STARTING OF INDUCTION MOTORS

- It is possible to start the motor by directly applying voltage. This may result in high current drawl from supply for a short period of time.
- By applying reduced voltage, ~~[illegible]~~ we can control high inrush current. But, the starting torque is reduced ($T_e \propto V^2$)

Starting ~~tech~~ techniques:

Squirell cage:

- Direct online starting
- Stator resistor (or reactor) starting
- Auto transformer starting
- Star - delta starting.

Slip ring :

- Rotor resistance.

Direct online Starting:

- Low power factor
- starting current is 5 to 7 times full load current
- Lead to voltage drop in power supply lines feeding the induction motor.

Relation between $T_{e,st}$ & $T_{e,fl}$.

$$T_e = \frac{3}{\omega_s} \cdot I_2^2 \frac{r_2}{s}$$

$$\frac{T_{e,st}}{T_{e,fl}} = \left[\frac{I_{2,st}}{I_{2,fl}}\right]^2 \cdot s_{fl}$$

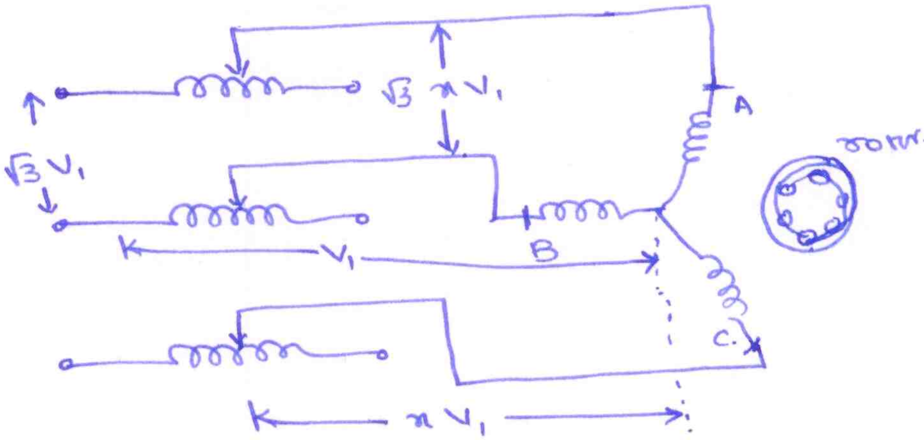
if no load current is neglected

$$\frac{T_{e,st}}{T_{e,fl}} = \left[\frac{I_{st}}{I_{fl}}\right]^2 \cdot S_{fl}.$$

for direct switching $I_{st} = I_{sc}$

Stator resistor (or reactor) starting:

- Only fraction (x) of supply voltage appears across the stator terminals



- The starting current is reduced.
- Reactor/resistor can be cut as motor picks up speed.
- $$I_{st} = \frac{x \cdot V_1}{Z_1} = x \cdot I_{sc}.$$

$$\left(\frac{T_{e,st}}{T_{e,fl}}\right) = \left[\frac{I_{st}}{I_{fl}}\right]^2 \cdot s_{fl}$$

$$= x^2 \cdot \left[\frac{I_{sc}}{I_{fl}}\right]^2 \cdot s_{fl}.$$

$$\frac{\text{Starting torque with reactor starting}}{\text{Starting torque with dol starting}} = x^2$$

- Series reactor is more costly when compared to resistor. Low energy loss.
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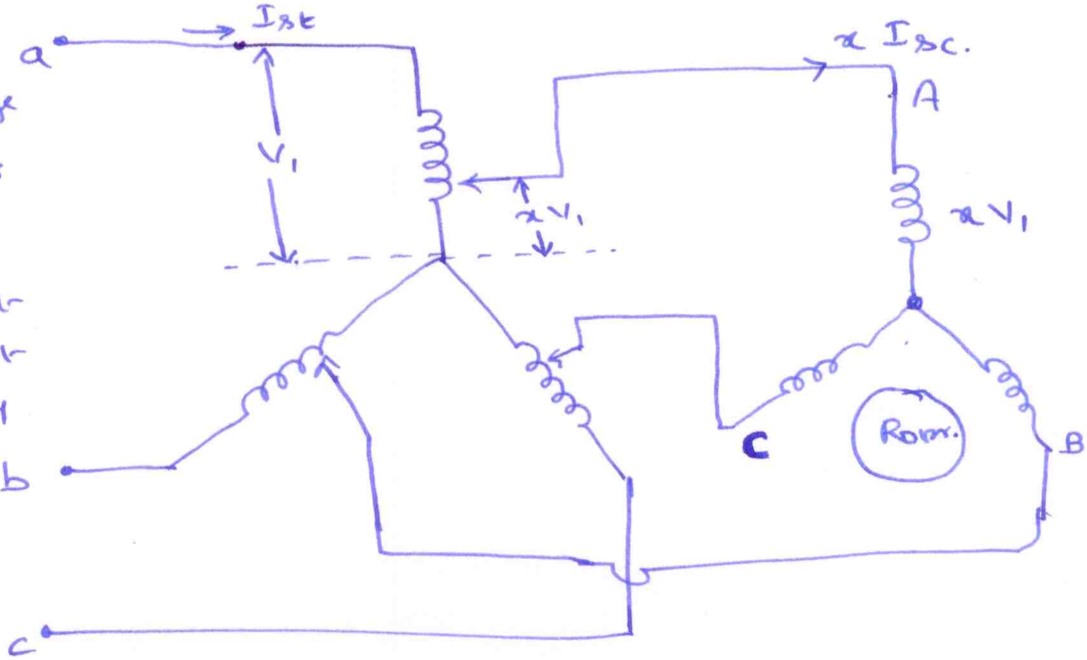
Auto Transformer Starting:

- A fraction of voltage is applied to stator ($x V_1$)
- The motor current and hence current drawn from supply is reduced.
- $x < 1$



Per phase starting current in the motor winding $= \frac{x \cdot V_1}{Z_1} = x \cdot I_{sc}$.

neglecting no load current of auto transformer

per phase output VA = per phase input VA.

$$I_{st} \cdot V_1 = x I_{sc} \cdot x \cdot V_1$$

$$\Rightarrow \boxed{I_{sc} = \frac{1}{x^2} \cdot I_{st}}$$

with respect to motor terminals

$$\frac{T_{e,st}}{T_{e,fl}} = \left[\frac{\text{per phase starting current in motor winding}}{\text{per phase full load current}}\right]^2 \cdot s_{fl}.$$

$$= \left[\frac{x \cdot I_{sc}}{I_{fl}}\right]^2 \cdot s_{fl}$$

$$= x^2 \cdot \left[\frac{I_{sc}}{I_{fl}}\right]^2 \cdot s_{fl}$$

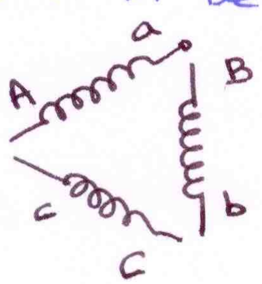
with respect to supply mains.

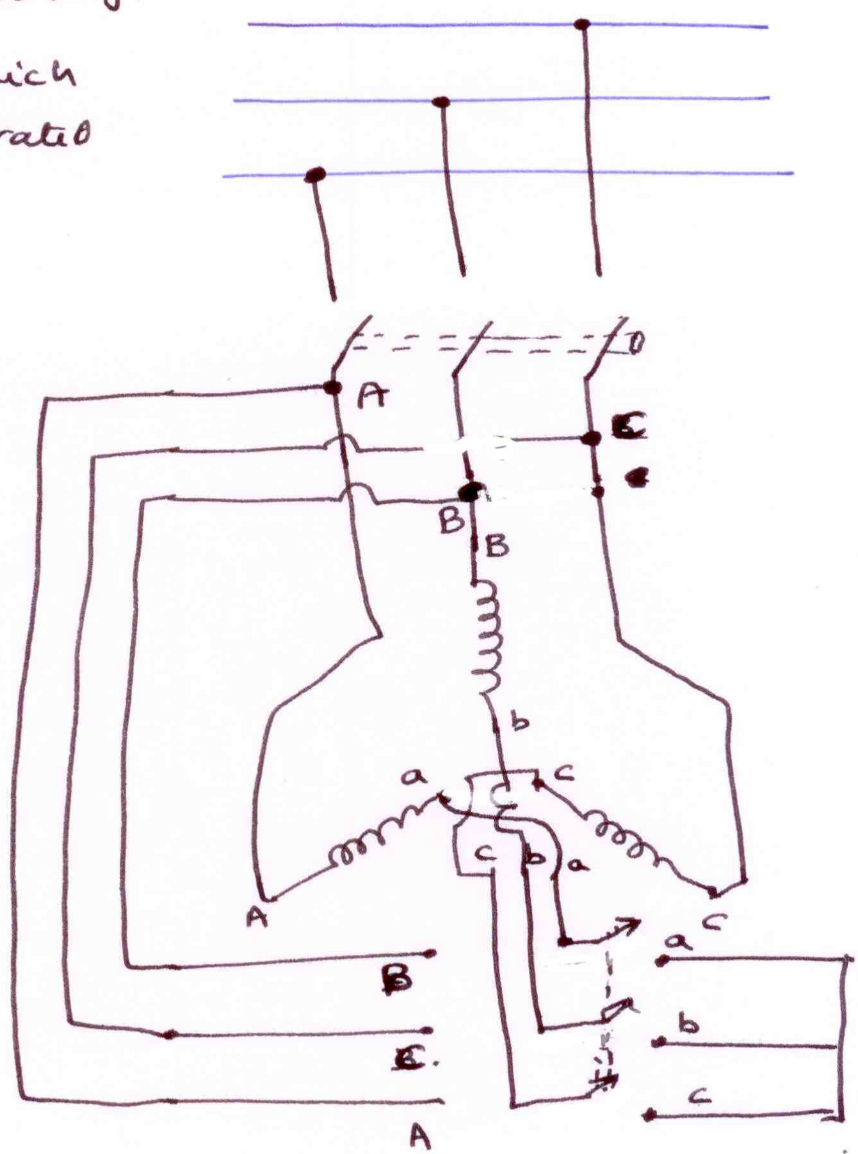
$$\frac{T_{e,st}}{T_{e,fl}} = \frac{1}{x^2}\cdot\left[\frac{I_{st}}{I_{fl}}\right]^2\cdot s_{fl} \qquad \left[\because\ I_{st} = x^2 \cdot I_{sc}\right]$$

$$\frac{T_{e,st}\text{, with auto transformer}}{T_{e,st}\text{ with DOL}} = \left[\frac{xV_1}{V_1}\right]^2 = x^2.$$

Star-delta Starting:

- Used for machine which are normally operated in Delta.
- Six terminals are available
- Triple pole double throw (TPDT) switch
- First connected in Star and then in Delta.





If V_L is the line voltage, per phase motor starting current ($I_{st,Y}$) is given by

$$I_{st,Y} = \frac{V_L}{\sqrt{3}\, Z_1}$$

If the stator winding is delta connected, by using direct switching.

$$I_{st,d} = \frac{V_L}{Z_1} = I_{sc,d}.$$

Line current $= \sqrt{3}\,\frac{V_L}{Z_1} = \sqrt{3}\, I_{st,d} = \sqrt{3}\, I_{sc,d}.$

Note that

$$I_{st,Y} = \frac{1}{\sqrt{3}}\, I_{st,d}.$$

$$\frac{\text{Starting line current with } Y\text{-}\Delta \text{ starter}}{\text{Starting line current with DOL}} = \frac{I_{st,Y}}{\sqrt{3} \cdot I_{st,d}} = \frac{\frac{1}{\sqrt{3}} \cdot \frac{V_L}{Z_1}}{\sqrt{3} \cdot \frac{V_L}{Z_1}} = \frac{1}{3}.$$

$$\frac{\text{Starting torque with } Y\Delta \text{ starter}}{\text{Starting torque with DOL}} = \frac{\left(\frac{V_L}{\sqrt{3}}\right)^2}{V_L^2} = \frac{1}{3}$$

- In auto x^f, if ratio of output voltage to supply voltage is $\frac{1}{\sqrt{3}}$, then both starting line current and torque are reduced by 1/3 when compared to DOL.

$$Y\text{-}\Delta \approx \text{auto } x^f \text{ with } x = \frac{1}{\sqrt{3}} = 0.58.$$

$$\frac{T_{e,st}(Y\Delta)}{T_{e,fl,d}} = \frac{\frac{1}{\omega_s} \cdot (I_{st\,Y})^2 \cdot \frac{r_2}{1}}{\frac{1}{\omega_s}\, (I_{fl,d})^2 \cdot \frac{r_2}{S_{fl}}}$$

$$= \frac{\left(\frac{1}{\sqrt{3}} \cdot I_{sc,d}\right)^2}{(I_{fl,d})^2} \cdot S_{fl}$$

$$= \frac{1}{3} \cdot \left[\frac{I_{sc,d}}{I_{fl,d}}\right]^2 \cdot S_{fl}$$

- Star delta starter is cheap compared to auto x^{f}. and hence widely used.
- Used for voltage $\leq 3.3kV$.
  At higher voltages, ~~for~~ delta connection requires large turns making motor expensive.