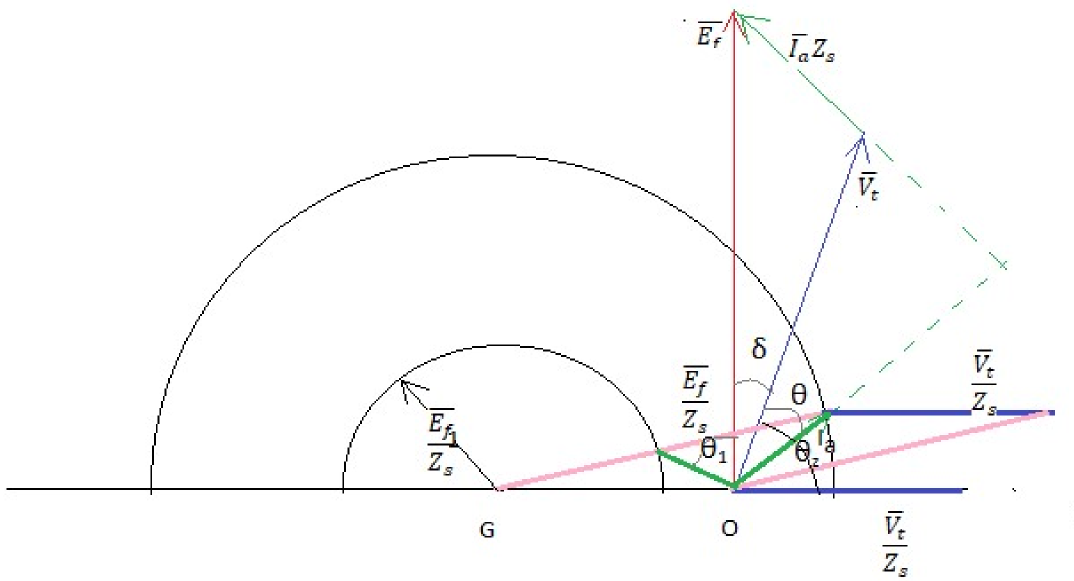
Circle Diagram of Turbo Alternator:

Excitation Circle:

$$\overline{E_f} = \overline{V_t} + \overline{I_a} Z_s$$

$$\overline{I_a} = \frac{\overline{E_f}}{Z_s} - \frac{\overline{V_t}}{Z_s}$$



(a) Excitation Circle Diagram of Turbo Generator

Power Circle:

$$P = V_t I_a \cos\theta + {I_a}^2 r_a$$

$${I_a}^2 + \frac{V_t}{r_a} I_a \cos\theta - \frac{P}{r_a} = 0$$

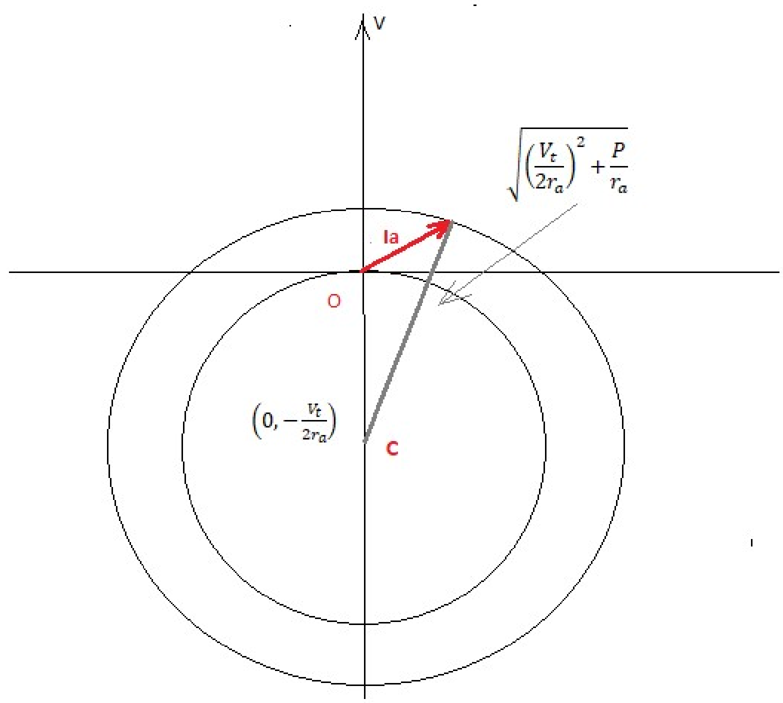
$${I_a}^2 \cos^2\theta + {I_a}^2 \sin^2\theta + \frac{V_t}{r_a} I_a \cos\theta - \frac{P}{r_a} = 0$$

Let x= $I_a \sin\theta$ and y= $I_a \cos\theta$; then

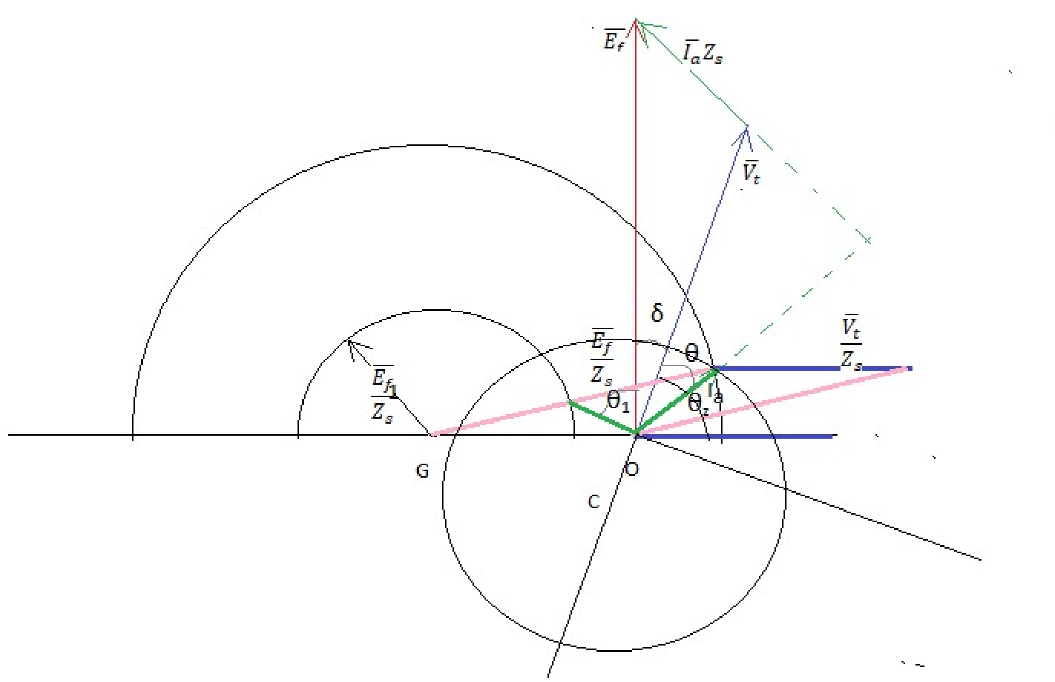
$$x^2 + y^2 + \frac{V_t}{r_a} y - \frac{P}{r_a} = 0$$

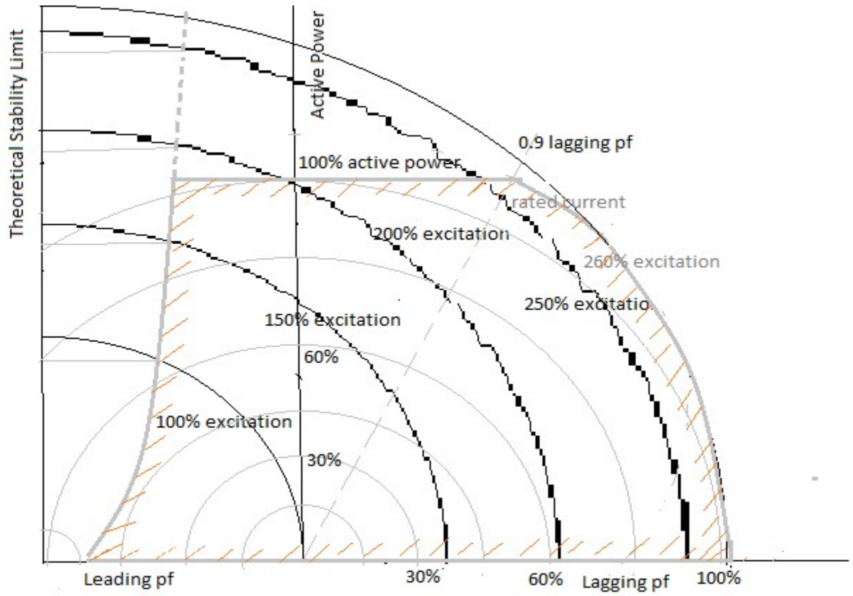
$$x^2 + y^2 + \frac{V_t}{r_a}y + \left(\frac{V_t}{2r_a}\right)^2 = \frac{P}{r_a} + \left(\frac{V_t}{2r_a}\right)^2$$

This is an equation of a circle with centre at $\left(0, -\frac{V_t}{2r_a}\right)$ and radius = $\sqrt{\left(\frac{V_t}{2r_a}\right)^2 + \frac{P}{r_a}}$



(b) Power Circle Diagram of Turbo Alternator





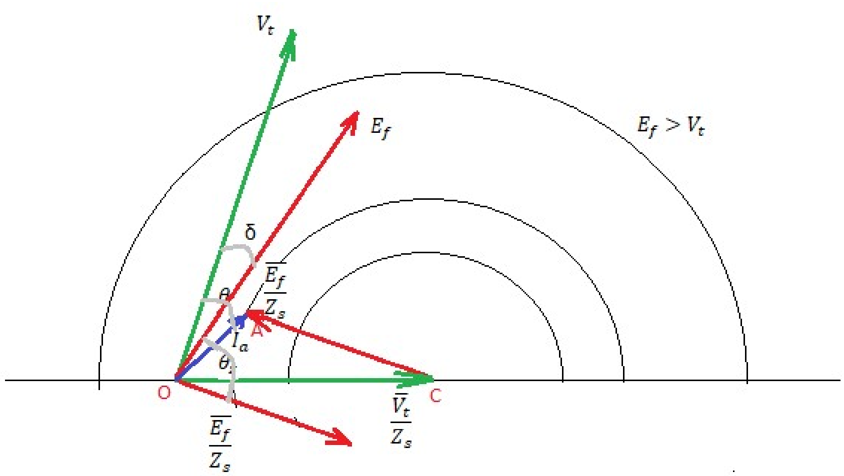
(c) Operating Chart of Turbo Alternator

Circle Diagram of Synchronous Motor:

Excitation Circle:

$$\overline{E_f} = \overline{V_t} - \overline{I_a} Z_s$$

$$\overline{I_a} = \frac{\overline{V_t}}{Z_s} - \frac{\overline{E_f}}{Z_s}$$



(d) Excitation Circle Diagram of Synchronous Motor

Power Circle

$$P = V_t I_a \cos\theta - {I_a}^2 r_a$$

$${I_a}^2 - \frac{V_t}{r_a} I_a \cos\theta + \frac{P}{r_a} = 0$$

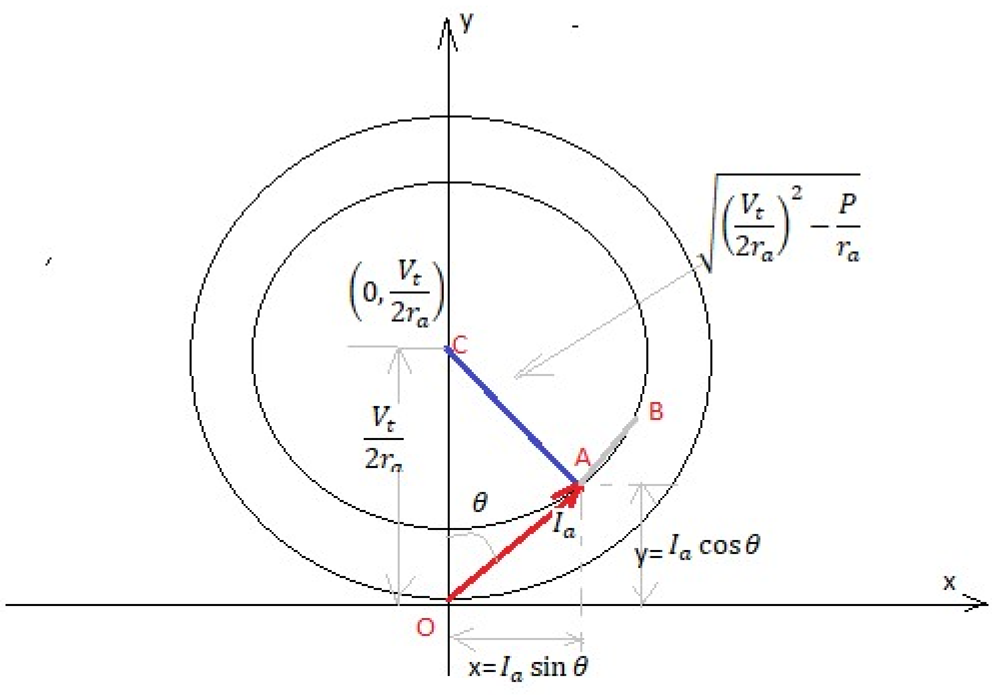
$${I_a}^2 \cos^2\theta + {I_a}^2 \sin^2\theta - \frac{V_t}{r_a} I_a \cos\theta + \frac{P}{r_a} = 0$$

Let x= $I_a \sin\theta$ and y= $I_a \cos\theta$; then

$$x^2 + y^2 - \frac{V_t}{r_a} y + \frac{P}{r_a} = 0$$

$$x^2 + y^2 - \frac{V_t}{r_a} y + \left(\frac{V_t}{2r_a}\right)^2 = -\frac{P}{r_a} + \left(\frac{V_t}{2r_a}\right)^2$$

This is an equation of a circle with centre at $\left(0, \frac{V_t}{2r_a}\right)$ and radius = $\sqrt{\left(\frac{V_t}{2r_a}\right)^2 - \frac{P}{r_a}}$



(e) Power Circle Diagram of Synchronous Motor

P=Shaft power+ Iron and mechanical losses

When P=0; the radius of the power circle is $=\frac{V_t}{2r_a}$; thus zero power circle passes through the point ‘O’. As the developed power increases the radius of the power circle decreases. For maximum power the radius is zero.

$$\sqrt{\left(\frac{V_t}{2r_a}\right)^2 - \frac{P_{max}}{r_a}} = 0$$

$$\left(\frac{V_t}{2r_a}\right)^2 = \frac{P_{max}}{r_a}$$

$$P_{max} = \frac{{V_t}^2}{4r_a}$$

For maximum power the power circle in the point ‘C’ itself. So, armature current = $\frac{V_t}{2r_a}$ and power factor is unity. So, maximum power input = $V_t I_a \cos\theta = V_t.\frac{V_t}{2r_a}.1 = \frac{{V_t}^2}{2r_a}$

$$\therefore \text{efficiency at maximum power output} = 50\%$$

V Curves:

Maximum theoretical excitation DD’ $=\frac{E_{\mathrm{f(max)}}}{Z_s}$, here excitation circle is tangential to zero power circle , so DD’= OC’

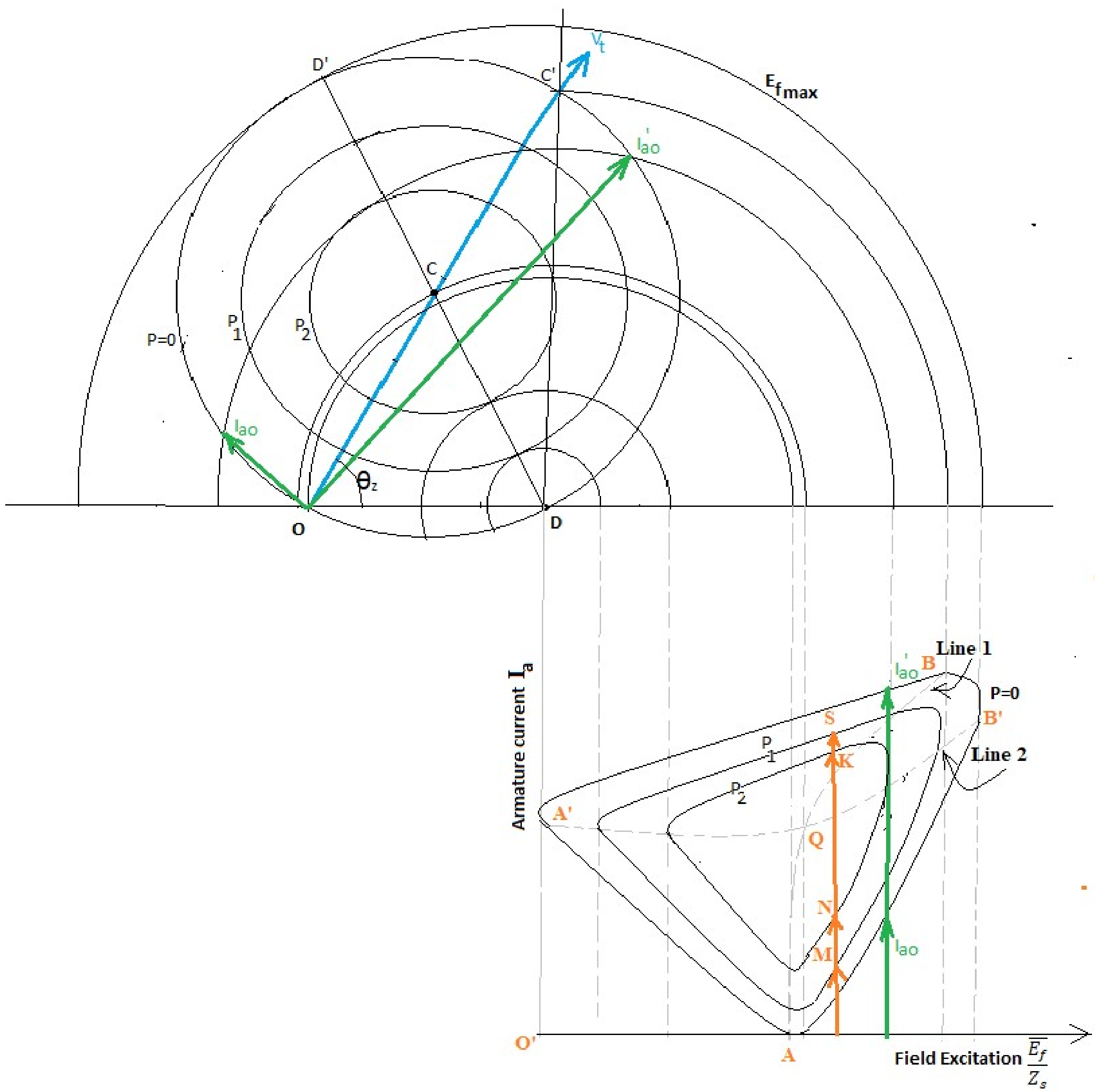
$$\therefore \frac{E_{\mathrm{f(max)}}}{Z_s} = \frac{V_t}{r_a}\ ;\ \ E_{\mathrm{f(max)}} = \frac{V_t}{r_a} Z_s$$

Minimum and maximum excitations for any power correspond to points on line DCD’.

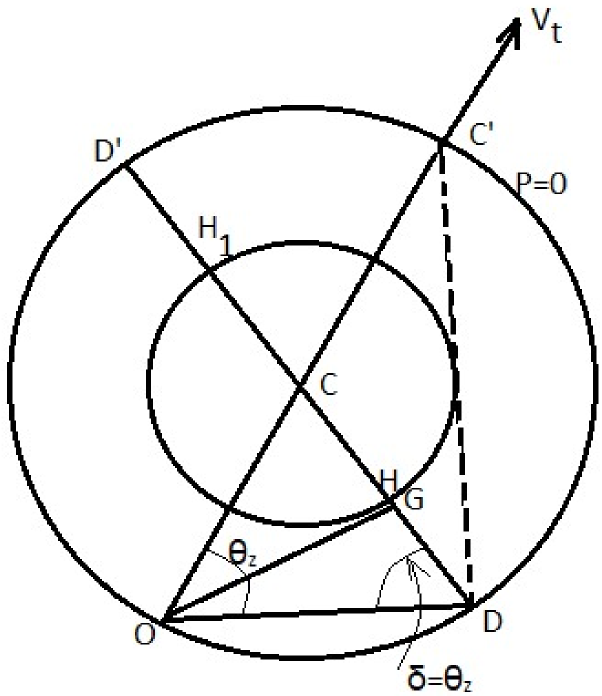
Minimum and maximum armature current for any power corresponds to points on line OCC’. The terminal voltage is along line OCC’. Therefore minimum and maximum currents occur at unity power factor.

The line A’QB’ i.e., ‘line 2’ connects all minimum and maximum excitation for any power.

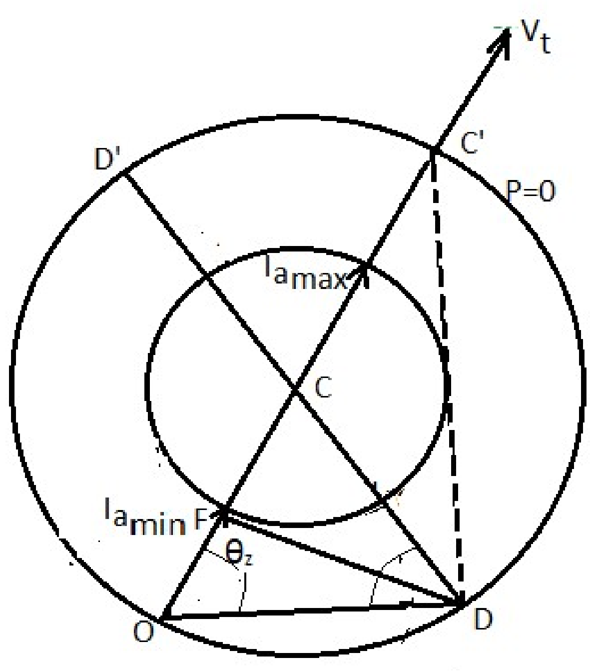
For P=0; the current I_a =OD (= O'A in the O-curve) for zero excitation . As excitation is increased I_a decreases and becomes minimum (=zero) when the excitation circle passes through point O. Then I_a starts increasing. For every value of excitation there are two values of Ia; the upper point is unstable.



(f) Construction of O-curves



(g) Condition for maximum and minimum excitation



(h) Condition for maximum and Minimum Armature Currents

In fig. (g) the current OG is tangent to the power circuit for which the CG and the power factor will be minimum for that power. This will corresponds to the minimum excitation.

In fig. (h) DF is drawn normal to OC . When the excitation $\frac{E_f}{Z_s}$ is equal to DO [=O'A in fig(f)] then I_a = 0 [point A in fig.(f)]and when excitation is less than DO current will be more. Current will be more also if excitation $\frac{E_f}{Z_s}$ is greater than DO.