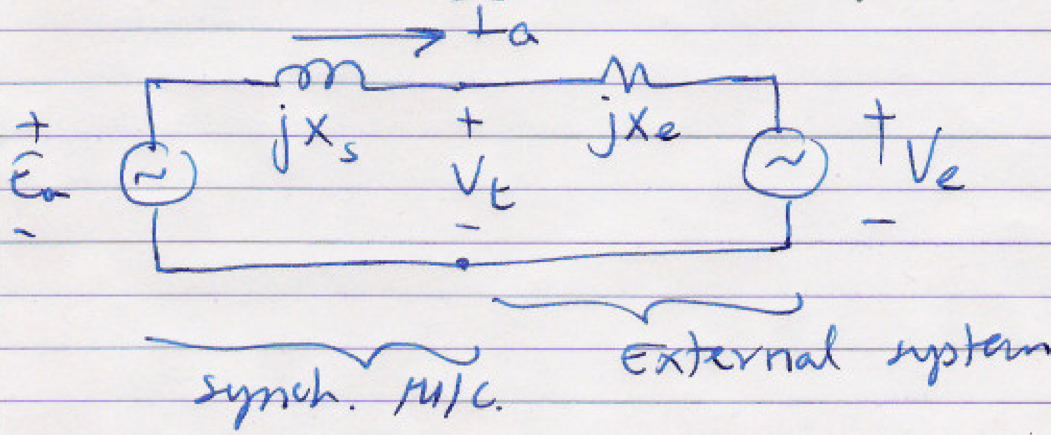
power_Angle characteristic of a synchronous M/C:-

The maximum power that a synch M/C can deliver is determined by the maximum torque that can be applied without losing synchronism.

The expression of the power supplied will be expressed in terms of ~~coil~~ the machine parameters and the the system that is connected to it (infinite bus).

I) Round-Rotor Machine:

consider the following per-phase equivalent circuit connected to an infinite bus.



Neglecting R_a

take V_t as a reference phasor.

$$\vec{V}_t = V_t \angle 0^\circ \quad , \quad \bar{E}_a = E_a \angle \delta .$$

δ _ power_angle or torque angle.

$$\therefore \quad I_a = \frac{\vec{E}_a - \vec{V}_t}{jX_s}$$

& the complex power

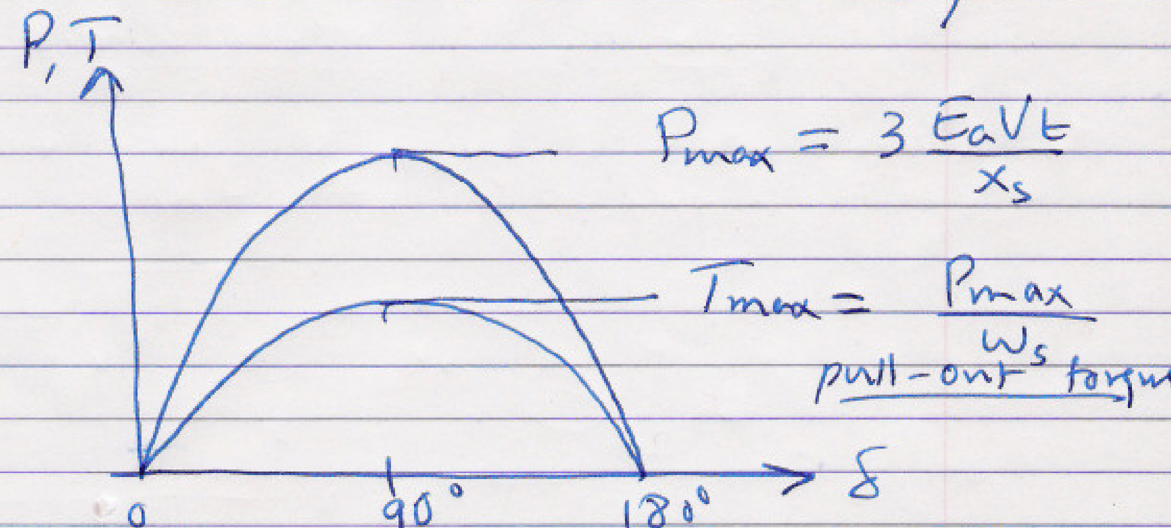
$$\vec{S} = P + jQ = 3 \vec{V}_t \vec{I}_a^{*}$$

$$P + jQ = 3V_t\angle 0^\circ \left(\frac{E_a\angle -\delta - V_t\angle 0^\circ}{-jX_s} \right)$$

$$= 3\left(\frac{E_a V_t}{X_s}\angle -\delta + 90^\circ - j\frac{V_t^2}{X_s} \right)$$

$$\therefore \quad P = 3\frac{E_a V_t}{X_s}\sin\delta$$

$$Q = 3\left(\frac{E_a V_t}{X_s}\cos\delta - \frac{V_t^2}{X_s} \right)$$



power-angle curve & torque-angle curve

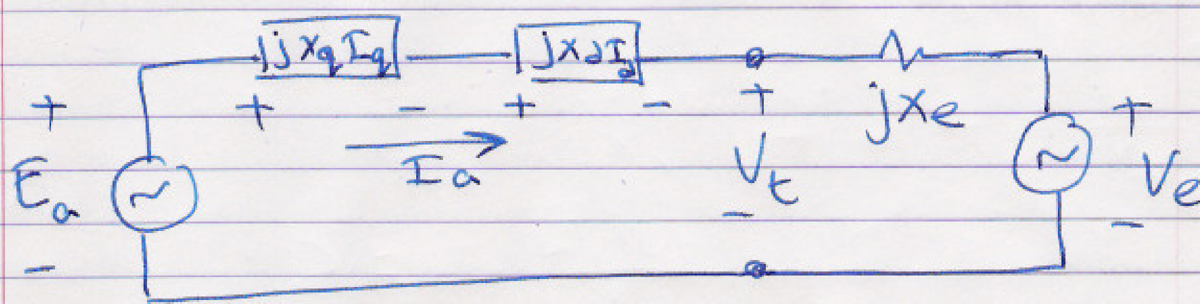
ω_s – synch frequency in rad/s

$$\omega_s = \frac{n_s}{60} \cdot 2\pi \quad (n_s = \text{synch. speed in rpm})$$

<u>observations:</u>

- The max power & torque occurs when $\delta = 90^\circ$.
- if $\delta > 90^\circ$, the generator steps out of synchronism.

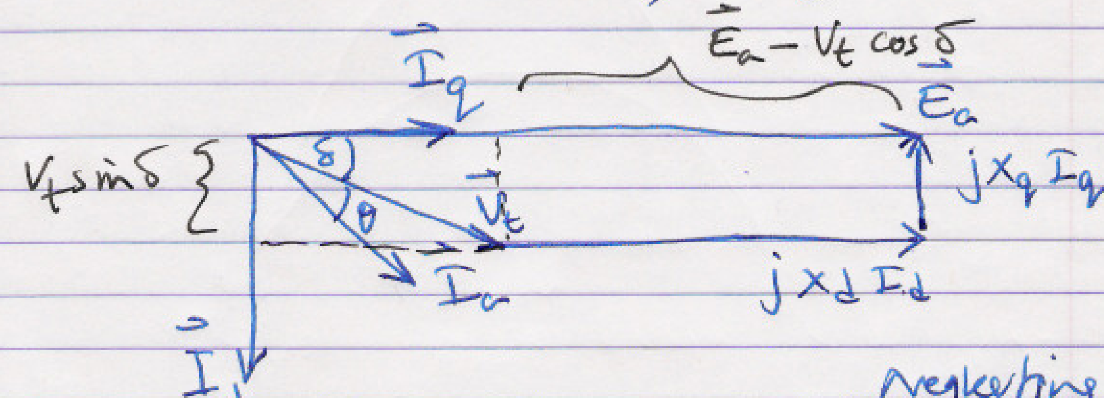
Salient-pole Machine:



Equivalent circuit of salient-pole generator connected to external system.

Take the generated voltage as a reference,

$$\vec{E}_a = E_a \angle 0^\circ, \quad \vec{V}_t = V_t \angle -\delta.$$



Neglecting R_a

Using the above phasor diagram.

$$I_q = \frac{V_t \sin\delta}{x_q}, \quad I_d = \frac{E_a - V_t\cos\delta}{x_d}$$

$$\vec{S} = P + jQ = 3\vec{V}_t\vec{I}_a^{\,*}$$

$$= 3V_t \angle -\delta \,(I_q - jI_d)^*$$

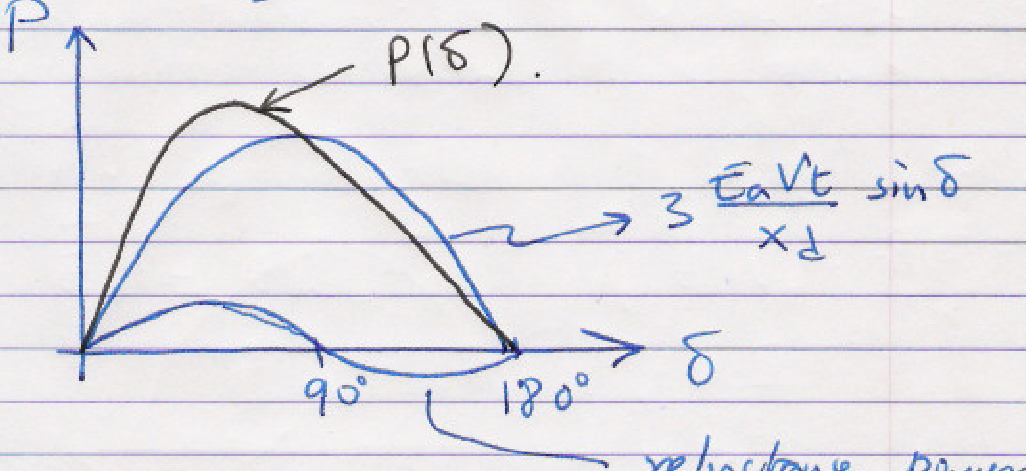
remember, the current I_a is refered to $\vec{E}_a$ in the above phasor diagram

$\therefore \; P + jQ = 3V_t \angle{-\delta} \left(I_q \angle 0^\circ + I_d \angle{-90^\circ} \right)$

substitute for I_q & I_d and simplify,

$$\therefore \quad P = 3\left[\frac{E_a V_t}{X_d}\sin\delta + \frac{V_t^2}{2}\left[\frac{1}{X_q} - \frac{1}{X_d}\right]\sin 2\delta\right]$$

$$Q = 3\left[\frac{E_a V_t}{X_d}\cos\delta - V_t^2\left(\frac{\sin^2\delta}{X_q} + \frac{\cos^2\delta}{X_d}\right)\right].$$



power-angle curve of a salient-pole synch generator.

Observations:

- The first term of P is identical to the power delivered by a round-type synch. M/C.
- The second term represents the effect of generator saliency, and it is called the reluctance power.
- In salient-pole m/c, $X_d > X_q$. When the salient m/c approaches a round rotor, the values of X_d & X_q will both approach X_s ⇒ P & Q for salient m/c reduced to P & Q eqns of round type.