Synchronous Motor

- It is an AC motor that runs at constant speed, regardless of load (as long as load is below a maximum value).
- Construction is similar to 3Φ induction motor (that creates a rotating magnetic field), except that either the rotor is a permanent magnet or carries dc current so it acts as a permanent magnet. Then the rotor tracks the stator's rotating magnetic field at a synchronous speed.
- When the load increases, rotor momentarily slows down causing the angle between stator field and rotor field to increase, which increases the torque (since the two fields are further apart), causing rotor to speed up and catch-up with the synchronous speed.

\[
\text{Er} \propto \text{If}; \quad T_{dev} \propto \text{Er} \sin \theta \quad \Rightarrow \quad P_{dev} \propto \text{Er} \sin \phi \quad (w = \text{const})
\]

Also, \( P_{dev} = 3\text{V}a\text{I}_a \cos \theta - 3\text{I}_a^2 R_s \Rightarrow P_{dev} \propto \text{I}_a \cos \theta \)

Also, \( \theta_{in} = 3\text{V}a\text{I}_a \sin \theta \leq 0 \) (if \( \theta \) is leading)

\( \Rightarrow \) Syn. motor acts as source of reactive power, \( \text{“Syn. capacitor”} \)
Synchronous motor (example)

- 480 V rms, 200 hp, 60 Hz, 8-pole, Δ-connected syn. motor operated leading, at \( P_{\text{dev}} = 50 \text{hp} \) and \( \text{pf.} = -0.9 \), \( R_s = 0 \), \( X_s = 1.4 \Omega \). Find \( \omega \), \( T_{\text{dev}} \), \( I_a \), \( E_r \), \( S \). Suppose \( I_f \) is const. and load increases to 100 hp.

Find new values of \( I_a \), \( E_r \), \( S \), \( \Theta \).

\[ \omega = \frac{2(60)(60)}{8} = 900 \text{ rpm}; \quad T_{\text{dev}} = \frac{P_{\text{dev}}}{\omega} = \frac{50 \text{ hp}}{900 \text{ rpm}} = \frac{50 \times 746}{900} \times \frac{1}{60} = 39.6 \text{ Nm.} \]

\( R_s = 0 \Rightarrow \text{No loss} \Rightarrow P_{\text{dev}} = P_{\text{in}} = 3V_a I_a \cos \Theta \)

\[ I_a = \frac{P_{\text{dev}}}{3V_a \cos \Theta} = \frac{50 \times 746}{3(480)(0.9)} = 28.78 \text{ A rms} \]

\( (\Delta \text{-connected} \Rightarrow V_a = V_{\text{line-to-line}} = 480) \)

\[ \text{pf.} = -0.9 \Rightarrow \Theta = \cos^{-1}(-0.9) = 25.84^\circ \quad (\text{leading}) \]

Thus \( I_a = 28.78 \angle 25.84^\circ \) \( (\text{If.} > 0 \Rightarrow I_a \text{ leads } V_a) \)

\[ E_r = V_a - jI_a X_s = 480 - j(28.78 \angle 25.84^\circ)(1.4) \]

\[ = 498.9 \angle -4.168^\circ \]

\[ \Rightarrow \text{torque angle} \; S = -4.168^\circ. \]

When load power is increased, \( S \) increases,

\[ P_{\text{dev}} \propto E_r \sin S \]

\[ \Rightarrow \frac{S_2}{\sin S_1} = \frac{P_2}{P_1} \Rightarrow \sin S_2 = \frac{150}{50} \sin(41.68^\circ) \]

\[ \Rightarrow S_2 = 83.6^\circ \Rightarrow E_{r_2} = 498.9 \angle -83.6^\circ \]

\[ I_{a_2} = \frac{V_a - E_{r_2}}{jX_s} = \frac{480 - 498.9 \angle -83.6^\circ}{j(1.4)} = 52.70 \angle 10.61 \text{ A rms} \]

\[ \Rightarrow \Theta_2 = 10.61 \Rightarrow \text{pf.}_2 = \cos \Theta_2 = 0.98 \]

Note as load is increased, \( \text{pf.} \) improves (gets closer to unity)

This can also be achieved by decreasing field current \( I_f \) so \( E_r \) decreases.

\( (E_r \propto I_f) \)