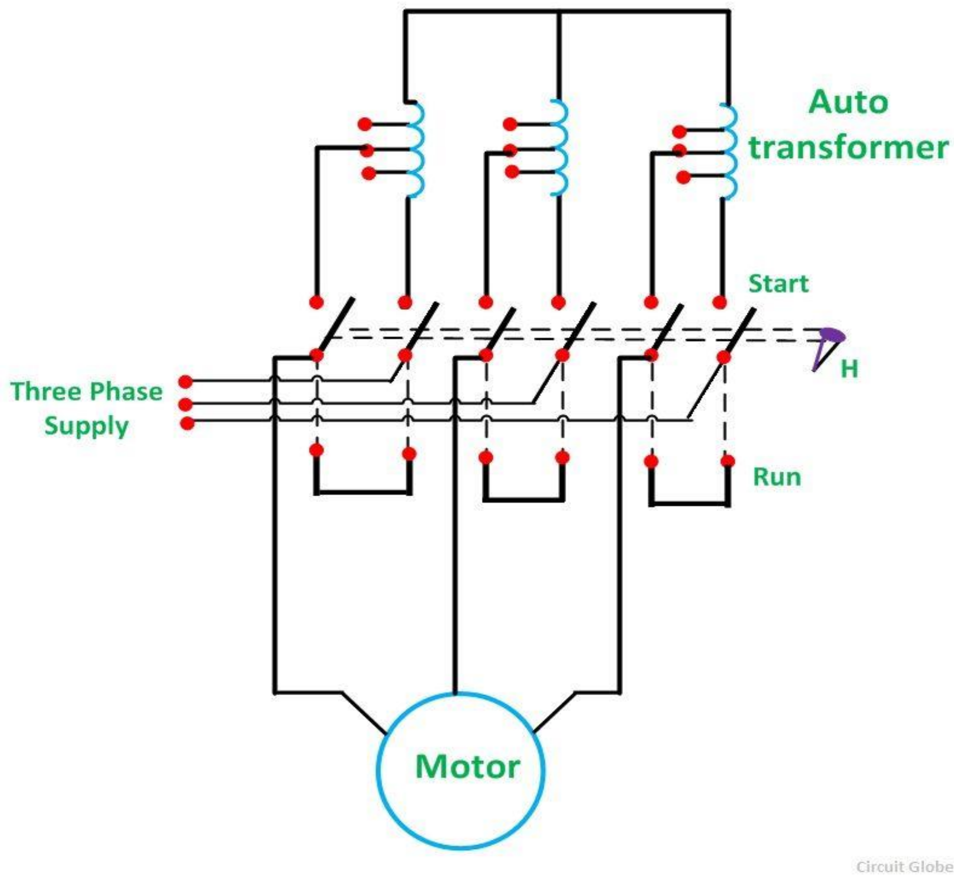
# Auto transformer Starter

An Auto transformer Starter is suitable for both star and delta connected motors. In this method, the starting current is limited by using a three-phase auto transformer to reduce the initial stator applied voltage.




It is provided with a number of tappings.

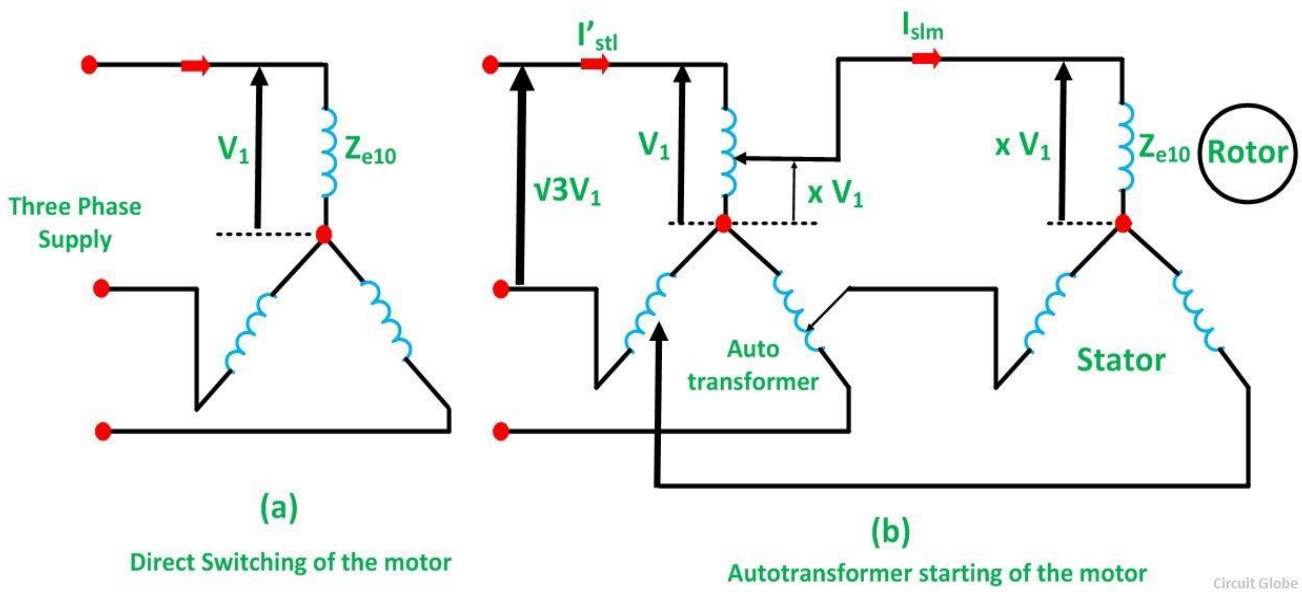
The starter is connected to one particular tapping to obtain the most suitable starting voltage.

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 the secondary of the auto transformer.

When the motor picks up the speed of about 80 percent of its rated value, the handle H is quickly moved to the RUN position. Thus, the auto transformer is disconnected from the circuit, and the motor is directly connected to the line and achieve its full rated voltage.

The figure (a) shown below shows the condition when the motor is directly switched on to lines and the figure (b) shows when the motor is started with the help of auto transformer.




Let,

- $Z_{e10}$ is the equivalent standstill impedance per phase of the motor referred to the stator side
- $V_1$ is the supply voltage per phase.

When the full voltage $V_1$ per phase is applied to the direct switching, the starting current drawn from the supply is given by the equation shown below.

$$I_{stl} = \frac{V_1}{Z_{e10}} \ldots\ldots\ldots (1)$$

With auto transformer starting, if a tapping of the transformer ratio x is used, then the voltage per phase across the motor is $xV_1$. Therefore, at the starting, the motor current is given by the equation.

$$I_{stm} = \frac{xV_1}{Z_{e10}} \;\ldots\ldots\ldots (2)$$

In a transformer, the ratio of currents is inversely proportional to the voltage ratio provided that the no load current is neglected. i.e.,

$$\frac{I_1}{I_2} = \frac{V_2}{V_1} \quad \text{or}$$

$$V_1 I_1 = V_2 I_2$$

If $I'_{stl}$ is the current taken from the supply by the auto transformer. Then,

$$V_1 I'_{stl} = (xV_1)\, I_{stm}$$

$$I'_{stl} = x\, I_{stm} \;\ldots\ldots\ldots. (3)$$

Substituting the value of $I_{stm}$ from the equation (2) in the equation (3) we get.

$$I'_{stl} = x\left(\frac{xV_1}{Z_{e10}}\right)$$

$$I'_{stl} = \frac{x^2 V_1}{Z_{e10}} \;\ldots\ldots\ldots. (4)$$

Therefore,

$$\frac{\text{Starting current with autotransformer}}{\text{Starting current with direct switching}} = \frac{I'_{stl}}{I_{stl}} = \frac{(x^2\, V_1/Z_{e10})}{(V_1/Z_{e10})} = x^2 \quad \ldots \ldots (5)$$

Since the torque developed is proportional to the square of the applied voltage, the starting torque with the direct switching is given as

$$T_{std} \propto V_1^2$$

$$T_{std} = k_2 V_1^2 \ldots \ldots (6)$$

Similarly, starting torque with auto transformer starter

$$T_{sta} \propto (xV_1)^2$$

$$T_{sta} = k_2 x^2 V_1^2 \ldots \ldots (7)$$

Therefore,

$$\frac{\text{Starting torque with autotransformer starter}}{\text{Starting torque with direct switching}} = \frac{k_2 x^2 V_1^2}{k_2 V_1^2} = x^2 \ldots \ldots \ldots (8)$$

With the auto transformer, at the starting, the motor current is given by the equation shown below.

$$I_{stm} = \frac{xV_1}{Z_{e10}} = xI_{sc} \ldots \ldots (9)$$

From the equation (3) and (9) we can conclude that

$$I'_{stl} = x^2 I_{sc} \dots\dots\dots..(10)$$

2018 Fall

4.a

A 2200 V, 2600 kW, 735 rpm, 50 Hz, 8 pole, 3-phase squirrel-cage induction motor has following parameters referred to the stator:

$R_s = 0.075\ \Omega$, $R_r' = 0.1\Omega$, $X_s = 0.45\ \Omega$, $X_r' = 0.55\ \Omega$. Stator winding is delta connected and consists of two sections connected in parallel.

(i) Calculate starting torque and maximum torque as a ratio of rated torque, if the motor is started by star-dalta switching. What is the maximum value of line current during starting?

(ii) Calculate transformation ratio of an auto-transformer so as to limit the maximum starting current to twice the rated value. What is the value of starting torque?

Solⁿ:-

We have,

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{8} = 750 \text{ rpm}$$

At rated operation

$$\text{slip}(s) = \frac{N_s - N}{N_s} = \frac{750 - 735}{750} = 0.02$$

<u>For full load phase current</u>

phase voltage $(V_p)$ = line voltage $(V_L)$ [$\because$ delta connected

$= 2200$ V

Full load phase current,

$$I_p = \frac{V_p}{\sqrt{\left(R_s + R_r'/s\right)^2 + \left(X_s + X_r'\right)^2}}$$

$$= \frac{2200}{\sqrt{\left(0.075 + \frac{0.1}{0.02}\right)^2 + \left(0.45 + 0.55\right)^2}}$$

$= 425.3$ A

Full load line current $(I_L) = \sqrt{3}\, I_p$

$= \sqrt{3} \times 425.3 = 736.7$ A

$$\omega_{ms} = \frac{\pi N}{30} = \frac{\pi \times 750}{30} = 78.54 \text{ rad/sec}$$

Full load torque $(T_{fL}) = \dfrac{3 I_p^2 R_r'/s}{\omega_{ms}}$

$$= \frac{3 \times (425.3)^2 \times 0.1}{0.02 \times 78.54}$$

$$= 34545.5 \text{ N-m}$$

(i) Maximum line current during starting $(I_{Ls})$

= phase current during starting $(I_{ps})$

[$\because$ star connection]

$$\Rightarrow I_{Ls} = \frac{V_p}{\sqrt{(R_s + R_r'/s)^2 + (X_s + X_r')^2}}$$

$$= \frac{2200/\sqrt{3}}{\sqrt{(0.075 + 0.1)^2 + (0.45 + 0.55)^2}}$$

[$\because V_p = V_L/\sqrt{3}$
$s = 1$ at start]

$$= 1251 \text{ A}$$

Starting torque $(T_{st}) = \dfrac{3 I_p^2 R_r'}{\omega_{ms}}$

$$= \frac{3 \times (1251)^2 \times 0.1}{78.54}$$

$$= 5979.3 \text{ N-m}$$

$$\therefore \frac{T_{st}}{T_{fl}} = \frac{5979.3}{34545.5} = 0.173$$

We have,

max$^m$ torque $(T_m) = \dfrac{3}{2\omega_{ms}} \left[ \dfrac{V_p^2}{R_s \pm \sqrt{R_s^2 + (X_s + X_r')^2}} \right]$

$$= \frac{3}{2 \times 78.54} \left[ \frac{(2200/\sqrt{3})^2}{0.075 + \sqrt{0.075^2 + (0.45 + 0.55)^2}} \right]$$

$$= 28588 \text{ N-m}$$

$$\therefore \frac{T_m}{T_{fl}} = \frac{28588}{34545.5} = 0.83$$

(ii) Starting current direct on line $= \dfrac{2200/\sqrt{3}}{\sqrt{(0.075+0.1)^2+1^2}}$

$= 3753.5\,A$

If $\alpha_t$ is the transformation ratio of auto transformer the ~~starting~~ line current with auto transformer will be

$\alpha_t^2 \times 3753.5\,A$

Thus from the given condition,

$\alpha_t^2 \times 3753.5 = 2 \times$ full load line current $(I_L)$

$\Rightarrow \alpha_t^2 \times 3753.5 = 2 \times 736.7$

$\Rightarrow \alpha_t = 0.627$

Starting motor line current $= \dfrac{\text{Starting line current}}{\alpha_t}$

$= \dfrac{2 \times 736.7}{0.627}$

$= 2350\,A.$

Starting motor phase current $(I_p) = \frac{2350}{\sqrt{3}}$

$= 1356.7 \text{ A}$

$\therefore$ Starting torque $= \frac{3 I_p^2 R_r'}{\omega_{ms}}$

$= \frac{3 \times (1356.7)^2 \times 0.1}{78.54}$

$= 7031 \text{ N-m}$

2016 Fall

4.b

A 220 V, 970 rpm, 100 A dc separately excited motor has an armature resistance of 0.05 Ω. It is braked by plugging from an initial speed of 1000 rpm. Calculate

(a) resistance to be placed in armature circuit to limit braking current to twice the full load value

(b) braking torque, and

(c) torque when the speed has fallen to zero.

*Solution*

At 970 rpm $\qquad E = 220 - 0.05 \times 100 = 215 \text{ V}$

At 1000 rpm $$E = \frac{1000}{970} \times 215 = 221.65 \text{ V}$$

(a) For plugging operation

$$R_B + R_a = \frac{E + V}{I_a} = \frac{221.65 + 220}{200} = 2.21\ \Omega$$

$$R_B = 2.21 - 0.05 = 1.16 \text{ ohms}$$

(b) $$T = \frac{E \times I_a}{\omega_m} = \frac{221.65 \times 200}{1000 \times 2\pi/60} = 423.3 \text{ N-m}$$

(c) At zero speed $E = 0$

$$I_a = \frac{V}{R_B + R_a} = \frac{220}{2.21} = 99.55 \text{ A}$$

As $T \propto I_a$, $$T = 423.3 \times \frac{99.55}{200} = 210.7 \text{ N-m}$$