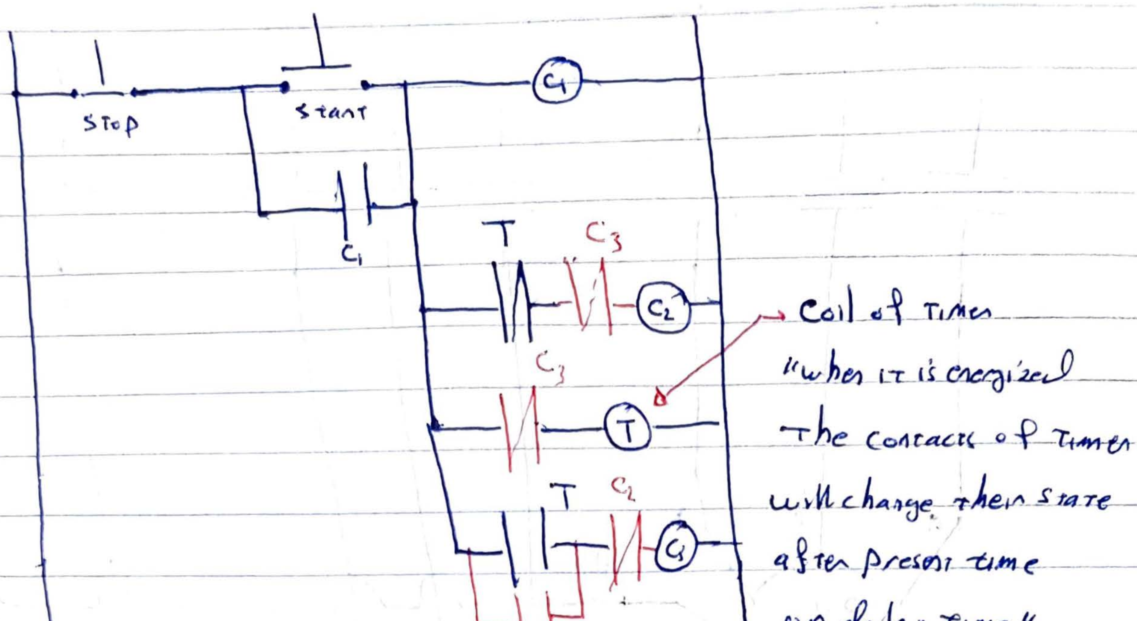
Video

# Control circuit for Y_Δ starter

③




* Red parameters using for Remove the Timer Coil when it is at Δ
* Try to add Reversed switch

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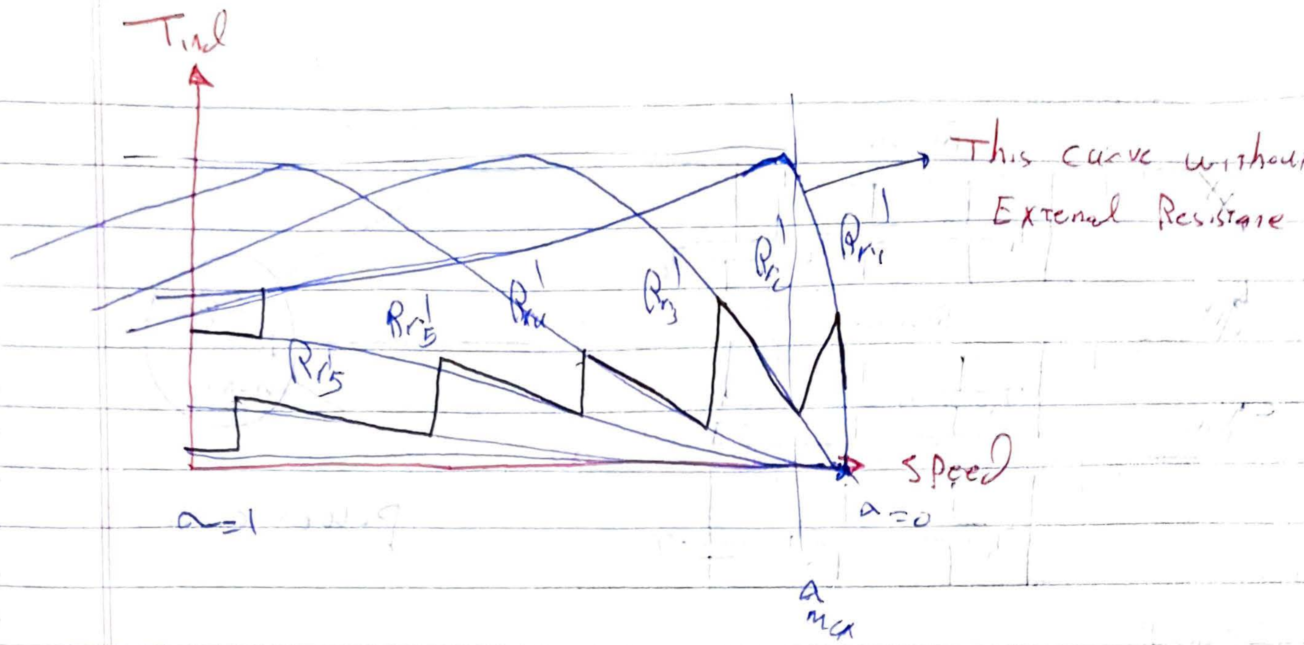
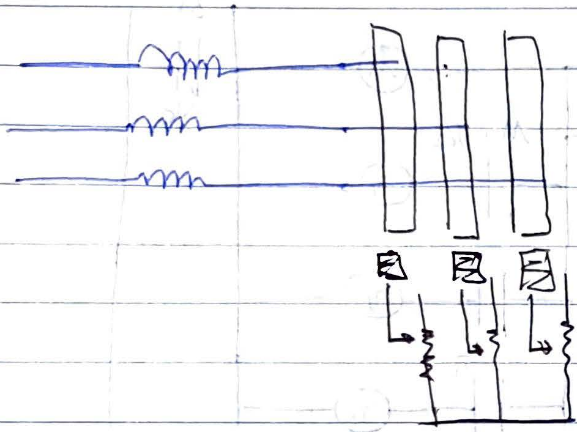
② changing the rotor resistance "wound rotor induction machine"

$$T_{max} = \frac{3V_{Th}^2}{2\omega_s\left[R_{Th} + \sqrt{R_{Th}^2 + (X_{Th} + X_r')^2}\right]}$$

$$S_{max} = \frac{R_r'}{\sqrt{R_{Th}^2 + (X_{Th} + X_r')^2}}$$



$$R'_{r6} > R'_{r5} > R'_{r4} > R'_{r3} > R'_{r2} > R'_{r1}$$

$$R'_r \uparrow \Rightarrow R_{RCL} \uparrow \Rightarrow \eta_{motor} \downarrow \; \& \; \eta_r = (1-s) \downarrow$$

③ Starters of induction motors:

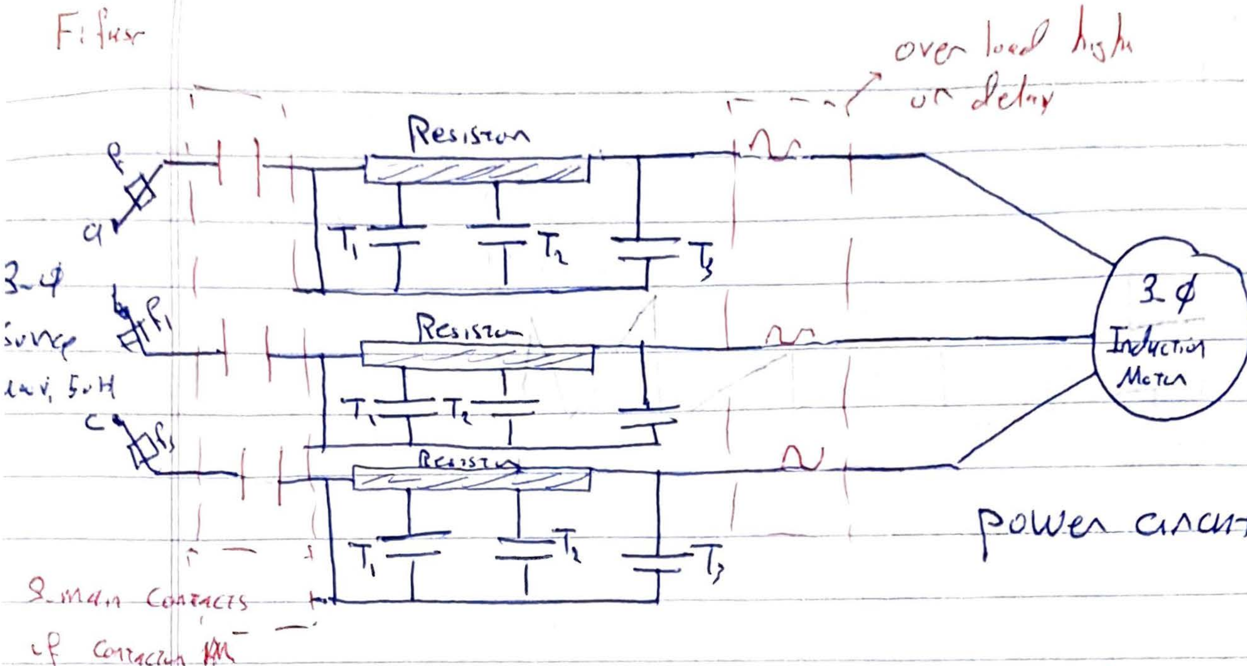
① Y-D starter ② Rotor resistor starter "wound rotor"

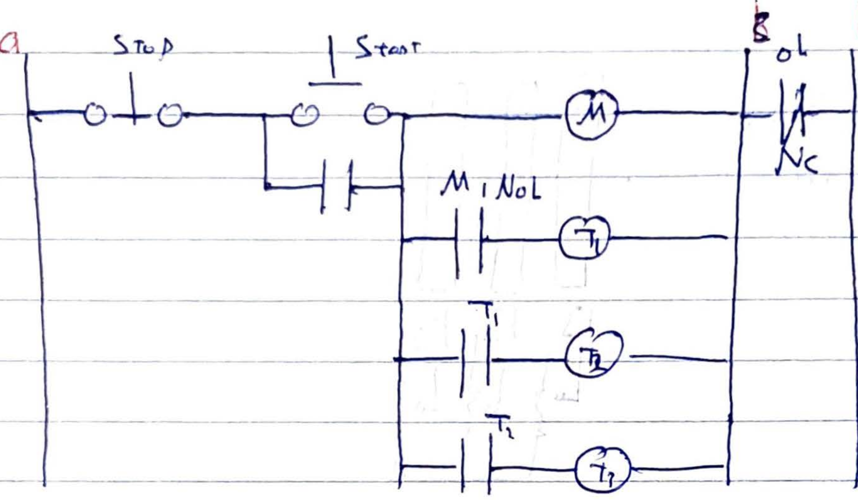
③ Stator resistor or inductor starter:

$$T_{ind} = \frac{3 V_{th}^2 \cdot \frac{R_r'}{s}}{\omega_s \left[ \left( \frac{R_r'}{s} + R_{th} \right)^2 + (X_{th} + X_r')^2 \right]} \quad ; \quad T_{start} = T_{ind} \Big|_{s=1}$$

$$R_{th} = \left( \frac{X_m}{X_m + X_s} \right)^2 R_s \simeq R_s$$

$$X_{th} = X_s \qquad \Longrightarrow R_s \uparrow \Rightarrow R_{th} \uparrow \Rightarrow T_{start} \downarrow$$




$T_1, T_2, T_3$ are three delay times operating in 3 steps

⊛ Protective features

① short circuit protection ⇒ Fuses

② under voltage protection

③ over Load protection

$F_1, F_2$ & $F_3$ are 3 Fuses to protect the motor from the short circuit faults.

④ Autotransformer "VARIAC".

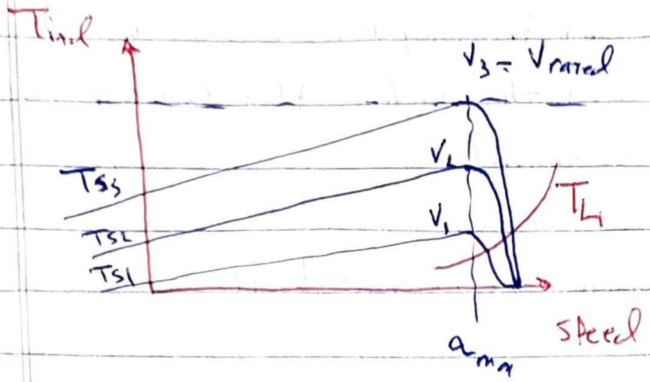
$$T_{ind,start} = \frac{3 V_{th}^2}{\omega_s\left[(R_{th}+R_r')^2 + (X_{th}+X_r')^2\right]} \quad , R_r'$$

$T_{ind,start} \propto V_{th}^2$ , $V_{th} \cong V_s$

$V_s \downarrow \Rightarrow V_{th} \downarrow \Rightarrow T_{ind,start} \downarrow$

⊛ $s_{max} = \frac{R_r'}{\sqrt{R_{th}^2 + (X_{th}+X_r')^2}}$

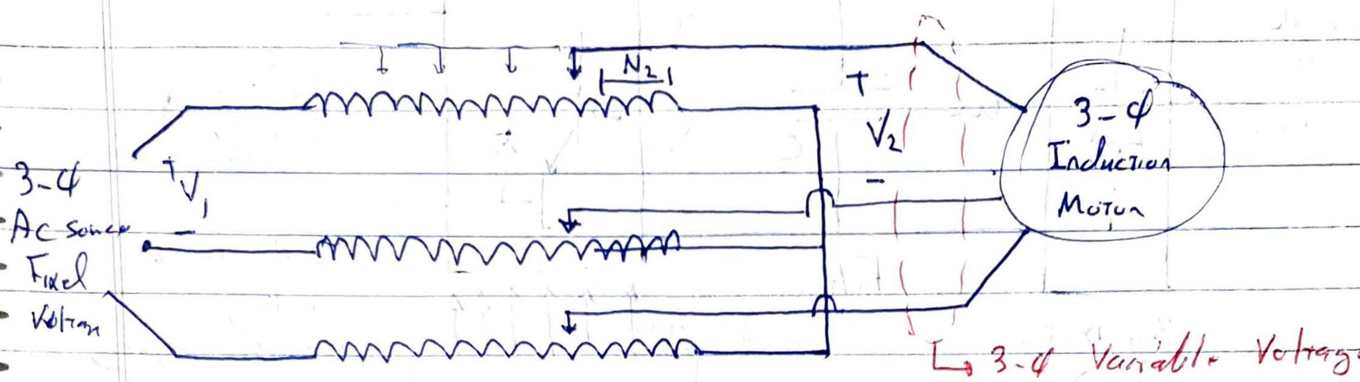
= constant [ $V_{th}$ [illegible]




$V_1 < V_2 < V_3$

$T_{S_1} < T_{S_2} < T_{S_3}$

The motor voltage is controlled using the auto transformer

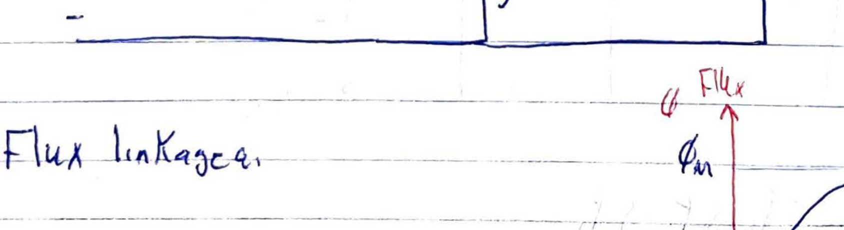



$$V_2 = \frac{N_2}{N_1} V_1 = \frac{V_1}{a_t} \qquad \text{where } a_t > 1$$

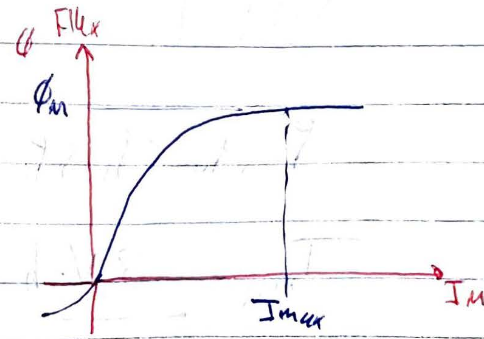
↳ Turned Ratio

$$T_{start} \propto \frac{1}{a_t^2}$$

⑤ Variable Voltage Variable Frequency Drive (VVVF Drive)




Flux linkage.




$$\phi_m = L_m I_m \Rightarrow \phi_m = L_m\left(\frac{E}{X_m}\right)$$

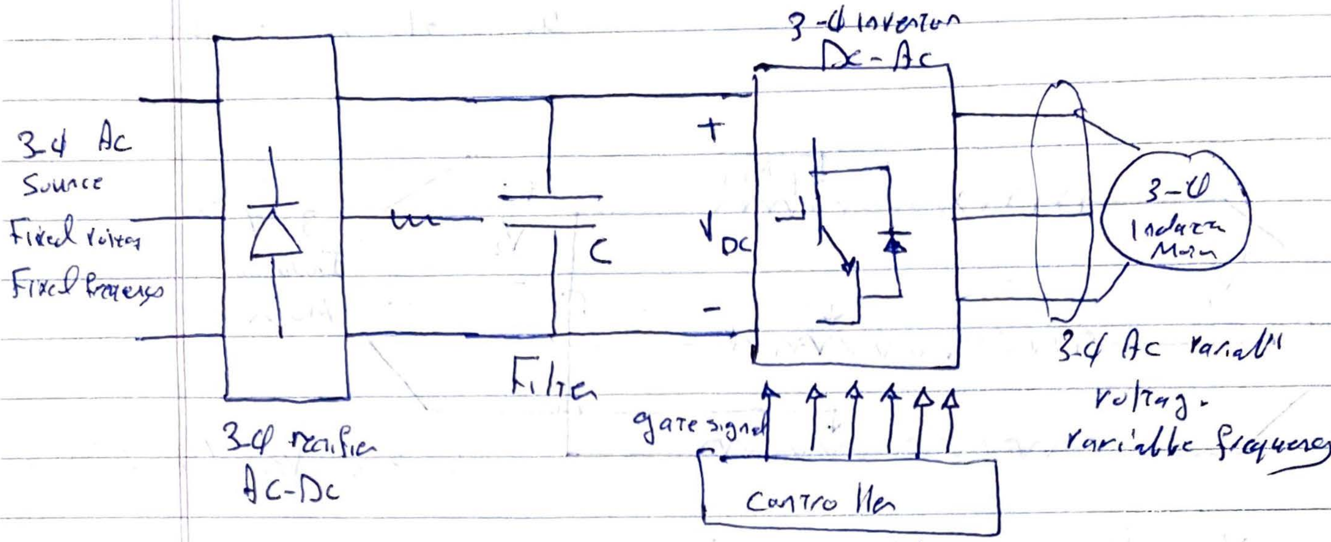
$$\phi_m = \cancel{L_m}\left(\frac{E}{w_e \cancel{L_m}}\right) = \frac{E}{w_e} = \frac{E}{2\pi f_e}$$

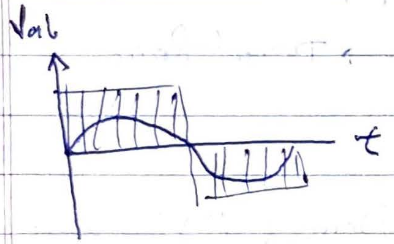
if the stator resistance and reactance are ignored, then $V_s \simeq E$

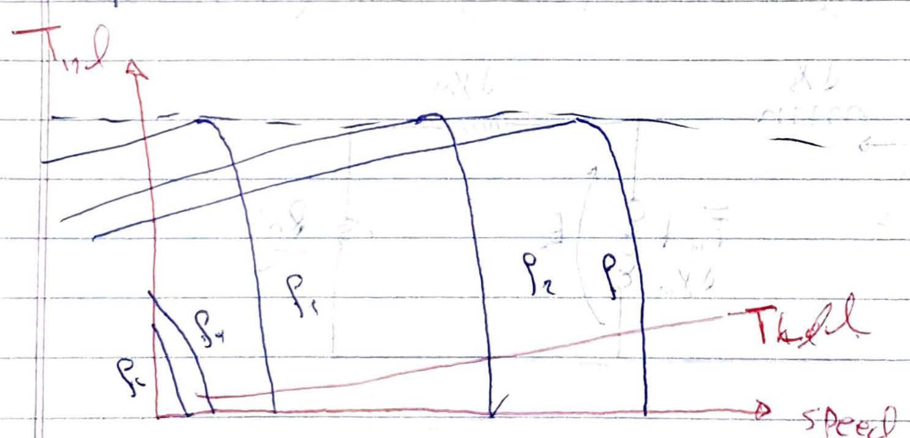
$\Rightarrow \phi_m \propto V_s / f_e$

$\phi_m \propto \frac{V}{f}$ ⇒ The voltage of frequency must decrease by the same ratio to keep the machine flux constant and not let it saturated.

After starting the voltage & frequency are increased by the same factor to reach the operating point.



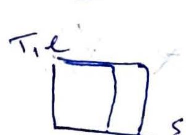




$f_5 < f_4 < f_3 < f_2 < f_1$

$$T_{max} = \frac{3 V_{th}^2}{2\omega_s \left[ R_{th} + \sqrt{R_{th}^2 + (X_{th} + X_2)^2} \right]}$$

if $R_{th}$ is cancelled

The $T_{ind}$ will be constant

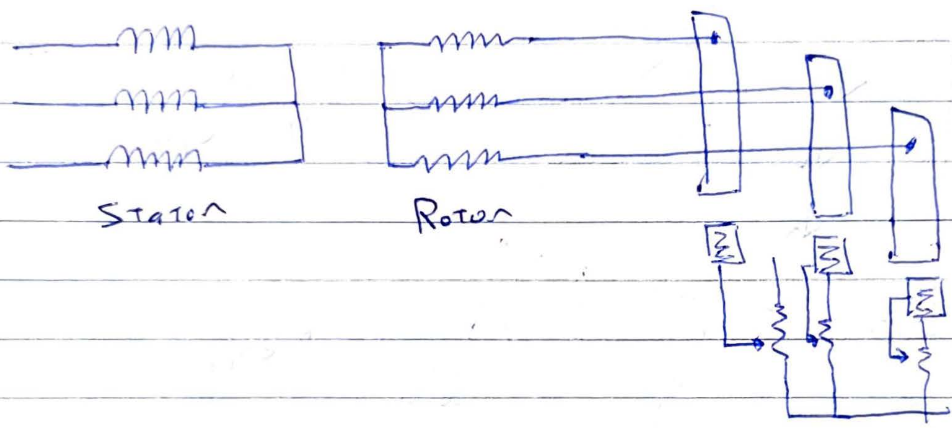


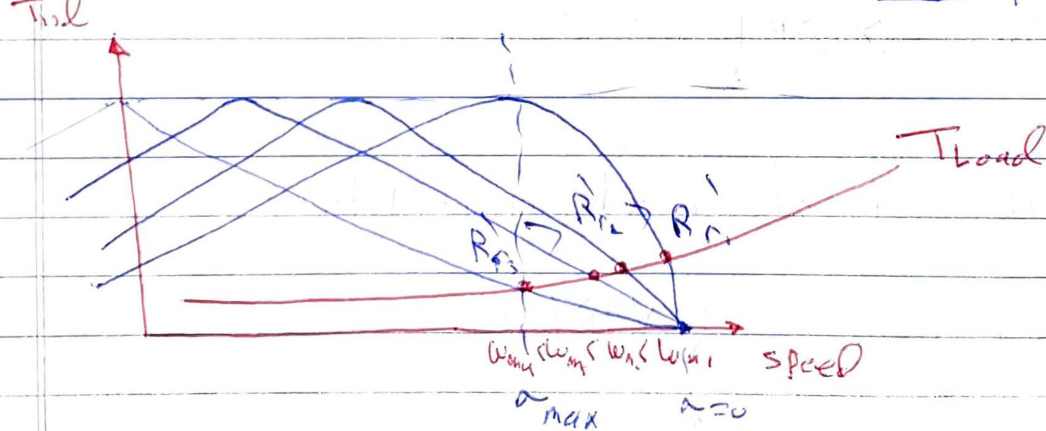
# Speed control of Induction Motor

① changing the Rotor resistance [wound rotor resistance]

(Constant) $T_{max} = \dfrac{3 V_{Th}^2}{2\omega_s \left[ R_s + \sqrt{R_s^2 + X_{eq}^2} \right]}$ ; $X_{eq} = X_r' + X_s$

$$s_{max} = \frac{R_r'}{\sqrt{R_s^2 + X_{eq}^2}}$$




$R_r' \uparrow \Rightarrow \omega_m \downarrow \Rightarrow s \uparrow \Rightarrow \eta_r = (1-s) \downarrow$ efficiency

Advantage Disadvantage

- Using variable resistors
- Using Power Converter.

} ⇒ How change $R_r'$

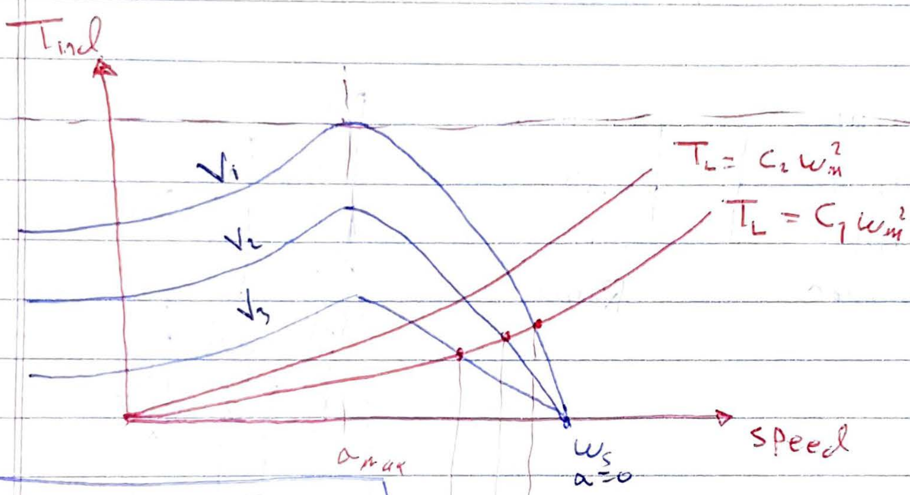
② changing the line voltage [Project]

$T_{max} \propto V_{Th}^2$

$$s_{max} = \frac{R_r'}{\sqrt{R_s^2 + X_{eq}^2}} = \text{Constant}$$

$$V_s \downarrow \Rightarrow V_{Th} \downarrow \Rightarrow \underbrace{(T_{max} \propto V_{Th}^2) \downarrow}_{\text{Disadvantage}} \Rightarrow \underbrace{\omega_m \downarrow}_{\text{advantage}}$$

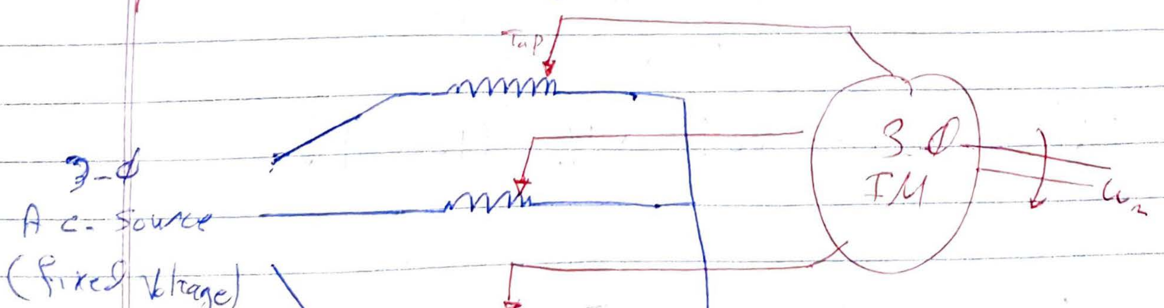
$$\Rightarrow s \uparrow \Rightarrow \underbrace{(\eta_r = 1 - s) \downarrow}_{\text{Disadvantage}}$$

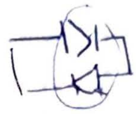



$\boxed{V_1 > V_2 > V_3 \Rightarrow \omega_{m_1} > \omega_{m_2} > \omega_{m_3}}$ $\omega_{m_3} < \omega_{m_2} < \omega_{m_1}$

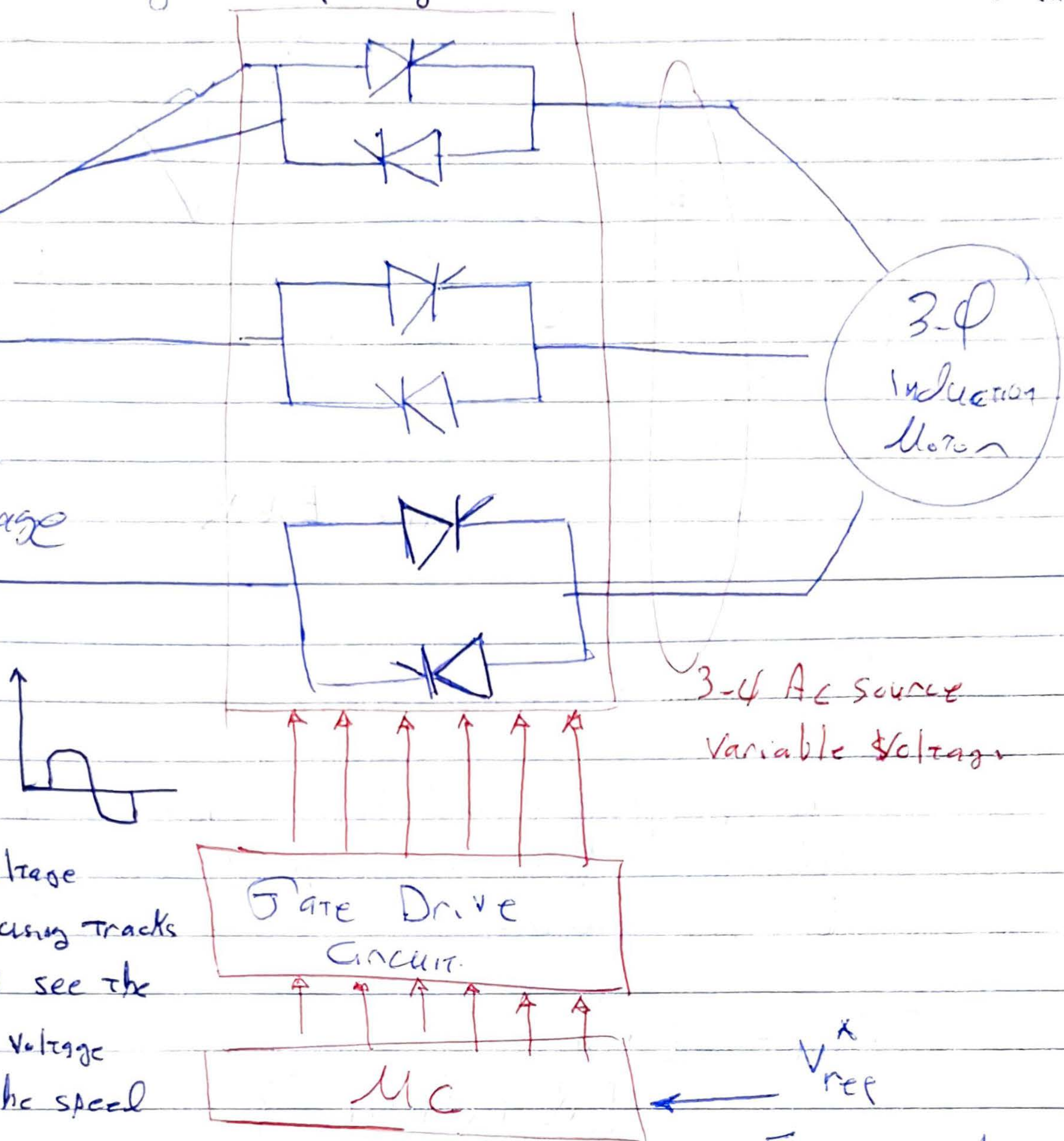
⊛ Methods to change the motor Voltage

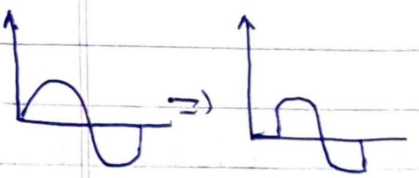
1) Auto-Transformer (VAR/AC)






2) 3-φ AC regulator (using power electronics)

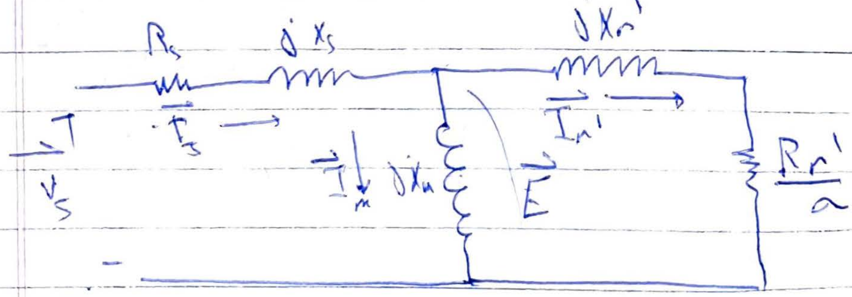


The RMS voltage be smaller using Tracks so the IM see the Fundamental voltage small, so the speed Deacrease.

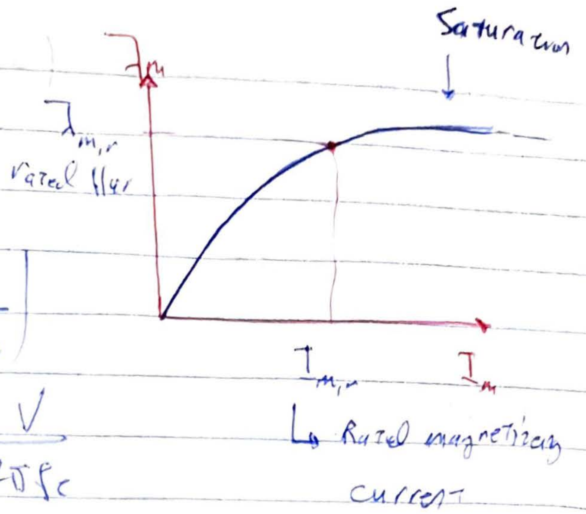
3) Variable Voltage Variable Frequency Drive

VVVF - Drive




* speed controlled by Flux

# Flux linkage




$$\lambda_m = L_m I_m$$

$$\lambda_m = L_m \left(\frac{E}{X_m}\right) = L_m \left(\frac{E}{\omega_e L_m}\right)$$

$$\lambda_m = \frac{E}{\omega_e} = \frac{E}{2\pi f_e} \approx \frac{V}{2\pi f_e}$$

$$\Rightarrow \boxed{\lambda_m \propto \frac{V}{f}}$$ , since $E \approx V_s$

when $\omega_m <$ rated speed $\Rightarrow$

The frequency and voltage must be changed by the same factor to keep $\lambda_m$ constant and not let it saturated

$$T_{max} = \frac{3 V_{Th}^2}{2\omega_s \left[R_s + \sqrt{R_s^2 + X_{eq}^2}\right]}$$

$$s_{max} = \frac{R_r'}{\sqrt{R_s^2 + X_{eq}^2}}$$

$$\boxed{\omega_s = \frac{\omega_e}{p}}$$

Constant

if we ignore $R_s \Rightarrow T_{max} = \frac{3 V_{Th}^2}{2\omega_s \omega_e L_{eq}} \propto \frac{V^2}{f^2} \Rightarrow$

$$s_{max} = \frac{R_r'}{\omega_e L_{eq}} \Rightarrow f \downarrow \Rightarrow s_{max} \uparrow$$

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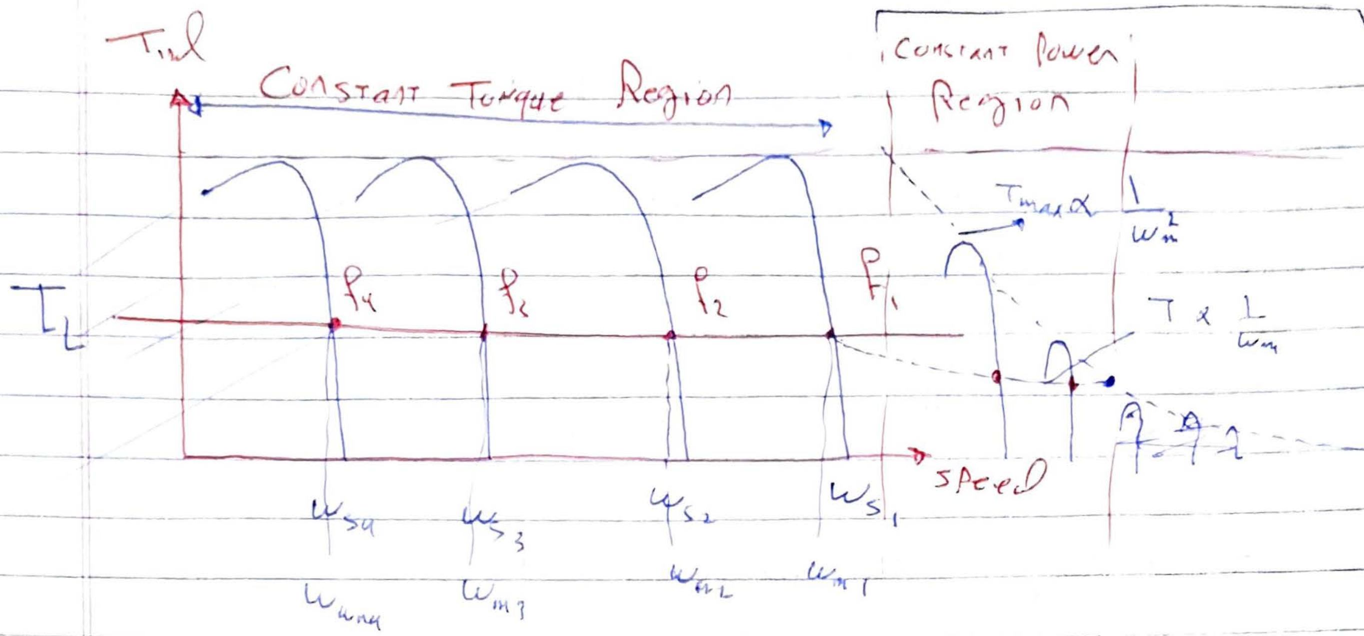



$f_1 > f_2 > f_3 > f_4 \Rightarrow w_{m4} > w_{m3} > w_{m2} > w_{m1}$

(Rated frequency)

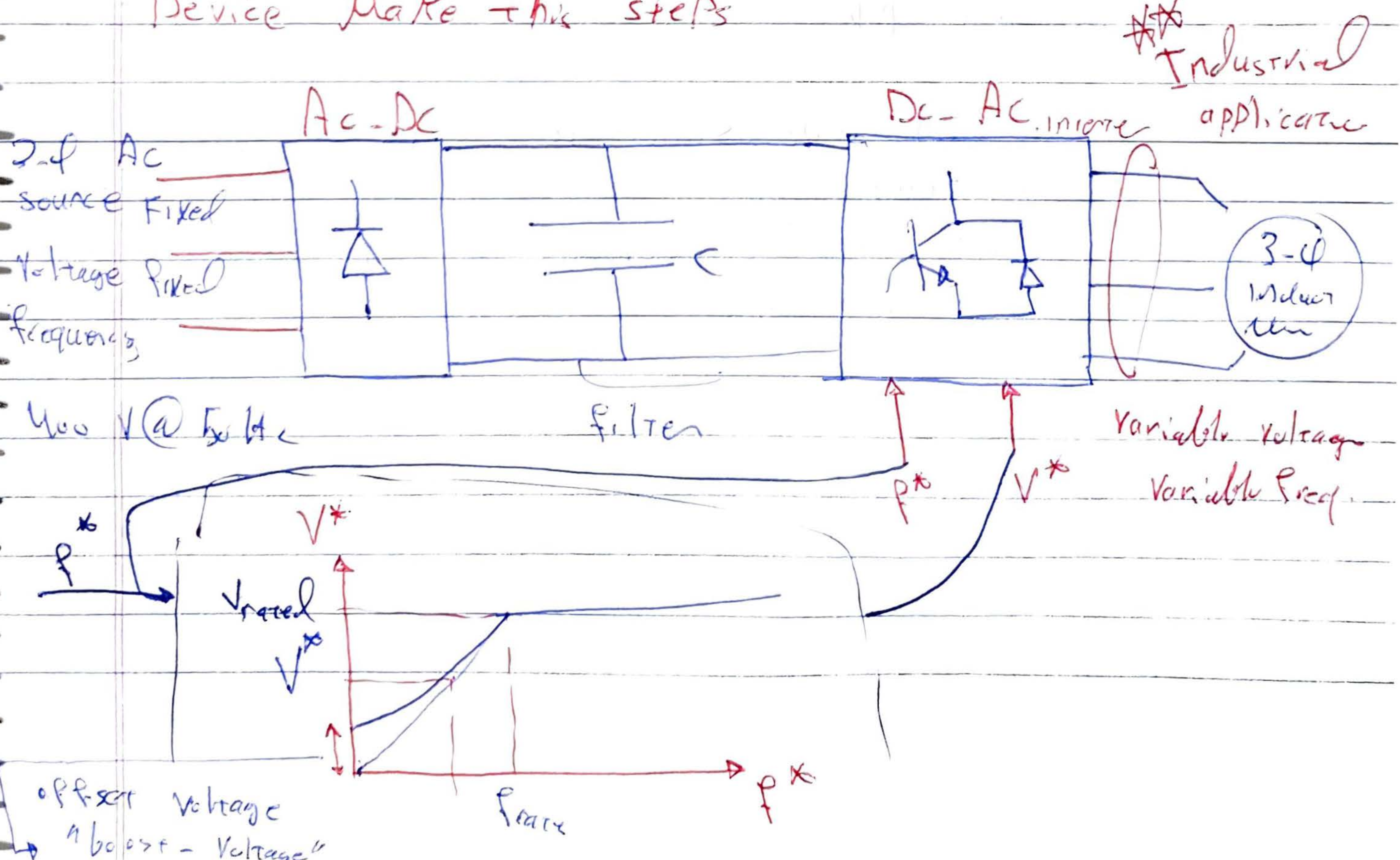
when $W_m >$ Rated speed

$\Rightarrow V = V_{rated}$

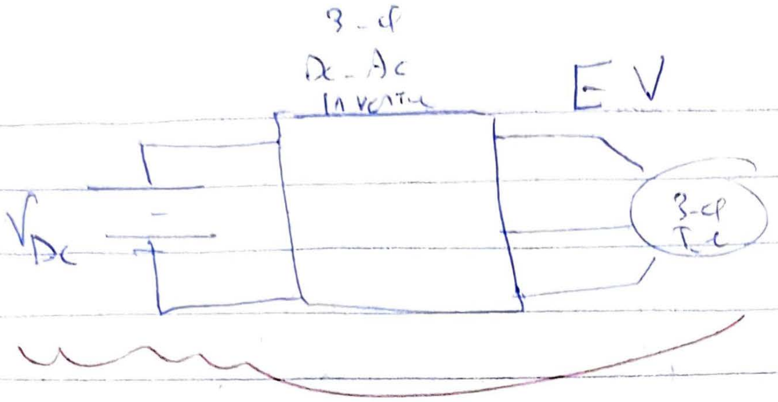
$\Rightarrow T_{max} \propto \frac{1}{w_{ms}^2}$ & $T_L \propto \frac{1}{w_m}$

$P_m = T_L w_m =$ rated power

Device Make this steps




To make up the voltage Drop accross $R_s$ at low frequency.




Electrical vehicles

④ changing the number of poles

$$n_s = \frac{120}{P} f_e$$

4.1) Method of consequent pole, In this method the number of poles is change by the Ratio of 1:2 Via simple switching operation

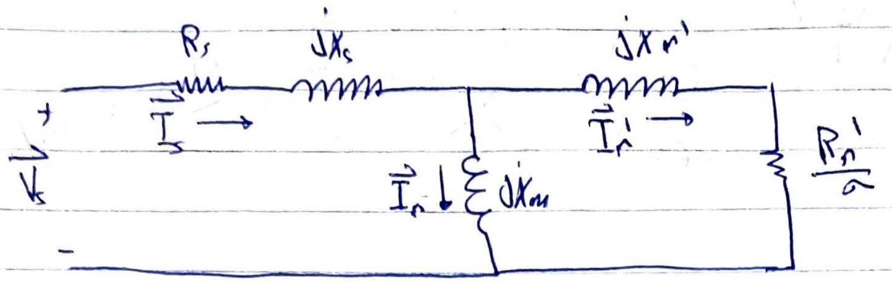
⟹ $\omega_m$ is connected by the ratio of 1:2

4.2) Multiple stator windings:
→ multiple stator windings with different number of poles

→ only one stator winding is energized at a time

→ This method increase the size, cost & weight of machine.

# Deteminiong the parameters of Induction motor.



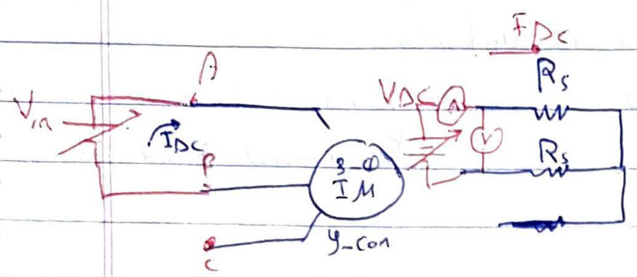

3 tests

① Dc test

② No Load Test

③ Locked rotor Test

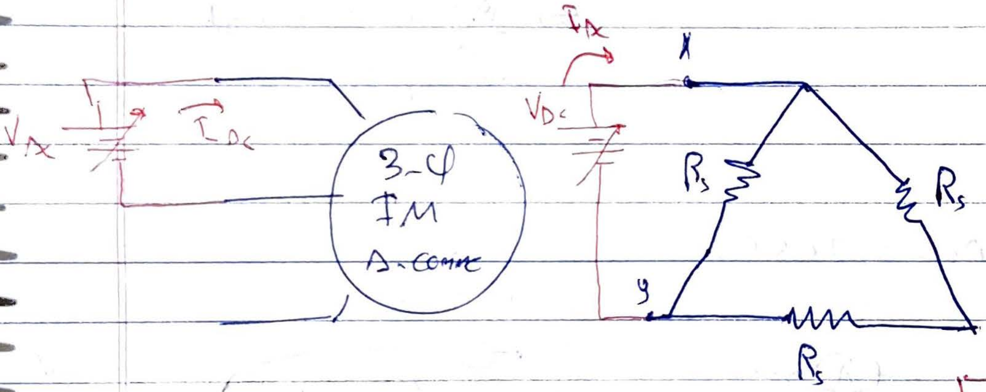
## ① D C Test:




Y - Connected

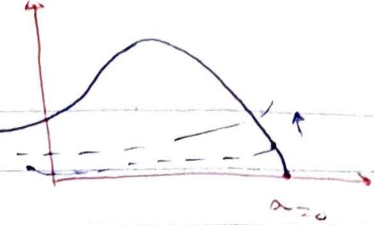
① adjust the current in the stator windings to be equal to motor rated current

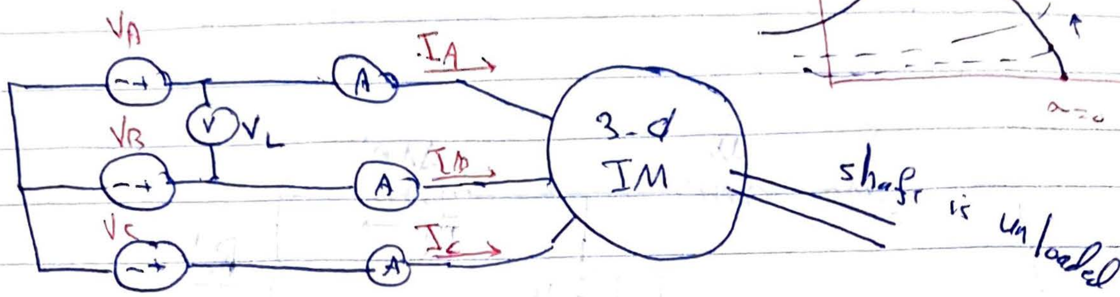
② Measure $V_{DC}$ & $I_{DC}$, Calculate $R_s \Rightarrow R_s = \frac{V_{DC}}{2 I_{DC}}$




$$\frac{V_{DC}}{I_{DC}} = R_{xy} = 2R_s // R_s = \frac{2}{3} R_s \Rightarrow \boxed{R_s = \frac{3}{2} \frac{V_{DC}}{I_{DC}}}$$

## ② No Load Test.






$|V_A| = |V_B| = |V_C|$ = motor rated voltage

frequency = rated frequency

1. Make sure that the shaft is unloaded
2. Connect the motor to a 3-φ source ( V = rated voltage, f = rated frequency)
3. Measure $V_L$
4. Measure $I_A$, $I_A$ & $I_C$
5. Estimate $I_L = \frac{I_A + I_B + I_C}{3}$

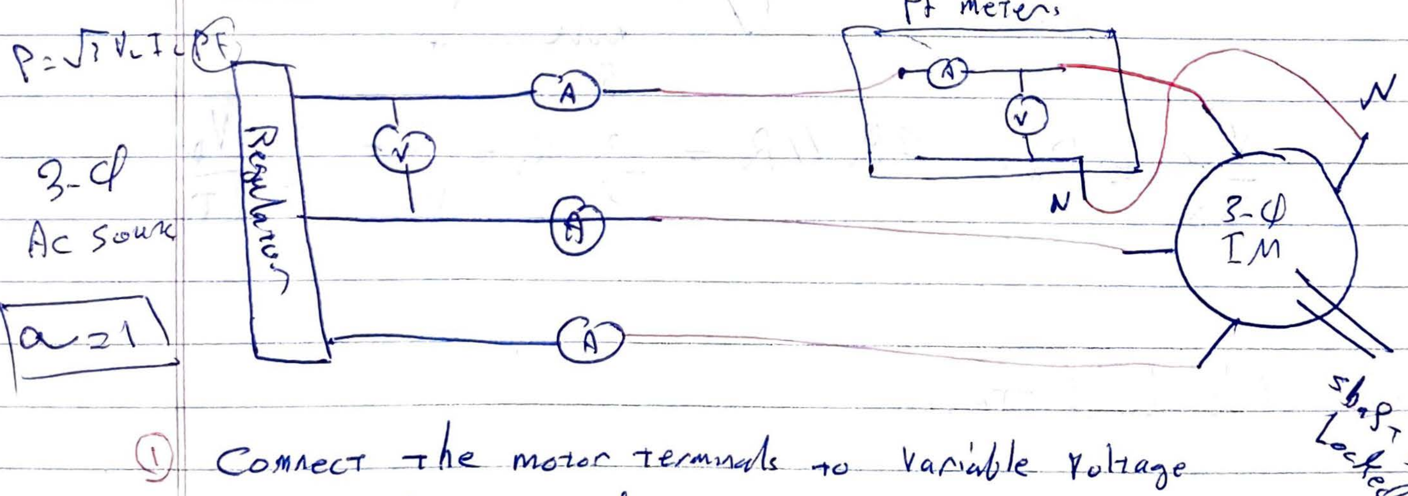
$$\frac{V_L/\sqrt{3}}{I_L} \approx X_s + X_m$$

Note: when the motor is unloaded ⇒ $a$ is very small

⇒ $\frac{R_r'}{a}$ is very high.

⇒ $I_r' \approx 0$

## 3 Locked rotor test




1. Connect the motor terminals to variable voltage variable frequency drive.

∴ $\frac{R_r'}{a}$ is very small ex. branch ignored

$f_r = a f_e$ ( The $f_r$ must be small always ) since $a=1$ its a problem.

② Set initially the motor voltage to zero and then increase it gradually

③ Adjust the motor frequency to be equal to 25% of rated frequency

④ Adjust the motor current to be equal to the motor's rated current

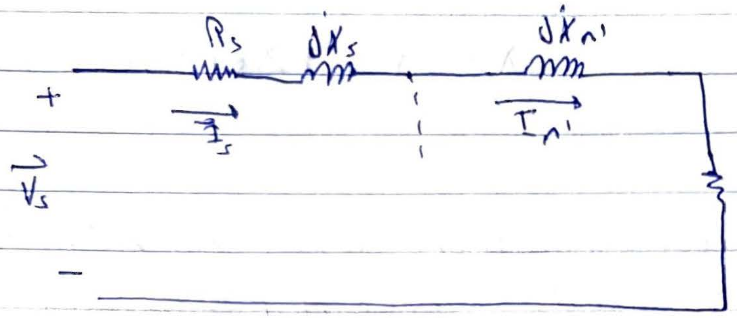
⑤ Measure $V_L$, $I_A$, $I_A$ & $I_C$

⑥ estimate $I_L = \frac{(I_A + I_B + I_C)}{3}$

⑦ Measure the power factor, PF

Notes: Since, the shaft is locked $\Rightarrow \sigma = 1 \Rightarrow \frac{R_r'}{\sigma}$ is very small

$\Rightarrow \vec{I}_s \approx \vec{I}_{r'}$





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$$\frac{V_L/\sqrt{3}}{I_L} = |Z_{LR}|$$

$$\Theta_{LR} = \cos^{-1}(PF)$$

$$Z_{LR} = (R_s + R_{r'}) + j(X_s + X_{r'}) \cdot \frac{f_{rated}}{f_{Test}}$$

$$|Z_{LR}| \cos \Theta_{LR} = R_s + R_{r'}$$

$$|Z_{LR}| \sin \Theta_{LR} = (X_s + X_{r'}) \cdot \frac{\cancel{f_{rated}}\ f_{Test}}{\cancel{f_{rated}}\ f_{Test}}$$

$\cdot \frac{f_{Test}}{f_{rated}}$

| Rotor design | $X_s$ | $X_{r'}$ |
|---|---|---|
| Wound rotor | $0.5\ X_{LR}$ | $0.5\ X_{LR}$ |
| Design A | $0.5\ X_{LR}$ | $0.5\ X_{LR}$ |
| Design B | $0.4\ X_{LR}$ | $0.6\ X_{LR}$ |
| Design C | $0.3\ X_{LR}$ | $0.7\ X_{LR}$ |
| Design D | $0.5\ X_{LR}$ | $0.5\ X_{LR}$ |

## Conclusion

DC Test $\longrightarrow$ $R_s = \dfrac{V_{DC}}{2 I_{DC}}$

No-load Test $\longrightarrow$ $\dfrac{V_L / \sqrt{3}}{I_L} = X_s + X_m$

Locked-rotor Test $\longrightarrow$ $R_r' + R_s = |Z_{LR}| \cos \theta_{LR}$

$$X_r' + X_s = |Z_{LR}| \sin \theta_{LR} \cdot \frac{f_{rated}}{f_{test}}$$

$$|Z_{LR}| = \frac{V_L / \sqrt{3}}{I_L}$$

Example: The following test data were taken on a 7.5 hp 4 pole, 208 V, 60 Hz, design A, Y-connected induction motor having a rated current of 28 A.

DC test

$V_{DC} = 13.6\,V$
$I_{DC} = 28\,A$

No load test

$V_L = 208\,V$
$I_A = 8.12\,A$
$I_B = 8.2\,A$
$I_C = 8.18\,A$

$f = 60\,Hz$

$$I_L = \frac{I_{A+B+C}}{3} = 8.17\,A$$

Locked test

$V_L = 25\,V$
$I_A = 28.1$
$I_B = 28.0\,A$
$I_C = 27.6\,A$

$I_L = 27.9\,A$

$f = 15\,Hz$
$PF = 0.762$

Draw the equivalent circuit?

Solution $R_s = \frac{V_{DC}}{2 I_{DC}} = \frac{13.6}{(2)(28)} \Rightarrow \boxed{R_s = 0.243\ \Omega}$ [from DC Test]

$R_s + R_r' = |Z_{LR}| \cos\theta_{LR}$ [from Locked Test]

$(X_s + X_r') \cdot \frac{f_{test}}{f_{rated}} = |Z_{LR}| \sin\theta_{LR}$

$|Z_{LR}| = \frac{25/\sqrt{3}}{27.9} = 0.517\ \Omega$, $\theta_{LR} = \cos^{-1}(PF) = \cos^{-1}(0.762) = 40.4°$

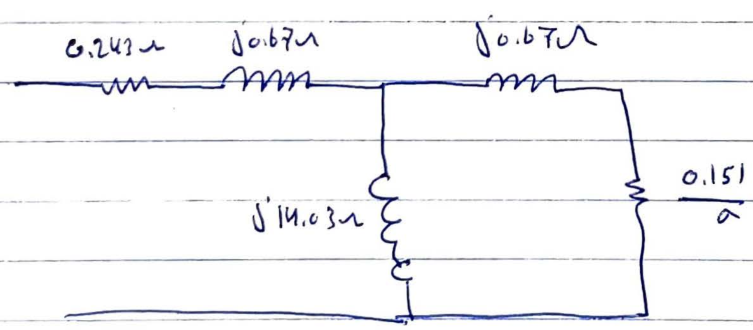
$(0.517)\cos(40.4°) = 0.243 + R_r' \Rightarrow \boxed{R_r' = 0.151\ \Omega}$

$(0.517)\sin(40.4) = (X_s + X_r')\left(\frac{15}{60}\right)$

$X_s + X_r' = 1.34\ \Omega \Rightarrow$ Design A $\Rightarrow$ $\boxed{\begin{array}{l} X_s = 0.67\ \Omega \\ X_r' = 0.67\ \Omega \end{array}}$

$\frac{V_L/\sqrt{3}}{I_L} = X_s + X_m$ [from No Load Test]

$\Rightarrow \boxed{X_m = 14.03\ \Omega}$




questions to solve are 1, 3, 4, 5, 6, 8, 10, 12, 15, 16, 23, 26, 27, 28.