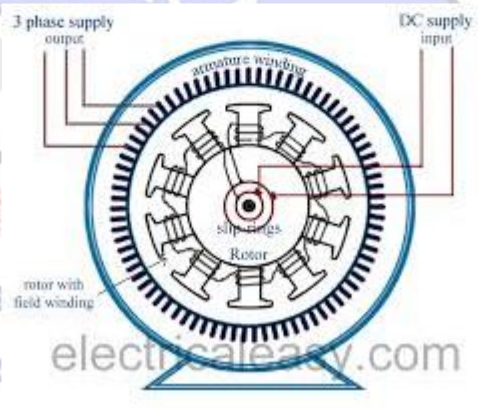
AC Machines II

Synchronous Machines

1-1 Introduction:

A synchronous machine is an A.C. machine in which the rotor moves at a speed, which bears a constant relationship to the frequency of the current in the armature winding. As a motor, the shaft speed must remain constant irrespective of the load, provided that the supply frequency remains constant. As a generator, the speed must remain constant if the frequency of the output is not to vary. The field of a synchronous machine is a steady one. In very small machines this field may be produced by permanent magnets, but in most cases the field is excited by a direct current obtained from an auxiliary generator, which is mechanically coupled to the shaft of the main machine.



1-2 Types of Synchronous Machines:

The armature or main winding of a synchronous machine may be on either the stator or the rotor. The difficulties of passing relatively large current at high voltages across moving contacts have made the stator wound armature the common choice for large machines. Stator-wound armature machines fall into two classes :(a) salient-pole rotor machines, and (b) non-salient-pole, or cylindrical-rotor, machines The salient-pole machine has concentrated field windings and generally is cheaper than the cylindrical-rotor machine when the speed is low, (less than 1,500 rev/min). Salient-pole alternators are generally used when the prime mover is a water turbine or a reciprocating engine. In the round or cylindrical rotor case, the held winding is placed in slots along the rotor length. The diameter is relatively small (I-1.5 m) and the machine is suitable for operation at high speeds (3000 or 3600 rpm) driven by a steam or gas turbine. Hence it is known as a turbo generator.

The frequency of the generated e.m.f, and speed are related by:

F=np/60

Where n is speed in rpm, and p is the number of pairs of poles.

A hydraulic turbine rotating at 50-300 rpm, depending on type. Thus needs many pole pairs to generate at normal frequencies.

Synchronous machines can be categorized into several classifications:

According to the arrangement of the field and armature windings, synchronous machines may be classified as ***rotating-armature type*** or ***rotating-field type***.

Rotating-Armature Type: The armature winding is on the rotor and the field system is on the stator.

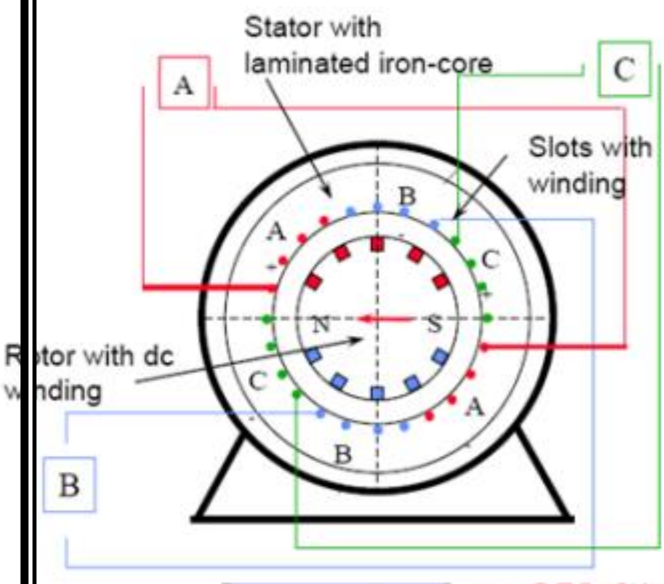
Rotating-Field Type: The armature winding is on the stator and the field system is on the rotor.

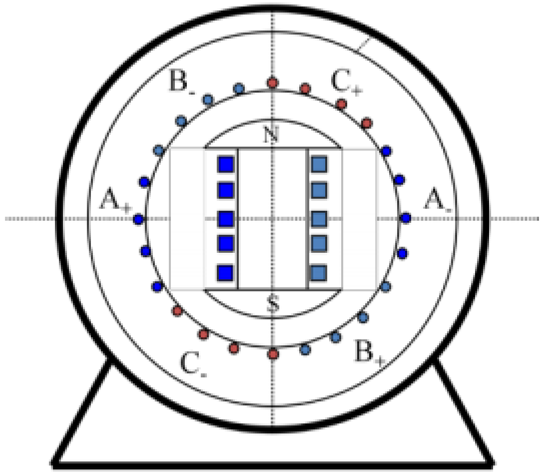
ADVANTAGES OF ROTATING FIELD OVER ROTATING ARMATURE

1. As everywhere A.C. is used, the generation level of A.C. voltage may be higher as 11 kV to 33 kV.
2. This gets induced in the armature. For stationary armature large space can be provided to accommodate large number of conductors and the insulation.
3. It is always better to protect high voltage winding from the centrifugal forces caused due to the rotation. So high voltage armature is generally kept stationary.
4. This avoids the interaction of mechanical and electrical stresses.
5. It is easier to collect larger currents at very high voltages from a stationary member than from the slip ring and brush assembly.
6. The voltage required to be supplied to the field is very low (110 V to 220 V d.c.) and hence can be easily supplied with the help of slip ring and brush assembly by keeping it rotating.
7. The problem of sparking at the slip rings can be avoided by keeping field rotating which is low voltage circuit and high voltage armature as stationary.
8. Due to low voltage level on the field side, the insulation required is less and hence field system has very low inertia.
9. It is always better to rotate low inertia system than high inertia, as efforts required to rotate low inertia system are always less.
10. Rotating field makes the overall construction very simple.
11. With simple, robust mechanical construction and low inertia of rotor, it can be driven at high speeds. So greater output can be obtained from an alternator of given size.
12. If field is rotating, to excite it by an external d.c. supply two slip rings are enough. One each for positive and negative terminals.
13. As against this, in three phase rotating armature, the minimum number of slip rings required is three and cannot be easily insulated due to high voltage levels.
14. The ventilation arrangement for high voltage side can be improved if it is kept stationary.

15. Due to all these reasons the most of the alternators in practice use rotating field type of arrangement.
16. For small voltage rating alternators rotating armature arrangement may be used.

According to the shape of the field, synchronous machines may be classified as ***cylindrical-rotor* (*non-salient pole*) machines** and ***salient-pole machines***.





***Cylindrical rotor* machines and *salient-pole machines*.**

According to the operation mod:

Synchronous Generator (Alternators)& Synchronous Motors

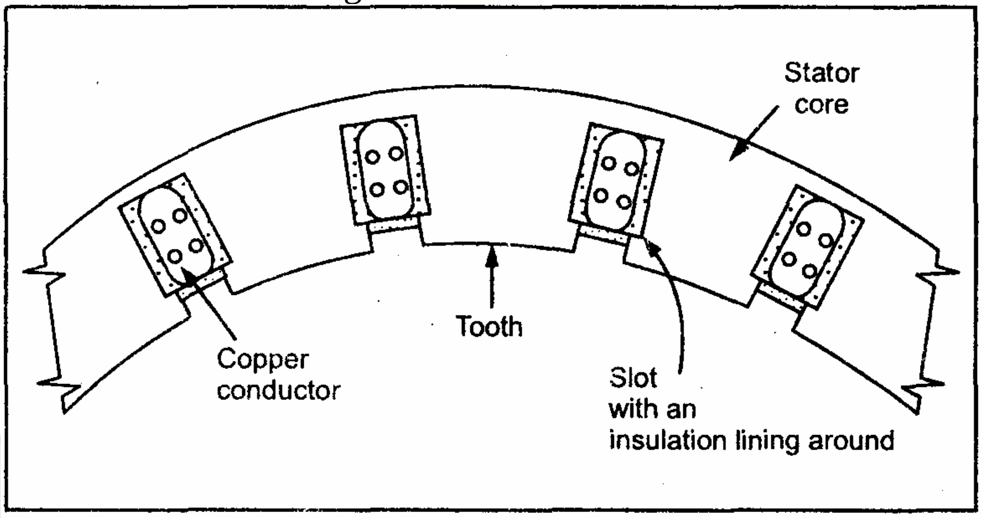
1-3 Construction of Synchronous Machines

In a synchronous generator, a DC current is applied to the rotor winding producing a rotor magnetic field. The rotor is then turned by external means producing a rotating magnetic field, which induces a 3-phase voltage within the stator winding.

STATOR

1. The stator is a stationary armature.
2. This consists of a core and the slots to hold the armature winding similar to the armature of a d.c. generator.
3. The stator core uses a laminated construction.

4. It is built up of special steel stampings insulated from each other with varnish or paper.
5. The laminated construction is basically to keep down eddy current losses.
6. Generally choice of material is steel to keep down hysteresis losses.
7. The entire core is fabricated in a frame steel plates.
8. The core F slots on its periphery housing the armature conductors.
9. Frame does carry any flux and serve the support to the core.
10. Ventilation is maintained with the help of holes in the frame. The section of a alternator stator is show the Figure



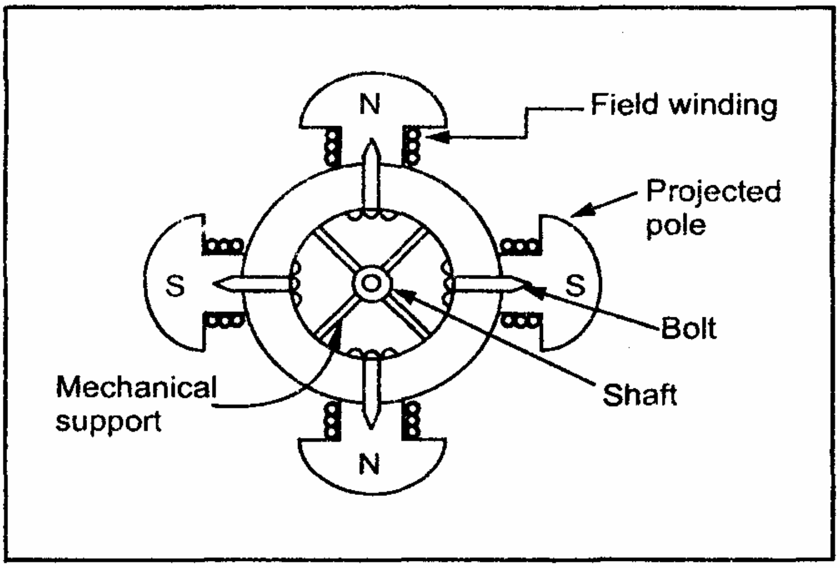
ROTOR

There are two types of rotors used in alternators,

i) Salient pole type ant:

ii) Smooth cylindrical type.

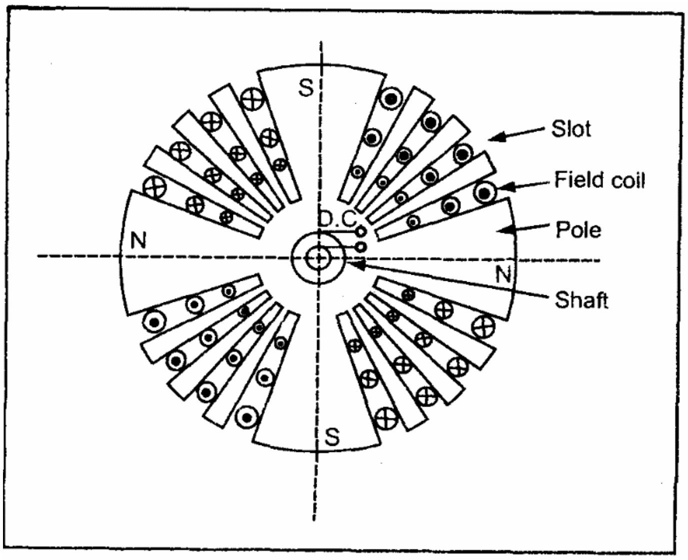
SALIENT POLE TYPE ROTOR



1. This is also called projected pole type as all the poles are projected out from the surface of the rotor.
2. The poles are built up of thick steel laminations.
3. The poles are bolted to t rotor as shown in the Figure.
4. The field winding is provided on the pc shoe. These rotors have large diameter and small axial lengths.
5. · The limiting factor for the size of the rotor is the centrifugal force acting on the member of the machine.
6. As mechanical strength of salient pole type is less, this is preferred for low speed alternators ranging from 125 r.p.m. to 500 r.p.m. The prime movers used to drive such rotor are generally water turbines.

SMOOTH CYLINDRICAL TYPE ROTOR

1. This is also called non salient type or non-projected pole type of rotor.
2. The rotor consists of smooth solid steel cylinder, having number of slots accommodate the field coil.
3. The slots are covered at the top with the help of steel o manganese wedge.
4. The un-slotted portions of the cylinder itself act as the poles.
5. The poles are not projecting out and the surface of the rotor is smooth which maintains uniform air gap between stator and the rotor.
6. These rotors have small diameters and large axial lengths.
7. This is to keep peripheral speed within limits.
8. The main advantage of this type is that these are mechanically very strong and thus preferred for high speed alternators ranging between 1500 to 3000 r.p.m.
9. Such high speed alternators are called ‘ turbo alternators’.
10. The prime movers used to drive such type of rotors are generally steam turbines, electric motors.



DIFFERENCE BETWEEN SALIENT AND CYLINDRICAL TYPE OF ROTOR

Salient Pole Type	Smooth Cylindrical Type
1 Poles are projecting out from the surface.	1. Unslotted portion of the cylinder acts as poles hence poles are non projecting.
2 *Air gap is non uniform.*	2. *Air gap is uniform due to smooth* cylindrical periphery.
3 Diameter is high and axial length is small.	3. Small diameter and large axial length is the feature.
4. Mechanically weak.	4. Mechanically robust.
5. Preferred for low speed alternators.	5. Preferred for high speed alternators i.e. for turboalternators.
6. Prime mover used are water turbines, I.C. engines.	6. Prime movers used are steam turbines, electric motors.
7. For same size, the rating is smaller than cylindrical type.	7. For same size, rating is higher than salient pole type.
8. Separate damper winding is provided.	8. Separate damper winding is not necessary.

• Field windings are the windings producing the main magnetic field (rotor windings)

• armature windings are the windings where the main voltage is induced (stator windings)

The rotor of a synchronous machine is a large electromagnet. The magnetic poles can be either salient (sticking out of rotor surface) or non-salient construction. Rotors are made laminated to reduce eddy current losses.

Two common approaches are used to supply a DC current to the field circuits on the rotating rotor:

1. Supply the DC power from an external DC source to the rotor by means of slip rings and brushes;

2. Supply the DC power from a special DC power source mounted directly on the shaft of the machine.

Slip rings are metal rings completely encircling the shaft of a machine but insulated from it. Graphite-like carbon brushes connected to DC terminals ride on each slip ring supplying DC voltage to field windings.

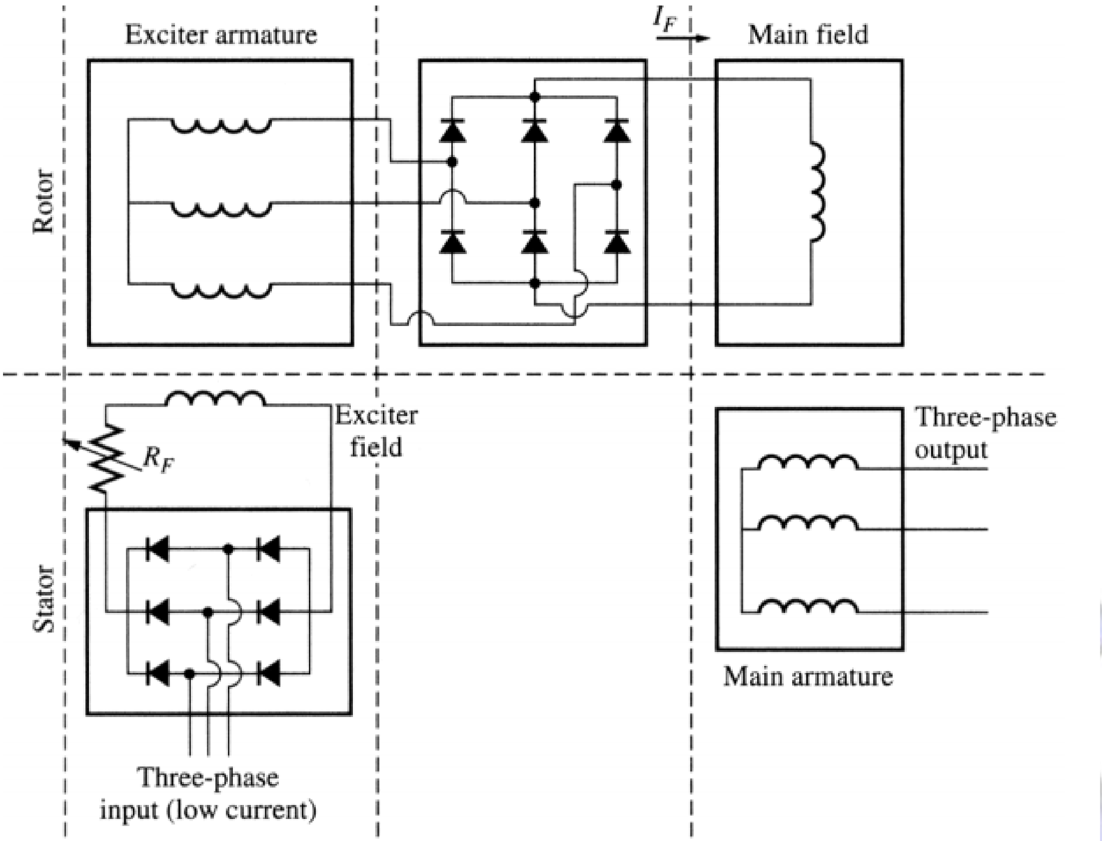
On large generators and motors, brushless exciters are used.

• A brushless exciter is a small AC generator whose field circuits are mounted on the stator and armature circuits are mounted on the rotor shaft.

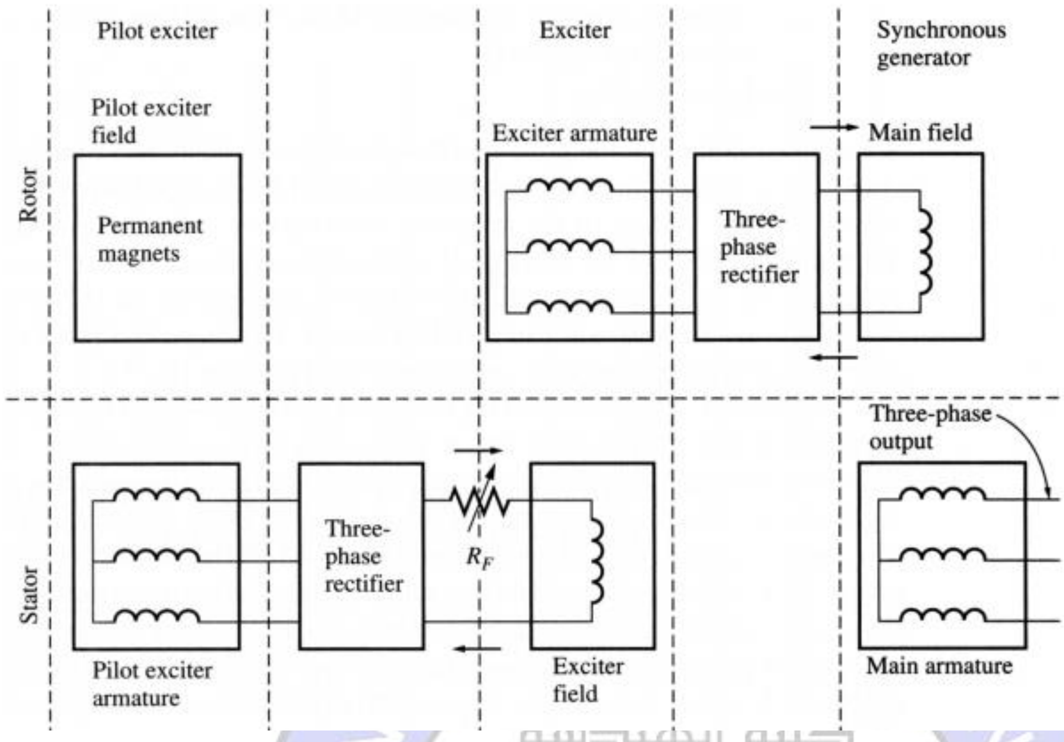
• The exciter generator's 3-phase output is rectified to DC by a 3-phase rectifier (mounted on the shaft) and fed into the main DC field circuit.

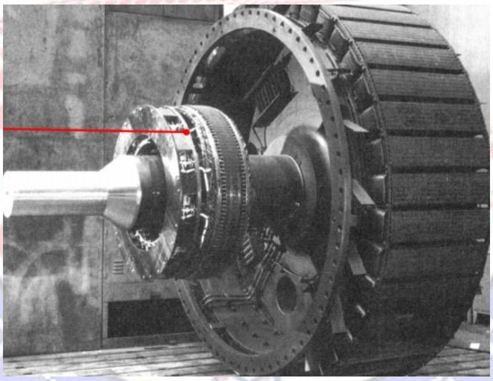
• It is possible to adjust the field current on the main machine by controlling the small DC field current of the exciter generator (located on the stator).

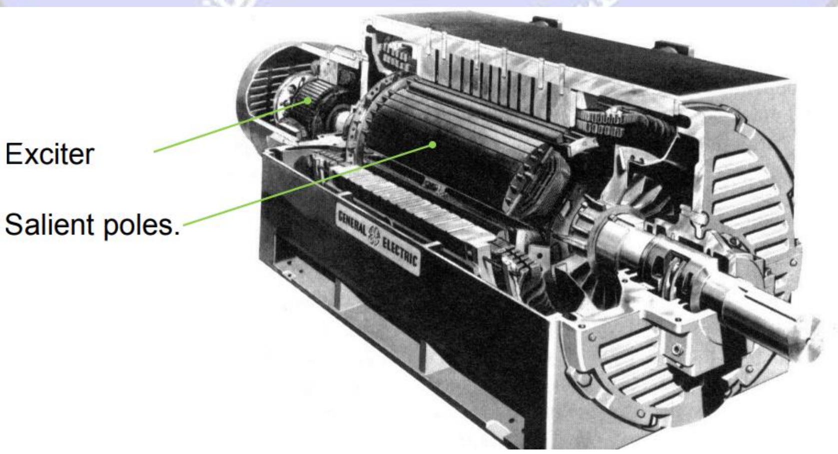
A brushless exciter: a low 3-phase current is rectified and used to supply the field circuit of the exciter (located on the stator). The output of the exciter's armature circuit (on the rotor) is rectified and used as the field current of the main machine.



To make the excitation of a generator completely independent of any external power source, a small pilot exciter is often added to the circuit. The pilot exciter is an AC generator with a permanent magnet mounted on the rotor shaft and a 3-phase winding on the stator producing the power for the field circuit of the exciter.







A rotor of large synchronous machine with a brushless exciter mounted on the same shaft

2- Synchronous Generator (Alternator):

The A.C generators or alternators are operating on the same fundamental principles of electromagnetic induction as DC generator they also consist of an armature winding and magnetic field, but there is on important difference between the two. In DC generator the armature rotates and the field system is stationary the arrangement in alternator is just the reverse of it. In their case standard construction consist of armature winding mounted on stationary element called(stator), and field winding on a rotating element called(rotor).

Then we have:

-Armature (stator), rotor (inductor)

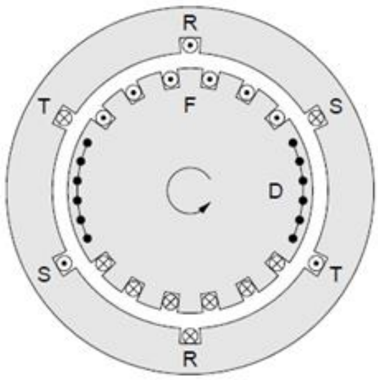
- Armature winding, excitation winding

- Damper winding.

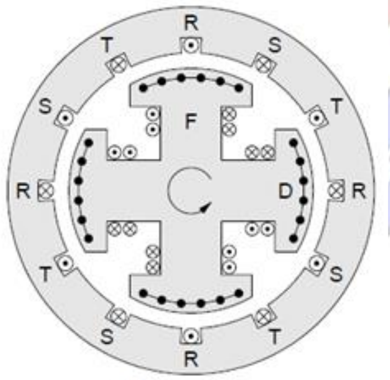
$V_o \approx 14\,KV$, $P_{ex} = 3\% P_o$, $V_{ex} = 100 - 250\,V$

-Stationary Armature and rotating inductor

Rotating Armature and stationary inductor



Round rotor



Salient pole rotor

2-1 Ventilation or Cooling of an Alternator

• The slow speed salient pole alternators are ventilated by the fan action of the salient poles which provide circulating air.

• Cylindrical rotor alternators are usually long, and the problem of air flow requires very special attention.

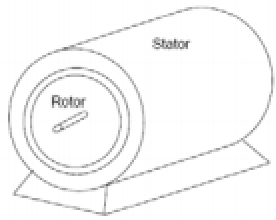
• The cooling medium, air or hydrogen is cooled by passing over pipes through which cooling water is circulated and ventilation of the alternator.

• Hydrogen is normally used as cooling medium in all the turbine-driven alternators because hydrogen provides better cooling than air and increases the efficiency and decreases the windage losses.

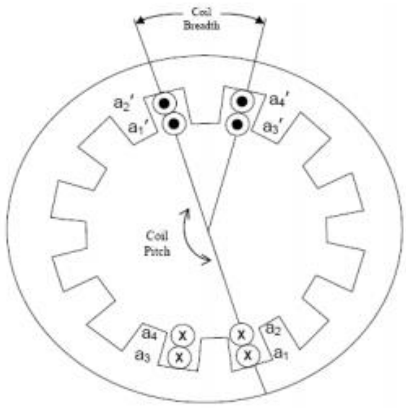
• Liquid cooling is used for the stators of cylindrical rotor generators.

2-2 Operating Principles:

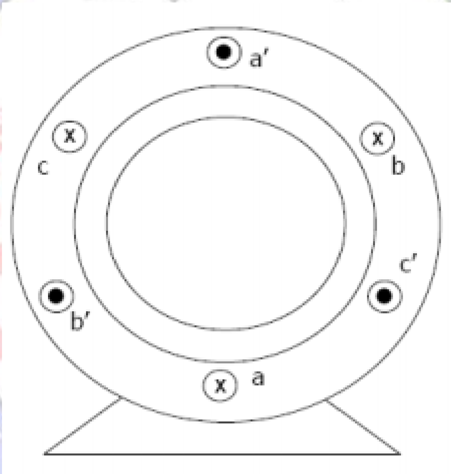
Principle of Operation A three-phase synchronous machine consists of an inner rotating cylinder called the rotor and an outer stationary housing called the stator as shown in Figure. A shaft runs through the rotor and it is balanced on bearings.



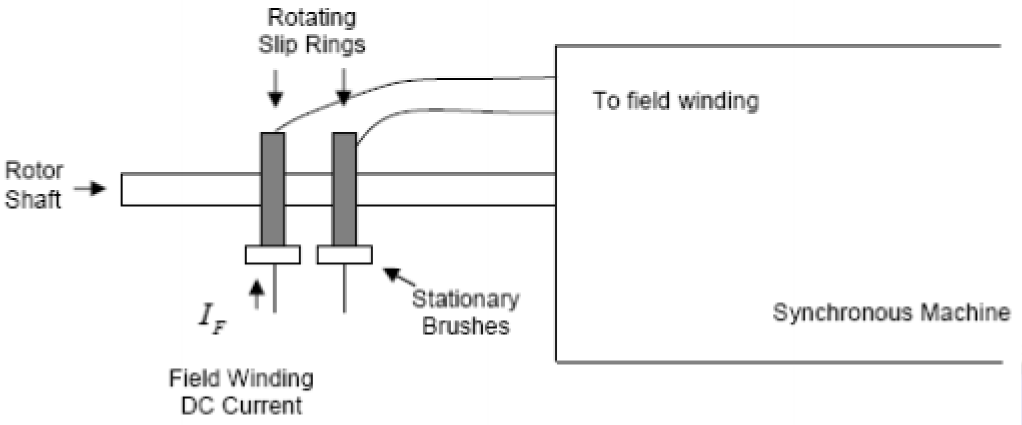
The internal periphery of a three-phase stator normally has a number of slots, the number typically being an integer multiple of six. A three-phase machine will require three identical coils of wire, each with many turns, and each coil is distributed in multiple stator slots. An example of one phase winding is shown in Figure. These windings are normally called the armature. The angular distribution of the turns is called the coil breadth. The angular distance between the sides of a given turn is termed the coil pitch. The other two-phase coils are positioned similarly about the stator periphery, with the centers of those coils spatially displaced by 120°.



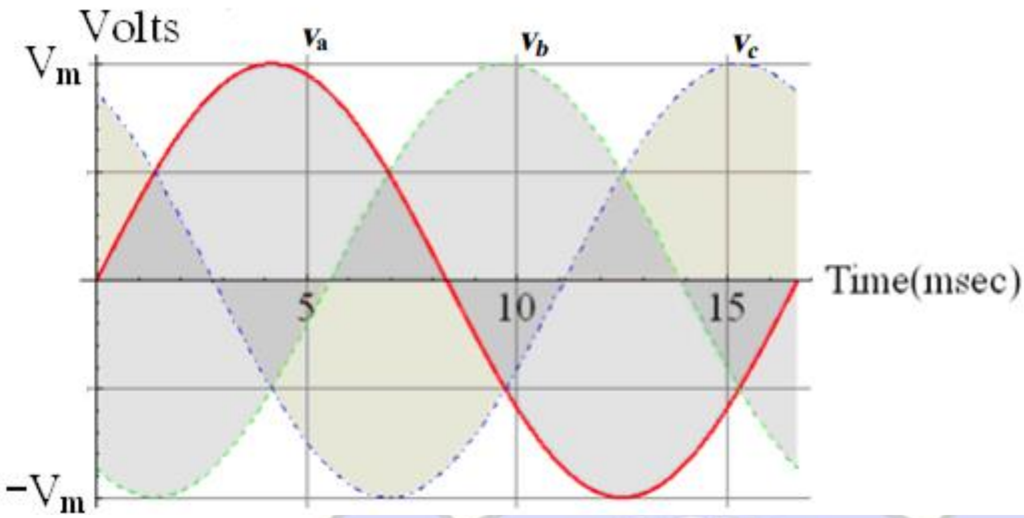
Instead of having to draw all of the slots and windings each time, we represent each distributed coil by a concentrated coil located in the center of the distribution. This is shown in Figure 5.4. The circle with a dot denotes that current is referenced out of the page while a circle with a cross indicates that current is referenced into the page. We use a, b, and c to reference the three stator phases represented in Figure.



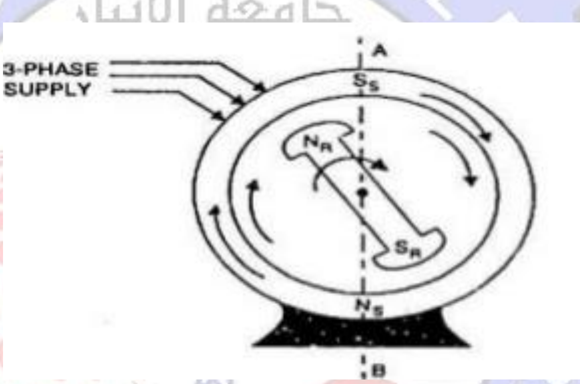
The rotor of a synchronous machine contains a winding called the field winding, which generates the magnetic field needed to generate a voltage (remember Faraday’s Law). For simplicity, we will consider the case of a round rotor with a uniform air gap about the circumference of the rotor. The rotor may be slotted with the turns of the field winding distributed in those slots. The field winding will be supplied with a DC current. You say, “Wait a second, the field winding is on the rotor, and the rotor is spinning. How can we supply DC current to something that is moving?” The simplest solution to this dilemma is to use slip rings and brushes as illustrated in Figure. Note that the end connections of the field winding are tied to two copper rings mounted on the rotor shaft. Stationary carbon brushes are then made to ride upon the rings. A stationary DC voltage source is then applied to the brushes allowing DC current to flow through the field winding. Since the brushes are not commutating (i.e., reversing the current) coils as in a DC machine, the wear and maintenance requirements are not as intensive.



The DC current flowing in the field winding will set up a magnetic field on the rotor (think North and South poles). The prime mover (mechanical engine) will then spin the rotor at what we will soon refer to as synchronous speed. The magnetic field sweeping past the stationary stator coils will induce voltages. This phenomenon is described by Faraday’s law, and was present as the back EMF in the DC motors you studied previously. Since the phase coils are spatially displaced, the induced voltages will be time displaced and will constitute a balanced set (i.e., same frequency, equal amplitude, and 120° displaced in phase). The voltage produced by each phase coil is shown in Figure. If we imagine that the rotor magnetic field moves past the “a” stator phase first, we would expect a strong induced voltage for the a-phase. As the rotor turns and moves its magnetic field past the b and c coils, those coils would also show a surge in voltage respectively. The sequence of voltages shown in the figure is termed the abc-phase sequence since the a-phase takes its peak first, then the b-phase and finally the c-phase. Note that the voltages all have the same frequency and equal amplitude but are displaced from each other by 120°. (As the rotor turns and moves past the a’, b’ and c’, the negative voltage peaks occur.)



$V_e \rightarrow I_e \rightarrow F_e \rightarrow \emptyset_e$-



At no load $V_1 = E_e = E_o$

n_r-prime mover speed

$F_i = \frac{P_{nr}}{60}$ emf frequency

At load $I_1 = I_a \rightarrow F_a \rightarrow \emptyset_a$ rotating with (n_s)

$n_s = \frac{60\ F_1}{P} = \frac{60}{P}\left(\frac{P_{nr}}{60}\right) = n_r$

$n_s = n_r$

2-3 Constructional Element

1-Armature: hollow cylinder assembled from silicon lamination, with slots to contain the windings open slots with parallel sides with double layer lap winding for voltage up to 11 KV

Semi open slots with single layer lap winding for voltage up to 33 KV

2-Salient poles or non-salient (cylindrical) rotors.

3-Damper winding, separate or complete.

It is starting winding in the motor and in the alternators:

a- Weakening the negative effect of unbalance loads.

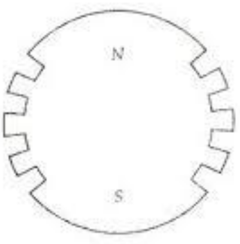
b-damps the rotor swinging due to sudden load change.

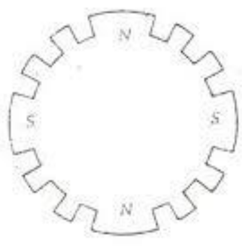
4- Excitation – from external source (250v) through the slip rings or brushes (diodes). Using (AVR) usually the winding from copper stripes

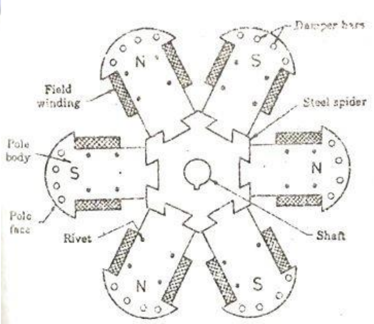
5-Cooling-close system used for cylindrical machines up to 25 µw. The advantage is:

a-It is density is 10% of the air

b-high thermal conductivity, which loads to 30% increase in loading.







Salient pole type rotor

2-4 Armature Reaction:

Armature reaction is the effect of armature flux on the mean field flux. In the case of alternator, the power factor of the load has a considerable effect on the armature reaction

1-Direct Axis, Quadrature Axis

$V_e \rightarrow I_e \rightarrow F_e \rightarrow \emptyset_e$

At $n_r \rightarrow E_{oA}, E_{oB}, E_{oC}$

At load $\rightarrow I_a \rightarrow F_a \rightarrow \emptyset_a$

$F_a = 1.35\, I_a\, Kw\, T_s$

Ψ- phase shift between I_a and E_o

From $\emptyset_e$ and $\emptyset_a$ result $\emptyset_g$- air gap flux

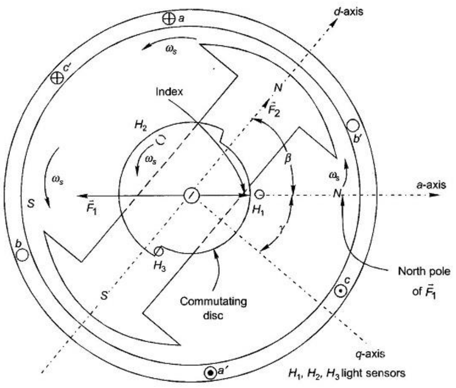
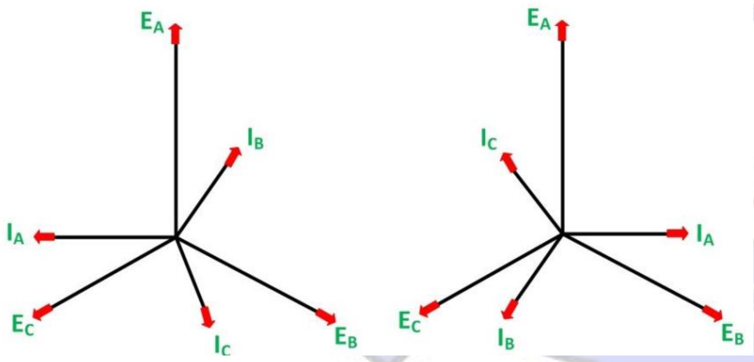


Fig. 8.84 *Brushless dc motor arrangement of sensors; 120° elect sensor code switching from 101 to 100*



2-Pure inductive load(R=0) then Ψ=90

$$I_A = 0 \quad , I_B = -\frac{\sqrt{3}}{2} \times I_m \quad , \quad I_C = \frac{\sqrt{3}}{2} \times I_m$$

Direct armature reaction and demagnetizing armature reaction.

$I_a \uparrow, \emptyset_a \uparrow \rightarrow \emptyset_g \downarrow, E_g \downarrow$

4-Pure capacitive load

Ψ=-90°

$\mathbf{I_A = 0}$, $\boldsymbol{I_B = \frac{\sqrt{3}}{2} \times I_m}$, $\boldsymbol{I_C = -\frac{\sqrt{3}}{2} \times I_m}$

Direct armature reaction magnetizing A.R

$I_a \uparrow, \emptyset_a \uparrow \rightarrow \emptyset_g \uparrow \rightarrow E_g \uparrow$

4-Pure Ohmic (resistive) load.

Ψ=0° ,, I_a in phase with E_a

$I_A = I_m , I_B , I_C = -\frac{I_m}{2}$

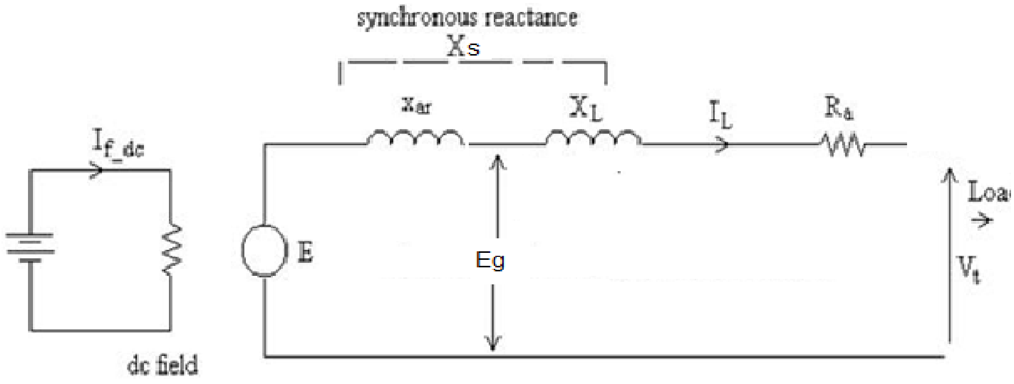
2-5 Phasor Diagram for Cylindrical Rotor Generator

1-saturated cylindrical rotor SM

$R_1, X_L, I_1, V_1, \cos\varphi$ and OCC

$F_e = F_g - F_a$, $F_e = I_e T_e$

$F_a = 1.35\ I_1\ K w T_s$



Per Phase Equivalent Circuit

-voltage regulation ($VR\%$)

$$VR\% = \frac{E_o - V_r}{V_r} \times 100\%$$

$$E_o = \mathrm{E_g} + (-E_a)$$

Advantages:

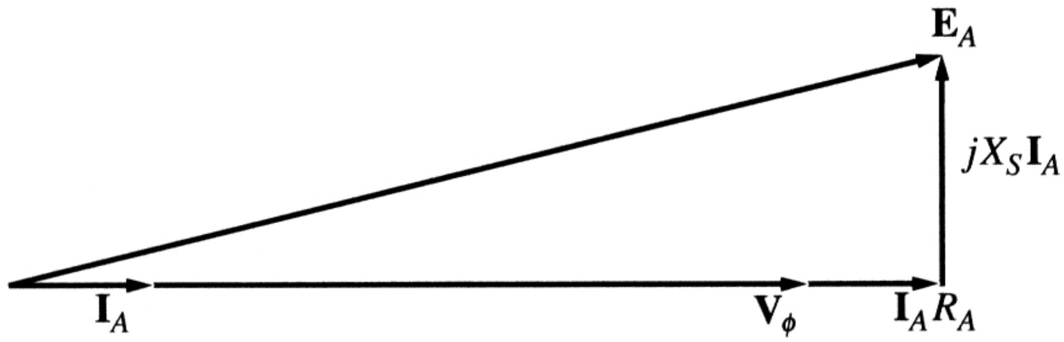
• Simple no load tests (for obtaining OCC and SCC) are to be conducted
• Calculation procedure is much simpler

Disadvantages:

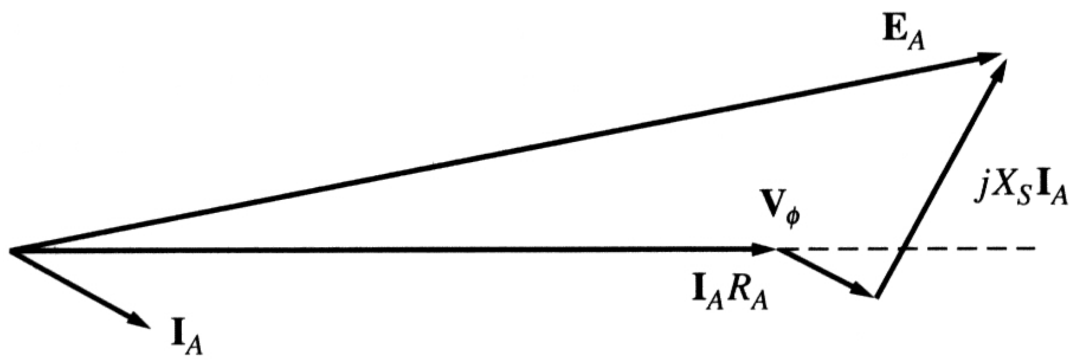
• The value of voltage regulation obtained by this method is always higher than the actual value.

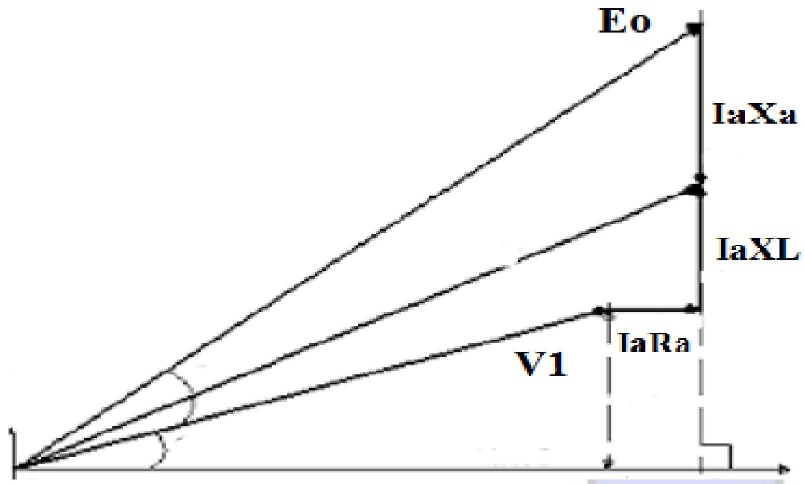
$E_a = -jI_aX_a$, $E_g = V_1 + I_1(R_a + jX_L$
$\mathrm{E_o} = \mathrm{V_1} + \mathrm{I_a R_a} + jI_a(X_L + X_a) = V_1 + I_a(R_a + jX_s$

For unity power factor: pure resistive load



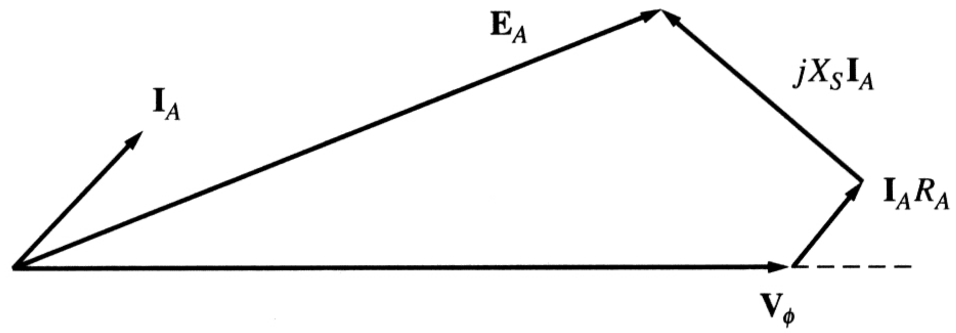
For lagging power factor: inductive load.





$$E_o = \sqrt{(V_1 \cos\theta_1 + I_a R_a)^2 + (V_1 \sin\theta_1 + I_a X_s)^2}$$

For leading: capacitive load



$$E_o = \sqrt{v_1 \ \cos\theta_1 + I_a R_a)^2 + (V_1 \sin\theta_1 - I_a X_s)^2}$$

2-6 Energy Diagram:

$$\sum P_{losses} = P_1 - P_2$$
$$= P_{fe} + P_{cua} + P_{cue} + P_{fw} + P_{add}$$

P_{fe}: **Iron Losses**

P_{cua}: **Cupper Losses in Armature**

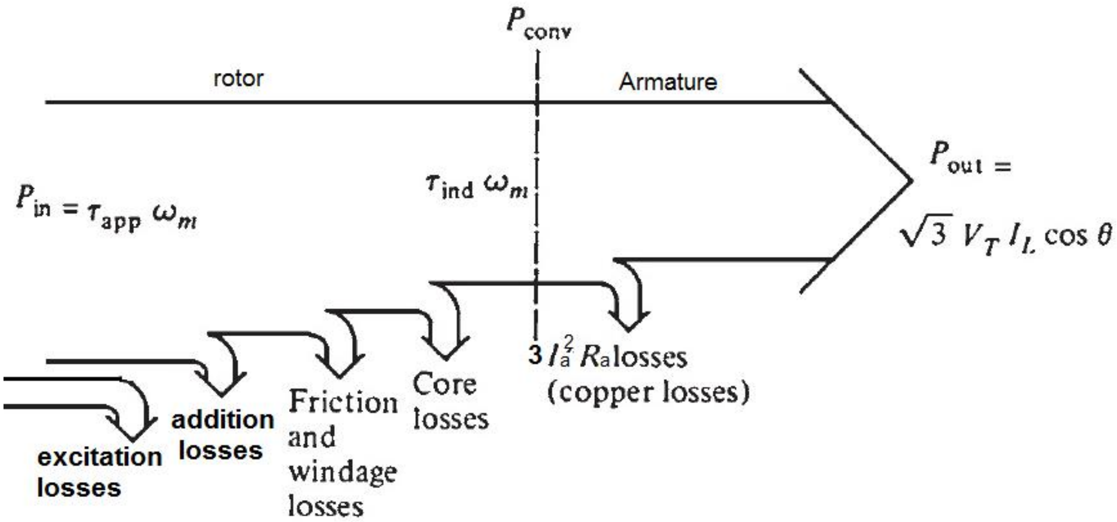
P_{cue}=**Cupper Losses in Excitation Winding**

P_{fw}: **Friction and Winding Losses**

P_{add}: **Addition Losses**

$$P_{cua} = 3I_a^2 \ R_a$$

$$P_{cue} = I_e^2 \ R_e$$



The power flow diagram of a synchronous generator.

$P_{add} = 0.5\%\, P_1 \quad , P_{fw} = 50\%\, P_{losses}$

$P_{em} = P_2 + P_{cua} \quad or \quad P_2 = P_{em} - P_{cua}$

:For separate excitation then

$P_i = \mathrm{P}_1 + \mathrm{P}_{ex}$

For self-excitation, then:

$P_o = P_2 - P_{ex}$

$$\eta\% = \frac{P_o}{P_i} \times 100\% = \frac{P_o}{P_o + P_{fw} + P_{fe} + P_{cua} + P_{ad}} \times 100\%$$

2-7 Measuring parameters of synchronous generator model

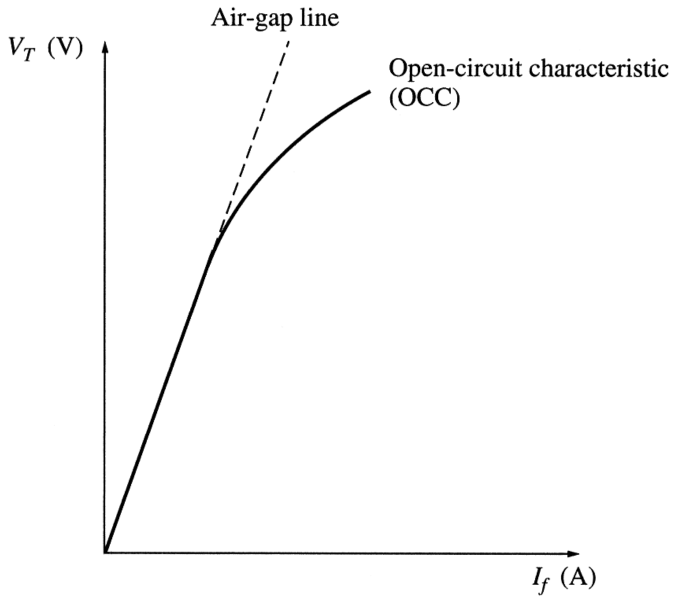
The three quantities must be determined in order to describe the generator model:
1.The relationship between field current and flux (and therefore between the field current *IF* and the internal generated voltage *EA*);
2.The synchronous reactance;
3.The armature resistance.

Open circuit Test:

The generator is rotated at the rated speed,
•all the terminals are disconnected from loads,
•the field current is set to zero first.

•Next, the field current is increased in steps and the phase voltage (whish is equal to the internal generated voltage *EA* since the armature current is zero) is measured.

Since the unsaturated core of the machine has a reluctance thousands times lower than the reluctance of the air-gap, the resulting flux increases linearly first. When the saturation is reached, the core reluctance greatly increases causing the flux to increase much slower with the increase of the mmf.



Short Circuit Test

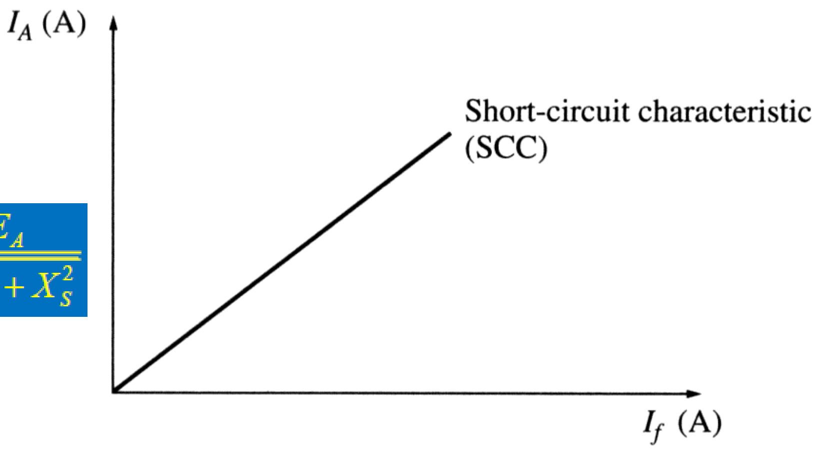
In here,

• The generator is rotated at the rated speed, with the field current is set to zero first, and all the terminals are short-circuited through ammeters.

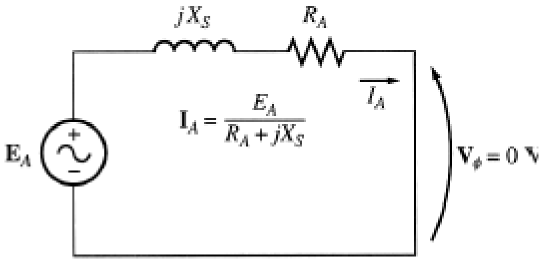
• Next, the field current is increased in steps and the armature current *IA* is measured as the field current is increased. The plot of armature current (or line current) vs. the field current is the short-circuit characteristic (SCC) of the generator.

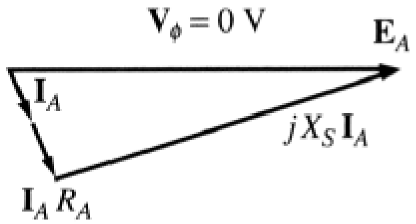
The SCC is a straight line since, for the short-circuited terminals, the magnitude of the armature current is

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



The equivalent generator's circuit during SC





An approximate method to determine the synchronous reactance *XS* at a given field current:

1. Get the internal generated voltage *EA* from the OCC at that field current.
2. Get the short-circuit current *IA,SC* at that field current from the SCC.
3. Find *XS* from

$$X_S \approx \frac{E_A}{I_{A,SC}}$$

Since the internal machine impedance is

$$Z_S = \sqrt{R_A^2 + X_S^2} = \frac{E_A}{I_{A,SC}} \approx X_S \qquad \{\text{since } X_S \approx R_A\}$$

2-8 Parallel operation of alternator:

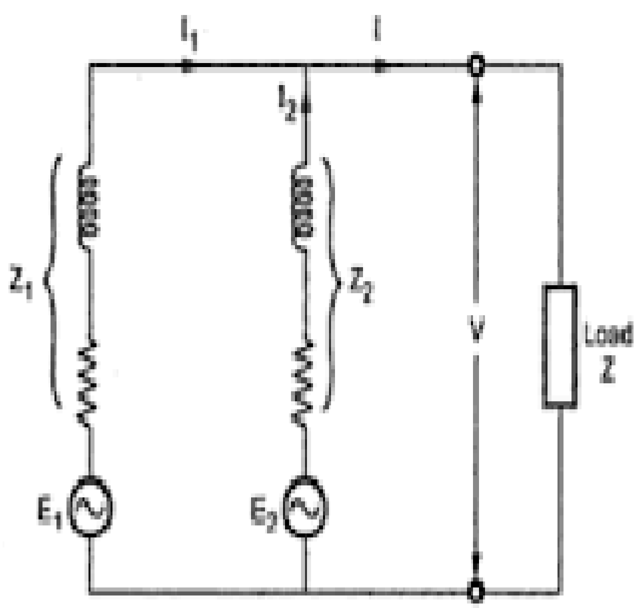
The operation of connecting an alternator in parallel with another alternator or with common bus bars is known as a synchronizing. Generally, alternators are used in power system where they are in parallel with many other alternators. It means that the alternator is connected to alive system of constant voltage and constant frequency.

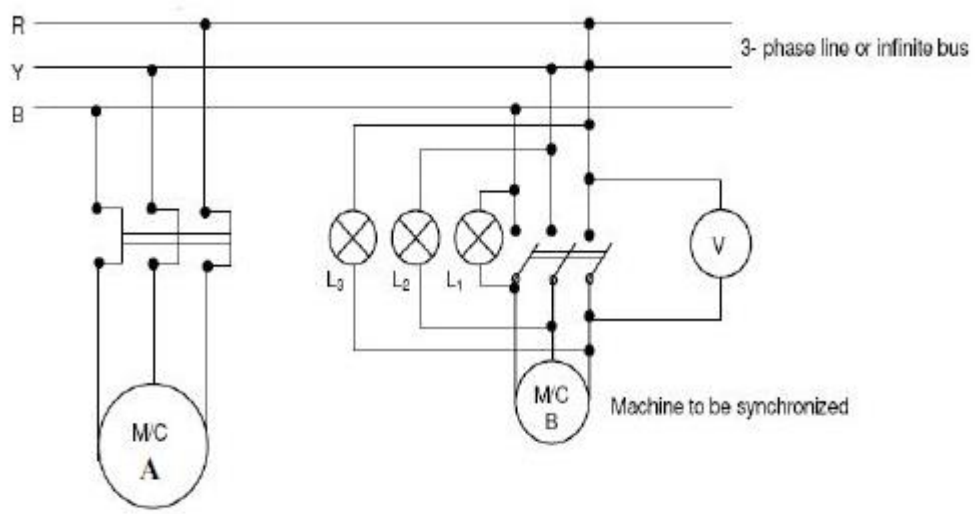
There are three conditions must be satisfied when connect the alternators in parallel:

1-The terminal voltage of incoming alternator must be the same as bus- bar voltage

2-the speed f the incoming machine must be such that its frequency ($f = \frac{P_o}{60}$) equals bus-bar frequency.

3-the phase of the alternator voltage must be identical with the phase of the bus-bar voltage.





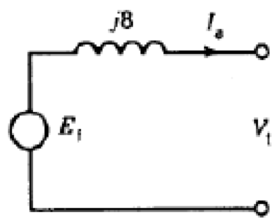
EXAMPLE

A 3ϕ, 5 kVA, 208 V, four-pole, 60 Hz, star-connected synchronous machine has negligible stator winding resistance and a synchronous reactance of 8 ohms per phase at rated terminal voltage.

Determine the excitation voltage and the power angle when the machine is delivering rated kVA at 0.8 PF lagging. Draw the phasor diagram for this condition.

Solution

The per-phase equivalent circuit for the synchronous generator



$$V_t = \frac{208}{\sqrt{3}} = 120 \text{ V/phase}$$

Stator current at rated kVA:

$$I_a = \frac{5000}{\sqrt{3} \times 208} = 13.9 \text{ A}$$

$\phi = -36.9°$ for lagging pf of 0.8

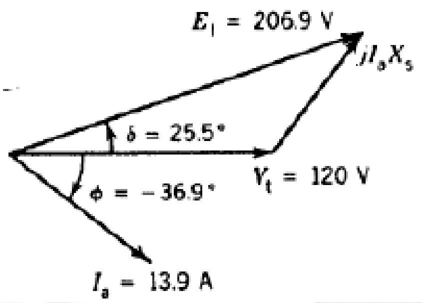
$$E_f = V_t\angle 0° + I_a jX_s$$

$$= 120\angle 0° + 13.9\angle -36.9° \cdot 8\angle 90°$$

$$= 206.9\angle 25.5°$$

Excitation voltage $E_f = 206.9$ V/phase

Power angle $\delta = +25.5°$



H.W

Q1) A four pole, three-phase synchronous generator is rated 250 MVA, its terminal voltage is 24 kV, the synchronous reactance is: 125%.

- Calculate the synchronous reactance in ohm.
- Calculate the rated current and the line to ground terminal voltage.
- Draw the equivalent circuit.
- Calculate the induced voltage, E_f, at rated load and pf = 0.8 lag.

(Ans: X_{syn}=2.88Ω, I_g=6.01∟-36.87°KA, E_{gn}=27.93∟29.74KV)

Q2) A3-phase, star connected alternator is rated at 1600Kva, 3500V. the armature effective resistance and synchronous reactance are 1.5Ω and 30Ω respectively per phase. Calculate the percentage regulation for a load of 1280Kw at power factor of a) 0.8 lagging b) 0.8 leading c) unity.

(Ans. 18.6, -11.99, 3.227)

Q3) A 3-phase, 120kV, 1.5 MVA, alternator, its star connected armature winding has 1Ω effective resistance and 10Ω synchronous reactance per phase find VR% at full load at: a) unity power factor, b) 0.8 lagging, c) 0.8 leading. (Ans. 1.56%, 7.36%, -5%)

Q4) A 3-phase, 0.8MVA, 3.3Kv, 50Kz, SG, its armature winding star connected and its iron and mechanical losses are 20kW, having 0.5Ω/phase armature resistance. When a 150V is applied to the excitation winding Ie=100A at cosφ=1 and Ie=120A at cosφ=0.8lagging. find the efficiency at rated load and unity power factor and 0.8 lagging. (Ans. 9205%, 90.46%)

Q5) A 3-phase, delta connected, 15MVA, 10kV alternator has an armature resistance of 0.4Ω/phase and syncronouse reactance of 1.2Ω/phase. Find the full load voltage regulation at 0.8 power factor leading and lagging. (Ans. -1.82%, 5.26%)