Lesson 18 Synchronous Motor Operation and Applications

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ET 332b

Ac Motors, Generators and Power Systems

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Learning Objectives

After this presentation you will be able to:

- Interpret a synchronous motor phasor diagram
- Explain how increasing mechanical load affects synchronous motor electrical characteristics
- Explain the difference between electrical and mechanical degrees in synchronous motor operation
- Compute the motor developed power and torque

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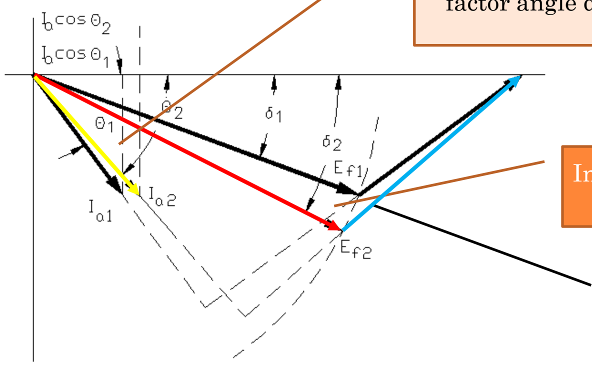
Load Change on Synchronous Motors



Armature current increases and power factor angle decreases.

Increasing torque increases δ

Increases the voltage drop between V_T and E_f.

More active power enters the motor to maintain speed and develop the new value of torque

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Electrical Degrees vs Mechanical Degrees in Synchronous Machines

Electrical power/torque angle measurement is related to the rotor phase shift by the following formula

$$\delta_e = \delta_m \cdot \left[\frac{P}{2}\right]$$

Where: δ_e = phase shift in electrical degrees
δ_m = mechanical phase shift in the rotating magnetic field of the rotor

Magnetic poles of synchronous and induction motors are 180 electrical degrees apart.

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ELECTRICAL DEGREES VS MECHANICAL DEGREES IN SYNCHRONOUS MACHINES

Example 18-1: A 100 hp, 460 V, 4-pole, wye-connected, cylindrical rotor synchronous motor is operating with a mechanical power angle of 5.5 degrees. Determine the electrical torque angle

Number of poles $P := 4$ Mechanical degrees $\delta_m := 5.5$

$$\delta_e := \delta_m \cdot \frac{P}{2}$$

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5.5

Electrical torque angle for the motor $\delta_e = 11$ degrees

Example 18-2: A 2-pole, 1000 hp, 6000 V, 3-phase wye-connected synchronous motor is operating at rated load and 0.8 leading power factor. At this operating point, the machine efficiency is 92%. The motor synchronous reactance is 4.2 ohms/phase Find:

a.) the motor power angle
b.) the power developed in the rotor
c.) the torque developed in the rotor (lb-ft)

EXAMPLE 18-2 SOLUTION (1)

Need to find angle δ. Start by finding the armature current

$$P_o = 1000\,hp\,(746\,W/hp) = 746{,}000\,W$$

$$P_{in} = \frac{P_o}{\eta} = \frac{746{,}000}{0.92} = 811{,}000\,W$$

$$P_{in} = \sqrt{3}\,V_{LL} I_L \cos\theta \qquad \cos\theta = F_p = 0.8$$

$$\frac{P_{in}}{\sqrt{3}\,V_{LL}\cos(\theta)} = |I_L| \qquad |I_L| = \frac{811{,}000}{\sqrt{3}(6000)(0.8)} = 97.55\,A$$

Use power factor to find current phase angle

$$\theta = \cos^{-1}(F_p) = \cos^{-1}(0.8) = 36.9^\circ \text{ Leading } +$$

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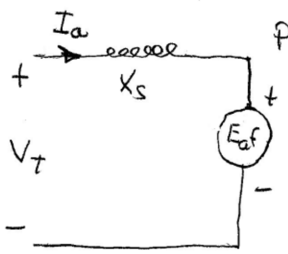
EXAMPLE 18-2 SOLUTION (2)

Find E_{af}

Wye connect motor. Need phase voltage



Per Phase model

$$V_T = \frac{6000\,V}{\sqrt{3}} = 3464\,V$$

$$\bar{E}_{af} = \bar{V}_T - \bar{I}_a \bar{X}_s = 3464\angle 0^\circ - 97.55\angle 36.9^\circ (4.2\angle 90^\circ)$$

$$E_{af} = 3464\angle 0^\circ - 409.7\angle 126.9^\circ$$

$$\boxed{E_{af} = 3724.4\angle -5^\circ}$$

$$\boxed{\delta = -5^\circ} \text{ angle on } E_{af}$$

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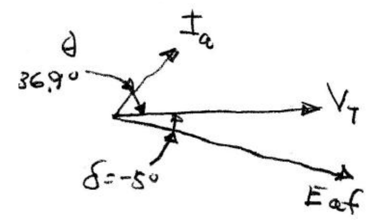
EXAMPLE 18-2 SOLUTION (3)

b.) Find the developed power

$P_D = 3 I_a V_T \cos(\theta - \delta)$ angle between I_a & E_{af}



Compute value

$$P_D = 3(92.55)(3464)\cos(36.9+5)$$

$$\boxed{P_D = 754{,}538\ W}$$

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EXAMPLE 18-2 SOLUTION (4)

c.) Use the developed power and motor speed to find torque

$$n_s = \frac{120f}{p} = \frac{120(60\,Hz)}{2} = 3600\ Rpm$$

$$T_D(lb\text{-}ft) = \frac{7.04(P_D)}{n_s} = \frac{7.04(754{,}538\,W)}{3600\ Rpm}$$

$$\boxed{T_D = 1476\ lb\text{-}ft}$$

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Synchronous Machine Operation and Excitation

Motor Operation: Increasing excitation increases magnetic field strength. Decreases power angle for a fixed load. Increases Max power.

$$P_{in} = \frac{-3\left|\overline{V}_T\right| \cdot \left|\overline{E}_f\right|}{\left|\overline{X}_s\right|} \sin(\delta)$$

Increasing E_f increases P_{in} for fixed δ and V_T

Alternator operation: Increasing excitation also decreas es δ which increases max power.

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Machine Excitation and Reactive Power Transfer

Increases in excitation also control reactive power transfer.

$$Q = \frac{3\left[\left|\overline{V}_T\right| \cdot \left|\overline{E}_f\right| \cdot \cos(\delta) - \left|\overline{V}_T\right|^2\right]}{\left|\overline{X}_s\right|}$$

For small δ, $\cos(\delta)$ approximately equal 1. Q mainly depends on magnitude of V drop. (V_T-E_f)

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Types of Machine Excitation

$E_f = V_T$ Called **normal excitation**. Synchronous motor supplies all magnetizing current to transfer power across air gap.

$E_f > V_T$ Called **overexcited**. Synchronous motor has surplus of reactive power. Supplies vars to power system. (leading F_p)

$E_f < V_T$ Called **underexcited**. Synchronous motor requires reactive power from system to transfer power across air gap. (Lagging F_p)

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End Lesson 18

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