Synchronous Motors

→ synchronous motor converts electrical Energy into mechanical energy.

→ synchronous motor is one type of 3-ϕ AC motor which operates from No load to full load.

→ It is similar in construction to a AC Generator (or) Alternator and It is working on the same principle of 3-ϕ Induction motor i.e Rotating magnetic field (RMF) theory and magnetic locking.

characteristics :-

→ It runs at synchronous speed only $(N_S = \frac{120f}{P})$

→ the speed can be changed by changing frequency only

→ It is not self starting (Inherently not self starting)

→ It can be operated at any Power factor i.e lagging, leading & unity p.f.

→ It is a double Excited machine

→ Rotor needs D.C supply

→ synchronous motors are rated between 150KW and 15MW and runs at speeds ranging from 150 to 1800 rpm

Applications :-

→ It is used as a synchronous condensor in power generations and substations (connected in parallel with bus bars to improve power factor).

→ It is used for improving power factory

→ It is used in textile mills, mining, cement & rubber factories.

→ the constant speed equipment such as fans, blowers centrifugal pumps & motor generator sets

Dis-advantages :-

→ DC excitation is required.

→ variable speeds are not possible.

→ Not self starting.

→ Hunting problem (magentic locking)

→ They can be started under load conditions

→ under overload conditions may loose synchronism

Synchronous motor can be operated by different ways by changing their excitation.

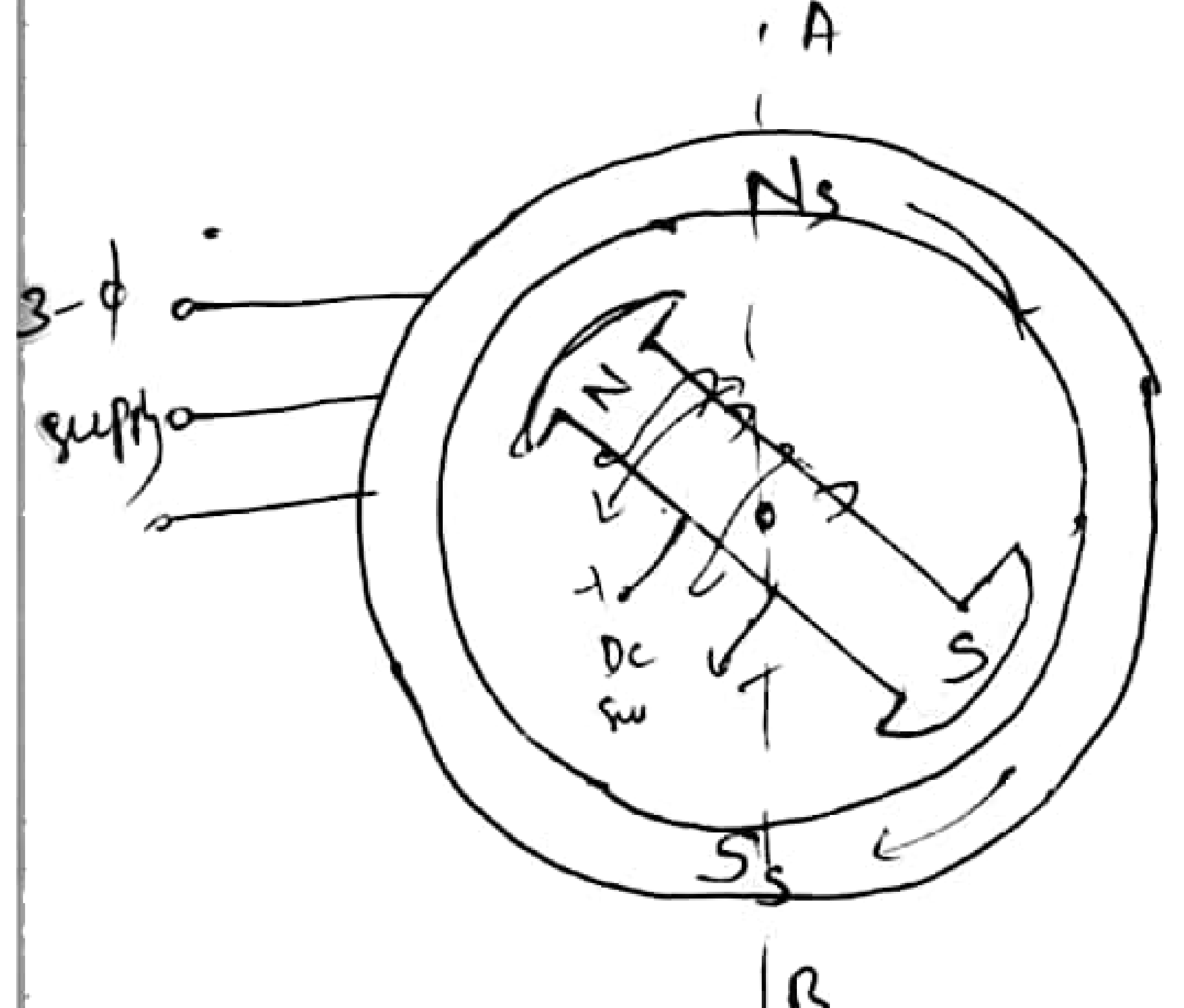
→ High cost

Why synchronous motor is not self starting :-

- It is doubly excited motor the stator is excited by a 3-ϕ AC supply and the rotor is excited by a D.C supply
- The stator produces rotating magnetic field (RMF) and the rotor produces stationary flux
- The relative speed b/w RMF and rotor flux which is called synchronous speed at the time of starting it should not be zero.
- The product of these two fluxes is not in phase and not unidirectional
- In one cycle of operation. The average torque per cycle is zero.
- The rotor is also having interia. Due to the interia of the rotor it vibrates at a fixed position instead of rotating.
- so because of all the reasons, we can say that the synchronous motor is not self starting machine.

Principle of operation:-

- when a 3-ϕ winding is fed by a 3-ϕ supply, magnetic flux of constant magnitude but rotating at synchronous speed, is produced.
- consider a two-pole stator of in which are shown two stator poles. (N_S and S_S) rotating at synchronous speed, say, in clockwise direction.



~~fig~~ fig-①

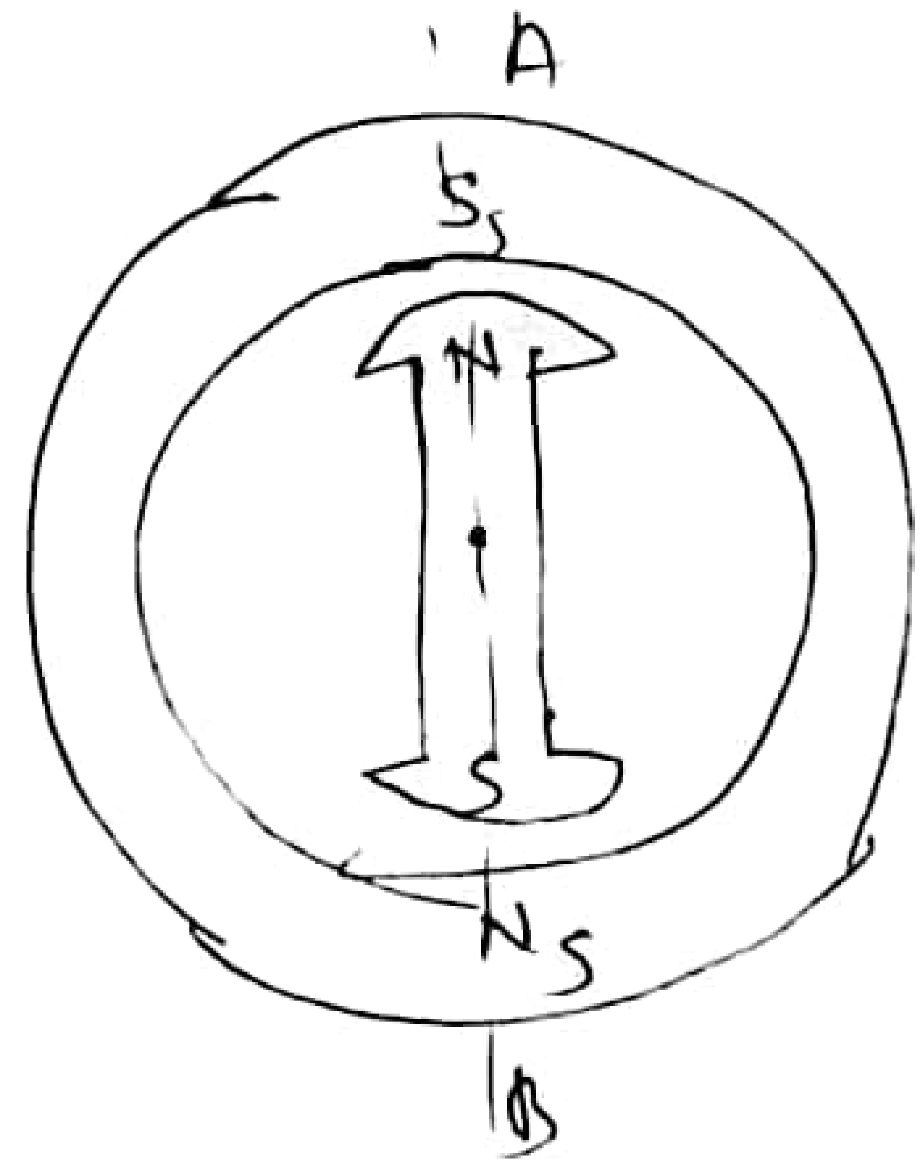


fig ②

- with the rotor position as shown, suppose the stator poles are at that instant situated at points A & B the two similar poles, N (of rotor) & N_s (of stator) as well as S and S_s will repel each other, with the result that the rotor tends to rotate in anti-clockwise direction.

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- But half a period later, stator poles, having rotated around, interchange their positions i.e N_S is at Point B & S_S at Point A.
- under these conditions N_S attracts S and S_S attracts N. Hence rotor trends to rotated clockwise (which is just the reverse of the first direction).
- Hence we find that due to continuous and rapid rotation of stator poles, the rotor is subjected to a torque which is rapidly reversing i.e, in quick succession.
- The rotor is subjected to torque which tends to move it first in one direction and then in the opposite direction.
- Owning to its large inertia, the rotor cannot instantaneously respond to such quickly-reversing torque with the result that it remains stationary.
- from the fig ② The stator and rotor poles are attracting each other.
- It means that if the rotor poles also shift their positions along with the stator poles, then they will continously experience a unidirectional torque i.e clockwise torque as shown in fig.

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COMPARISION BETWEEN SYNCHRONOUS MOTOR and INDUCTION MOTOR :

SYNCHRONOUS MOTOR	INDUCTION MOTOR.
1) construction is complicated	1) construction is simple particularly in the case of squirrel cage IM
2) It is double excited machine.	2) It is single excited machine.
3) It is not self starting	3) It is self starting..
4) It is constant speed motor	4) It is variable speed motor.
5) The speed is always synchronous speed irrespective of the load.	5) speed is always less than synchronous speed.
6) speed control is not possible.	6) speed control is possible but difficult.
7) It can be used as synchronous condensor.	7) It cannot be used as a synchronous condensor.
8) It can be operated at any pf (lagging, leading & UPF)	8) It can be operated only at lagging pf.
9) Hunting problem is present	9) Hunting problem is not present
10) It is costly and maintainance is more.	10) It is cheap and maintaince is less.

Phasor diagram of synchronous motor under No load:

i) with out L/S

$$E_{ph} \longleftarrow\!\!\longrightarrow V_{ph}$$

$$|E_b| = |V_{ph}| \Rightarrow I_{ph} = 0$$

$$E_b = 4.44\, K_p K_d f \phi T \longrightarrow (1)$$

$$E_{bph} = V_{ph} - I_a Z_s \longrightarrow (2)$$

$$V_{ph} = E_{bph} + I_a Z_s \longrightarrow (3)$$

$$I_{aph} = \frac{V_{ph} - E_{bph}}{Z_s} \longrightarrow (4)$$

$$Z_s = R_a + jX_s \longrightarrow (5)$$

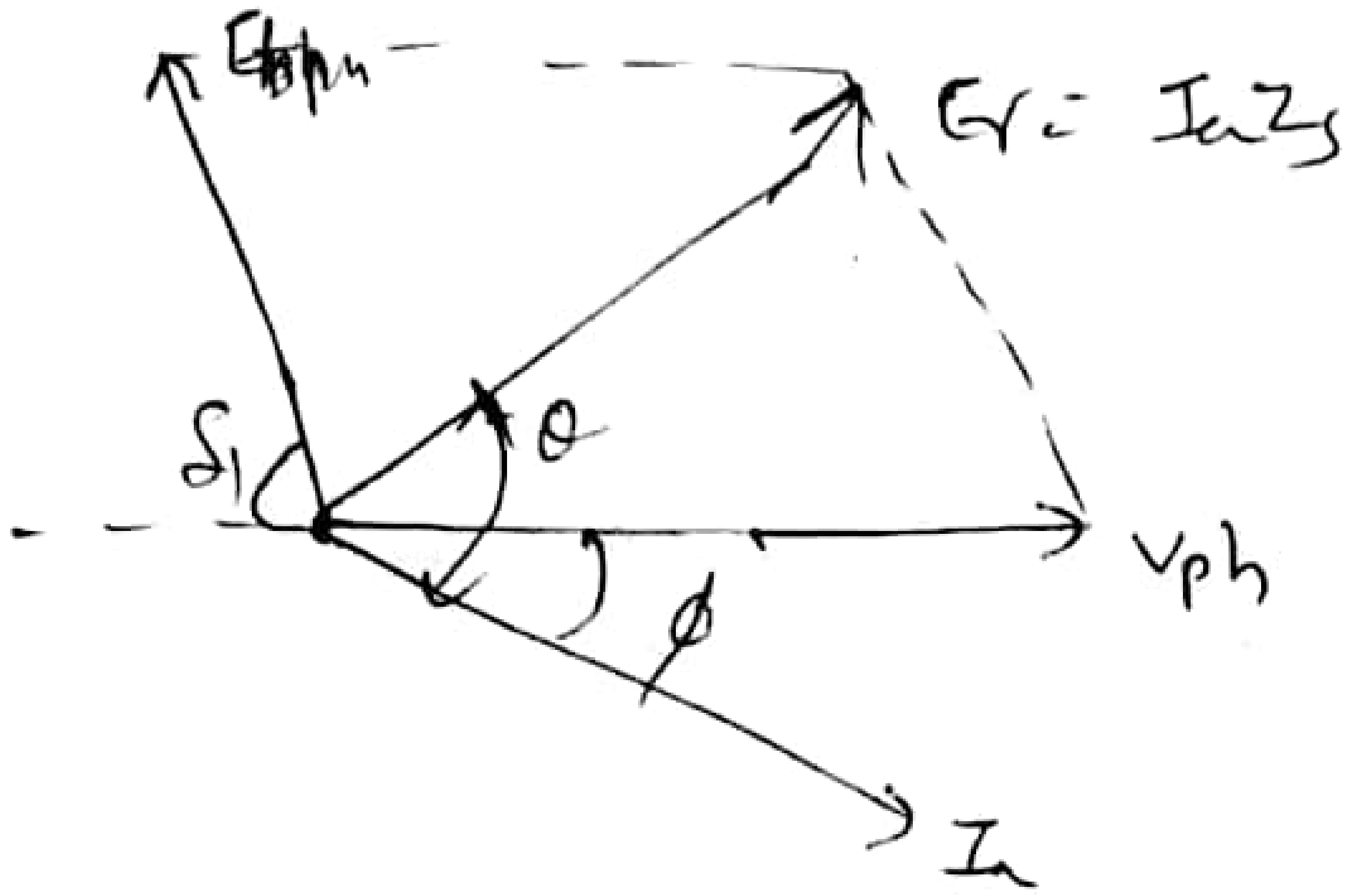
$$Z_s = \sqrt{R_a^2 + X_s^2} \;-\; (6)$$

$\therefore$ θ = Impedance angle (or) Internal p.f angle

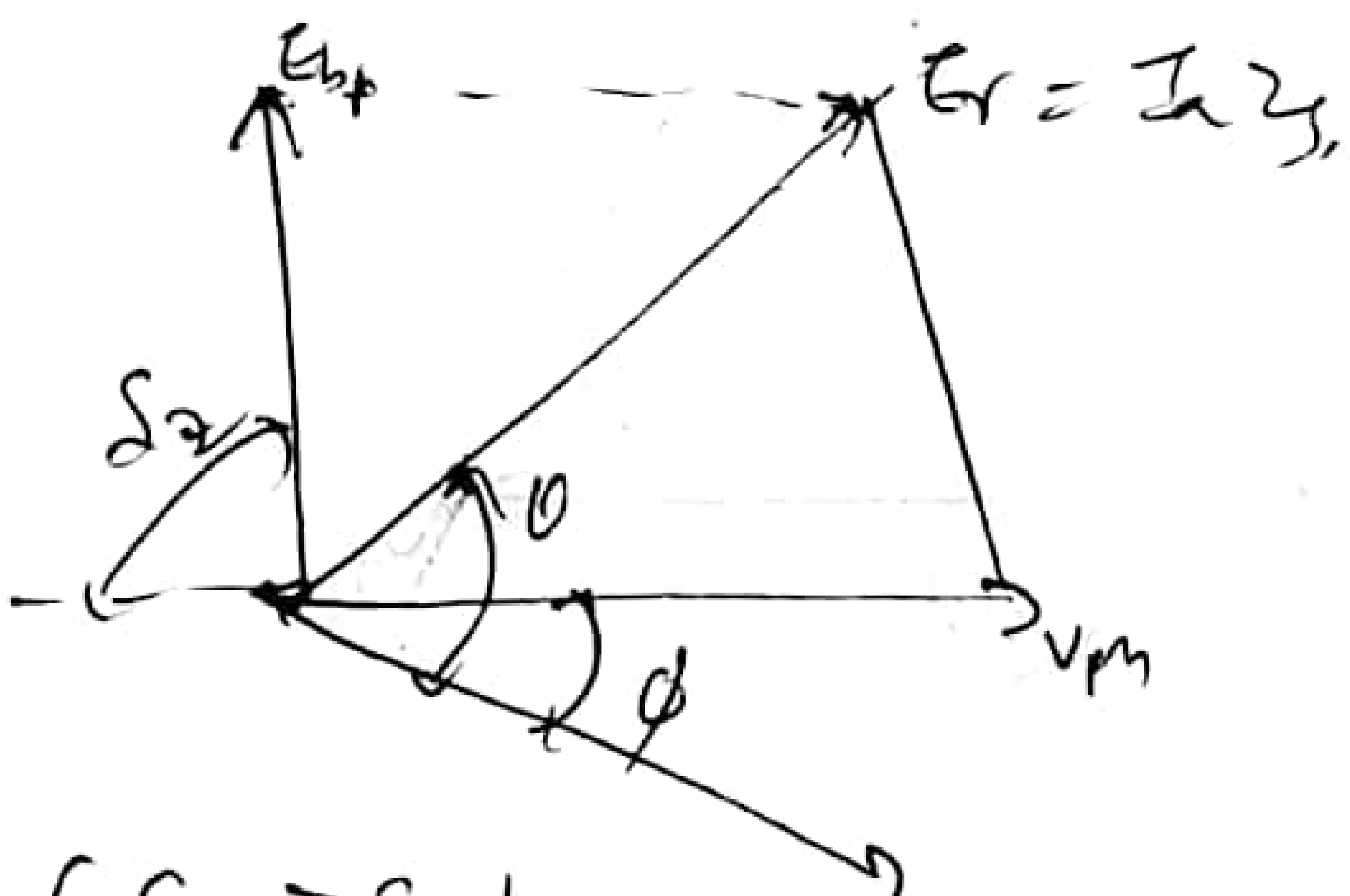
$$\theta = \tan^{-1}\left(\frac{X_s}{R_a}\right) \longrightarrow (7)$$

with losses.

i) light loads :- load angle (δ) is small



ii) Heavy loads :- load angle (δ) is more.



($\delta_2 > \delta_1$)

where

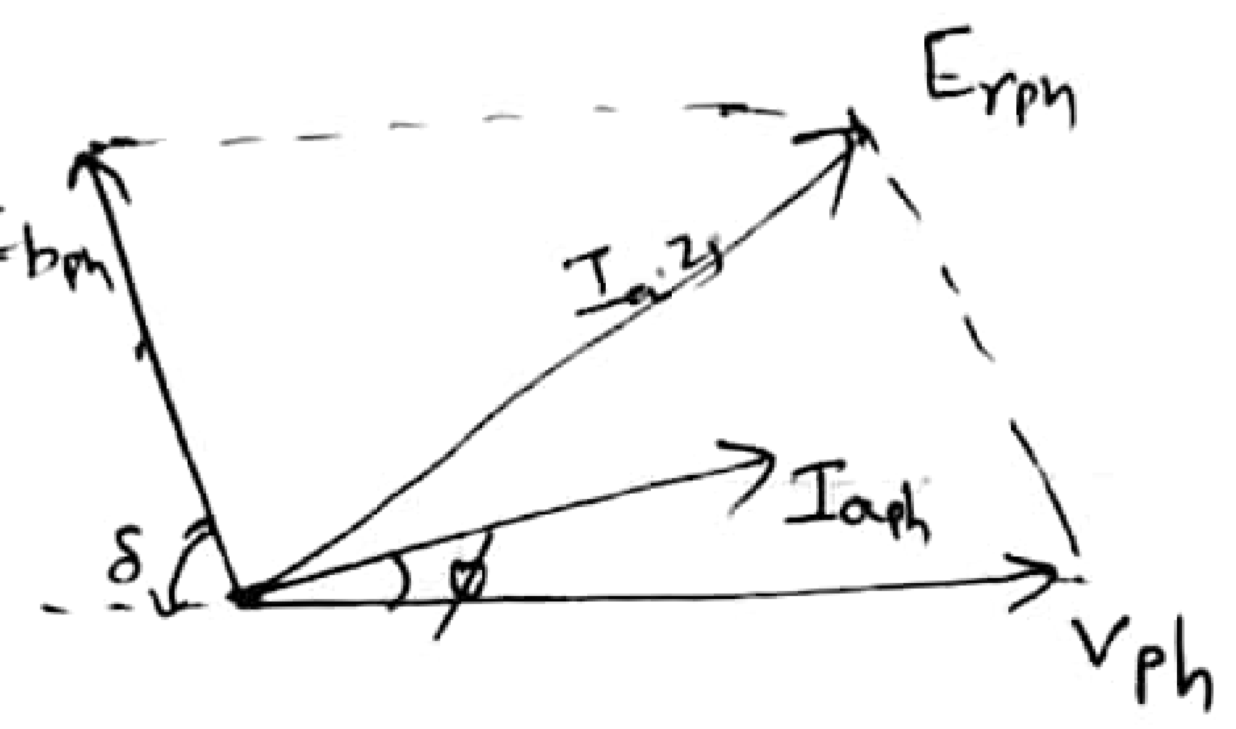
ϕ is power factor angle b/w V & I_a

θ is internal power factor angle b/w E_r and I_a

'δ' is called load angle (or) torque angle b/w E_b & V (or) power angle (or) Retardangle

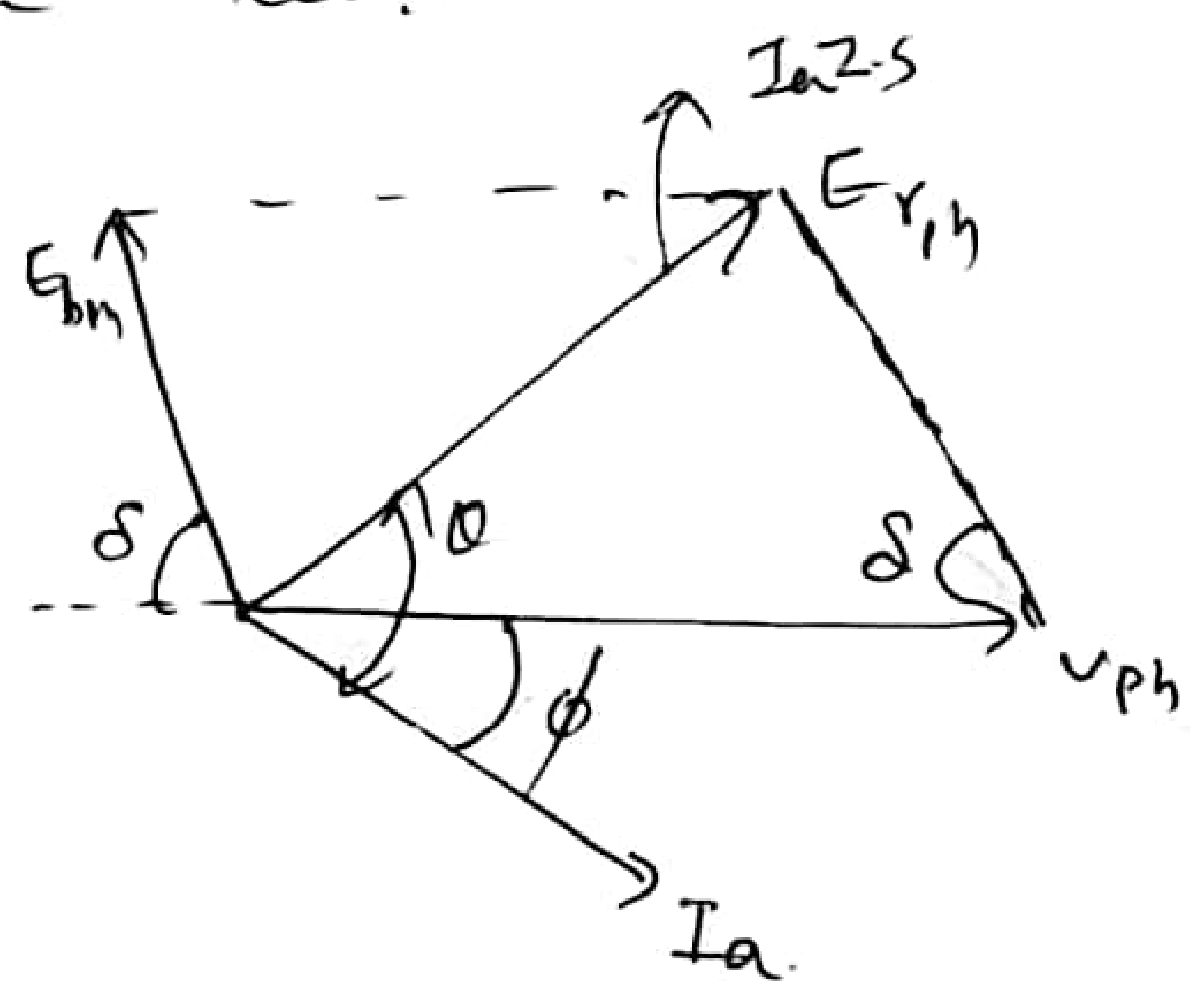
Phasor diagram for Non-salient pole (or) cylindrical pole, under load condition:

i) Leading p.f

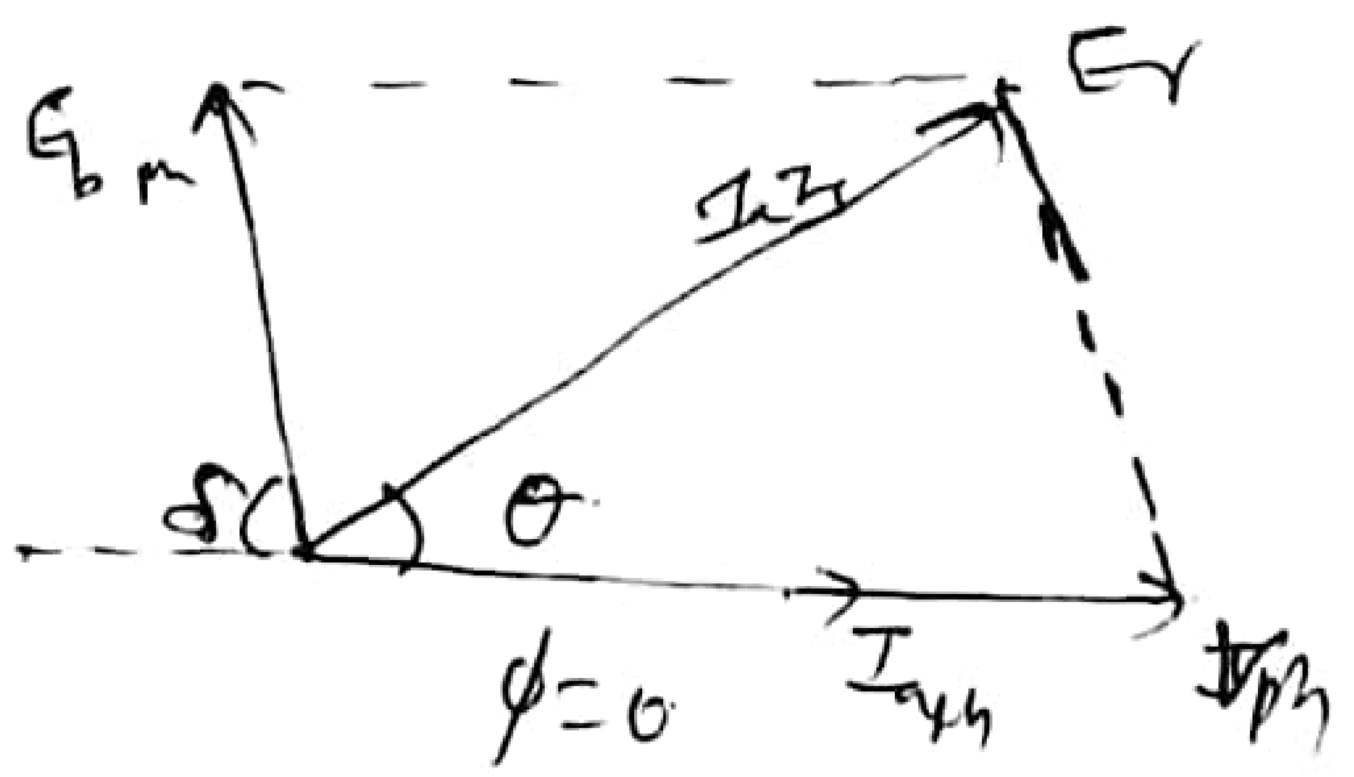


$\therefore I_{aph} = \frac{E_{rph}}{|Z_s|}$

ii) lagging p.f.



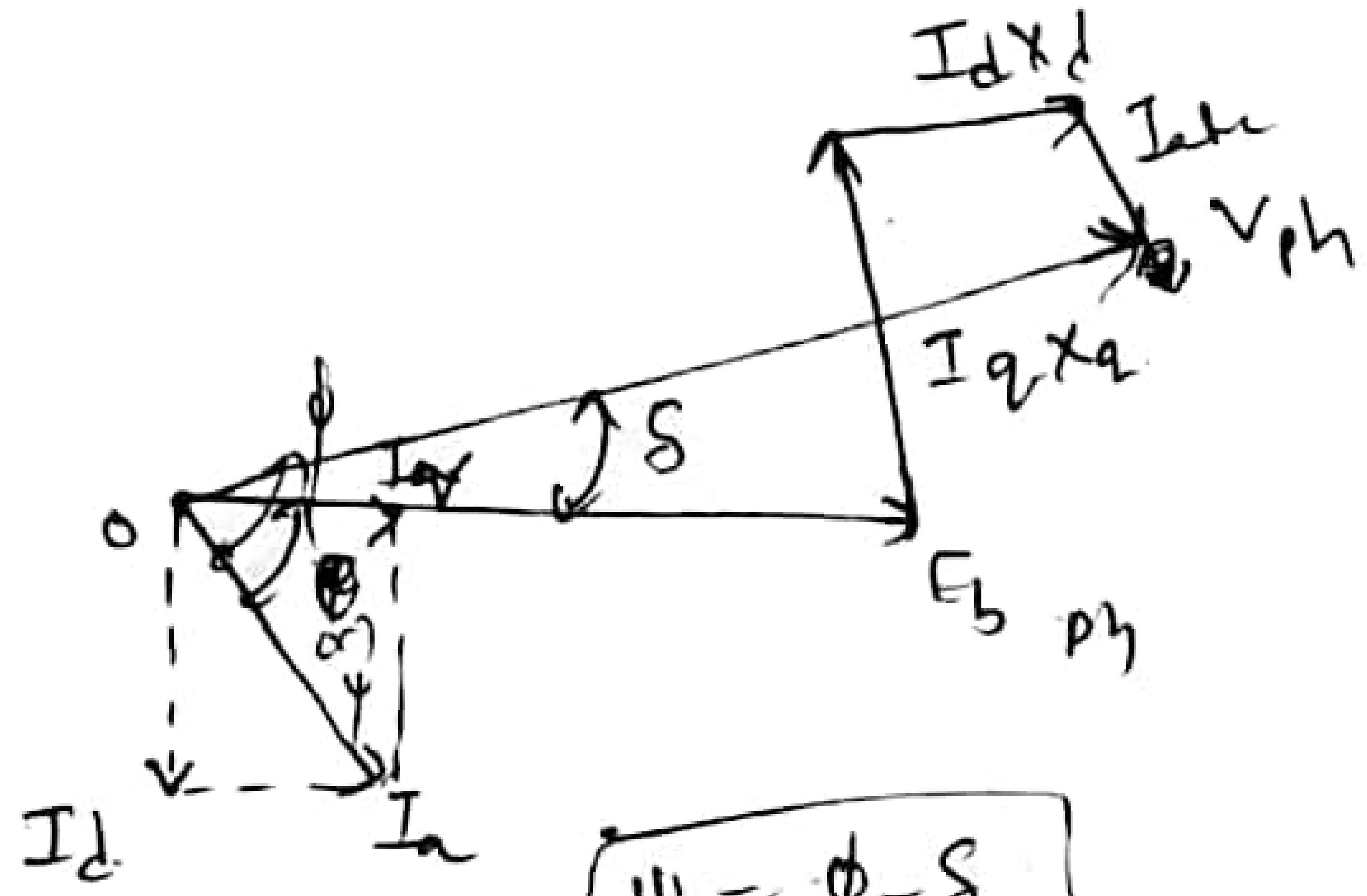
iii) unity p.f



Phasor diagrams for Salient pole :-

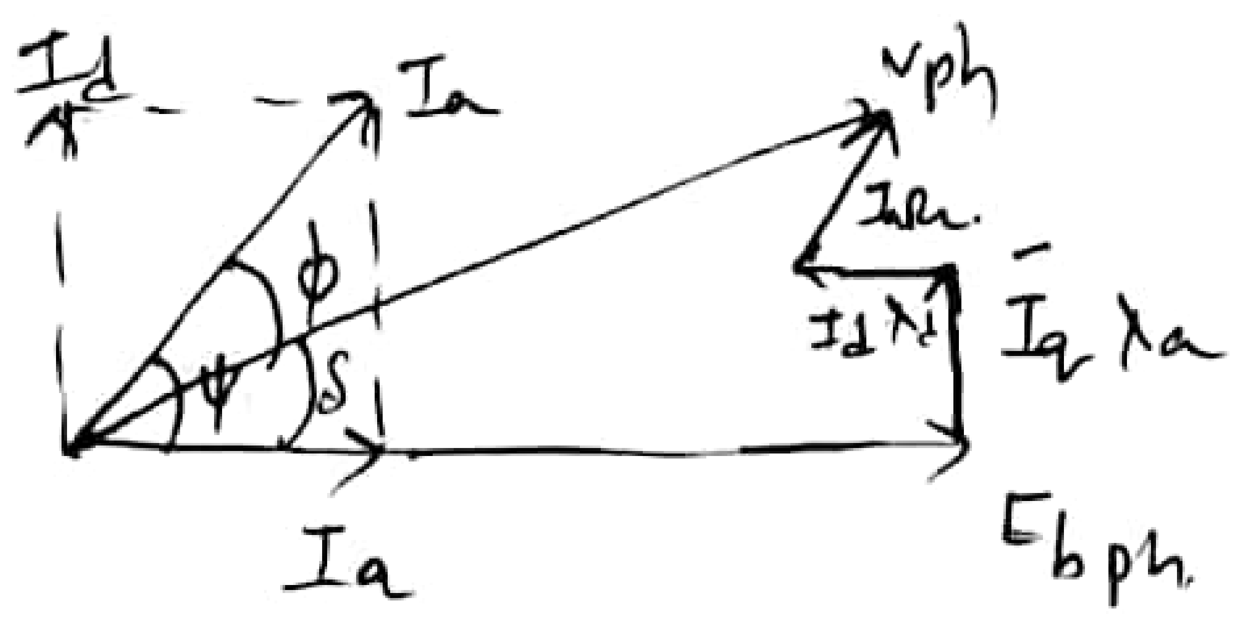
According to two reaction theory (discussed in synchronous generators unit-4) for lagging, leading and unity power factors, the phasor diagrams are as shown below.

i) lagging p.f :-



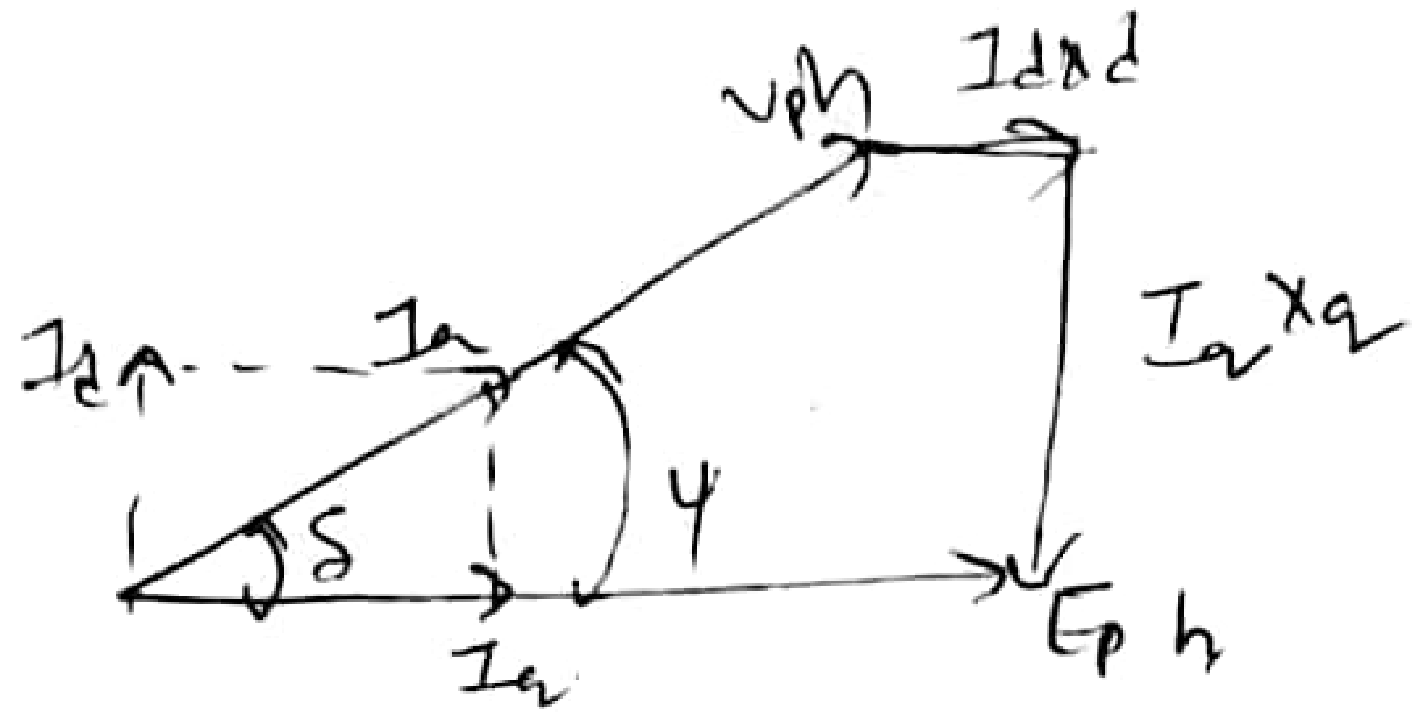
$$\boxed{\psi = \phi - \delta}$$

2) leading p.f :-



$$\boxed{\psi = \phi + \delta}$$

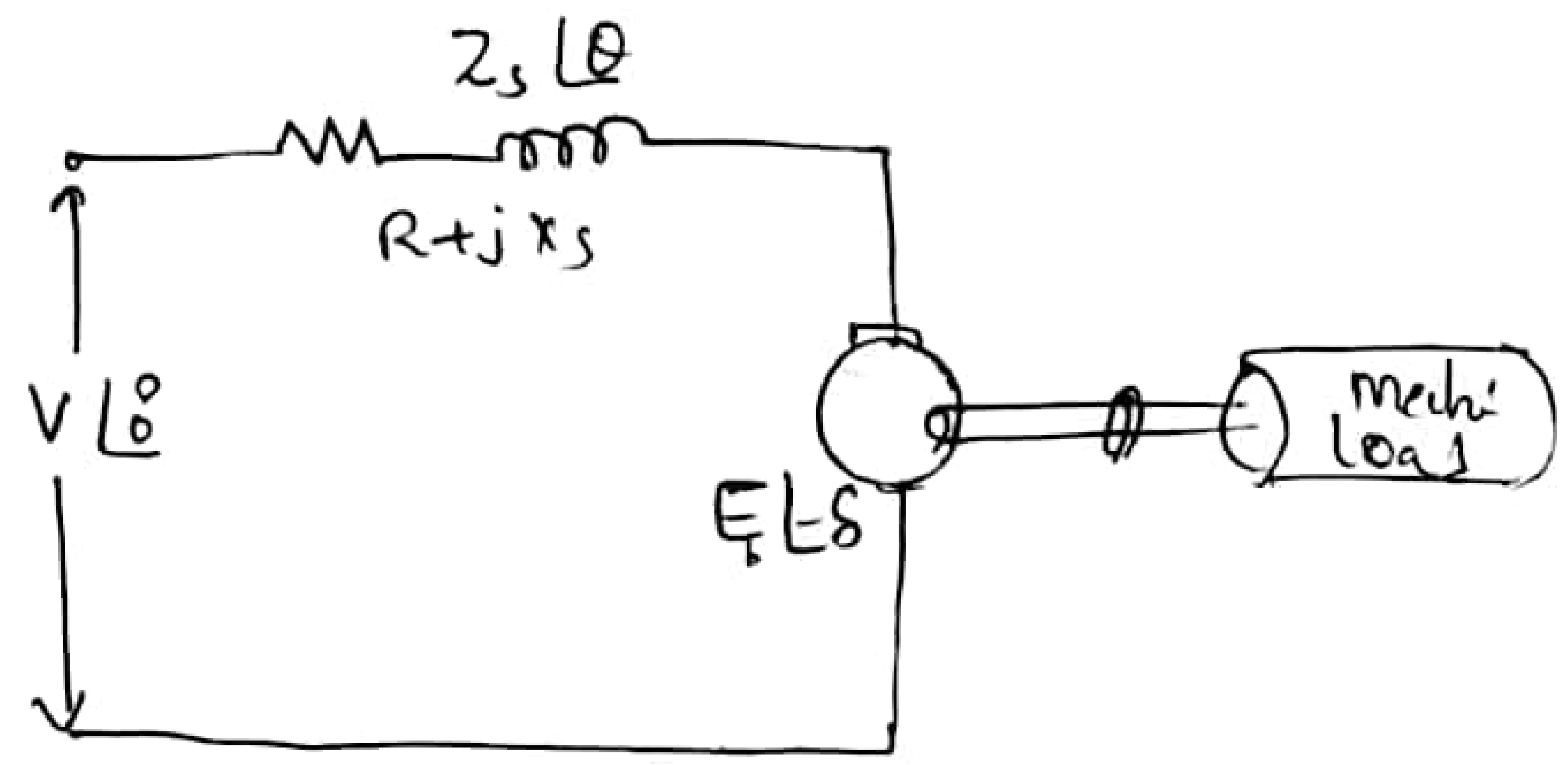
3. U.P.F.



$\phi = 0$

Power flow equations of synchronous motor:

The equivalent circuit diagram of synchronous motor is given in below.



where 'Ia' be the Armature current

'Zs' be synchronous impedance

'Eb' be the back emf

'V' be supply voltage.

where the emf induced in synchronous motor will lag beyond an angle 'δ'

$$\therefore \quad V = E_b + I_a Z_s$$

$$\therefore \quad I_a = \frac{\bar{V} - \bar{E}_b}{Z_s} = \frac{V\angle 0 - E\angle -\delta}{Z_s\angle\theta}$$

$$\therefore \quad I_a = \frac{V}{Z_s}\angle -\theta - \frac{E}{Z_s}\angle -\theta-\delta$$

complex current (or) conj current

$$I_a^* = \frac{V}{Z_s}\angle\theta - \frac{E_b}{Z_s}\angle\theta+\delta$$

∴ complex power input $S = P+jQ = VI_a^*$

$$\therefore S = V\angle 0^\circ \left[\frac{V}{Z_s}\angle\theta - \frac{E_b}{Z_s}\angle\theta+\delta\right]$$

$$S = \left[\frac{V^2}{Z_s}\angle\theta - \frac{E_bV}{Z_s}\angle\theta+\delta\right]$$

By separating the real and img values i.e

The real values with cosin value and img with sine value

$$\therefore P+jQ = \left[\frac{V^2}{Z_s}\cos\theta - \frac{E_bV}{Z_s}\cos(\theta+\delta)\right] + j\left[\frac{V^2}{Z_s}\sin\theta - \frac{E_bV}{Z_s}\sin(\theta+\delta)\right]$$

from the above Eq separate real power (P) & reactive power 'Q'

$$\therefore P = \frac{V^2}{Z_s}\cos\theta - \frac{E_bV}{Z_s}\cos(\theta+\delta)$$

$$Q = \frac{V^2}{Z_s}\sin\theta - \frac{E_bV}{Z_s}\sin(\theta+\delta)$$

If R_a is very small then Z_s become X_s

$\therefore$ $Z_s = X_s$ & angle become $\theta = 90°$

$$\tan\theta = \frac{X_s}{R_a} \Rightarrow \tan\theta = \frac{X_s}{0} \Rightarrow \tan\theta = 0$$

$$\theta = \tan^{-1}(0) = 90°$$

$$\therefore P = \frac{V^2}{\cancel{Z}_s}\cos 90° - \frac{E_b V}{\cancel{Z}_s}\cos(90+\delta)$$

$$\therefore P = 0 + \frac{E_b V}{\cancel{Z}_s}\sin\delta \qquad \left[\because \text{If } R_a = 0,\ \theta = 90°\right]$$

$$\therefore \boxed{P = \frac{E_b V}{X_s}\sin\delta}$$

similarly

$$Q = \frac{V^2}{X_s}\sin 90° - \frac{E_b V}{X_s}\sin(90+\delta)$$

$$Q = \frac{V^2}{X_s} - \frac{E_b V}{X_s}\cos\delta$$

$$\therefore \boxed{Q = \frac{V}{X_s}\left[V - E_b\cos\delta\right]}$$

Condition for maximum Power input :-

$$P_{in} = \frac{V^2}{Z_s} \cos\theta - \frac{E_b V}{Z_s} \cos(\theta+\delta)$$

for getting max i/p power $\frac{d P_{in}}{d\delta} = 0$

$$\therefore \frac{d P_{in}}{d\delta} = 0 = \frac{d}{d\delta}\left[\frac{V^2}{Z_s}\cos\theta - \frac{E_b V}{Z_s}\cos(\theta+\delta)\right]$$

$$0 = 0 + \frac{E_b V}{Z_s} \sin(\theta+\delta)$$

$$\sin(\theta+\delta) = 0$$

$$\theta+\delta = \cancel{180} \sin^{-1}(0) = 180^\circ$$

$$\therefore \theta+\delta = 180$$

$$\boxed{\delta = 180 - \theta}$$

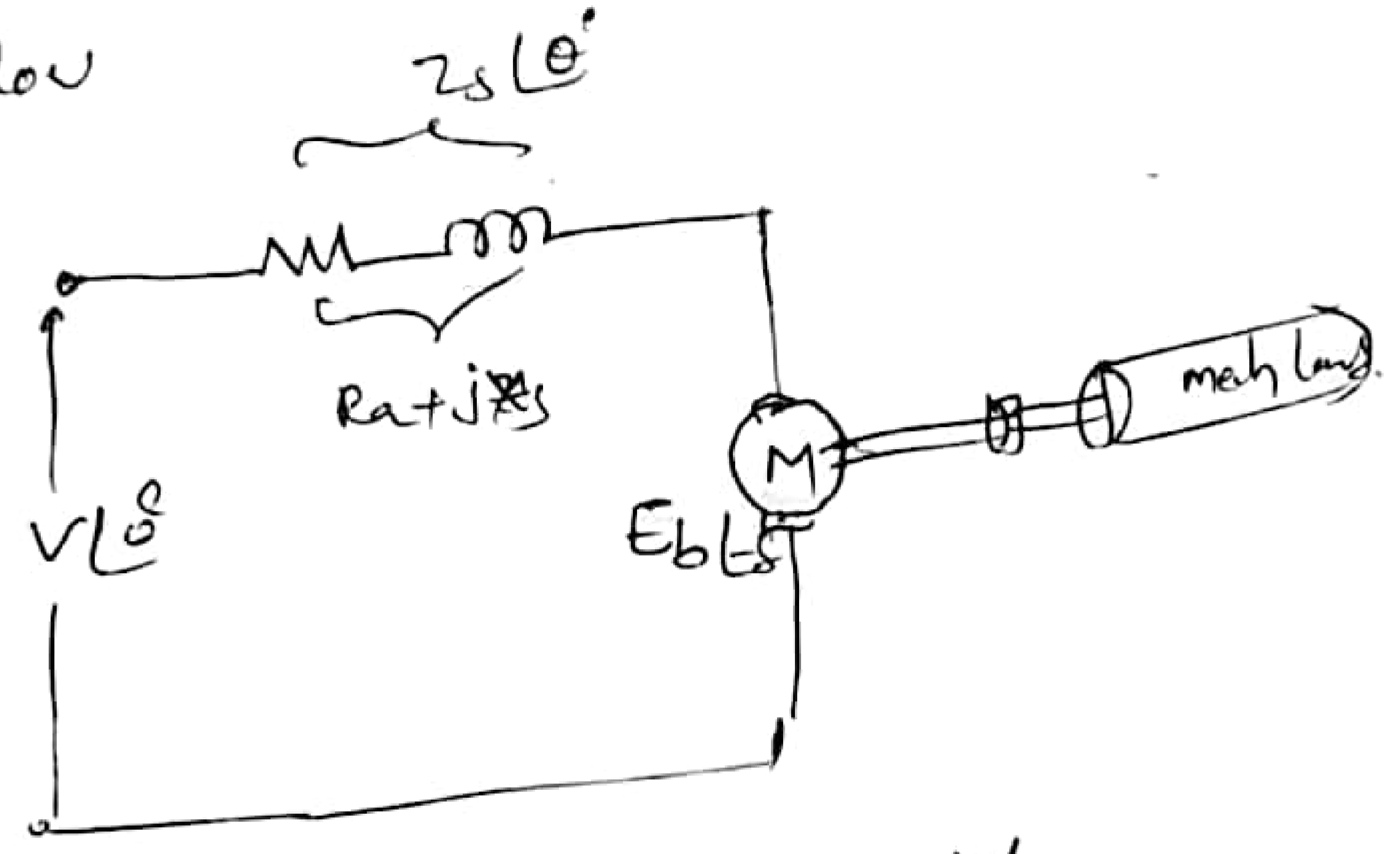
i.e The condition for max Power

$$\therefore P_{in\,max} = \frac{V^2}{Z_s}\cos\theta - \frac{E_b V}{Z_s}\cos(180^\circ) \quad (\because \theta+\delta = 180)$$

$$\therefore \boxed{P_{in\,max} = \frac{V^2}{Z_s}\cos\theta + \frac{E_b V}{Z_s}} \quad [\because \cos 180 = -1]$$

- Mechanical power developed in synchronous motor:-

The equivalent circuit of synchronous motor is given below



from the above equivalent ckt

$$V = E_b + I_a Z_s$$

$$\therefore \quad I_a = \frac{\bar{V} - \bar{E_b}}{Z_s} = \frac{V\angle 0 - E_b \angle -\delta}{Z_s \angle \theta}$$

$$I_a = \frac{V}{Z_s}\angle -\theta - \frac{E_b}{Z_s}\angle -\theta - \delta$$

~~from~~ for finding complex power we will take conj. current i.e I_a^*

$$\therefore \quad I_a^* = \frac{V}{Z_s}\angle \theta - \frac{E_b}{Z_s}\angle \theta + \delta$$

$\therefore$ mechanical power developed is given by

$$P_{mech} = Re\left[E_b I_a^*\right]$$

$$\therefore P_{mech} = Re\left(E_b \angle \delta \left[\frac{V}{Z_s} \angle \theta - \frac{E_b}{Z_s} \angle (\theta+\delta) \right] \right)$$

$$= Re\left(\frac{E_b V}{Z_s} \angle \theta - \delta - \frac{E_b^2}{Z_s} \angle \theta + \delta - \delta \right)$$

$$P_{mech} = Re\left[\frac{E_b V}{Z_s} \angle \theta - \delta - \frac{E_b^2}{Z_s} \angle \theta \right]$$

By taking Real terms

$$P_{mech} = \frac{E_b V}{Z_s} \cos(\theta - \delta) - \frac{E_b^2}{Z_s} \cos\theta$$

If $X_s >> R_a$ then neglecting R_a then

Z_s becomes X_s i.e $Z_s = X_s$ & $\theta = 90^\circ$

$$\therefore P_{mech} = \left[\frac{E_b V}{\cancel{X_s}} \cos(90 - \delta) - \frac{E_b^2}{\cancel{X_s}} \cos 90^\circ \right]$$

$$\boxed{P_{mech} = \frac{E_b V}{X_s} \sin \delta}$$

• Condition for maximum mechanical power developed

∴ Let use consider cal take

$$P_{mech} = \frac{E_b V}{Z_s} \cos(\theta - \delta) - \frac{E_b^2}{Z_s} \cos\theta$$

$$\therefore \frac{d P_{mech}}{d\delta} = 0$$

$$\frac{d}{d\delta}\left[\frac{E_b V}{Z_s} \cos(\theta-\delta) - \frac{E_b^2}{Z_s}\cos\theta\right] = 0$$

$$\therefore \frac{E_b V}{Z_s} \sin(\theta - \delta) - 0 = 0$$

$$\frac{E_b V}{Z_s} \sin(\theta - \delta) = 0$$

$$\sin(\theta - \delta) = \sin 0$$

$$\theta - \delta = 0$$

$$\boxed{\theta = \delta} \rightarrow \text{condition for } P_{mech} \text{ max}$$

$$\therefore P_{mech}(\text{max}) = \frac{E_b V}{Z_s} \cos(\theta - \theta) - \frac{E_b^2}{Z_s} \cos\theta$$

$$\therefore \boxed{P_{mech}(\text{max}) = \frac{E_b V}{Z_s} - \frac{E_b^2}{Z_s}\cos\theta}$$

Torque developed in syn. motor

$$\therefore \quad P_{mech}/ph = \frac{E_b V_{ph} \cos(\theta - \delta)}{Z_s} - \frac{E_b^2}{Z_s} \cos\theta \rightarrow (1)$$

for 3-ϕ synchronous motor, mechanical power developed is given by

$$P_{mech} = 3\left[\frac{E_b V_{ph} \cos(\theta - \delta)}{Z_s} - \frac{E_b^2}{Z_s} \cos\theta\right] \rightarrow (2)$$

$$\therefore \quad T_{Gross} = \frac{Power}{\omega}$$

$$\therefore \quad P_{mech} = \frac{2\pi N \, T_{Gross}}{60}$$

$$\therefore \quad T_{Gross} = \frac{P_{mech}}{(2\pi N_s/60)}$$

$$\therefore \quad T_{Gross} = \frac{3\left[\frac{E_b V_{ph} \cos(\theta - \delta)}{Z_s} - \frac{E_b^2}{Z_s} \cos\theta\right]}{(2\pi N_s/60)}$$

→ A 3-phase, 400V, 50Hz, 37.3 kW, star-connected synchronous motor has a full-load efficiency of 88%. The synchronous impedance of motor is $(0.2+j1.6)\ \Omega$/phase. If the excitation of the motor is adjusted to give a leading p.f 0.9, calculate for full-load (i) the induced emf ii) total mechanical power developed.

Sol

supply voltage /ph ⇒ $V_{ph} = \dfrac{V_L}{\sqrt{3}} = \dfrac{400}{\sqrt{3}} = 230.94V$

Power input (P_{in}) $= \dfrac{\text{output Power } (P_{out})}{\text{efficiency } (\eta)}$

$$\therefore P_{in} = \frac{37.3 \text{ kW}}{0.88} = 42.386 \text{ kW}$$

$\therefore$ full-load current, $I = \dfrac{P_{in}}{\sqrt{3}\, V_L \cos\phi}$

$$\therefore I = \frac{42.386 \times 10^3}{\sqrt{3} \times 400 \times 0.9} = 67.98 \text{ A}$$

$\therefore$ Impedance /ph $Z_s' = (0.2 + j1.6)$

$$Z_s = \sqrt{(0.2)^2 + 1.6^2} = 1.6125\ \Omega$$

$\therefore$ Impedance drop /ph $E_r = I Z_s$

$$E_r = 67.98 \times 1.6125 = 109.6V$$

$\therefore$ Phase angle $\phi = \cos^{-1}(0.9) = 25.84°$

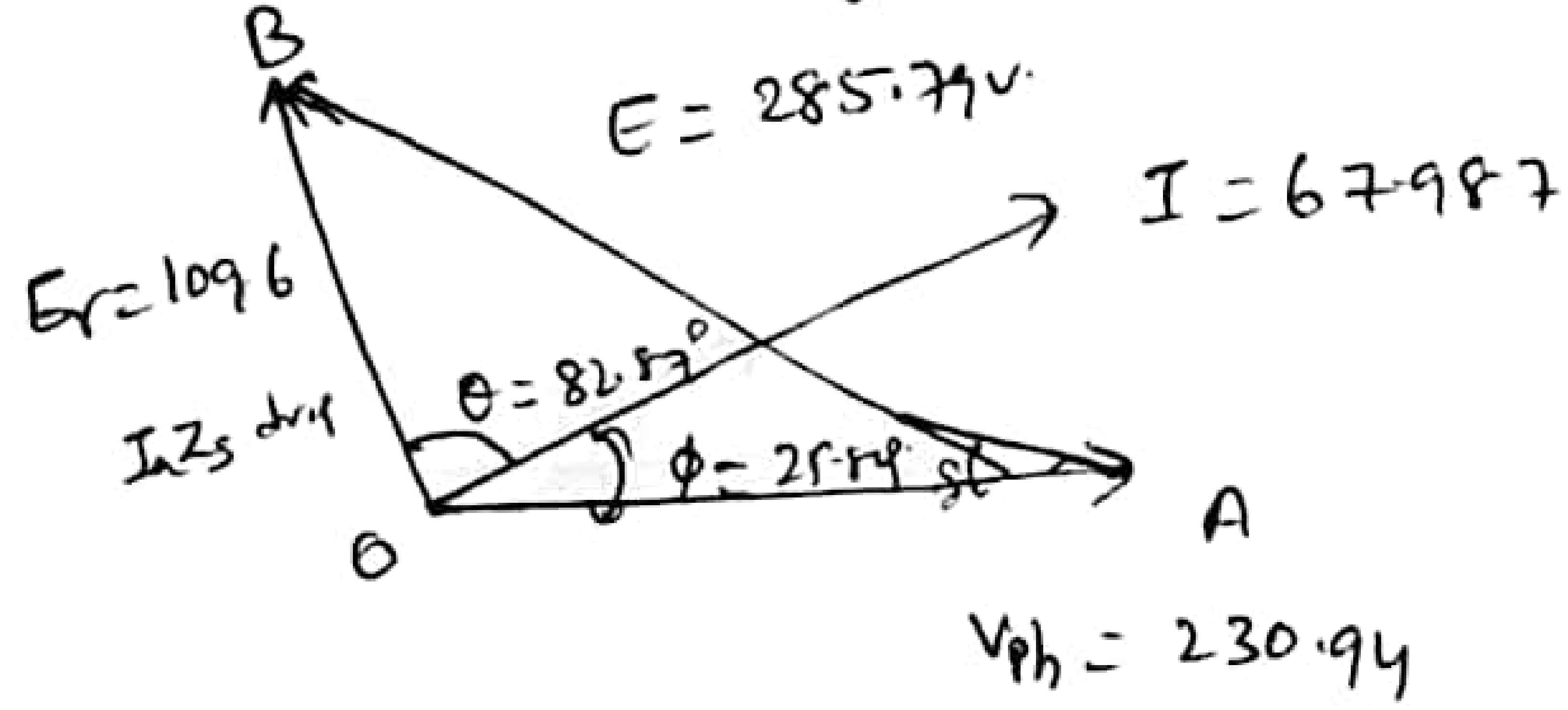
Internal angle $\theta = \tan^{-1}\left(\frac{X_s}{R_a}\right) = \tan^{-1}\left(\frac{1.6}{0.2}\right)$

$\therefore \theta = 82.87°$

$\therefore \theta + \phi = 82.87° + 25.84° = 108.71°$

$\therefore \cos(\theta+\phi) = \cos 108.71° = -0.321$

From the phasor diagram given below.



Excitation emf per phase.

$$E = \sqrt{V^2 + E_r^2 - 2VE_r\cos(\theta+\phi)}$$

$$E = \sqrt{(230.94)^2 + 109.6^2 - 2 \times 230.94 \times 109.6 \times (-0.321)}$$

$$E = 285.79\text{ v.}$$

(i) Excitation emf (line value) $= \sqrt{3} \times 285.79 = 495$ v.

(ii) total copper l/s $= 3 \times I^2 R_a = 3 \times (67.98)^2 \times 0.2 = 2{,}773$ w

ii) Total mechanical power developed

$$P_{mech} = \text{power i/p} - \text{total cu l/s}$$

$$= 42{,}386 - 2{,}773$$

$\therefore P_{mech} = 39.613$ kw

→ A 3-phase star-connected non-salient pole synchronous motor connected to a 6.6 kV mains has an armature impedance of $(2.5 + j15)\ \Omega/ph$. The excitation of the machine gives a generated emf of 7.0 kV. The iron & friction losses amount to 10 kW. Determine the output of the motor when operating at a load angle of 31° (electrical)

Sol

Supply voltage (line to line) $V_L = 6.6\ kV$

Excitation emf (line to line) $E = 7.0\ kV$

Impedance per phase $Z_s = (2.5 + j15) = 15.207 \angle 80.53^\circ$

load angle 'δ' $= 31^\circ$

Internal angle $\theta = \tan^{-1}\frac{X_s}{R_a} = \tan^{-1}\left(\frac{15}{2.5}\right) = 80.54^\circ$

∴ mechanical power developed

$$P_{mech} = \frac{E_L V_L}{Z_s}\cos(\theta - \delta) - \frac{E_L^2}{Z_s}\cos\theta$$

$$\therefore P_{mech} = \frac{7000 \times 6600}{15.207}\cos(80.54 - 31^\circ) - \frac{7000^2}{15.207}\cos 80.54$$

$$\therefore P_{mech} = 1{,}971{,}458.3 - 529{,}596.6 = 1441.86\ kW$$

$\therefore$ motor output = mech i/p − iron & friction L/s

$= 1441.86 \times 10^3 - 10 \times 10^3$

$\therefore$ motor output $= 1431.86\ kW$

→ A 20 kW, 400 V, 3-phase, star-connected synchronous motor has per phase impedance of $(0.15 + j0.90)\,\Omega$. Determine the induced emf, torque angle and mechanical power developed for full load at 0.8 p.f lagging. Assume 92% efficiency of the motor. Draw phasor diagram.

Sol

$$\text{motor i/p} = \frac{\text{m.o/p}}{\eta} = \frac{20 \times 10^3}{0.92} = 21.739\text{ kW}$$

$\therefore$ Armature current, $I = \dfrac{\text{moter i/p}}{\sqrt{3}\, V_L \cos\phi} = \dfrac{21,739}{\sqrt{3} \times 400 \times 0.8}$

$\therefore \quad I = 39.222\text{ A}$

$\therefore$ supply voltage per phase $V_{ph} = \dfrac{V_L}{\sqrt{3}} = \dfrac{400}{\sqrt{3}} = 230.94\,\Omega$

Resultant voltage $E_r = I \times Z_s = 39.222 \times \sqrt{0.15^2 + 0.9^2}$

$E_r = 35.787\text{ V}$

Internal angle $\theta = \tan^{-1}\left(\dfrac{X_s}{R_a}\right) = \tan^{-1}\left(\dfrac{0.9}{0.15}\right) = 80.537°$

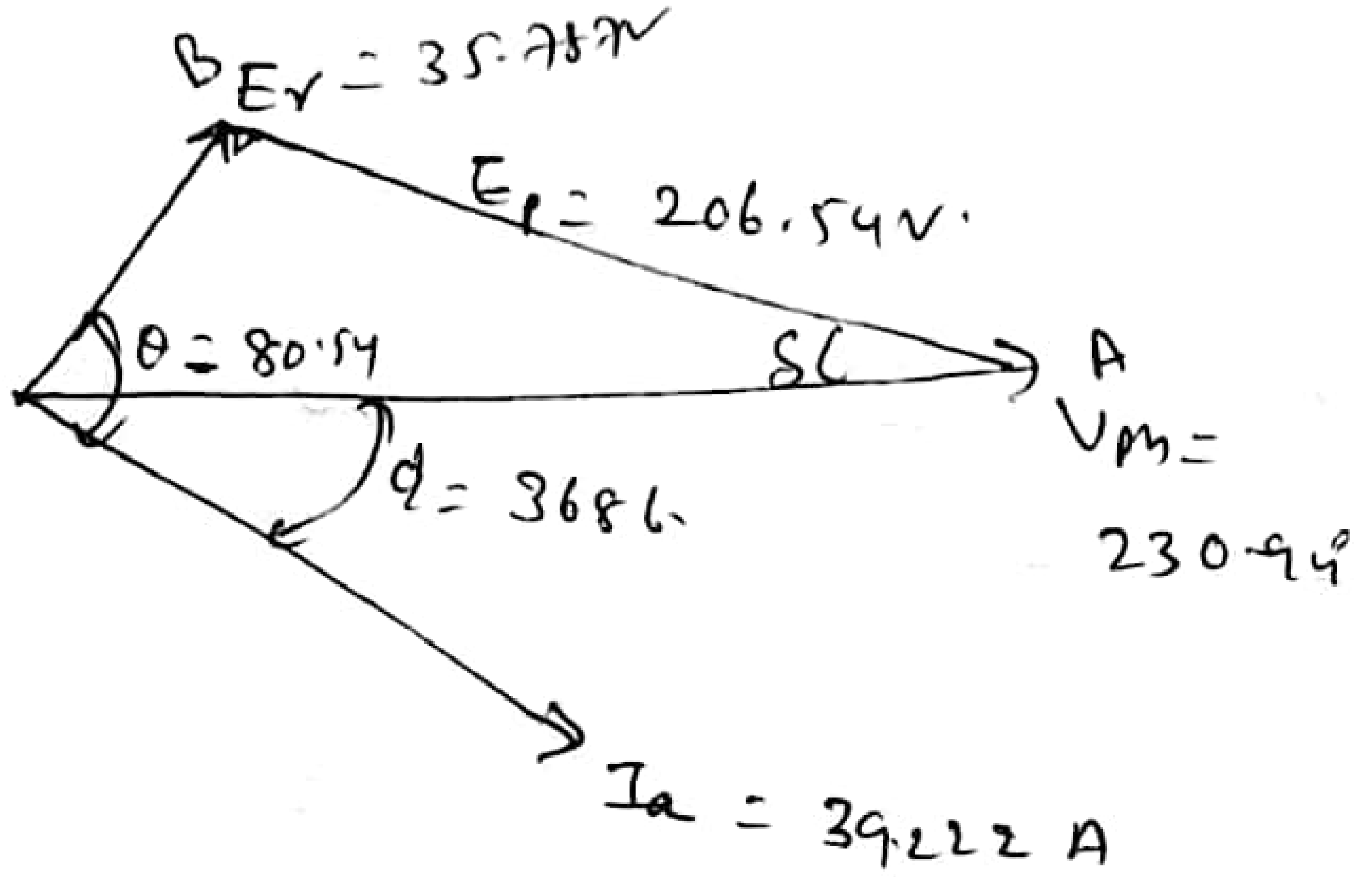
Induced emf per phase $E_{ph} = \sqrt{V^2 + E_R^2 - 2VE_R\cos(\theta - \phi)}$

$E_{ph} = \sqrt{(230.94)^2 + (35.787)^2 - 2 \times 230.94 \times 35.787 \times \cos(80.537 - 36.87)}$

$\therefore$ $E_{ph} = \sqrt{53,333.3 + 1,2807 - 11,956.6}$

$E_{ph} = 206.54V$.

The phaser diagram



line value of Induced emf,

$E_L = \sqrt{3}\, E_p = \sqrt{3} \times 206.54 = 357.73\,V$

$\therefore$ mechanical power developed $= P_{out} - 3I^2 R_a$

$= 21,739 - 3 \times (39.222)^2 \times 0.15 = 21.047$ kw

cor)

$P_{mech} =$ -

also from phas dia

$$\frac{E_r}{\sin\delta} = \frac{E_p}{\sin(\theta - \phi)}$$

$$\frac{35.787}{\sin\delta} = \frac{206.54}{\sin(80.54^\circ - 36.86)}$$

$\therefore$ $\sin\delta = \frac{35.787 \times \sin(43.667)}{206.54} = 0.11964$

$\therefore$ Torque angle $(\delta) = \sin^{-1} 0.11964 = 6.87^\circ$

→ A 2,000 V, 3-phase, 4-pole, Y-connected synchronous motor runs at 1,500 rpm. The excitation is constant and corresponds to an open-circuit voltage of 2000 V. The resistance is negligible as compared to synchronous reactance of 3 Ω per phase. Determine power input, power factor & torque developed for an armature current of 200 A.

<u>sol</u>

$$V_{ph} = \frac{2000}{\sqrt{3}} = 1154.7\,V$$

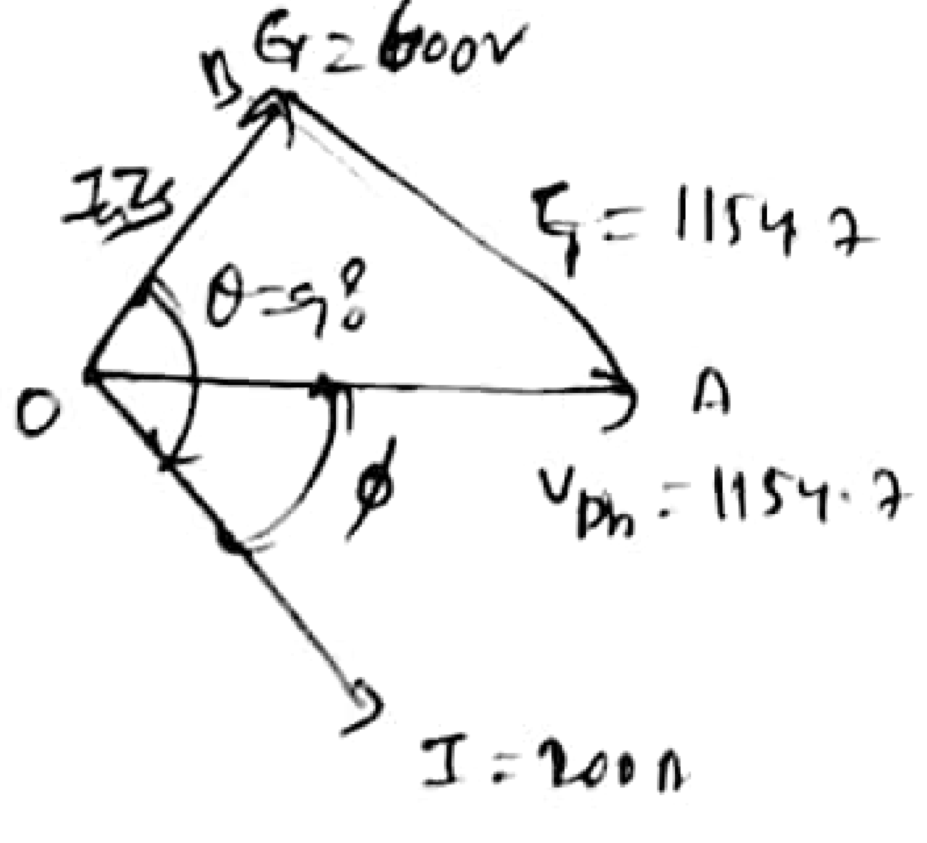
Induced E.m.f $E_{ph} = \frac{2000}{\sqrt{3}} = 1154.7\,V.$

Input phase current $I = 200\,A$

Impedance drop / ph $E_r = IZ_s = 200 \times 3 = 600\,V$

∴ Internal angle, $\theta = 90°$ (∵ resistance negligible)

∴ Assuming armature current lagging behind the supply voltage by an angle 'ϕ'. shown in fig,



∴ In ΔAOB we have

$$E^2 = V^2 + E_r^2 - 2VE_r\cos(90° - \phi)$$

$$\therefore \cancel{1,154.7^2} = \cancel{1154.7^2} + 600^2 - 2 \times 1154.7 \times 1154.7 \times \cancel{\cos(90° - \phi)}\ \sin\phi$$

$$\therefore \sin\phi = \frac{450}{2 \times 1154.7} = 0.1948$$

$$\therefore \phi = \sin^{-1}(0.1948) = \cancel{11.2363°}\ 15.05°$$

(i) $p.f = \cos\phi = \cos(15.05°) = 0.981$ (lagging)

(ii) Power I/P $= \sqrt{3}\, V_L I_L \cos\phi = \sqrt{3} \times 2000 \times 200 \times 0.981 = 679.65$ kW

(iii) Torque $T = \frac{\text{Power O/P}}{2\pi N_s/60} = \frac{\text{Power I/P} - \text{copper L/s in armature}}{2\pi N_s/60}$ (∵ copper L/s = 0)

$$\therefore T = \frac{679.65 \times 10^3}{2\pi \times 1500/60} = 4326.82\ N\text{-}m$$

16.11 DIFFERENT TORQUES OF A SYNCHRONOUS MOTOR

The torque required to operate the driven machine at every moment between the initial breakaway and the final shutdown is important in determination of the motor characteristics. The various torques associated with synchronous motors are termed starting torque, running torque, pull-in torque, and pull-out torque.

1. Starting Torque. It pertains to the ability of the motor to accelerate the load. The starting torque, sometimes also called the *breakaway torque*, required by the driven machine may be as low as 10%, as in case of centrifugal pumps, and as high as 200 or 250% of full-load torque, as in case of loaded reciprocating two-cylinder compressors.

The synchronous motor has got no self-starting torque, but in modern synchronous motors, almost any reasonable torque can be had by proper design of the damper windings (by changes in the resistance and size of the damper winding).

2. Running Torque. It is the torque developed by the motor under running conditions. It is determined by the output power and speed of the driven machine. The peak output power determines the maximum torque that would be required by the driven machine. The motor must have a breakdown or a maximum running torque greater than this value so as to avoid stalling of the machine.

3. Pull-in Torque. It refers to the ability of the motor to pull-into synchronism when changing from induction to synchronous motor operation.

4. Pull-out Torque. It pertains to the ability of the motor to remain in synchronism under rated load conditions.

The maximum torque which the motor will develop without pulling out of step (or synchronism) is called the *pull-out torque*.

Its value varies from 1.25 to 3.5 times the full-load torque.