Voltage Regulation of Alternator by Zero power factor method

This is also called **the general method, Potier reactance (or triangle) method** of obtaining the voltage regulation.

In the e.m.f. method. the phasor diagram involving voltages is used, For the **z.p.f** method, the e.m.fs. are handled as voltages and the m.m.fs. as field ampere-turns or field amperes.

Zero-power-factor characteristic (**z.p.f c.**), in conjunction with **O.C.C.**, is useful in obtaining the armature leakage reactance **X_l** and armature reaction m.m.f. **F_a** For an alternator, **z.p.f c.** is obtained as follows

- The synchronous machine is run at rated synchronous speed by the prime-mover.
- A purer inductive load is connected across the armature terminals and field current is increased till full load armature current is flowing.
- The load is varied in steps and the field current at each step is adjusted to maintain full-load armature current. The plot of armature terminal voltage and field current recorded at each step, gives the zero -power-factor characteristic at full-load armature current.

The **O.C.C.** and **z.p.f c.** are shown in Fig.3(b). For field excitation **F_f** or field current **I_f**, equal to **OP** the open-circuit voltage is **PK**. With the field excitation and speed remaining unchanged, the armature terminals are connected to a purely inductive load such that full load armature current flows. An examination of Fig. 3(a) and (b) reveals that under zero power. factor load, the net excitation **F_r** is **OF** which is less than **OP** (=**F_f**)by **F_a** According to the resultant m.m.f. **OF** the air-gap voltage **E_r** is **FC** and if **CB=IX_l** is subtracted from **E_r= FC**, the terminal voltage **FB = PA = V_t** is obtained. Since **z.p.f c.** is a plot between the terminal voltage and field current **I_f** or **F_f**, which has not changed from its no-load value of **OP**, the point **A** lies on the **z.p.f.c.** The triangle **ABC** so obtained is called the ***Potier triangle,*** where **CB=IX_l** and **BA = F_a**. Thus, from the Potier triangle, the armature leakage reactance **X_l** and armature reaction m.m.f. **F_a** can be determined.

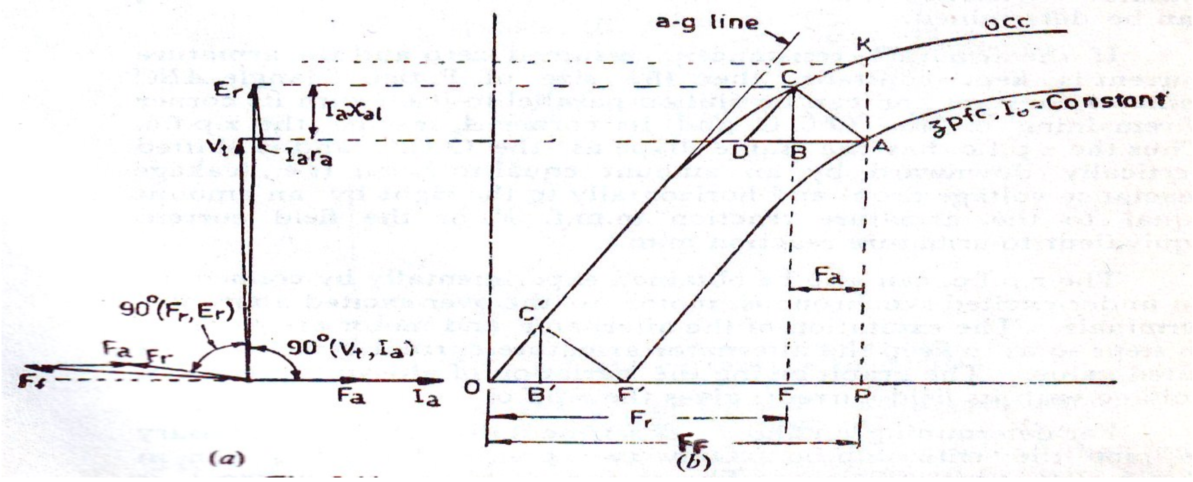


Fig 3 (a) General phasor diagram of Round-Rotor Alternator at zero power factor
(b) O.C.C., z.p.f c. And potier triangle

If the armature resistance is assumed zero and the armature current is kept constant, then the size of Potier triangle **ABC** remains constant and can be shifted parallel to itself with its corner **C**, remaining on the **O.C.C.** and its corner **A**, tracing the **z.p.f.c.** Thus the **z.p.f.c.** has the same shape as the **O.C.C.** and is shifted vertically downward by an amount equal to IX_l (i.e., ieakage reactance voltage drop) and horizontally to the right by an amount equal to the armature reaction m.m.f. F_a.or the field current equivalent to armature reaction m.m.f.

For determining IX_l and F_a experimentally, it is not necessary to plot the entire **z.p.f.c.** Only two points **A** and **F'** shown in Fig 3(b) are sufficimt. The point **A**(**PA**=rated voltage) is obtained by actually loading the alternator so that the rated armature current flows in the alternator. The other point **F'** on the **z.p.f.c.** corresponds to the zero terminal voltage and can, therefore, be obtained by performing short-circuit test. So here **OF'** is the field current required to circulate short-circuit current equal to the armature current (generally rated current) at which the point **A** is determined in the zero(near zero) power-factor test.

Now draw a horizontal line **AD**, parallel and equal to **F'O**. Through point **D**, draw a straight line parallel to the air-gap line, intersecting the **O.C.C.** at **C**. Draw **CB** perpendicular to **AD**. Then **ABC** is the Potier triangle from which

$$BC = IX_l$$

$$AB = F_a$$

Since the armature current **I** at which the point **A** is obtained, is Known, X_l can be calculated.

Then determine the air-gap voltage E_r by the relation,

$$E_r = V_t + I\,(\,R_a + j\,X_l\,)$$

According to the magnitude of E_r obtain F_r from **O.C.C.** and draw it leading E_r by 90°, The armature reaction m.m.f. F_a and armature leakage reactance X_l, can be determined from the Potier triangle, as explained before. Now F_a is drawn in phase with **I** as shown in Fig. 3(a) Then

$$F_f = F_r - F_a$$

is obtained and corresponding to F_f, excitation voltage E_f (or E_o) is recorded from **O.C.C.** and the voltage regulation obtained.

Z.p.f. method requires **O.C.C.** and **z.p.f.c.,** and gives quite accurate results.

Example :

A 220 V, 50 Hz, 6-pole star-connected alternator with, ohmic resistance of 0.06 Ω/ph, gave the following data for open-circuit, short-circuit and full-load zero-power-factor characteristics :

Find the percentage voltage regulation at full-load current of 40 amps at power-factor of 0.8 lag by (a) e.m f. method (b) z. p. f .

Field current, A	**0.2**	**0.4**	**0.6**	**0.8**	**1.0**	**1.2**	**1.4**	**1.8**	**2.2**	**2.6**	**3.0**
O.C. voltage, V	**29**	**58.0**	**87.0**	**116**	**146**	**172**	**194**	**232**	**261.5**	**284**	**300**
S.C. current, A	**6.6**	**13.2**	**20.0**	**26.5**	**32.4**	**40.0**	**46.3**	**59**	**-**	**-**	**-**
z.p.f. terminl voltage, v	**-**	**-**	**-**	**-**	**-**	**0.0**	**29**	**88**	**140**	**177**	**208**

Solution :

Rated per phase voltage = 220 / √3 = 127 V
Per phase values for O.C.C. and z.p.f.c. are tabulated below and O.C.C., S.C.C. and z.p.f.c. are plotted in fig 5.

Field current, A	**0.2**	**0.4**	**0.6**	**0.8**	**1.0**	**1.2**	**1.4**	**1.8**	**2.2**	**2.6**	**3.0**
O.C. voltage, V	**16.7**	**33.5**	**50.2**	**67**	**84.3**	**99.3**	**112**	**134**	**151**	**164**	**173**
z.p.f. terminl voltage,	**-**	**-**	**-**	**-**	**-**	**0.0**	**16.73**	**50.8**	**80.8**	**102**	**120**

A- E.M.F. Method:

$\mathbf{Z_s}$ = O.C. voltage / S.C. current
From above tables, $\mathbf{Z_s} \approx 134 / 59 = 2.27\ \Omega$
Here $\mathbf{X_s} \approx \mathbf{Z_s} = 2.27\ \Omega$, since $\mathbf{R_a}$ is quite small.

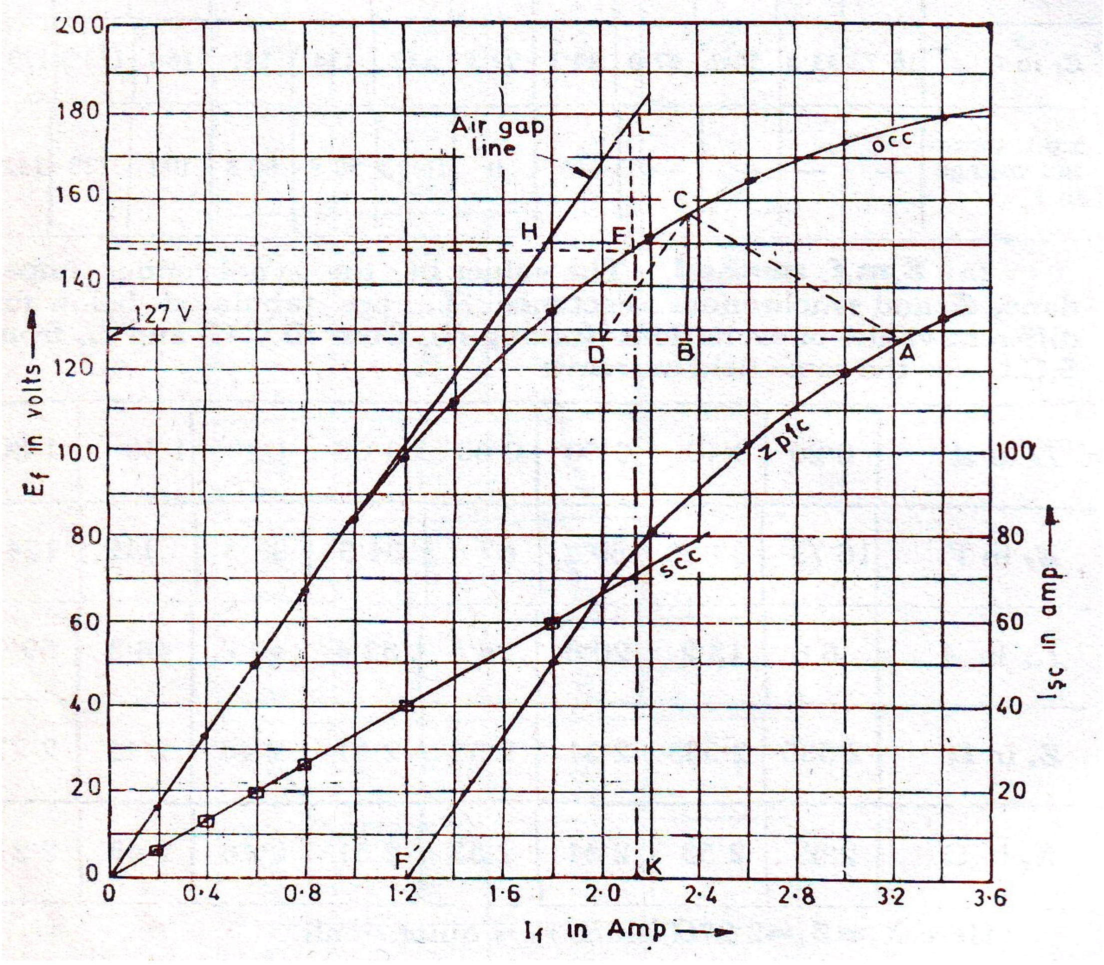
$$\mathbf{E_o = \sqrt{[(V_t \cos\varphi + I R_a)^2 + (V_t \sin\varphi + I X_S)^2]}}$$
$$= \sqrt{[(127 * 0.8 + 40 * 0.06)^2 + (127 * 0.6 + 40 * 2.27)^2]}$$
$$\mathbf{= 196 \text{ volts}}$$

Percentage regulation = $\mathbf{(E_o - V_t) / V_t * 100\%}$
$= (196 - 127) / 127 * 100 = 54\%$

B- Zero power factor Method:

First of all, the Potier triangle **ABC** is drawn as described before, Point **A** corresponds to the rated voltage of 127 V on the **Z. p.f.c.** The line **AD** is drawn parallel and equal to **F'O** = 1.2 A.Then **DC** is drawn parallel to the air-gap line, meeting the **O.C.C.** at point **C.** Perpendicular **CB** on **AD,** lives $\mathbf{IX_l}$ drop equal to 30 volts.

Armature leakage reactance $\mathbf{X_l} = 30 / 40 = 0.75\ \Omega$
The air-gap voltage $\mathbf{E_r}$,
$\mathbf{E_r = V_t + I\ (\ R_a + j\ X_l\ )} = 127(0.8+j0.6) + 40*(0.06+j0.75)= 148.6\angle 45.6^o$
Or $= \sqrt{\mathbf{[(\ V_t \cos\varphi + I\ R_a)^2 + (\ V_t \sin\varphi +\ I\ X_l)^2]}}$
$=\sqrt{\ [(127 * 0.8 + 40 * 0.06)^2 + (127 * 0.6 + 40 * 0.75)^2]}$
= 148.6 volts



Corresponding to $\mathbf{E_r}$ = 148.6 V, the field current $\mathbf{F_r}$ from O.C.C. is 2.134 A, the armature m.m.f. $\mathbf{F_a}$, from Potier triangle is **AB** = 0.84 A.

$\mathbf{F_r} = 2.134\ \angle(45.6^o + 90^o) = 2.134\ \angle 135.6^o$
$\mathbf{F_a} = 0.84$ A
$\mathbf{F_f = F_r - F_a} = 2.134\ \angle 135.6^o - 0.84$
$= 2.797\ \angle 147.7^o$ A
For $\mathbf{F_f} = 2.797$ A, the excitation voltage from O.C.C. is $\mathbf{E_o}$=169.0 volts
Percentage regulation = $\mathbf{(E_o - V_t)\ /\ V_t * 100\%}$
$= (169 - 127) / 127 * 100 = 33.1\%$

As already stated, **z.p.f.** method gives quite accurate results and here the voltage regulation with this method is 33.1%.

The voltage regulation by **e.m.f.** method is 54% , This value is much higher than the accurate value of 33.1 % and in view of this, this method may be called pessimistic method.

The Automatic Voltage Regulator

The method of operation in the power station is to maintain the terminal voltage of the alternator at the rated value and to adjust the excitation with change in load current accordingly. As the variations in load may be very violent both as regards magnitude and rapidity, it is clear that hand regulation of the excitation is impossible and that automatic means must be adopted. Now the flux per pole of a large turbo-alternator may amount to several webers, and therefore the self-induction of the field winding will be very high.

Consider, for example, a 15,000 kVA, 4 pole turbo-alternator having a flux per pole of 1.15 webers, a rotor current of 600 amperes, and a rotor winding of 66 turns per pole.

L(per pole)=(Flux per ampere) * (No. of turns)

$$= (1.15 / 600) * 66 = 0.127 \text{ henry}$$

And Inductance, **L** = 4 * 0.127 = 0.508 henry for the whole winding

Winding resistance, **R**=0.2 Ω

The time constant = **L** / **R** = 0.508 / 0.2 = 2.54

The time constant **L** / **R** of the field circuit gives the value in seconds, and is the time taken for the flux to reach 0.6321 of its final value. With modern large two-pole, turbo-alternators the time constant is considerably greater. What is required in the power station that there shall be an almost instantaneous increase in excitation to the desired value. An increase in load calls for an increase in excitation. This increase is made much greater than is ultimately required, and as a result the flux builds up very rapidly. Before the flux can build up too far, the excitation is reduced again. This is known as the "overshooting-the-mark" principle. There are two types of quick acting regulator which work on this principle :

(a) the vibrator type, in which a fixed resistance is rapidly cut in and out.

(b) the rheostat type in which the resistance is variable.

Transistor-Cruntrolled or Transistor Type-Automatic Voltage Regulators

The automatic voltage regulation is affected by matching a quantity proportional to the alternator voltage against a 'reference'. The difference between these two, called 'error' has to be rectified before it can be fed to the excitor, and this is affected by means of transistor amplifiers. This is a 'brushless' method of voltage control for an alternator. Here no slip rings, commutators and brush gear is required. These types of regulators are also called electronic voltage regulators

The reference circuit is supplied by voltage feed back from the alternator, the general scheme of control has been illustrated in block diagram of fig 6.

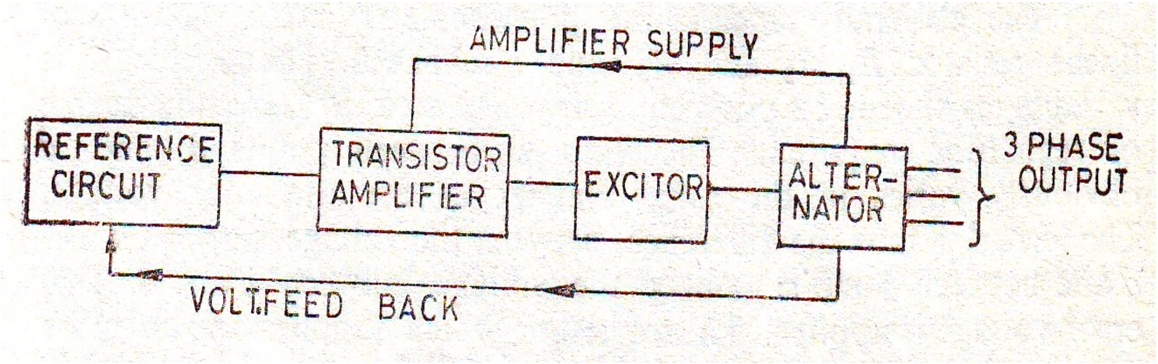


Fig 6 Block diagram of the control system of a transistor-controlled alternator