Alternator

Basic Principle –

Ac generators or alternators operate on the same fundamental principles of electromagnetic induction as d c generators. They also consists of an armature winding and magnetic field. But there is one important difference betn the two. whereas in d.c generators, the armature Rotates and the field System is Stationary, the arrangement in alternator is just reverse of it. In this case, the standard construction Consists of armature winding mounted on a Stationary element called Stator and field winding on a rotating element called Rotor.

Stationary Armature

Advantages of having Stationary armature are

① The out put current can be led directly from fixed terminals on the Stator (or armature winding) to the load ckt, without having to pass it through brush Contact.

② It is easier to insulate stationary armature winding for high A C voltages, which may has as high a value as 30kV or more.

③ The sliding contacts, ie slip-rings are transfered to the low voltage - low power d.c field circuit which can therefore, be easily insulated.

4) The armature windings can be more easily braced to prevent any deformation, which could be produced by the mechanical Stresses set up as a result of short ckt Current and the high centrifugal forces brought into play.

Details of construction

Main parts of an alternator are ① Stator frame
(II) Stator core
(2) Rotor
ⓒ Salient pole type
(ii) Cylindrical type

① Stator frame —

In alternator it is used for holding the armature Stamping and winding in position. Low Speed Large-diameter alternators have frames which because of ease of manufacturer, are cast in section. ventilation is maintained with the help of holes cast in the frame it self. The provision of radial ventilating spaces in the Stampings assists in cooling the machine.

But these days, instead of using castings frames are generally ~~fa~~ fabricated from mild steel plates welded together in such a way as to form a frame having a box type section.

② Stator Core —

The armature core supported by the Stator frame and is built up of laminations of special magnetic Iron or Steel alloy. The core is laminated to minimise loss due to eddy currents. The laminations are Stamped out in complete ring (for Smaller m/c) or in segment (for larger M/c). The laminations are insulated from each other and have Spaces betn them for allowing the Cooling air to pass through. The slots for housing the armature conductor lie along the inner periphery of the core and are Stamped out at the Same time when lamination are formed.

The wide open type slots has the advantage of permitting easy installation of form wound coils and their easy removal in case of repair. But the disadvantage of distributing the air gap flux in to bunches or tufts, that produce ripples in the wave of the generator emf. The semi closed types slots are better in this respect, but do not allow the use of form wound coils. The wholly-closed type slots or tunnels do not disturb the air gap flux but

(i) they tend to increase the inductance of the winding

(ii) the armature conductors have to be threaded through, thereby increasing initial labour and cost of winding

(iii) they present a complicated problem of end connection.

Rotor —

There are two types of rotor are used in alternators.

① Salient pole type

(ii) Smooth-Cylindrical type.

(i) Salient pole-type —

It is also called projecting type pole.

It is used in low and medium-speed alternators.

It has a large number projecting poles, having their cores bolted on to a heavy magnetic wheel of cast iron or steel of good magnetic quality. Such generators are characterised by their large diameters and short axial length. The pole and pole shoes are laminated to minimize heating due to eddy currents. The large machine field windings consists of rectangular copper strip wounded on edge.

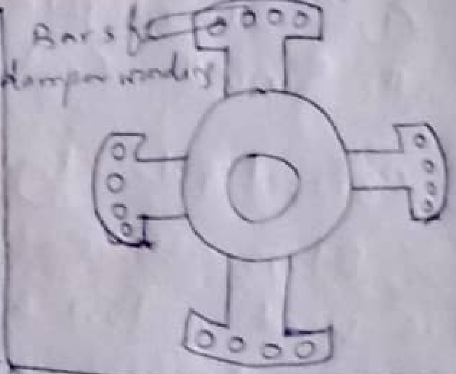
(ii) Smooth - Cylindrical type -

Smooth or cylindrical type of rotor are used in Steam turbine driven alternators, ie turboalternator which run at very high Speed. This rotor Consists of a Smooth solid forged Steel cylinder, having a number of slots milled out at intervals along the outer periphery for accomodating fields coils. Such rotors are designed mostly for 2-pole, 4-pole turbogenerator

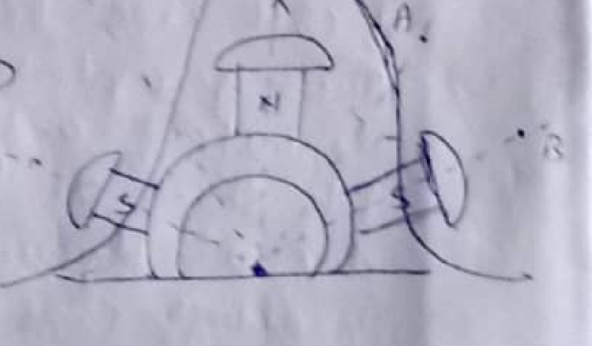
Damper winding -

Most of the alternators have their pole-shoes slotted for receiving copper bars of a grid or damper winding. The copper bars are short ckted at both ends by heavy copper rings. These dampers are usefull in preventing the hunting in generators and are needed in synchronous motor to provide the starting torque. Turbogenerators usually do not have these damper windings because the solid field poles them ~~self~~ selves act as efficient damper.

Speed and frequency -



One Cycle of emf is induced in a conductor when one pair of poles passes over it. The emf in armature conductor goes through one cycle in angular distance equal to twice the pole pitch as shown in fig.



Let P = total no of magnetic poles

N = rotative speed of the rotor in rpm

f = frequency of generator emf in Hz

Since one cycle of emf is produced when a pair of poles passes past a conductor, the number of cycles of emf produced in one revolution of the rotor is equal to the number of pair of poles.

$\therefore$ No of cycles/revolution $= P/2$ and No of revolution/sec $= \frac{N}{60}$

$$\therefore \text{frequency} = \frac{P}{2} \times \frac{N}{60} = \frac{PN}{120} \text{ Hz}$$

$$f = \frac{PN}{120} \text{ Hz}$$

Armature Winding —

~~In~~ The armature winding of alternator are differ from those dc machine. In d.c machine the armature winding are closed path but in alternator the armature windings are open ckt. One end of the winding is joined to the neutral point and the other is brought out.

The two type armature windings most commonly used for 3-ϕ alternators are

① Single layer winding

② Double layer winding.

Short pitch winding —

A coil is said to be full pitch if one side of the coil is placed in the centre of the N-pole of the other side of the coil is placed in the centre of the South pole. ~~that it~~ Then the Short pitch means One side of the coil is placed if in the Center of the N-Pole and other side of the

coil is not placed in the center of the cont [illegible]
then it is called Short pitch coil.

Advantages of Short pitch coil —

① They save copper of end connection

② They improve the wave forms of the generated emf, ie, the generated emf can be made to approximate to a sine wave more easily and the distorting harmonics can be reduced or totally eliminated.

③ Due to elimination of high frequency harmonics eddy current of hysteresis losses are reduced there by increasing the efficiency.

The dissadvantage of using short pitch coil is that the total voltage around the coil is reduced Because the voltage induced in the two sides of the short pitch coils are slightly out of phase.

The pitch factor or coil span factor K_p or K_c is defined

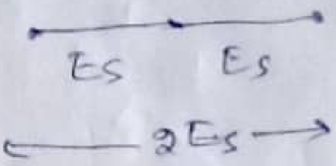
$$= \frac{\text{vector sum of the induced emf per coil}}{\text{arithmatic sum of the induced emf per coil}}$$

It is always less than unity.

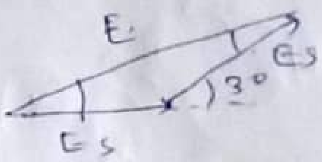
let E_s be the induced emf in each side of the coil. If the coils are full pitched then total emf induced in the coil would have been $2E_s$.

If it is short pitch by 30°(elect) then their resultant is E which is the vector sum of two voltage 30° (elect) apart .

$$E = 2E_s \cos\frac{30}{2} = 2E_s \cos 15^\circ$$



$$K_c = \frac{\text{vector sum}}{\text{Arithmatic sum}}$$



$$= \frac{\cancel{2E_s} \cos 15}{\cancel{2E_s}} = \cos 15^\circ$$

In general, if the coil span falls short of full pitch by an angle α° (elect)

the $\boxed{K_c = \cos\frac{\alpha}{2}}$

Distribution or Breadth factor —— (K_d)

The distribution factor (K_d) is defined as

$$= \frac{\text{emf with distributed winding}}{\text{emf with Concentrated winding.}}$$

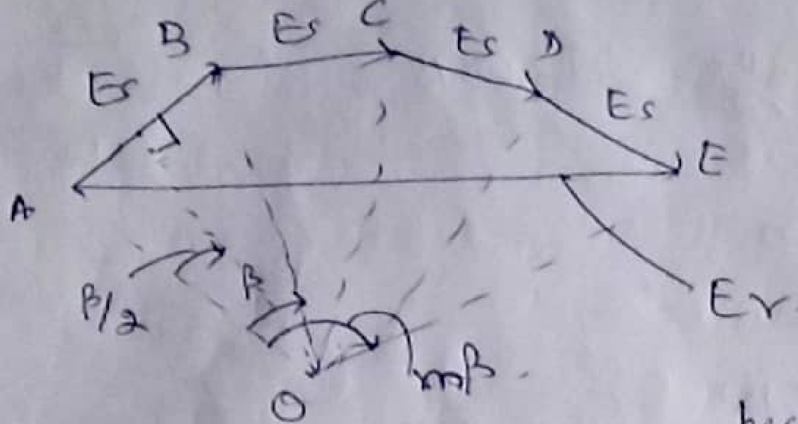
Let β be the value of angular displacement betn the slots. Its value is

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

Let m = No. of slots/phase/pole

$m\beta$ = phase spread angle.

Then the resultant voltage induced in one polar group would be mE_s. Whe E_s is the emf induced in one coil side. from this figure we Calculate.



(If m is large, then the curve ABCDE will become a part of a circle of radius r.)

$AB = E_s = 2r \sin \beta/2$

Arithmatic sum is $= mE_s = m \times 2r \sin \beta/2$

vector sum $= AE = E_r = 2r \sin m\beta/2$

$$K_d = \frac{\text{Vector sum of the coils emfs}}{\text{Arithmatic sum of the coils emf}}$$

$$= \frac{2r \sin m\beta/2}{m \times 2r \sin \beta/2} = \boxed{\frac{\sin m\beta/2}{m \sin \beta/2}}$$

Equation of Induced EMF -

Let Z = No. of Conductors or coils sides in series/phase

$= 2T$ where T is the no. of turns

P = No. of Poles

f = frequency of induced emf in Hz

ϕ – flux/pole in webers

K_d = distribution factor = $\dfrac{\sin m\beta/2}{m \sin \beta/2}$

K_c or K_p = Pitch or coil span factor = $\cos \alpha/2$

K_f = form factor = 1.11

N = rotor rpm

In one revolution of the rotor (i.e. in $60/N$ second) each stator conductor is cut by a flux of ϕP webers

$d\phi = P\phi$ and $dt = \dfrac{60}{N}$ seconds

∴ Average emf induced per conductor $= \dfrac{d\phi}{dt} = \dfrac{\phi P}{60/N} = \dfrac{\phi N P}{60}$

Now we know that $f = \dfrac{PN}{120}$ or $N = \dfrac{120f}{P}$

Substituting this value of N above, we get

Average emf per conductor $= \dfrac{\phi \cancel{P}}{\cancel{60}} \times \dfrac{\overset{2}{\cancel{120}} f}{\cancel{P}} = 2\phi f$ volt.

If there are Z conductors in series/phase, then average emf/phase $= 2f\phi Z$ volt $= 4f\phi T$ volt

RMS value of emf/phase $= 1.11 \times 4f\phi T = 4.44 f\phi T$ volt

∴ Actually available voltage/phase $= 4.44 K_c K_d f\phi T$ volt.

Synchronous Reactance -

For same field excitation, terminal voltage is decreased from its no-load value E_0 to V. This is because of

① drop due to armature Resistance IR_a

② drop due to leakage Reactance IX_L

③ drop due to armature Reaction

The drop in voltage due to armature Reaction may be accounted for by assuming the presence of a fictitious reactance X_a in the armature winding. The value of X_a is such that IX_a, represent the voltage drop due to armature Reaction.

The Leakage reactance X_L and the armature reactance X_a may be combined to give synchronous reactance X_s.

Hence $\boxed{X_s = X_L + X_a}$

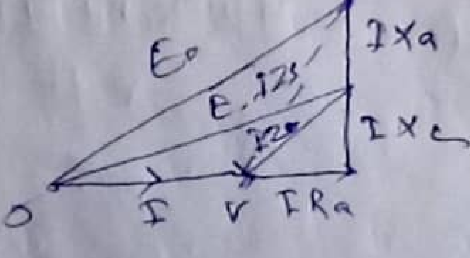
Therefore total voltage drop in an alternator under load is $= IR_a + jIX_s = I(R_a + jX_s) = IZ_s$ where Z_s is known as Synchronous ~~Reactance~~ Impedance.

Vector diagrams of a loaded alternator -

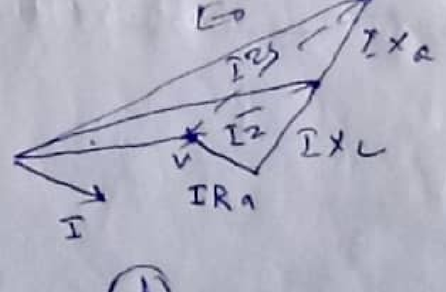
E_0 = No load emf

E = Load induced emf. It is the induced emf after allowing for armature Reaction.

E is vectorially less than E_0 by IX_a.



ⓐ
(unit pf)



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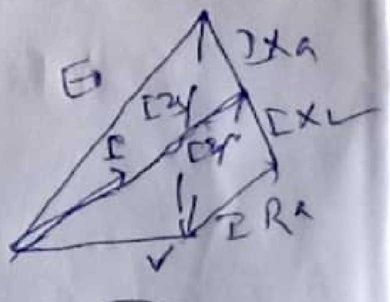
(Lagging pf)



ⓒ
(Leading pf)

Voltage Regulation —

The voltage Regulation of an alternator is defined as the rise in voltage when full load is removed. (field excitation and speed remaining same) divided by the Rated terminal voltage.

$$\therefore \text{\% regulation 'up'} = \frac{E_0 - V}{V} \times 100.$$

Determination of voltage Regulation —

In the case of small machine, the regulation may be found by direct-loading. The procedure is as follows

The alternator is driven at synchronous speed and the terminal voltage is adjusted to its rated value V. The load is varied until the wattmeter and ammeter (connected for the purpose) indicate the rated values at desired pf. The entire load is thrown off while the speed and field excitation are kept constant. The open circuit or no load voltage E_0 is read. Hence regulation can be found from

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

Synchronous Impedance Method —

Following procedural steps are involved in this method

① O.CC is plotted by OCC test.

② SCC is drawn from the data given by the short circuit test. It is a straight line passing through the origin. Both these curves are drawn on a common field current Base.

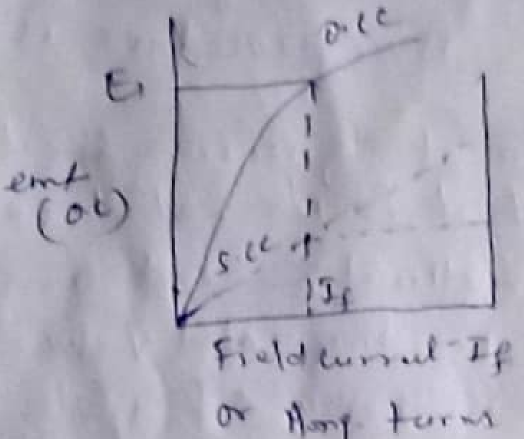
Consider a field current I_f. The O.C voltage corresponding to this field ~~ie~~ current is E_1. When winding is short ckted the terminal voltage is zero. Hence it may be assumed that the whole of this voltag E_1 is being used to circulate the armature short circuit current I_1 against the synchronous impedance Z_s

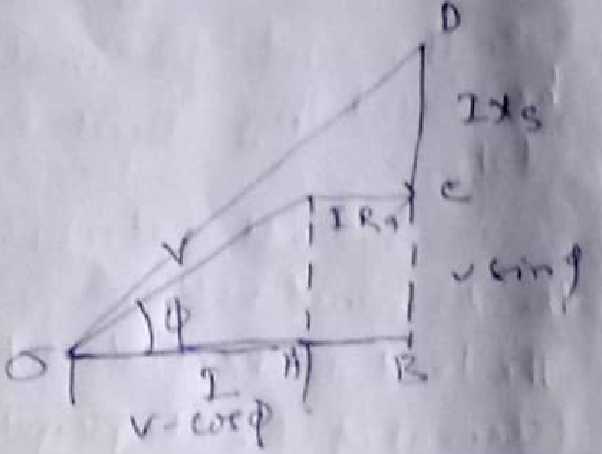
$$\therefore E_1 = I_1 Z_s \qquad \therefore Z_s = \frac{E_1 \text{ (open circuit)}}{I_1 \text{ (Short ckt)}}$$

③ Since R_a can be ~~found~~ determined by ohms law

$$X_s = \sqrt{Z_s^2 - R_a^2}$$

④ Knowing R_a and X_s vector diagram is shown as ~~the~~ follows





$$OD = E_0 \quad \therefore E_0 = \sqrt{OB^2 + BD^2}$$

$$E_0 = \sqrt{(V\cos\phi + IR_a)^2 + (V\sin\phi + IX_s}$$

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

Parallel Operation of Alternator —

The operation of connecting an alternator in parallel with another alternator or with common bus-bars is known as Synchronising. For proper Synchronisation of alternator the following three condition must be satisfied

① The terminal voltage (effective) of the incomming alternator must be the same as bus-bar voltage.

② The speed of the incomming machine must be such that it frequency ($= \frac{PN}{120}$) equals bus-bar frequency

③ The phase of the alternator voltage must be identical with the phase of the bus bar voltage. It means that the switch must be closed the instant the two voltages have correct phase relationship

Synchronizing of Alternator -