SNS COLLEGE OF ENGINEERING

Kurumbapalayam (Po), Coimbatore – 641 107

An Autonomous Institution

Accredited by NBA – AICTE and Accredited by NAAC – UGC with 'A' Grade
Approved by AICTE, New Delhi & Affiliated to Anna University, Chennai

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

COURSE NAME : 19EE401 SYNCHRONOUS AND INDUCTION MACHINES

II YEAR /IV SEMESTER

UNIT – I SYNCHRONOUS GENERATOR

Determination of Voltage Regulation

- Direct method
- Indirect method(predetermine method)
  - ➢ Synchronous impedance or E.M.F. method
  - ➢ Ampere-turn or M.M.F. method
  - ➢ ZPF or potier method

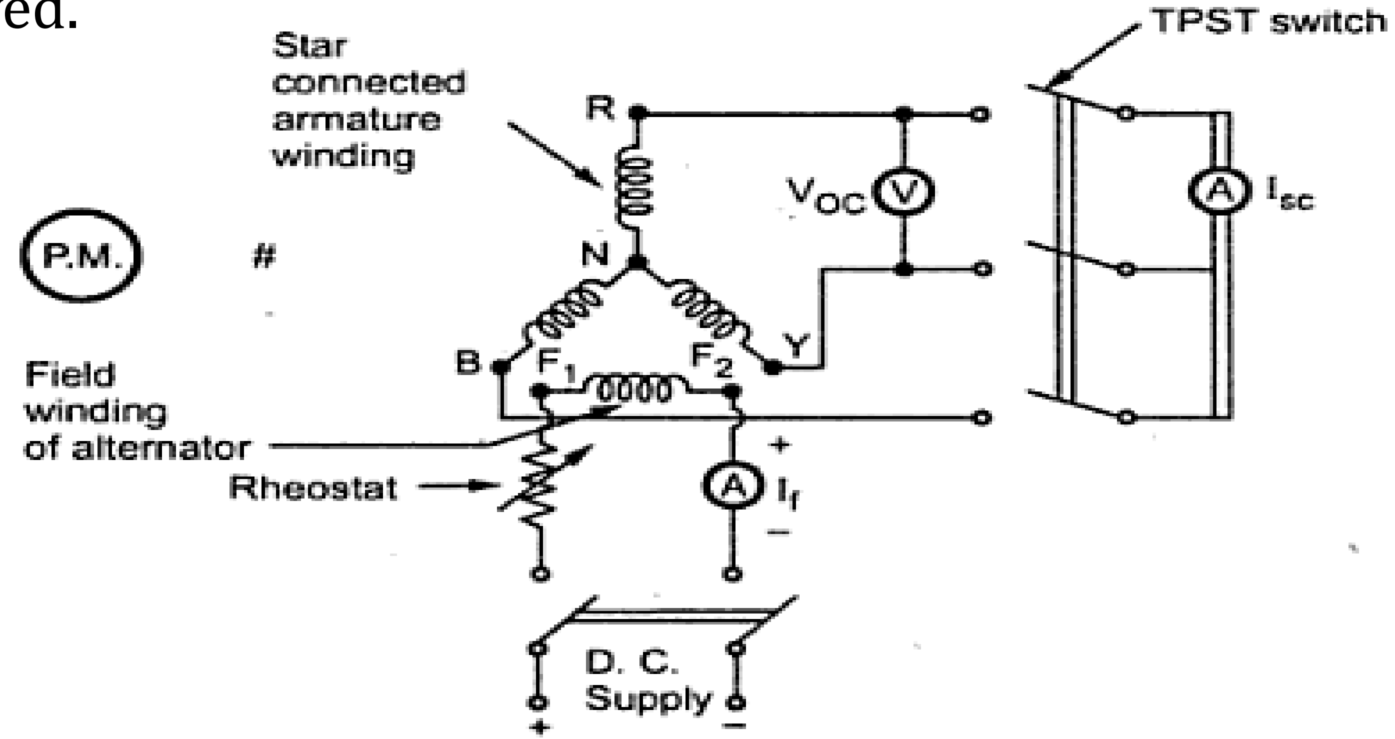
Open Circuit Test

(i) Start the prime mover and adjust the speed to the synchronous speed of the alternator.

(ii) Keeping rheostat in the field circuit maximum, switch on the DC supply.

(iii) The TPST switch in the armature circuit is kept open.

(iv) With the help of rheostat, field current is varied from its minimum value to the rated value. Due to this, flux increases, increasing the induced emf. Hence voltmeter reading, which is measuring the value of open circuit voltage increases. For various values of field current, voltmeter readings are observed.



Synchronous impedance or E.M.F. method

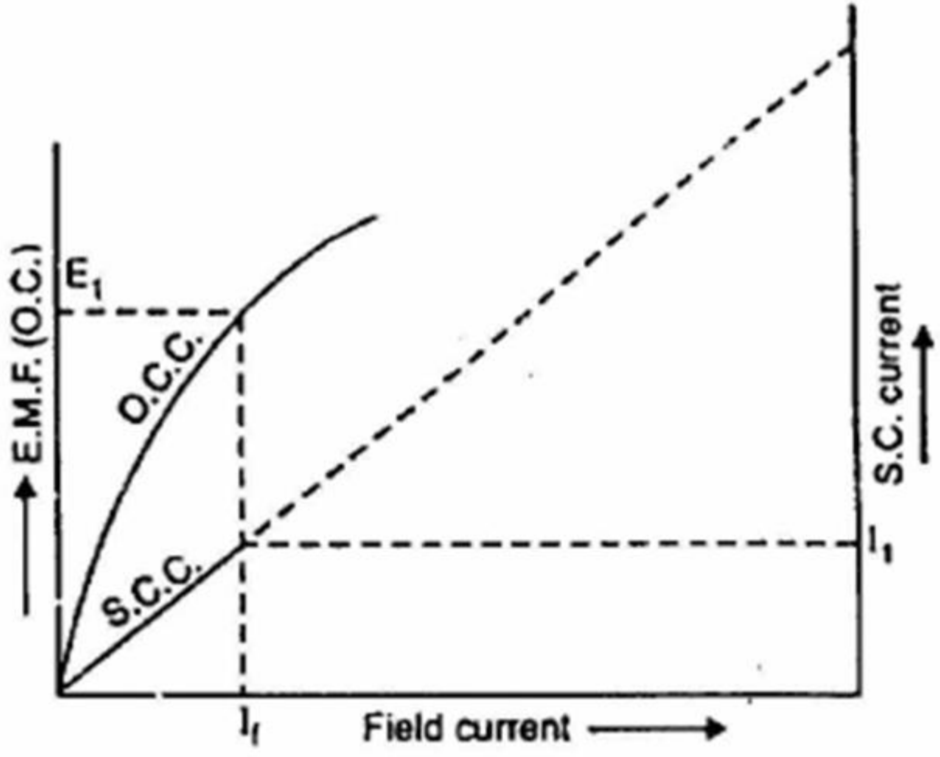
In this method of finding the voltage regulation of an alternator, we find the synchronous impedance Z_s (and hence synchronous reactance X_s) of the alternator from the O.C.C. and S.S.C. For this reason, it is called synchronous impedance method. The method involves the following steps:

(i) Plot the O.C.C. and S.S.C. on the same field current base as shown in Fig. (10.24).

(ii) Consider a field current I_f. The open-circuit voltage corresponding to this field current is E_1. The short-circuit armature current corresponding to field current I_f is I_1. On short-circuit p.d. = 0 and voltage E_1 is being used to circulate the snort-circuit armature current I_1 against the synchronous impedance Z_s. This is illustrated in Fig. (10.25).

$$\therefore \quad E_1 = I_1 Z_s \quad \text{or} \quad Z_s = \frac{E_1 \text{ (Open - circuit)}}{I_1 \text{ (Short - circuit)}}$$

Note that E_1 is the phase value and so is I_1.



(ii) The armature resistance can be found as explained earlier.

$$\therefore \quad \text{Synchronous reactance, } X_s = \sqrt{Z_s^2 - R_a^2}$$

(iv) Once we know R_a and X_s, the phasor diagram can be drawn for any load and any p.f. Fig. (10.26) shows the phasor diagram for the usual case of inductive load; the load p.f. being cos ϕ lagging. Note that in drawing the phasor diagram, current I_a has been taken as the reference phasor. The I_aR_a drop is in phase with I_a while I_aX_s drop leads I_a by 90°. The phasor sum of V, I_aR_a and I_aX_s gives the no-load e.m.f. E_0.

$$E_0 = \sqrt{(OB)^2 + (BC)^2}$$

Now $\quad OB = V\cos\phi + I_aR_a$

and $\quad BC = V\sin\phi + I_aX_s$

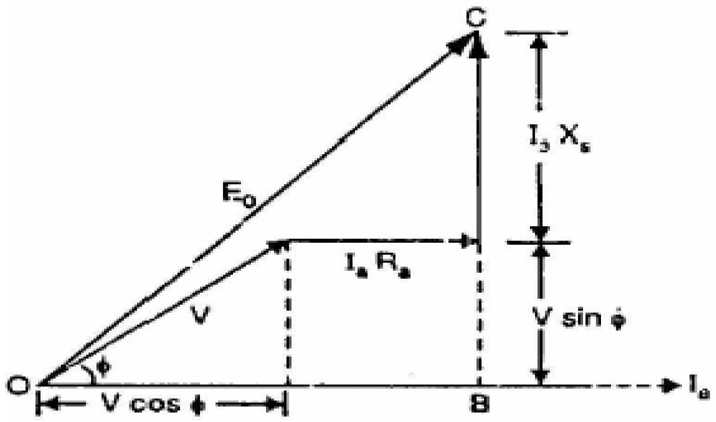


Fig.(10.26)

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

Advantages and Limitations of Synchronous Impedance Method

The main advantage of this method is the value of synchronous impedance Z_s for any load condition can be calculated. Hence regulation of the alternator at any load condition and load power factor can be determined. Actual load need not be connected to the alternator and hence method can be used for very high capacity alternators.

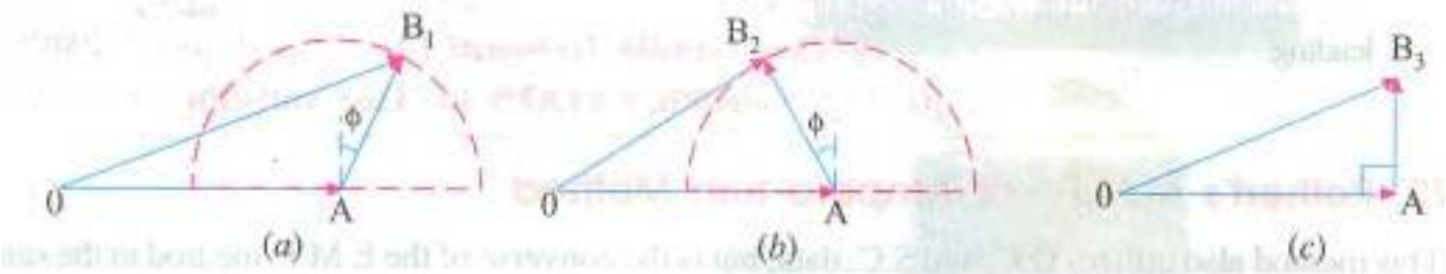
The main limitation of this method is that the method gives large values of synchronous reactance. This leads to high values of percentage regulation than the actual results. Hence this method is called pessimistic method.

Ampere Turn(AT)or MMF method

- This method of finding voltage regulation considers the opposite view to the synchronous impedance method. It assumes the armature leakage reactance to be additional armature reaction.
- Neglecting armature resistance (always small), this method assumes that change in terminal p.d. on load is due entirely to armature reaction.
- The same two tests (viz open-circuit and short-circuit test) are required as for synchronous reactance determination; the interpretation of the results only is different.
- Under short-circuit, the current lags by 90° (Ra considered zero) and the power factor is zero. Hence the armature reaction is entirely demagnetizing. Since the terminal p.d. is zero, all the field AT (ampere turns) are neutralized by armature AT produced by the short circuit armature current.

From the O.C.C., field current OA required to produce the operating load voltage V (or V + I_aR_a cos ϕ) is determined [See Fig. (10.30)]. The field current OA is laid off horizontally as shown in Fig. (10.31).

From S.C.C., the field current OC required for producing full-load current I_a on short-circuit is determined. The phasor AB (= OC) is drawn at an angle of (90° + ϕ) i.e., $\angle$ OAB = (90° + ϕ) as shown in Fig. (10.31).



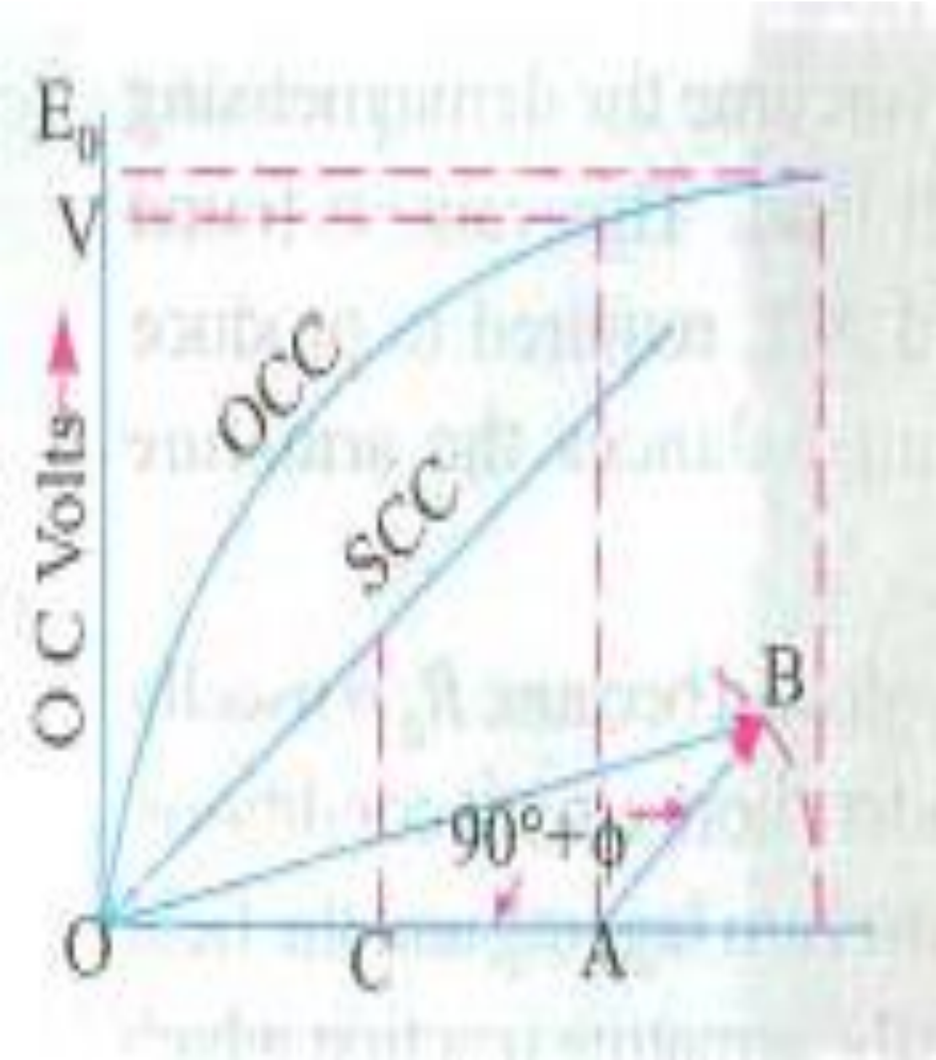
The phasor sum of OA and AB gives the total field current OB required.

$$OB = I_f = \sqrt{(I_{f1})^2 + (I_{f2})^2 - 2(I_{f1}I_{f2}cos(90 \pm \phi)}$$

The O.C. voltage E_0 corresponding to field current OB on O.C.C. is the no-load e,m.f.

$$\therefore \quad \% \text{ voltage regulation} = \frac{E_0 - V}{V} \times 100$$

This method gives a regulation lower than the actual performance of the machine. For this reason, it is known as Optimistic Method.



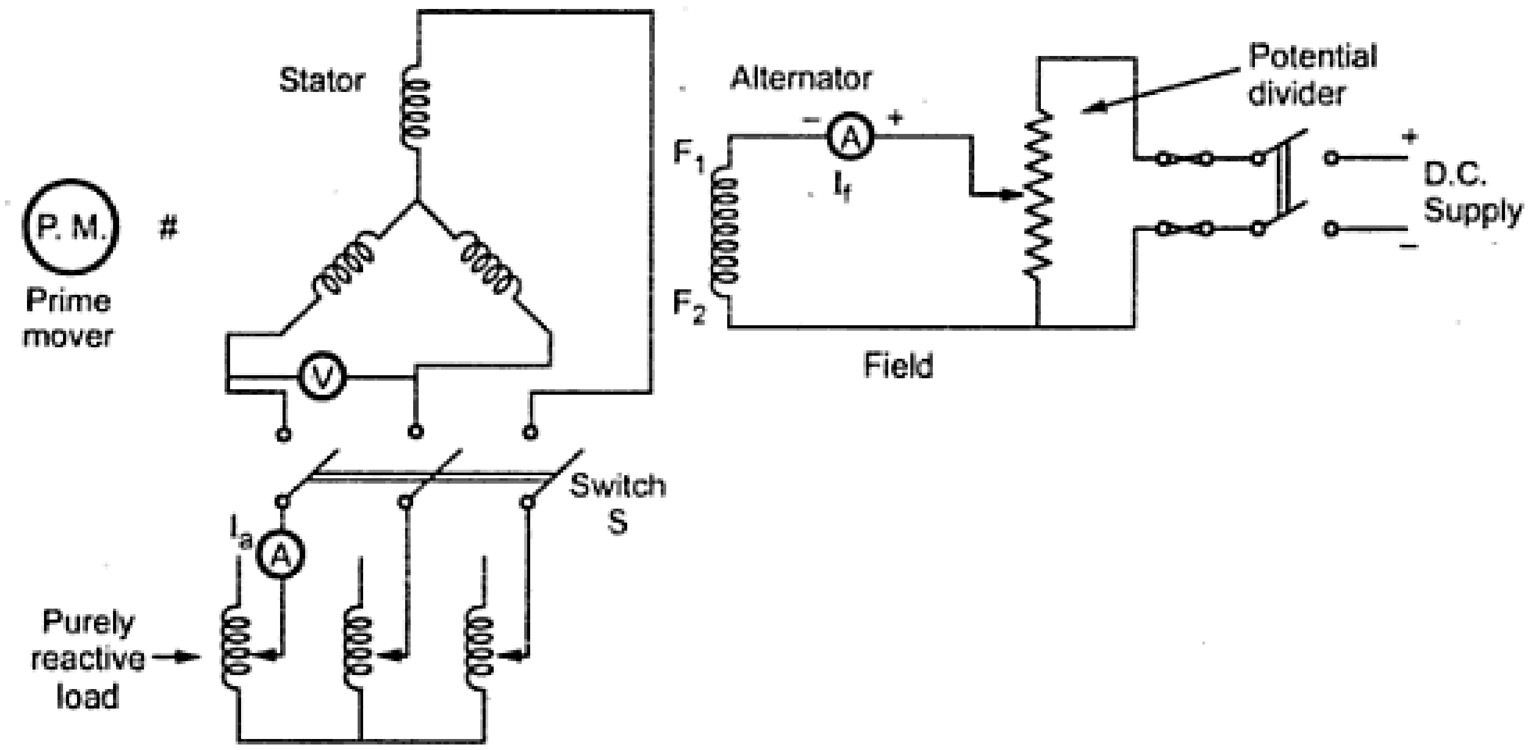
E0
V
OCC
SCC
O C Volts
B
90°+ϕ
O
C
A

ZPF or potier method

Key Point : *This method is based on the separation of armature leakage reactance and armature reaction effects. The armature leakage reactance X_L is called Potier reactance in this method, hence method is also called Potier reactance method.*

To determine armature leakage reactance and armature reaction m.m.f. separately, two tests are performed on the given alternator. The two tests are,

1. Open circuit test
2. Zero power factor test.



Zero Power Factor Test

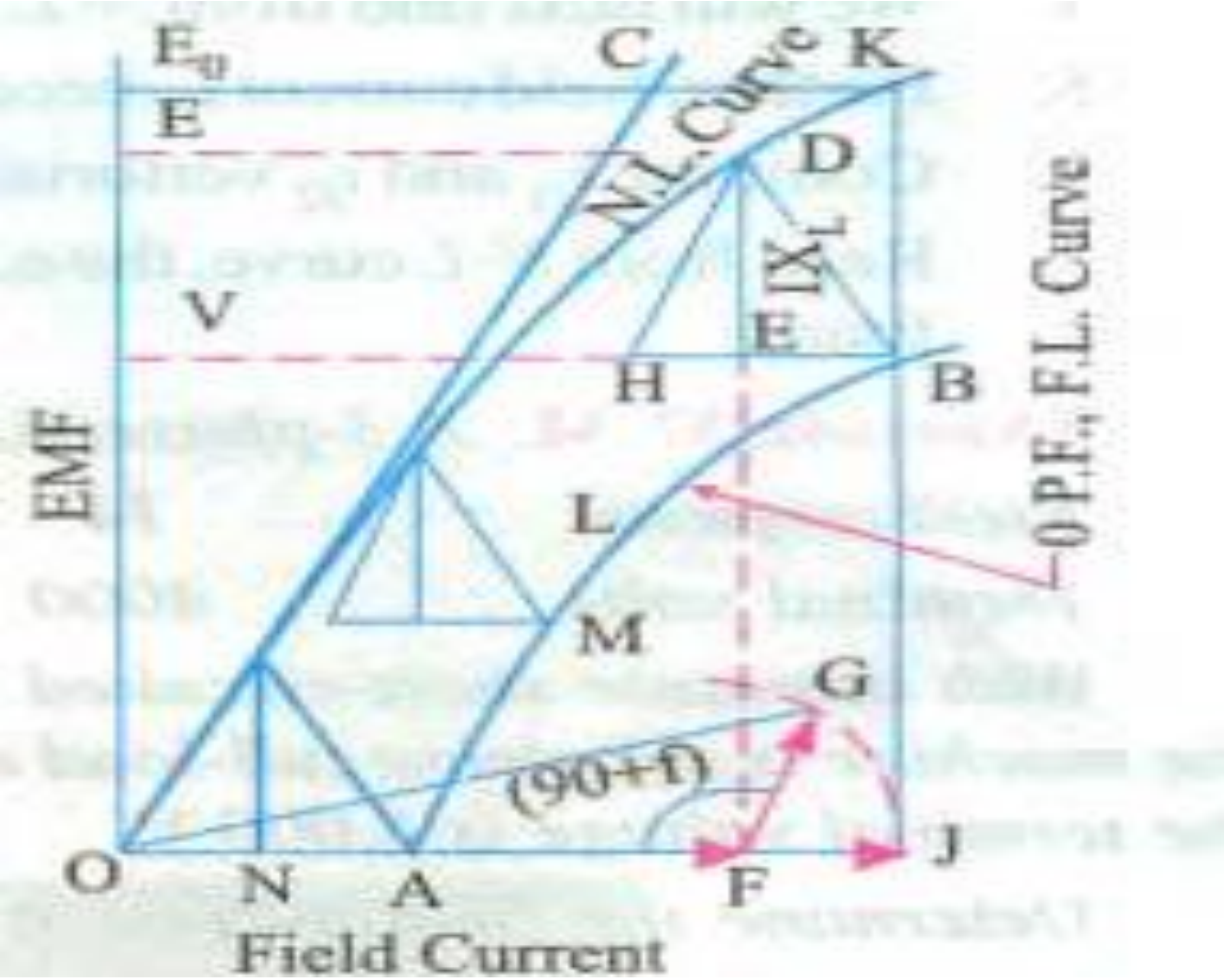
To conduct zero power factor test, the switch S is kept closed. Due to this, a purely inductive load gets connected to an alternator through an ammeter. A purely inductive load has power factor of cos 90° i.e. zero lagging hence the test is called zero power factor test.

The machine speed is maintained constant at its synchronous value. The load current delivered by an alternator to purely inductive load is maintained constant at its rated full load value by varying excitation and by adjusting variable inductance of the inductive load. Note that, due to purely inductive load, an alternator will always operate at zero p.f. lagging.

Key Point : *In this test, there is no need to obtain number of points to obtain the curve. Only two points are enough to construct a curve called* ***zero power factor saturation curve.***

This is the graph of terminal voltage against excitation when delivering full load zero power factor current.

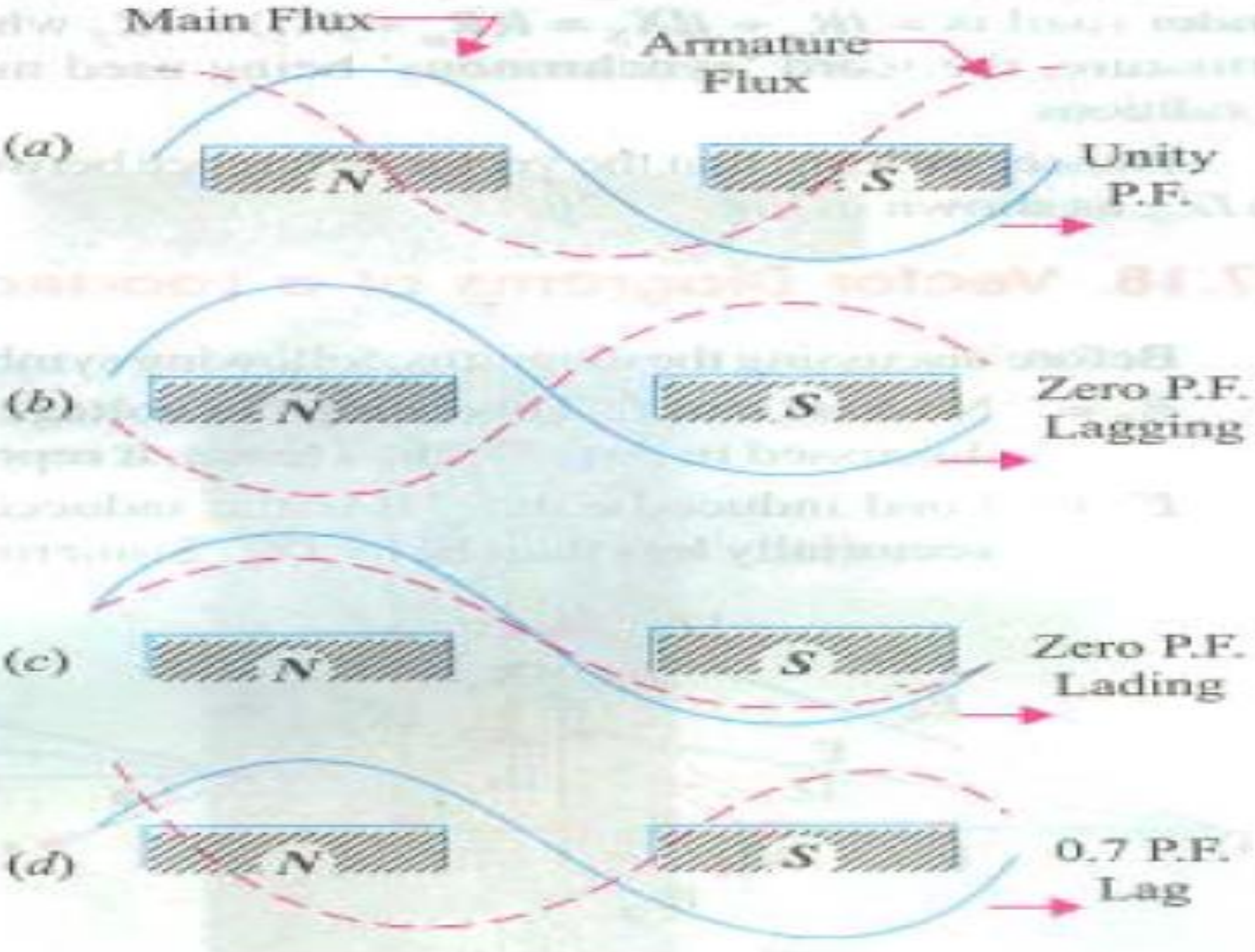
One point for this curve is zero terminal voltage (short circuit condition) and the field current required to deliver full load short circuit armature current. While other point is the field current required to obtain rated terminal voltage while delivering rated full load armature current. With the help of these two points the zero p.f. saturation curve can be obtained as,



E0
C
N.L.Curve
K
E
D
IXL
V
E
H
B
0 P.F., F.L. Curve
EMF
L
M
G
(90+f)
O
N
A
F
J
Field Current

Armature Reaction in Alternator

- When an alternator is running at no-load, there will be no current flowing through the armature winding.
- The flux produced in the air-gap will be only due to the rotor ampere-turns.
- When the alternator is loaded, the three-phase currents will produce a totalling magnetic field in the air-gap. Consequently, the air-gap flux is changed from the no-load condition.
- The effect of armature flux on the flux produced by field ampere-turns (i. e. rotor ampere-turns) is called armature reaction.
    - When load p.f. is unity
    - When load p.f. is zero lagging
    - When load p.f. is zero leading


Main Flux
Armature Flux
(a)
N
S
Unity P.F.
(b)
N
S
Zero P.F. Lagging
(c)
N
S
Zero P.F. Lading
(d)
N
S
0.7 P.F. Lag

REFERENCES

- Gupta., J.B., "Theory and Performance of Electrical Machines", S.K. Katarina & Sons, 15th Edition, 2015.
- Kothari, D.P., Nagrath, I.J., "Electric Machines", McGraw Hill Publishing Company Ltd, 5th 2017.
- Fitzgerald, A.E., Charles Kingsley, Stephen. D. Umans, "Electric Machinery", Tata McGraw Hill Publishing Company Limited, 2013.
- Murugesh Kumar, K., "Induction and Synchronous machines", Vikas Publishing House Private Ltd, 2016.

THANK YOU