M.M.F. Method of Determining Regulation

This method of determining the regulation of an alternator is also called Ampere-turn method or Rothert's M.M.F. method. The method is based on the results of open circuit test and short circuit test on an alternator.

For any synchronous generator i.e. alternator, it requires m.m.f. which is product of field current and turns of field winding for two separate purposes.

1. It must have an m.m.f. necessary to induce the rated terminal voltage on open circuit.
2. It must have an m.m.f. equal and opposite to that of armature reaction m.m.f.

Note : In most of the cases as number of turns on the field winding is not known, the m.m.f. is calculate and expressed i terms of the field current itself.

The field m.m.f. required to induce the rated terminal voltage on open circuit can be obtained from open circuit test results and open circuit characteristics. This is denoted as F_O.

We know that the synchronous impedance has two components, armature resistance and synchronous reactance. Now synchronous reactance also has two components, armature leakage reactance and armature reaction reactance. In short circuit test, field m.m.f. is necessary to overcome drop across armature resistance and leakage reactance and also to overcome effect of armature reaction. But drop across armature resistance and also to overcome effect of armature reaction. But drop across armature resistance and leakage reactance is very small and can be neglected. Thus in short circuit test, field m.m.f. circulates the full load current balancing the armature reaction effect. The value of ampere-turns required to circulate full load current can be obtained from short circuit characteristics. This is denoted as F_{AR}.

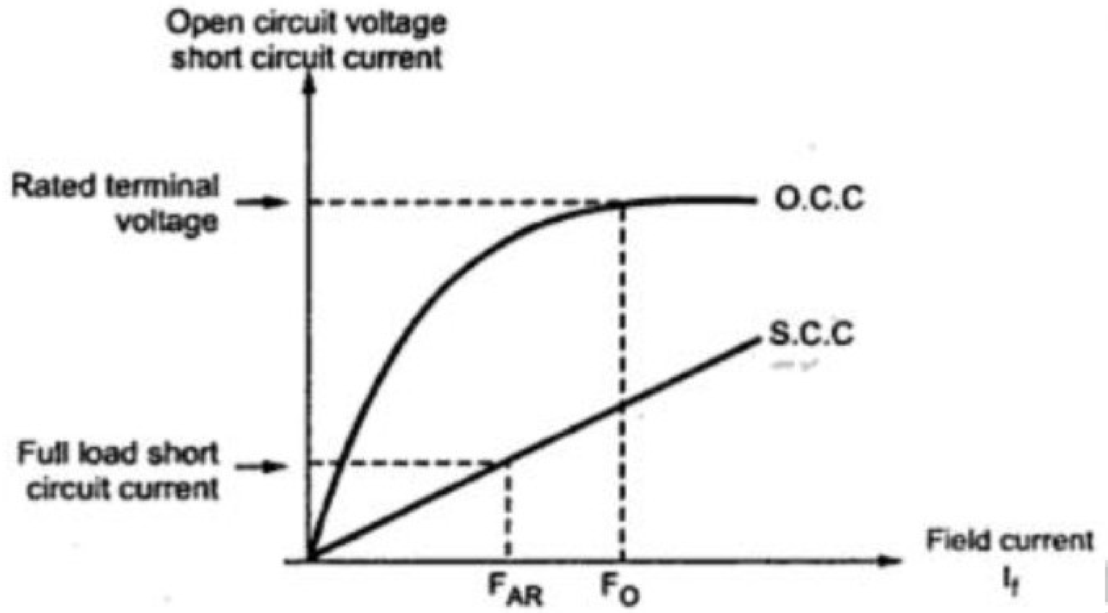

Figure 1.21 OCC & SCC

If the alternator is supplying full load, then total field m.m.f. is the vector sum of its two components F_O and F_{AR}. This depends on the power factor of the load which alternator is supplying. The resultant field m.m.f. is denoted as F_R. Let us consider the various power factors and the resultant F_R. Under short circuit condition as resistance and leakage reactance of armature do not play any significant role, the armature reaction reactance is dominating and hence the power factor of such purely reactive circuit is zero lagging. Hence F_{AR}gives demagnitising ampere turns. Thus the field m.m.f. is entirely used to overcome the armature reaction which is wholly demagntising in nature. The two components of total field m.m.f. which are F_O and F_{AR} are indicated in O.C.C. (open circuit characteristics) and S.C.C. (short circuit characteristics)

Zero lagging p.f. : As long as power factor is zero lagging, the armature reaction is completely demagnetising. Hence the resultant F_R is the algebraic sum of the two components F_O and F_{AR}. Field m.m.f. is not only required to produce rated terminal voltage but also required to overcome completely demagnetising armature reaction effect.

Zero leading p.f. : When the power factor is zero leading then the armature reaction is totally magnetising and helps main flux to induce rated terminal voltage. Hence net field m.m.f. required is less than that required to induce rated voltage normally, as part of its function is done by magnetising armature reaction component. The net field m.m.f. is the algebraic difference between the two components F_O and F_{AR}.

Unity p.f. : Under unity power factor condition, the armature reaction is cross magnetising and its effect is to distort the main flux. Thus and F are at right angles to each other and hence resultant m.m.f. is the vector sum of F_O and F_{AR}.

ASA Modification of M.M.F. Method

We have seen that neither of the two methods, M.M.F. method and E.M.F. method is capable of giving the reliable values of the voltage regulation. The error in the results of these methods is mainly due to the two reasons,

1. In these methods, the magnetic circuit is assumed to be unsaturated. This assumption is unrealistic as in practice. It is not possible to have completely unsaturated magnetic circuit.

2. In salient pole alternators, it is not correct to combine field ampere turns and armature ampere turns. This is because the field winding is always concentrated on a pole core while the armature winding is always distributed. Similarly the field and armature m.m.f.s act on magnetic circuits having different reluctances in case of salient pole machine hence phasor combination of field and armature m.m.f. is not fully justified.

Inspite of these short comings, due to the simplicity of constructions the ASA modified from of M.M.F. method is very commonly used fore the calculation of voltage regulation.

Blondel's Two Reaction Theory (Theory of Salient Pole Machine)

It is known that in case of nonsalient pole type alternators the air gap is uniform. Due to uniform air gap, the field flux as well as armature flux very sinusoidally in the air gap. In nonsalient rotor alternators, air gap length is constant and reactance is also constant. Due to this the m.m.f.s of armature and field act upon the same magnetic circuit all the time hence can be added vectorially. But in salient pole type alternators the length of the air gap varies and the reluctance also varies.

Hence the armature flux and field flux cannot vary sinusoidally in the air gap. The reluctances of the magnetic circuits on which m.m.fs act are different in case of salient pole alternators.

Hence the armature and field m.m.f.s cannot be treated in a simple way as they can be in a nonsalient pole alternators

The theory which gives the method of analysis of the distributing effects caused by salient pole construction is called two reaction theory. Professor Andre Blondel has put forward the two reaction theory.

Note : According to this theory the armature m.m.f. can be divided into two components as,

1. Components acting along the pole axis called **direct axis** 2. Component acting at right angles to the pole axis called **quadrature axis**
2. The relucatnce offered to the m.m.f. wave is lowest when it is aligned with the field pole axis. This axis is called direct axis of pole i.e. d-axis. The relucatnce offered is highest when the m.m.f. wave is oriented at 90 to the field pole axis which is called quadrature axis i.e. q-axis. The air gap is least in the centre of the poles and progressively increases on moving away from the centre. Due to such shape of the pole-shoes, the field winding wound on salient poles produces the m.m.f. wave which is nearly sinusoidal and it always acts along the pole axis which is direct axis.

Let F_f be the m.m.f. wave produced by field winding, then it always acts along the direct axis. This m.m.f. is responsible to produce an excitation e.m.f. $E_f$which lags F_f by an angle 90_o .

When armature carries current, it produces its own m.m.f. wave F_{AR}. This can be resolved in two components, one acting along d-axis (cross-magnetising). Similarly armature current I_a also can be divided into two components, one along direct axis and along quadrature axis. These components are denoted as, F_d = Component along direct axis $\mathbf{F_{AR}}$ **: }** F_q = Component along quadrature axis I_d = Component along direct axis $\mathbf{I_a}$ **: }** I_q = Component along quadrature axis

The positions of F_{AR}, F_d and F_q in space are shown in the Figure. 1.22. The instant chosen to show these positions is such that the current in phase R is maximum positive and is lagging E_f by angle Ψ.

The phasor diagram corresponding to the positions considered is shown in the Figure 1.22. The I_a lags E_f by angle Ψ.

It can be observed that F_d is produced by I_d which is at 90_o to E_f while F_q is produced by I_q which is in phase with E_f.

The flux components of Φ_{AR} which are Φ_d and Φ_q along the direct and quadrature axis respectively are also shown in the Figure.1.23. It can be denoted that the reactance offered to flux along direct axis is less than the reactance offered to flux along quadrature axis. Due to this, the flux Φ_{AR} is no longer along F_{AR} or I_a. Depending upon the reluctances offered along the direct and quadrature axis, the flux Φ_{AR} lags behind I_a.

Direct and Quadrature Axis Synchronous Reactance

We know that, the armature reaction flux Φ_{AR} has two components, Φ_d along direct axis and Φ_q along quadrature axis. These fluxes are proportional to the respective m.m.f. magnitudes and the permeance of the flux path oriented along the respective axes.

∴ $\Phi_d = P_d F_d$

where P_d = permeance alomng the direct axis

Permeance is the reciprocal of reluctance and indicates ease with which flux can travel along the path.

But F_d = m.m.f. = K_{ar} I_d in phase with I_d

The m.m.f. is always proportional to current. While K_{ar} is the armature reaction coefficient.

∴ $\Phi_d = P_d\ K_{ar}\ I_d$ Similarly

$\Phi_q = P_q\ K_{ar}\ I_q$

As the reluctance along direct axis is less than that along quadrature axis, the permeance P_d along direct axis is more than that along quadrature axis, ($P_d < P_q$). Let E_d and E_q be the induced e.m.f.s due to the fluxes Φ_d and Φ_q respectively. Now E_d lags Φ_d by 90_o while E_q lags Φ_q by 90_o

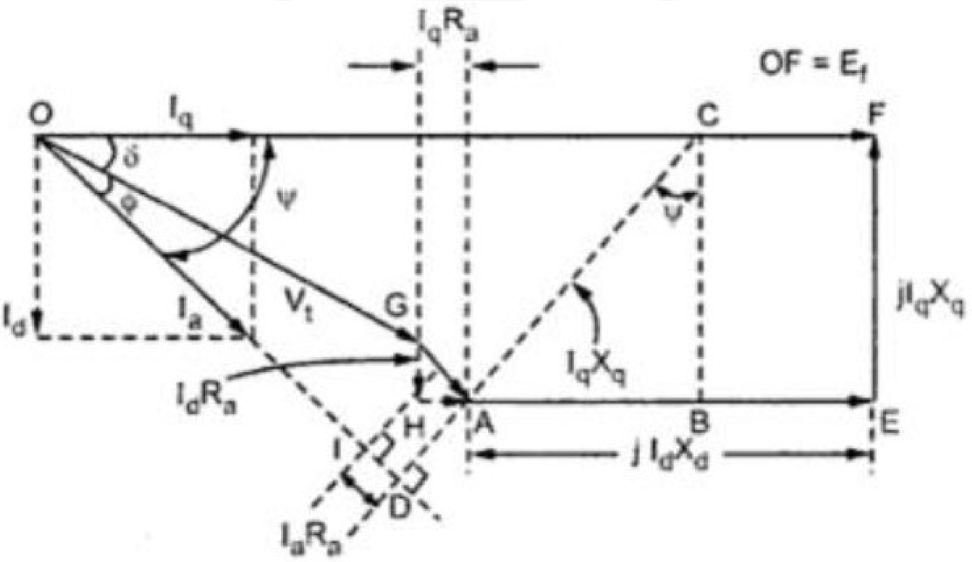

Figure 1.22 Xd and Xq axis

$$\tan\psi = \frac{V_t \sin\phi + I_a X_q}{V_t \cos\phi + I_a R_a}$$

Determination of Xd and Xq Using Slip Test

The method used to determine X_q and X_d, the direct and quadrature axis reactance is called slip test. In an alternatore we apply excitation to the field winding and voltage gets induced in the armature. But in the slip test, a three phase supply is applied to the armature, having voltage must less than the rated voltage while the field winding circuit is kept open. The circuit diagram is shown in the Figure1.23.

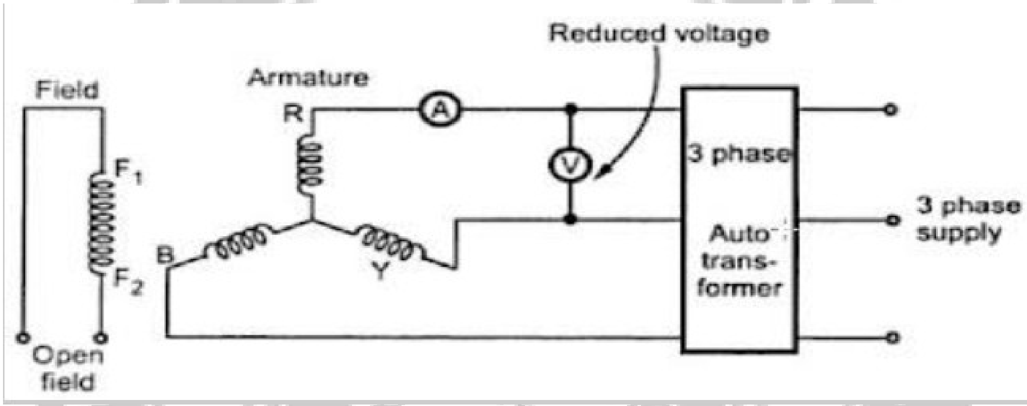

Figure 1.23 Determination of Xd and Xq Using Slip Test

The alternator is run at a speed close to synchronous but little less than synchronous value.
The three phase currents drawn by the armature from a three phase supply produce a rotating flux. Thus the armature m.m.f. wave is rotating at synchronous speed Note that the armature is stationary, but the flux and hence m.m.f. wave produced by three phase armature currents is rotating. This is similar to the rotating magnetic field existing in an induction motor.
The rotor is made to rotate at a speed little less than the synchronous speed. Thus armature m.m.f. having synchronous speed, moves slowly past the filed poles at a slip speed (n_s -n) where n is actual speed of rotor. This causes an e.m.f. to be induced in the field circuit.
When the stator m.m.f. is aligned with the d-axis of field poles then flux Φ_d perpoles is set up and the effective reactance offered by the alternator is X_d.
When the stator m.m.f. is aligned with the q-axis of field poles then flux Φ_q perpole is set up and the effective reactance offered by the alternator is X_q.
As the air gap is nonuniform, the reatance offered also varies and hence current drawn the armature also varies cyclically at twice the slip frequency.
The r.m.s. current is minimum when machine reactance is X_d and it is maximum when machine reactance is X_q. As the reactance offered varies due to nonuniform air gap, the voltage drops also varies cyclically. Hence the impedance of the alternator also varies cyclically. The terminal voltage also varies cyclically. The voltage at terminals is maximum when current and various drops are minimum while voltage at terminals is minimum when current and various drops are maximum.
It can observed that rotor field is aligned with the armature m.m.f., its flux linkage are maximum, but the rate of change of flux is zero. Hence voltage induced in field goes through zero at this

instant. This is the position where alternator offers reactance X_d. While when rate of change of flux associated with rotor is maximum, voltage induced in field goes through its maximum. This is the position where alternator offers reactance X_q.