STAR- DELTA STARTER

This is the cheapest starter of all and hence used very commonly for the induction motors. It uses tripple pole double throw (TPDT) switch. The switch connects the stator winding in star at start. Hence per phase voltage gets reduced by the factor 1/√3. Due to this reduced voltage, the starting current is limited.

When the switch is thrown on other side, the winding gets connected in delta, across the supply. So it gets normal rated voltage. The windings are connected in delta when motor gathers sufficient speed.

The arrangement of star-delta starter is shown in the Fig. 4.3.1

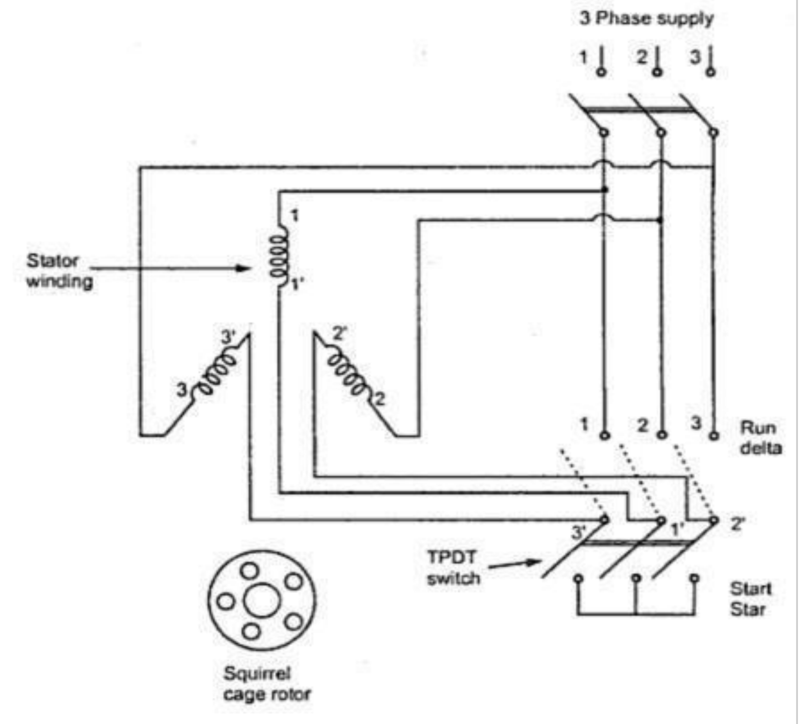


Fig4.3.1 Star-delta starter

The operation of the switch can be automatic by using relays which ensures that motor will not start with the switch in Run position. The cheapest of all and maintenance free operation are the two important advantages of this starter. While its limitations are, it is suitable for normal delta connected motors and the factor by which voltage changes is 1/√3 which can not be changed.

1.1 Ratio of T_{st} to $T_{F.L.}$

We have seen in case of autotransformer that if x is the factor by which the voltage is reduced then,

$$\therefore \quad \frac{T_{st}}{T_{F.L.}} = x2\left[\frac{I_{sc}}{I_{F.L.}}\right]^2 \times s_f$$

Now the factor x in this type of starter is 1/√3.

$$\therefore \quad \frac{T_{st}}{T_{F.L.}} = \frac{1}{3}\left(\frac{I_{sc}}{I_{F.L.}}\right)^2 s_f$$

where I_{sc} = Startingphase current when delta connection with rated voltage

$I_{F.L.}$ = Full load phase current when delta connection

Example : A three phase induction motor has a ratio of maximum torque to full load torque as 2.5 : 1. Determine the ratio of starting torque to full load torque if star-delta starter is used. The rotor resistance and standstill reactance per phase are 0.4 and 4 respectively.

Solution : The given ratio is, $T_m / T_{F.L.} = 2.5$

The rotor values are, $R_2 = 0.4\Omega$ $X_2 = 4\Omega$

Now $T_m = (kE_2^2)/(2X_2)$

$\therefore$ $T_{F.L.} = T_m/2.5 = (kE_2^2)/(5X_2) = (kE_2^2)/20$ .... (1)

Now $T_{st} = (k E_2^2 R_2)/(R_2^2 + X_2^2)$

With star-delta starter $E_2 = E_2/\sqrt{3}$

$$\therefore \quad T_{st} = \frac{k\left(\frac{E_2}{\sqrt{3}}\right)^2 R_2}{R_2^2 + X_2^2} \quad \text{... (2)}$$

Taking ratio of (2) and (1),

$$\frac{T_{st}}{T_{F.L.}} = \frac{k\left(\frac{E_2}{\sqrt{3}}\right)^2 R_2}{R_2^2 + X_2^2} \times \frac{20}{k E_2^2} = \frac{20 \times 0.4}{3[(0.4)^2 + (4)^2} = \mathbf{0.165}$$

ROTOR RESISTANCE STARTER

To limit the rotor current which consequently reduces the current drawn by the motor from the supply, the resistance can be inserted in the rotor circuit at start. This addition of the resistance in rotor in the form of 3 phase star connected rheostat. The arrangement is shown in the Fig. 4.3.2

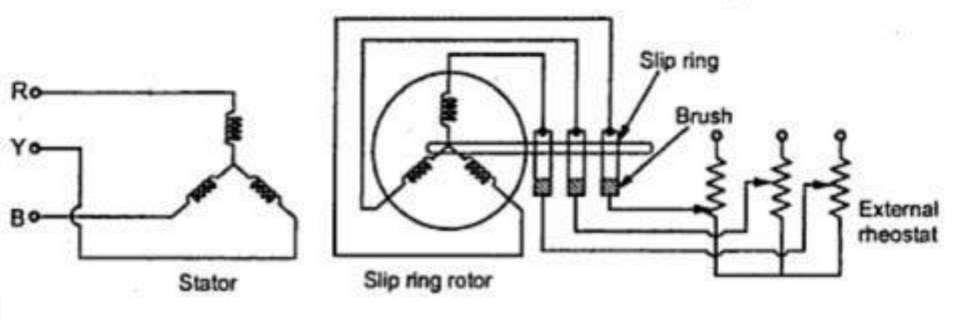


Fig. 4.3.2 Rotor resistance starter

The external resistance is inserted in each phase of the rotor winding through slip ring and brush assembly. Initially maximum resistance is in the circuit. As motor gather speed, the resistance is gradually cut-off. The operation may be manual or automatic.

We have seen that the starting torque is proportional to the rotor resistance. Hence important advantage of this method is not only the starting current is limited but starting torque of the motor also gets improved.

Note : The only limitation of the starter that it can be used only for slip ring induction motors as in squirrel cage motors, the rotor is permanently short circuited.

Calculation of Steps of Rotor Resistance Starter

The calculation of steps of rotor resistance starter is based on the assumptions that,

1. The motor starts against a constant torque
2. The rotor current fluctuates between two fixed values, a maximum and a minimum, denoted as I_{2max} and I_{2min}.

The Fig. 4.3.3, shows a single phase of a three phase of a three phase rheostat to be inserted in the rotor. The starter has n steps, equally divided into the section AB. The contact point after each step is called stud. The total resistances upto each stud from the star point of star connected rotor as denoted as R_1, R_2,
....R_{n-1}.

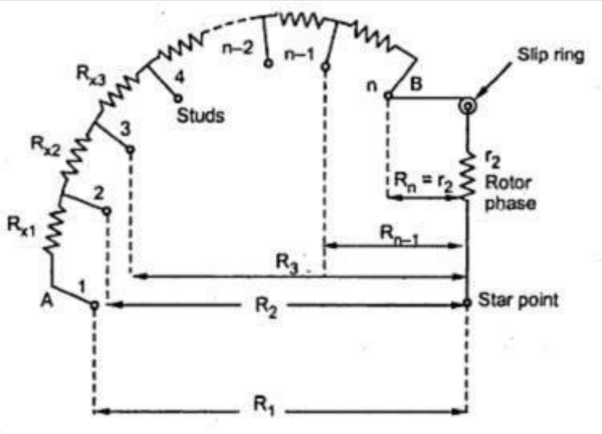
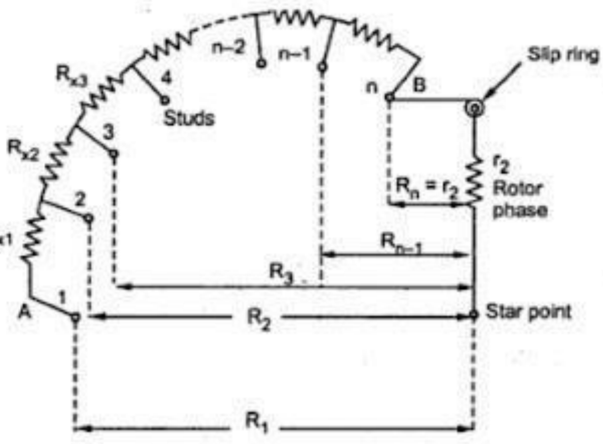


Fig. 4.3.3 Steps of rotor resistance

It consists of rotor resistance r_2 and the external resistances R_{x1}, R_{x2}...etc. At the time of reaching to the next step, current is maximum . Then motor gathers speed, slip reduces and hence while leaving a stud, the current is I_{2min}.



Let E_2 = Standstill rotor e.m.f. per phase

When handle is moved to stud 1, the current is maximum given by,

$$I_{2max} = \frac{s_1 E_2}{\sqrt{R_1^2 + (s_1 X_2)^2}} = \frac{E_2}{\sqrt{\left(\frac{R_1}{s_1}\right)^2 + X_2^2}}$$

where s_1 = Slip at start = 1

while moving to stud 2, the current reduces to I_{2min} given by,

$$I_{2min} = \frac{E_2}{\sqrt{\left(\frac{R_1}{s_2}\right)^2 + X_2^2}} \qquad \text{where } s_2 < s_1$$

Just reaching to stud 2, the current again increases to I_{2min} as the part of external resistance R_{x1} gets cut-off.

$$\therefore \qquad I_{2max} = \frac{E_2}{\sqrt{\left(\frac{R_2}{s_2}\right)^2 + X_2^2}}$$

While leaving stud 2, the slip changes to s_3 and current again reduces to,

$$I_{2min} = \frac{E_2}{\sqrt{\left(\frac{R_2}{s_3}\right)^2 + X_2^2}}$$

While just reaching to stud 3, R_{x2} gets cut off completely and current again increases to,

$$I_{2max} = \frac{E_2}{\sqrt{\left(\frac{R_3}{s_3}\right)^2 + X_2^2}}$$

Hence at the last n^{th} stud, the maximum current is,

$$I_{2max} = \frac{E_2}{\sqrt{\left(\frac{r_2}{s_n}\right)^2 + X_2^2}}$$

where s_n = Slip under normal running condition

At n^{th} stud no external resistance is in series with rotor.

$$\therefore \qquad I_{2max} = \frac{E_2}{\sqrt{\left(\frac{R_1}{s_1}\right)^2 + X_2^2}} = \frac{E_2}{\sqrt{\left(\frac{R_2}{s_2}\right)^2 + X_2^2}} = \dots \frac{E_2}{\sqrt{\left(\frac{r_2}{s_n}\right)^2 + X_2^2}}$$

i.e. $$\frac{R_1}{s_1} = \frac{R_2}{s_2} = \ldots \frac{r_2}{s_n} \quad \ldots (1)$$

And $$I_{2min} = \frac{E_2}{\sqrt{\left(\frac{R_1}{s_2}\right)^2 + X_2^2}} = \frac{E_2}{\sqrt{\left(\frac{R_2}{s_3}\right)^2 + X_2^2}} = \ldots \frac{E_2}{\sqrt{\left(\frac{R_{n-1}}{s_n}\right)^2 + X_2^2}}$$

i.e. $$\boxed{\frac{R_1}{s_2} = \frac{R_2}{s_3} = \ldots \frac{R_{n-1}}{s_n}} \quad \ldots (2)$$

From (1) and (2) we can write,

$$\frac{s_2}{s_1} = \frac{s_3}{s_2} = \frac{s_4}{s_3} \ldots = \frac{R_2}{R_1} = \frac{R_3}{R_2} = \frac{R_4}{R_3} = \ldots = \frac{r_2}{R_{n-1}} = K \quad \ldots (3)$$

where K = Constant

From (1), $R_1 = s_1 r_2/s_n$ but $s_1 = 1$ at start

$$\therefore \quad R_1 = \frac{r_2}{s_n} \quad \ldots (4)$$

Once R_1 is known, other resistances can be calculated.

$R_2 = KR_1$, $R_3 = K R_2 = KKR_1 = K^2 R_1$

$R_4 = K^3 R_1, \ldots\ldots\ldots r_2 = K^{n-1} R_1$

From last expression of r_2,

$$\boxed{K = \left(\frac{r_2}{R_1}\right)^{\frac{1}{n-1}} = (s_n)^{1/n-1}}$$

where n = Number of starter studs

Thus the resistances of various sections can be obtained as,

$$\boxed{\begin{aligned} R_{x1} &= R_1 - R_2 = R_1 - KR_1 = (1-K) R_1 \\ R_{x2} &= R_2 - R_3 = KR_1 - K^2R_1 = K(1-K) R_1 = K R_{x1} \\ R_{x3} &= K^2 R_{x1} \ldots \ldots \end{aligned}}$$

In this way the various steps of rotor resistance starter can be calculated.

DIRECT ONLOAD LINE STARTER(D.O.L.)

In case of small capacity motors having rating less than 5 h.p., the starting current is not very high and such motors can withstand such starting current without any starter. Thus there is no need to reduce applied voltage, to control the starting current. Such motors use a type of starter which is used to connect stator directly to the supply lines without any reduction in voltage. Hence the starter is known as direct on line starter.

Though this starter does not reduce the applied voltage, it is used because it protects the motor motor from various severe abnormal conditions like over loading, low voltage, single phasing etc.

The Fig. 4.3.4 shows the arrangement of various components in direct on line starter.

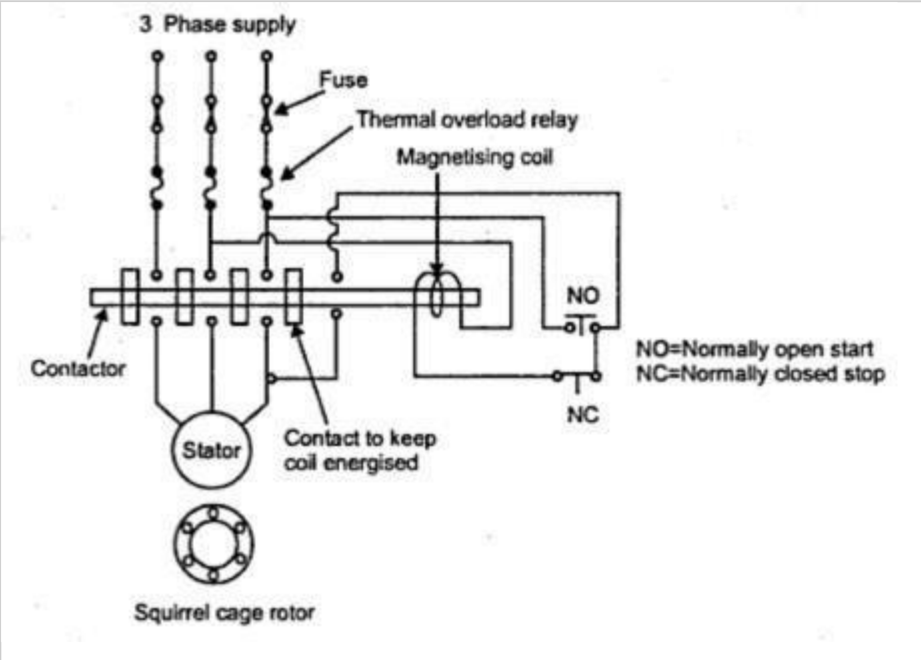


Fig.4.3.4 D.O.L. starter

The NO contact is normally open and NC is normally closed. At start, NO is pushed for fraction of second due to which coil gets energized and attracts the contactor. So stator directly gets supply. The additional contact provided, ensures that as long as supply is ON, the coil gets supply and keeps contactor in ON position. When NC is pressed, the coil circuit gets opened due to which coil gets de-energized and motor gets switched OFF from the supply.

Under over load condition, current drawn by the motor increases due to which is an excessive heat produced, which increases temperature beyond limit. Thermal relays get opened due to high temperature, protecting the motor from overload conditions.