Synchronous Generator

Synchronous generators are classified on the bases of power Generation.

① Turbo Generators ② Hydro generators ③ Gas Turbo Generators.

Specifications :- specifications are used as guidelines to operate the synchronous machine within the specified limits. Following are the ratings of syn. machines.

1. Rated voltage → 3.3KV, 6.6KV, 11KV.
2. Power rating → 10MW, 20MW, 50MW, 100MW, 500MW
3. Excitation voltage → 100V – 1000V
4. Excitation current → 5A – 20Amp.
5. Speed → Speed in RPM (3000 rpm)
6. Cooling system → Forced air
   Hydrogen cooled
   Water cooled.
7. Types of Rotor → salient pole or Non salient pole
8. Short circuit Ratio
9. Class of Insulation
10. Temp. Limits
11. Connections.
12. Frequency.

MODULE – II

Installation :- physical Inspection & foundation details required for installation.

Physical Inspection :- At the site, the syn. generator is stored in a safe place. Before keeping in store it must be inspected physically, check the missing parts or damaged parts of machine. The m/c is partially unpacked for checking preferably in presence of representative of the suplier. Large capacity syn. generators are delivered in a disassembled conditions.

Foundation :- Foundation required for the Large alternators depending upon the type of mounting.

① Vertical mounting ② Horizontal mounting

3) Vertical mounting:- Vertical mounted covering two floors, the basement & the ground floor. Foundations should be seperated from columns & other supporting structures of the building so as to prevent the transfer of vibrations of the machine to the building.

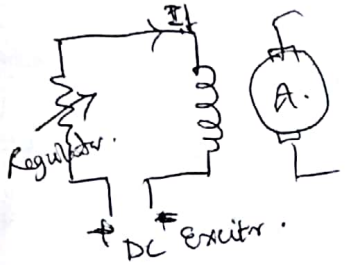
Foundation dimensions are specified by the manufacturers in the drawing. The foundation must be provided with holes to receive anchor bolts securing the bed plates. The holes & anchor bolts shall be fixed in the concrete.

Installation of an Alternator:-

- Installation of bed plate & the levelling of bed plate.
- Installation of the bearing pedestals & levelling of the bearing.
- Checks on stator and rotor
- Assembly of the rotor on to the shaft
- Installation of the stator
- Installing rotor in the stator
- Checking air gap between stator & rotor
- Preparation of shaft couplings
- Fixing the shaft coupling on shaft.
- Preparation of shaft alignment
- Installation of cooling systems.
- Drying out
- Testing

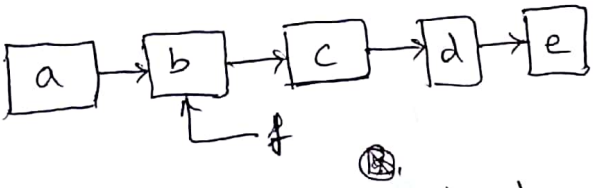
For the installation activities should be carried out by technically skilled staff.

Excitation System:- The rotor of a synchronous M/C needs DC for excitation. The field current is supplied and controlled by the excitation system. An excitation system includes all the equipment required for supply of field current & voltage regulator system.



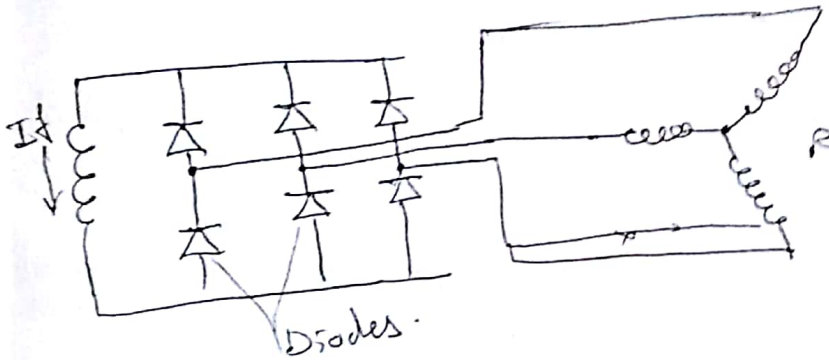
Excitation response is the rate of change of exciter voltage & is expressed in terms of volts per second. The main function of the excitation system is to supply and regulate field current.

Brushless excitation system:- Figure shows the block diagram of brushless excitation system.



a → Paramanent Magnet alternator.
b → Magnetic Amplifier
c → AC exciter.
d → Silicon diode rectifier
e → Main generator field.
f → Feed back of generator.

The silicon diode rectifier is mounted on the same shaft to excite the field of the main generator. An ac exciter is used to feed power to the rotating rectifier. The field of the ac exciter is fed by a magnetic amplifier that controls & regulates the output voltage of the main generator. The voltage & frequency of ac exciter are selected so as to optimise the performance of the overall system.



Cooling System:- If machine works continuously & it get heated; ie I^2R losses and other losses in the electrical m/c appear as heat raising the temp. of each internal part. ∴ Coolants are used to reduce the heat. The heated primary coolant may be replaced by a new coolant at a lower temp. or may be cooled by secondary coolant in the form heat exchanger. The temp. rise is significantly affects the life of the winding insulation. Heat removed by a combination of conduction, convection and by radiation from outer surfaces.

The terms used in cooling system are as

ⓐ Primary coolant: ⓑ Secondary coolant ⓒ Heat exchanger

ⓓ Open ckt. cooling ⓔ Closed ckt. cooling.

Cooling system may be classified as.

- ⊙ Emergency cooling system
- ⊙ Dependent circulating ckt components.
- ⊙ Independent " " "
- ⊙ Integral " " "
- ⊙ Machine mounted " " "
- ⊙ Seperately " " " "

The nature of the coolant.

Gases: Air – A
Hydrogen – H
Nitrogen – N
Carbon dioxde – C

Liquid:
Water – W
oil – U

Hydrogen Cooling for Turbo-generators:-

The thermal conductivity of Hydrogen is about 7-times that of air. The density of hydrogen is 0.07 times of that of air. The specific heat of hydrogen is 14 times that of air.

Hence hydrogen gas is prefessed to air as a coolant in large alternators of capacity above 60MW & above. It reduces the noise and improves heat transfer.

Water Cooled Machines:-

In direct cooling method, water is used as cooling medium and it is circulated through stator conductors & rotor conductors. The speed of the water flow in the channels is about 2.5 m/sec. If water at higher speed effeiently removes the heat.

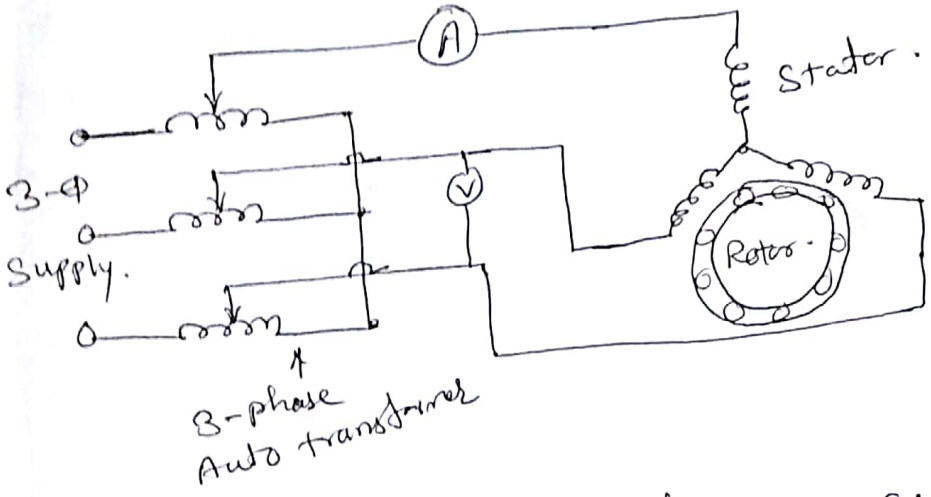
* Drying out of Syn. Machines.

The winding & insulating materials are absorb moisture if it is not used or newly installed. To expel the moisture content by thermal heating process is called drying out. ~~The~~ The moisture is evaporated from the winding due to thermal diffusion. The insulation resistance is measured by means of DC megaohm meter (Megger). To measure insulation resistance of windings rated upto 1000V, megger of 500V/1000V are used.

Polarization index is the ratio of insulation resistance of 60 sec. megger reading to the insulation resistance of 15 sec. megger reading. $PI = \frac{I_0 R_{60}}{I_0 R_{15}}$

Drying out Procedure.

Figure shows the circuit for drying out of syn. M/c. This is most convenient method of drying.



The machine stator winding are supplied with low voltage. The input voltage, current, power & temperature of winding, temperature of body, temperature of air are periodically measured. The end shields of the machines are removed. The M/c body is covered with tarpaulin. No cool air blow, over the hot winding.

Other drying out process as like I.M.

Commissioning Tests:- Following are the commissioning tests.

1) Insulation tests.
2) Measurement of resistance of armature & field winding.
3) Waveform & telephone interference test.
4) Line charging capacity test.

1) Measurement of Insulation Resistance:- The insulation resistance of stator winding to earthed frame, rotor winding to earthed frame, phase to phase winding and bearing insulation resistance is measured using megger. The megger readings for 15 sec. & 60 sec are taken to find the polarization index. The polarization index gives the extent of dryness of the insulation is given by

$$PI = \frac{I_0 R_{60}}{I_0 R_{15}}$$

Megger Sketch.

Drying out shall be done if the insulation resistance is less than the specified values.

2) Measurement of Armature Resistance:-

Voltmeter & Ammeter method:- In which voltage is applied across the winding & current through the windings are noted at the specified temp. Then the resistance is calculated $R = \frac{V}{I}$. This is suitable for field resistance measurements.

As resistance is sensitive to temperature, temperature is also recorded. & three to five readings are taken.

The variation of resistance of the phases of armature winding is allowed by 5%.

⊙ Measurement of field winding Resistance:-

Field resistance of syn. generator is normally measured at stand still condition by allowing rotor being exposed to a sufficient time. This is for the entire rotor to reach the ambient temperature. When this reference resistance is measured, the current circulation through the field coil shall be low so as not to cause change in temperature.

Field resistance at standstill, because both the resistance & temp. can be determined during running more accurate result will ~~neat to~~ get, when generator running near to normal speed.

Resistance may be calculated for temperature by using formula.

$$R_2 = \frac{(K + t_2)}{(K + t_1)} \times R_1$$

where $R_2 \rightarrow$ Unknown resistance at temp. $t_2^\circ C$.

$K \rightarrow$ Constant

$R_1 \rightarrow$ Resistance measured at $t_1^\circ C$.

By knowing R_1, R_2 & t_1 are known & t_2 can be determined

$K = 235$ for Copper Conductor.

$K = 225$ " Aluminium "

(5)

Slip Test: & calculation of X_q & X_d.

During Slip test, subnormal symmetrical three phase voltage of magnitude 10 to 20% of the rated voltage is applied to the armature terminals of the machine. The field of the alternator is open circuited or short circuited.

The prime mover is run at slightly less than syn. speed. Armature current & voltages are measured using indicating instruments. Ammeter & voltmeter readings will indicate two values which are to be taken as minimum & Maximum quantities respectively.

To find $X_q \rightarrow X_q = \frac{V_{min.}}{\sqrt{3}\, I_{max.}}$ Ω.

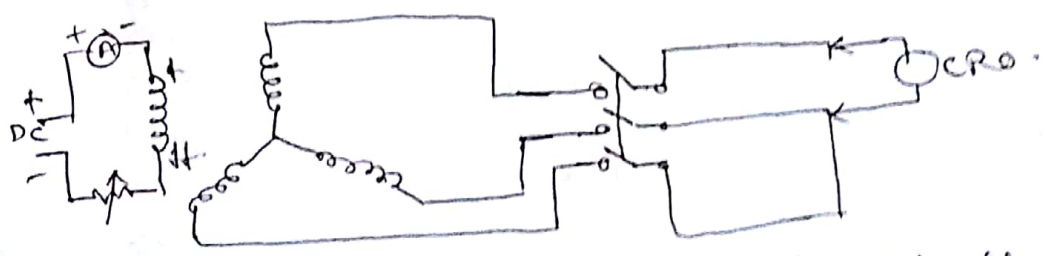
If I_{max} do not coincide with V_{min}, use in calculations I_{max} as a base & its corresponding voltage.

If during the test, the residual voltage of the machine is in the limits of 0.1 to 0.3 of the supply test voltage, the value of the current is determined using the formulae.

$$I_{max} = \sqrt{I_{av}^2 - \left[\frac{V_{res.}}{\sqrt{3}\, X_d}\right]^2} \quad \Omega$$

Where I_{av} is the half sum of the two consecutive maxima of the current envelop curve.

$$\therefore \quad X_d = \frac{V_{max.}}{\sqrt{3}\, I_{min.}} \quad \Omega.$$



closed switch then it is SC test.

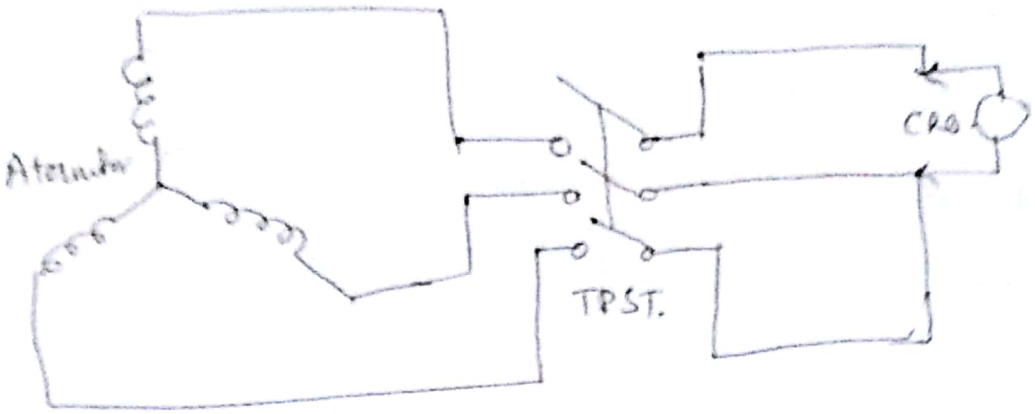
Sudden Short Circuit Test on Generator

When alternator is subjected to sudden short circuit the current in 3-φ is increases suddenly to a high value (8 to 10 times of full load current) during the first quarter cycle. Flux crossing airgap is large during first couple of cycles. The reactance during this period is least & the short circuit is high. This reactance offered during sub-transient period is called as sub-transient reactance X_d''. The first few cycles are covered under subtransient state. After few cycles the decrement in rms value of short circuit current is less rapid than that during the 1st few cycles. This state is called as Transient state. & the reactance offered during this period is called as transient reactance X_d'.

The circuit breaker contacts, open during this period. Finally the transient dies out & the current reaches a steady sinusoidal state called the steady state & the reactance offered during this state is called as steady state reactance X_d.

The sudden 3-phase SC test is conducted at rated speed and at desired no load voltage. The 3-phases are shorted suddenly. The terminal voltages of the machine, the excitation current & welding temp. are measured just before the short circuit.

If sudden short circuit test cannot be performed at rated armature voltage, it is recommended that the test should be conducted at several armature voltages. (Eg. 0.3, 0.5 & 0.2 pu of rated armature voltage)



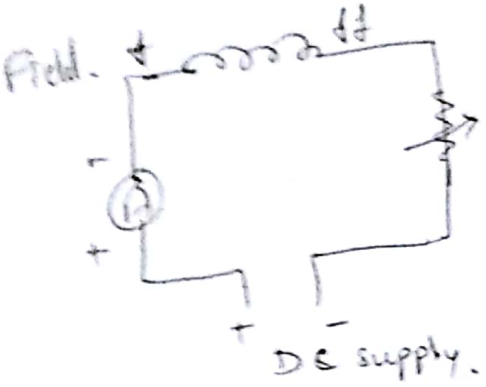


Fig: Sudden S C Test. (3-φ)

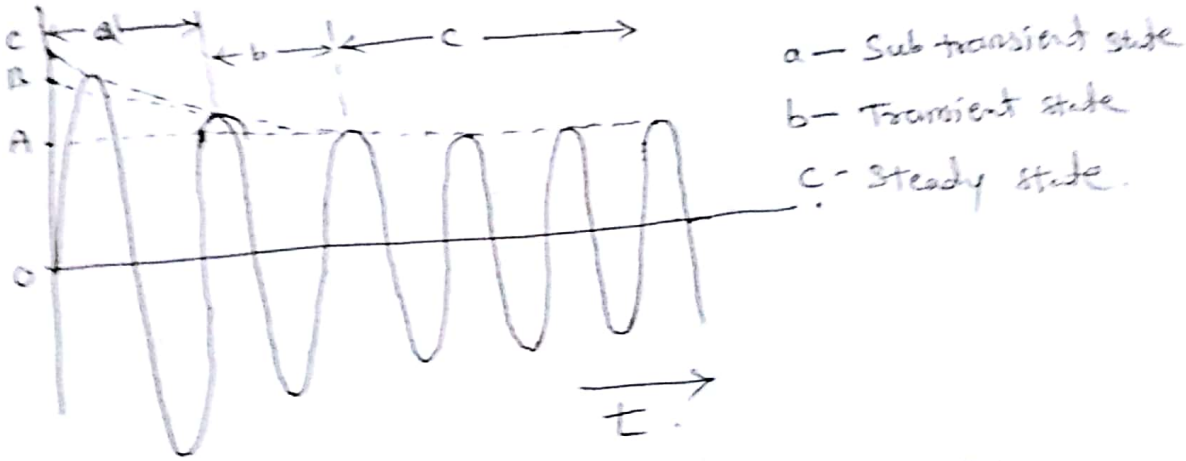


Fig: Oscillosceps of current in the phase having Zero DC.

The currents & reactances are given by the following expressions.

$$I = \frac{OA}{\sqrt{2}} = \frac{E_a}{X_d}, \quad X_d \rightarrow \text{Steady state reactance} = \frac{E_a}{I}$$

$$I' = \frac{OB}{\sqrt{2}} = \frac{E_a}{X_d'}, \quad X_d' \rightarrow \text{Transient reactance} = \frac{E_a}{I'}$$

$$I'' = \frac{OC}{\sqrt{2}} = \frac{E_a}{X_d''}, \quad X_d'' \rightarrow \text{Sub} \quad " \quad = \frac{E_a}{I''}$$

Where OA, OB, OC are intercepts of X-axis as shown in above Fig.

E_a → Positive sequence emf, per phase [Rms value induced by the generator]

I → Steady state Short circuit current rms value

I' → Transient Short circuit current " "

I'' → Sub " " " " " "

X_d → Direct axis reactance

X_d' → Direct axis transient reactance.

X_d'' → Direct axis Sub-transient reactance.

Temp. Rise Test on Syn. Generator

Temperature of various parts of electrical m/c can be measured by one of the following methods.

① Thermometer

② Thermo-couple method

③ Estimating the mean rise in temp. using the resistance temp. coefficient: ie Resistance method:-

1. Thermometer :- This method gives temp. of the surface at one point only. & it is not applicable to find temp by resistance method.

2. Thermo-Couple :- This gives the temp. at one interval point. This temp. detectors are generally built into machines of 5 MVA & above having core length of 1 meter & more; between the layer of ~~armature~~ armature winding, in the slot portion & at various other points at which highest temp are likely to develop.

3. Resistance method :- In this method the temp. of the windings is calculated by the increase in the resistance of the winding. The resistance is measured

(12) before & after the test and the winding temperatures at the end of the test to be obtained by the below formula.

$$\frac{T_2 + K}{T_1 + K} = \frac{R_2}{R_1}$$

$T_2 \rightarrow$ Temp. of the winding °C at the end of the test

$T_1 \rightarrow$ " " " °C prior to the test.

$R_1 \rightarrow$ Initial resistance of the winding (cold)

$R_2 \rightarrow$ Resistance of the winding at the end of the test.

$K \rightarrow$ 235. for pure copper
234 " pure Aluminium

For practical purpose.

$$T_2 - T_3 = \frac{R_2 - R_1}{R_1}(K + T_1) + T_1 - T_3 .$$

where T_3 – is the temp. °C of cooling medium at the end of the test.