SNS COLLEGE OF TECHNOLOGY

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COIMBATORE-35

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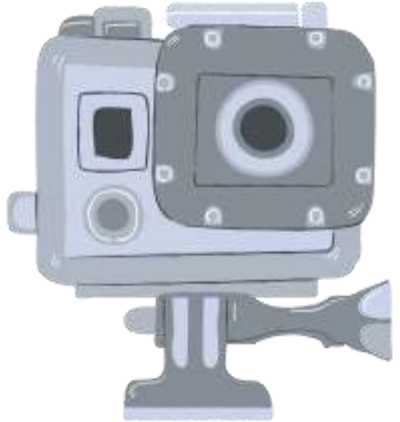
DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

COURSE NAME: 23EET204/ ELECTRICAL MACHINES II

II YEAR / IV SEMESTER

Unit 1 – SYNCHRONOUS GENERATOR

Topic 7: Voltage regulation - EMF, MMF, and ZPF methods

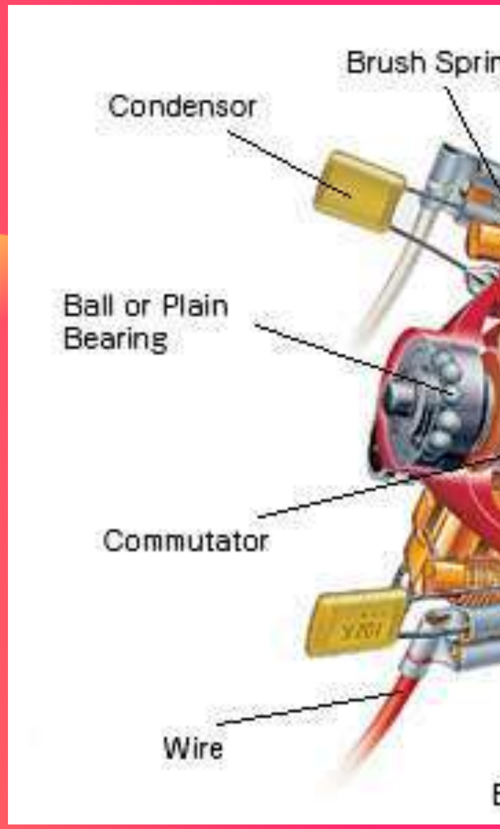


VOLTAGE REGULATION

Voltage Regulation of an alternator is defined as the change in terminal voltage from NO load to full load divided by full-load voltage.

$$\% \, Voltage\ Regulation = \frac{\text{NO load } voltage - Full\ load\ voltage}{Full\ load\ Voltage} \text{ x } 100$$

$$\% \text{ Voltage Regulation } = \frac{E_0 - V}{V} \times 100$$

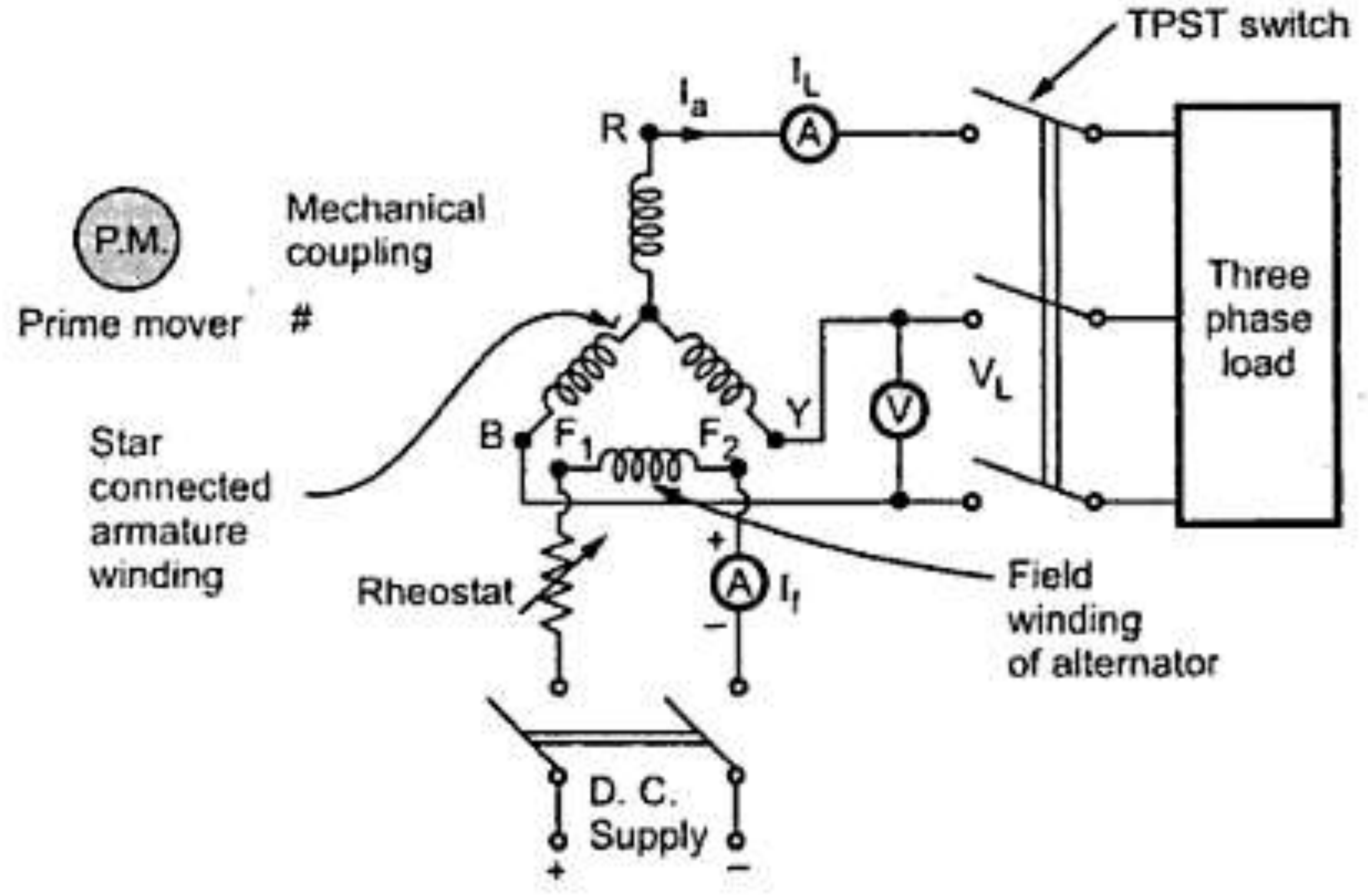


Methods

There are different methods available to determine the voltage regulation of an alternator,

1.Direct loading method
2. Synchronous impedance method or E.M.F. method
3. Ampere-turns method or M.M.F. method
4. Zero power factor method or Potier triangle method
5. ASA modified from of M.M.F. method
6. Two reaction theory

Direct loading method



Direct loading method

The star connected armature is to be connected to a three phase load
The field winding is excited by separate d.c. supply.

To control the flux i.e. the current through field winding, a rheostat is inserted in series with the field winding.

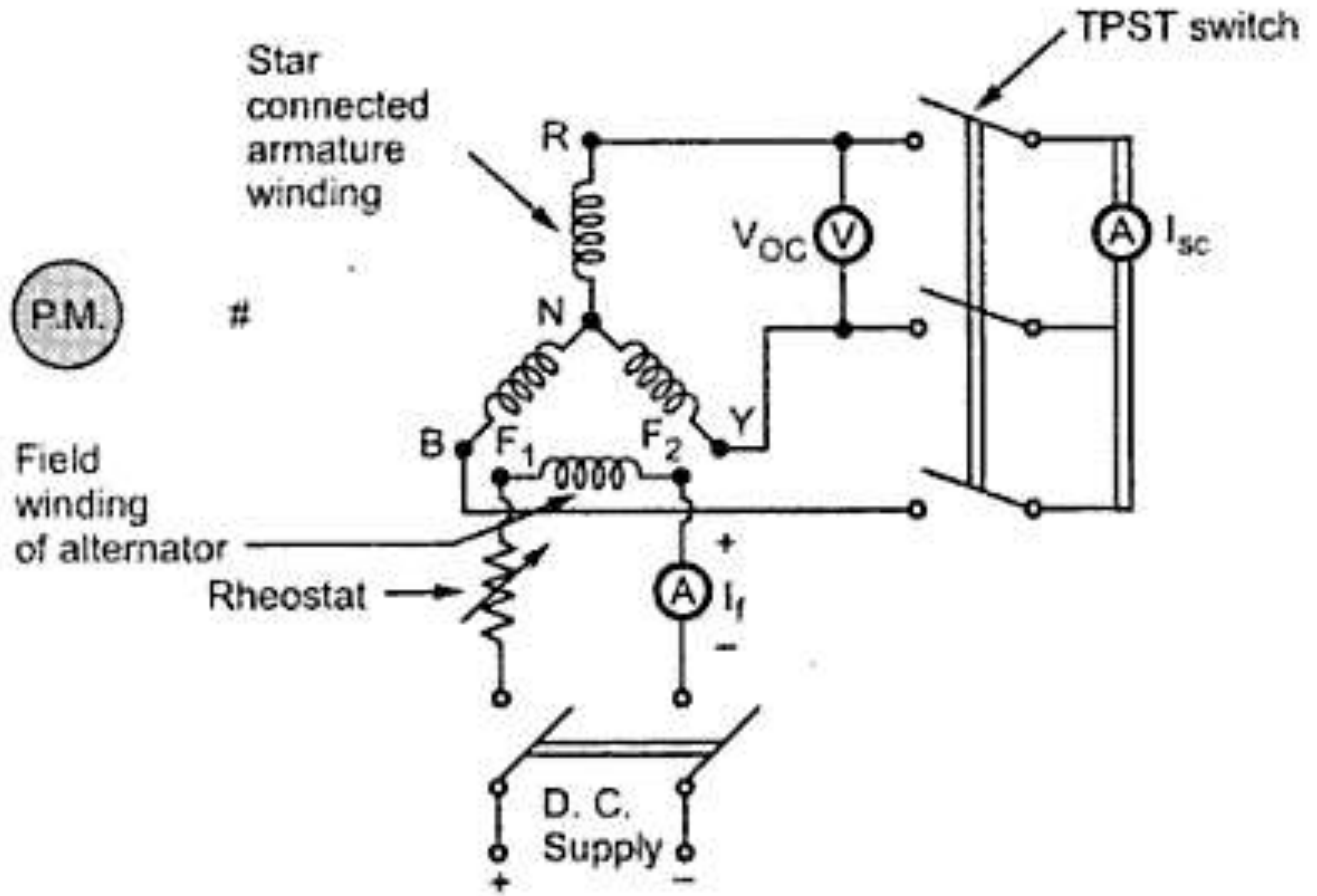
The prime mover drives the alternator at its synchronous speed.

$E_{ph} \; \alpha \; \Phi$ ..... (From e.m.f. equation)

$$\% \text{ Reg} = \frac{E_{ph} - V_{ph}}{V_{ph}} \times 100$$

For high capacity alternators, that much full load can not be simulated or directly connected to the alternator. Hence method is restricted only for small capacity alternators.

Synchronous Impedance Method or E.M.F. Method



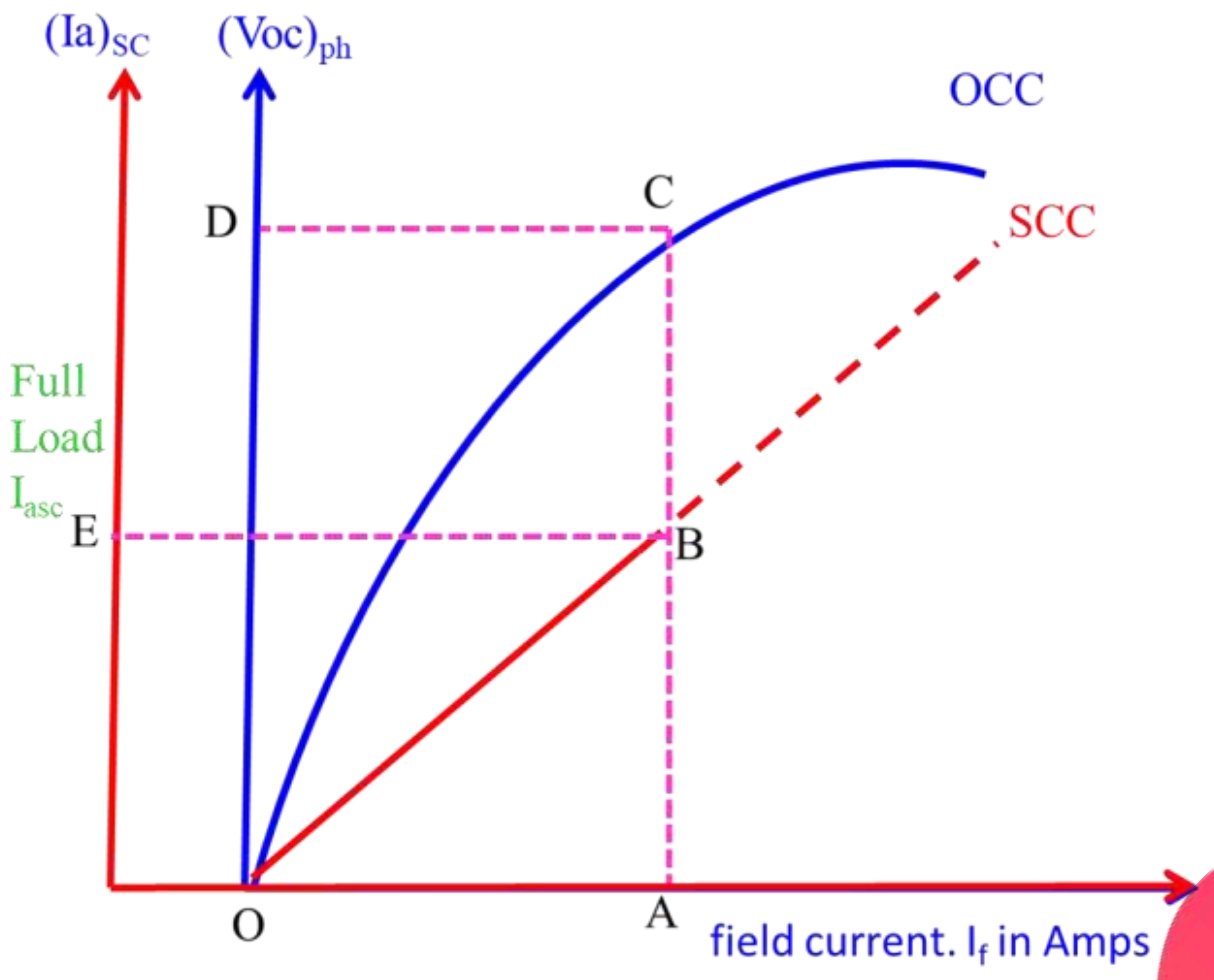
Synchronous Impedance Method or E.M.F. Method

The method requires following data to calculate the regulation.

1. The armature resistance per phase (R_a).

2. Open circuit characteristics which is the graph of open circuit voltage against the field current. This is possible by conducting open circuit test on the alternator.

3. Short circuit characteristics which is the graph of **short circuit current** against field current. This is possible by conducting short circuit test on the alternator.



Zs is calculated.

Ra measured and Xs obtained.

For a given armature current and power factor, Eph determined - regulation is calculated.

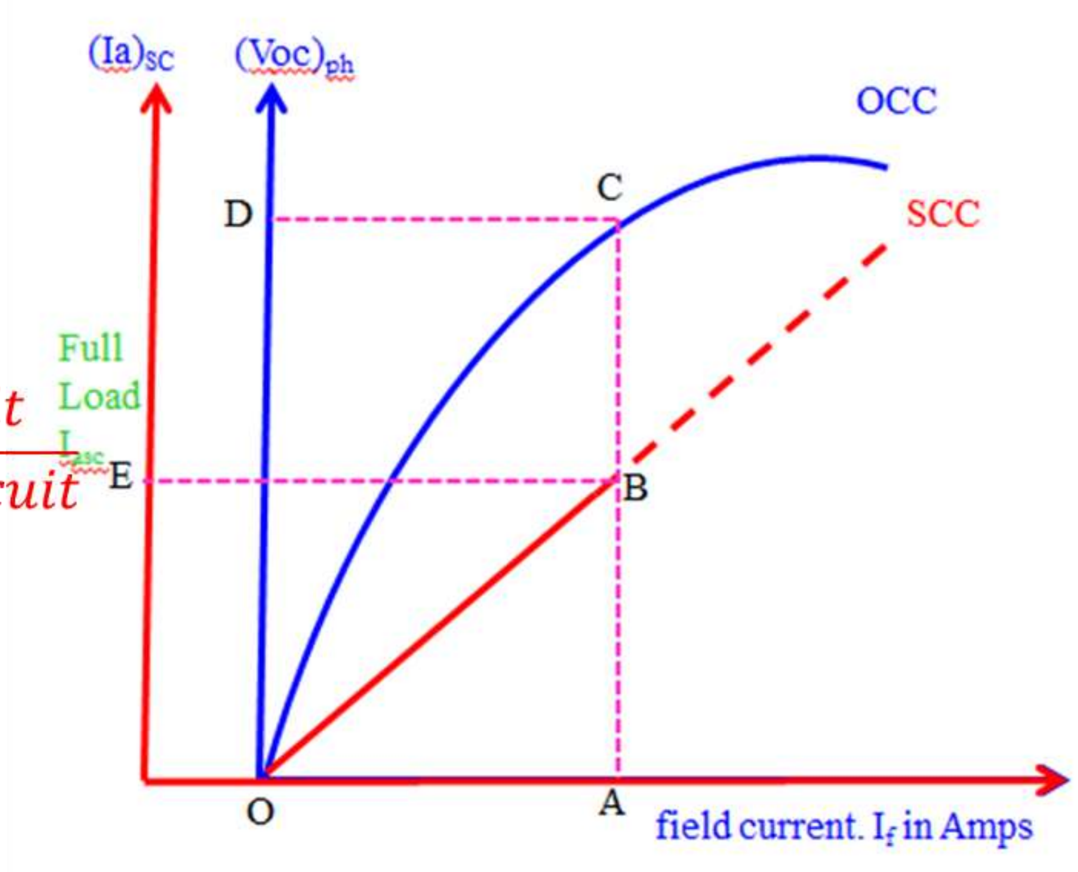
Synchronous Impedance Method or E.M.F. Method

Synchronous Impedance

$$Zs = \frac{(Voc)ph}{Iasc}$$

$$Zs = \frac{Phase\ emf\ on\ Open\ Circuit}{Phase\ Current\ on\ Short\ Circuit}$$

$$Zs = \frac{OD\ (Voc)ph}{OE\ (Iasc)}$$

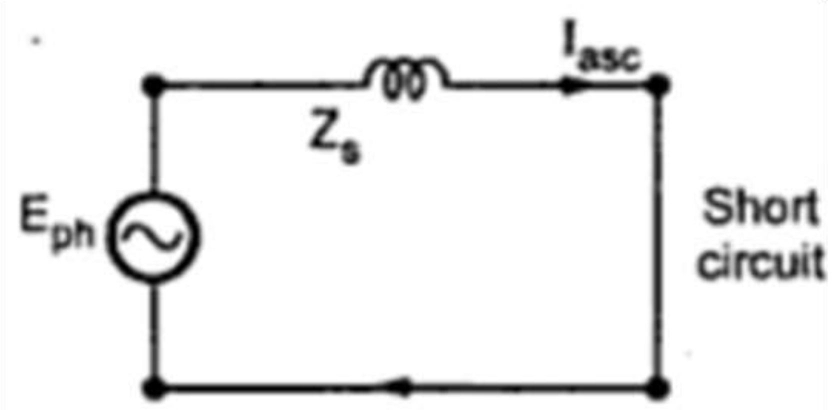


Regulation Calculation

$Zs = \sqrt{(Ra)^2 + (Xs)^2}$

Xs

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

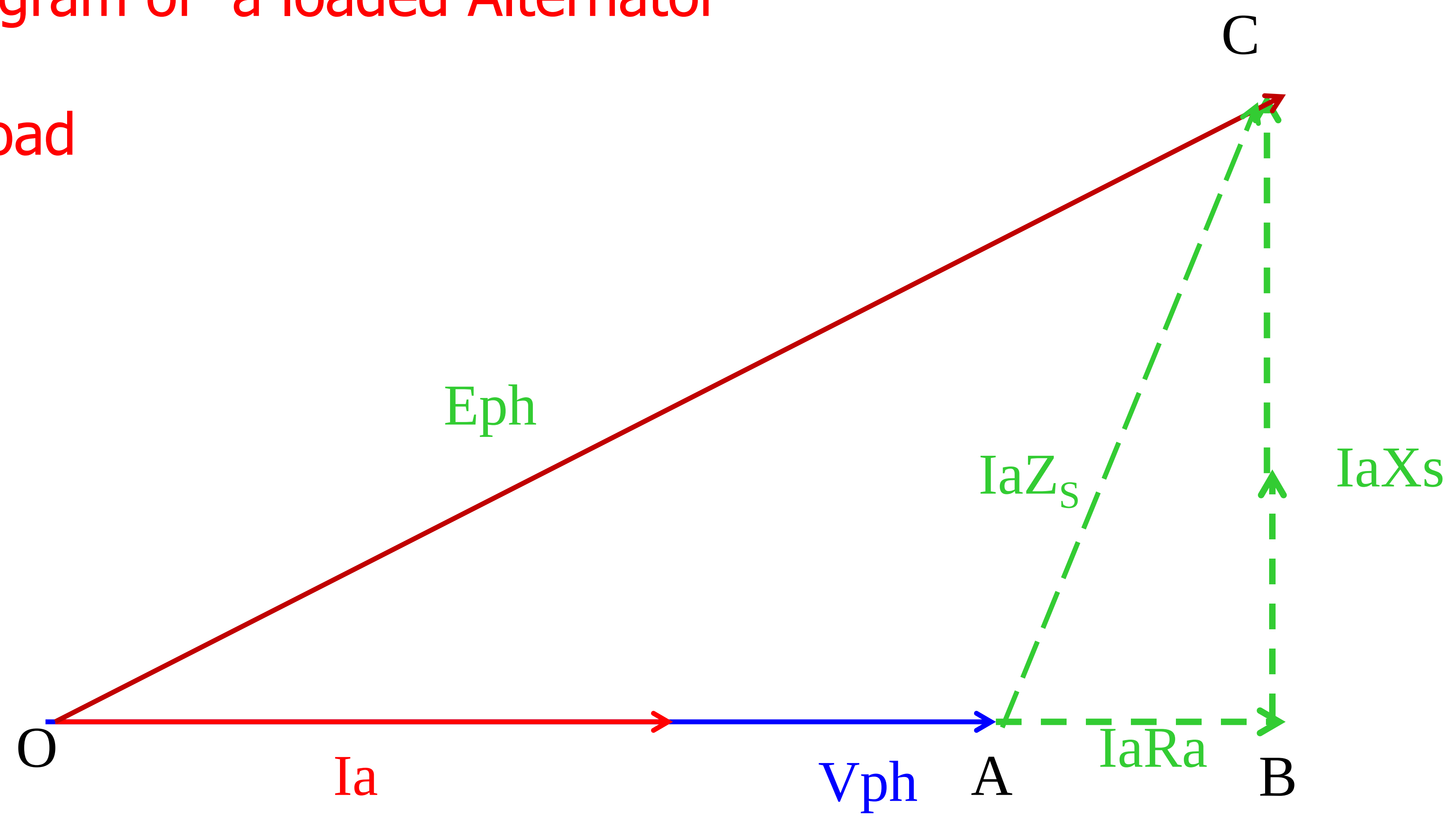


$$Eph = \sqrt{(Vph \cos \Phi + Ia\ Ra)^2 + (Vph \sin \Phi \pm Ia\ Xs)^2}$$

$$\%\ Regulation = \frac{E_{ph} - V_{ph}}{V_{ph}} \times 100$$

Phasor Diagram of a loaded Alternator

Unity PF Load



Reference as Voltage (V)

OA – Vph

AB – IaRa

BC – IaXs

AC – IaZs

OC – Eph

Consider Δ OBC

$$(OC)^2 = (OB)^2 + (BC)^2$$

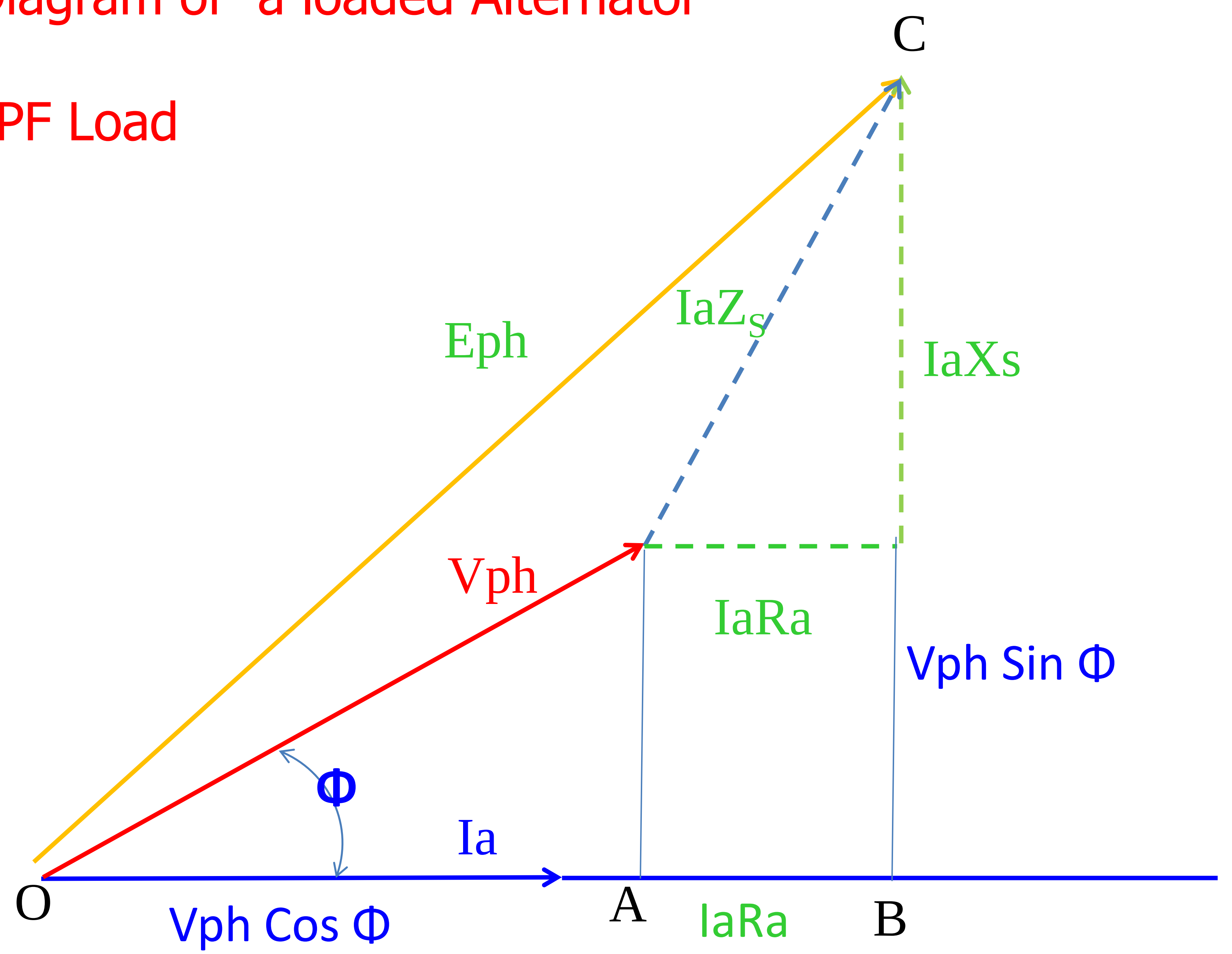
$$(Eph)^2 = (OA + AB)^2 + (BC)^2$$

$$(Eph)^2 = (Vph + IaRa)^2 + (IaXs)^2$$

$Eph = \sqrt{(Vph + IaRa)^2 + (IaXs)^2}$

Phasor Diagram of a loaded Alternator

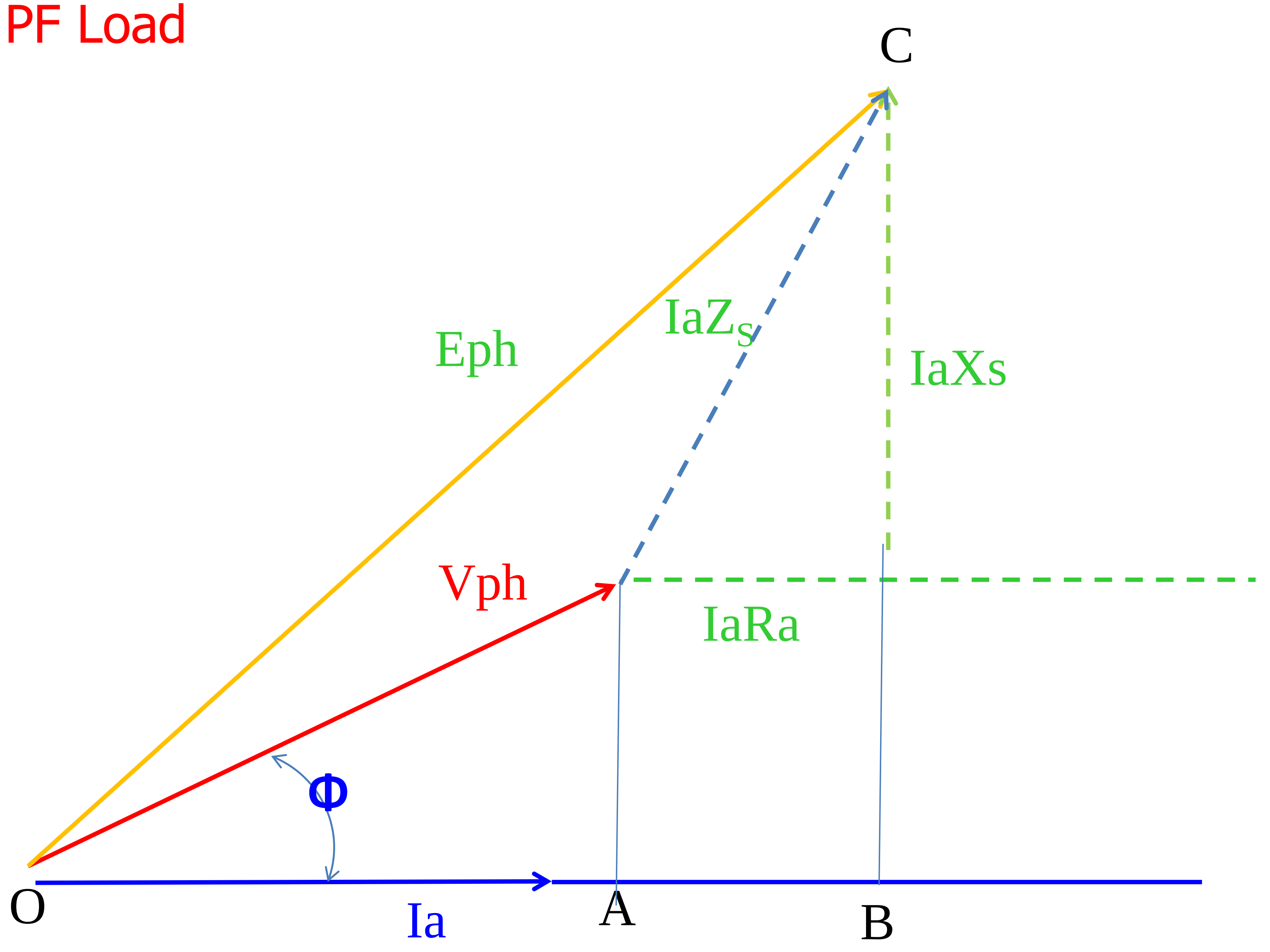
Lagging PF Load



$$Eph = \sqrt{(Vph \cos \Phi + Ia\, Ra)^2 + (Vph \sin \Phi + Ia\, Xs)^2}$$

Phasor Diagram of a loaded Alternator

Leading PF Load



$$Eph = \sqrt{(Vph \cos \Phi + Ia\ Ra)^2 + (Vph \sin \Phi - Ia\ Xs)^2}$$

Synchronous Impedance Method or E.M.F. Method

Advantages of Synchronous Impedance Method

The main advantages of this method is the value of synchronous impedance Z_s for any load condition can be calculated.

Regulation of the alternator at any load condition and load power factor can be determined.

Actual load need not be connected to the alternator

This method can be used for very high capacity alternators

Limitations of Synchronous Impedance Method

The main limitation of this method is that this 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.

MMF method (Ampere turns method)

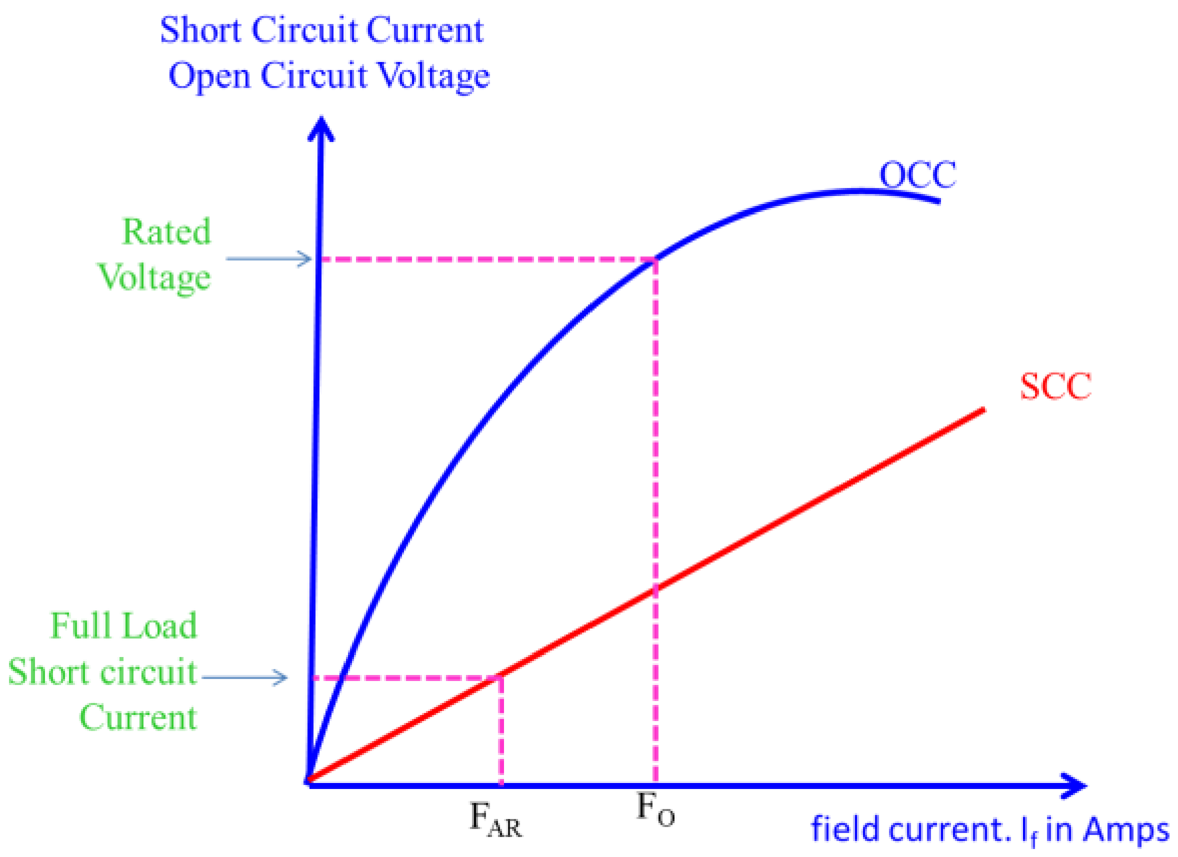
This method of determining the regulation of an alternator is also called **Ampere-turn method or Rothert's M.M.F. method.**

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.

MMF method (Ampere turns method)



OC & SC tests conducted

field currents

If1 (field current required to **produce a voltage** of (Vph + Iaph Ra cosΦ) on **OC)**

If2 (field current required to produce the given **armature current** on SC) are added at an angle of (90±Φ).

For this total field current, Eph found from OCC and regulation calculated.

Zero Power Factor Method (ZPF Method) or Potier method

This method is also called Potier method.

In the operation of any alternator, Voltage drop occurs in

Armature resistance drop(IRa)
Armature leakage reactance drop IX_L

Mainly due EMF quantity

Armature reaction. → is basically M.M.F. quantity

In the **synchronous impedance** method all the quantities are treated as **E.M.F. quantities**

In the **MMF Method** all the quantities are treated as **M.M.F. quantities**

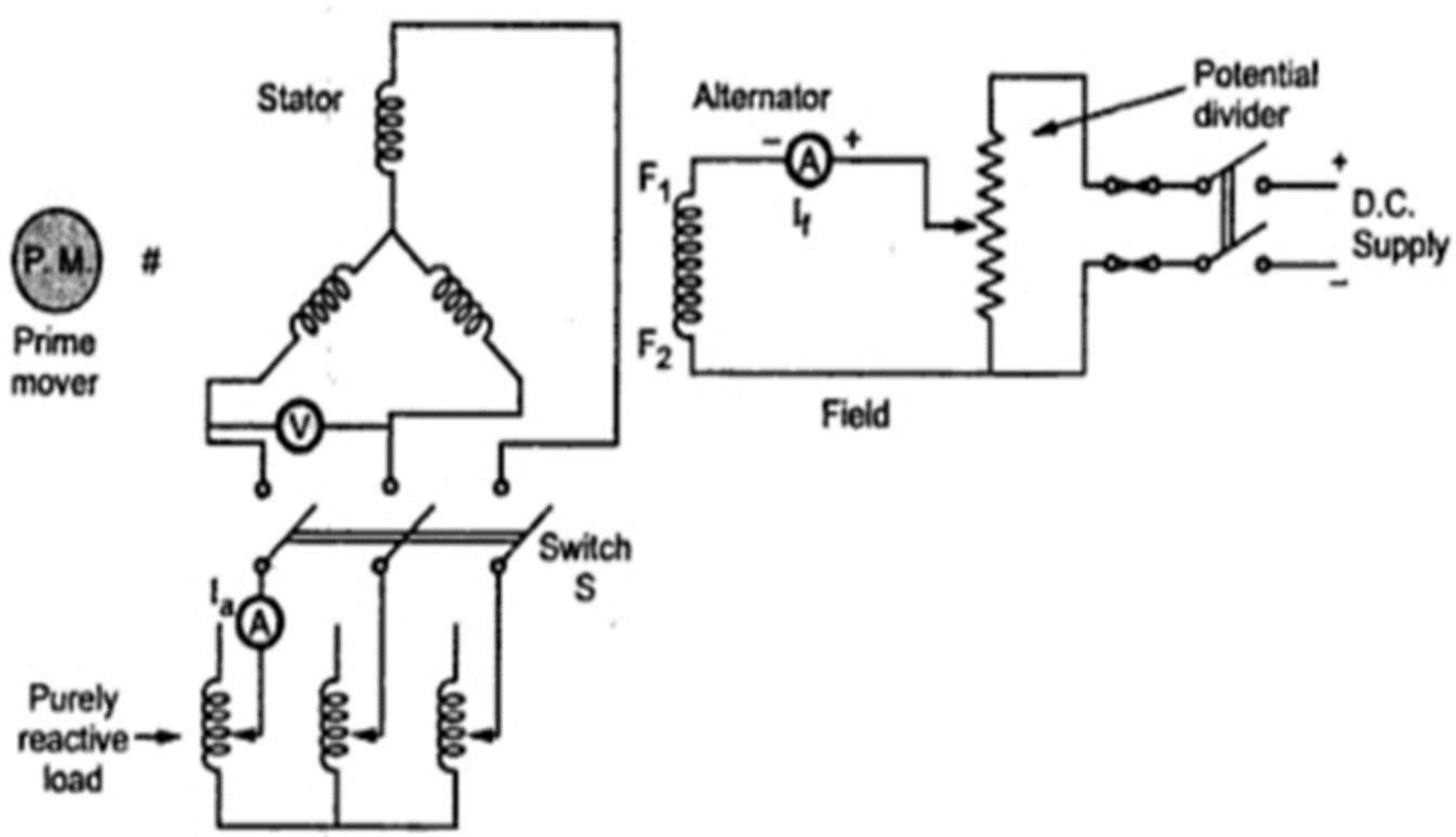
The ZPF method is based on the Separation of
Armature leakage reactance (X_L) and
Armature reaction effect

The armature leakage reactance X_L is called **Potier reactance**

Zero Power Factor Method (ZPF Method) or Potier method

To determine armature leakage reactance (EMF) and armature reaction (MMF) **separately**, two tests are performed on the alternator

1. Open circuit test
2. Zero power factor test



Open circuit test

Switch Open

P.M. to drive Ns

Potential Divider from 0 to Rated Value

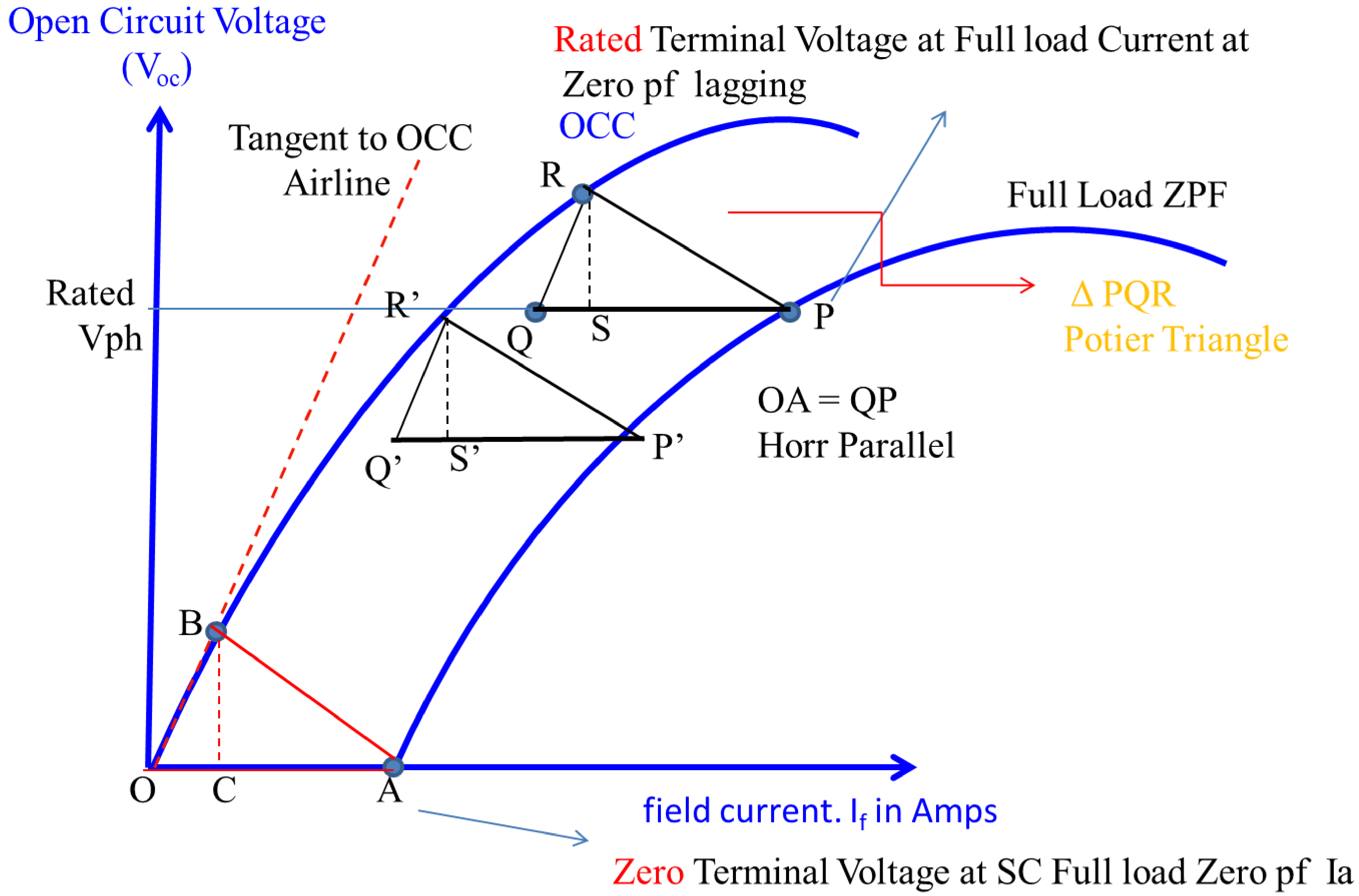
Zero power factor test

Switch Closed

Purely Inductive Load

Purely Inductive Load has PF Cos 90

Zero Power Factor Method (ZPF Method) or Potier method



RS Voltage Drop Armature Leakage Reactance (IX_L)

PS Gives I_f necessary to overcome Demagnetizing Armature Reaction

SQ rep I_f required to induce an EMF balancing of leakage reactance (RS)