MODULE – 5

Synchronous generators (continuation): Open circuit and short circuit characteristics, Assessment of reactance- short circuit ratio, synchronous reactance, and adjusted synchronous reactance and Potier reactance. Voltage regulation by EMF, MMF, ZPF and ASA methods.

Performance of synchronous generators: Capability curve for large turbo generators and salient pole generators. Starting, synchronizing and control. Hunting and dampers.

10 Hours

Modern power systems operate at some standard voltages. The equipments working on these systems are therefore given input voltages at these standard values, within certain agreed tolerance limits. In many applications this voltage itself may not be good enough for obtaining the best operating condition for the loads. A transformer is interposed in between the load and the supply terminals in such cases. There are additional drops inside the transformer due to the load currents. While input voltage is the responsibility of the supply provider, the voltage at the load is the one which the user has to worry about. If undue voltage drop is permitted to occur inside the transformer the load voltage becomes too low and affects its performance. It is therefore necessary to quantify the drop that takes place inside a transformer when certain load current, at any power factor, is drawn from its output leads. This drop is termed as the voltage regulation and is expressed as a ratio of the terminal voltage (the absolute value per se is not too important).

Voltage regulation of an alternator is defined as the rise in terminal voltage of the machine expressed as a fraction of percentage of the initial voltage when specified load at a particular power factor is reduced to zero, the speed and excitation remaining unchanged.

Methods Of Predetermination Of Regulation

• Synchronous impedance method (EMF method)

• Magneto Motive Force method (MMF method)

• Zero Power Factor method (ZPF method)

• American Standards Association method (ASA method)

• Synchronous impedance method (EMF method) :

The experiment involves the determination of the following characteristics and parameters:

1. The open -circuit characteristic(the O.C.C)

2. The short-circuit characteristic(the S.C.C)

3. The effective resistance of he armature winding.

The O.C.C is a plot of the armature terminal voltage as a function of field current with a symmetrical three phase short-circuit applied across the armature terminals with the machine running at rated speed. At any value of field current, if E is the open circuit voltage and Isc is the short circuit current then for this value of excitation

$$\mathbf{Zs = E/Sic}$$

At higher values of field current, saturation increases and the synchronous impedance decreases. The value of Zs calculated for the unsaturated region of the O.C.C is called the unsaturated value of the synchronous impedance.

If Ra is the effective resistance of the armature per phase, the synchronous reactance

Xs is given by

$$\mathbf{Xs = sqrt\ (Za^2 - Ra^2)}$$

If V is the magnitude of the rated voltage of he machine and the regulation is to be calculated for a load current I at a power factor angle f, then the corresponding magnitude of the open circuit voltage E is

$$\mathbf{E = V + IZs}$$

Here bold letters indicate complex numbers.

Regulation =(E-V)/V

Procedure:

1. Open circuit characteristic

Connect the alternator as shown in FIG.1. The prime move in this experiment is a D.C. shunt motor, connected with resistances in its armature and field circuits so as to enable the speed of the set to be controlled. Run the set at the rated speed of the alternator, and for each setting of the field current, record the alternator terminal voltage and the field current. Note that there is no load on the alternator. Record readings till then open circuit voltage reaches 120% of the rated voltage of the machine.

2. Short circuit characteristic

(FIG.2) Connect as in FIG.1, but short-circuit the armature terminals through an ammeter. The current range of the instrument should be about 25-50 % more than the full load current of the alternator. Starting with zero field current, increase the field current gradually and cautiously till rated current flows in the armature. The speed of the set in this test also is tom be maintained at the rated speed of the alternator.

3. Measure the D.C. resistance of he armature circuit of the alternator. The effective a.c resistance may be taken to be 1.2 times the D.C. resistance.

Report:

1. Plot on the same graph sheet, the O.C.C (open circuit terminal voltage per phase

versus the field current), and the short-circuit characteristic (short-circuit

armature current versus the field current).

2. Calculate the unsaturated value of the synchronous impedance, and the value

corresponding to rated current at short circuit. Also calculate the corresponding values of the synchronous reactance.

3. Calculate regulation of the alternator under the following conditions:

· Full load current at unity power factor

· Full load current at 0.8 power factor lagging.

· Full -load current at 0.8 power factor leading.

FIG.1 Alternator connection for open circuit test

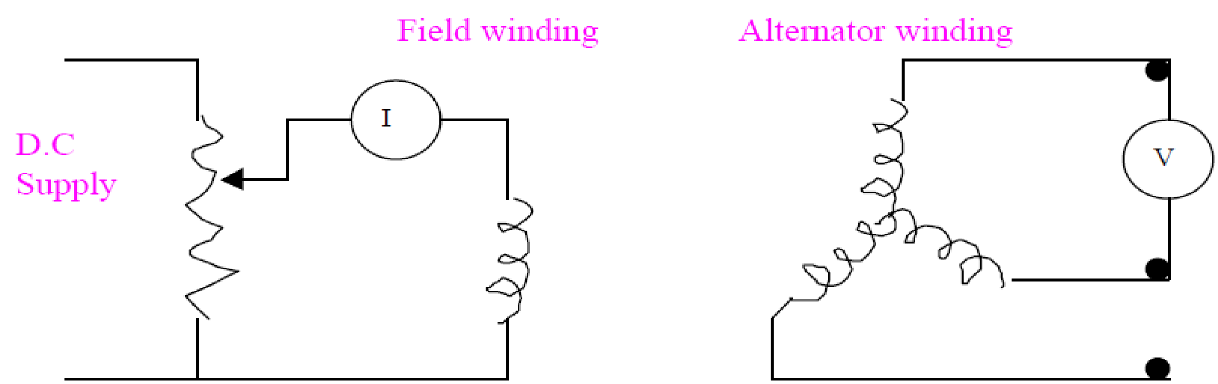
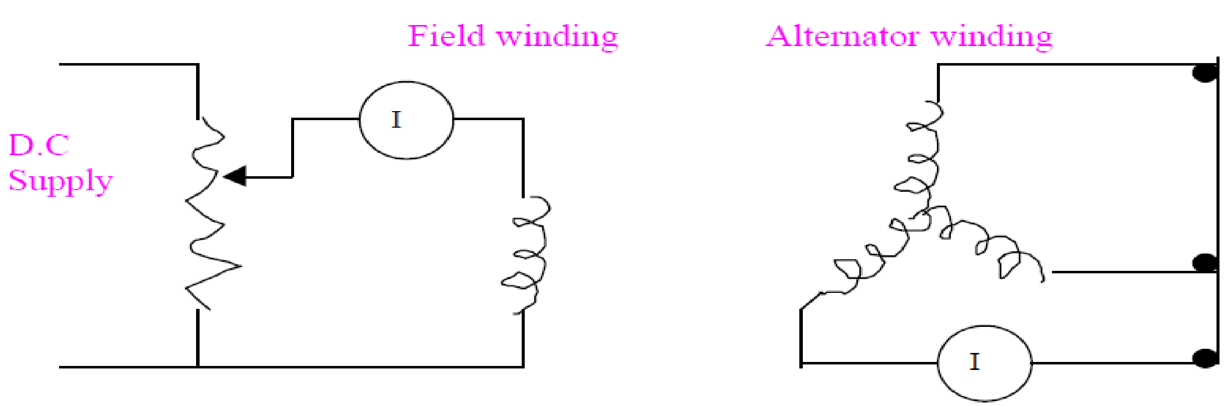
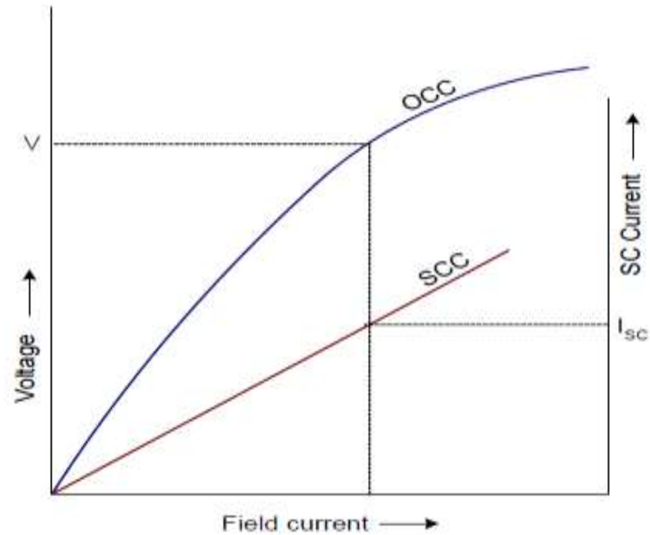


FIG.2 Alternator connection for short circuit test





Where

V = rated phase voltage

Isc = short circuit current corresponding to the field current producing the rated voltage

Synchronous impedance per phase,

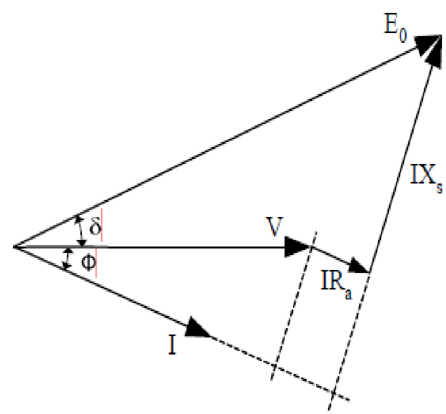
$$Z_s = V / I_{sc}$$

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

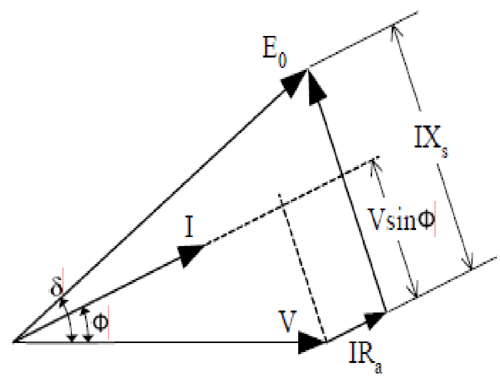
For any load current I and phase angle Φ,

find E0 as the vector sum of V, IRa and IXs

For lagging power factor

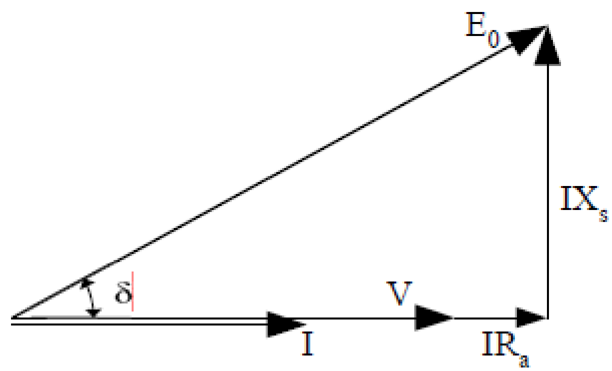


$$E_0 = \sqrt{(V\cos\Phi + IR_a)^2 + (V\sin\Phi + IX_s)^2}$$



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

For Unity Power factor



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

MMF method:

(Ampere turns method)

This method is based on the MMF calculation or no. of ampere turns required to produced flux which gives Rated Voltage at Open Circuit and Rated Current at Short Circuit. From open circuit characteristic field current *If*1 gives rated voltage *V* and *If*2 to cause the short circuit current which is equal to Full Load Current.

Steps to find regulation by using MMf method

1. By suitable tests plot OCC and SCC

2. From the OCC find the field current *If1* to produce rated voltage, *V*.

3. From SCC find the magnitude of fieldcurrent *If2* to produce the required armature current.

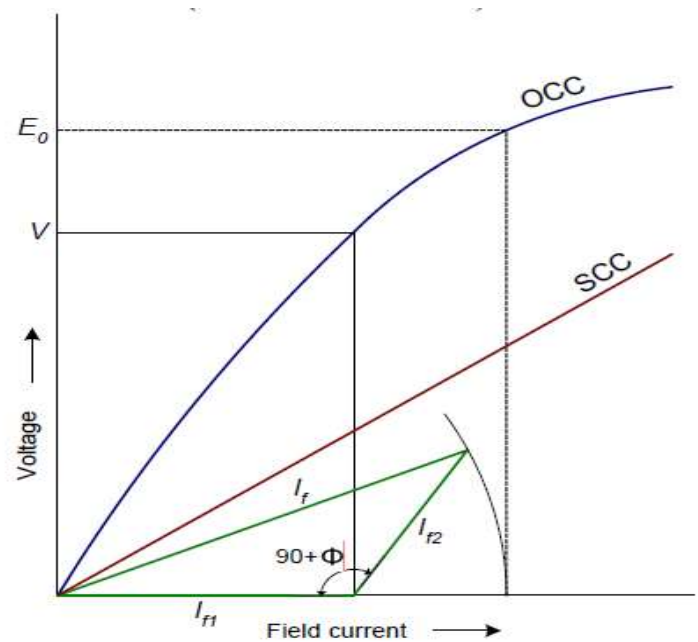
4. Draw *If2* at angle (90+Φ) from *If1*,

where Φ is the phase angle of current from voltage.

If current is leading, take the angle of *If2* as (90-Φ).

5. Find the resultant field current, *If* and mark its magnitude on the field current axis.

6. From OCC. find the voltage corresponding to *If*, which will be *E0*.



Potier method of predetermining the voltage regulation of an alternator.

ZERO POWER FACTOR METHOD (OR) POTIER METHOD:

- This method is based on the separation of armature leakage reactance drop and the armature reaction effect.This is more accurate than the emf and mmf methods. The experimental data required is

  No load curve (or) O.C.C

  S.C.C

  Armature resistance

- Full load zero power factor curve (or) wattles load characteristics.
- The ZPF lagging characteristics is a reaction between terminal voltage and excitation when armature is delivering F.L. current at zero power factor.

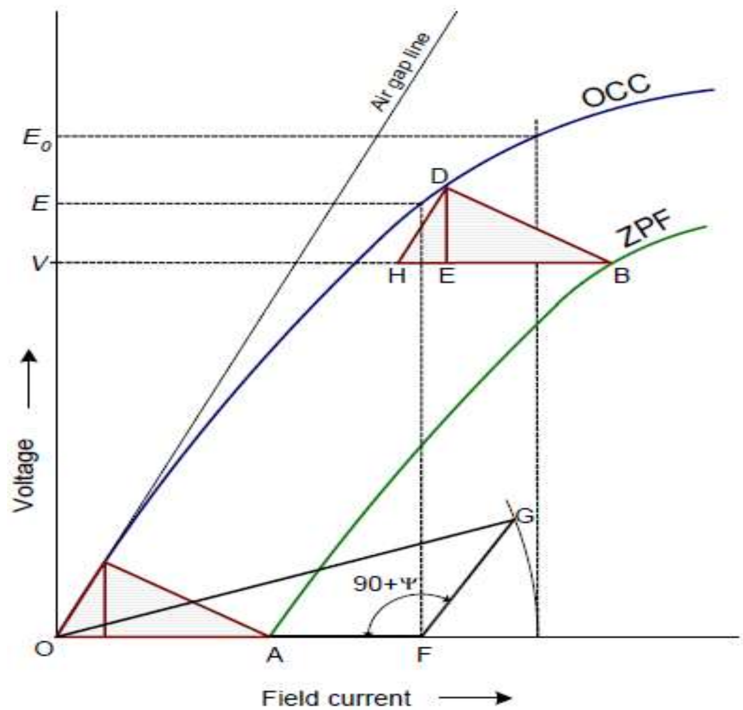
- The reduction in voltage due to armature reaction is found from above and (ii) voltage drop due to armature leakage reactance XL (also called potier reactance) is found from both. By combining these two, EO can be calculated.
- It should be noted that if we vectorially add to V the drop due to resistance and leakage reactance XL, we get E. If E is further added the drop due to armature reaction (assuming lagging power factor), then we get Eo.
- The zero power factor lagging curve can be obtained If a similar machine is available which may driven at no-load as a synchronous motor at practically zero power factor (or) By loading the alternator with pure reactors.
- By connecting the alternator to a 3Φ line with ammeter and wattmeters connected for measuring current and power and by so adjusting the field current that we get full-load armature current with zero wattmeter reading.
- Point B was obtained in this manner when wattmeter was zero.
- Point A is obtained from a short circuit test with full load armature current. Hence OA represents field current which is equal and opposite to the demagnetizing armature reaction and for balancing leakage drop at full load.
- Knowing these two points, full load zero power factor curve can be drawn as under.
- From B, BH is drawn equal to and parallel to OA.
- From H, HD is drawn parallel to initial straight part of N-L curve i.e., parallel to OC which is tangential to N-L curve.
- Hence, we get point D on no-load curve, which corresponds to point B on full-load zero power factor curve.
- The triangle BHD is known as potier triangle.
- This triangle is constant for a given armature current and hence can be transferred to give use other points like M,L etc.
- Draw DE perpendicular to BH.
- The length DE represents the drop in voltage due to armature leakage reactance XL.

- BE gives the field current necessary to overcome demagnetizing effect of armature reaction at full load and EH for balancing the armature drop DE.
- Let V be the terminal voltage on full load, then if we add to it vertically the voltage drop due to armature leakage reactance alone (neglecting Ra), then we get voltage E= DF (and not Eo). Field excitation corresponding to E is given by OF.
- The voltage corresponding to this excitation is JK = Eo

  % regulation=Eo-V/V

Assuming a lagging power factor with angle Φ, vector for I is drawn at an angle of Φ to V.

- IaRa is drawn parallel to current vector and IXL is drawn perpendicular to it.
- OD represents voltage E.
- The excitation corresponding to it i.e., OF is drawn at 90° ahead of it FG (=Na=BE) representing field current equivalent of full load armature reaction is drawn parallel to current vector OI.
- The closing side OG gives field excitation for Eo.
- Vector for Eo is 90° lagging behind OG.
- DC represents voltage drop due to armature reaction



Steps:

1. By suitable tests plot OCC and SCC

2. Draw tangent to OCC (air gap line)

3. Conduct ZPF test at full load for rated voltage and fix the point B.

4. Draw the line BH with length equal to field current required to produce full load current at short circuit.

5. Draw HD parallel to the air gap line so as to touch the OCC.

6. Draw DE parallel to voltage axis. Now, DE represents voltage drop *IXL* and BE represents the field current required to overcome the effect of armature reaction.

Triangle BDE is called Potier triangle and XL is the Potier reactance

7. Find E from *V*, *IXL* and Φ. Consider *Ra* also if required. The expression to use is

$$E = \sqrt{(V\cos\Phi + IR_a)^2 + (V\sin\Phi + IX_L)^2}$$

8. Find field current corresponding to *E*.

9. Draw FG with magnitude equal to BE at angle (90+Ψ) from field current axis,

where Ψ is the phase angle of current from voltage vector *E* (internal phase angle).

10. The resultant field current is given by OG. Mark this length on field current axis.

11. From OCC find the corresponding *E0*

American Standards Association Method (ASA Method)

• The field currents If1 (field current required to produce the rated voltage of Vph from theair gap line).

• If2 (field current required to produce the given armature current on short circuit) added at an angle of (90± Φ).

• Load induced EMF calculated as was done in the ZPF method - Corresponding to this EMF, the additional field current (If3) due to saturation obtained from OCC and air gap line - If3 added to the resultant of If1 and If2 -For this total field current, Eph found from OCC and regulation calculated.

Steps:

1. Follow steps 1 to 7 as in ZPF method.

2. Find *If1* corresponding to terminal voltage *V* using air gap line (OF1 in figure).

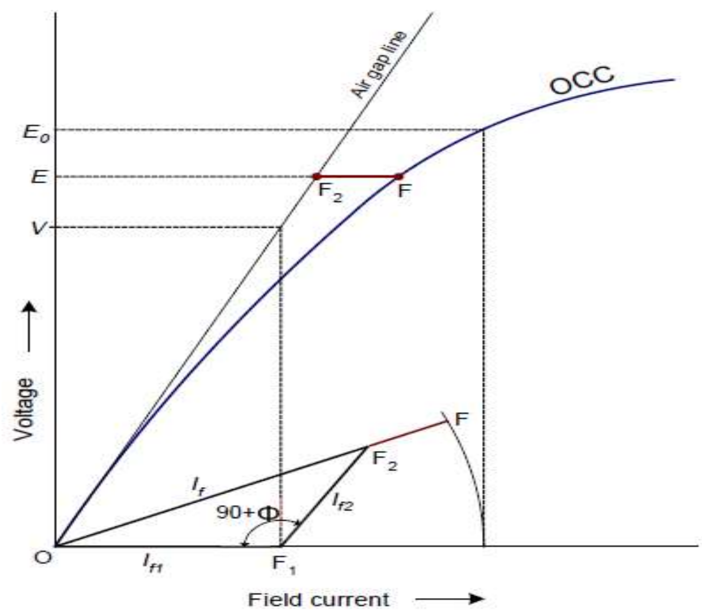
3. xDraw *If2* with length equal to field current required to circulate rated current

during short circuit condition at an angle (90+Φ) from *If1*. The resultant of *If1* and *If2* gives *If* (OF2 in figure).

4. Extend OF2 upto F so that F2F accounts for the additional field current accounting

for the effect of saturation. F2F is found for voltage E as shown.

5. Project total field current OF to the field current axis and find corresponding voltage E0 using OCC.



HUNTING AND DAMPER WINDING

Sudden changes of load on synchronous motors sometimes set up oscillations that are superimposed upon the normal rotation, giving rise to periodic variations of a very low frequency in speed. This effect is known as hunting or phase-swinging. Occasionally, the trouble is aggravated by the motor having a natural period of oscillation approximating to the hunting period, when it is possible for the motor to phase-swing into the unstable region, thus causing it to fall out of synchronism.

Damper Winding

The tendency to hunt can be minimized by the addition of a mechanical flywheel, but this practice is rarely adopted, the use of a damper winding being preferred. Assuming that the speed of rotation of the magnetic flux is constant, there is relative movement between the flux and the damper bars if the rotation of the field system is also absolutely uniform. No emfs are induced in the damper bars and no current flows in the damper winding, which is not operative. Whenever any irregularity takes place in the speed of rotation, however, the polar flux moves from side to side of the pole, this movement causing the flux to move backwards and forwards across the damper bars. Emfs are induced in the damper bars forwards across the damper winding. These tend to damp out the superimposed oscillatory motion by absorbing its energy. The damper winding, thus, has no effect upon the normal average speed, it merely tends to damp out the irregularities in the speed, thus, acting as a kind of electrical flywheel. In the case of a three-phase synchronous motor the stator currents set up a rotating mmf rotating at uniform speed (except for certain minor harmonic effects), and if the rotor is rotating at uniform speed, no emfs are induced in the damper bars.

SYNCHRONOUS CONDENSER

We know that over excited synchronous motor operates at unity or leading power factor. Generally, in large industrial plants the load power factor is lagging. The specially designed synchronous motor which runs at zero load takes leading current approximately near to 90° leading. When it is connected in parallel with inductive loads to improve power factor, it is known as synchronous condenser. Compared to static capacitor the power factor can improve easily by variation of field excitation of motor. Phasor diagram of a synchronous condenser connected in parallel withan inductive load is given below.

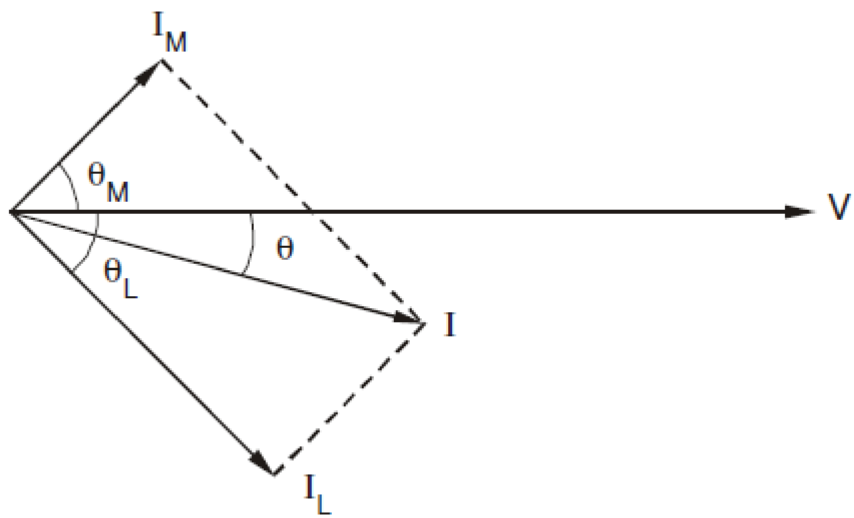


Figure 7.9 : Phasor Diagram

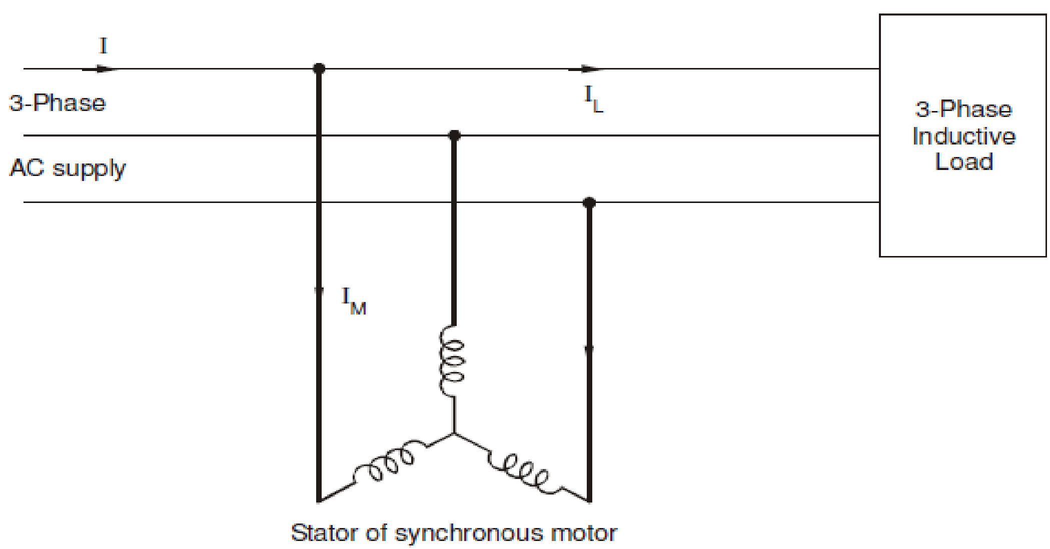


Figure 7.10 : Connection of Synchronous Motor with Connected Load