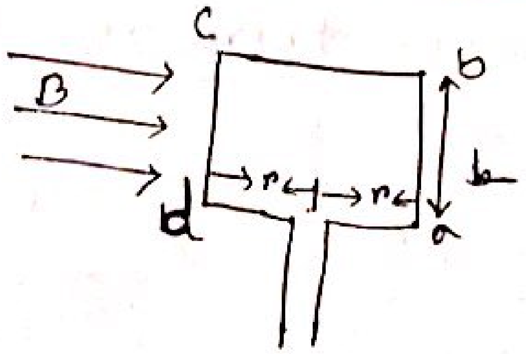
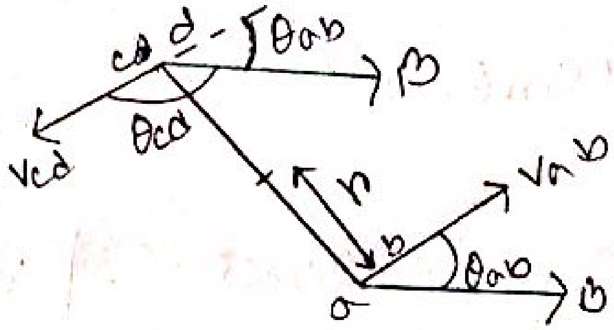
Synchronous generator / Alternator

TOPIC :- "How AC generator generates"



Voltage induced for this $e_{ind} = (\bar{V} \times \bar{B}) \cdot \bar{L}$



V = velocity
B = magnetic field
L = length

eind is different segments :-

segment AB :-

$e_{ab} = V_{ab} B \sin\theta_{ab} \cdot L$

$= V_{ab} B L \sin\theta_{ab}$

The direction of $\vec{V} \times \vec{B}$ is into the board, And the direction of L is also into the board, so angle between $(\vec{V} \times \vec{B})$ and L is 0^0.

$e_{ab} = L V_{ab} B \sin\theta_{ab}$

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segmet bc

direction of $\vec{v}\times\vec{B}$ is into the copy. An the direction of L is parallel with $\vec{v}\times\vec{B}$. Angle between them is 90°

$e_{ab} = 0$

segment da

$e_{da} = 0$

segment cd

$e_{cd} = V_{cd} B l \sin\theta_{cd}$

$e_{tol} = e_{ab} + e_{cd}$

$= VBl\sin\theta_{ab} + VBl\sin\theta_{cd}$

$= 2VBl\sin\theta_{ab}$

| $V_{cd} = V_{ab}$
| $\theta_{ab} = (180^\circ - \theta_{cd})$

$= 2(\omega r)Bl\sin\theta$

$= 2L(\omega r)B\sin\theta$

$= (2Lr)\omega B\sin\theta$

| Area of the loop
| $A = 2rL$

$= A\omega B\sin\theta$

$= (AB)\omega\sin\theta$

| AB = Area X flux density

$= \cancel{\phi_m \omega \sin\omega t}$

$= \phi_{max}\,\omega\sin\theta$

$= \phi_m\omega\sin\omega t$ [emf induced for single loop]

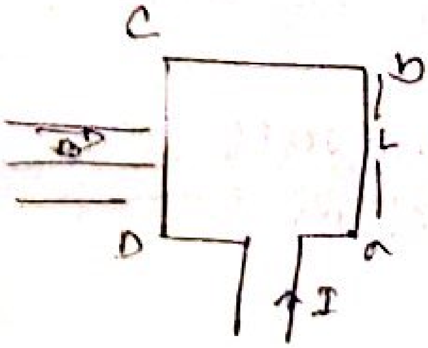
So, when the area is perpendicular then the flux density is maximum

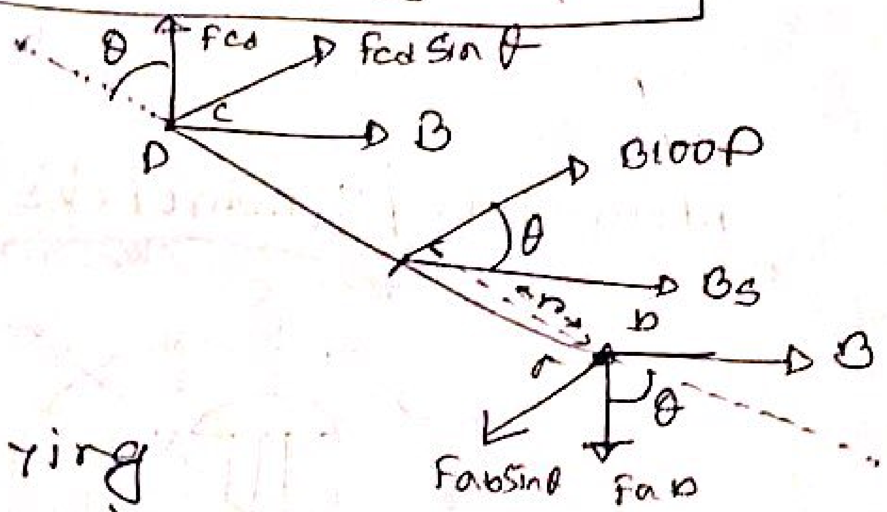
$\phi_{max}\omega \sin\omega t$

$\Rightarrow E_m \sin\omega t$ $\quad$ [E_m = Amplitude of Sinusodial voltage ($\phi_{max}\omega$)]

ϕ_{max}.

Induced torque in a AC Machine





For a current carrying conductor $f = i(\bar{l} \times \bar{B})$

<u>For segment ab :</u> B is parallel with the page

l is into the page, $f_{ab} = (\bar{l} \times \bar{B})$ is downward direction.

$f_{ab} = iLB$

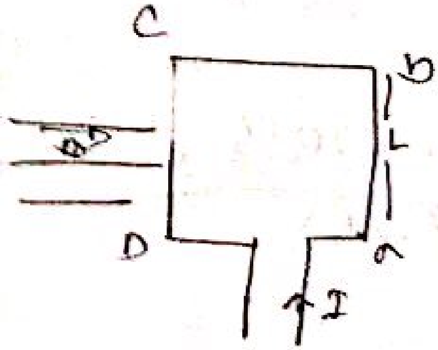
<u>For segment cd :</u> direction of length is out of the page, so direction of fcd is upwards

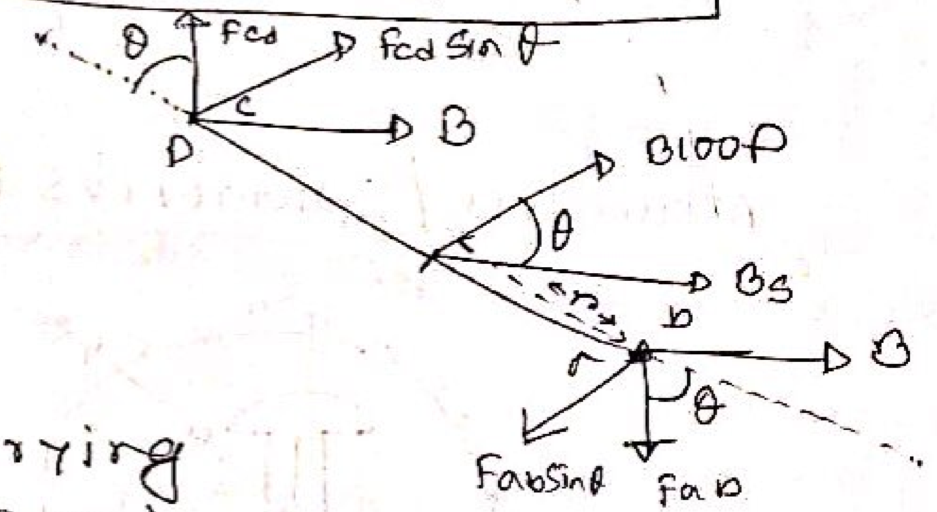
so, when the area is perpendicular then the flux density is maximum

$\phi_{max}\,\omega \sin\omega t$

$\Rightarrow E_m \sin\omega t$ [E_m = Amplitude of sinusoidal voltage ($\phi_{max}\,\omega$)] ϕ_{max}.

Induced torque in a AC Machine





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for segment ab : B is parallel with the page

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$f_{ab} = iLB$

for segment cd : direction of length is out of the page, so direction of f_{cd} is upwards

⇒ At stator a current is flowing through the coil, thus a magnetic field is produced, which creats another emf, which is "armature reaction emf".

Now,

$B_{net} = \vec{B_R} + \vec{B_s}$, $V_\phi = E_A + E_{stat}$ [voltage produced by armature magnetic field]

$E_{stator} \propto I_a$; $E_{stator} = -jXI_a$

$V_\phi = E_A - jXI_a$

$= E_A - jXI_a - jX_aI_a - I_aR_a$

$= E_A - jX_sI_a - I_AR_A$

$E_A = V_\phi + I_AR_A + jX_sI_A$

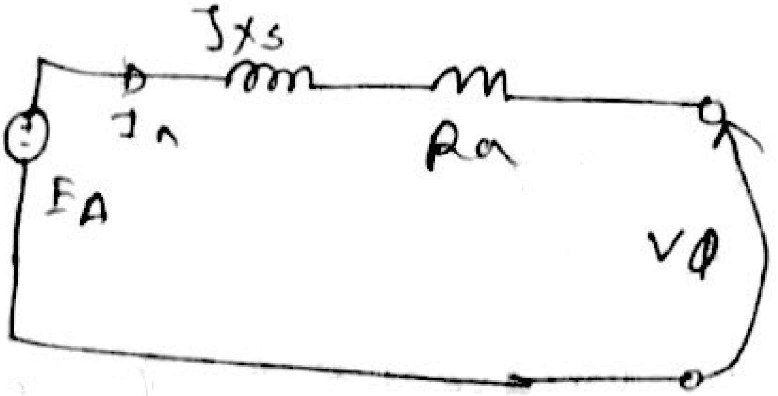
X = armature reactance

X_A = self induced reactance.

$X_s = X + X_a$

= Synchronous reactance

I_aR_a = coil Resistance.



equivalent circuit of alternator

$F_{cd} = ilB$

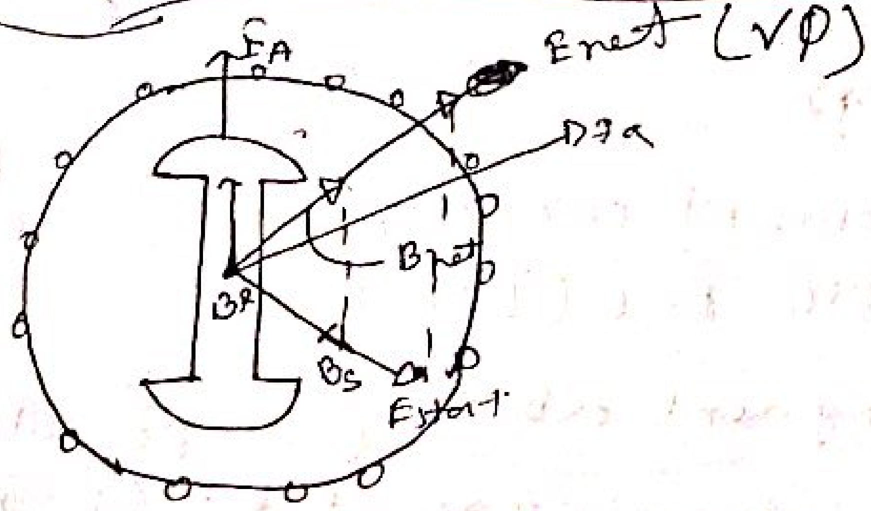
$$\tau = 2r \times iLB\sin\theta$$
$$= (2rl)\, iB\sin\theta$$
$$= (Ai)\, B\sin\theta$$
$$= K B_{loop} B_S \sin\theta$$

[magnetic field induced in a current loop is proportional to Ai]

$$\tau = K\, \bar{B}_{loop} \times \bar{B}_S$$

[$\bar{B}_{loop}$ & $\bar{B}_S$ angle between them is θ]

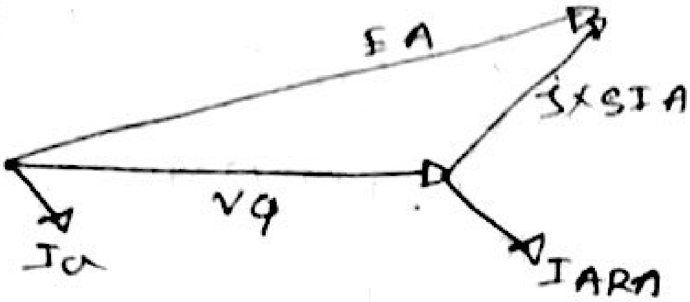
Alternator / Synchronous Generator



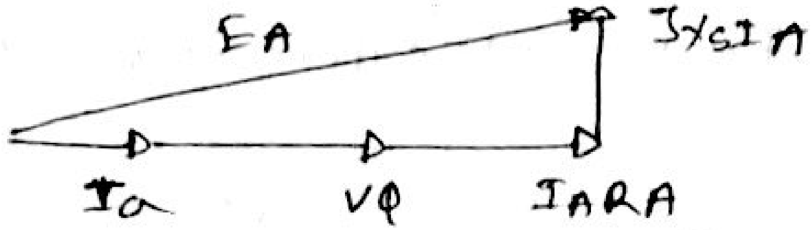
Here the rotor rotates. and armature is fixed. Rotor produces a flux by connecting it to a DC supply.

Ia will lag EA.

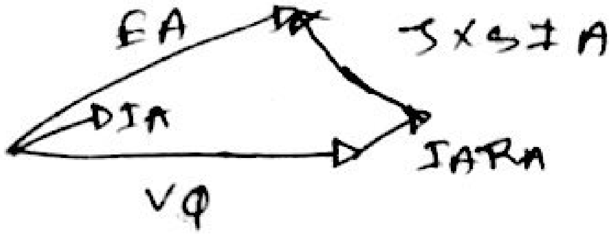
Lagging load (capacitive):-



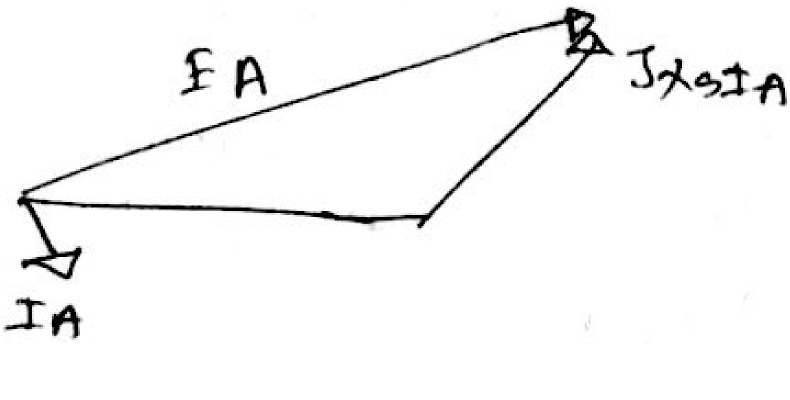
Unity power factor load (Resistive):-



leading load :- (inductive)

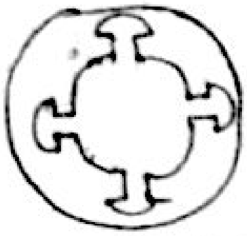


=> for Practical generator so $I_A R_A$ is much smaller than $JX_S I_A$, so sometime it is not considered



⑤ two types of Rotor

(I) Salient pole rotor (II) Non-Salient pole



salient pole.

⑥ 4 reason why terminal voltage or generated voltage occur -

(I) Armature reactance

(II) Armature resistance

(III) Stator's self induced reactance

(IV) Shape of the rotor.

⑦ $\tau_{ind} = k\, B_{loop} \times B_S$

$$= k\, \bar{B}_R \times \bar{B}_S$$

$$= k\, \bar{B}_R \times (\bar{B}_{net} - \bar{B}_R)$$

$$= k\, (\bar{B}_R \times \bar{B}_{net})$$

⑧ For a generator induced torque is a opposing torque, which opposes the rotation. By opposing this we convert energy from machanical to electrical.

NOW,

~~$P_{conv} = P_{in}$~~

$P_{conv} = \tau_{ind} \cdot \omega_m$ [τ_{ind} = Opposite torque]

$= 3 E_A I_A \cos\gamma$

(*) Static stability limit : Therotitical maximum power than can get from an alternator.

when $\sin\theta = 1$, then P_{out} = max.

$$P_{max} = \frac{3 V_\phi E_A}{X_S}$$

Below the static stability limit the power rating is more convenient.

Tests :

⇒ open circuit test : The terminal s opem, E_A is found from open circuit est.

I_f					
E_A / V_{OC}					

Terminal voltage is E_A. I_f doesnot drop on $X I_A$.

$\therefore E_A = V_T$ OC.

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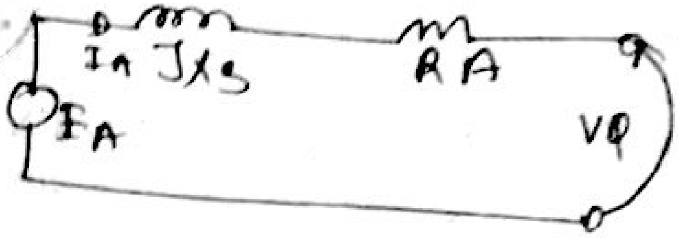
⇒ Short circuit test:



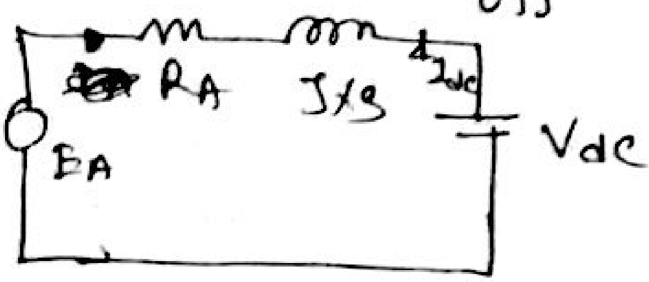
terminal is shorted. Excitation should be low in shrot circuit test, Now,

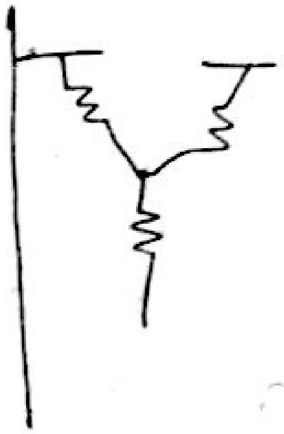
$$I_A = \frac{E_A}{\sqrt{X_s^2+R_A^2}}$$

$$I_A = \frac{E_A}{X_S}$$

$$X_S = \frac{E_A}{I_A}$$

⇒ DC test: In DC machine is off





in Y line current is same as phase current

$$I_{dc} = \frac{V_{dc}}{R_A}$$

$$R_A = \frac{V_{dc}}{I_{dc}}$$

Example- 4-1 :- A 200 K-VA, 480 - V, 50 Hz Y connected synchronous generator with a rated field current of 5A was tested, and the data was taken:

(i) $V_{T.OC}$ at rated I_F was 540 V

(ii) $I_{L,SC}$ at the rated I_F is 300A

(iii) When a dc voltage of 10V was applied to two of the terminals, a current of 25 A was mesured.

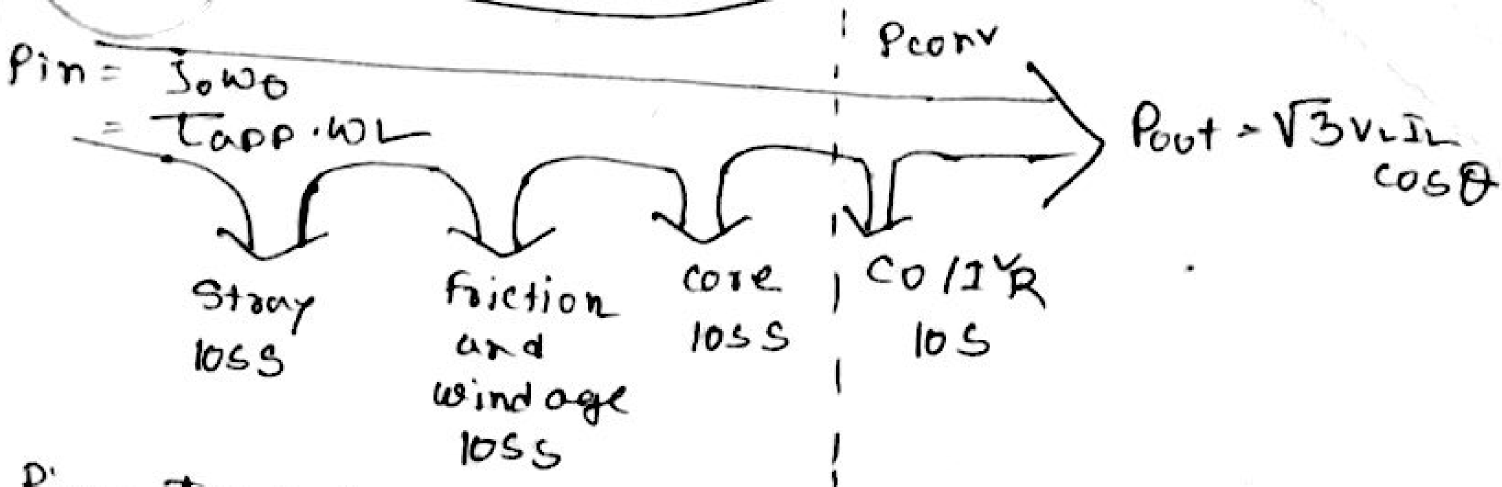
Find the values of armature resistance and the approximate synchronous reactance in ohms that ~~would~~ would be used in the generator model at the rated condition.

⇒ As it is Y-connected, then, the direct current in the resistance test flows through two windings.

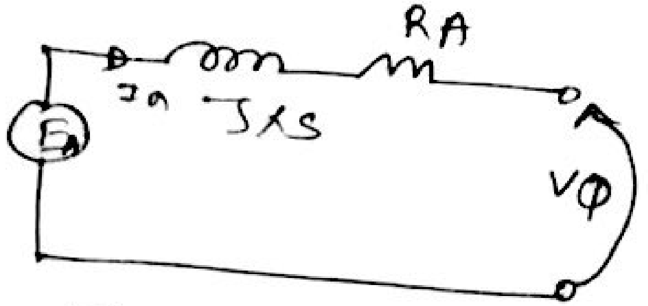
$$2R_A = \frac{V_{DC}}{I_{DC}} = \frac{10V}{25A}$$

$$\therefore R_A = \frac{10V}{25 \times 2A} = 0.2\Omega$$

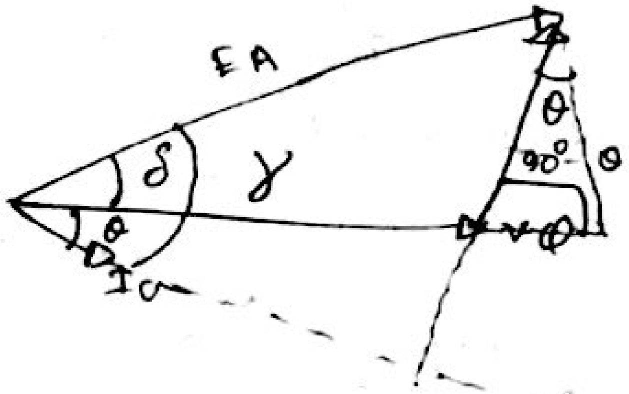
Power flow diagram :-



P_{in} = Torque , P_{out} = electrical power .



1phase equvalent circuit .



$\therefore P_{out} = 3 V\phi I_A \cos\theta$ [3phase so multiply by 3]

$= 3 V\phi \dfrac{E_A \sin\delta}{X_S}$, $I_A \cos\theta = \dfrac{E_A \sin\delta}{X_S}$.

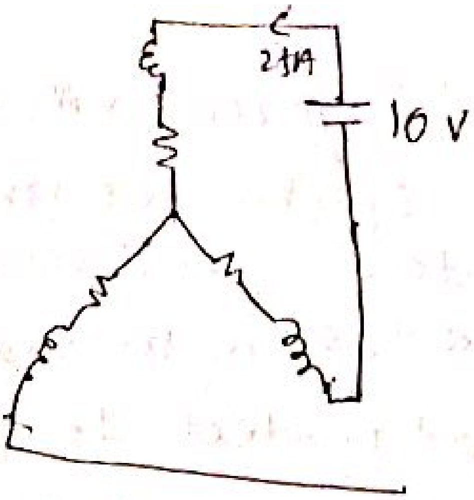
[δ = torque angle]

$\Rightarrow P_{conv}$ or converted power is the mechanical power that is converted to electrical power . As P_{conv} is high efficiency is high .

$$S = \frac{E_A}{I_A}$$

$$= \frac{\cancel{50}\, 540/\sqrt{3}}{300A}$$

$$= 1.09\,\Omega$$



If Δ connected then,

$$R_{eq} = \frac{2R_A \times R_A}{2R_A + R_A}$$

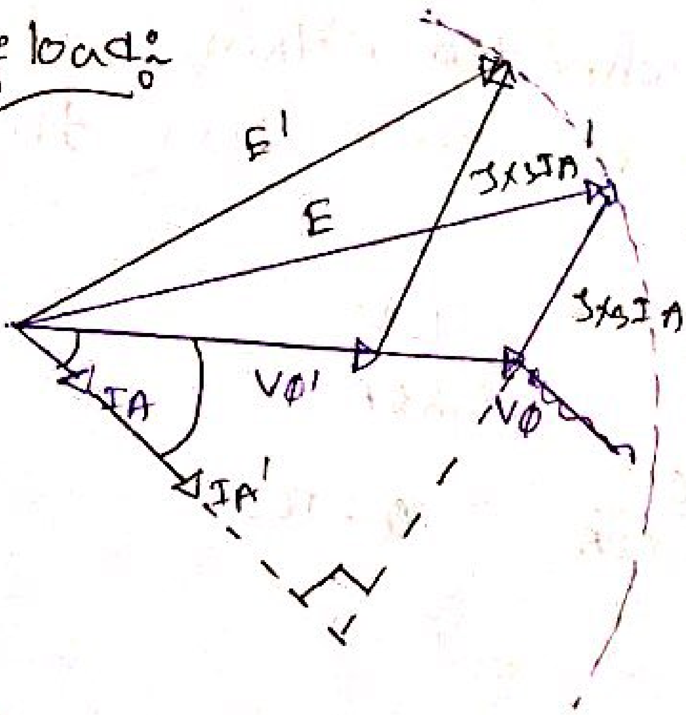
$$= \frac{2}{3} R_A$$

$$\frac{2}{3} R_A = \frac{V_{dc}}{I_{dc}}$$

Effect of load change in synchronous motor:

In load if Reactive power increase, then terminal voltage decreases.

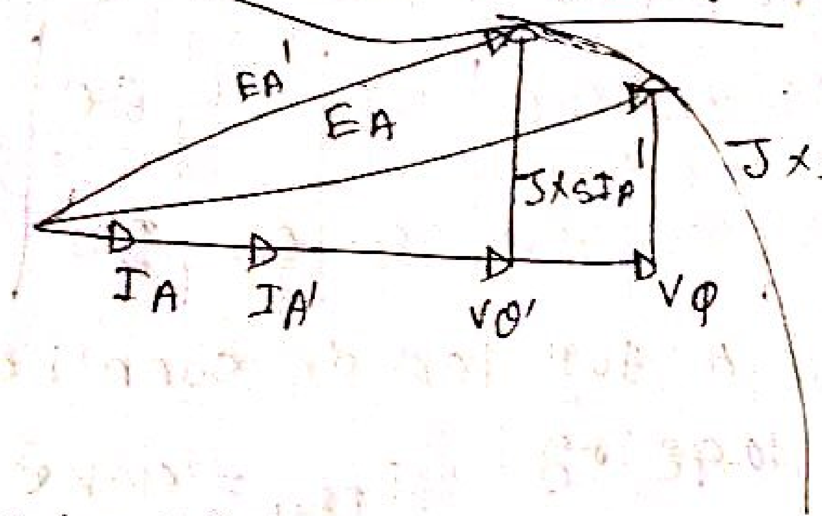
(1) Lagging load:



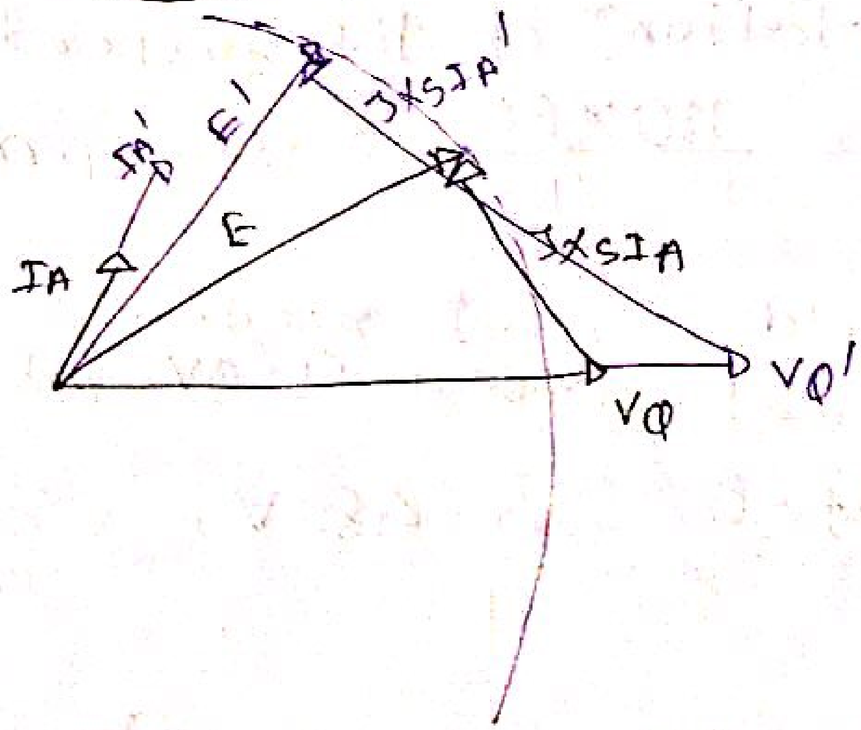
I_A' angle changes, if I_A' is more than $I_A' > I_A$, so jX_sI_A increase

EA cannot increase because it depends on excitation

(ii) Unity power factor load:



(iii) Leading load:



example - 4.2

A 480 V, 60 Hz, Δ-connected, Alternator has synchronous resistance of 0.1 Ω

I_f	1.5	2.3	3.3	4.0	4.5	5.0	6.0	8
$V_{T,OC}$	200	300	400	450	480	515	545	580

$R_A = 0.015\ \Omega$, At full load, supplies 1200 A at 0.8 PF lagging, $F_{F\&WL} = 40\,kW$, $P_{core} = 30\,KW$.

(a) Speed of rotation of the generator?

$N_s = \frac{120 f_e}{P} = \frac{120 \times 60}{4} = 1800\ rpm.$

(b) How much field current needed to supply to make terminal voltage 480 V at no load?

At, no load. $I_f = 0$, $V_T = 480V$,

$\therefore I_F = 4.5 A$

(c) If the generator connected to a load and it draws 1200 A at 0.8 PF lagging. How much field current require to keep terminal voltage at 480 V

P_{in} = losses + P_{out}

$= P_{cu} + P_{SLW} + P_{core} + P_{out}$

$= (7\cancel{08}\ 12\,kW + 21.6\,kW + 30\,kW + 40\,kW)$

$= 889.6\,kW$

$\therefore \eta = \frac{P_{out}}{P_{in}} = \frac{789.12}{889.6} \times 100\%$

$= 89.75\%$

(x) torque applied to the generator:

$P_{in} = \tau_{app} \times \omega$

$\therefore \tau_{app} = \frac{P_{in}}{2\pi \frac{N}{60}}$

$= \frac{889.6 \times 10^3}{2\pi \frac{1800}{60}} = 4719\,Nm.$

$P_{conv} = \tau_{ind} \times \omega$

$P_{conv} = P_{out} + P_{cu}$

$= (798.12 + 21.6)\,kW$

$= 819.72\,kW$

$\therefore \tau_{ind} = \frac{819.72 \times 10^3}{2\pi \frac{1800}{60}}$

$= 4348.74\,Nm$

A.), 480V,

$E = V\phi + R_A I_A + jX_S I_A$

$= 480V + (0.015\,A)\left(\frac{1200A}{\sqrt{3}}\angle -36.87\right)$

$+ (j0.1)\left(\frac{1200A}{\sqrt{3}}\angle -36.87\right)$

$= 480V + 10.39\angle -36.87 + j\,69.2\angle -36.87$

$= 480+$

$= 532\angle 5.3^0 V$

$\therefore I_f = 5.6A$.

(d) How much power generator supplying? How much power supplied to the generator by prime mover? efficiency.

$\Rightarrow P_{out} = \sqrt{3}\, V_L I_L \cos\theta$

$= \sqrt{3}\; 480 \times 1200 \times \cancel{\cos(0.8)}\; 0.8$

$= 798.12\,KW$;

$P_{cu} = 3 I_A^2 R_A$

$= 3\left(\frac{1200}{\sqrt{3}}\right)^2 \times 0.015$.

$= 21.6\,KW$

(x) $V_R = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$

$= \frac{532 - 480}{480}$

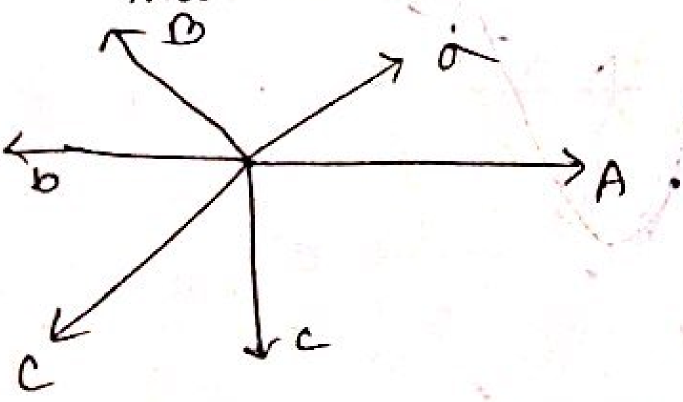
$= 10.83\%$

Parallel operation of Alternator:

For connecting alternator with another power system: we have to fulfil the some condition-

(i) Same line voltage:- we can obseve it by connecting a voltmeter.

(ii). Same phase sequence:- Same sequence must be same.



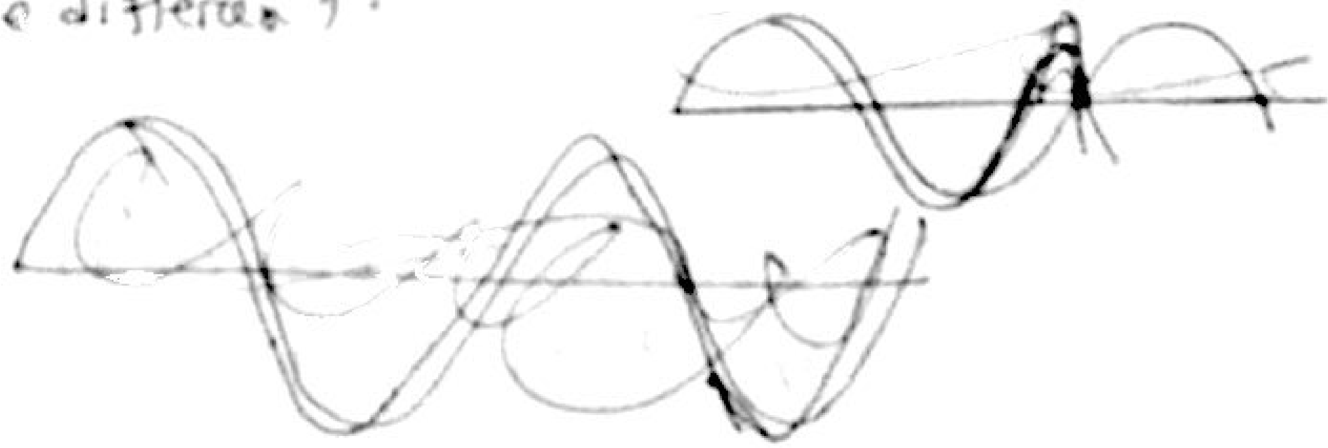
we can cheack this by using synchronous module or using induction motor. If the phase is different we swap the phase to adjust the incorrect phase sequence

[induction motor — as a checker
A B C if the phase is different
1 2 3
3m
than motor will not run]

(iii) Phase angle same: phase angle must be same. If the all lights of synchronous module turn on and off together than it is same phase angle.

(iv) Same frequency :-

ⓐ if connected with other generator in no load condition freq ~~must~~ will be different.



~~As at same frequency~~

then more we draw power from generator, the frequency decreases.
In the diagram to compensate power is drawn, speed will decrease if the frequency decrease.

Governor mechanism:

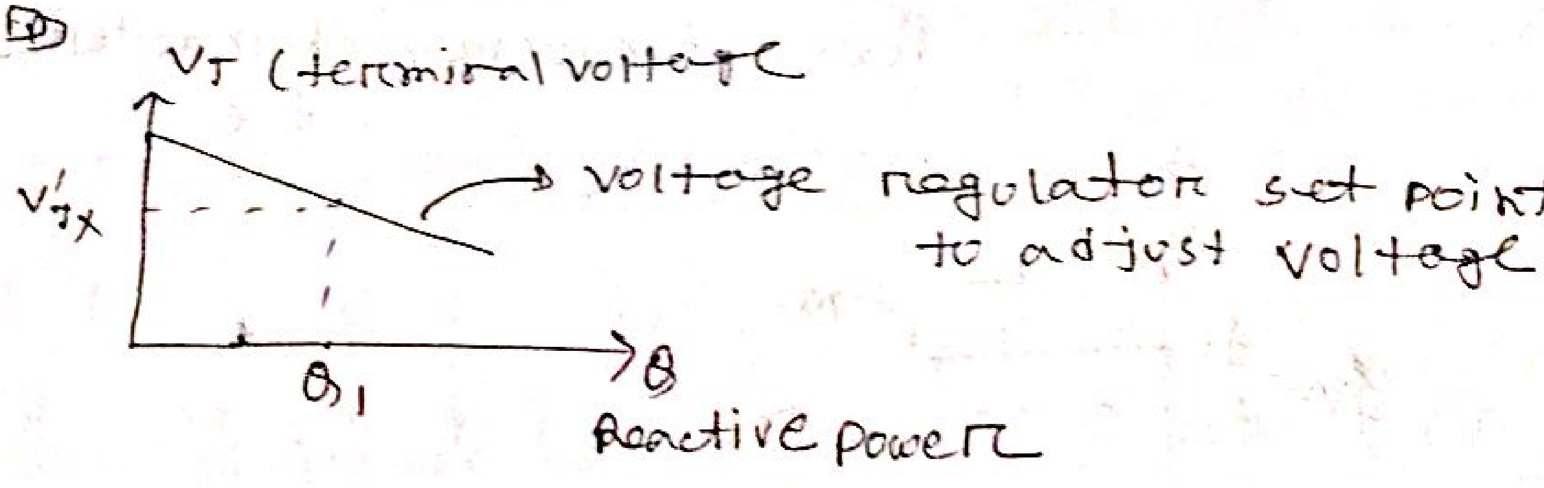
with this we can calculate the system output.

$$m = \frac{f_{NL} - f_{SYS}}{P}$$

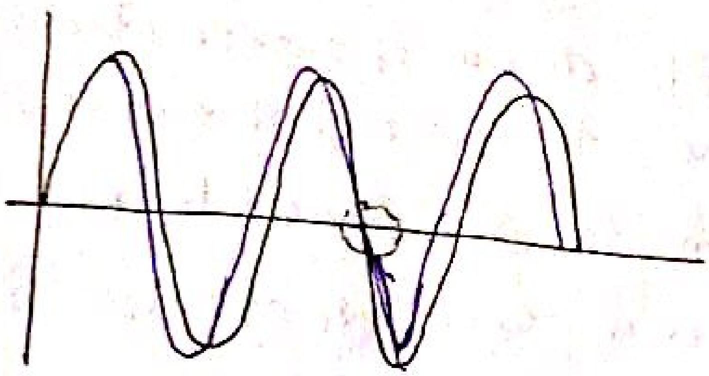
frequency = Real Power

$$P = \frac{1}{m}(f_{NL} - f_{SYS})$$

$$P = S_P (f_{NL} - f_{SYS})$$



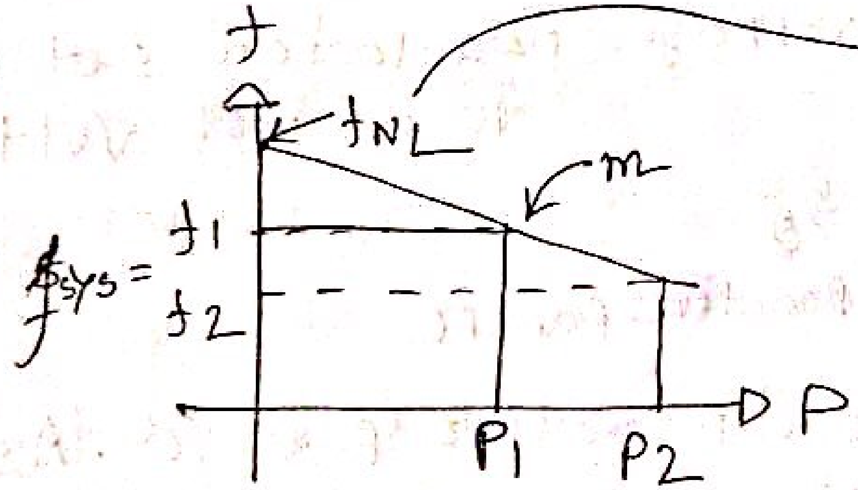
voltage depends on reactive power. As high the reactive power, as low the terminal voltage. so more we draw



at same frequency initially phase difference will remain for always. So it will same phase for sometime and different phase for sometime.

(b) If power system. Then the frequency of alternator must be heigher than the power system.

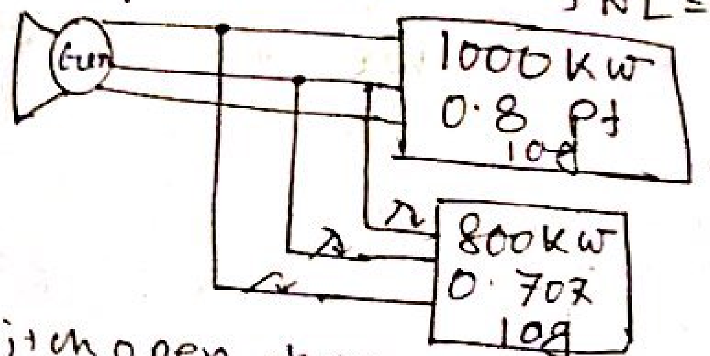
Power-frequency characteristic



f_{NL}, when no power, $P=0$

reactive power from generator
V_T decreases.

(*) $SP = 1\,MW/Hz$ $\quad f_{NL} = 61\,MHz$



(i) with switch open the operating freq?

$P = SP(f_{NL} - f_{sys})$

$1 = 1(61 - f_{sys})$

$\Rightarrow f_{sys} = 60\,Hz$

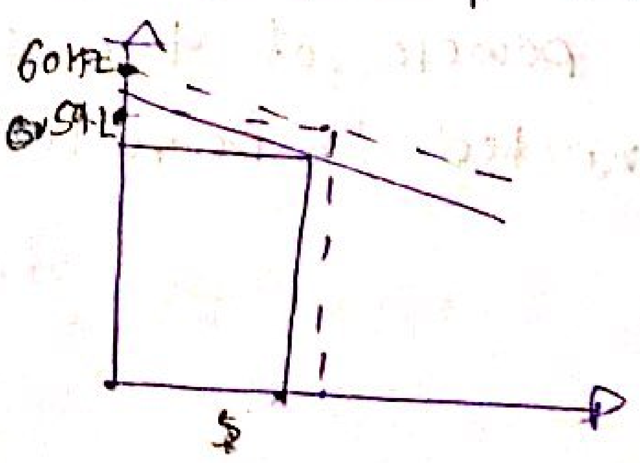
(ii) with switch close the operating freq? for f_{sys}

$1.8 = 61 - f_{sys}$

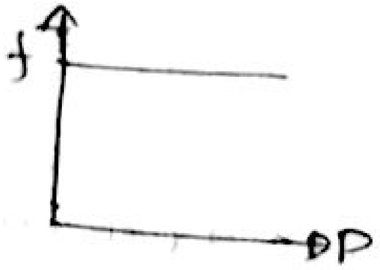
$\therefore f_{sys} = 59.2\,Hz$.

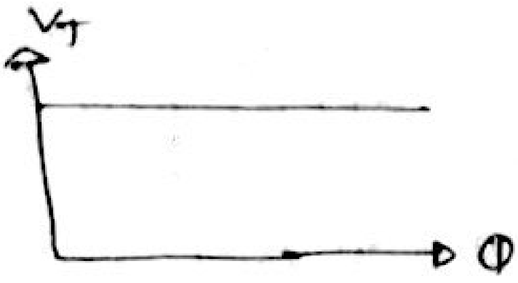
P = output power of generator
f_{nl} = No-load frequency of gen
f_{sys} = operating frq. of system
SP = slope of the curve.

Governor set points to adjust frequency. By increasing the points, the frequency can be increased.

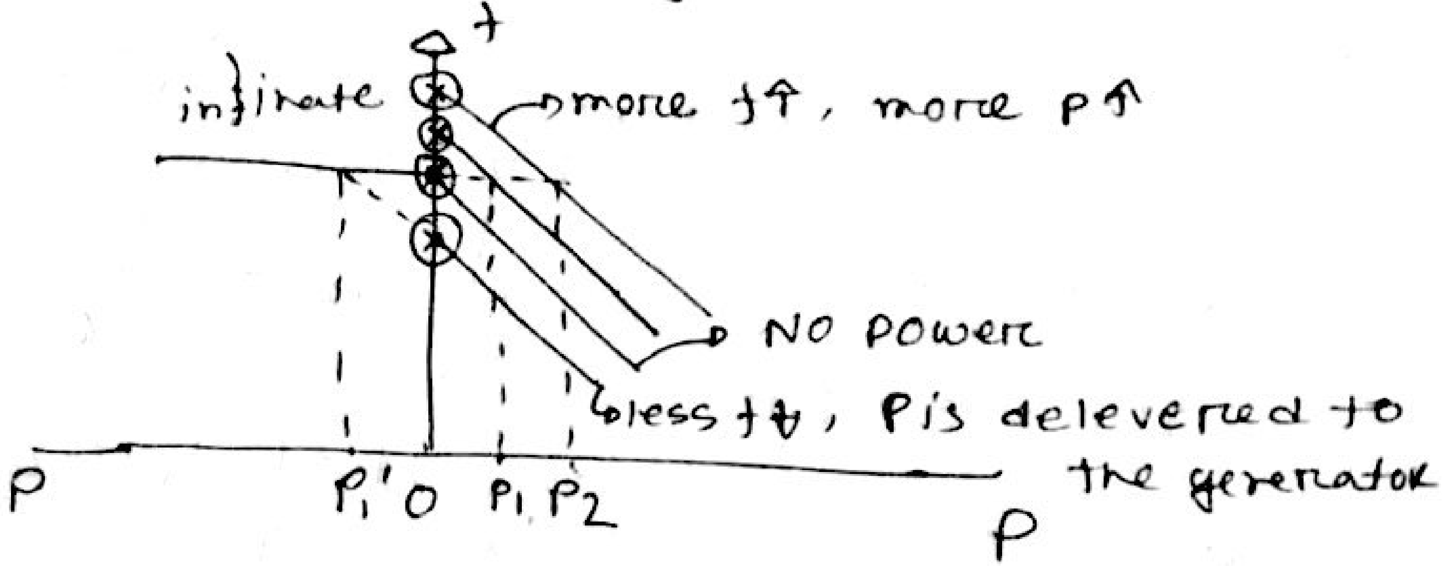


In a infinite power system frequency never changes, though we ~~indo~~ include more generator.



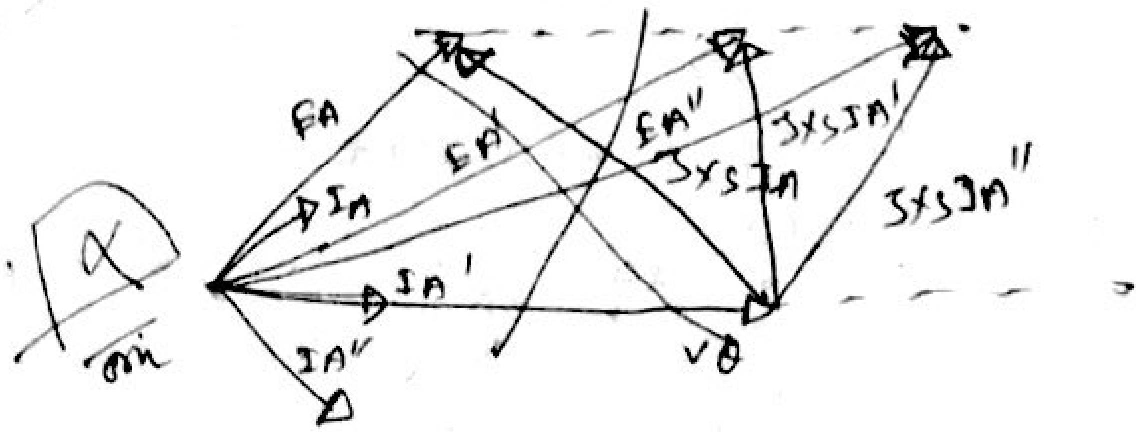


"House diagram"



this house diagram shows the relation betwe
the frequency and power of two systems
than would be connected in parallel.

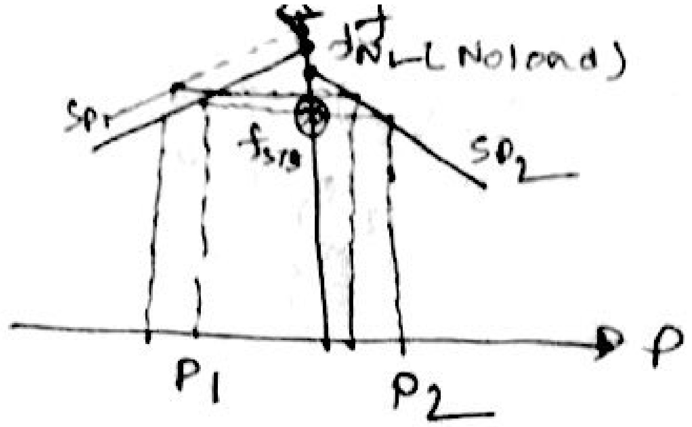
Effect of field current change:



If the current is leading we can not supply reactive power. so current must be lagging to supply reactive power. for that we have to increase the excitation. If E_A increase I_A gets lagging

EA changes so we change the governor set points.

As $I_A \cos\theta$ same for two vectors the power Remain same.



$P_{Total} = P_1 + P_2$

$P_1 = SP_1 (f_{NL_1} - f_{sys})$, $P_2 = SP_2 (f_{NL_2} - f_{sys})$

$P_T = SP_1 (f_{NL_1} - f_{sys}) + SP_2 (f_{NL_2} - f_{sys})$

Example - 4.6

GN-1, $f_{NL_1} = 61.5\,Hz$ and $SP_1 = 1\,MW/Hz$.

GN-2, $f_{NL_2} = 61.0\,Hz$ and $SP_2 = 1\,MW/Hz$.

Total power 2.5 MW at 0.8 PF lagging.

(a) What is the system freq? How much power is supplied by the two generator.

$P_{Total} = SP_1 (f_{NL_1} - f_{sys}) + SP_2 (f_{N_2} - f_{sys})$

$\Rightarrow 2.5\,MW = 1\,(61.5\,Hz - f_{sys}) + 1\,(61.0 - f_{sys})$

$\Rightarrow 2.5 = 61.5 + 61.0 - 2 f_{sys}$

$\Rightarrow f_{sys} = \frac{122.5 - 2.5}{2} = 60\,Hz$

$\Rightarrow P_1 = SP_1 (f_{NL} - f_{SYS})$

$= 1 (61.5 - 60 Hz)$

$P_1 = 1.5 MW$

$\therefore P_2 = P_T - P_1$

$= (2.5 - 1.5) MW$

$= 1 MW.$

(b) If the load increase by 1 MW. what is the new system freq and power of each generator.

$P_T = (2.5 + 1) = 3.5 MW$

$P_T = SP_1 (f_{NL_1} - f_{SYS}) + SP_2 (f_{NL2} - f_{SYS})$

$\Rightarrow 3.5 = 1 (61.5 - f_{SYS}) + 1 (60.61 - f_{SYS})$

$\Rightarrow f_{SYS} = \dfrac{122.5 - 3.5}{2}$

$= 59.5 Hz$

$P_1 = (1 MW/Hz)(61.5 Hz - 59.5 Hz)$

$= 2.0 MW$

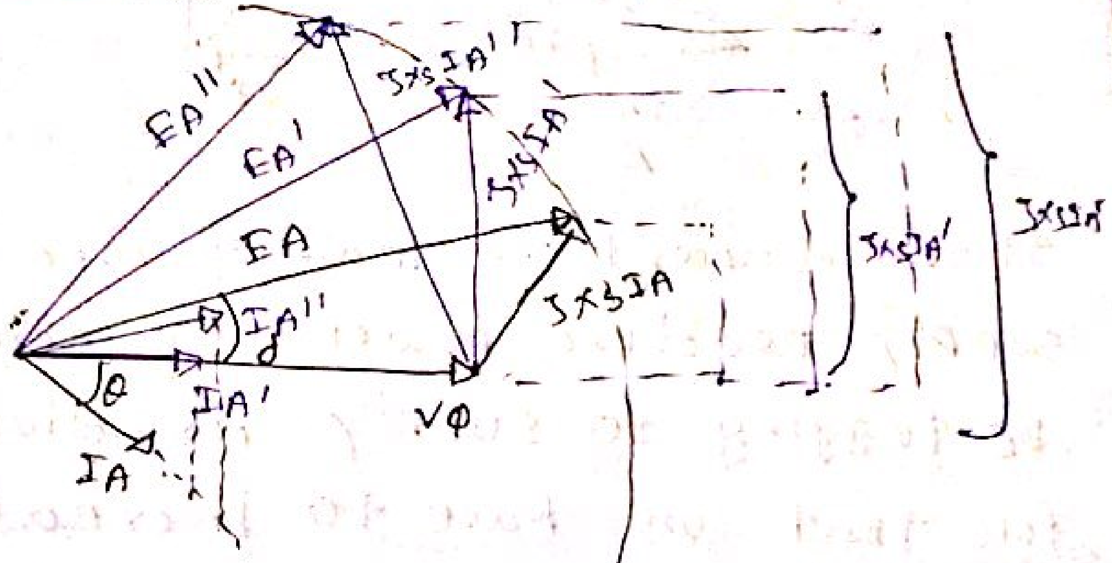
$P_2 = P_T - P_1 = 1.5 MW$

power

Form this we can say

$$P = \frac{\sqrt{3} V_\phi E_A \sin\delta}{X_S}$$, so V_ϕ, E_A and

& X_S is fixed, so power increase if the $\sin\delta$ is increases.



$P = \sqrt{3} V_\phi I_A \cos\theta$. Real power is proportional to $E_A \sin\delta$.

So $I_A \cos\theta < I_A' \cos\theta$, so angle increase so the power increases.

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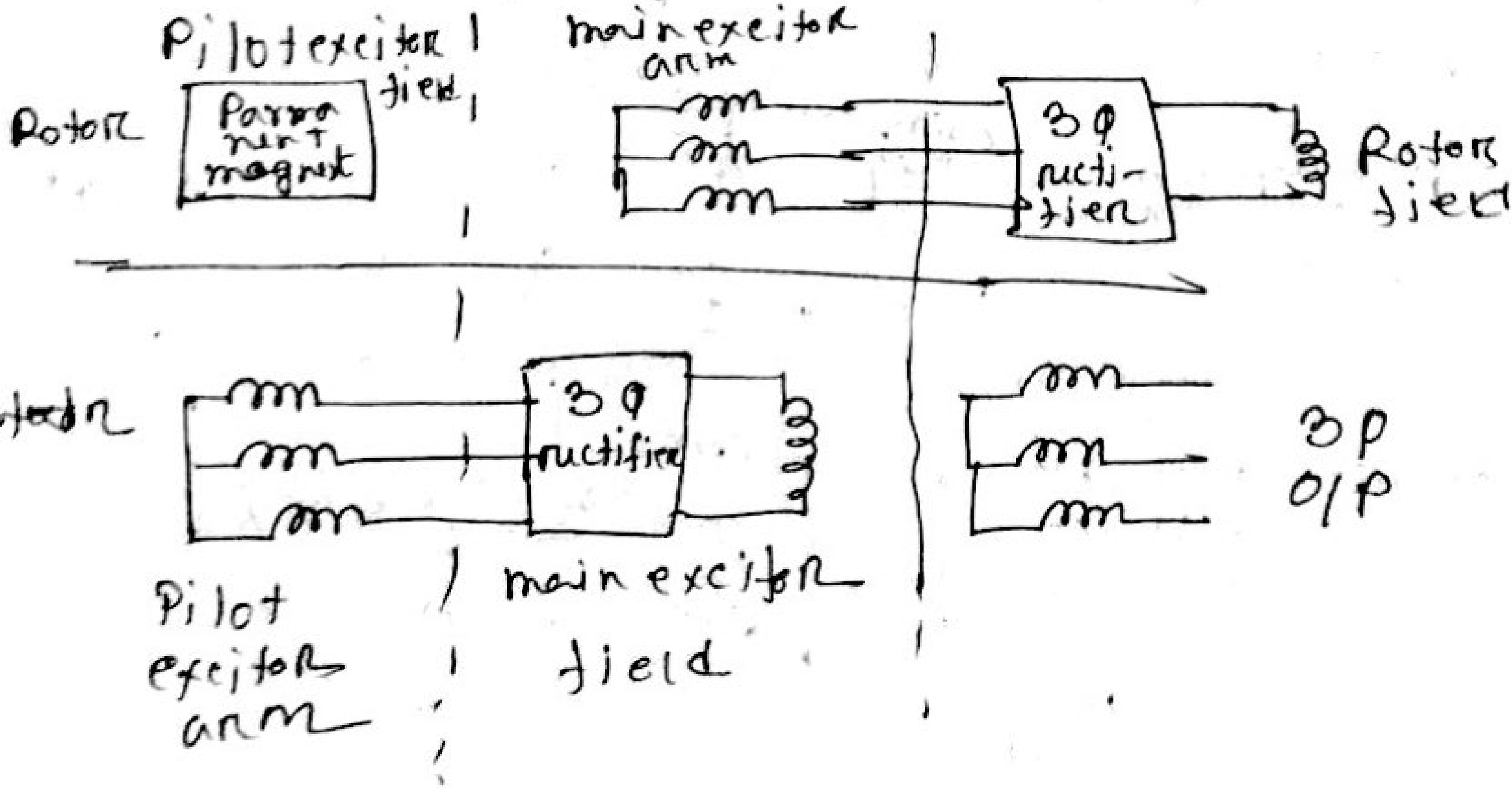
~~so~~ for this we use another mathod named as pilot excitor.

(iii) Pilot excitor: ~~It has inst~~ It is independent power. pilot excitor supply external power to the main excitor. mainly this excitor is a parmanent magnet.

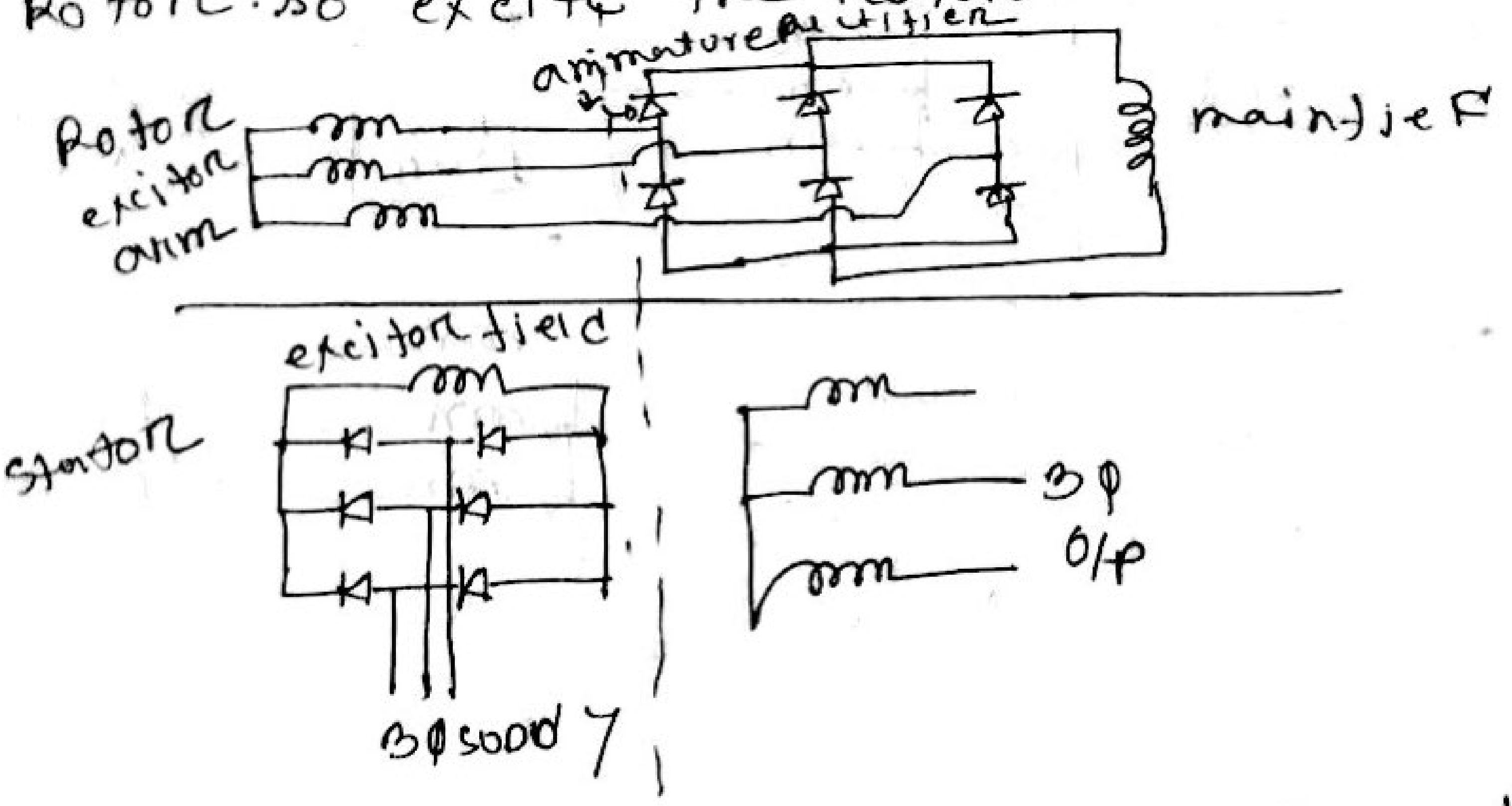


(i) Brush & Sliprings :

Brush and slipring used to provide DC supply to any rotating ~~moto~~ structure

(ii) Rotor exciter : (Brushless exciter)

~~By supplying~~ A coil is placed beside the Rotor. so excite the rotor.



disadvantage - if there is no external power source then it will not work. It is depended on external power source.