Unit 3

Synchronous m/cs — [Syn Gr (or) Alternator / Syn m/o

Alternator:-

DC generator		Alternator
Stator → Field		Armature
Rotor → Armature		field

Adg of stationary armature

1) Armature cwdgs designed for 6.6kV or 11kV or 33kV cwdg insulation is easy if it is on stator.

2) The large ct can be easily collected from stationary armature. large ct collection thro' commutator and brush as very difficult.

3) Stationary armature construction leads to lesser leakage flux & hence reduced armature leakage reactance. This leads to improved voltage regulation.

4) Rotating field structure required only 2 slip rings so insulation reduced.

5) B'cos of low vge field cwdg on rotor the amount of copper & insulation required are less. ∴ rotor has lesser weight & inertia.

6) Most of the heat is generated in armature. When armature is on stator, the ventilation & holes for cooling can be wider leading to better ventilation & heat dissipation.

Construction:-

① Stator frame:-

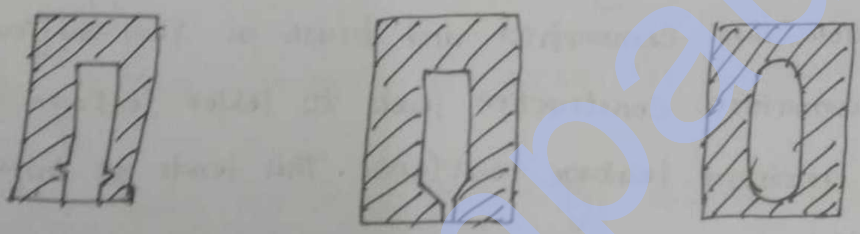
— used for holding the armature stampings & cwdgs in position.

— fabricated from mild steel plate welded together.

② **Stator Core:-**

* build up of lamination of special magnetic iron or steel alloy. (dynamo sheet steel of 0.5mm thickness)
* Core is laminated to minimize loss due to eddy cts.
* lamination are stamped out in complete rings for smaller m/c or in segments for large m/ch.
* lamination are insulated from each other & have spaces b/w them for allowing the cooling air to pass through.
* different shapes of armature slots.

wide open   semiclosed



③ **Stator wdg:-** [Δ wdg / Y wdg

arrangement of stator phase wdgs in slots may be different types.

a) **Concentrated wdg:**

No. of slots = No. of poles.

b) **Distributed wdg:-**

the conductors are embedded in several slots under one pole.

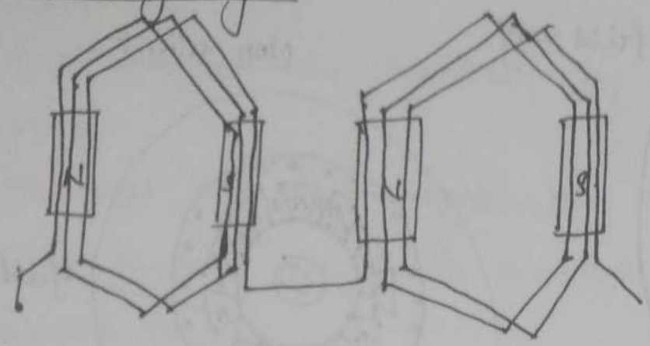
adv:- 1) waveform distortion due to harmonics can be eliminated.

2) It reduces armature reaction & armature reactance.

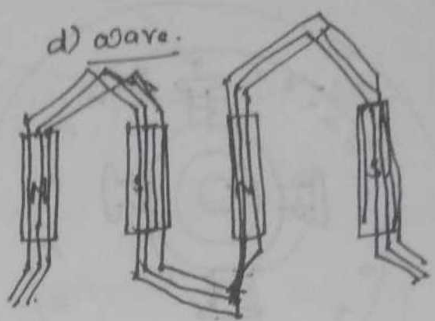
3) Even distribution of Cu loss occurs & the cooling becomes efficient.

4) the conductors are evenly distributed.

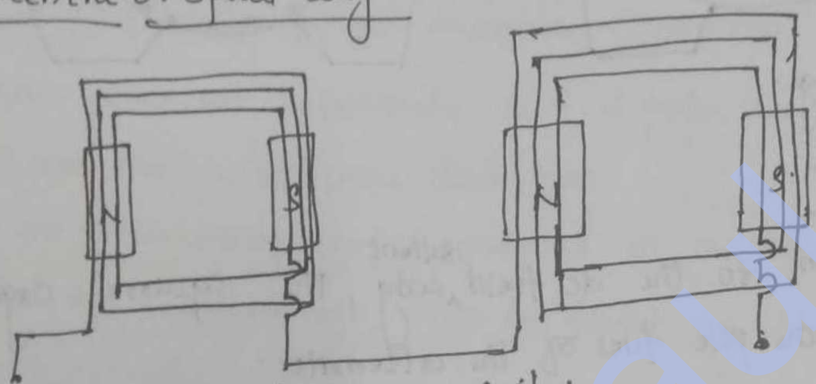
c) Lap (single layer)



d) wave.



e) concentric or sprial codg.



Pitch of the outer coil = 5; middle = 3; inner coil = 1

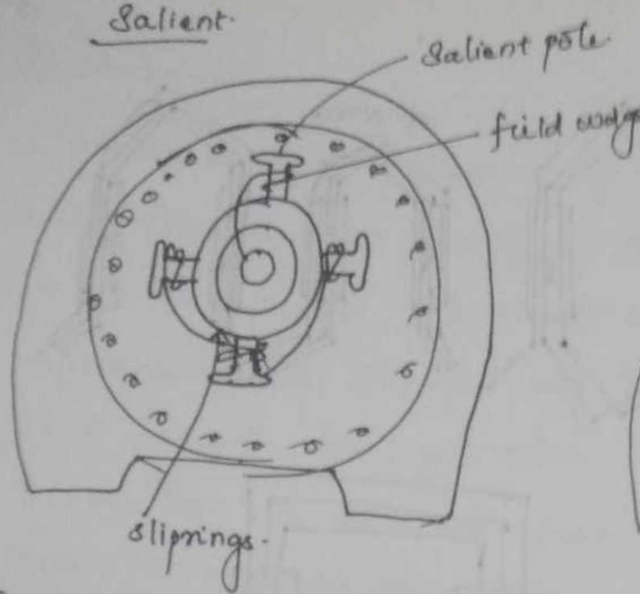
Rotor 2 types — Salient / Non salient or cylindrical.

1) salient (or) projecting pole:-

* used in low & medium speed alternation.
* It has large no of projecting poles.
* large diameter & short axial lengths.
* poles & pole shoes are laminated to minimize heating due to eddy cls.
* heavy magnetic wheel of cast iron or steel of good magnetic quality.

b) smooth cylindrical:-

* used in very high speeds.
* 2 pole or 4 pole - speed 3600rpm (or) 1800rpm.
* small diameter & very long axial length.
* rotor consists of a smooth solid forged steel cylinder, having a no. of slots milled out at materials along the outer perphiry for accommodating fill coils.



Damping wdg:-

* In addition to the dc field, salient wdg, the squirrel cage wdg is embedded in the pole faces of the alternator.
* At normal cdn, the squirrel cage wdg does not carry any ct since the rotor moves at synchronous speed.
* If load changes, the rotor speed begin to fluctuate.
* This produces momentary speed variation above & below the synchronous speed (hunting).
* A voltage is induced in the squirrel cage wdg.
* ct flows in the wdg, reacts with the magnetic field of the stator.
* the forces developed damper the oscillation of the rotor.
* This squirrel cage wdg is called damper wdg.
* It consists of heavy cu loads, they are short ckted at both ends by heavy cu. rings.

Frequency & Speed.

No. of cycles / revolution: No. of pairs of poles = $P/2$.

No. of revolution/sec : $N/60$.

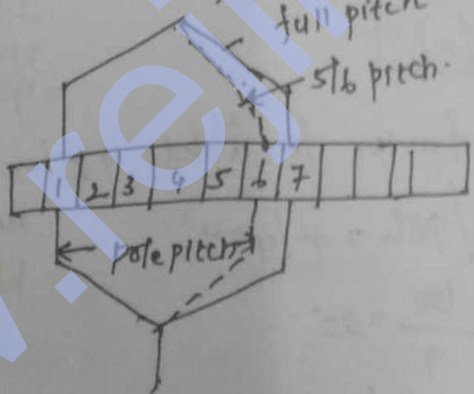
No. of cycles / sec (or) freq. $= P/2 \times N/60 = PN/120$. $\boxed{f = PN/120}$ $\boxed{N_s = \frac{120f}{P}}$ ← syn speed.

Working principle:-

* field magnets are magnetised by applying 125V or 250V through slipings.
* The rotor and field magnets are driven by the prime mover.
* When the rotor rotates, the armature conductors are cut by the magnetic flux.
* An emf is induced in the armature conductors.
* Magnetic poles are alternately N & S pole, this emf acts in one direction and then in the other direction.
* Hence an alternating emf is induced in the stator conductors.
* direction of induced emf can be found by flemings right hand rule.

Full-pitched coil - coils having span which is equal to one pole-pitch (ie) spanning one 180°.

Short pitched coil - coil span is equal 5/6 of a pole pitch.

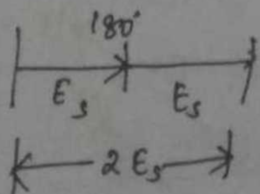


pitch factor (or) coil span factor:

In short pitch induced emf in the 2 sides of coil are not in phase hence their resultant given by vector is always < their arithmetic sum.

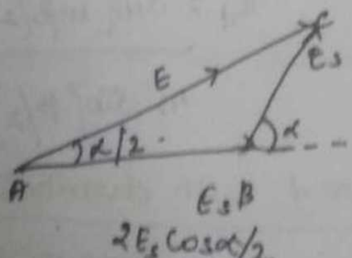
$$K_p \text{ (or) } K_c = \frac{\text{Vector sum of the induced emfs/coil}}{\text{arithmetic sum of the induced emfs/coil}} < \text{unity}$$

$E_r = 2E\cos\alpha/2$.



$$K_p = \frac{2E_s \cos\alpha/2}{2E_s}$$

If $\alpha = 30°$ 5/6 $180/6 = 30°$



$k_p = \cos 15° = 0.966$ always less than unity.

Slots / pole = 180°

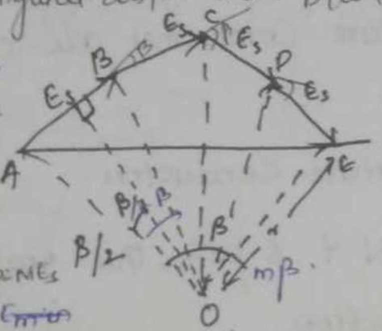
eg slots = 24 pole = 4

$24/4 = 6$ ← full pitch.

Distribution (or) Breadth (or) wdg (or) Spread factor.

The ratio of the Vector sum of the emf induced in all the coils distributed in a no. of slots under one pole to the ar. sum of the emf induced.

Let β → Angular displacement b/w the slots. Its value is



Emf induced in 1 phase under one pole.

Resultant vge in one polar group = mEs

m - No of slots/ph/pole

$\beta = \frac{180°}{\text{No of slots/pole}} = \frac{180°}{n}$

E_s – Vge induced in one coil side.

m_β – phase spread angle.

$A \cdot B = E_s = 2r \cdot \sin\beta/2$

Emf induced in each coil side $= 2AM = 2 \times OA \sin\beta/2$.

Arithmetic Sum $= m \cdot E_s = m \cdot 2r \cdot \sin(\beta/2)$

Ar. sum $= m \times 2 \times OA \sin\beta/2$

Vector Sum $= AE = E_r = 2r \cdot \sin(m\beta/2)$

$k_d = \frac{\text{Vector sum}}{\text{Arithmetic sum}} = \frac{2r \cdot \sin(m\beta/2)}{m \cdot 2r \cdot \sin(\beta/2)}$

The resultant emf $E_r = 2 \times OA \sin\frac{AOB}{2} = 2OA \sin\frac{m\beta}{2}$

$$k_d = \frac{\sin(m\beta/2)}{m \cdot \sin(\beta/2)}$$

each phase coils are not concentrated in one slot it is distributed in no. of slots to form polar group the emf generated in end connected are out of phase. It has total 36 slots 9 slots/pole. If Bal 1, 2, 3 belong to R phase it forms one polar group.

Cal. the distribution factor for a 36 slot 4 pole, single layer 3φ wdg.

n = No. of slots / pole $= 36/4 = 9$

$\beta = \frac{180°}{n} = \frac{180}{9} = 20°$

m: No. of slots / ph / pole.

$= \frac{36}{3 \times 4} = 3$.

$k_d = \frac{\sin(m\beta/2)}{m \sin(\beta/2)} = 0.96$

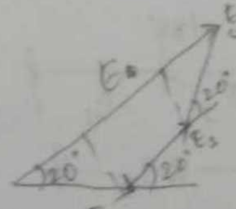
Angular displacement b/w two slot is $180/9 = 20°$

Vect sum $E = E_s \cos 20° + E_s + E_s \cos 20°$

$= 2E_s \cos 20° + E_s$

$= 2E_s \times 0.93 + E_s$

$= 2.88 E_s$



$\therefore k_d = \frac{\text{e.m.f with distributed wdg}}{\text{Concentrated wdg}} = \frac{3 \text{ slots/pole}}{1 \text{ slots/pole}} = E/3E_s = \frac{2.88 E_s}{3E_s} = 0.96$.

Emf induced if the wdg is

EMF eqn:

Z - No. of Conductors or coilsides in series/ph.

Z = 2T (T - No. of Coils or turn per ph)

P → No. of poles.

f → freq of induced emf

φ → flux/pole in wb

k_d - distribution factor = $\frac{\sin(m\beta/2)}{m \cdot \sin(\beta/2)}$

k_c (or) k_p = $\cos(\alpha/2)$

k_f = form factor = 1.11

N - rotor speed (rpm)

In one revolution of the rotor (60/N) each stator conductor is cut by a flux of φP wbs.

$d\phi = \phi P \qquad dt = 60/N$

Avg emf induced/conductor = $\frac{d\phi}{dt} = \frac{\phi P}{60/N}$

$N = 120f/P$

Av. emf/conductor = $\frac{120f}{P} \cdot \frac{\phi P}{60} = 2f\phi$

If there are Z conductors

Av. emf = $2f\phi \cdot Z = 4f\phi T$ $(\because Z = 2T)$

Form factor = $\frac{\text{RMS Value}}{\text{Avg. Value}} = 1.11$

RMS Value of emf/ph = $4.44 f\phi T$

↳ actual value of induced emf if all the coils in a phase were 1) full pitched

2) Concentrated in one slot.

The actual available vge is reduced in the ratio of these 2 factors.

$$Emf/ph = 4.44\, k_d k_c \cdot f \phi T$$

If the alternator in star connected then the $V_L = \sqrt{3}\, V_{ph}$

Alternator on load.

* load is Valid, its terminal vge is also found to vary.
* This Variation in terminal vge V is due to the following reasons.

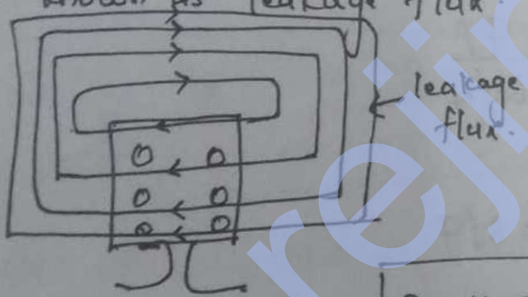
1) vge drop due to armature resistance, R_a.
2) Voltage " " leakage reactance, X_L.
3) " " " reaction.

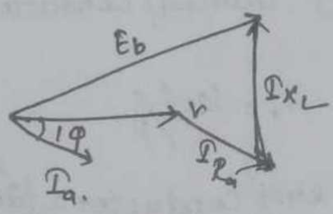
a) Armature Resistance (R_a)

drop across R_a + inphase with I_a.

b) Armature leakage Reactance (X_L)

When ct thro the armature Conduction, fluxes are setup which donot comes the airgap, but the different paths such fluxes are known as leakage flux.





$$E = V + I(R_a + jX_L)$$

Armature Reaction:-

* the effect of armature flux on the main field flux.
* the p.f of the load has a coondrable effect on the armature reaction.

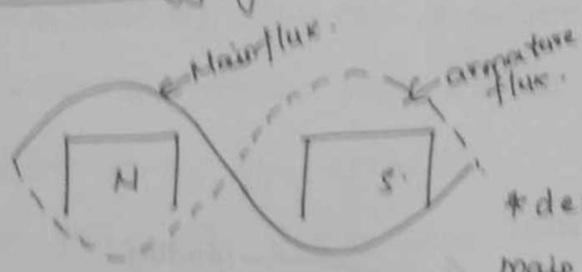
3 Cases:
1) when load of pf is UPF
ii) " pf is zero lagging
iii) " " " leading.

* mmf (or) Amp. turn wave.
* times relative to the poles its amplitude is proportional to the load ct but its position depends on the pf of the load.

1) UPF

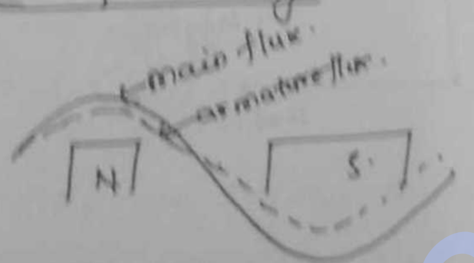
* the armature flux is unmagnetising.
* the result is that the flux at the leading tips of the poles is reduced while it is ↑ed at the tips.

2) Zero pf lagging:-



* the armature flux is in direct opposition to the main flux.
* the main flux is reduced.
* demagnetizing - weakening of the main flux less emf is generated.

3) Zero pf leading:-



* 90° forward
* inphase with the main field flux.
* results in added main flux.
* the armature reaction is wholly magnetizing.
* results in greater induced emf

Synchronous Reactance:

For the same field excitation, terminal vge is ~~derived~~ decreased from its no load value E_0 to V b'coz of
1) drop due to armature resistance IR_a
2) drop due to leakage reactance IX_L
3) drop due to armature reaction IX_a.

$X_s = X_L + X_a$

Total vge drop $IR_a + jIX_s = I(R_a + jX_s)$

Vector diagram:

E_0 - no load emf, E - loaded induced emf

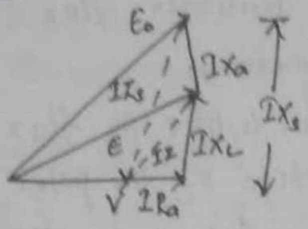
V - terminal vge.

$Z = \sqrt{(R_a^2 + X_s^2)}$

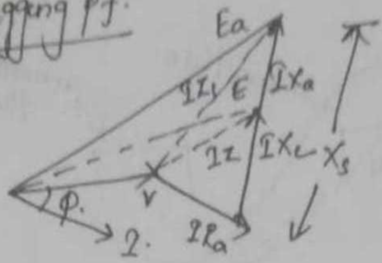
I - armature ct/ph

φ - load pf angle.

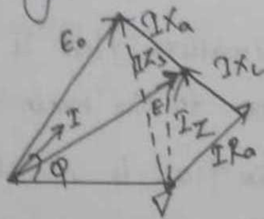
UPF



lagging pf.



leading pf

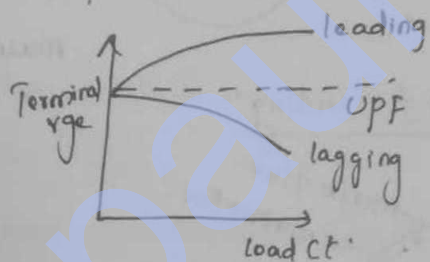


Voltage regulation:-

E_0 - No load emf

V - terminal vge - reduced under loaded cdn.

$$\% \text{ reg} = \frac{E_0 - V}{V} \times 100$$



Determination of vge regulation.

1) syn. impedance (or) Emf method.
2) Ampere - turn or MMF method.
3) Zero pf method.

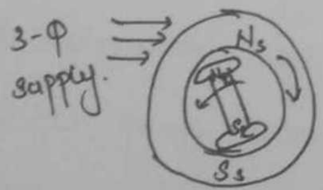
All these methods require i) Ra ii) oc iii) sc test.

Synchronous m/r:-

* operates at constant speed at no load to full load.
* Commutation is same as Ac g/r. It has a revolving field which must be separately excited from a Dc source.
* pf can be varied over a wide rage of lagging + leading values of changing the DC field excitation.
* high η + low initial cost.
* used to improve the pf of 3φ AC indirectional ckts.

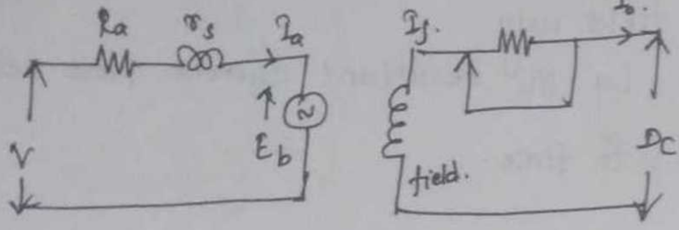
Principle of operation:-

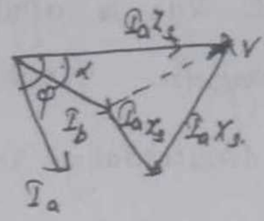
* dc vge is applied to field codg.
* magnetic field produced by the resultant current flow will also be sinusoidally varying w.r to time.
* 3φ vge is applied to a 3-φ codg the flux produced will be the resultant of all the 3 pulsating field.
* 2 fictitious stator poles marked N_s + S_s assumed to rotate clkwise at a sync speed N_s.
* Rotor poles (2) N_R + S_R are formed by the dc excitation.



* N_s + N_R are together + S_s + S_R are together.
* poles repel each other. N_s + S_s moving in clockwise direction.
* N_R + S_R anticlockwise direction.
* Half a cycle later, S_s N_R + N_s S_R attracted + the rotor tries to rotate in the clockwise direction.
* this implies that the rotor experiences torque in different directions every half a cycle.
* As a result the rotor is at standstill due to large inertia.
* It has no floating torque load cannot start by itself.
* Rotor is rotated by a prime mover in the same direction as the synchronously rotating stator field.
* N_s + S_R + N_R + S_s get attached + locked one another.
* rotates at syn speed.

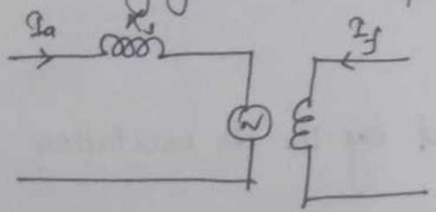
Equivalent ckt of a synchronous m/c.

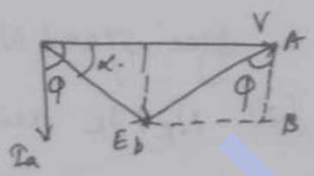




Power developed by a syn. m/c:-

R_a is negligible as compared to its syn reactance X_s.





$\cos\phi = \frac{AB}{I_a X_s}$

$AB = I_a X_s \cos\phi$ — (1)

$\sin\alpha = \frac{AB}{E_b} \Rightarrow AB = E_b \sin\alpha$ — (2)

equate (1) & (2)

$E_b \sin\alpha = I_a X_s \cos\phi$

$\times V$; $V \cdot E_b \sin\alpha = V I_a X_s \cos\phi$

$V I_a \cos\phi = \frac{E_b \cdot V}{X_s} \sin\alpha$

↓

m/c power i/p /ph

$P_{in} = \frac{E_b V}{X_s} \sin\alpha = \frac{3 E_b V}{X_s} \sin\alpha$

Cu loss - negligible so gross mechanical power $P_m = P_{in}$

$P_m = \frac{3 E_b V}{X_s} \cdot \sin\alpha$

Gross torque developed, $T = \frac{P_m}{N_m}$

$T = \frac{3 E_b V}{\omega_m X_s} \sin\alpha$

$T = \frac{3 E_b V}{2\pi N X_s} \sin\alpha \quad \left(\omega_m = \frac{2\pi N}{60}\right)$

$= \frac{60}{2\pi} \frac{P_m}{N}$ $\boxed{T = \frac{9.55 P_m}{N}}$ Nm

max pull out occurs when $\alpha = 90°$

Diff torques of a syn. m/c

1) Starting torque:

* torque developed by the m/c when full vge is applied to its stator wdg.
* Also called breakaway torque.
* 10% in Centrifugal pumps.
* 200 to 250% of full load torque in loaded reciprocating 2 cylinder compressors.

2) Running torque:-

* torque developed by the m/c under running cdn.
* determined by the horse power + speed of the driven m/c.
* the peak horse pwr determines the max. torque that could be required by the driven m/c.
* the motor must have a breakdown or max. running torque greater than this value in order to avoid stalling.

3) Pull in torque:-

* Syn. m/c is started as IM till it run 2 to 5% below syn. speed.
* then excitation is switched on + the rotor pulls in to slip with the synchronously rotating stator field.
* the amount of torque at which the m/c will pull in to step is called the pull in torque.

Pull out torque:-

* the max torque which the m/c can develop without pulling out of step or synchronism is called pull out torque.

Starting methods:

From dc Source:

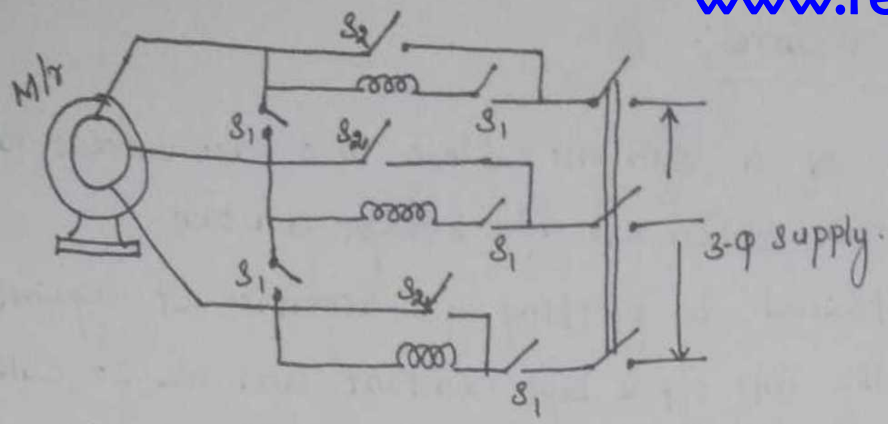
* dc Compound m/c is Coupled to the shaft of the syn m/c
* Syn m/c is excited & synchronized with the ac supply mains
* dc m/c is disconnected from the supply Damper wdg (or) squirrel cage wdg.
* damper wdg is connected on the rotor poles of the syn m/c
* It Consists of short Circuited Cu bars embedded in the face of the field poles
* 3φ supply is Connected to the stator wdg a rotating field is established.
* this rotating field interacts with the emf produced in the rotor cage & produces a torque to start the m/c like 3φ IM.
* m/c attain 95% of the syn speed the rotor wdg is Connected to exciter terminals & the rotor is finally magnetically locked by the rotating field of the stator & the m/c then run at syn speed.

Direct Coupled IM

* No of poles of the IM is kept 2 no's less than the no of poles of the syn m/c
* Syn speed can be easily attained.
* Before the syn m/c is Connected to a supply it should be synchronized with the busbar
* Once the normal operation is made the small IM can be removed

load + dampers:

* while starting the damper bars are not Connected to the end rings but are Connected to external resistances thro' slip rings



→ When vge is applied, the rotor is stationary. The rotating field of the stator wdg induces a very large e.m.f in the rotor during the starting period. though the value of this e.m.f goes on decreasing as the rotor gathers speed.

→ Normally field wdgs are meant for 110.V but during starting period there are many thousands of volts induced in them.

→ Rotor wdgs have to be highly insulated for withstanding such vges.

→ When full line vge is switched on to the armature at rest, a very large current, usually 5 to 7 times the full load ar. current is drawn by the motor.

Procedure for starting a syn. m/r.

1. First main field wdg is S.C
2. Reduced vge with the help of auto-transformers is applied across stator terminals. The m/r starts up.
3. When it reaches a steady speed, a weak dc excition is applied by removing the S.C on the main field wdg. If excitation is sufficient then the m/c will be pulled in to synchronism.
4. Full supply vge is applied across stator terminals by cutting out the auto. transformers.
5. The m/r may be operated at any desired power factor by changing the dc excitation.

Construction of V Curves:-

→ The V-Curves of a Syn m/c Show how ar. Current Varies with its field current when m/c i/p is kept Constant.

→ These are obtained by plotting a c armature ct against dc field ct while m/c i/p is kept Constant and are so called because of their shape.

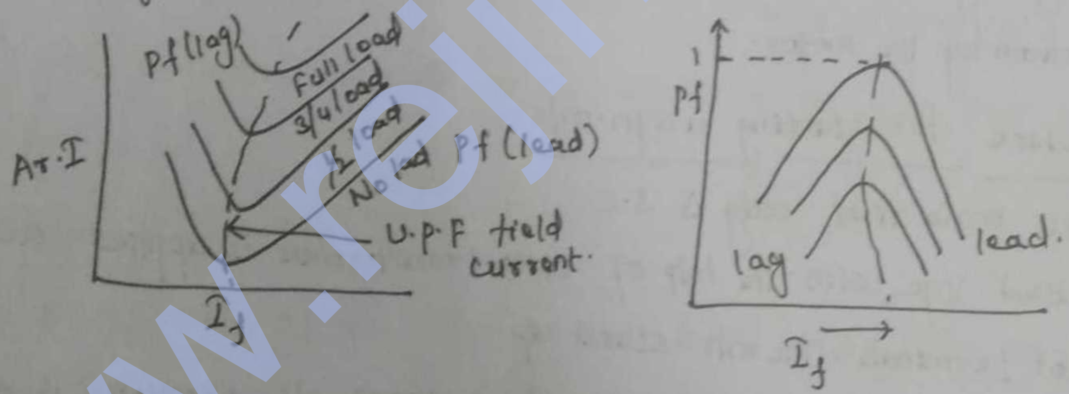
→ To draw this curve the m/c is run from Constant voltage + Constant frequency bus-bars.

→ pwr i/p to m/c is kept Constant at a definite Value.

→ field ct is ↑ed in small steps + Corresponding ar. Currents are noted.

→ when plotted we get a V-curve for a particular Constant m/c i/p.

→ Similar Curves has to be drawn by keeping m/c i/p Constant for differrent Values.



→ The ct taken by the m/c will be minimum when the ct I_a is inphase with the vge or the p.f of the m/c is unity.