

Determination of Voltage Regulation

The following are the three methods which are used to determine the voltage regulation of smooth cylindrical type Alternators

- 1. Synchronous impedance / EMF method**
- 2. Ampere-turn / MMF method**
- 3. Potier / ZPF method**

1. Synchronous impedance / EMF method

Synchronous impedance is calculated from OCC and SCC as $Z_s = E_a / I_{sc}$ (for same I_f)

A compromised value of Z_s is normally estimated by taking the ratio of (E_a / I_{sc}) at normal field current I_f . A normal field current I_f is one which gives rated voltage V on open circuit.

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

Advantages:

- Simple no load tests (for obtaining OCC and SCC) are to be conducted
- Calculation procedure is much simpler

Disadvantages:

- The value of voltage regulation obtained by this method is always higher than the actual value.

2. Ampere-turn / MMF method

The ampere-turn /MMF method is the converse of the EMF method in the sense that instead of having the phasor addition of various voltage drops/EMFs, here the phasor addition of MMF required for the voltage drops are carried out. Further the effect of saturation is also taken care of.

Data required for MMF method are:

- Effective resistance per phase of the 3-phase winding R
- Open circuit characteristic (OCC) at rated speed/frequency
- Short circuit characteristic (SCC) at rated speed/frequency

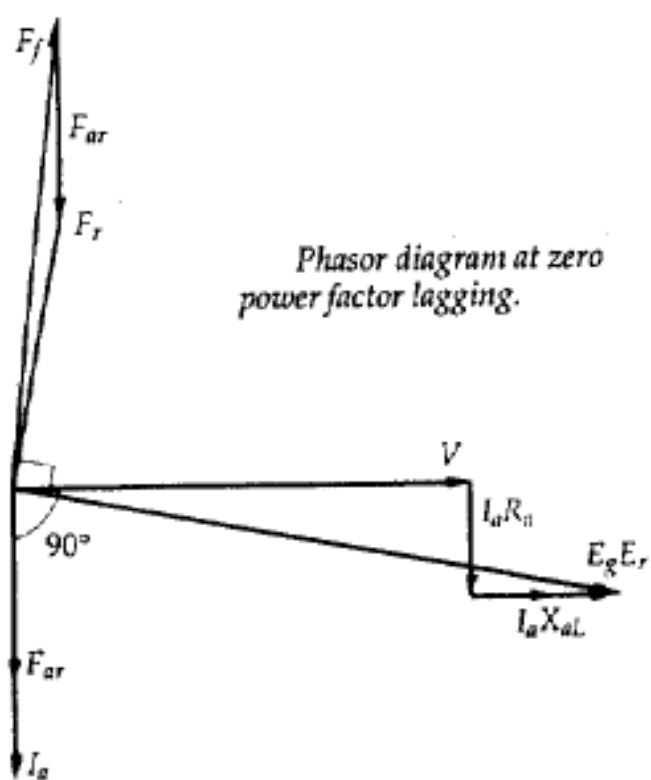
Compared to the EMF method, MMF method, involves more number of complex calculation steps. Further the OCC is referred twice and SCC is referred once while predetermining the voltage regulation for each load condition. Reference of OCC takes care of saturation effect. As this method requires more effort, the final result is very close to the actual value. Hence this method is called optimistic method.

ZERO-POWER FACTOR CHARACTERISTIC (ZPFC)

The zero-power factor characteristic (ZPFC) of an alternator is a curve of the armature terminal voltage per phase plotted against the field current obtained by operating the machine with constant rated armature current at synchronous speed and zero lagging power factor. The ZPFC is sometimes called Potier Characteristic after its originator.

For maintaining very low power factor, alternator is loaded by means of reactors or alternatively by an underexcited synchronous motor. The shape of ZPFC is very much like that of the O.C.C. displaced downwards and to the right.

The phasor diagram corresponding to zero-power factor lagging load



the terminal phase voltage V is taken as the reference phasor. At zero power factor lagging, the armature current I_a lags behind V by 90° . Draw $I_a R_a$ parallel to I_a and $I_a X_{aL}$ perpendicular to I_a .

$$V + I_a R_a + I_a X_{aL} = E_g$$

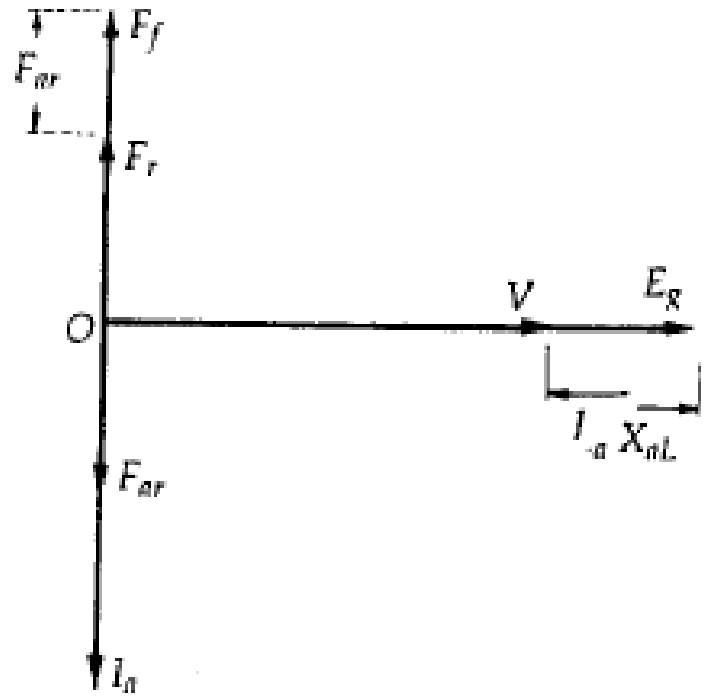
E_g is the generated voltage per phase.

F_{ar} = armature reaction mmf. It is in phase with I_a .

F_f = mmf of the mainfield winding (field mmf)

F_r = resultant mmf

The field mmf F_f is obtained by subtracting F_{ar} from F_r , so that $F_r = F_f + F_{ar}$.
 If the armature resistance R_a is neglected, the resulting phasor



Phasor diagram at ZPF lagging with R_a neglected

it is seen that the terminal phase voltage V , the reactance voltage drop $I_a X_{aL}$ and the generated voltage E_g are all in phase. Therefore V is practically equal to the numerical (arithmetical) difference between E_g and $I_a X_{aL}$.

$$V = E - I_a X_{aL} \quad (1)$$

Also the three mmf phasors F_f , F_r and F_{ar} are in phase. Their magnitudes are related by the equation

$$E_f = F_r + F_{ar} \quad (2)$$

The arithmetical relations given in Eqs. (1) and (2) form the basis for the Potier triangle.

Equation (2) can be converted into its equivalent field-current form by dividing its both sides by T_f , the effective number of turns per pole on the rotor field.

$$\therefore \frac{E_f}{T_f} = \frac{F_r}{T_f} + \frac{F_{ar}}{T_f}$$

or

$$I_f = I_r + I_{ar} \quad (3)$$

Potier triangle

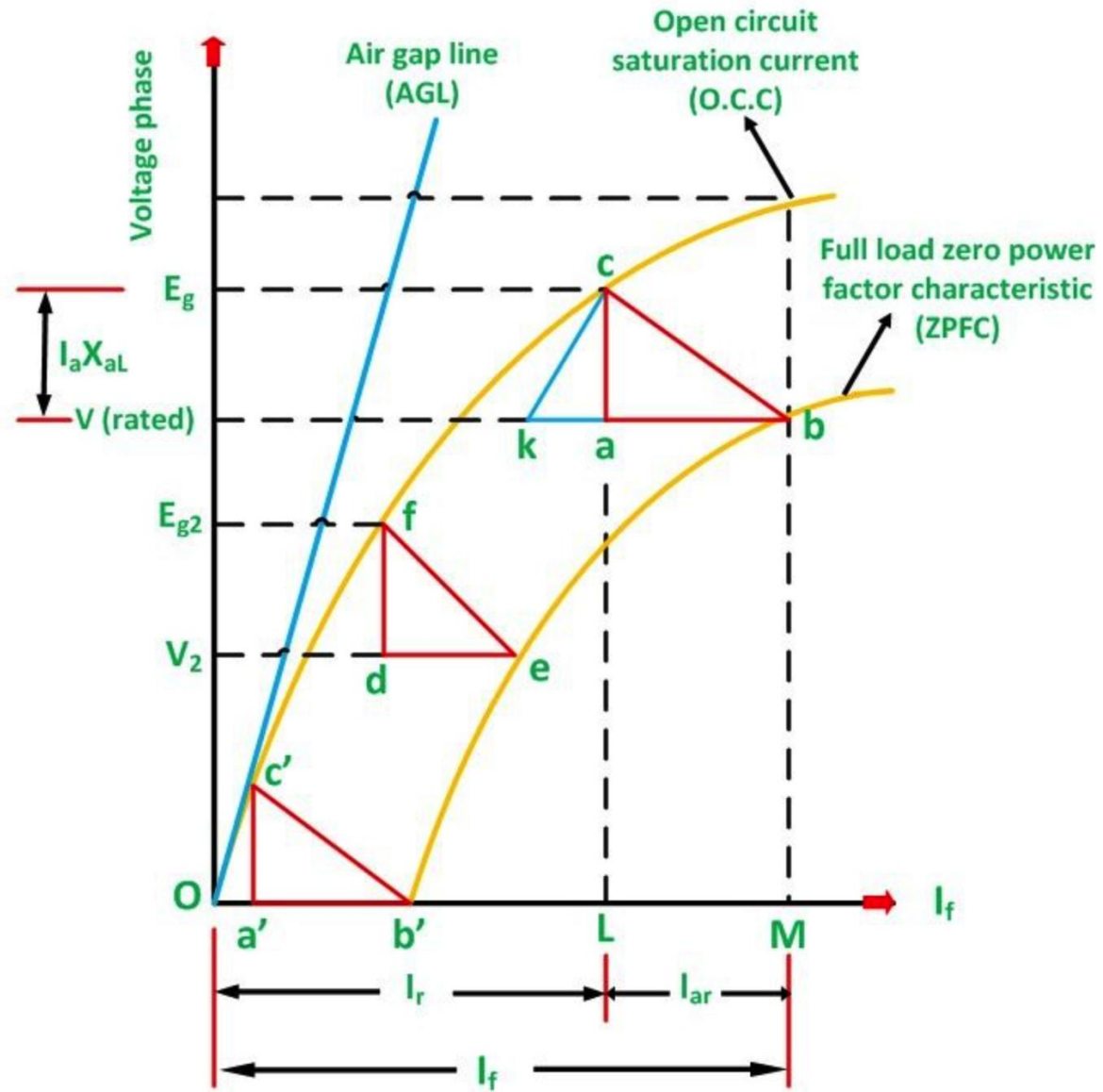
The **Potier triangle** determines the voltage regulation of the machines. This method depends on the separation of the leakage reactance of armature and their effects. The graph of the Potier triangle is shown in the figure below. The triangle formed by the vertices a, b, c has shown below in the figure is called **Potier Triangle**.

Consider a point B on the Zero Power Factor Curve corresponding to rated terminal voltage V and a field current of $OM = I_f = F_f/T_f$. If, for this condition of operation the armature reaction MMF has a value expressed in equivalent field current will be given as

$$LM \left[= I_{ar} = \frac{F_{ar}}{T_f} \right]$$

Then the equivalent field current of the resultant MMF would be represented as shown below.

$$OL \left[= I_r = \frac{F_r}{T_f} \right]$$



This field current OL would result in a generated voltage $E_g = L_c$ from the no-load saturation curve. Since for lagging Zero Power Factor operation, the generated voltage will be

$$E_g = V + I_a X_{aL}$$

The vertical distance ac must be equal to the leakage reactance voltage DROP $I_a X_{aL}$ where I_a is the rated armature current.

Therefore,

$$X_{aL} = \frac{\text{Voltage ac per phase}}{\text{Rated armature current}}$$

For **Zero Power Factor** operation with rated current at any other terminal voltage, such as V_2 . As the armature current is of the same value, both the I_a and X_{aL} voltage and the armature MMF must be of the same value. Therefore, for all the conditions of operation with rated armature current at zero lagging power factor, the Potier Triangle must be located between the terminal voltage V , a point on the ZPFC and the corresponding E_g point on the O.C.C.

If the Potier triangle cab is moved downward so that the side ab is kept horizontal and b is kept on the ZPFC, the point c will move on the O.C.C. When the point b , reaches the point e , the Potier triangle cab will move on the position fde shown in the figure. The location of point f on the O.C.C will determine the voltage E_{g2} . When the point b , reaches the point b' , the Potier Triangle will be in the position $c'a'b'$. This is the limiting position which corresponds to short the circuit condition because the terminal voltage is zero at the point b' .

The initial part of the O.C.C is almost linear, another triangle $Oc'b'$ is formed by the O.C.C. The hypotenuse of the Potier triangle and the baseline. A similar triangle such as ckb , can construct from the Potier triangle in any other location by drawing a line kc parallel to Oc' .

Steps for Construction of Potier Triangle on ZPFC

- Take a point b on the ZPFC preferably well upon the knee of the curve.
- Draw bk equal to b'O. (b' is the point for zero voltage, full load current). Ob' is the short circuit excitation F_{sc} .
- Through k draw, kc parallel to Oc' to meet O.C.C in c.
- Drop the perpendicular ca on to bk.
- Then, to scale ca is the leakage reactance drop $I_a X_{aL}$ and ab is the armature reaction MMF F_{aR} or the field current I_{faR} equivalent to armature reaction MMF at rated current.

The effect of field leakage flux in combination with the armature leakage flux gives rise to an equivalent leakage reactance X_p , known as the Potier Reactance. It is greater than the armature leakage reactance.

For cylindrical rotor machines, the Potier reactance X_p is approximately equal to the leakage reactance X_{aL} . In salient pole machine, X_p may be as large as 3 times X_{aL} .

$$\text{Potier Reactance } X_p = \frac{\text{Voltage drop per phase which is equal to (ac)}}{(\text{ZPF rzted armature current per phase } I_a)}$$

Assumptions for Potier Triangle

The following assumptions are made in the Potier Triangle Method. They are as follows:-

- The armature resistance R_a is neglected.
- The O.C.C taken on no load accurately represents the relation between MMF and Voltage on load.
- The leakage reactance voltage $I_a X_{aL}$ is independent of excitation.
- The armature reaction MMF is constant.

It is not necessary to plot the entire ZPFC for determining X_{aL} and F_a , only two points b and b ` are sufficient. Point b corresponds to a field current which gives the rated terminal voltage while the ZPF load is adjusted to draw rated current. Point b ` corresponds to the short circuit condition ($V = 0$) on the machine. Thus, $O b `$ is the field current required to circulate the short circuit current equal to the rated current.