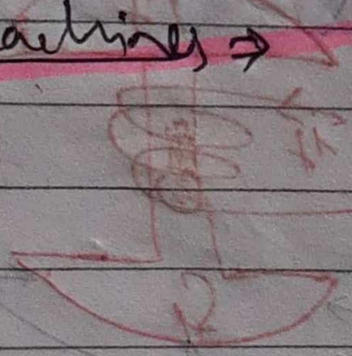
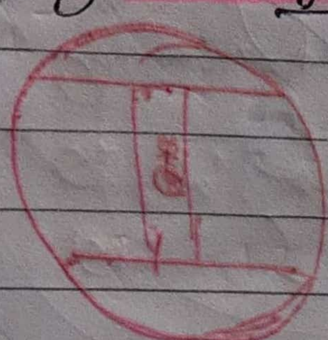
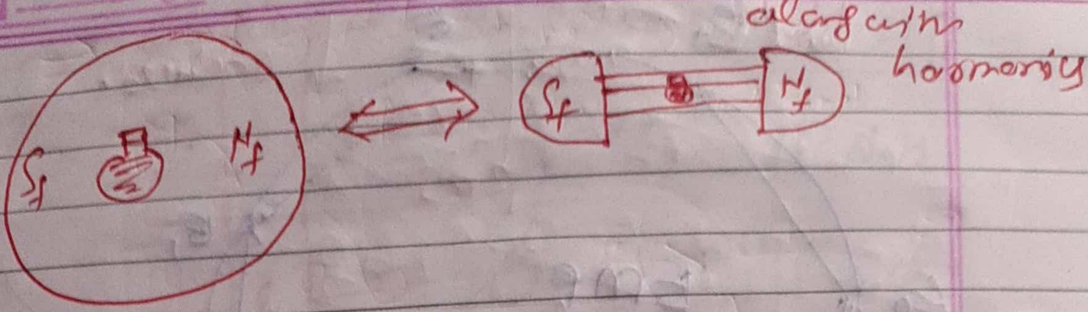
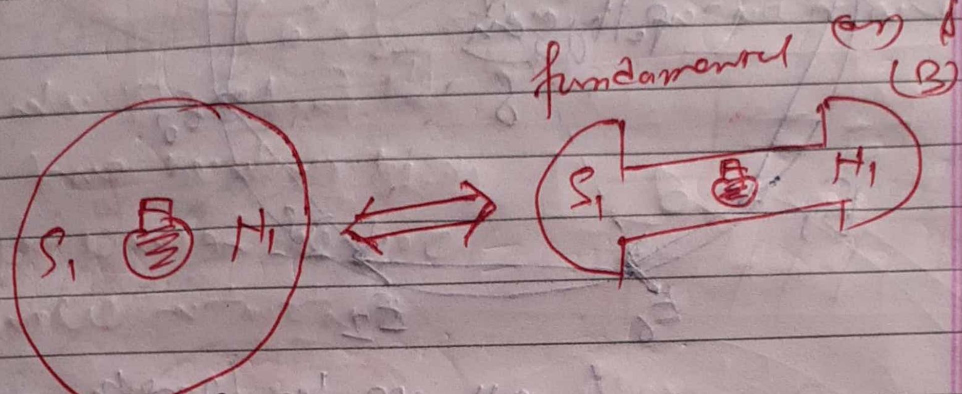
Phase-II

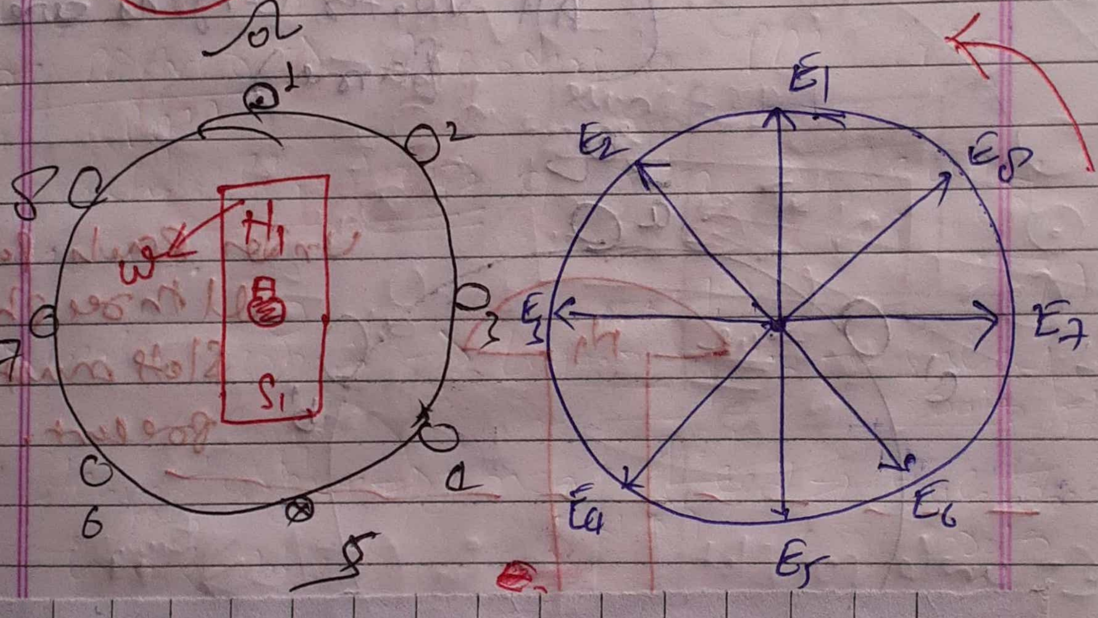
Distribution of Winding in Synchronous machines ⇒

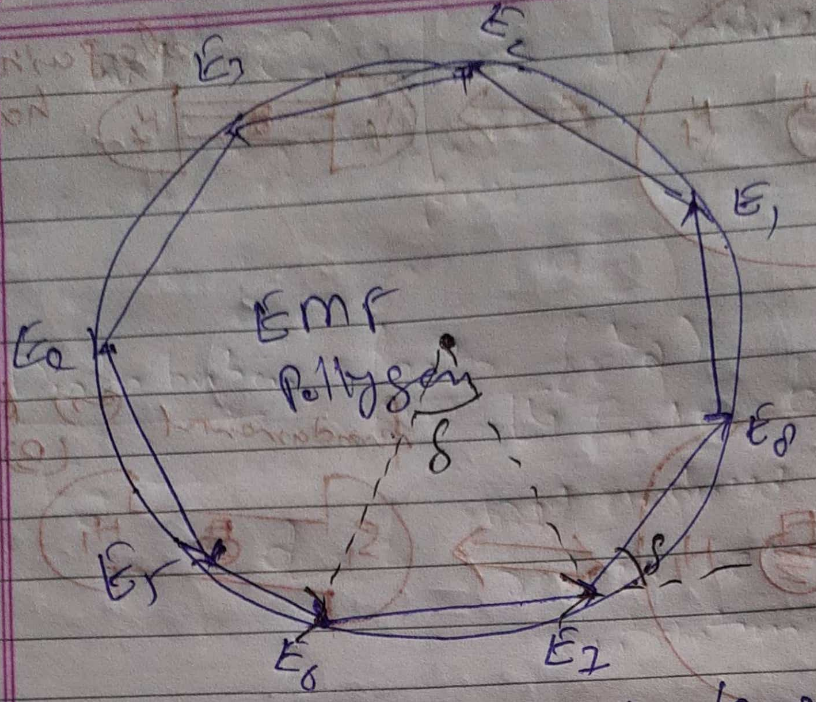




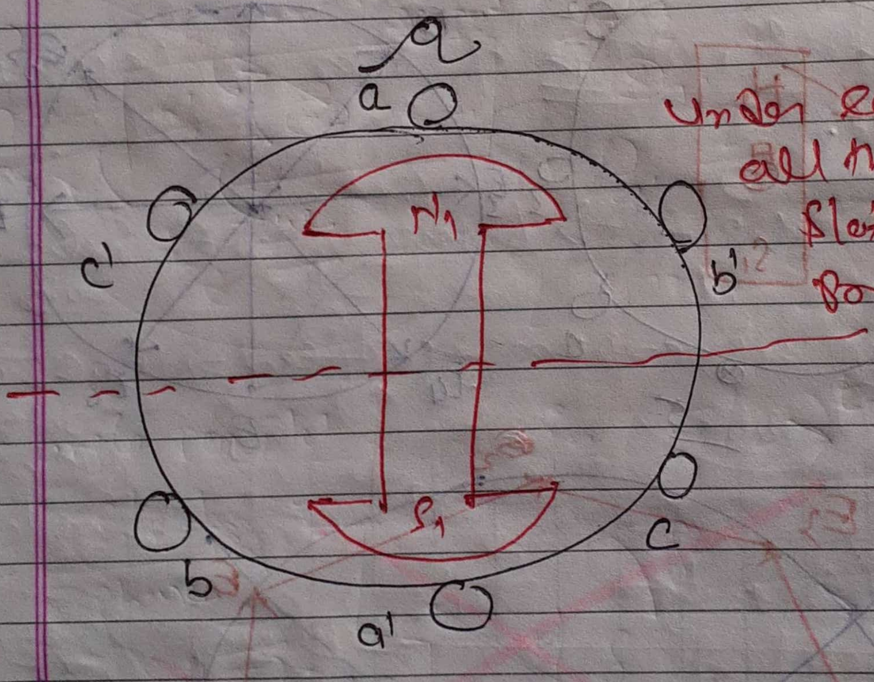

S_f
H_f
S_f
H_f
along axis
harmonics


fundamental (or) sinusoidal
(B)
S_1
H_1
S_1
H_1


1
2
3
4
5
6
7
8
H_1
S_1
w
E_1
E_2
E_3
E_4
E_5
E_6
E_7
E_8



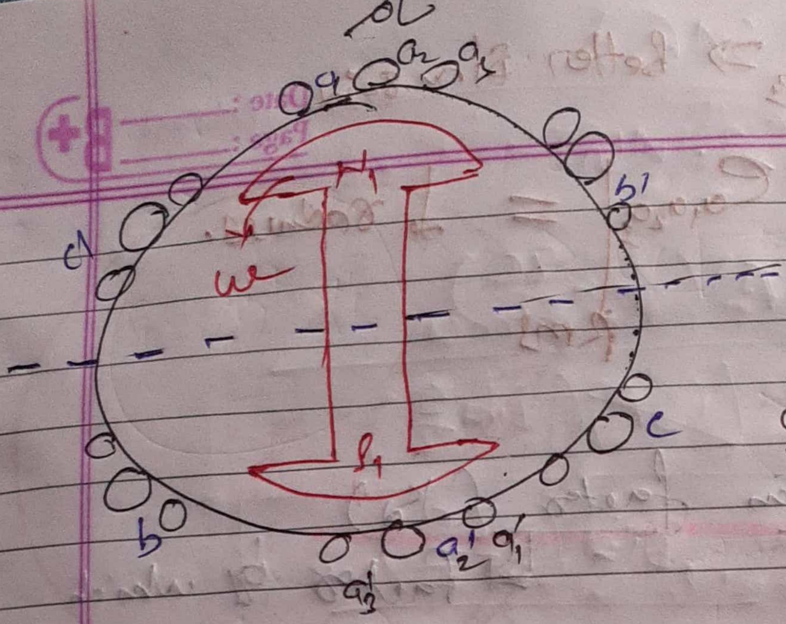
(All vector lengths are same)



Under each pole, all three phase slots must be present.

Distribution of winding ⇒

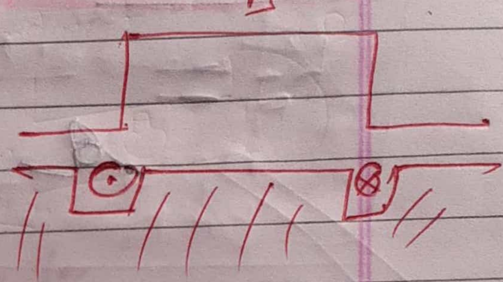
Date:
Page:



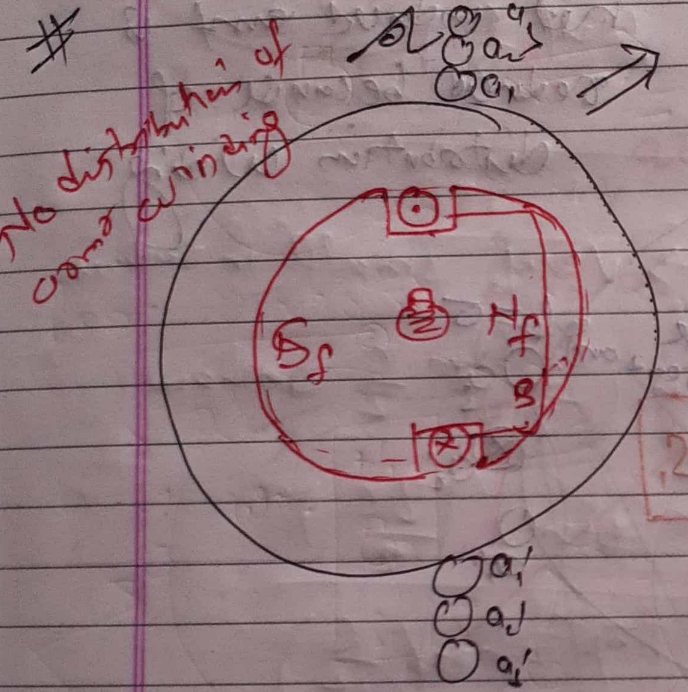
~~6 slots~~

18 slots

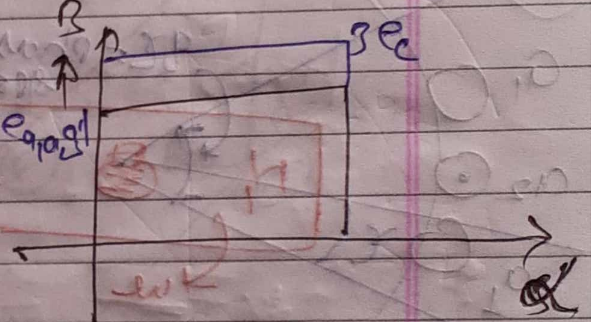
$S/P/P = 3$

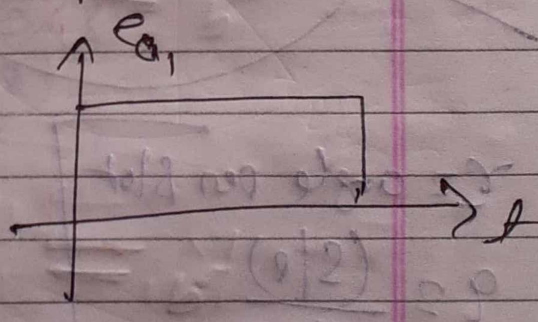


No distribution of conc winding

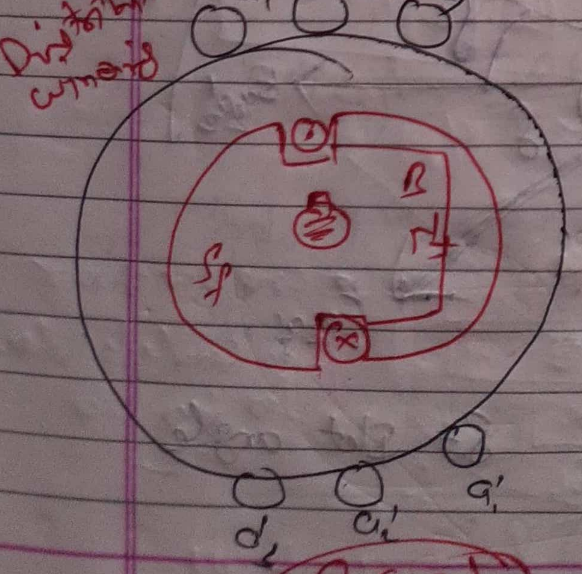


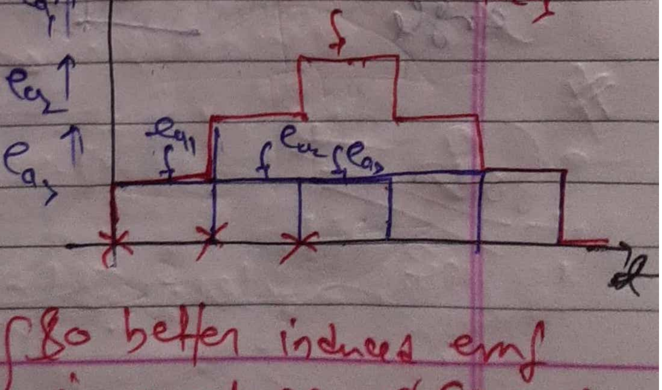
$e_c \propto B$





Distribution winding





$e_{rms}\ f_p$

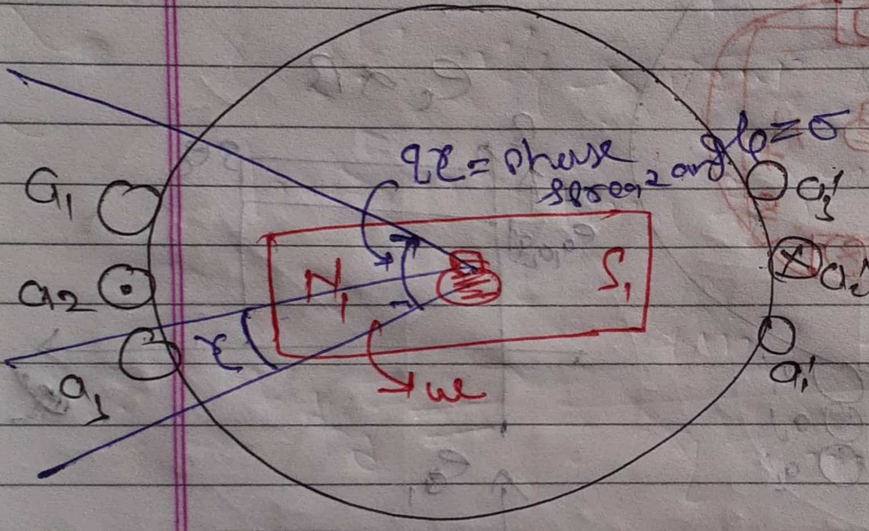
So better induced emf in armature cond $(a_1 a_2 a_3)$ per phase

• $e_{a_1 a_2 a_3} \Rightarrow$ Better sinusoid

but $e_{a_1 a_2 a_3}\big|_{Rms} = \downarrow$ reduced

Distribution factor (K_d)

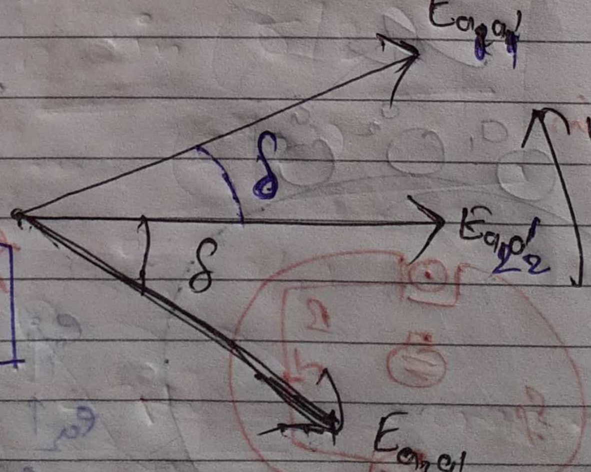
↳ factor by which net induced emf is reduced because of distribution winding



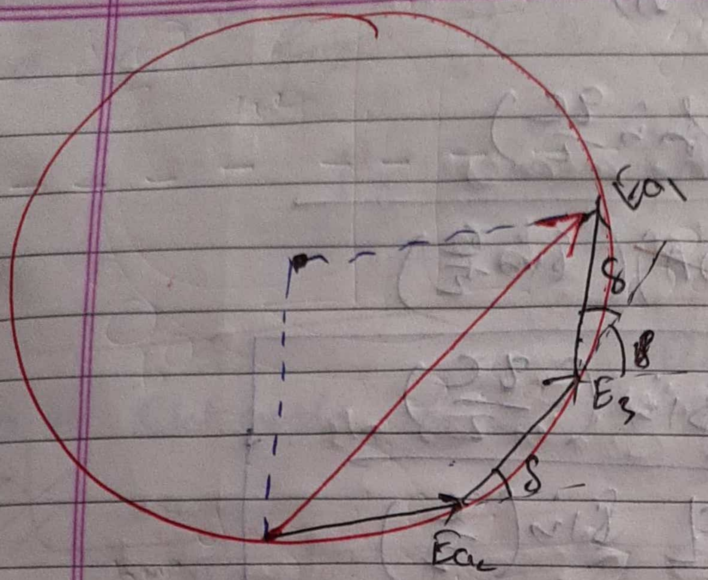
γ = angle per slot

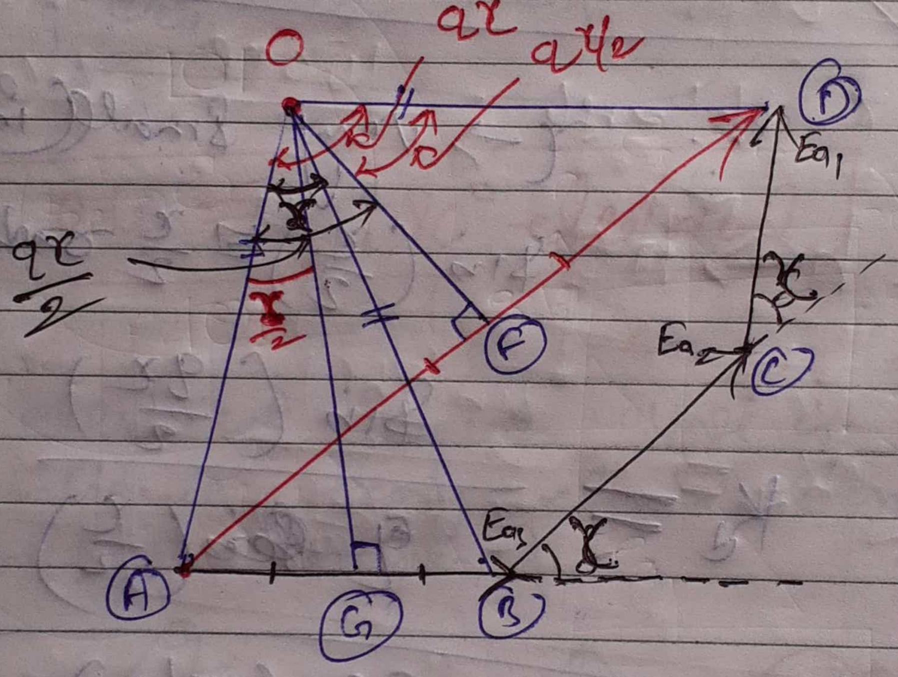
$q = \frac{(S/P)}{\text{phase}}$

Phase spread (σ) $= q\gamma$
angle



δ = slot angle





$$\sin\frac{x}{2} = \frac{AG}{OA}$$

$$\sin\left(\frac{qx}{2}\right) = \frac{AF}{OA}$$

$$K_d = \frac{\text{Induced voltage with distribution wdg}}{\text{Induced voltage without distribution}}$$

$$= \frac{(AD)}{q(AB)}$$

$$= \frac{\cancel{2}(AF)}{q(\cancel{2}\cdot AG)}$$

$$= \frac{\cancel{(OA)}\left(\sin\frac{q\gamma}{2}\right)}{q\,\cancel{(OA)}\left(\sin\frac{\gamma}{2}\right)}$$

$$\boxed{K_d = \frac{\sin\left(\frac{q\gamma}{2}\right)}{q\,\sin\left(\frac{\gamma}{2}\right)}}$$

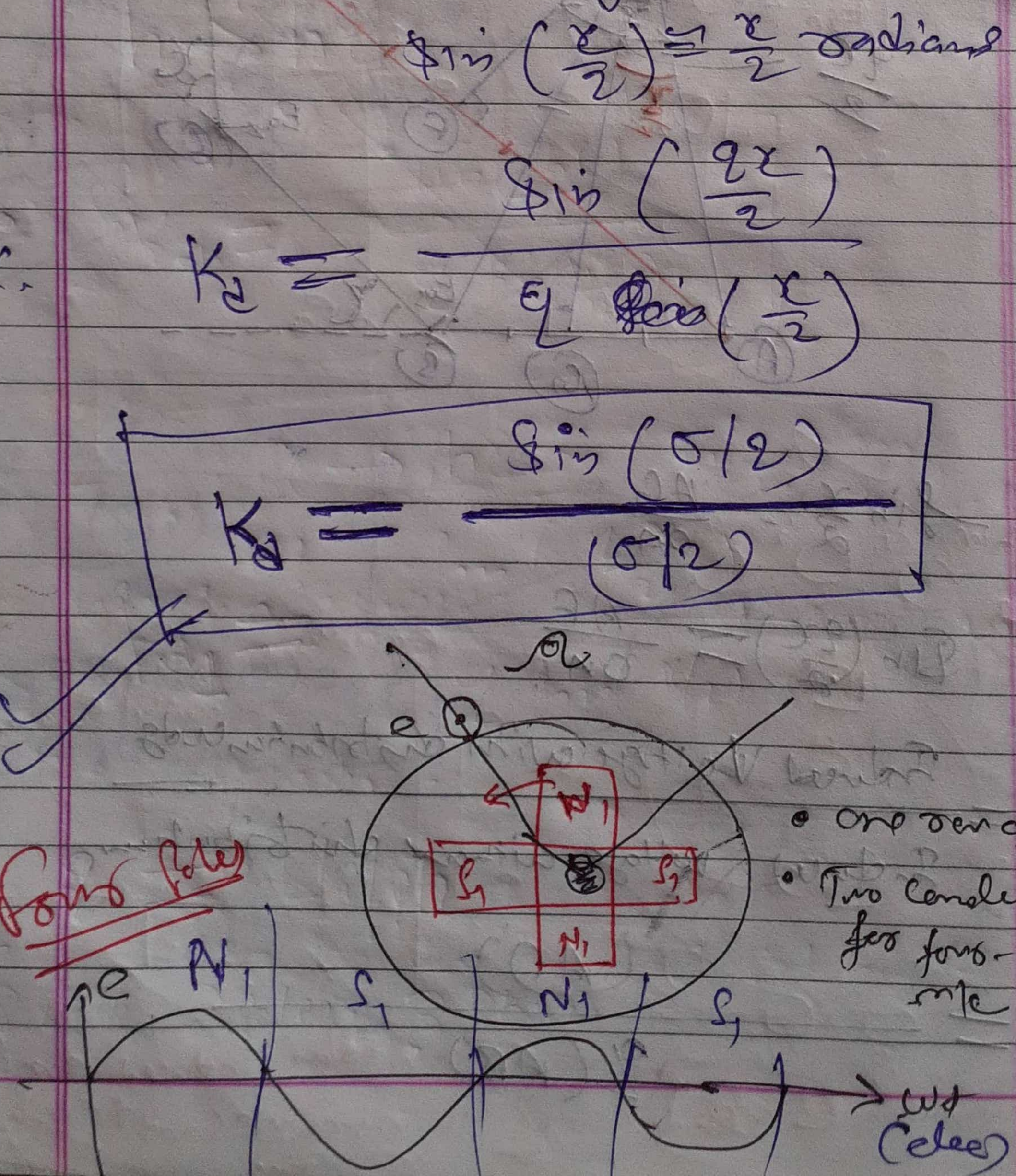
∵ $\gamma \rightarrow$ very small (in radians)

$\sin\left(\frac{\gamma}{2}\right) \cong \frac{\gamma}{2}$ radians

$$\therefore\ K_d = \frac{\sin\left(\frac{q\gamma}{2}\right)}{q\,\cancel{\sin}\left(\frac{\gamma}{2}\right)}$$

$$\boxed{K_d = \frac{\sin(\sigma/2)}{(\sigma/2)}}$$

Four poles



- One set of coils
- Two concentric coils, for four-poles m/c

- So $\boxed{\text{one pole}}$ is covering $\boxed{180^\circ \text{ electrical}}$

- So for P-poles

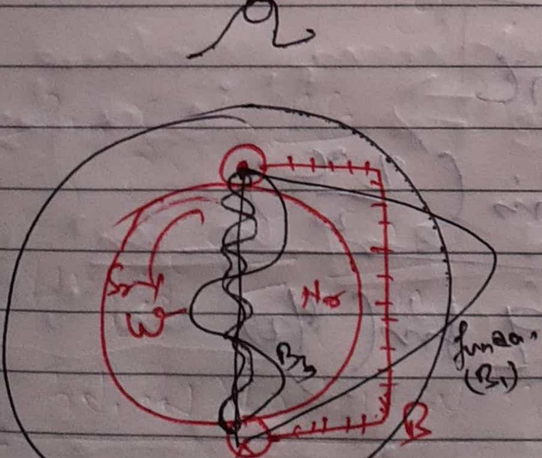
$$P \times 180^\circ \equiv \text{Total slot angles available (elec.)}$$

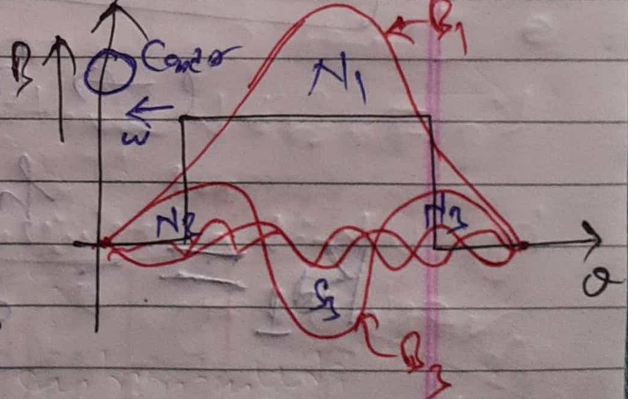
- Slot angle $\boxed{\gamma = \dfrac{P \times 180^\circ}{S} \text{ (elec.)}}$

$$\boxed{\theta_{ele.} = \frac{P}{2}\,\theta_{mech.}}$$

* $\boxed{1 \text{ pole} \equiv 180^\circ \text{ electrical}}$

- If electrical induced voltage is considered, only electrical angle (degree) is considered.





- All the harmonics (B_3, B_5, B_7, ...) will also rotate at synchronous speed N_s same as B_1 speed of N_s.

Num Date:
Page:

- Physically existing poles $= P$

Then Due to h harmonics
Num of induced poles $= hP$

$$\begin{cases} \text{fundamental poles rotates} \Rightarrow N_s \\ h\,\text{poles} \Rightarrow N_s \end{cases}$$

- γ slot angle $= \dfrac{180 \times P}{S}$ (ele)

$h \rightarrow h\gamma$

- $$\boxed{K_{dh} = \frac{\sin\left(\frac{q h \gamma}{2}\right)}{q \sin\left(\frac{h\gamma}{2}\right)}}$$

$\gamma \rightarrow h\gamma$

$$K_{d1} = \frac{\sin\left(\frac{q\gamma}{2}\right)}{q \sin(\gamma/2)}$$

- $q = S/P/ph$

Let
18 slots, 2 poles, 3 Phases

$q = 3$ (integer)

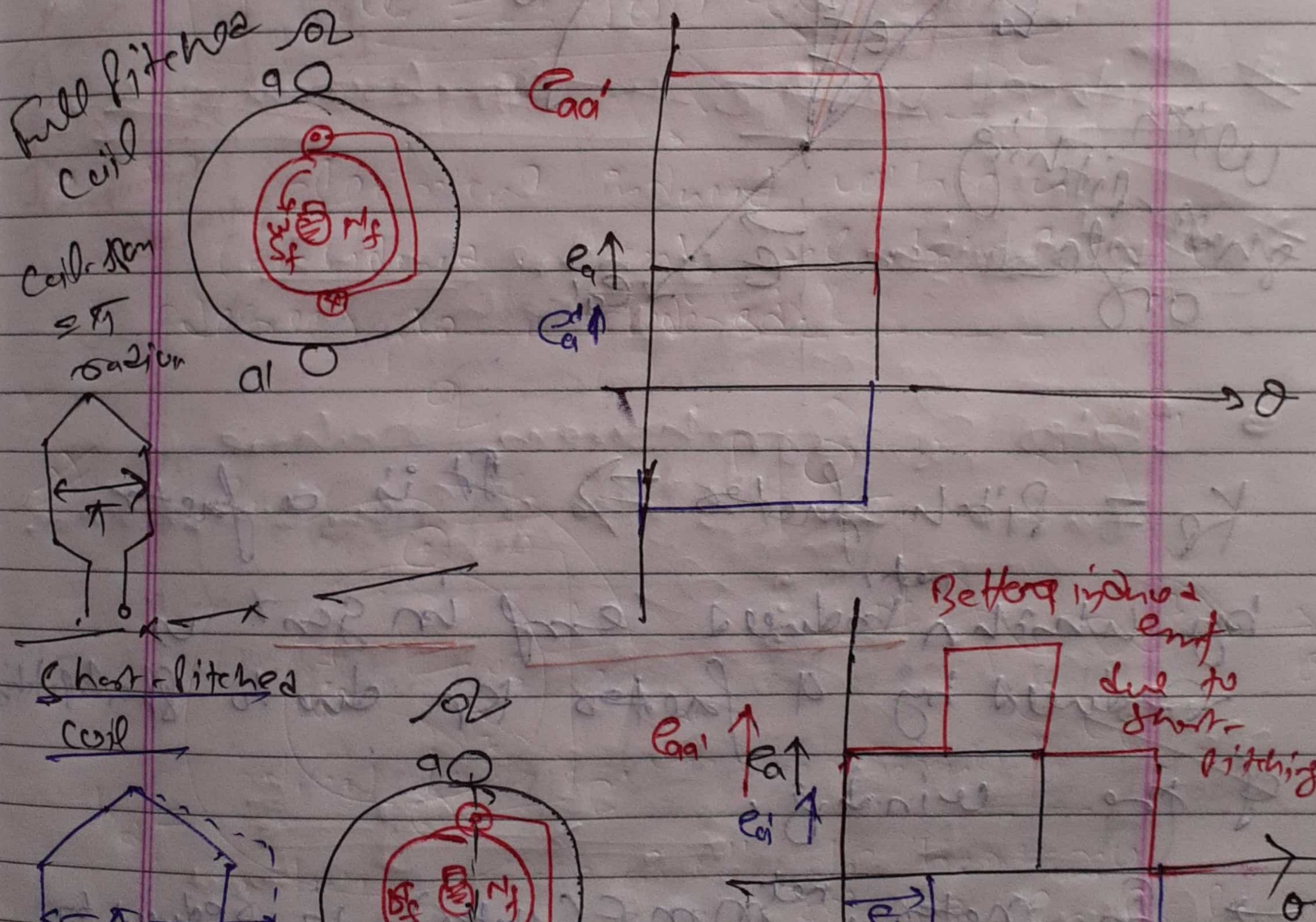
↳ Integral slot winding

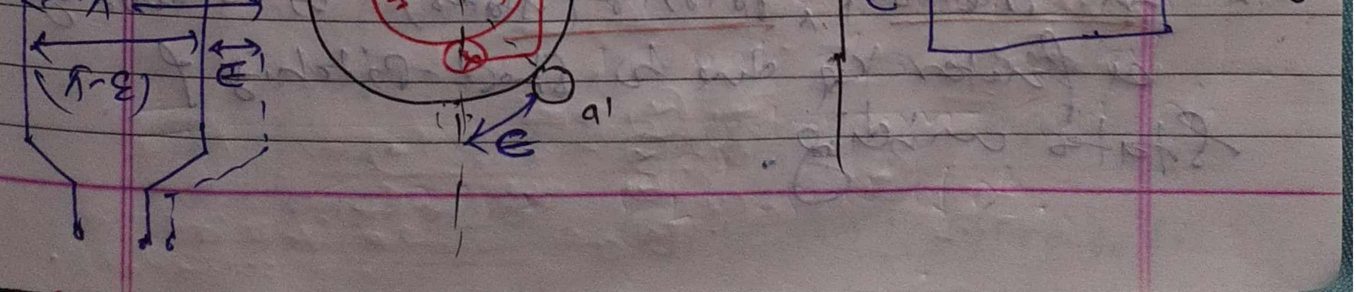
- If $\text{Slot/phase} = q = \frac{(S/P)}{\text{phase}} = \boxed{2.5} = \frac{5}{2}$ fractional slot winding

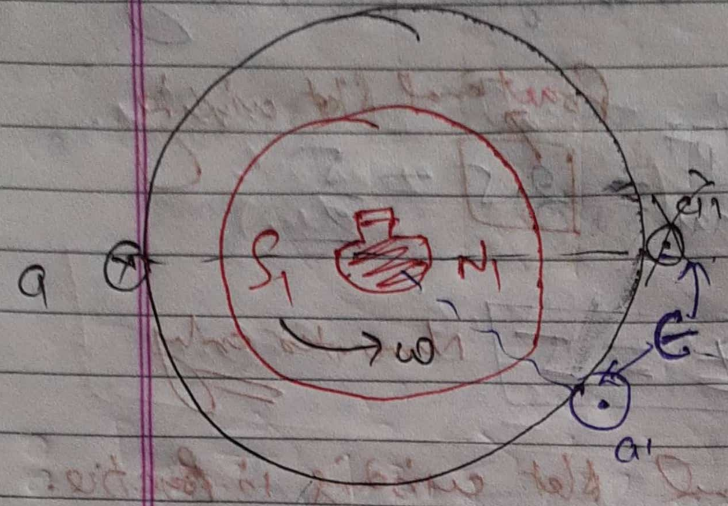
then $\boxed{q = 5}$ Numerator only

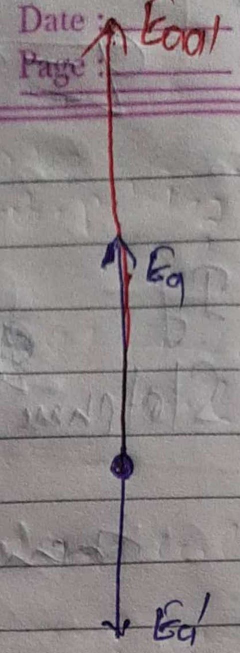
→ Usually fractional slot winding in practice.

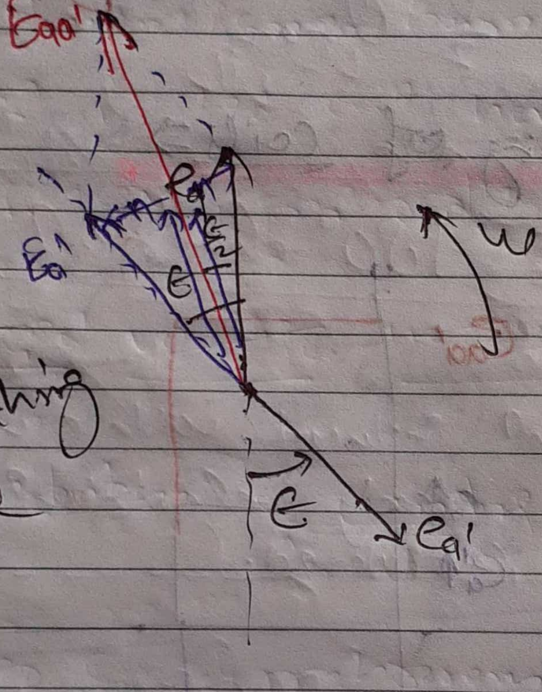
Short Pitching of Coils ⇒











With short-pitching angle

K_p = Pitch factor ⇒ It is a factor by which net induced emf in gen^r is reduced by a factor K_p due to short-pitching of the winding.

→ In motor, net mmf (stator) is reduced by a factor K_p due to short-pitching of stator winding.

$E_{ag} = 2\left(E_a \cos\frac{\epsilon}{2}\right)$

$E_{ag} = 2E_a \cos(\epsilon/2)$ (with short pitching)

Pitch factor

$$K_p = \frac{\text{Induced voltage with short-pitched coil}}{\text{Induced voltage with full pitched coil}}$$

$$K_p = \frac{2E_a \cos(\epsilon/2)}{2E_a}$$

$$\boxed{K_{p_1} = E_a \cos(\epsilon/2)}$$

for fundamental component of induced voltage

Due to h. harmonics:-

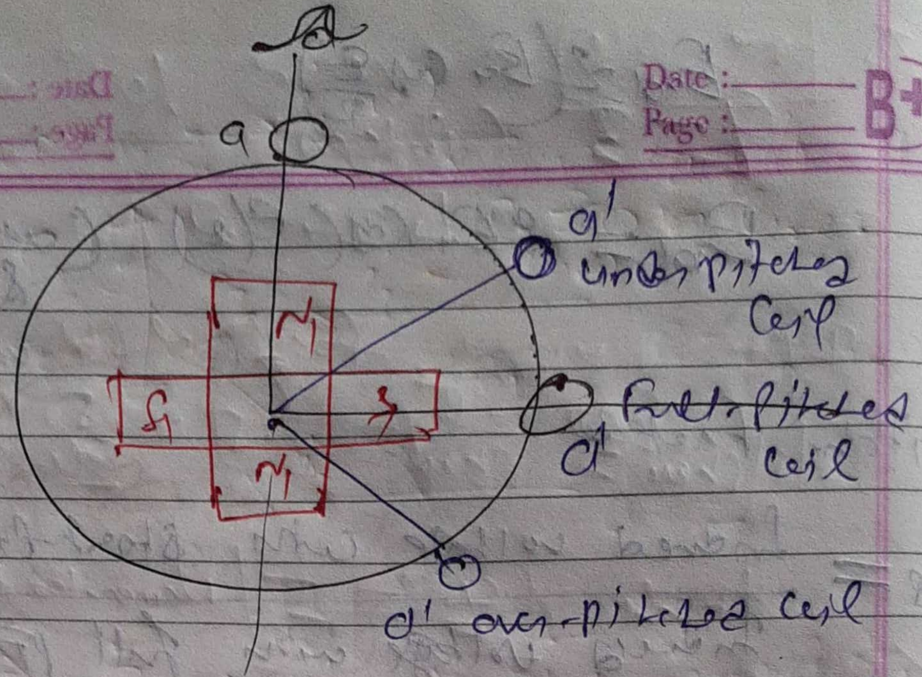
$$\epsilon \Rightarrow h\epsilon$$

$$\boxed{K_{ph} = E_a \cos\left(\frac{h\epsilon}{2}\right)}$$

To vanish h-harmonic induced voltage

$$K_{ph} = 0 \Rightarrow \frac{h\epsilon}{2} = \frac{\pi}{2} \Rightarrow \boxed{\epsilon = \frac{\pi}{h}} \text{ radian}$$

- Using short-pitched coil
  Cu. fixed for induced emf E_{ag} ⇒
  To have rated emf E ⇒ turns are increased. Cu. is still increased.

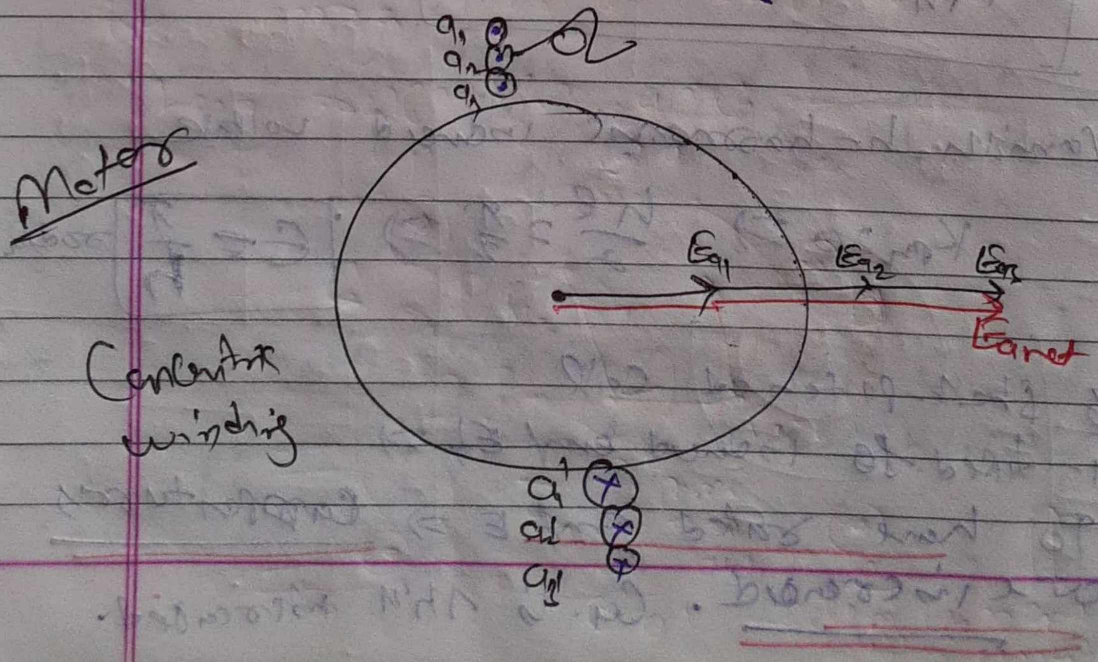


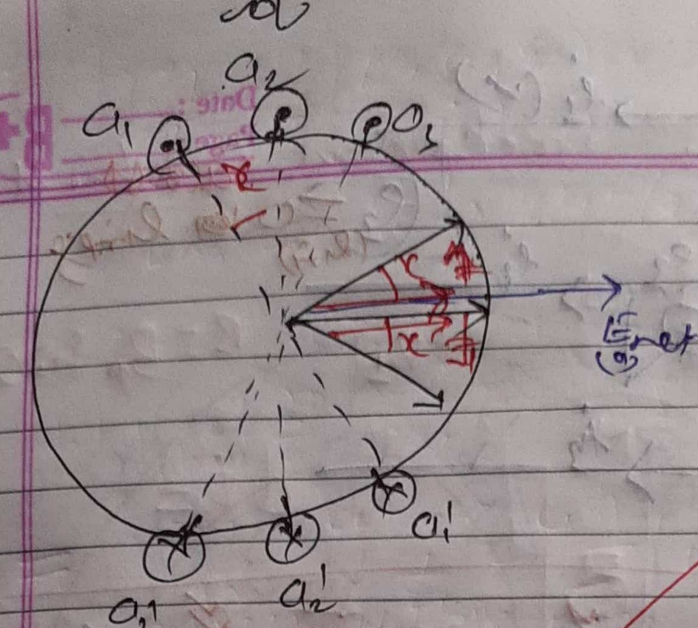
- Short-pitched coil and over pitched coil, reduce same harmonics, but short pitched coil have less overhang copper as compared to over-pitched coil.

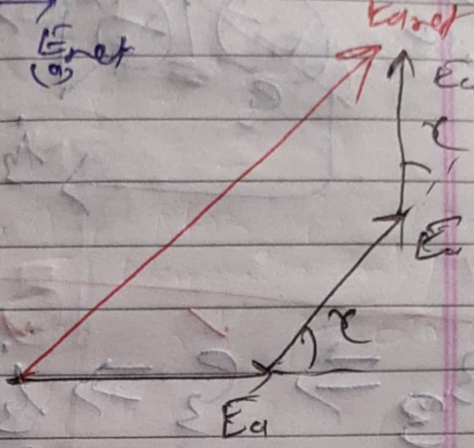
~~Induced voltage in Synchronous machine~~

Distribution of winding Part-3

- Stator of Synchronous machine is same as Stator of Induction machine.

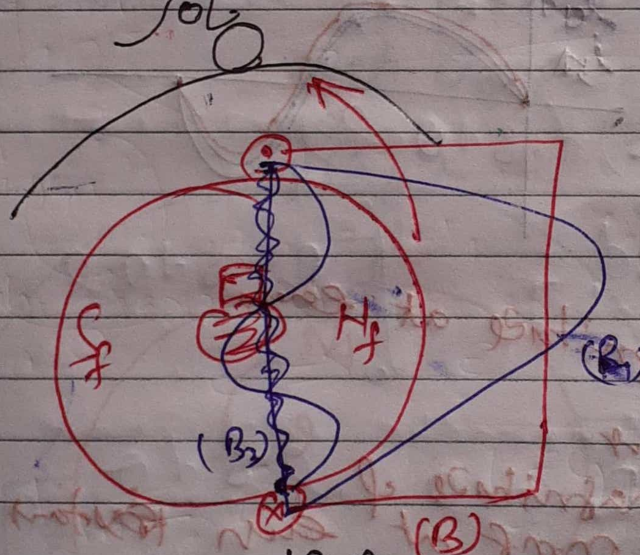


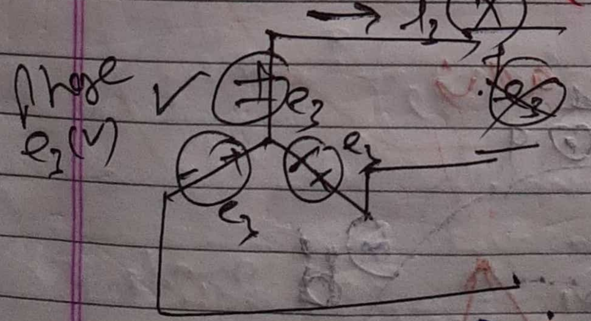


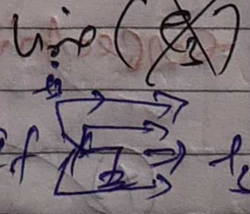


Distributed Winding

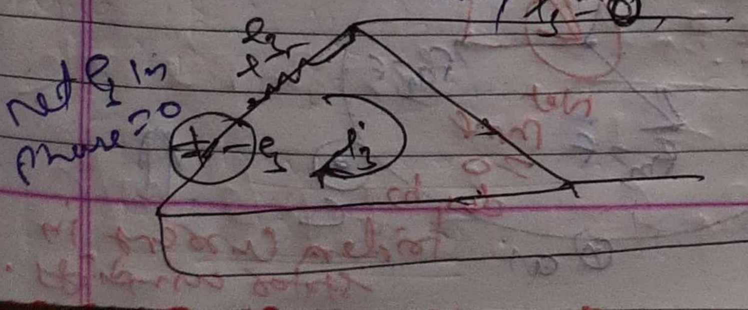
$$\boxed{\underset{\text{(distri. wdg)}}{E_{a(net)}} < \underset{\text{(Concentric wdg)}}{E_{a(net)}}}$$



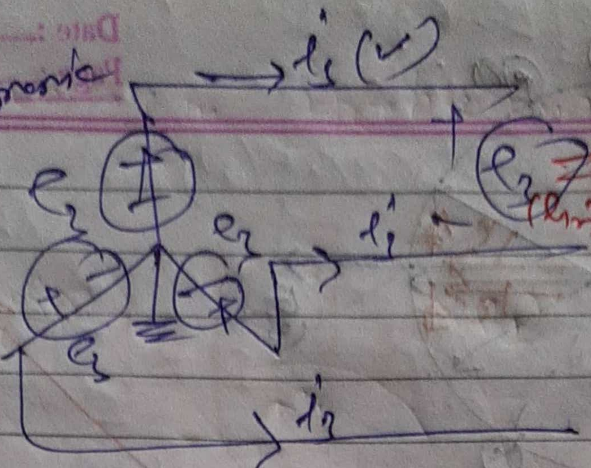




If ... i_3 flow in the armature circuits.



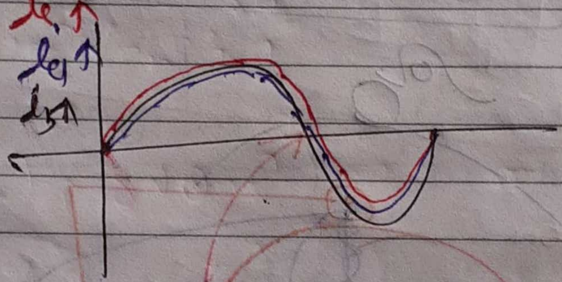
Third harmonic induced voltage



$$\boxed{B_3 \Rightarrow e_3 \Rightarrow i_3' \Rightarrow \text{Net mmf (due to } i_3') = 0}$$

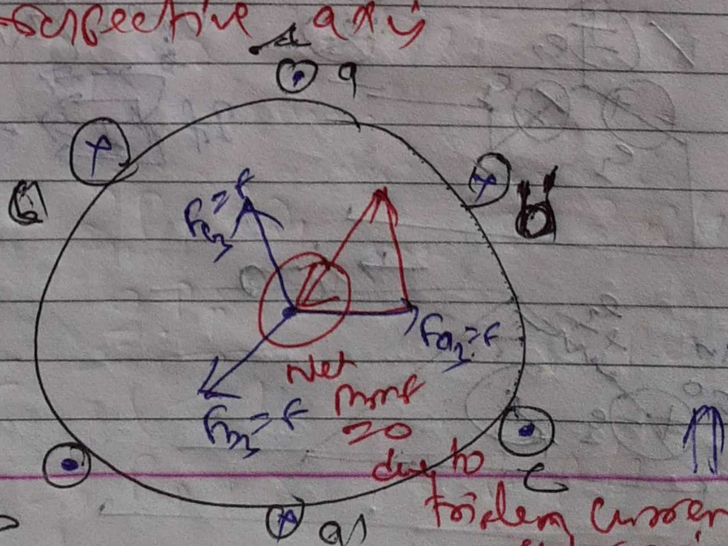
space, time, time, space

Triplen Harmonic



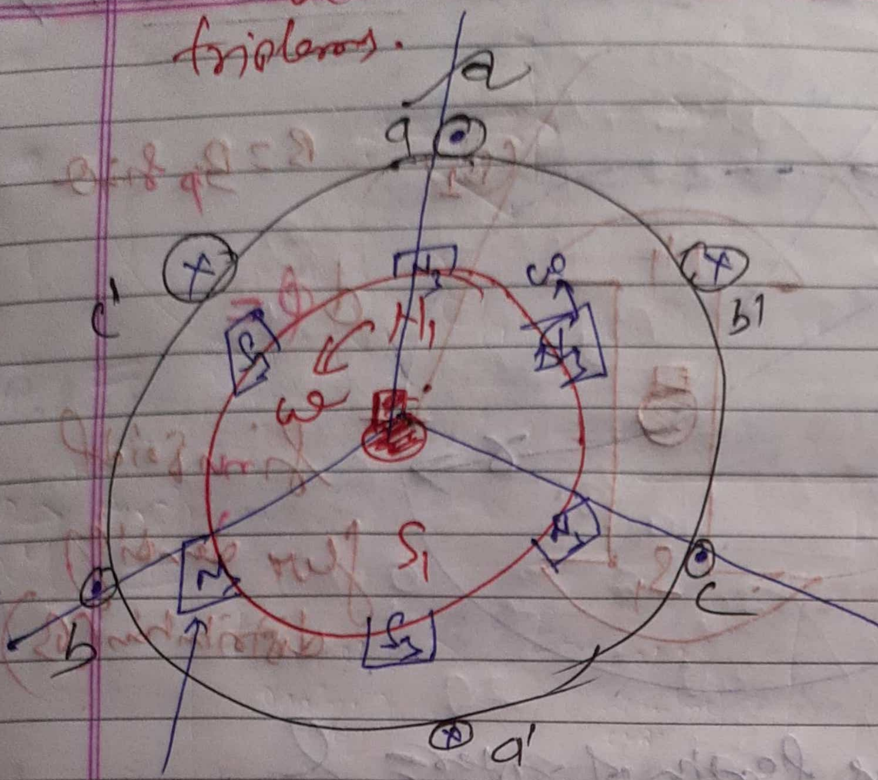
i_{a3}, i_{b3}, i_{c3} → same magnitude at each instant

i.e. same magnitude of mmf at each instant along their respective axis



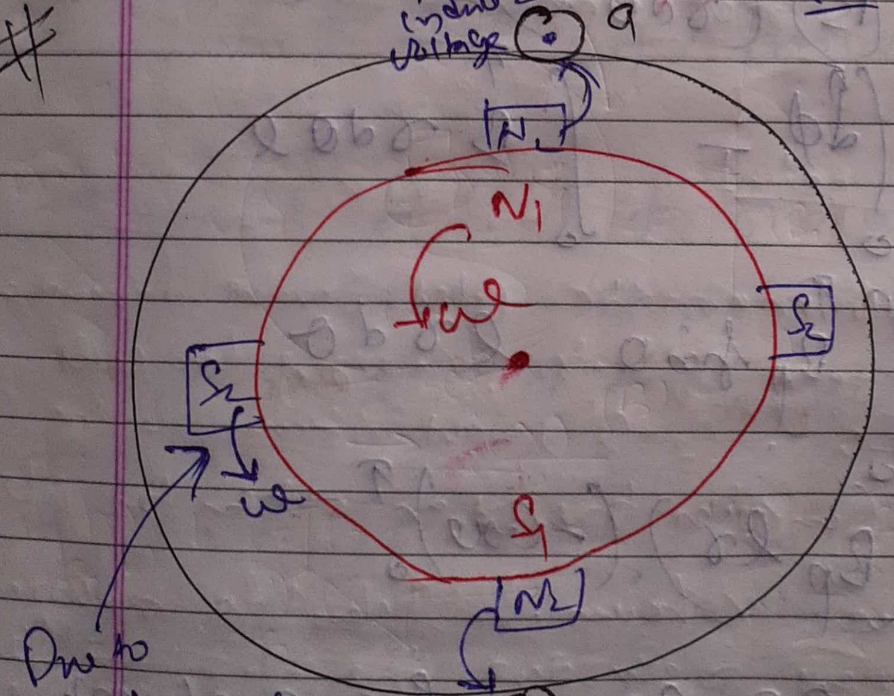
due to triplen currents in stator windings.

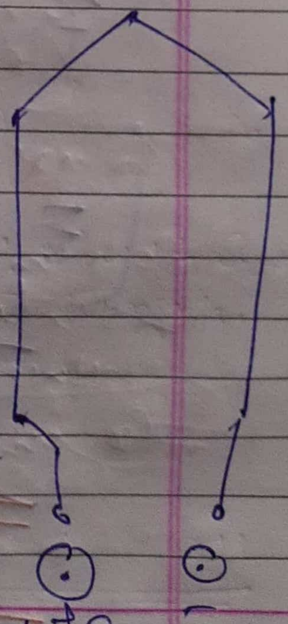
⇒ So no torque due to triplen harmonics Since no AR due to triplens.



Poles induced due to $i_{a_3}, i_{b_3}, i_{c_3}$ but Net MMF = 0,

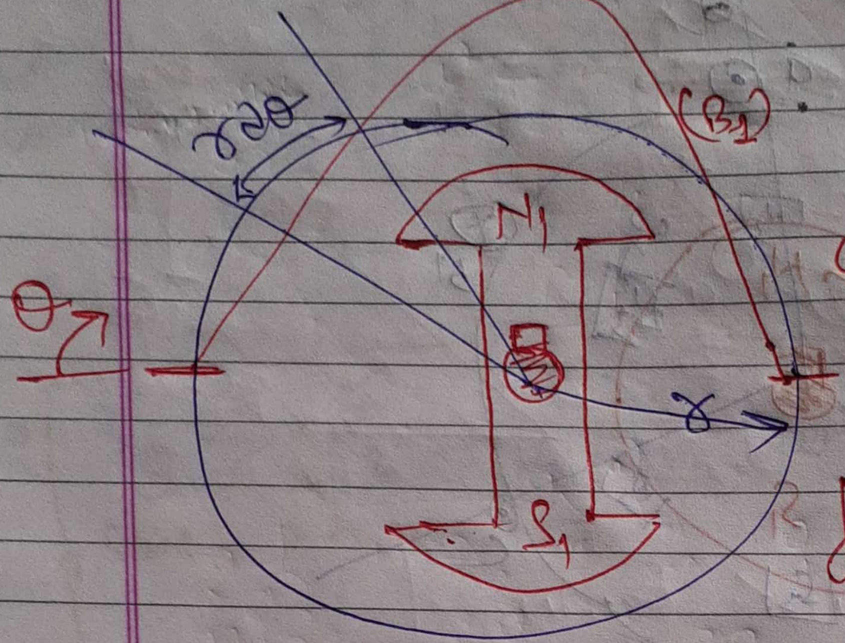
#





For even harmonics ($e_{net} = 0$)

Induced voltage in Synchronous Machines ⇒



$B = B_p \sin\theta$

$d\phi =$

sinusoidal flux density distribution (B)

Let active length of rotor = l
(axial length)

$$d\phi = (B)(r\,d\theta\, l)$$

avg flux per pole
$$\phi = \int_0^{\pi} d\phi = \int_0^{\pi} B\, r\, d\theta\, l$$

$$= \int_0^{\pi} B_p \sin\theta \; l\, r\, d\theta$$

$$= (B_p l r)\left(-\cos\theta\right)_0^{\pi}$$

$$= 2 B_p l r \quad \text{for 2-pole m/c}$$

$$= \frac{2 B_p l r}{\left(\frac{P}{2}\right)} \quad \text{for P pole m/c}$$

$$= \frac{4}{P} B_p l r \quad \text{for P pole m/c}$$

Note!

flux per pole

$$\phi_{PP} = \frac{4}{P} B_p l r$$

for sinusoidal flux density distribution in air-gap

Induced voltage in a Condr

$$e_{cond} = B l (v)$$ velocity

$$= (B_p \sin\theta)(l)\left(2\pi r \left(\frac{N}{60}\right)\right)$$ rev/sec

$$= \phi \pi \left(\frac{N}{60}\right) \sin\theta$$ rev/sec, space

$$= \phi \pi \cdot (f) \sin(\omega t)$$

$$e_{turn} = 2 \phi \pi f \sin(\omega t)$$

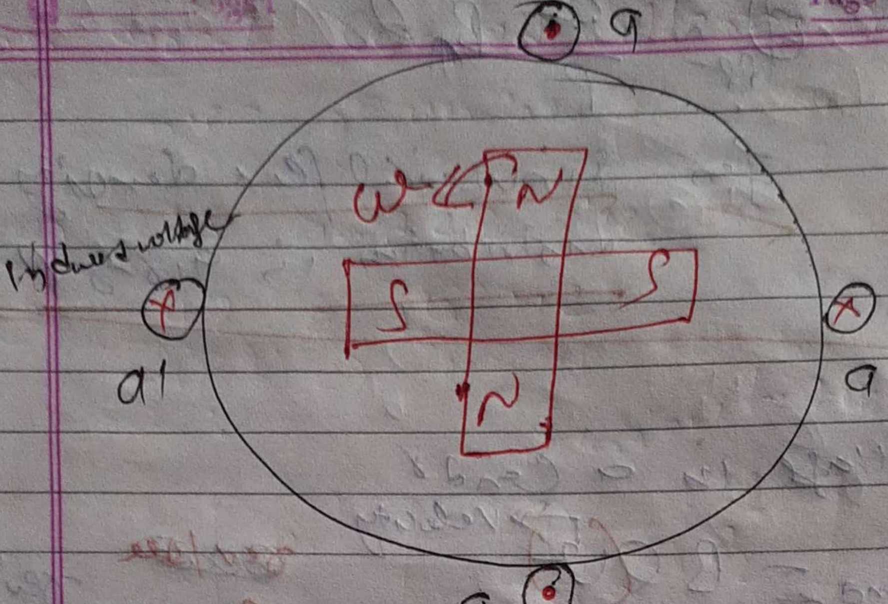
$$e_{coil} = 2 \phi \pi f N_{se} \sin(\omega t)$$

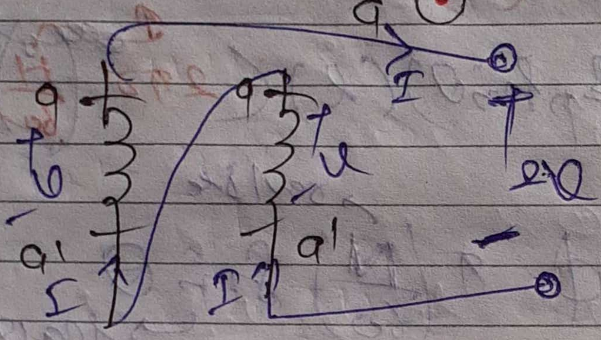
$$\boxed{E_{ph} = \sqrt{2} \pi f \phi N_{se} K_p K_d}$$

per phase induced emf

flux per pole

N_{se} = Series turns per phase

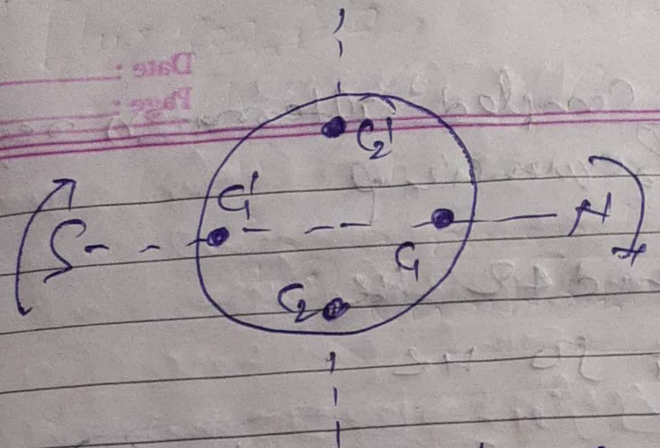




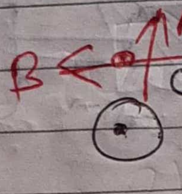
N_{ph} = Series connected turns per phase

Problem set-1

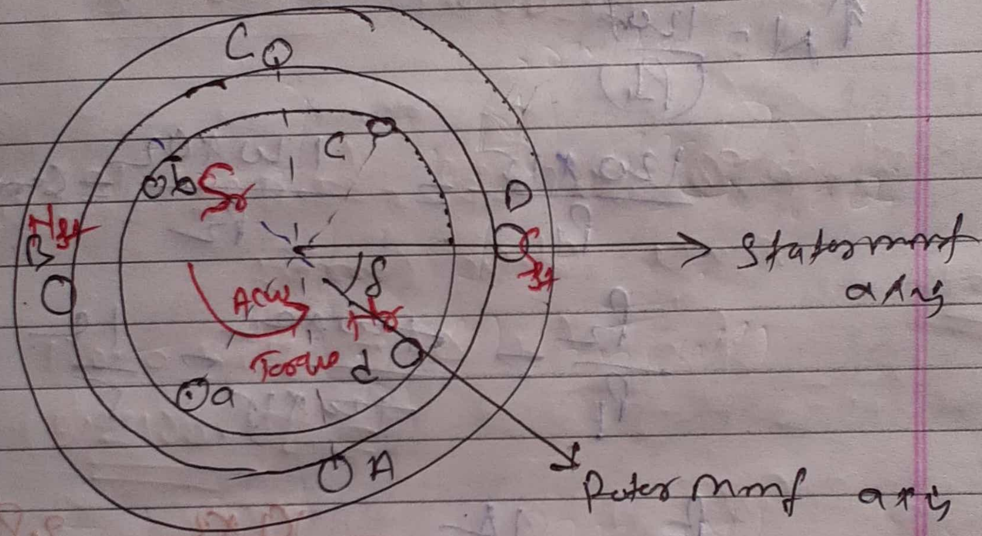
1Qus: Two magnetic poles revolve around a stationary armature carrying two coils (C_1-C_1', C_2-C_2') as shown in the figure. Consider the instant when the pole position as shown. Identify the correct statement regarding the polarity of the ~~induced emf~~ at this instant in coil sides C_1 and C_2.



(a) ⊙ in C_1, and also emf in C_2



Qus



Qus. A hydraulic turbine having rated speed of 250 rpm is connected to a synchronous gen^r. In order to produce power at 50 Hz, the number of poles required in the gen^r are?

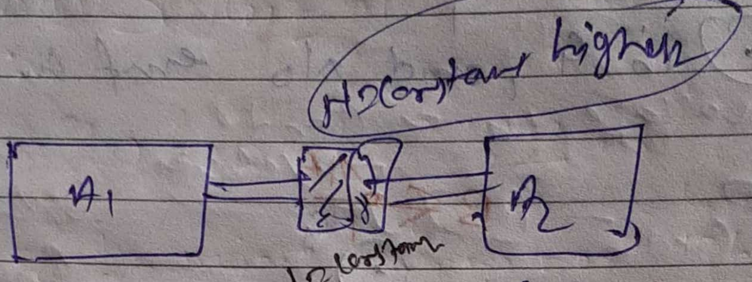
$$f = \frac{PN}{120} \Rightarrow P = \frac{120f}{N}$$

$$P = \frac{\cancel{120}^{24} \times 50}{\cancel{250}_{5}} = 24 \text{ poles}$$

Qus Find the highest speed and corresponding number of poles for two direct coupled alternators required to give frequencies of

(a) 15 and 42 Hz

(b) 42 & 50 Hz



15 Hz　　　　　　42 Hz

$$\uparrow N = \frac{120f}{(P\downarrow)}$$

$$\frac{120\times 15}{P_1} = \frac{120\times 42}{P_2} = \text{Con}$$

$$\frac{P_2}{P_1} = \frac{\cancel{120}\times 42}{\cancel{120}\times 15} = \frac{14}{5}$$

$$\frac{P_2}{P_1} = \frac{14}{5} = \frac{14\times 2}{5\times 2} = \frac{28}{10}$$

$\boxed{N\uparrow \Rightarrow P\downarrow}$

$$\left.\begin{aligned} P_2 &= 28 \\ P_1 &= 10 \end{aligned}\right\} N = \text{highest}$$

$$N = \frac{120\times 15}{10} = \underline{180\ \text{rpm}}$$

(b) $\overset{f_1}{42\ \text{Hz}}$ & $\overset{f_2}{50\ \text{Hz}}$

$$\frac{120\times 42}{P_1} = \frac{120\times 50}{P_2} \Rightarrow \frac{P_2}{P_1} = \frac{\cancel{50}^{25}}{\cancel{42}_{21}}$$

$$\frac{P_2}{P_1} = \frac{25}{21}$$

$P \to min \Rightarrow N = highest$

$$\frac{P_2}{P_1} = \frac{25}{21} \times \frac{2}{2} = \frac{50}{42}$$

$P_2 = 50$ for $N_{highest} = \frac{120 \times 50}{50} = 120$ rpm

$P_1 = 42$

Que) A 50Hz synchronous ~~motor~~ clock is correct at 7 AM. From 7 AM to 1 PM the average frequency is 49.95 Hz. From 1 PM to 6 PM is 49.90 HZ. What must be the average frequency for remainder of the 24 hours in order that the clock be correct again at 7 AM? By how much is the clock incorrect at 6 PM?

Ans) @ 7 AM ⇒ Correct

6hrs @ 7AM to 1PM ⇒ $f = 49.95$ Hz

5hrs @ 1PM to 6PM ⇒ $f = 49.90$ HZ

13hrs @ 6PM to 7 AM ⇒ $f = ?$ (Correct)

@ 7 AM to 6PM ⇒ ~~frequency~~ (cycles) left $= (6 \times 3600)(0.05) + (5 \times 3600)(0.10)$

$= 2880$ cycles

→ Tomorrow correct at 7AM

$= (\cancel{13 \times 3600} \times 50)$ cycles $+$ ~~2880 cycles~~ $=$

Requirement = $11 \times 3600 \times 50$

$= 1980000$ cycles

Left $= 2880$ cycles

Δ cycles $= 1977120$

$$\Delta f = \frac{1977120}{3600}$$

Extra freq to inject in for next 13 hrs to make correct

$$\Delta f = \frac{2880}{13 \times 3600} = 0.061 \text{ Hz}$$

Net freq applied for next 13 hrs to make clock correct

$$f' = f + \Delta f = 50 + 0.061$$
$$= 50.061 \text{ Hz}$$

(ii)

Time delay up to 6 Pm

$$= \frac{2880 \text{ cycles lost}}{50 \text{ cycles/sec}} = \frac{2880}{50} \text{ sec}$$

$= 57.6$ sec delay

Ques: A three phase 10 pole star connected alternator at 600 rpm. It has 120 slots with 8 conductors per slot and the conductors of each

Phase are connected in series. Determine the phase and line emfs if the flux pole is 56 mwb.

Ans:

3ϕ, 10P, Y, 600 rpm, 120 slots,

$\boxed{8 \text{ condr per slot}}$,

$\phi_{m} = 56$ mwb

$K_p = 1$, $K_d = \dfrac{\sin\left(\frac{q\gamma}{2}\right)}{q \sin\left(\gamma/2\right)}$

$q = \dfrac{S/P}{m} = \dfrac{120}{10 \times 3} = 4$

$\gamma = \dfrac{(10)(180^\circ)}{120} = 15^\circ$ ele,

$K_d = \dfrac{\sin\left(\frac{4 \times 15}{2}\right)}{4 \sin\left(\frac{15}{2}\right)} = \dfrac{0.5}{4 \times 0.1305}$

$= 0.9578$

$E_{ph} = \sqrt{2} \pi f \phi_{m} N_{se}$

$= \sqrt{2}\pi \times 50 \times 56 \times 10^{-3} \times \left[120 \times 8 \times \frac{1}{2} \times \frac{1}{3}\right] \times 0.9578$

$= 1983.475 \times (0.9578)$

$= 1899.7725$ volts

$E_{line} = \sqrt{3} \times 1899.7725$

$= 3290.4061$ volts

Ques. Determine the root mean square value of the individual harmonic components and of the total induced emf per phase of a 50Hz, 3 phase alternator from the following data:

10 poles, S/P/ph = 2, Cond^r per slot (2 layers) = 4,

Coil span = 150°,

ϕ_{pp} = 0.12 wb

20% 3rd harmonic air gap flux. All the coils are connected in series.

Ans.

$$K_{p1} = \cos\left(\frac{\psi}{2}\right) = \cos\left(\frac{30}{2}\right) = 0.9659$$

$$K_{p3} = \cos\left(\frac{3\psi}{2}\right) = \cos\left(\frac{3 \times 30}{2}\right) = 0.7071$$

$$K_{d1} = \frac{\sin\left(\frac{q\gamma}{2}\right)}{q\sin\frac{\gamma}{2}} = \frac{\sin\left(\frac{2 \times 30°}{2}\right)}{2\sin\left(\frac{30°}{2}\right)} = \frac{0.5}{2 \times 0.258} = 0.9659$$

$$K_{d3} = \frac{\sin\left(\frac{3q\gamma}{2}\right)}{q\sin\left(\frac{3\gamma}{2}\right)} = \frac{\sin\left(\frac{3 \times 2 \times 30°}{2}\right)}{2\sin\left(\frac{3 \times 30°}{2}\right)} = \frac{0.866}{2 \times 0.707} = 0.707$$

$$\gamma = \frac{10 \times 180°}{(2 \times 10 \times 3)} = 30°$$

$E_{ph_1} = \sqrt{2}\pi f \phi_{m_1} N_{se} K_{d_1} K_{p_1}$

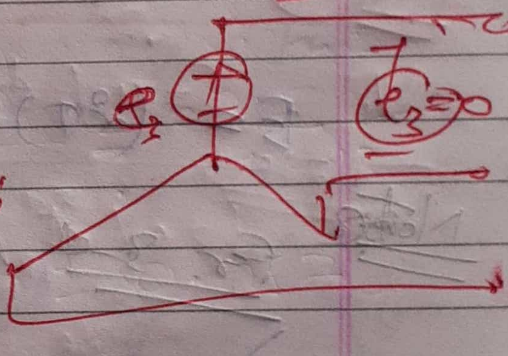
$= \sqrt{2}\pi \times 50 \times 0.12 \times \left(2\times10\times3\times4\times\frac{1}{2}\times\frac{1}{3}\right) \times 0.9589 \times 0.9659$

$= 993.420$ volt

$E_{ph(3)} = \sqrt{2}\pi(3\times50)\times(0.20\times0.12)\times\left(2\times10\times3\times4\times\frac{1}{2}\times\frac{1}{3}\right)(0.7071\times0.7071)$

$= 106.2299$ volt

$\cancel{E_{line} = E_{ph} =} \sqrt{E_{ph_1}^2 + E_{ph(3)}^2} = \cancel{1021.12 \text{ volt}}$



$E_{line} = \sqrt{3}\, E_{ph(1)}$
(3rd harmonic not in line)

$E_{ph} = \sqrt{E_{ph(1)}^2 + E_{ph(3)}^2} = 999.08$ volt

$E_{line} = \sqrt{3}\cdot E_{ph(1)} = 1720.60$ volt

Note ⇒ If E_1, E_3, E_5

$E_{ph} = \sqrt{E_1^2 + E_3^2 + E_5^2}$

$E_{line} = (\sqrt{3})\left\{\sqrt{E_1^2 + E_5^2}\right\}$

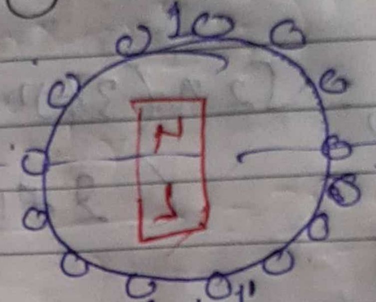
Date :
Page :

Problem Set-2

Ques: The armature of a single-phase alternator is completely wound with T single turn coils distributed uniformly, the induced voltage in each turn is 2 volts (rms). The emf of the whole winding — ?

(a) 2T volt (b) 1.11T volt (c) 1.414T volt

(d) 1.273T volts.



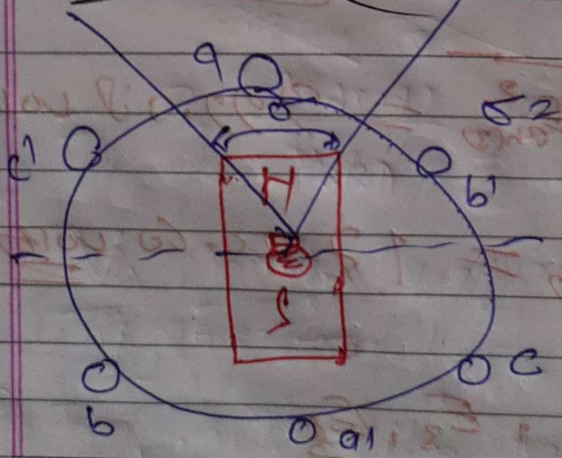
Sol: T coils

$$K_d = \frac{\sin\left(\frac{q\alpha}{2}\right)}{q\sin\left(\frac{\alpha}{2}\right)} = \frac{\sin(\sigma/2)}{\left(\frac{\sigma}{2}\right)} \qquad \sigma = \pi$$

$$K_d = \frac{\sin(\pi/2)}{\left(\frac{\pi}{2}\right)} = \frac{2}{\pi}$$

$$E = (2T)\left(\frac{2}{\pi}\right) = \frac{4}{\pi}T = 1.273T$$

Note: For 3ϕ (Narrow spread)



$$\sigma = \frac{\pi}{3}$$

$$K_d = \frac{\sin\left(\frac{q\alpha}{2}\right)}{q\sin\left(\frac{\alpha}{2}\right)} = \frac{\sin(\sigma/2)}{\left(\frac{\sigma}{2}\right)} = \frac{\left(\frac{1}{2}\right)}{\left(\frac{\pi}{6}\right)} = \frac{3}{\pi}$$

$$\boxed{K_{d(3\phi)} = \frac{3}{\pi}}$$

Date :
Page : B+

Note

For uniformly distributed winding.

$$K_{d(1\phi)} = \frac{2}{\pi}$$

$$K_{d(3\phi)} = \frac{3}{\pi}$$

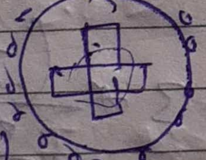
Qus: A 20 pole alternator is having 180 identical stator slots with 6 conductors in each slot. All the ~~slots~~ coils of a phase are in series. If the coils are connected to realize single-phase winding, the generated voltage is V_1. If the coils are reconnected to realize three-phase star-connected winding, the generated phase voltage is V_2. Assuming full pitch, 1-layer winding, the ratio V_1/V_2 is ___

(a) $1/\sqrt{3}$ (b) $1/2$ (c) $\sqrt{3}$ (d) 2

$K_p = 1$

1 φ

20 poles, 180 slots, 6 conductors per slot



$$K_{d(1\phi)} = \frac{\sin\left(\frac{q\gamma}{2}\right)}{q \sin(\gamma/2)}$$

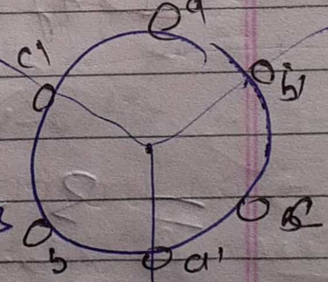
$$q = \frac{(180)}{20 \times 1} = 9$$

$$\gamma = \frac{(180^\circ)(20)}{180} = 20^\circ$$

$$K_{d(1\phi)} = \frac{\sin\left(\frac{9 \times 20^\circ}{2}\right)}{(9)\sin(10^\circ)}$$

$$= \frac{1}{9 \sin(10^\circ)}$$

3 φ



$$q = \frac{(180)}{20 \times 3} = 3$$

$q = 3$ $\quad$ $\gamma = 20^\circ$

$$K_{d(3\phi)} = \frac{\sin\left(\frac{3 \times 20^\circ}{2}\right)}{3 \sin\left(\frac{20^\circ}{2}\right)}$$

$$= \frac{\left(\frac{1}{2}\right)}{3 \sin(10^\circ)} =$$

$$= \frac{1}{6 \sin(10^\circ)}$$

Date :
Page :

V_1

$E_{1\phi} = \sqrt{2}\pi f \phi_{pp} N_{s1} K_{d_1} K_p$

V_2

$E_{3\phi} = \sqrt{2}\pi f \phi_{pp} N_{s3} K_{d_3} K_p$ (phase)

$$\frac{V_1}{V_2} = \frac{N_{s_1} K_{d_1}}{N_{s_3} K_{d_3}} = \frac{[(\cancel{180 \times 6})/2] \times K_{d_1}}{(180 \times 6 \times \frac{1}{2} \times \frac{1}{3}) \times K_{d_3}}$$

$$\frac{V_1}{V_2} = 3 \frac{K_{d_1}}{K_{d_3}} = 3 \times \frac{\left(\frac{1}{9}\right)}{\left(\frac{1}{6}\right)} = 3 \times \frac{6}{9} = 2$$

$$\boxed{\frac{V_1}{V_2} = 2}$$

Note (1)

$$\frac{V_1}{V_2} = \frac{\cancel{\sqrt{2}\pi f \phi_{pp}}\left(\boxed{180 \times 6 \times \frac{1}{2}}\right) \times K_{d_{1\phi}}}{\cancel{\sqrt{2}\pi f \phi_{p}}\left(\boxed{180 \times 6 \times \frac{1}{2} \times \frac{1}{3}}\right) \times K_{d(3\phi)}}$$

$$= 3 \frac{K_{d(1\phi)}}{K_{d(3\phi)}} = 3 \times \frac{\left(\frac{2}{\pi}\right)}{\left(\frac{3}{\pi}\right)} = 2$$

$$\boxed{\frac{V_1}{V_2} = 2}$$

$$\frac{V_{1\phi}}{V_{3\phi}} = 2 \Rightarrow \boxed{V_{1\phi} = 2 V_{3\phi}}$$

Note ③

Date :
Page :

B+

$S_{1\phi} = V_{1\phi} I_{ph}$

$= 2 V_{3\phi} I_{ph}$

(Cu. cond. same)

$I_{ph} \rightarrow$ same

$S_{3\phi} = 3 V_{3\phi} I_{ph}$

$= 3 (2 V_{3\phi}) I_{ph}$

$= 3 V_{3\phi} I_{ph}$

$\frac{S_{3\phi}}{S_{1\phi}} = \frac{3}{2} \Rightarrow \boxed{S_{3\phi} = 1.5 S_{1\phi}}$

for same cost of m/c,

3ϕ connection gives 50% more power as compared to 1-ϕ connection.

Que: A 3-ϕ alternator is wound with a 60 degree phase-spread arm. winding and develops 300 KVA. If the arm. is reconnected utilizing all the coils for 1-ϕ operation with a phase spread of 180°, the new rating of the m/c is ___?

(a) 100 KVA (b) 200 KVA (c) 250 KVA (d) 300 KVA

Ans: 3ϕ

$\sigma = 60°$

$S_{3\phi} = 300 KVA$

$K_{d3\phi} = \frac{\sin(30°)}{(\frac{\pi}{6})} = \frac{6}{2\pi}$

$K_{d3\phi} = \frac{3}{\pi}$

1ϕ

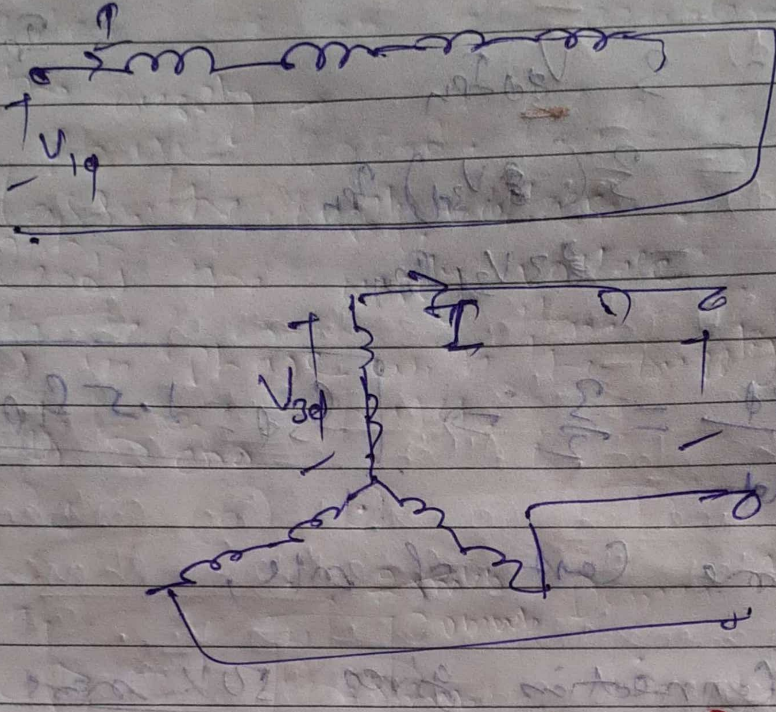
$\sigma = 180°$

$K_{d1\phi} = \frac{\sin(90°)}{(\frac{\pi}{2})} = \frac{2}{\pi}$

$\frac{S_{1\phi}}{S_{3\phi}} = \frac{\sqrt{2}\pi f \phi_{pp} \cdot (N_{se1}) K_{d1} (I)}{3 (\sqrt{2}\pi f \phi_{pp} \cdot (\frac{N_{se1}}{3}) K_{d3\phi}) (I)}$

Date :
Page :

$$\frac{S_{1\phi}}{S_{3\phi}} = \frac{3}{2}\frac{K_{d1}}{K_{d3}} = \frac{3}{2}\left(\frac{2}{\pi}\right)\left(\frac{\pi}{3}\right) = \frac{2}{3}$$



$$\frac{S_{1\phi}}{S_{3\phi}} = \frac{2}{3} \Rightarrow S_{1\phi} = \frac{2}{3} * 300$$

$$\boxed{S_{1\phi} = 200\,KVA}$$

<u>Note</u> $\Rightarrow$ $S_{3\phi} = 1.5\, S_{1\phi} = \frac{3}{2} S_{1\phi}$

$$S_{1\phi} = 300(1-0.5)$$

$$S_{1\phi} = \frac{2}{3} S_{3\phi} = \frac{2}{3} \times 300 = 200\,KVA$$

<u>Ques</u> The phase sequence of a 3ϕ alternator will reverse if

(a) The field curr is reversed keeping the direction of rotation same

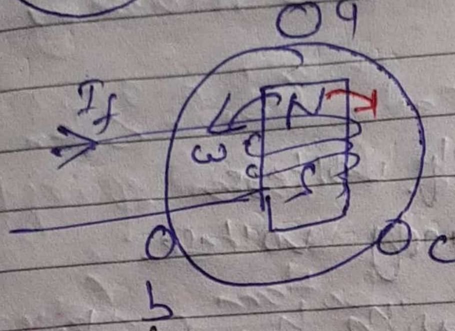
(b) The field current remaining the same but the direction of rotation is reversed.

(c)

(d)

Date :
Page :
B+

(c) X



(b)

abc
acb

Ques: It is desirable to eliminate 5th harmonic voltage from the voltage of an alternator. The coils should be short pitched by an electrical angle of

(a) 30° (b) 36° (c) 72° (d) 18°

$K_{p_n} = \cos(n\beta/2)$

$\cos\left(\frac{5\beta}{2}\right) = 0$

$\frac{5\beta}{2} = \frac{\pi}{2}, \frac{3\pi}{2}, \ldots$

$\beta = \frac{2}{5}\frac{\pi}{2}, \frac{2}{5}\frac{3\pi}{2}, \ldots$

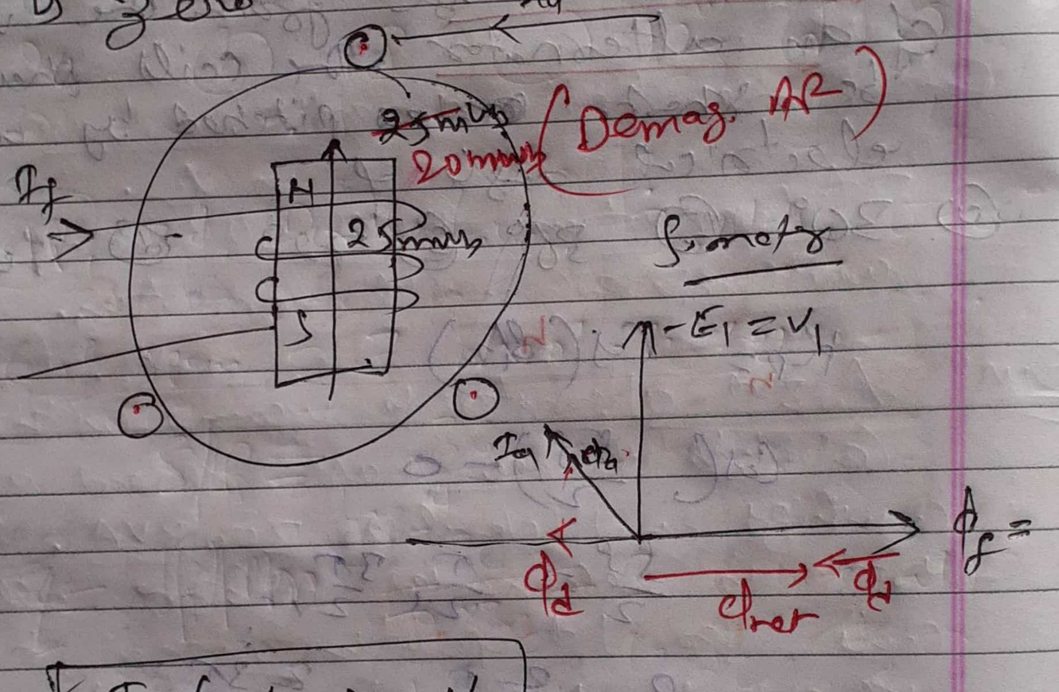
$\beta = \frac{180°}{5}, \frac{6}{15}(180°), \ldots$

$\boxed{\beta = 36°}$

Ques: The flux per pole in a synchronous motor with field cct ON and the stator disconnected from supply is found to be 25 mwb. When the stator is connected to the rated supply with the field excitation unchanged, the flux per pole in the machine is found to be 20 mwb

While the motor is running on no load. Assuming no-load losses to be zero, the no-load current drawn by the motor from the supply -

(a) lags the supply voltage
(b) leads the supply voltage
(c) is in phase with the supply voltage
(d) is zero



$\boxed{I_a \text{ leads the } V_1}$

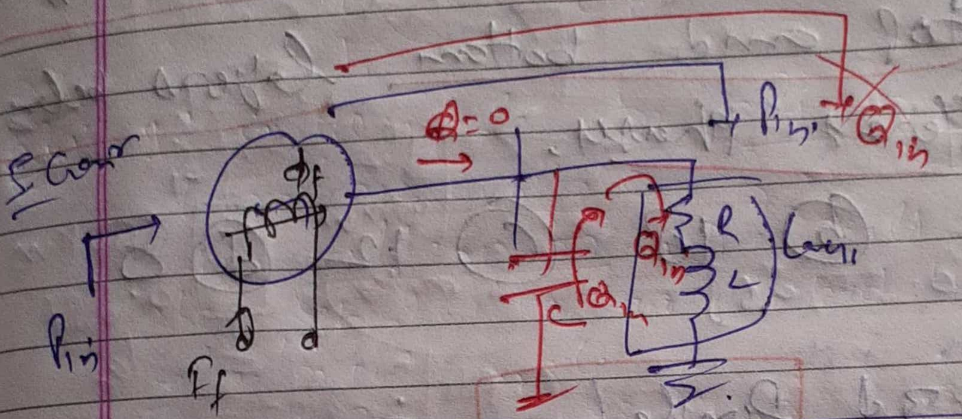
Ques: A stand alone engine driven synchronous gen is feeding a partly inductive load. A capacitor is now connected across the load to completely nullify the inductive current. For this operating condition.

(a) The field current and the fuel input have to be reduced.

(b) the field curr & fuel input have to be increase.

(c) the field current has to be increased and fuel input left unaltered.

(d) the field curr has to be reduced and fuel input unaltered.



overexcited ⇒ $I_f \downarrow$ to Nominal excitation

Note ⇒

1. Over-excited Syn. machine $(E > E_0)$
   ⇒ Deliver Reactive Power

2. Nominal excited Syn. machine $(E = E_0)$
   ⇒ Neither deliver nor absorb reactive power.

3. Under-excited Syn. machine $(E < E_0)$
   ⇒ Absorb reactive power.

Date :
Page :

B+

Qus. A 4-pole, 3-phase, double-layer winding is housed in a 36-slot stator for an AC machine with 60° phase spread. Coil-span is 7 short-pitched. Number of slots in which top and bottom layers belong to different phases.

(a) 24 (b) 18 (c) 12 (d) 0

4P, 3 ϕ, $\boxed{\text{Double layer}}$, 36 slots, $\sigma = 60°$

Coil span = 7 short-pitched

$$S/P = \frac{36}{4} = 9$$

$$q = S/P\,m = \frac{36}{4 \times 3} = 3 \text{ (integral)}$$

$N_1 \rightarrow$

	✓	✓		✓	✓		✓	✓
a	a	a	c'	c'	c'	b	b	b
a	c'	c'	c'	b	b	b	a'	a'
1	2	3	4	5	6	7	8	9

6

$S_1 \rightarrow$

	✓	✓		✓	✓		✓	✓
a'	a'	a'	c	c	c	b'	b'	b'
a'	c	c	c	b'	b'	b'	a	a
1	2	3	4	5	6	7	8	9

6

$N_1 \rightarrow$

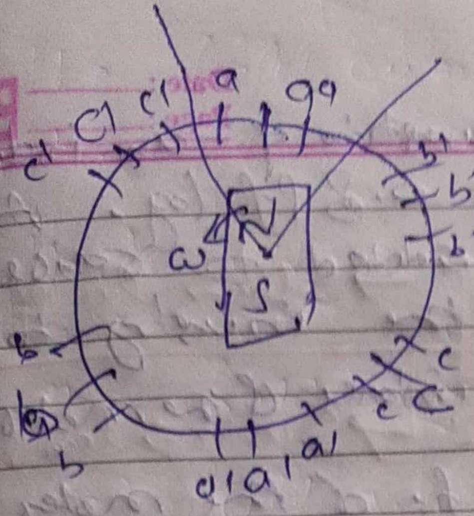
	✓	✓		✓	✓		✓	✓
a	a	a	c'	c'	c'	b	b	b
a	c'	c'	c'	b	b	b	a'	a'
1	2	3	4	5	6	7	8	9

6

$S_1 \rightarrow$

	✓	✓		✓	✓		✓	✓
a'	a'	a'	c	c	c	b'	b'	b'
a'	c	c	c	b'	b'	b'	a	a
1	2	3	4	5	6	7	8	9

6

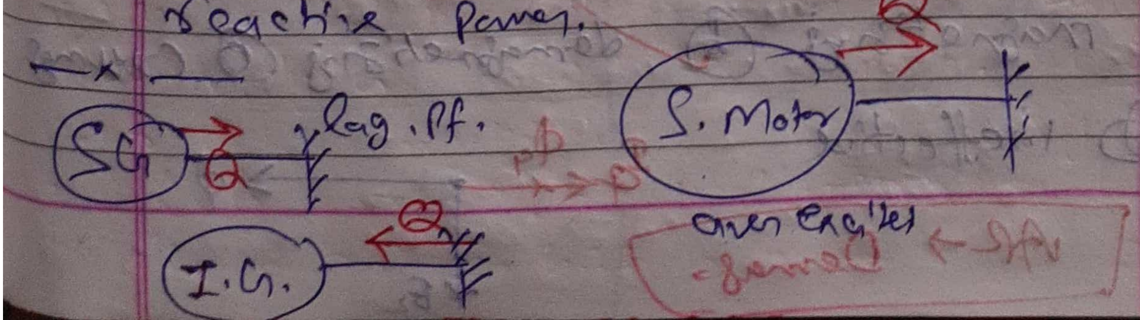


$\therefore$ Ans $= 6 \times 4 = 24$

Que A synchronous genr connected to an infinite bus is overexcited.
Considering only the reactive power, from the point of the system, the m/c acts as
(a) a capacitor (b) an inductor (c) a resistor
(d) none of these.

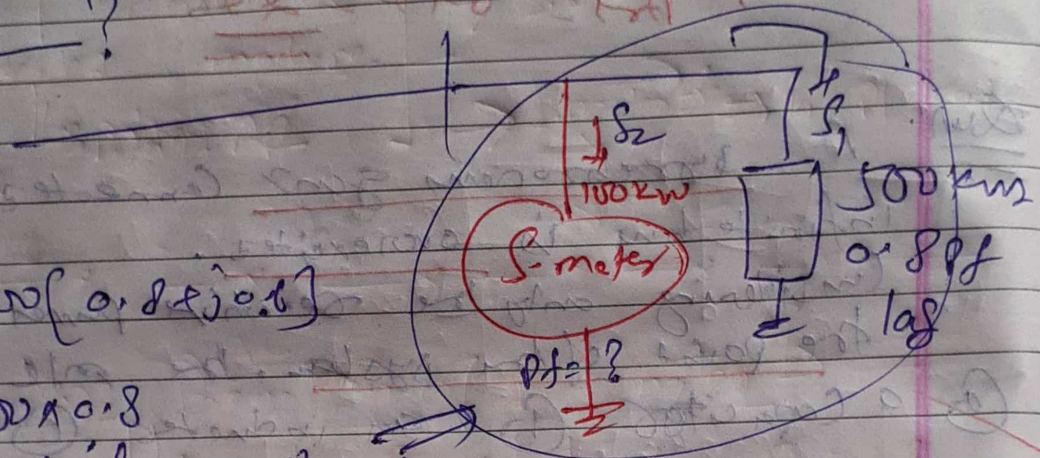
Que: Consider a system consisting of a synchronous genr working at a lagging power factor, a synchronous motor working as an overexcited condenser and a directly grid-connected induction genr. Consider capacitive VAR to be source and inductive VAR to be a sink of reactive power. Which of the following statement is true?

(a) Syn. motor and Syn. Genr are sources and induction genr is a sink of reactive power.



Que: The power consumption of an industry is 500 KVA at 0.8 pf lag. A syn motor is added to raise the power factor of the industry to unity. If the power intake of the motor is 100 kW, the p.f. of the motor is ___?

Ans:



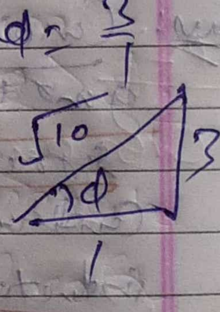
$S_1 = 500(0.8 + j0.6)$

$= 500 \times 0.8 + j(500 \times 0.6)$ lpf

$= \square + j\left(\frac{500 \times 6}{10}\right) = 300$ kVAR

$S_2 = 100 - j300$ kVAR

$\tan\phi = \frac{3}{1}$

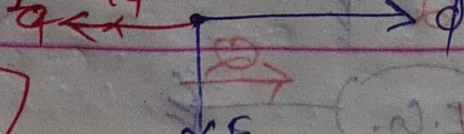


S.motor p.f $= \cos\phi = \frac{1}{\sqrt{10}}$ lead

$= 0.32$ leading

Que: A synchronous gen is feeding a zero power factor (lagging) load at rated current. The armature reaction is

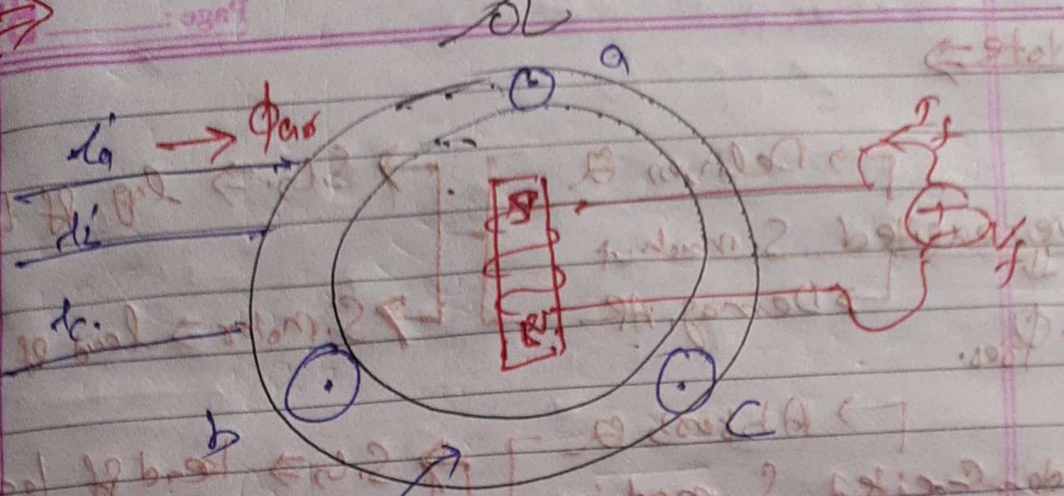
(a) magnetizing (b) demagnetizing (c) cross mag (d) ineffective



AR → Demag.

Date :
Page : B+

Note ⟹



air-gap flux ϕ_{R} = 100 flux lines
to maintain $E = E_{rated}$

• If $\vec{\phi}_{air} = \vec{\phi}_f + \vec{\phi}_{ar}$

Nominally excitated ⟹ No AR

If $\phi_f = 100$ lines $= \phi_0$; $\phi_{ar} = 0$ (instance) ⟹ $\phi_{air} = 100$ lines, $E = E_r$

over excited ⟹ Demag. AR

If $\phi_f = 120$ lines ; $\phi_{ar} = -20$ lines (instance) ⟹ $\phi_{air} = 100$ lines, $E = E_r$

mag. AR

If $\phi_f = 80$ lines (under-excited) ; $\phi_{ar} = +20$ lines (instance) ⟹ $\phi_{air} = 100$ lines, $E = E_r$

	S. Gen^r	(S. Motor)
O.E. ⟹	lag. Pf, Demag. AR	lead Pf; Demag. AR
U.E. ⟹	lead Pf, Mag. AR	lag Pf, Mag. AR
N.E. ⟹	UPf	UPF

Note →

Over-excited S. machine → Deliver Q ; → Demag. AR

⇓

$\phi_f > \phi_{res}$

→ S.G. ⇒ lag pf load

→ S. Motor ⇒ lead pf load

Under-excited S. machine → Absorb Q ; → Mag. AR

$\phi_f < \phi_{res}$

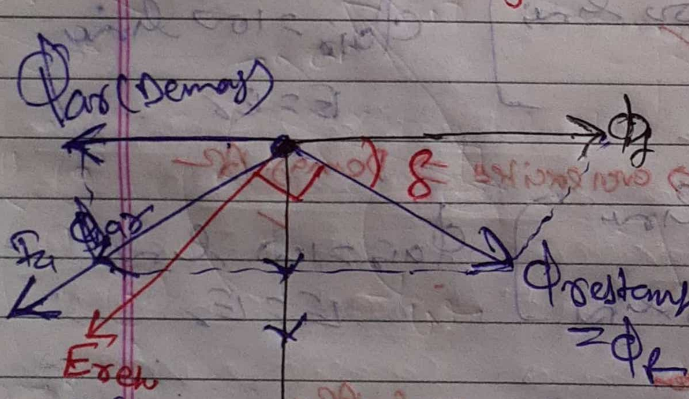
→ S.G ⇒ lead pf load

→ S. motor ⇒ lag pf load

— x — x — x — x — x — x — x —

Armature Reaction of Alternator →

→ ϕ_f leads ϕ_R by δ angle.



$E_R < E_f$

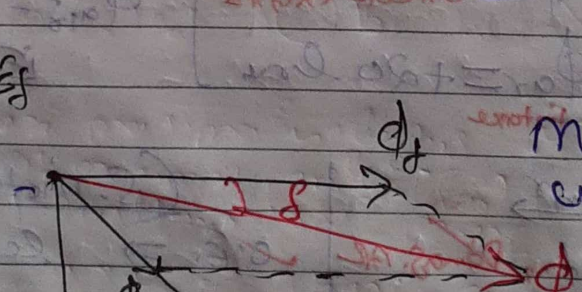
(or)

$\phi_f > \phi_R$

Overexcited

Delivers Q

Demag-AR

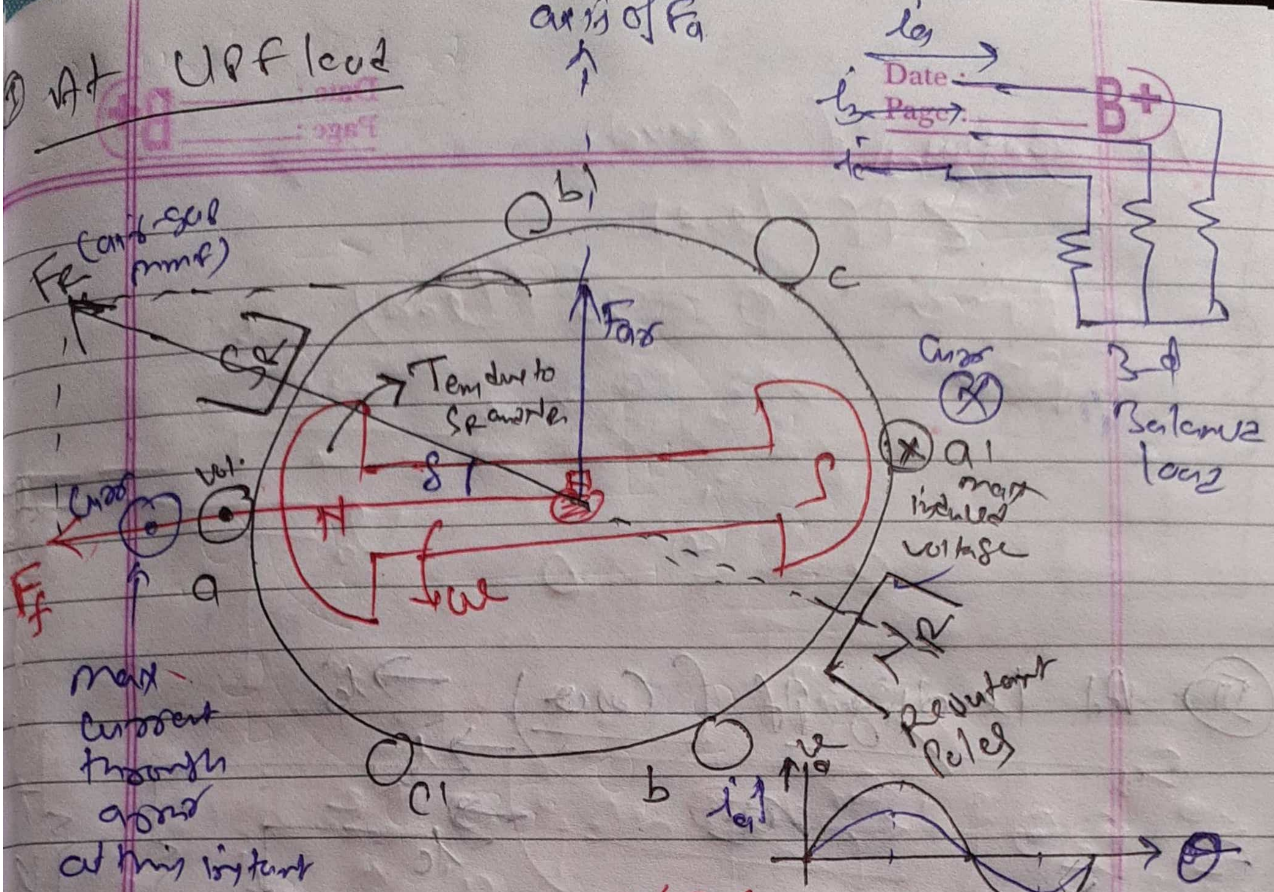


Mag-AR

under-excited

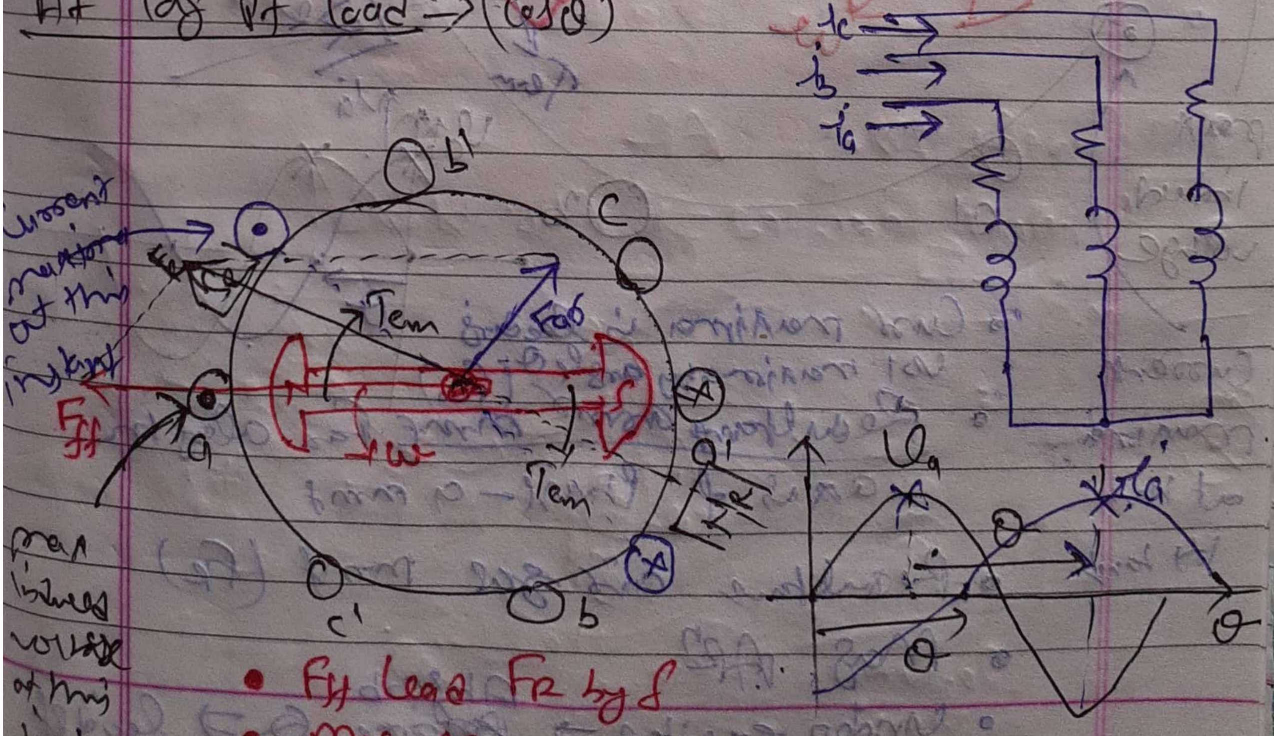
Absorb Q

① At UPF load



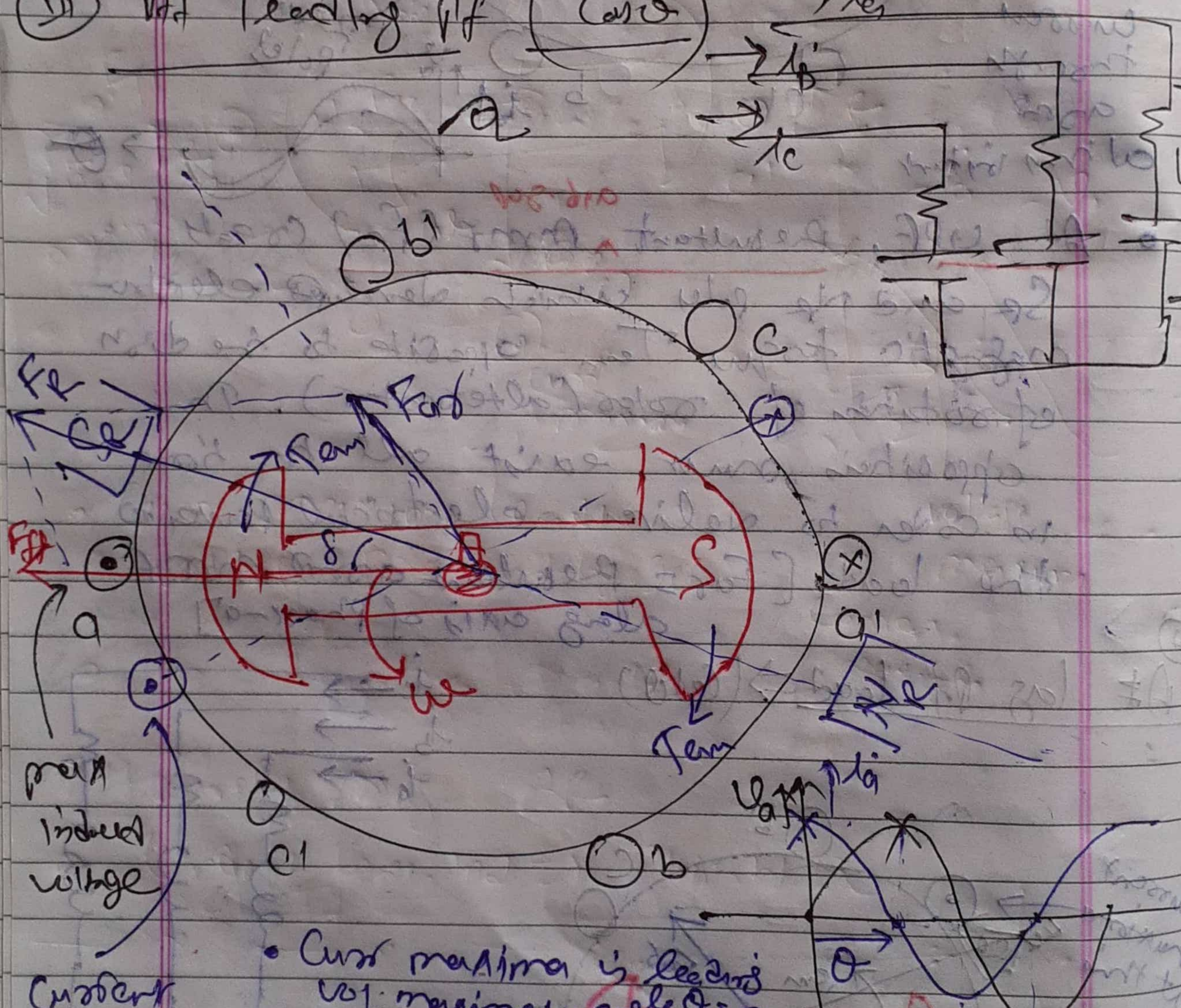
- **At UPF, Resultant air-gap mmf (Fr) creates** SR and NR poles which develops electromagnetic torque Tem opposite to the dirn of rotation of rotor (alternator). This opposition must exist all the time in order to deliver electrical power to the load. [Far = Resultant armature mmf along axis of phase-a]

② At lag pf load ⇒ (cos θ)



- Ff lead Fr by δ
- Mag. AR
- over excited

(III) At leading pf ($\cos\theta$)



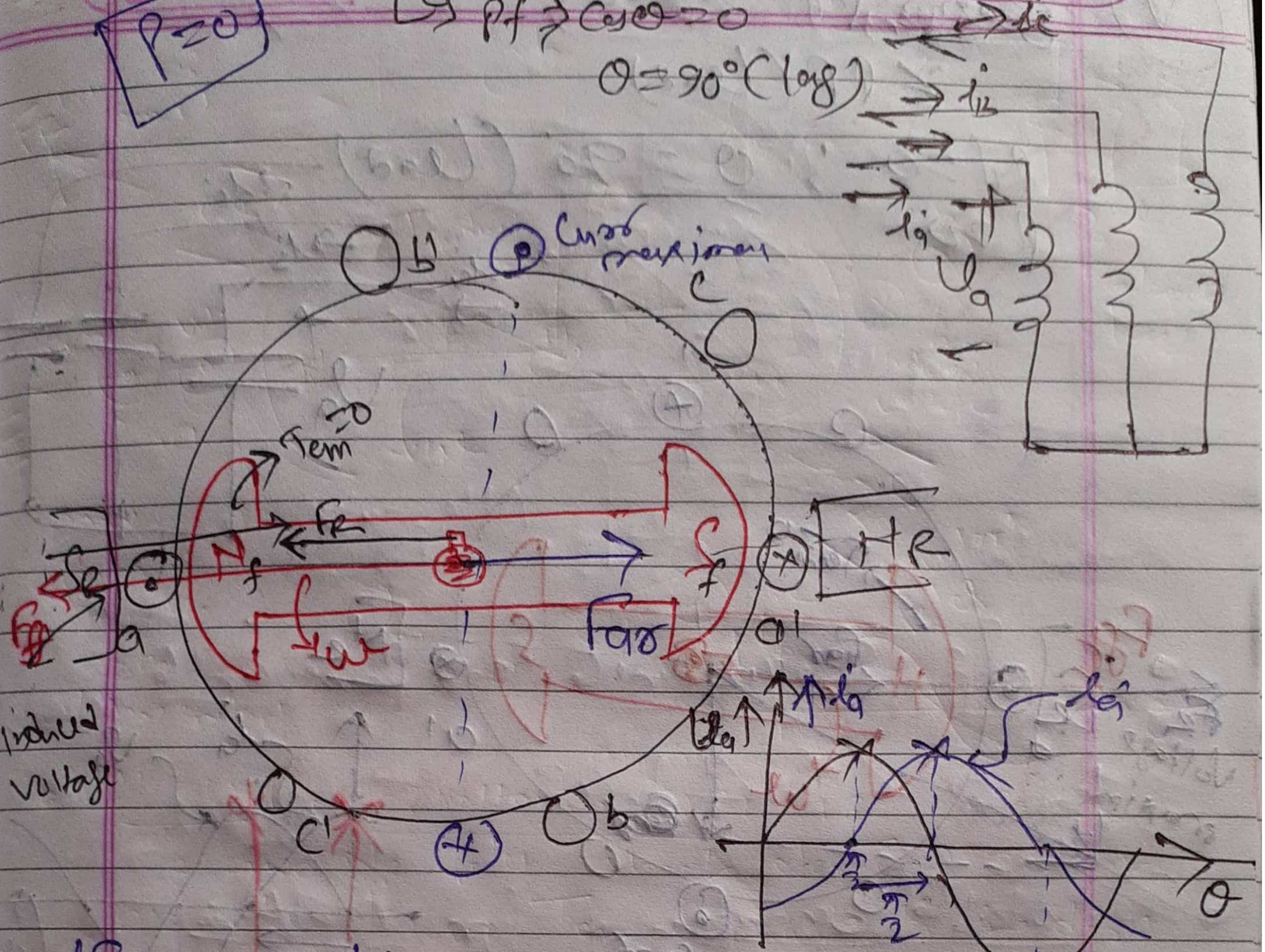
- Curr maxima is leading vol maxima by angle θ (F_{ar})
- Resultant arm mmf F_{ar} along the axis of phase - a mmf
- Resultant air gap mmf (F_R)
- Mag AR
- Under excited ⇒ Absorb Q ⇒ lead pf load

(iv) At zero pf lag load

$\boxed{P=0}$

↳ pf ⇒ $\cos\theta = 0$

$\theta = 90°$ (lag)



- {Sr and Nf} are synchronous; {Hr and Sf} are rotating at synchronous speed but in this situation (zero pf lag), air-gap induced poles do not apply any ele-mag. torque over field poles ($T_{em} = 0$), so no active power is delivered to load (ideal condition).

Curr maxima is 90° after the voltage maxima

Note ⇒ To compensate F & W loss, some active power is supplied.

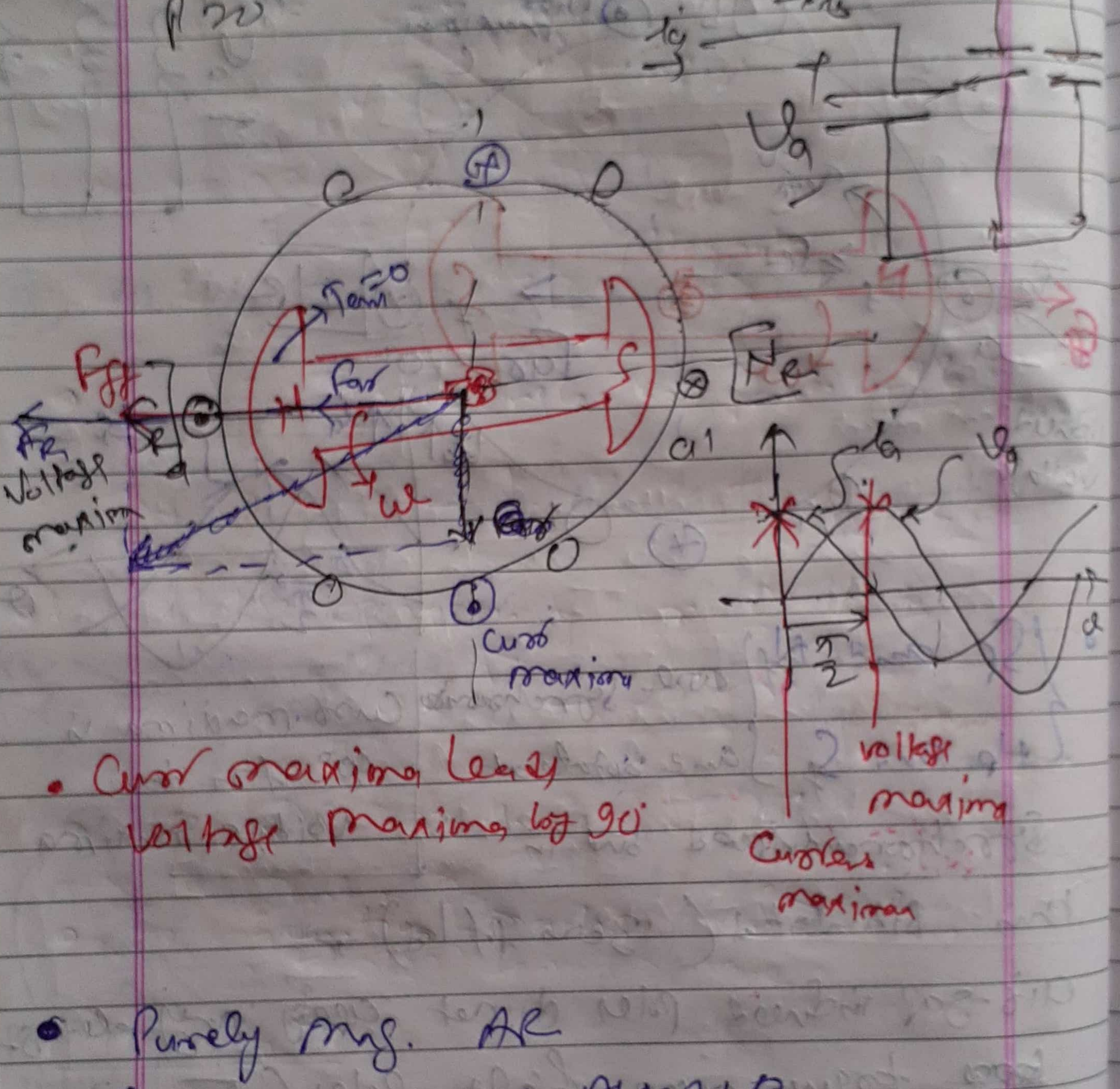
- Purely Demag AR.
- over-excited ⇒ Deliver Q ⇒ Demag. AR

(V) Zero Pf load

ZPF (lead)

Pf = 0 ; θ = 90° (lead)

P = 0

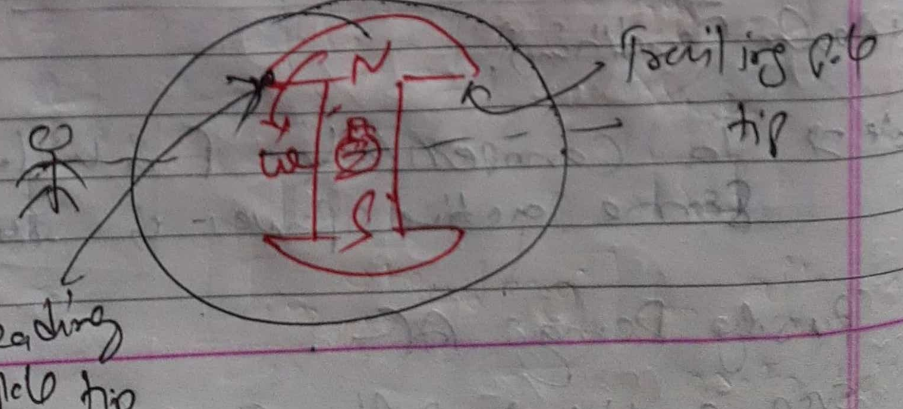


- Curr maxima leads voltage maxima by 90°

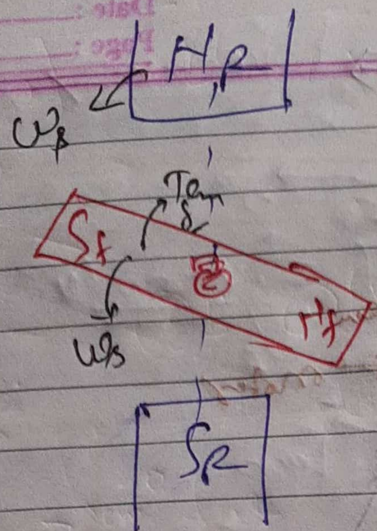
- Purely Mag. AR
- Under-excited ⇒ Absorbs Q

--- x --- x --- x ---

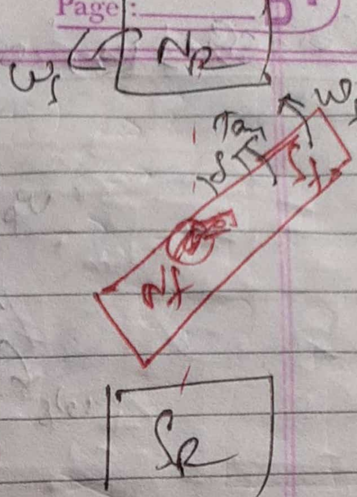
(I)



II



(Alternator)



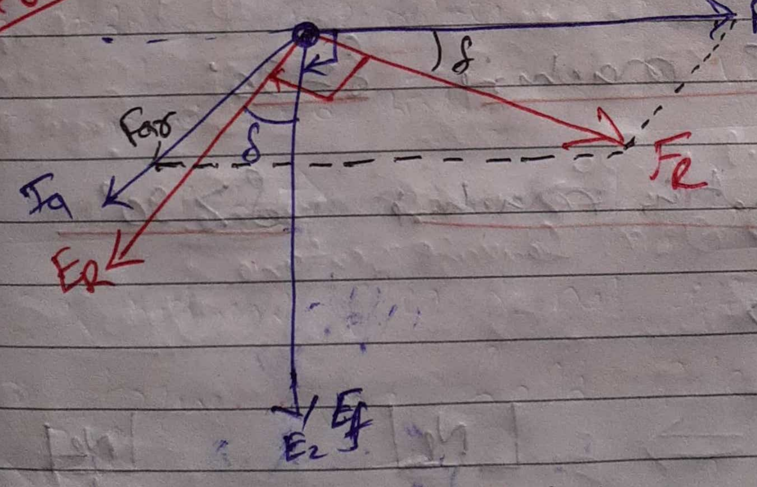
(S. motor)

(F_f leads F_R by δ angle)

(F_f lags F_R by δ angle)

III

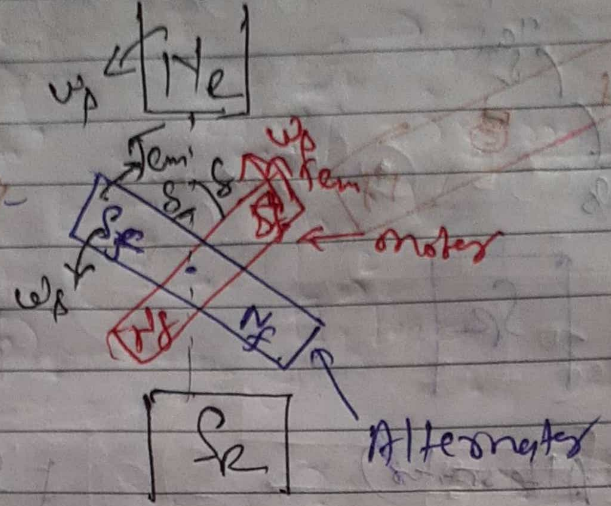
Alternator



Since time and space both are synchronized in synchronous machine, that's why space (mmf) and time (voltage, current) are drawn on same phasor plane.

Date :
Page :

Conclusions of ARM ⇒



- δ = Torque angle (or) Power angle

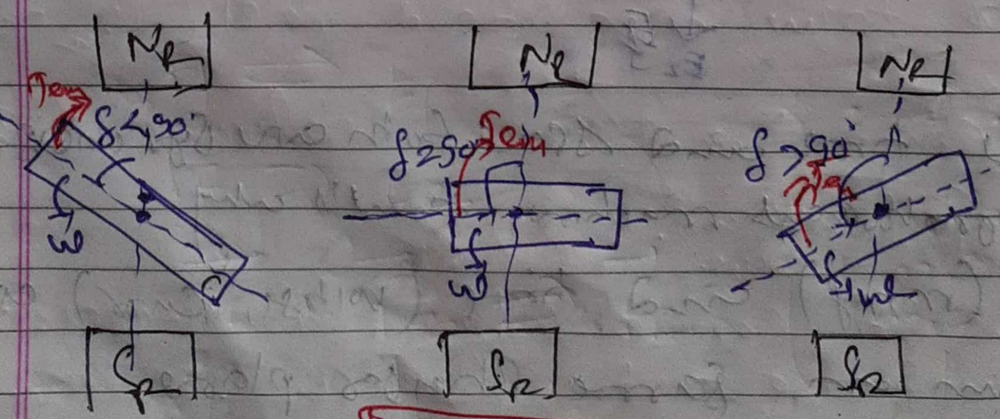
$$0 < \delta < 180^\circ$$

- For stable operation of syn. machine

$$0 < \delta < 90^\circ$$

- for DC machine $\delta = 90^\circ$
- for Induction machine $\delta > 90^\circ$

Alternator ⇒



$\boxed{T_{em\,max} \text{ when } \delta = 90^\circ}$ for alternator to motor both

- For $\boxed{\text{alternator}}$ ⇒ $\boxed{\text{Field mmf}}$ $\boxed{\text{leads}}$ $\boxed{\text{Resultant mmf (air-gap mmf)}}$ by δ angle (~~[illegible]~~).

- For $\boxed{\text{S. motor}}$ ⇒ $\boxed{\text{Field mmf}}$ $\boxed{\text{lags}}$ $\boxed{\text{resultant mmf}}$ by δ angle.

Note ⇒

Over-excited S. Machine ⇒ Demag. ARn ⇒ Delivers Q
Under-excited Sy. machine ⇒ Mag. ARn ⇒ Absorbs Q

S. Machine absorbs Q ⇒ It is like inductor
S. machine Delivers Q ⇒ It is like capacitor

- Alternator → Absorbs Q → It is like inductor
  ⇒ Its P.f. of load ⇒ leading ⇒ load is Capacitive

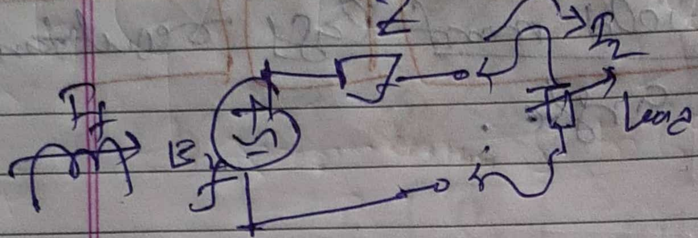
- Motor → Absorbs Q ⇒ It is like inductor
  ⇒ Its Pf (motor) = lagging

- Alternator → Delivers Q ⇒ It is like Capacitor
  ⇒ It's load is inductive ⇒ Pf ⇒ lagging

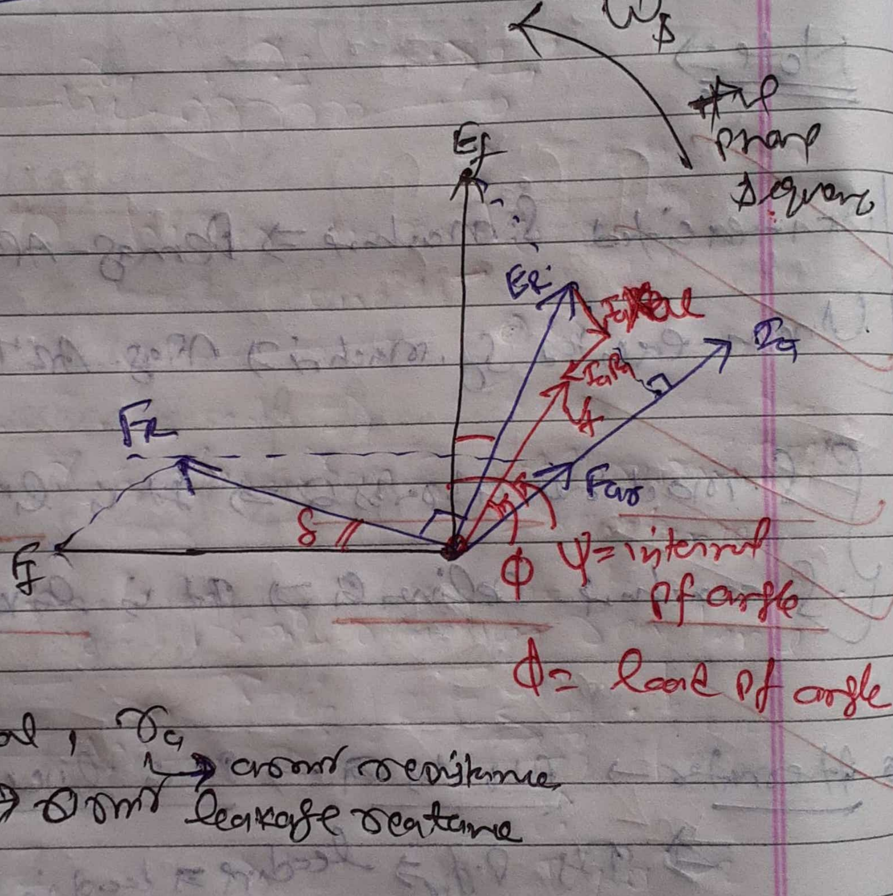
- Motor → Delivers Q ⇒ It's like Capacitor
  ⇒ load Pf (motor) = leading

Introduction to Phasor Diagram ⇒

I_f, E_f, P_m ; I_a, θ_a, f ⇒ variable



Alternator



ψ = internal pf angle

φ = load pf angle

X_{al}, r_a → armature resistance
↳ armature leakage reactance

$F_f \Rightarrow E_f$

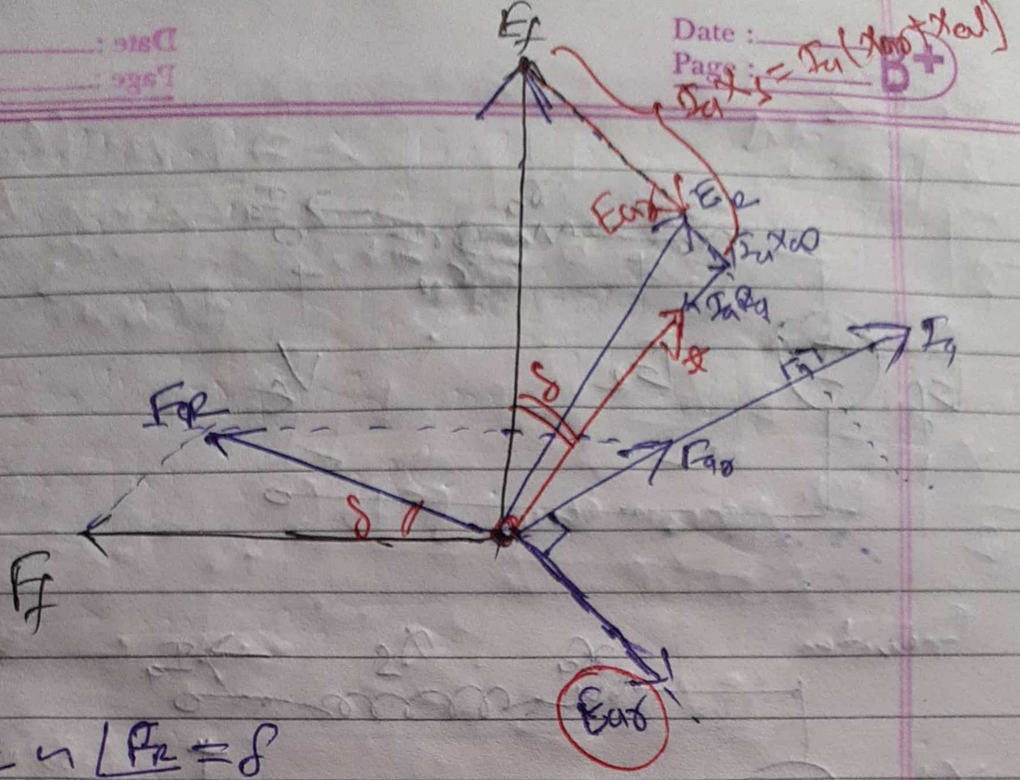
$F_R \Rightarrow E_R$

$\vec{F_f} + \vec{F_{ar}} \Rightarrow \vec{F_R}$

mmf to Emf conversion

$\boxed{\vec{E_f} + \vec{E_{ar}} \Rightarrow \vec{E_R}}$

Emf method



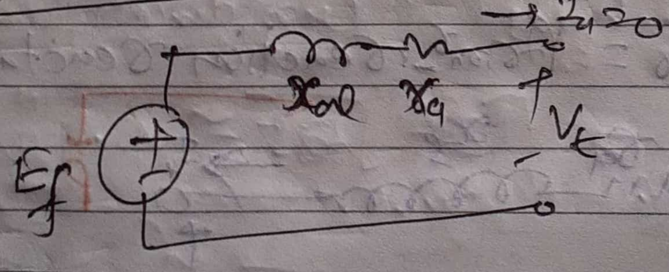
$\angle F_f \sim \angle F_R = \delta$

(In space)

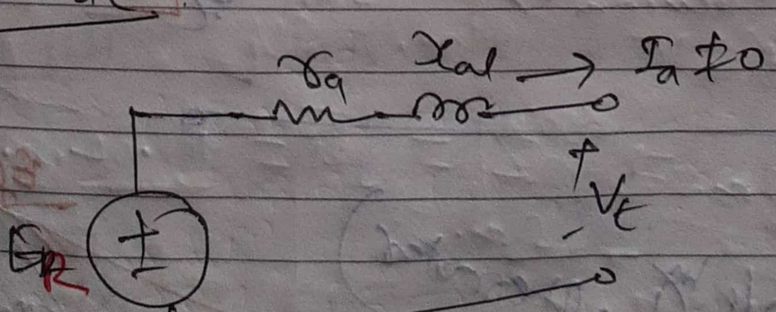
$\angle E_f \sim \angle V_t \cong \delta$; Because E_R is not available.

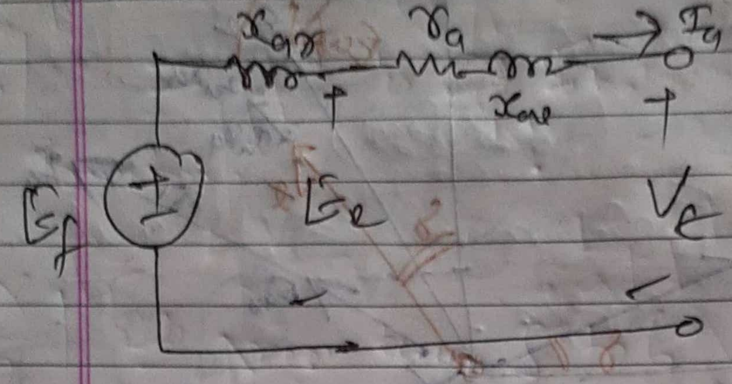
(In time)

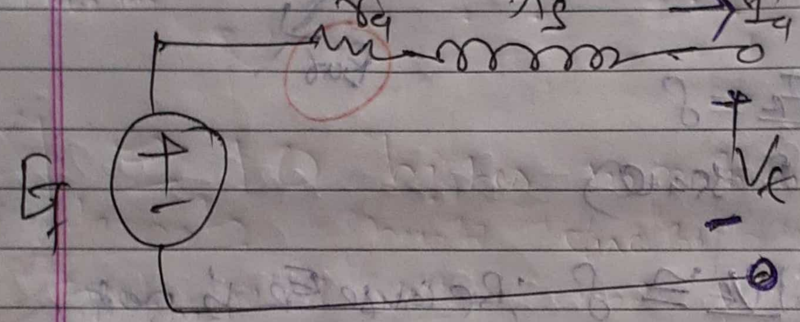
@ No-load



@ Load :

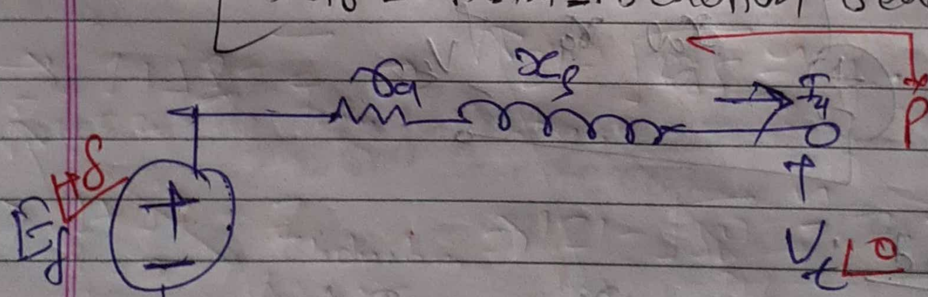






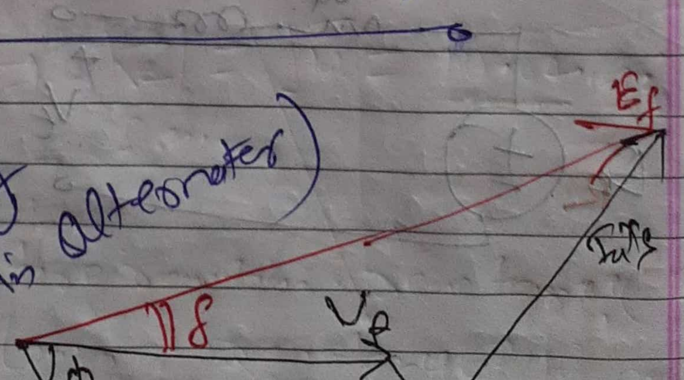
$X_s = X_{ar} + X_{al}$ = Synchronous Reactance

X_{ar} = Armature reaction reactance

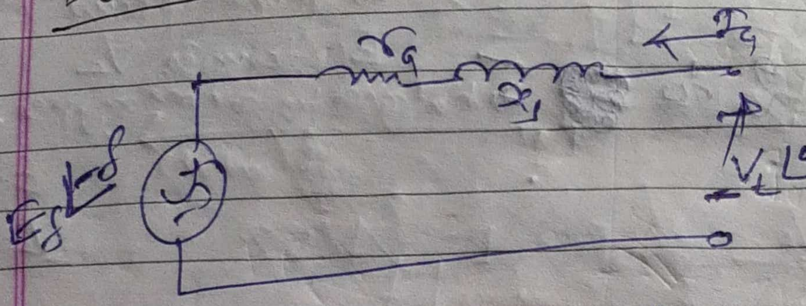


(alternator)

(E_f leads V_t by angle δ in alternator)



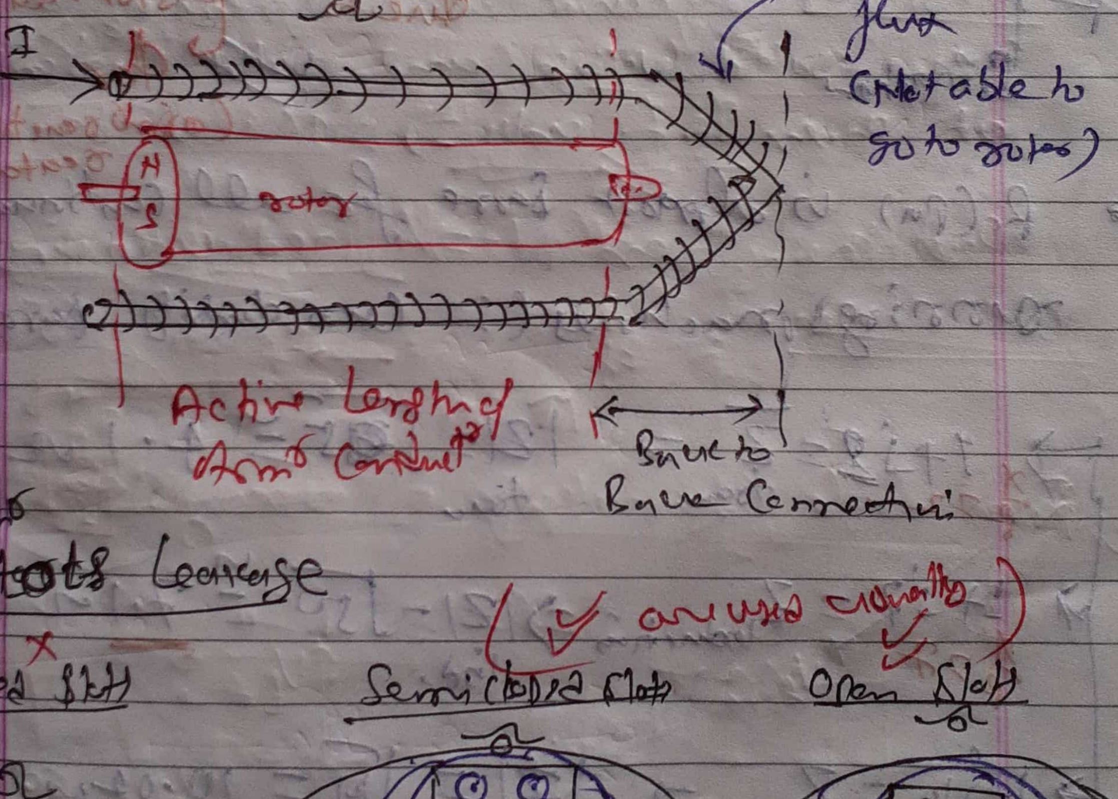
Synchronous Motor ⇒



(E_f lags V_t by angle δ
in S.motor)

Leakage In Synchronous Machines ⇒

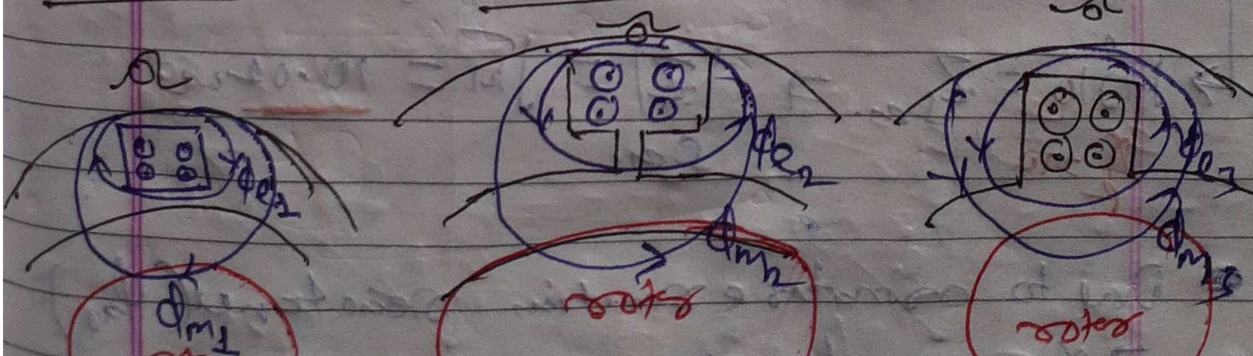
① Back to Back leakage



② Arm^ᵒ Slots Leakage

(✓ are used normally ✓)

Closed slot   Semi closed slot   Open slot



$$\phi_e\Big|_{\text{Closed slot}} > \phi_e\Big|_{\text{Semi-closed}} > \phi_e\Big|_{\text{open slots}}$$

Date :
Page :

Note ⇒

$\left.\frac{X}{R}\right|_{\text{Transformer}} = 2$ to 5

$\left.\frac{X}{R}\right|_{\text{Induction}} =$ ~~some times~~ 5 to 6

$\left.\frac{X}{R}\right|_{\text{S.machine}} \geq 10$ higher in machine due to

- Base to Base (ϕ_{l})
- Slot leakage ϕ_{l_2}
- ϕ_{ar} (armature reaction reactance)

- R (pu) is almost same for all continuous running machines (∵ current density same).

$1 + j2 = Z_{tran} \Rightarrow |Z|_{tran} = \sqrt{5} \simeq 4.1\,\Omega$; $\frac{X}{R} \simeq 2$

$1 + j7 = Z_{induction} \Rightarrow |Z|_{ind.} = \sqrt{50} \simeq 7.1\,\Omega$; $\frac{X}{R} \simeq 7$

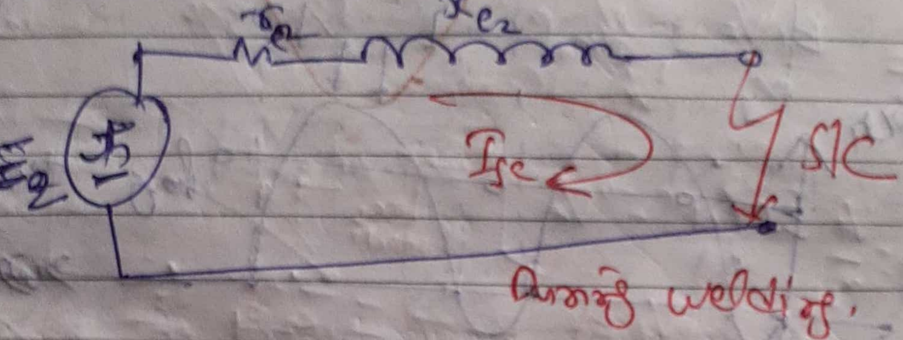
$1 + j10 = Z_{S.m.} \Rightarrow |Z|_{S.m.} = \sqrt{101} = 10.04\,\Omega$; $\frac{X}{R} \simeq 10$

- Due to armature reaction reactance (ϕ_{ar}) ⇒ X_{ar} ⇒ Leakage reactance of S. machine becomes highest among all machines.

Date :
Page :

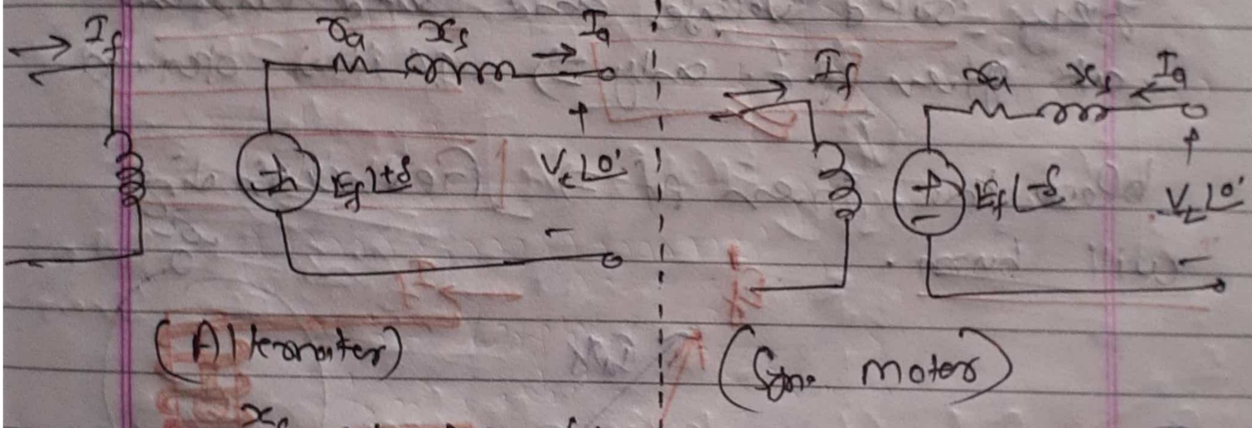
Note ⇒ $\boxed{\text{In welding } x^r}$

leakage reactance is kept high in order to protect it from distinctive short-cut current.



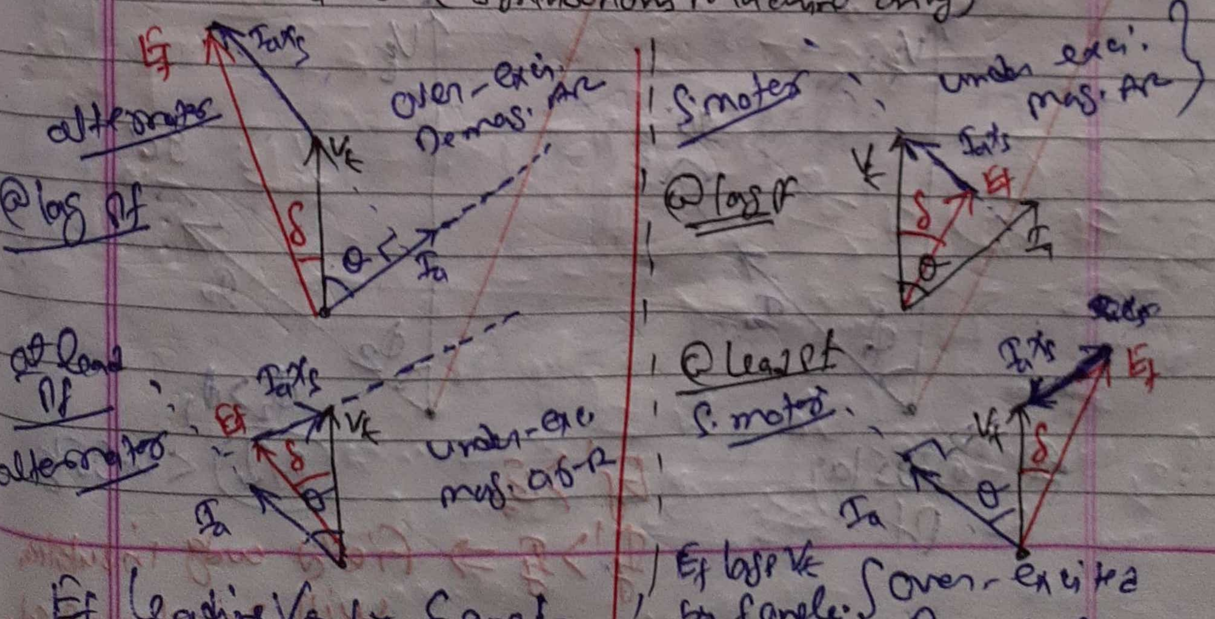
If $x_{e2}\uparrow \Rightarrow I_{sc}\downarrow$.

Phasor Diagram @ Cylindrical Rotor ⇒



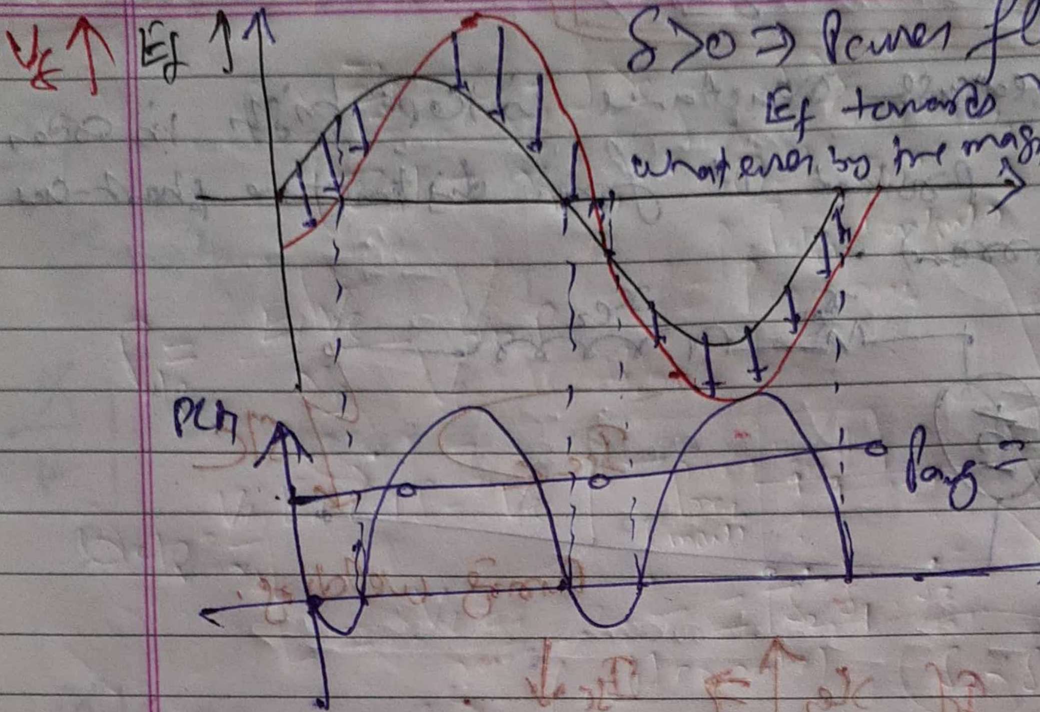
$\frac{x_s}{r_a} \approx 10 \Rightarrow$ very high

$\Rightarrow r_a \to 0$ (Synchronous Machine only)



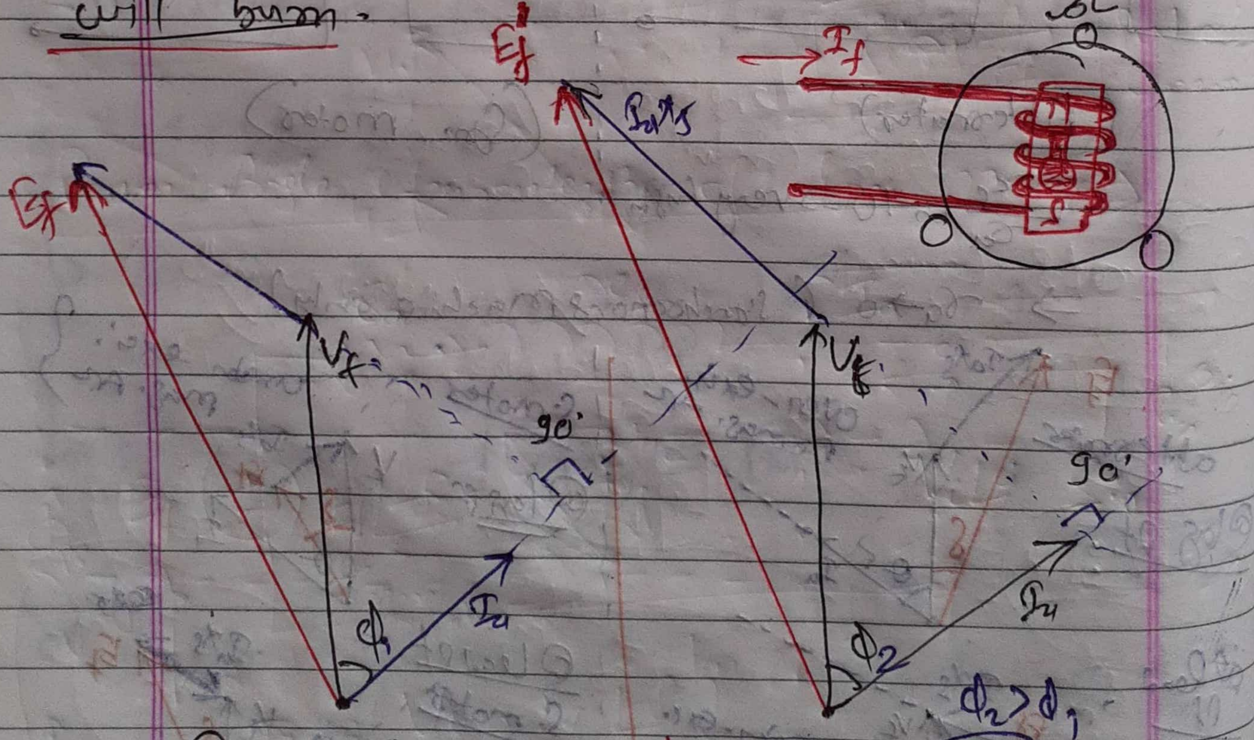
E_f leading V_t by δ angle

E_f lags V_t by δ angle. $\begin{cases}\text{over-excited} \\ \text{Demag. AR}\end{cases}$



$\delta > 0 \Rightarrow$ Power flow from E_f towards V_t whatever be the magnitudes of E_f and V_t

Alternator should be designed (operated) at a given rated voltage and rated current at given $\boxed{\text{p.f. only}}$ $\Rightarrow$ If it is operated below the given pf $\Rightarrow$ $\boxed{\text{field winding}}$ will burn.



@ 0.95 lag pf

$E_f' > E_f$

$\boxed{pf\downarrow} < 0.95$ lag

$E_f' > E_f \Rightarrow$ field wdg insulation will get damaged.