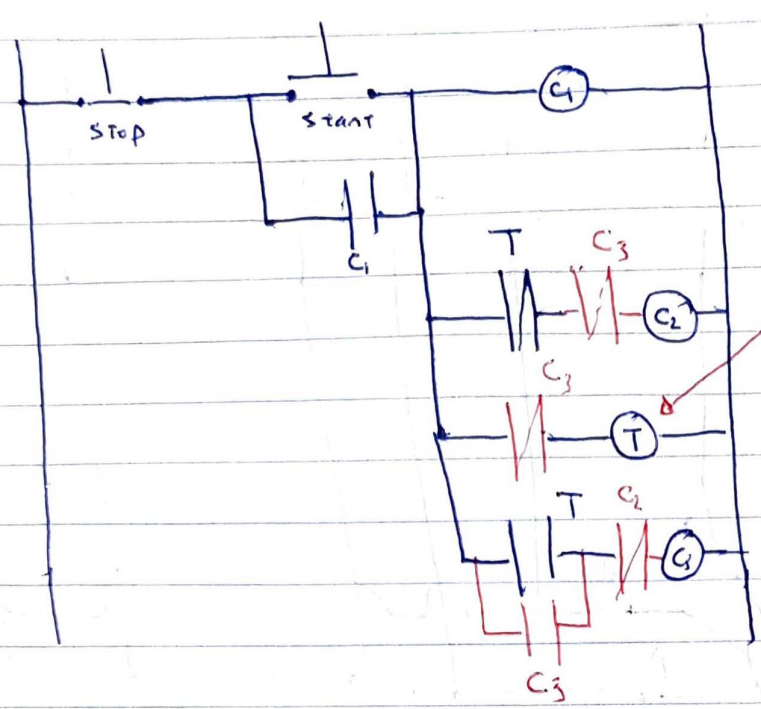


idea

Control circuit for $\star$ - Δ starter



coil of timer
when it is energized
the contacts of timer
will change their state
after preset time
or delay time

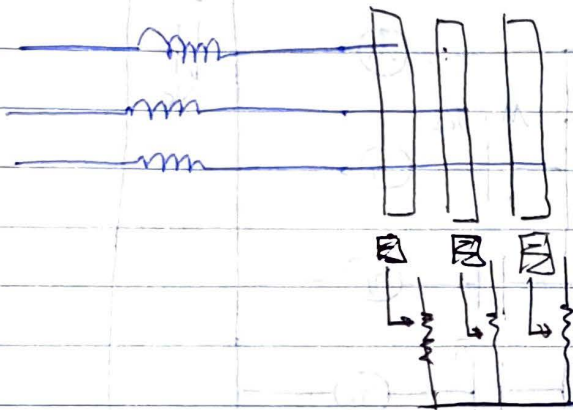
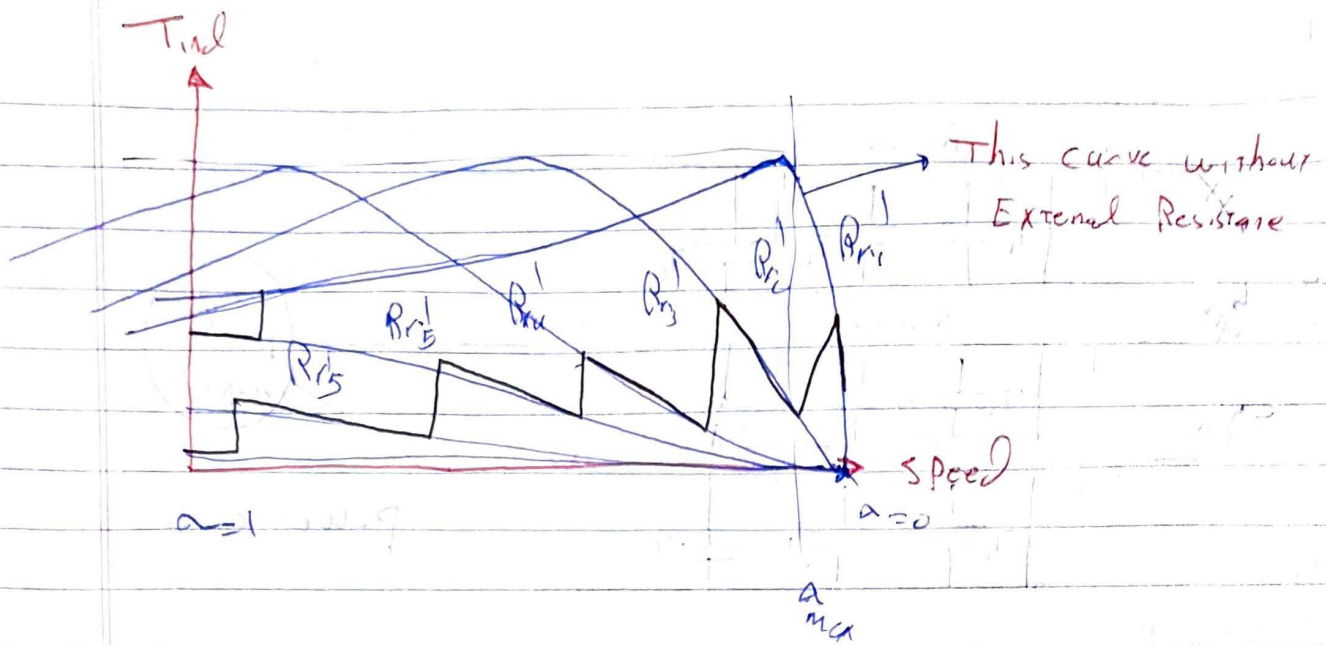
* Red Parameters using for Remove the Timer coil when it is at Δ

* Try to add Reversed switch

② changing the rotor resistance "wound rotor induction machine"

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

$$\cos \phi_{max} = \frac{R_{r'}}{\sqrt{R_{th}^2 + (X_{th} + X_{r'})^2}}$$



$$R'_6 > R'_5 > R'_4 > R'_3 > R'_2 > R'_1$$

$$R'_1 \uparrow \Rightarrow R_{rel} \uparrow \Rightarrow \gamma_{mora} \downarrow \Rightarrow \gamma_r = (1 - \alpha) \downarrow$$

③ States of Induction Motors

- ① V-D state ② Rotor resistor state "Wound Rotor"

- ③ Stator Resistor on Induction Starter &c

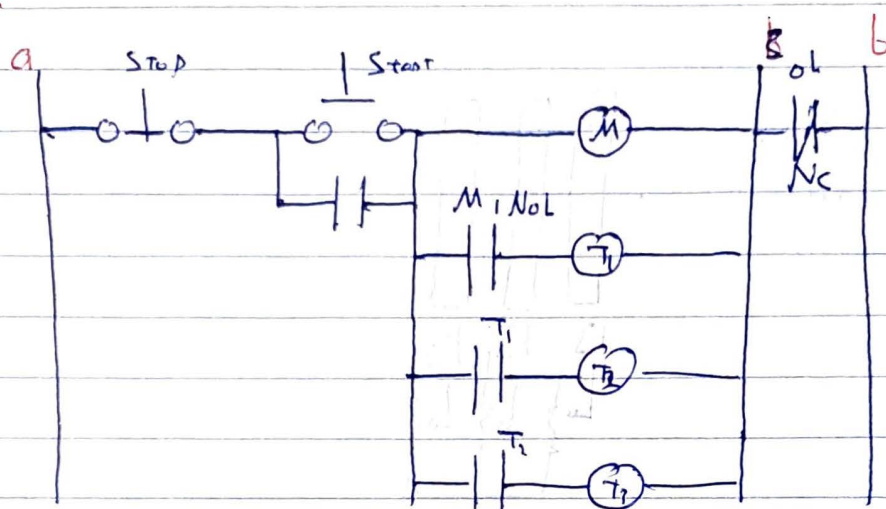
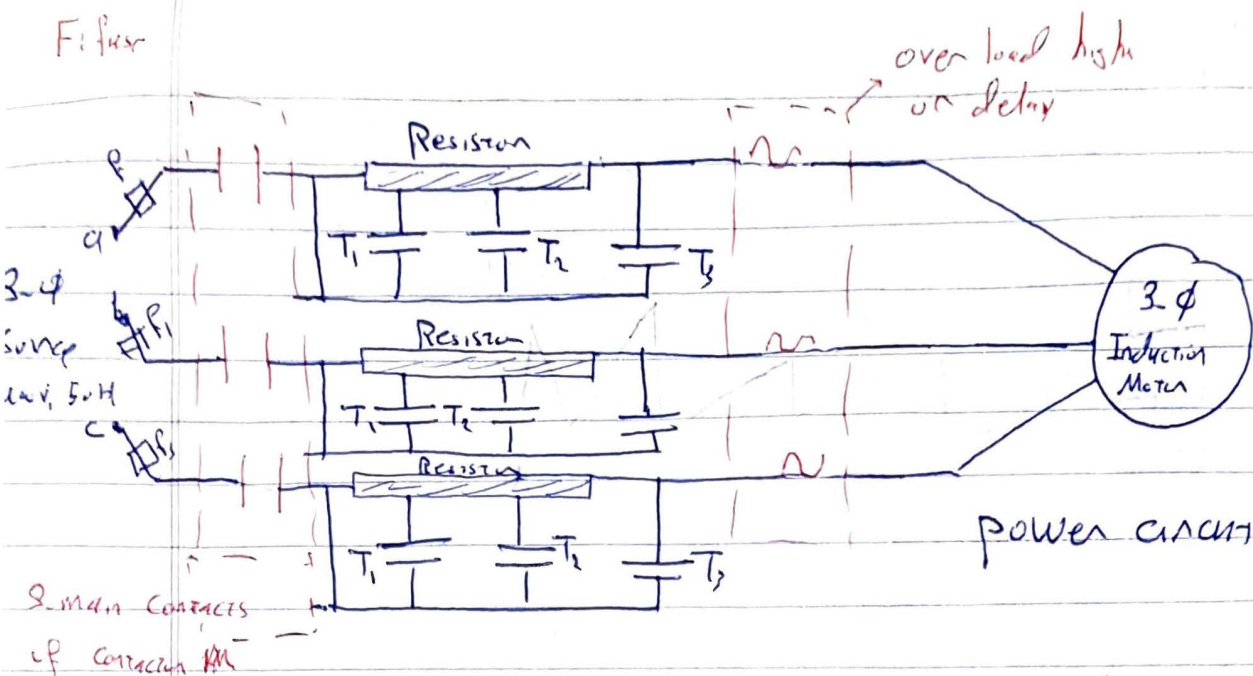
$$T_{ind} = \frac{3 V_{th}^2 \cdot \frac{R'_1}{\alpha}}{\omega_s \left[\left(\frac{R'_1}{\alpha} + R_{th} \right)^2 + (X_{th} + X'_1)^2 \right]} \quad ; \quad T_{start} = T_{ind} |_{\alpha=1}$$

$$R_{th} = \left(\frac{X_m}{\omega_s} \right) \cdot R_s \approx R_s$$

$$X_{th} = X_s$$

$$\Rightarrow R_s \uparrow \Rightarrow R_{th} \uparrow \Rightarrow T_{start} \downarrow$$

Figure



T_1, T_2, T_3 are three delay times operating in 3 stops

* Protective Features

- ① short circuit protection $\Rightarrow$ Fuses
- ② Under voltage protection
- ③ over Load protection

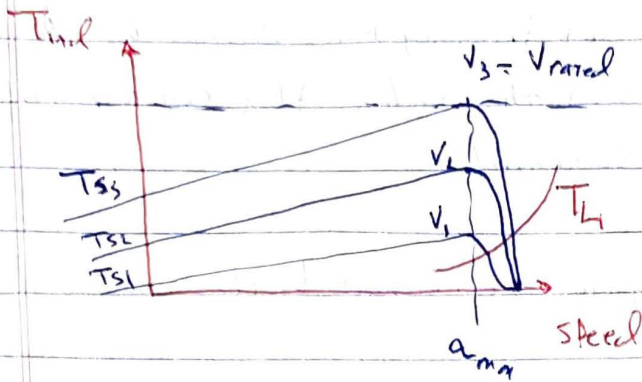
F_1, F_2, F_3 are 3 Fuses to protect the motor from the short circuit faults.

④ Autotransformer 'VARIAc'.

$$T_{ind, start} = \frac{3 V_{th}^2}{\omega_s [(R_{th} + R_{al})^2 + (X_{th} + X_{al})^2]}$$

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

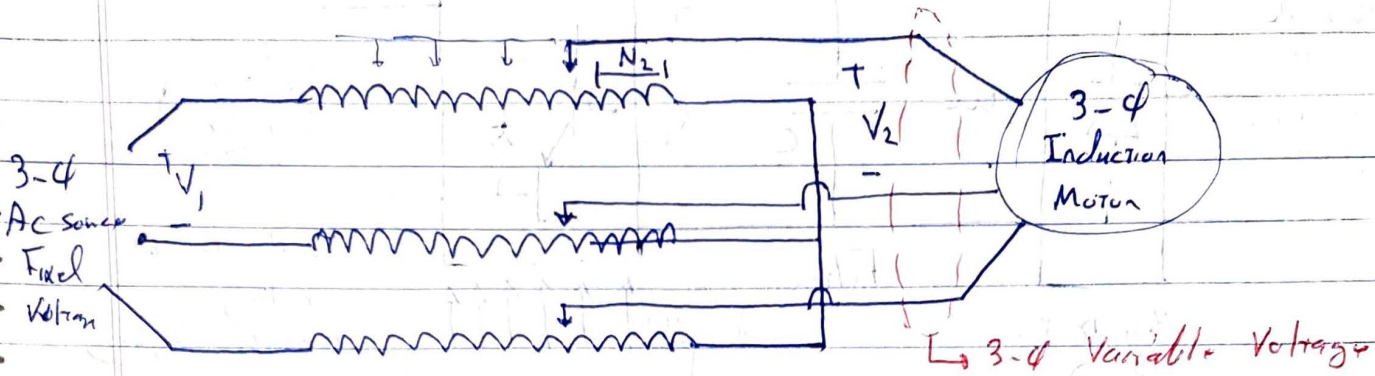
$$I_{max} = \frac{R_{al}}{\sqrt{R_{th}^2 + (X_{th} + X_{al})^2}} = \text{Constant} \left[\frac{V_{th}}{V_s} \right]$$



$$V_1 < V_2 < V_3$$

$$T_{S1} < T_{S2} < T_{S3}$$

The motor voltage is controlled using the auto transformer

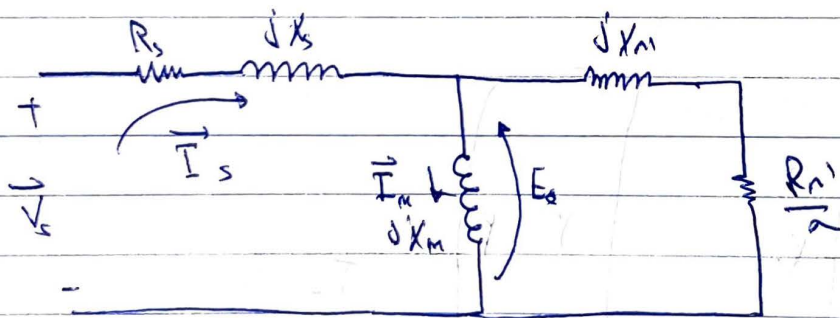


$$V_2 = \frac{N_2}{N_1} V_1 = \frac{V_1}{a_t} \quad \text{where } a_t > 1$$

↳ Turned Ratio

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

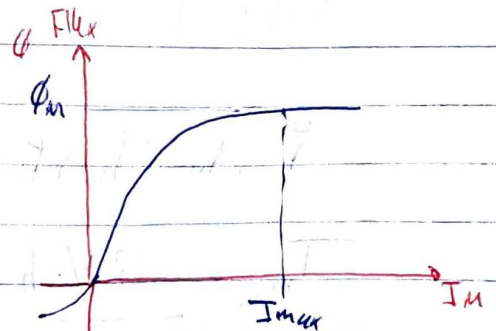
⑤ Variable Voltage Variable Frequency Drive (VVVF Drive)



Flux linkages,

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

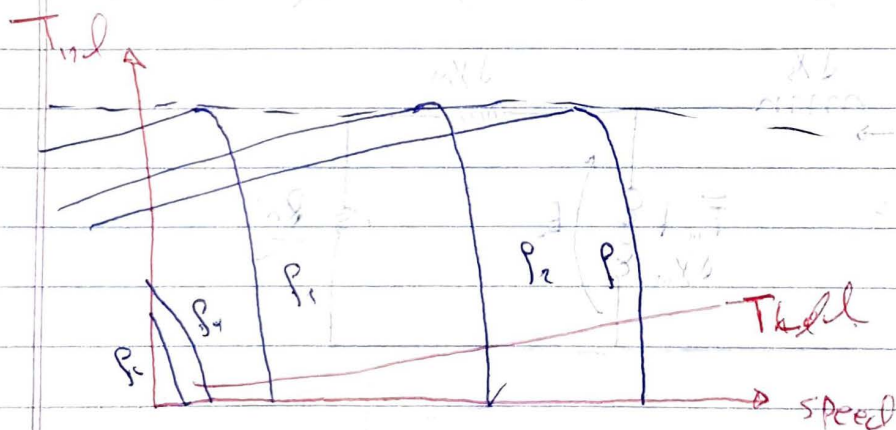
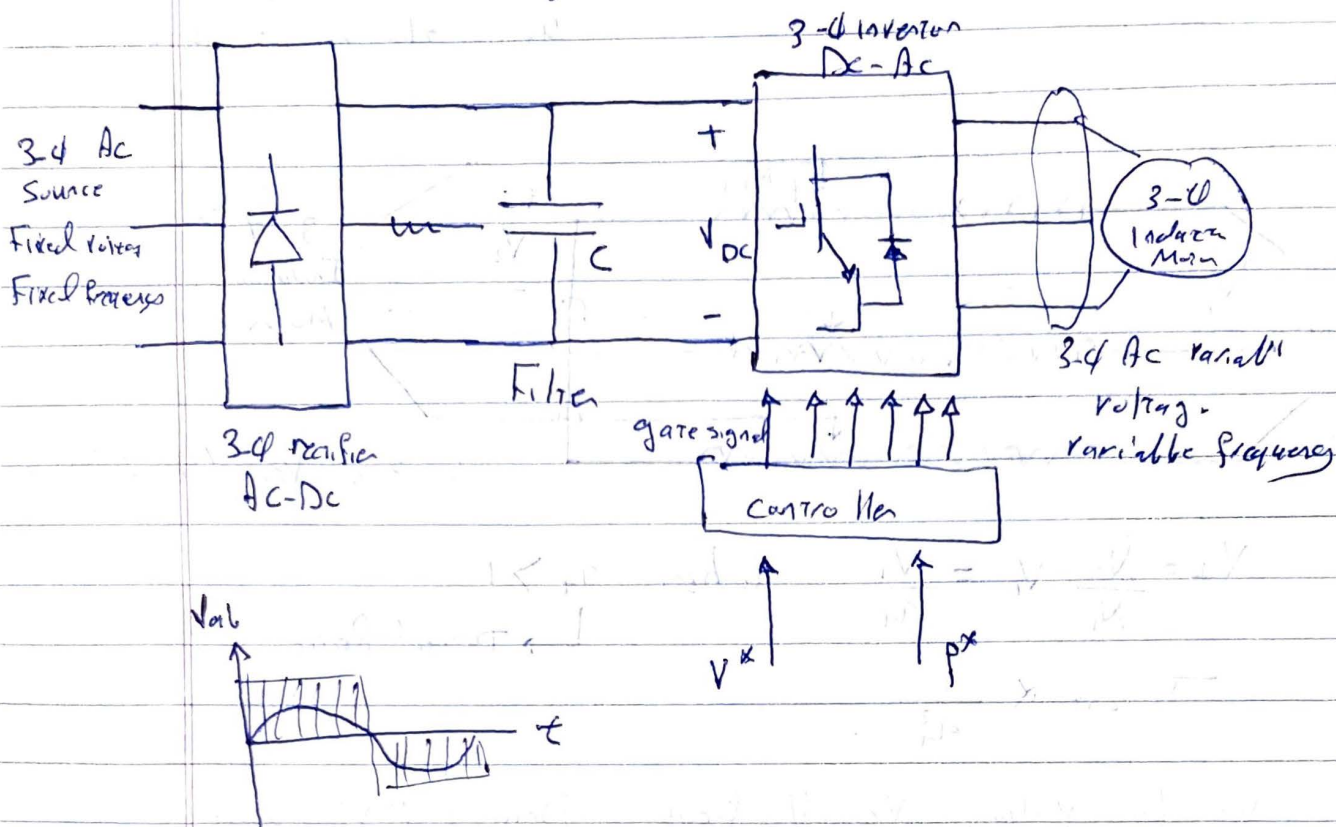
$$\phi_m = L_m \left(\frac{E}{\omega_e L_m} \right) = \frac{E}{\omega_e} = \frac{E}{2\pi f_e}$$



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

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

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



$$P_5, P_4, P_3, P_2, P_1$$

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

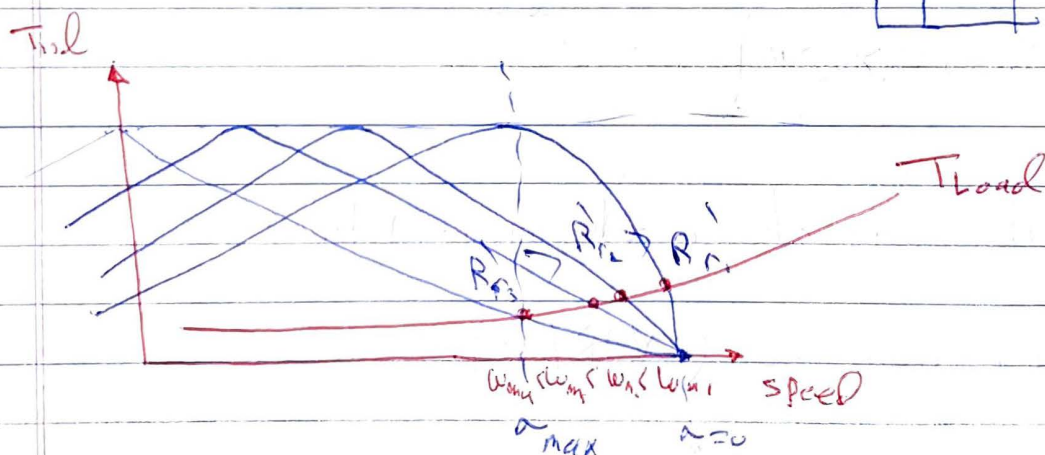
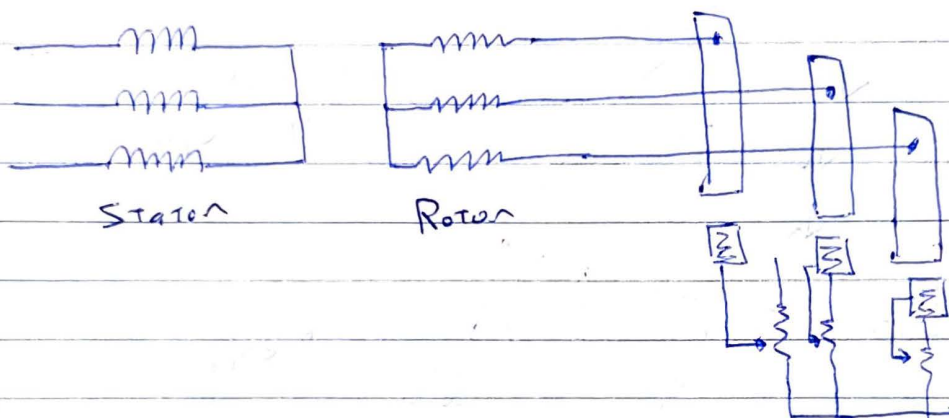


Speed control of Induction Motor

① changing the Rotor resistance [wound rotor resistance]

$$T_{\max} = \frac{3 V_{Th}^2}{2 \omega_s [R_s + \sqrt{R_s^2 + X_{eq}^2}]} \quad ; \quad X_{eq} = X_r + X_s$$

$$a_{max} = \frac{R_a'}{\sqrt{R_s^2 + X_{eq}^2}}$$



$R_i \uparrow \Rightarrow W_m \downarrow \Rightarrow a \uparrow \Rightarrow Y_n = (1-a) \downarrow$
 Advantage Disadvantage

- Using variable resistors
 - Using Power Converter
- ⇒ How change R_{in}

Imp. ppts

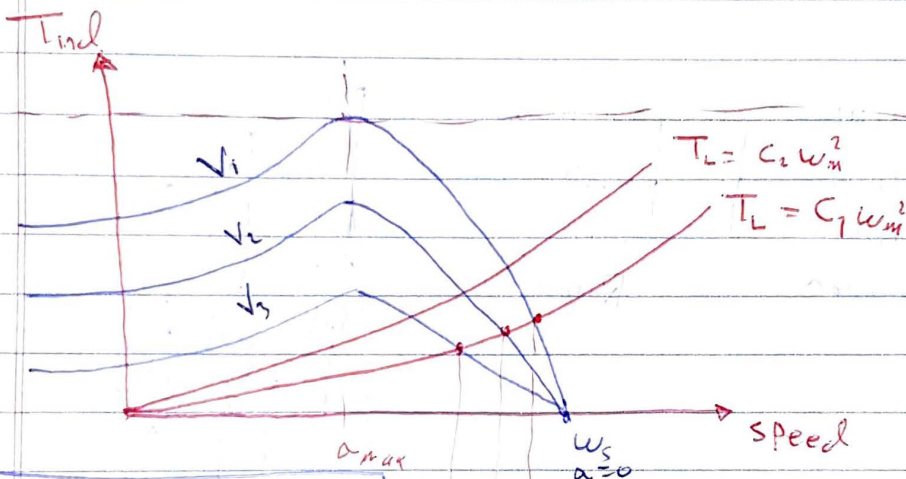
②. Changing the line Voltage [Project]

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

$$\lambda_{max} = \frac{R'_a}{\sqrt{R_s^2 + X_{eq}^2}} = \text{Constant}$$

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

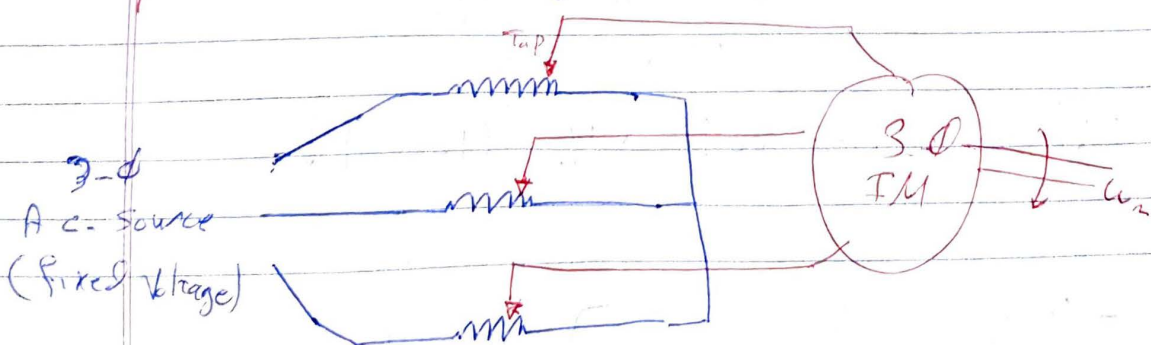
$$\Rightarrow \alpha \uparrow \Rightarrow \underbrace{(4_p = 1 - \alpha)}_{\text{Disadvantage}} \downarrow$$



$$V_1 > V_2 > V_3 \Rightarrow \omega_{m1} > \omega_{m2} > \omega_{m3}$$

③ Method, to change the motor Voltage

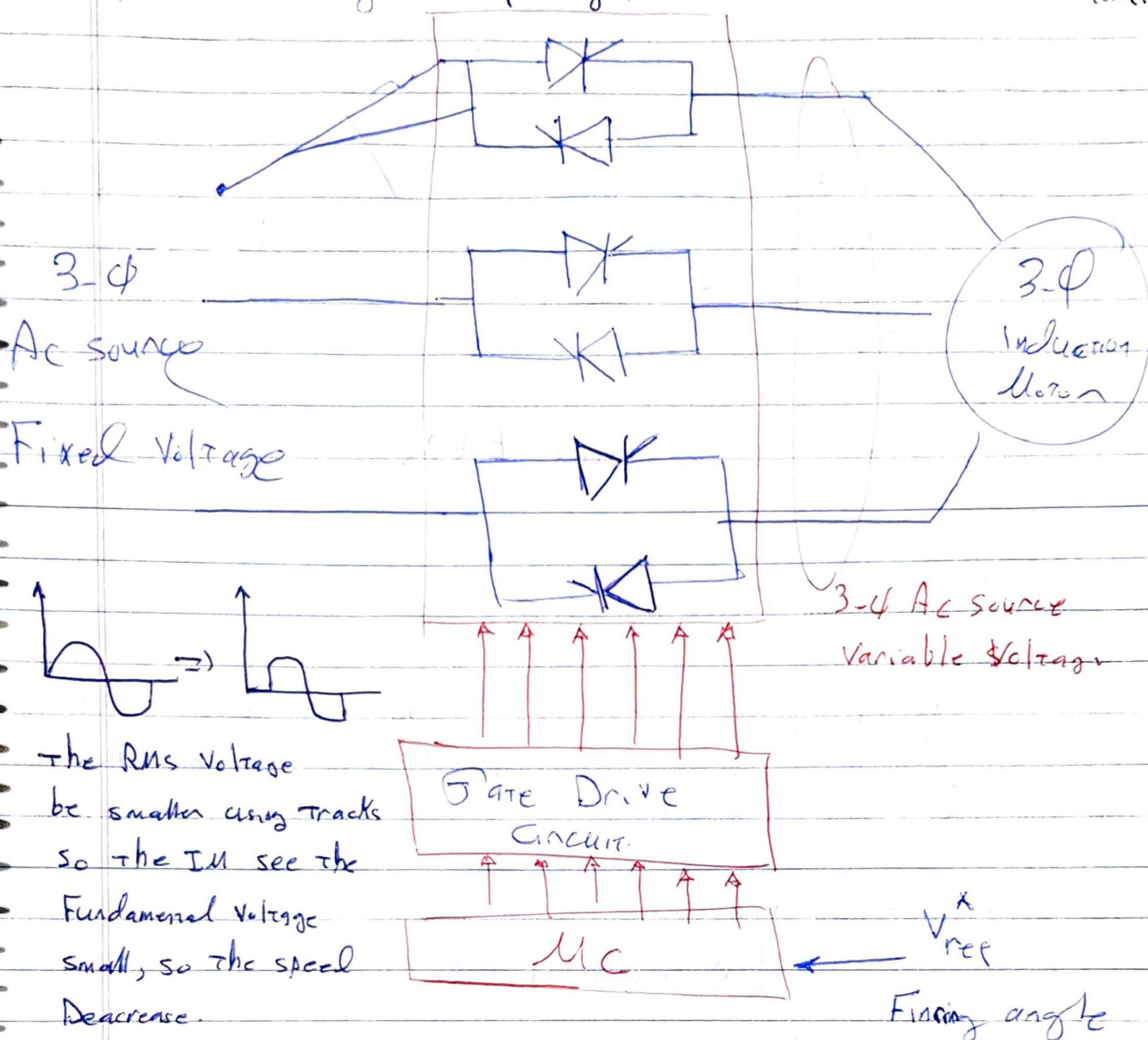
1) Auto-Transformer (VAR/AC)



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

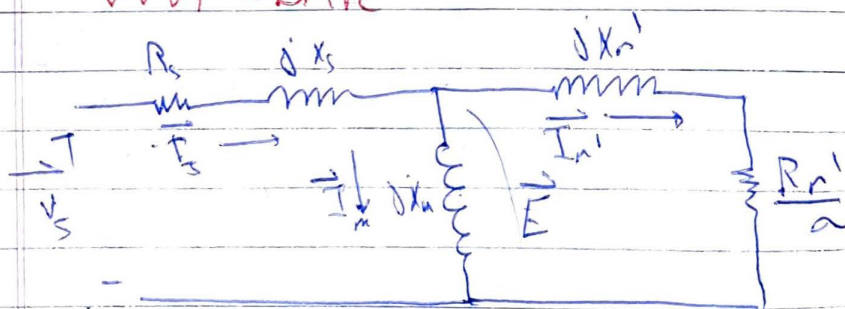


because you
guarantee
direction
for (H2C)



3) Variable Voltage Variable Frequency Drive

VVVF-Drive



⊙ speed controlled by Flux

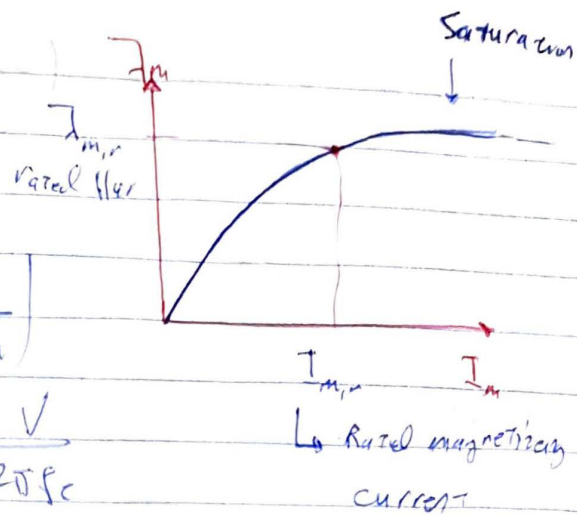
Flux linkage

$$\lambda_m = L_m I_m$$

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

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

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



when $\omega_m < \text{rated speed} \Rightarrow$

The frequency and voltage must be changed by the same factor to keep λ_m constant and not let it saturate

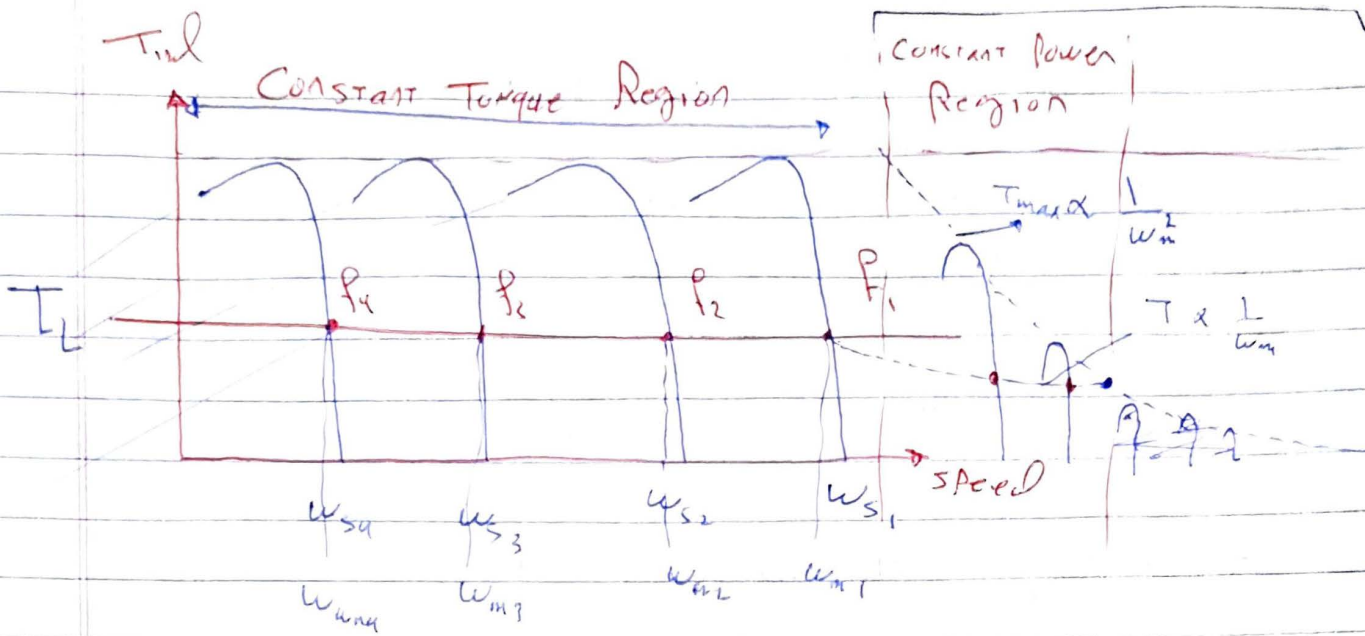
$$T_{max} = \frac{3 V_{th}^2}{2\omega_s [R_s + \sqrt{R_s^2 + X_{eq}^2}]}$$

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

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

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

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



$$P_1 > P_2 > P_3 > P_4 \Rightarrow \omega_{m4} > \omega_{m3} > \omega_{m2} > \omega_{m1}$$

(Rated frequency)

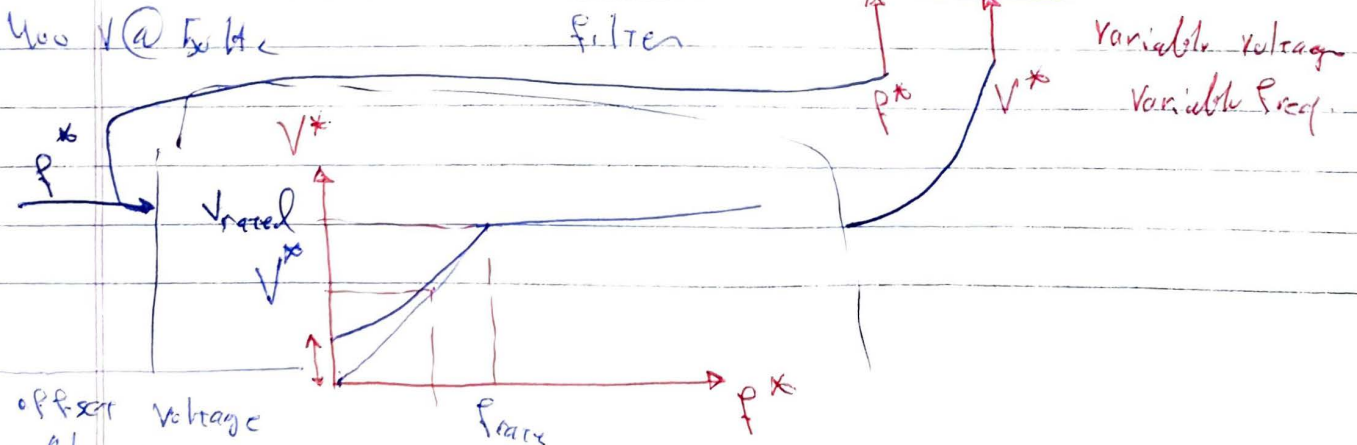
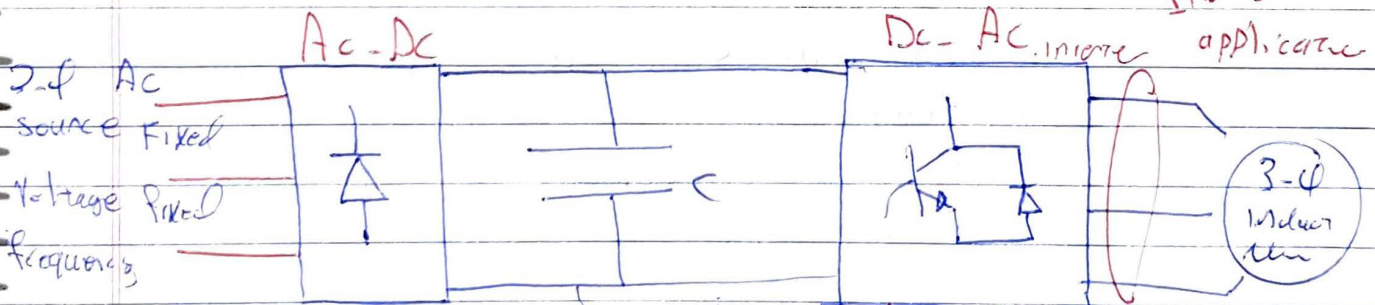
when $\omega_m >$ Rated speed

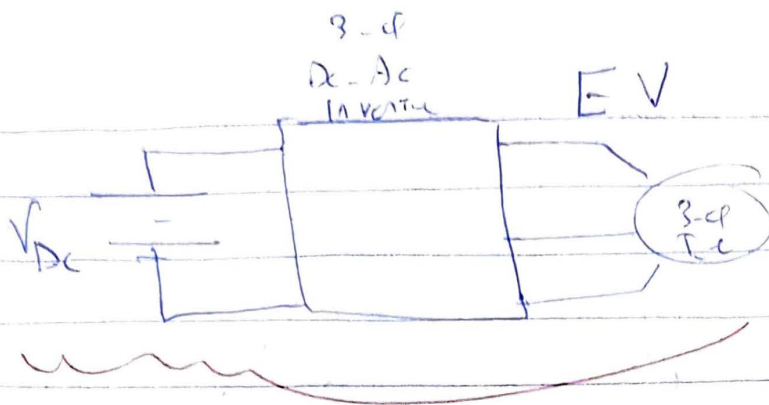
$$\Rightarrow V = V_{rated}$$

$$\Rightarrow T_{max} \propto \frac{1}{\omega_{m2}} \propto T \propto \frac{1}{\omega_m}$$

$$P_m = T_L \omega_m = \text{rated power}$$

Device Make this steps





Electrical vehicles

④ changing the number of poles

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

4.1) Method of consequent pole, In this method the number of poles is changed by the ratio of 1:2 via simple switching operation

⇒ V_m is connected by the ratio of 1:2

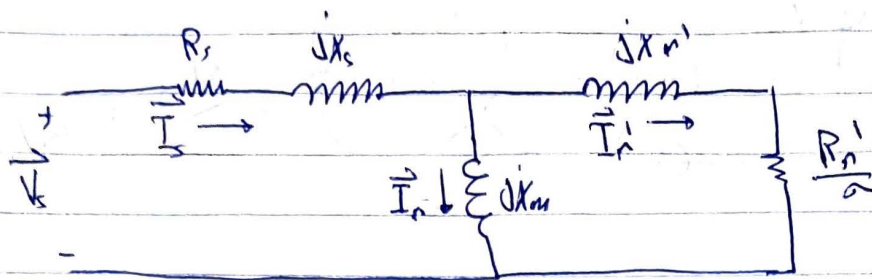
4.2) Multiple stator windings;

→ multiple stator windings with different number of poles

→ only one stator winding is energized at a time

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

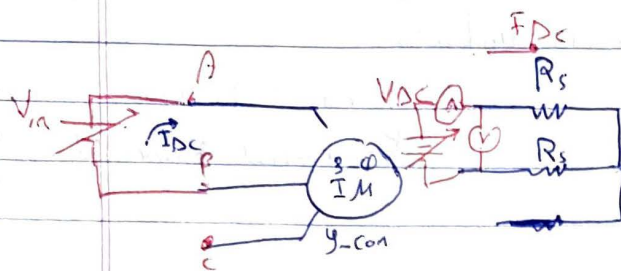
Determining the Parameters of Induction motor.



3 tests

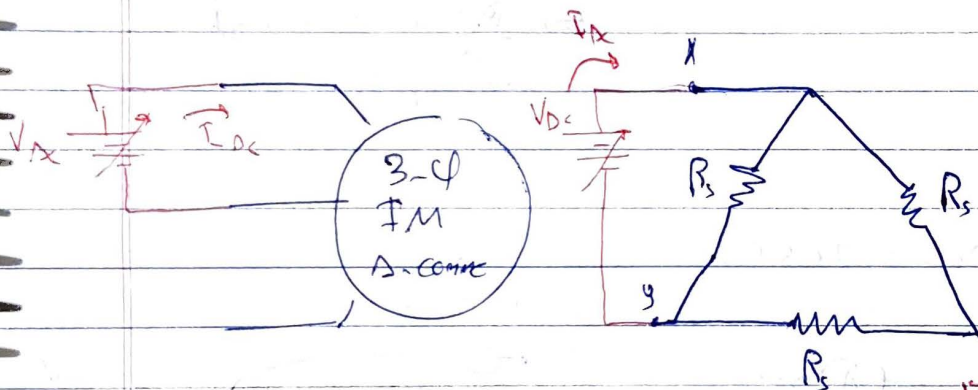
- ① Dc test
- ② No Load Test
- ③ Locked rotor Test

① Dc Test



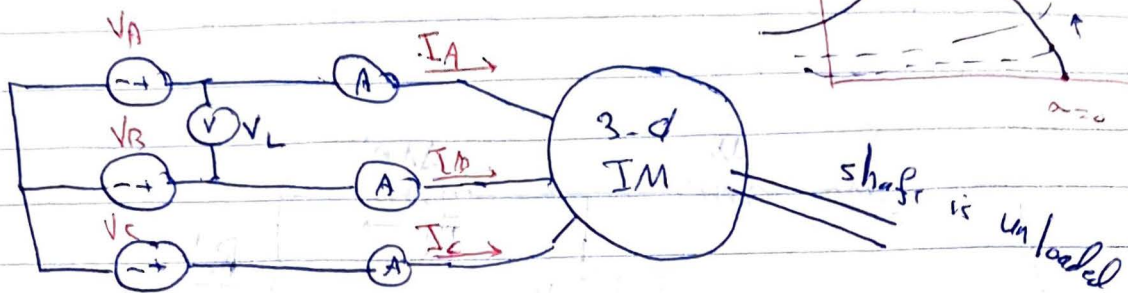
Y-Connected

- ① adjust the current in the stator windings to be equal to motor rated current
- ② Measure V_{dc} & I_{dc} , calculate $R_s \Rightarrow R_s = \frac{V_{dc}}{2 I_{dc}}$



$$\frac{V_{dc}}{I_{dc}} = R_{X\Delta} = 2R_s \text{ or } R_s = \frac{2}{3} R_s \Rightarrow R_s = \frac{3}{2} \frac{V_{dc}}{I_{dc}}$$

② No Load Test



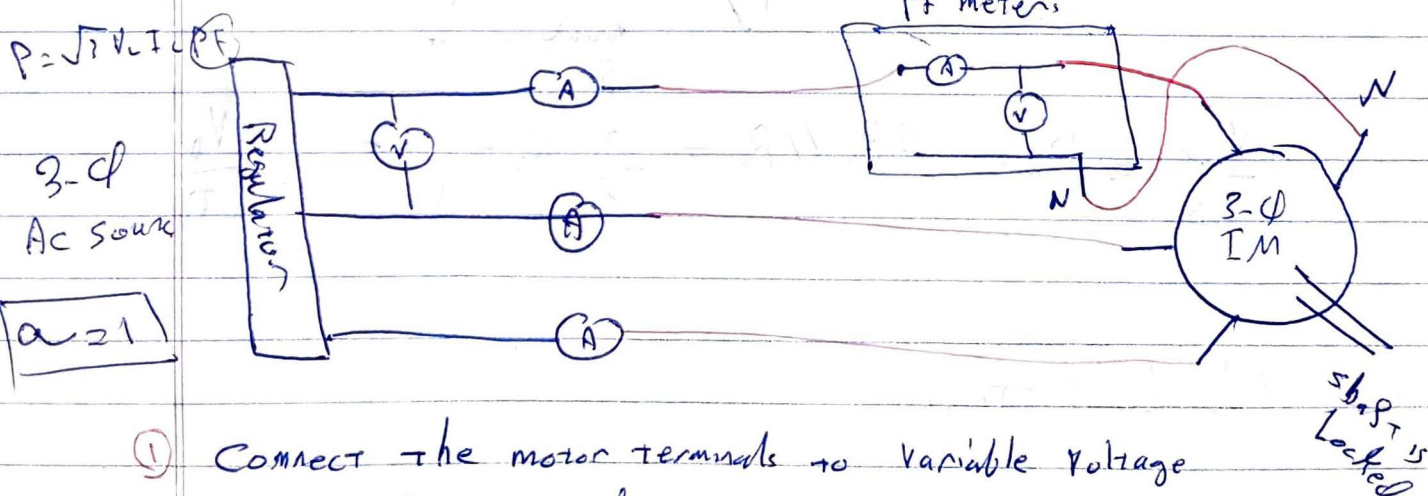
$|V_A| = |V_B| = |V_C| = \text{motor-rated voltage}$
 frequency = rated frequency

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

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

Note: when the motor is unloaded $\Rightarrow \alpha$ is very small
 $\Rightarrow \frac{P_{r1}}{a}$ is very high
 $\Rightarrow I_r' \approx 0$

③ Locked rotor test

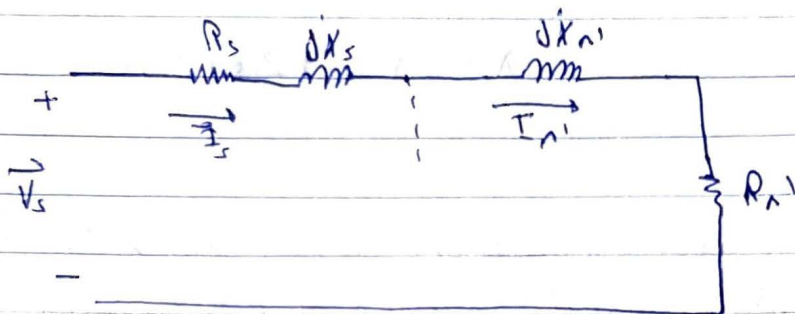


- ① Connect the motor terminals to variable voltage
 variable frequency drive.

$P_r = a P_e$ (The P_r must be small always) since $a=1$ is 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_B & I_C
- ⑥ estimate $I_L = (I_A + I_B + I_C)$
- ⑦ Measure the power factor, PF

Note: Since the shaft is locked $\Rightarrow \alpha = 1 \Rightarrow \frac{P_r}{a}$ is very small
 $\Rightarrow \vec{I}_s \approx \vec{I}_r$



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

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

$$Z_{LR} = (R_s + R_r') + j(X_s + X_r') \cdot \frac{P_{rated}}{P_{test}}$$

$$|Z_{LR}| \cos \theta_{LR} = R_s + R_r'$$

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

ROTOR design

	X_s	X_r'	$\frac{P_{test}}{P_{rated}}$
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

$$\text{DC Test} \rightarrow R_s = \frac{V_{DC}}{2I_{DC}}$$

$$\text{No-load Test} \rightarrow \frac{V_L / \sqrt{3}}{I_L} = X_s + X_m$$

$$\text{Locked-rotor Test} \rightarrow R'_r + R_s = |Z_{LR}| \cos \theta_{LR}$$

$$X'_r + X_s = |Z_{LR}| \sin \theta_{LR} = \frac{P_{rated}}{P_{test}}$$

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

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

$$V_{DC} = 13.6 \text{ V}$$

$$I_{DC} = 28 \text{ A}$$

No load test

$$V_L = 208 \text{ V}$$

$$I_A = 8.12 \text{ A}$$

$$I_B = 8.2 \text{ A}$$

$$I_C = 8.18 \text{ A}$$

$$P = 60 \text{ W}$$

$$I_L = \frac{I_A + I_B + I_C}{3} = 8.17 \text{ A}$$

Locked test

$$V_L = 25 \text{ V}$$

$$I_A = 28.1 \text{ A}$$

$$I_B = 28.0 \text{ A}$$

$$I_C = 27.6 \text{ A}$$

$$P = 15 \text{ W}$$

$$PF = 0.762$$

$$I_L = 27.9 \text{ A}$$

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

$R_s + R_n' = |Z_{LR}| \cos \theta_{LR}$ [from Locked Test]
 $(X_s + X_n') \cdot \frac{P_{TEST}}{P_{rated}} = |Z_{LR}| \sin \theta_{LR}$

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

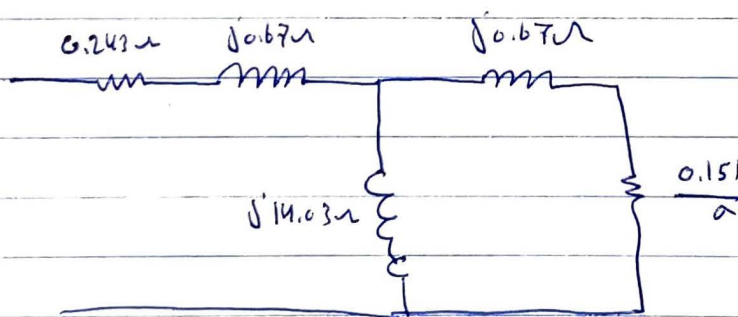
$(0.517) \cos(40.4^\circ) = 0.243 + R_n' \Rightarrow R_n' = 0.151 \Omega$

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

$X_s + X_n' = 1.34 \Omega \Rightarrow \text{Design A} \Rightarrow \begin{cases} X_s = 0.67 \Omega \\ X_n' = 0.67 \Omega \end{cases}$

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

$\Rightarrow X_m = 14.03 \Omega$



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