Lesson 19 Power Factor Correction Using Synchronous Motors

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ET 332b

Ac Motors, Generators and Power Systems

Learning Objectives

After this presentation you will be able to:

- Explain how a synchronous motor can provide reactive power to other electric loads
- Use circuit model and power formulas to find the amount of reactive power a synchronous motor must deliver to produce a given power factor
- Find the motor excitation voltage required to give a desired reactive power

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Power factor Correction Using Synchronous Motors

Overexcited motor supplied mechanical power to load and reactive power to the inductive loads of system

Synchronous Condenser
Synchronous motor designed for power factor correction. No shaft.

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Synchronous Condenser Example

Example 19-1: 3-phase, 460 V 60 Hz system

Load 1: 6-pole, 60 Hz, 400 hp induction motor operating at 75% rated output , Efficiency = 90% F_p = 82% Laggin
Load 2: 75 kW delta connected resistance heater
Load 3: 300 hp 60 Hz 4-pole Y-connected cylindrical rotor synchronous motor operating at 50% rated torque angle of -16.4 degrees Efficiency = 95%X_s = 0.667 ohms/phase

Find: a.) system active power load;
b.) power factor of the synchronous motor;
c.) system power factor;
d.) percentage change in synchronous motor excitation to correct system power factor to 1.0;
e.) power angle for condition in part d.

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Example Solution

Find the input active power of all the loads using the load factor and efficiency.

LOAD 1 L.F = 0.75 $\eta = 0.90$

$$P_{in1} = \frac{(400hp)(746W/hp)(0.75)}{0.90}$$

P_{in1} = 248,667 W INDUCTION MOTOR

Load 2 P_{in2} = 75 kW Resistive heater

Load 3 Synchronous motor

L.F. = 0.5 $\eta = 0.95$

$$P_{in3} = \frac{(300hp)(746W/hp)(0.5)}{0.95}$$

P_{in3} = 117,790 W

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Example Solution Continued

Find the total input power

$$P_T = P_{in1} + P_{in2} + P_{in3}$$

$$P_T = 248{,}667W + 75{,}000W + 117{,}790W$$

$$\boxed{P_T = 441{,}457W}$$

Answer Part a

Part b. F_p of synchronous motor

$X_s = 0.667\ \Omega/\text{phase}$

$\delta = -16.9°$

$$P_{in} = \frac{-3|\bar{V}_T||\bar{E}_f|}{X_s}\sin(\delta)$$

$$V_T = \frac{460V}{\sqrt{3}} = 265.6V$$

$$|\bar{E}_f| = \frac{-P_{in}X_s}{3|\bar{V}_T|\sin(\delta)}$$

$$|\bar{E}_f| = \frac{(-117{,}790W)(0.667\Omega)}{3(265.6)\sin(-16.9°)}$$

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Example Solution Continued

$$|\bar{E}_f| = \frac{-78{,}565.93}{3(265.6)(-0.2823)}$$

$$|\bar{E}_f| = 349.3\ V$$

$$\bar{E}_f = 349.3\angle -16.4^\circ$$

Remember

$\bar{E}_f = \bar{V}_T - \bar{I}_a \bar{X}_s$

$\bar{V}_T = 265.6\angle 0^\circ\ V$

$\bar{X}_s = 0.667\angle 90^\circ\ \Omega$

SOLVE FOR $\bar{I}_a$ TO FIND F_p

$$\bar{E}_f - \bar{V}_T = -\bar{I}_a \bar{X}_s \Rightarrow \frac{\bar{V}_T - \bar{E}_f}{\bar{X}_s} = \bar{I}_a$$

Phasor of armature current

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Example Solution Continued

Compute the value of armature current

$$\frac{265.6\angle 0^\circ - 349.3\angle -16.4^\circ}{0.667\angle 90^\circ} = \bar{I}_a$$

$$\frac{128.64\angle 125.2^\circ}{0.667\angle 90^\circ} = \bar{I}_a$$

$$180.9\angle 35.16^\circ = \bar{I}_a$$

CURRENT LEADS VOLTAGE by 35.16°

$F_p = \cos\theta \quad \theta = 35.16^\circ$

$F_p = \cos(35.16^\circ) =$ **0.818 LEAD** Ans b

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Example Solution Continued

Part c. Find system power factor. Construct power triangles for all loads

Load 1
$F_{p1} = 0.82$

$$S_1 = \frac{P_{in1}}{F_{p1}} = \frac{248,667\,W}{0.82} = 303,252\ VA$$

$$Q_1 = \sqrt{S_1^2 - P_{in1}^2} = \sqrt{303,252^2 - 248,667\,W^2}$$

$Q_1 = 173,571$ VARS

Load 2 only $P_{in} = 75,000$ W
$Q = 0$

Load 3
$F_p = 0.818$
from previous calculation

$$S_3 = \frac{P_{in3}}{F_{p3}} = \frac{117,790\,W}{0.818} = 142,998\ VA$$

Example Solution Continued

Find the reactive power produced by the synchronous motor

$$Q_3 = \sqrt{S_3^2 - P_{in3}^2} = \sqrt{(143,998)^2 - (117,790)^2}$$

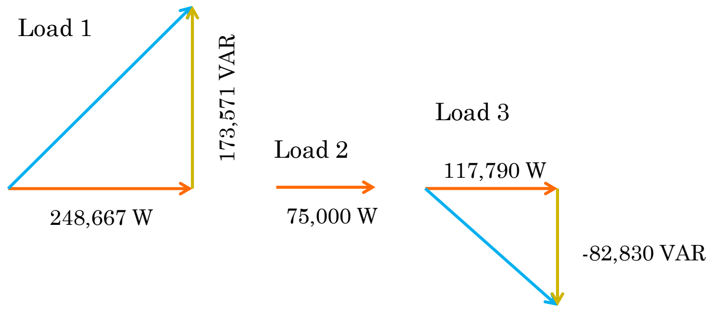
$Q_3 = -82830$ VAR
LEADING F_p
CAPACITIVE EFFECTS

Sum Real & Reactive Powers

$P_{in1} = 248,667$ W	$Q_1 = 173,571$ VAR
$P_{in2} = 75,000$ W	$Q_2 = 0$ VAR
$P_{in3} = 117,790$ W	$Q_3 = -82,830$ VAR

Example Solution Continued

Construct power triangles



$P_T = 248{,}667\text{W} + 75{,}000\text{W} + 117{,}790\text{W}$

$P_T = 441{,}457\text{W}$

$Q_T = 173{,}571 - 82830\text{ VAR}$

$Q_T = 90{,}741\text{ VAR}$

$S_T = 441{,}457 + j90{,}741\text{ VA}$

Example Solution Continued

Find the apparent power of the total system

$|S_T| = \sqrt{P_T^2 + Q_T^2} = \sqrt{441{,}457^2 + 90{,}741^2}$

$|S_T| = 450{,}686\text{ VA}$

$F_p = \frac{P_T}{|S_T|} = \frac{441{,}457\text{W}}{450{,}686\text{ VA}} = \boxed{0.98\text{ Lag}}$ ANS C

Part d. Find excitation of synchronous motor for system unity F_p

FOR UNITY F_p, Synchronous motor must Supply -90,791 VARS extra 82,830 required for motor operation

$S_T = 441{,}457 + j90{,}741\text{ VA}$

Example Solution Continued

Determine the required motor reactive power

$$S_3' = P_3 - j(82{,}830 + 90{,}741) = 117{,}790 - 173{,}571j$$

$$\bar{S}_3' = 209{,}765\angle{-55.83^\circ}$$ Total motor power phasor

Find power/phase

$$\bar{S}_{3p}' = \frac{209{,}765}{3}\angle{-55.8^\circ} = 69{,}922\angle{-55.8^\circ}$$

$$\bar{S}_{3p}' = \bar{V}_T \bar{I}_a^*$$ V_T = phase voltage Y-connected

$$V_T = \frac{460\text{V}}{\sqrt{3}} = 265.6\text{V}$$

$$\bar{V}_T = 265.6\angle{0^\circ}\ \text{V}$$

Example Solution Continued

Compute the armature current

$$69{,}922\angle{-55.8} = 265.6\angle{0^\circ}\ \bar{I}_a^*$$

$$\frac{69{,}922\angle{-55.3}}{265.6\angle{0^\circ}} = \bar{I}_a^* \Rightarrow \bar{I}_a^* = 263.3\angle{-55.8^\circ}$$

$$\bar{I}_a = 263.3\angle{55.8^\circ}$$

$$\bar{E}_f = \bar{V}_T - \bar{I}_a \bar{X}_s \qquad \bar{X}_s = 0.667\angle{90^\circ}$$

$$\bar{E}_f = 265.6\angle{0^\circ} - 263.3\angle{55.3}(0.667\angle{90^\circ})$$

$$\boxed{E_f = 422.6\angle{-13.4^\circ}}$$

E_{f1} = voltage at the original operating point and F_p

$$\Delta E_f = \frac{|E_f| - |E_{f1}|}{|E_{f1}|} \times 100\%$$

$$\Delta E_f = \frac{422.6 - 349.3}{349.3} \times 100\% = \boxed{20.98\%}$$

Torque angle $\delta = -13.4^\circ$

END LESSON 19

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