Salient Pole Synchronous Machines

— In cylindrical rotor synchronous machine

↳ Air-gap is uniform

⇓

So, reluctance is almost constant

↳ (and it doesn't depend on the orientation of the field poles with respect to the armature mmf.)

⇓

So, the effect of armature reaction and leakage reactance, can be accounted by one reactance only.

⇓

i.e. Synchronous Reactance, X_s.

→ In salient-pole rotor & synchronous machine.

↳ Air-gap is Not-uniform.

⇓

Reluctance along direct-axis is small, compared to reluctance along quadrature-axis.

(∵ Along d-axis, air-gap is small and along q-axis, air-gap is large)

⇓

So, armature reaction mmf cannot be accounted using one equivalent reactance.

Polar axis =	Direct axis =	d-axis
Inter-polar axis =	Quadrature axis =	q-axis

→ Two-Reaction Theory.

- In salient-pole machines, the problem associated with variable reluctance due to variable air-gap can be resolved using two-reaction theory.

- So, two-reaction theory helps us in understanding the operation of salient-pole machines.

- According to two-reaction theory, the armature reaction mmf F_{ar} can be resolved into two components. → F_{ar_d} along d-axis and
  → F_{ar_q} along q-axis.

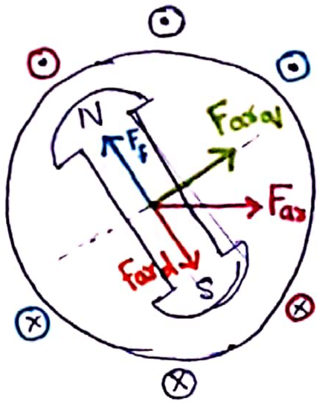
- The armature current can also be resolved into two components → I_d along d-axis and I_q along q-axis.

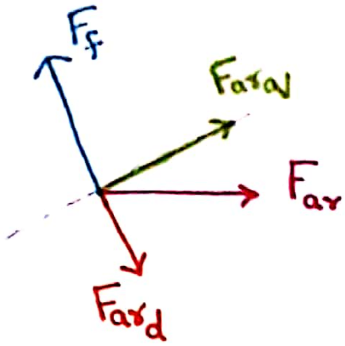
- So, according to two-reaction theory, two values of synchronous reactance are taken while analysing the operation of salient-pole synchronous machines.

  X_q → q-axis synchronous reactance

  X_d → d-axis synchronous reactance.

- Excitation emf E_f lags F_f by 90°. So, F_f lies ~~in~~ along d-axis and E_f lies along q-axis.





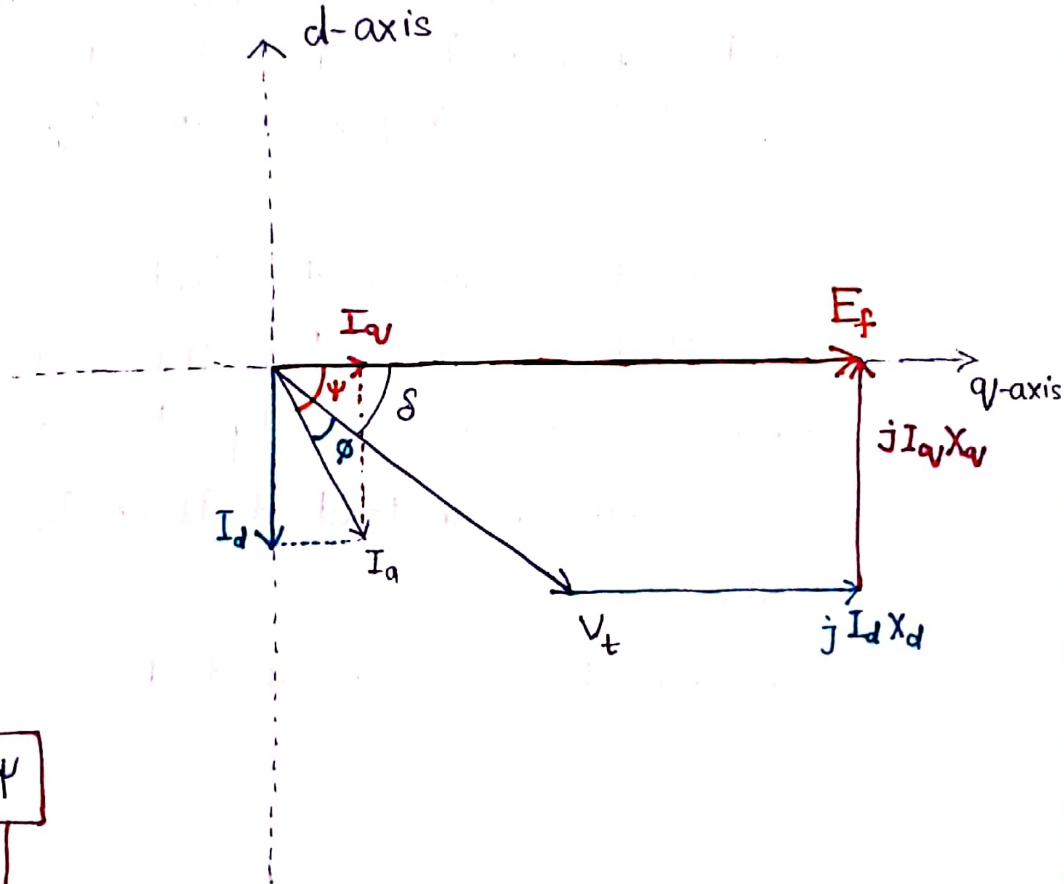
Phasor diagram for (two-reaction theory) Salient pole machine.

Assumptions

(i) $R_a \simeq 0$

(ii) Generator is over-excited.

(iii) E_f is drawn horizontally, for easier understanding.



let,

$\rightarrow \psi = \phi + \delta$

$\because$ $\boxed{I_q = I_a \cos\psi}$

$\boxed{I_d = I_a \sin\psi}$

Scanned with CamScanner

Expression for excitation emf in salient-pole machine (using phasor diagram).

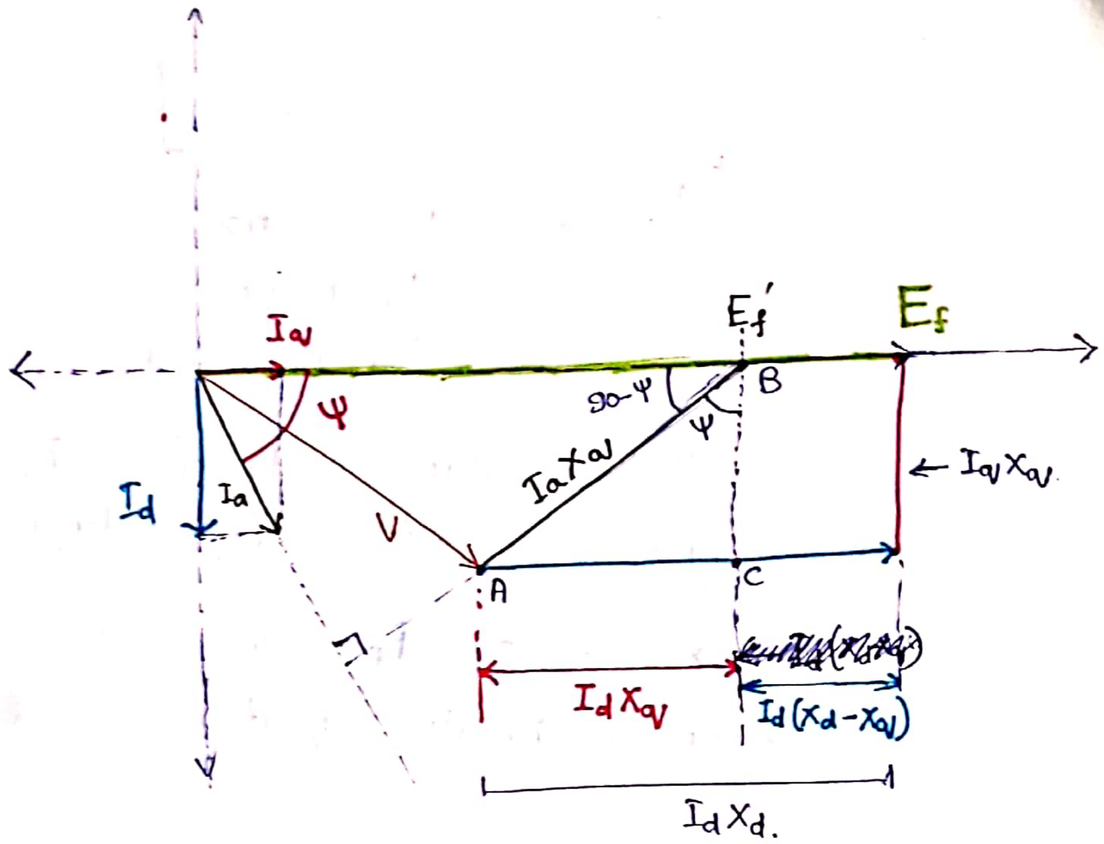
- From Phasor diagram, it appears that E_f can be found ~~from phasor diagram~~, using

$$\vec{E_f} = \vec{V_t} + j\vec{I_d}X_d + j\vec{I_q}X_q$$

But this expression cannot be used untill we find I_d and I_q, and for it we need to find δ. ($\because I_d = I_a \sin(\phi+\delta)$ and $I_q = I_a \cos(\phi+\delta)$).

→ So, first we need to find δ, and then the magnitude of E_f. For this we modify the phasor diagram slightly. We find a voltage E', using I_a, instead of I_d or I_q and this gives value of δ.

→ From E' we can find E_f.



In $\triangle ABC$.

$\angle ABC = \psi$

$BC = I_q X_q$

$\Rightarrow$ we have to find length of AB in terms of I_a.

$$\cos\psi = \frac{BC}{AB} = \frac{I_q X_q}{AB}$$

$$\Rightarrow AB = \frac{I_q \cdot X_q}{\cos\psi} \quad \text{—(i)}.$$

and we know,

$I_q = I_a \cos\psi$

$$\Rightarrow \frac{I_q}{\cos\psi} = I_a \quad \text{—(ii)}$$

Putting (ii) in (i),

$$\boxed{AB = I_a X_q}$$

Similarly,

~~AC = Id Xd~~

$$\boxed{AC = I_d X_q}$$

Now,

$$\boxed{\vec{E}_f' = \vec{V}_t + j\,\vec{I}_a X_q}$$

↳ Here, V_t is known.
I_a is known.
X_q is known.

So, we can easily find E_f', which will give information regarding δ.

After finding E_f'; we can find E_f, using even arithmatic equation as E_f' and E_f are in phase.

$$\rightarrow \boxed{|\vec{E}_f| = |\vec{E}_f'| + |\vec{I}_d (X_d - X_q)|}$$

or

we can use δ, to find magnitude of E_f.

$$\boxed{E_f = V_t \cos\delta + I_d X_d}$$

Power Output in Salient pole machine.

$$P_{out} = V \cdot I_a \cos\phi.$$

Per phase

Now, $\phi = \psi - \delta$

$$\Rightarrow P_{out} = V \cdot I_a \cos(\psi - \delta)$$

$$= V \cdot I_a \left\{ \cos\psi \cdot \cos\delta + \sin\psi \cdot \sin\delta \right\}$$

$$\Rightarrow P_{out} = V I_a \cos\psi \cdot \cos\delta + V \cdot I_a \sin\psi \cdot \sin\delta$$

We know, $I_a \cos\psi = I_q$ and

$I_a \sin\psi = I_d$.

Imp

$$\Rightarrow \boxed{P_{out} = V \cdot \cos\delta \cdot I_q + V \sin\delta \cdot I_d.}$$

$\hookrightarrow$ ∵ we can see active power output is sum of all the → product of in-phase component of current and voltage.

→ Multiplying Numerator and Denominator by X_q in 1st term and X_d in second term, we get.

$$P_{out} = \frac{V \cdot \cos\delta}{X_q} \cdot I_q X_q + \frac{V \cdot \sin\delta}{X_d} \cdot I_d \cdot X_d$$

we know,

$I_q \cdot X_q = V \sin\delta$ and $I_d X_d = E_f - V\cos\delta$

$\because$

$$P_{out} = \frac{V.\cos\delta}{X_q} \cdot V\sin\delta + \frac{V.\sin\delta}{X_d}\left\{E_f - V\cos\delta\right\}$$

$$= \frac{V^2}{X_q}\sin\delta.\cos\delta + \frac{V.E_f}{X_d}.\sin\delta - \frac{V^2}{X_d}\sin\delta\cos\delta$$

$$\Rightarrow P_{out} = \frac{V.E_f}{X_d}\sin\delta + \frac{V^2}{2X_q}\sin 2\delta - \frac{V^2}{2X_d}\sin 2\delta$$

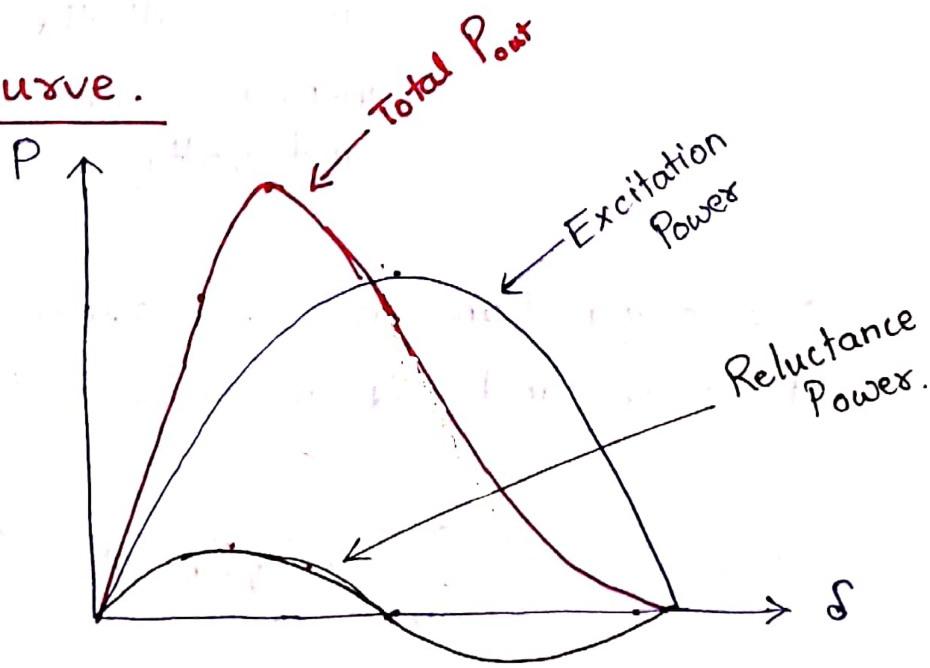
$$\boxed{P_{out} = \underbrace{\frac{V.E_f}{X_d}\sin\delta}_{\text{Excitation power or Electro-magnetic power}} + \underbrace{\frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta}_{\text{Reluctance power or Power due to saliency.}}}$$

P_{out} → Per phase power output from Salient pole alternator.

Excitation power or Electro-magnetic power

Reluctance power or Power due to saliency.

Power-angle curve.



at P_{max}, δ lies between 45° and 90°