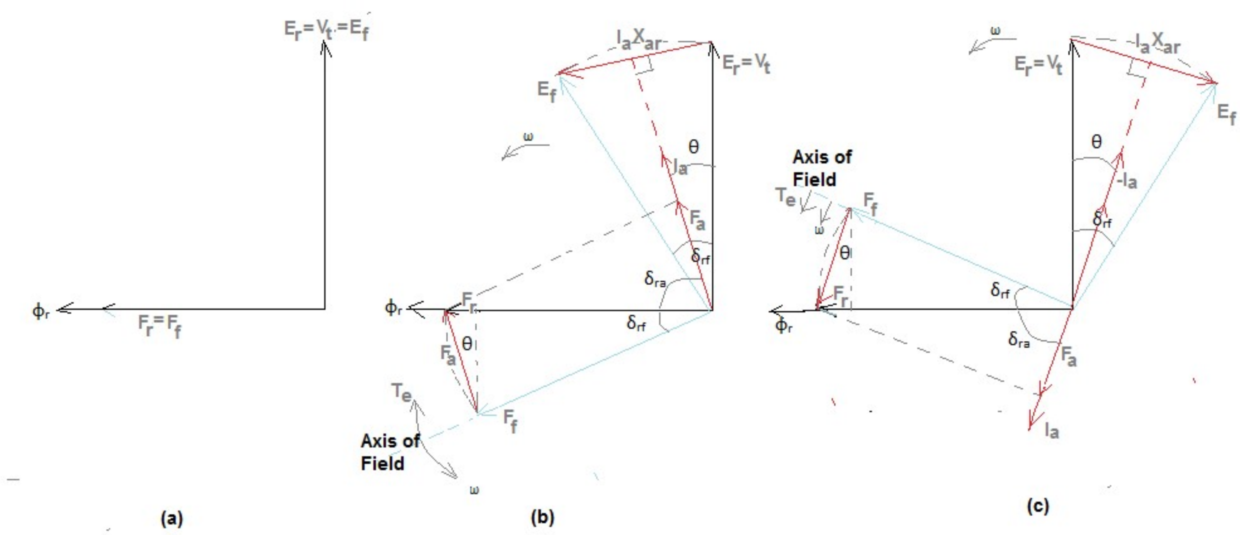
## Physical Concepts of Synchronous Machine Operation

In a well designed synchronous machine $r_a$ and $x_{al}$ are quite small. Neglecting the voltage drop due to , $E_r = V_t$. If the machine is connected to the bus bar then $E_r$ is constant and equal to constant bus bar voltage . Under this condition the air gap flux is given by

$$\emptyset_r = \frac{V_t}{\sqrt{2}\pi f k_w N_{ph}}$$

In the above equation all quantities on the right hand side are constant. So air gap flux is constant.




At no load $I_a = 0$, $F_a$=0 and $\delta_{rf}$ between $F_f$ and $F_r$ is zero- as shown in fig (a). For $F_a$=0 the machine is neither generating or motoring. If the field current is kept constant $F_f$ and $E_f$ remains constant .

If prime mover input is increased then the field will go ahead of resultant flux $\phi_r$ and resultant mmf $F_r$. As field has moved ahead, $F_f$ also moves ahead of $F_r$ by an angle $\delta_{rf}$ and $E_f$ also moves ahead of $E_r$ by an angle $\delta_{rf}$ The machine acts as a generator. Appearance of $\delta_{rf}$ between $F_f$ and $F_r$ gives rise to development of electromagnetic torque

$$T_e = \frac{\pi}{8} P^2 F_f \emptyset_r \sin \delta_{rf}$$

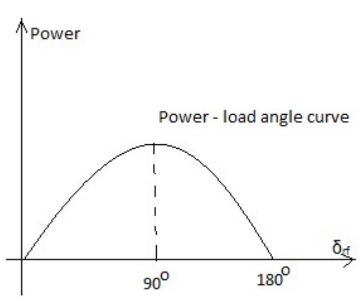
At steady state condition the generated torque equals the prime mover torque. As seen from fig. (b) since the equation $\overline{F_r} = \overline{F_f} + \overline{F_a}$ holds good and $F_a$ comes into existence. To develop $F_a$ armature current Ia must flow in phase with $F_a$ as shown in the figure (b). $I_a$ has a component in phase with $V_t$ , so the machine is acting as a generator, delivering power to the bus bar. The electrical power output is $mV_tI_a\cos\theta$. If losses are ignored. Electrical power output is equal to mechanical power input $T_e\omega_s$.

If external load is gradually put on the machine shaft, the field poles slips back with respect to air gap flux $\phi_r$ . When field poles are lagging $F_r$ the machine acts as a motor. As field has moved backward, $F_f$ also moves back of $F_r$ by an angle $\delta_{rf}$ and $E_f$ also moves back of $E_r$ by an angle $\delta_{rf}$ The machine acts as a motor. Since the equation $\overline{F_r} = \overline{F_f} + \overline{F_a}$ holds good and $F_a$ comes into existence. To develop $F_a$ armature current $I_a$ must flow in phase with $F_a$ as shown in the figure ( c). $I_a$ has a component in phase opposition with $V_t$ , so the machine is acting as a motor, taking power from the bus bar. The electrical power input is $mV_tI_a\cos\theta$. If losses are ignored. Electrical power input is equal to mechanical power output $T_e\omega_s$.

Now from fig. (b) and ( c)

$F_f \sin \delta_{rf} = F_a \cos\theta = CI_a \cos\theta$ ; $\quad \therefore V_t I_a \cos\theta = \frac{V_t F_f}{C} \sin \delta_{rf}$ ; ----(1)

C and $V_t$ are constant , so for constant $F_f$ power varies with $\delta_{rf}$ as shown in fig. (d).




(d)

It is also seen from fig. (b) and (c)

$$F_f \cos\delta_{rf} + F_a \sin\theta = F_r$$

$$F_f \cos\delta_{rf} + CI_a \sin\theta = F_r$$

$$\frac{V_t F_f}{C}\cos\delta_{rf} + V_t I_a \sin\theta = \frac{V_t F_r}{C} \qquad \text{-----(2)}$$

If the machine is connected to the infinite bus bar then $V_t$ is constant , so, $F_r$ is constant. If we increase the field current, then $F_f$ will increase. If the power input is constant, then from eq.(1), the angle $\delta_{rf}$ should decrease, so that $F_f \sin\delta_{rf}$ is constant. Again from eq. (2) as $\delta_{rf}$ decreases, $\cos\delta_{rf}$ increases. So, $F_f \cos\delta_{rf}$ increases. So, $V_t I_a \sin\theta$ should decrease, as the right hand side is a constant. $V_t$ can not change, so $I_a \sin\theta$ decreases. So, reactive power flow decreases. So, for an alternator if we increase field current reactive power decreases.

In fig.(b) the initial power factor is leading , and the generator was delivering reactive power to the bus. So as we increase the excitation, the reactive power delivered by the generator starts decreasing and the power factor first becomes unity then lagging ( i.e. the generator now takes reactive power from the bus) . So, an over excited generator runs at lagging power factor.

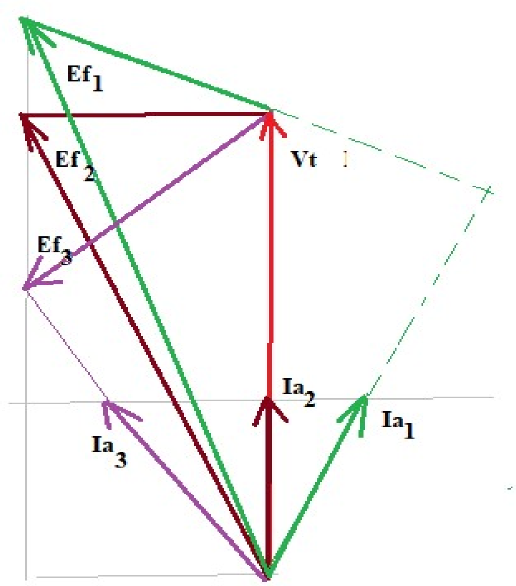



Fig. (e) Phasor diagram of an Alternator

From fig. (e) it is seen that magnitude of armature current is minimum for unity power factor and the magnitude increases as the power factor changes. So, if we plot armature current ($I_a$) vs. Field current ($I_f$) curve it looks like a V. The V-curve for a synchronous generator is shown in Fig. (f)

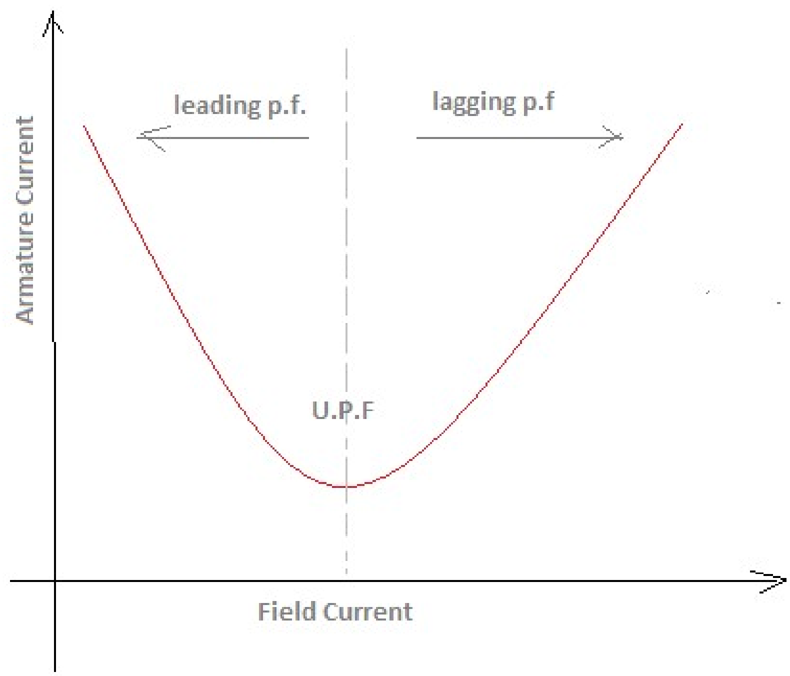



Fig. (f) V-curve for a Synchronous Generator

In fig.(c) the initial power factor is lagging , and the synchronous motor was taking reactive power from the bus. So as we increase the excitation, the reactive power drawn by the motor starts decreasing and the power factor first becomes unity then leading ( i.e. the motor now delivers reactive power to the bus) . So, an over excited motor runs at leading power factor.

From fig. (g) it is seen that magnitude of armature current is minimum for unity power factor and the magnitude increases as the power factor changes. So, if we plot armature current ($I_a$) vs. Field current ($I_f$) curve it looks like a V. The V-curve for a synchronous motor is shown in Fig. (h)

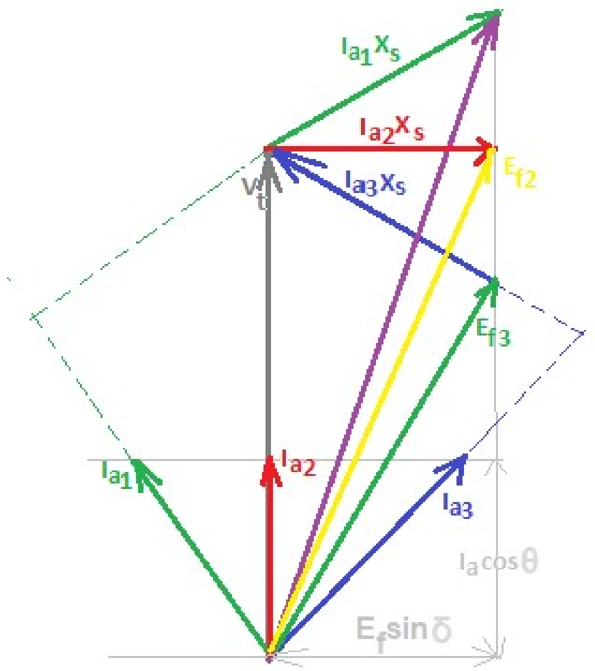



Fig. (g) Phasor diagram of an Synchronous Motor

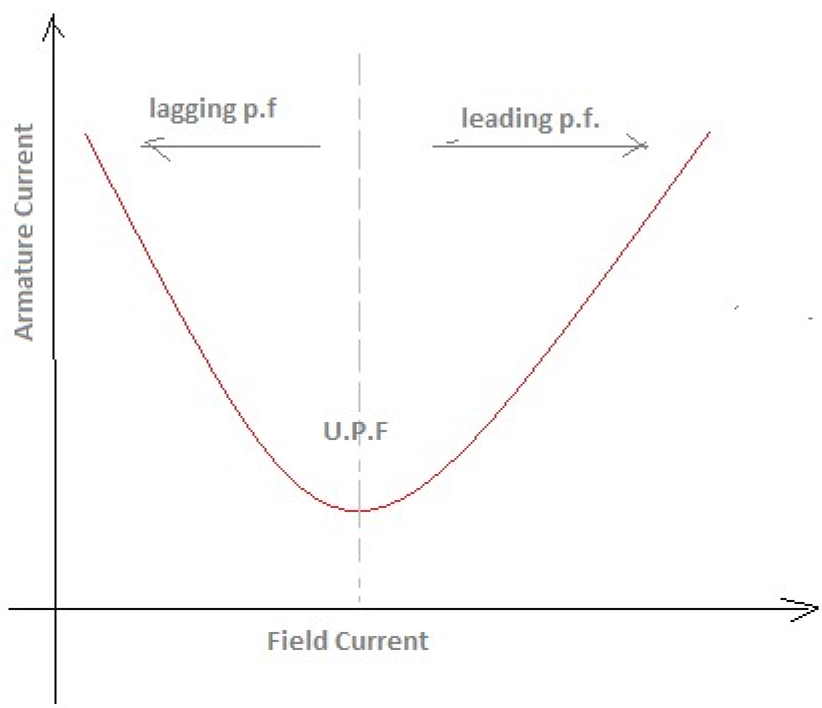



Fig. (h) V-curve for a Synchronous Motor