Chapter 6 Synchronous Motors

→ Not as common as induction motors (more complicated)

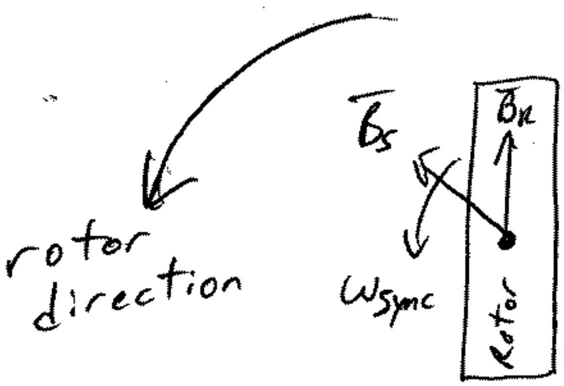
→ has some advantages for low speed / high power applications

6.1 Basic Principles of Motor Operation

I_f produces steady $\bar{B}_R$ in rotor

3ϕ I_A produce a rotating $\bar{B}_S$ (rotates @ $\omega_{sync} = \frac{2\omega_e}{P}$)

Since $\bar{\tau}_{ind} = K\bar{B}_R \times \bar{B}_S$ $\bar{B}_{rotor}$ tries to "catch-up" to $\bar{B}_{stator}$

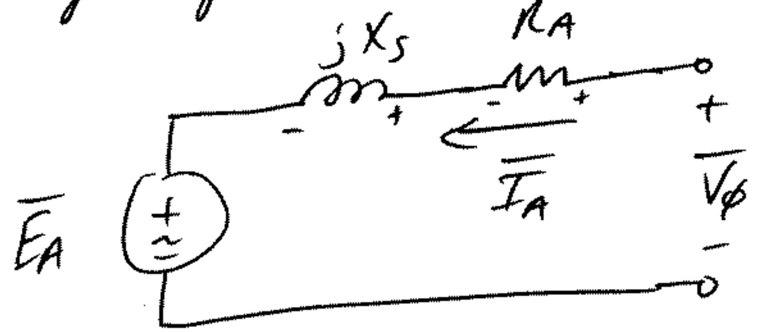


6.1 cont.

Equivalent Circuit Model

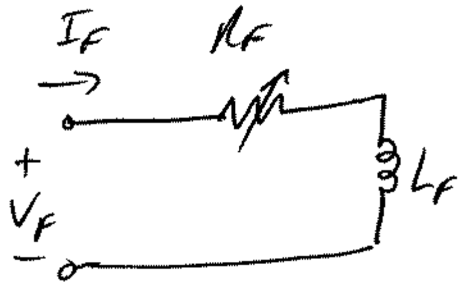
→ Same, except direction of $\bar{I}_A$ reversed so that it uses electrical power

per-phase



Armature

Field



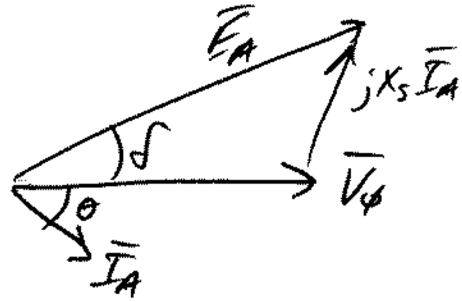
By KVL $\quad \bar{V}_\phi = \bar{I}_A (R_A + jX_S) + \bar{E}_A$

or

$$\bar{E}_A = \bar{V}_\phi - \bar{I}_A (R_A + jX_S)$$

6.1 cont.

Generator (lagging pf)

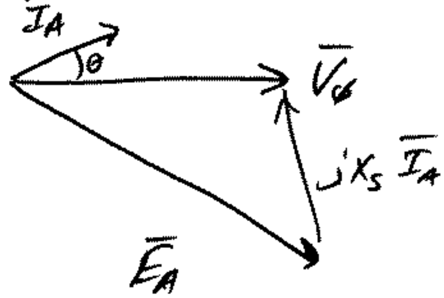


$\bar{V}_\phi$ lags $\bar{E}_A$

$\bar{\tau}_{ind}$ opposes $\bar{\tau}_{app}$ & ω_m

Motor

current direction reversed



$\bar{E}_A$ lags $\bar{V}_\phi$!

$\bar{\tau}_{ind}$ in direction of ω_m

6.2 Steady-state Synchronous Motor Operation

→ motor already turning @ $\omega_m = \omega_{sync}$

→ motor connected to "infinite bus" (not affected by motor)

↳ ω_m / f_e constant as well as terminal voltage (V_T & V_ϕ)

→ I_A can & will vary with load

→ E_A can be changed by changing I_f

$$\tau_{ind} = K B_R B_{net} \sin\delta = \frac{3 V_\phi E_A \sin\delta}{\omega_m X_s}$$

6.2 cont.

Maximum (AKA pull-out) torque occurs when $\delta = 90°$

$$T_{max} = K B_r B_{net} = \frac{3 V_\phi E_A}{\omega_m X_s}$$

can increase I_f to increase this + maximize T_{max}

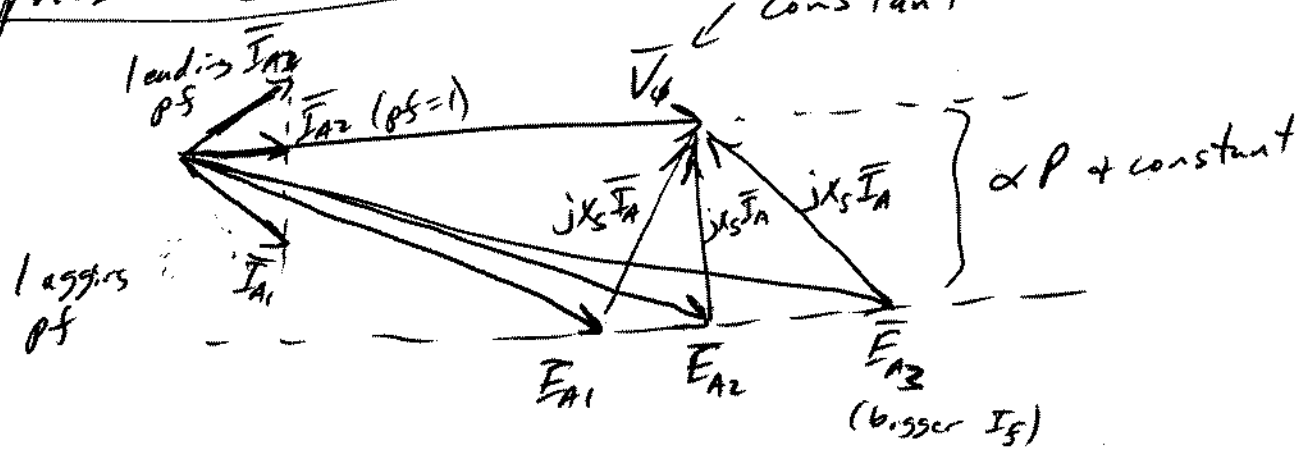
If load exceeding T_{max} applied → bad things happen (torque surges, ...)

Effect of Field Current Changes on Synchronous Motor

Increasing I_f increases $|\bar{E}_A| \propto K \omega_m \phi$ (I_f)

However, the load power is not affected by $|\bar{E}_A|$ since ω_m remains constant as does V_ϕ

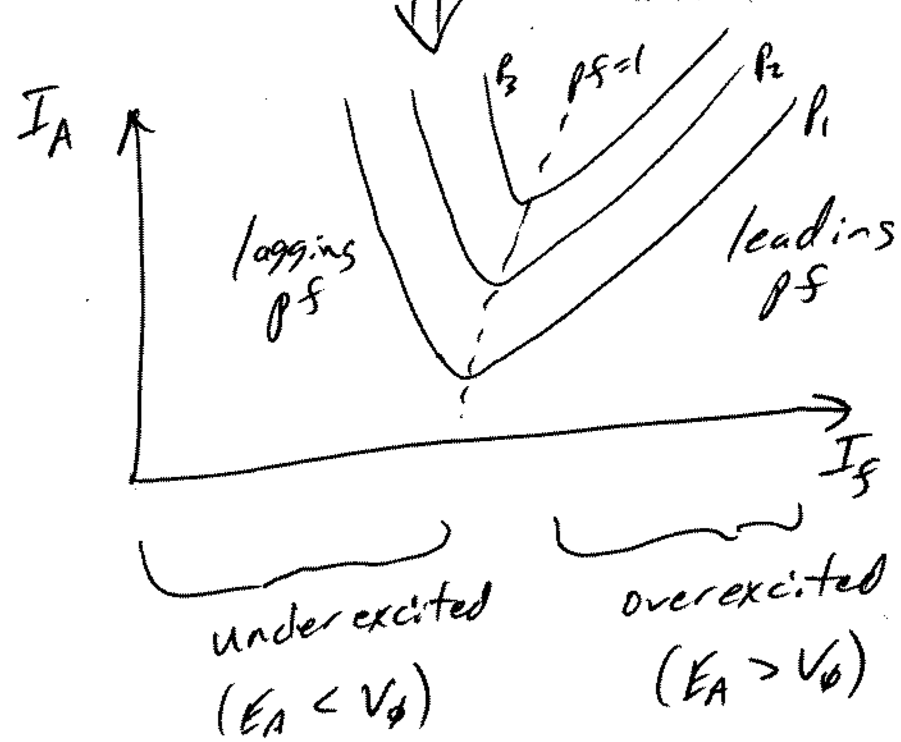
phasor diagram



6.2 cont.

⇒ By adjusting I_f for a given load, a synchronous motor's pf is adjustable!

synchronous motor V-curves



⇓

Various pf correction possibilities

→ save energy by minimizing Q_{TOT}

→ capacitor banks more efficient (no friction losses)

6.3 Starting Synchronous Motors

When we first flip the switch $\omega_m = 0$.

How do we get up to ω_{synch}?

W/out intervention a synchronous motor at rest would just vibrate (not rotate) when AC power is applied.

1) Reduce $\bar{B}_{stator}$ speed of rotation to allow rotor to start moving + catch-up w/in first half-cycle. Then, gradually increase up to ω_{sync}

2) Use ext. prime mover to "spin up" the synch. motor (think model-T w/ hand crank) Disconnect/de-couple once up to speed (awkward)

3) Use damper/amortisseur windings

:)

6.3 cont.

Discuss options

1) → Possible these days w/ power electronics to have a variable freq. synch. motor

2) Possible since no-load torque of synch motor much less than τ_{max}
↳ use brushless excitation sys.

3) Most popular/common method uses amortisseur/damper windings

a) Main field windings disconnected from V_f & shorted out.

b) AC power applied to stator produces rotating $\bar{B}_{stator}$ which induces voltage on shorted windings $e_{ind} = (\bar{v} \times \bar{B}) \cdot \bar{l}$

↑ relative velocity

This produces a current which in turn produces $\bar{B}_w$ (winding mag. flux density)

6.3 cont.

Now the stator mag. field $\bar{B}_s$ + damper windings mag. field $\bar{B}_w$ interact to induce a torque on the rotor $\bar{\tau}_{ind} = K\bar{B}_w \times \bar{B}_s$

↳ starts turning + slowly will approach ω_{sync} (won't ever catch-up or V_{rel} would fall to zero)

c) Re-connect V_f + apply I_f + motor will catch-up to ω_{sync}

d) apply loads to shaft of motor

Damper windings also help w/ stability!

Counteract changes from ω_{sync}

6.4/6.5 Synch. gen. + motors essentially same machines w/ same ratings