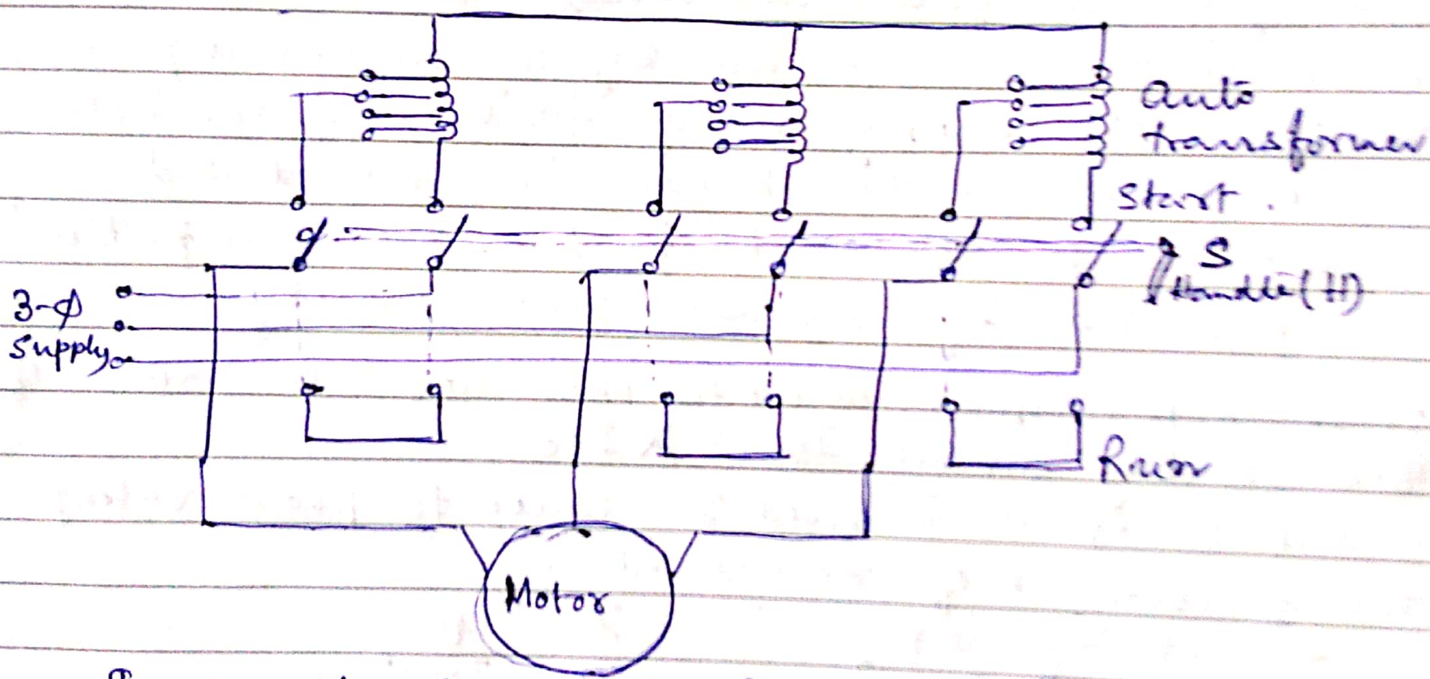
But, $I_{stYP} = \frac{V_L/\sqrt{3}}{Z_{e10}}$; $I_{st\Delta P} = \frac{V_L}{Z_{e10}}$.

$I_{stYP} = \frac{1}{\sqrt{3}} I_{st\Delta P}$ & $I_{stYP}^2 = \frac{1}{3} I_{st\Delta P}^2$

$$\frac{\text{starting torque with star-delta starting}}{\text{full-load torque with stator windin in delta}} = \left(\frac{I_{stYP}}{I_{fL\Delta P}}\right)^2 S_{fL} = \frac{1}{3}\left(\frac{I_{st\Delta P}}{I_{fL\Delta P}}\right)^2 S_{fL}$$

Auto- Transformer Starter

An auto-transformer starter is suitable for both star and delta connected motors. In this method, the starting current is limited by using a 3-ϕ auto-transformer to reduce the initial stator applied voltage. The auto-transformer is provided with a number of tappings.



In practice, the starter is connected to one particular tapping to obtain the most suitable starting voltage. A double throw switch S is used to connect the auto-transformer in the circuit for starting. When the handle H of the switch S in the START position, the primary of the auto-transformer is connected to the supply line and the motor is connected to secondary of the auto transformer. When the motor picks up the speed, say about 80% of its rated value, the handle H is quickly moved to the RUN position. The auto-transformer is disconnected from the circuit and the motor is directly connected to the line and gets its full rated voltage. The handle is held in the RUN position by the undervoltage relay. In case the supply voltage fails or falls below a certain value, the handle is released and returns to the OFF position. Overload protection is provided by thermal overload relays.

Let the auto-transformer reduced the phase voltage to the fraction X of normal value the starting current. $I_{st} = X I_{sc}$

(The auto-transformer is used to reduce the phase voltage to the fraction k of normal value.

and the starting torque $T_{st} = X^2 T_{sc}$

$$\therefore \frac{T_{st}}{T_{fL}} = \left(\frac{I_{st}}{I_{fL}}\right)^2 S_{fL} = X^2 \left(\frac{I_{sc}}{I_{fL}}\right)^2 \cdot S_{fL}.$$

Note: The star-delta starter is nothing but an auto-transformer starter with a fixed tapping of 58%.