Q1):

EXAMPLE 6.2

The following data are obtained for a 3ϕ, 10 MVA, 14 kV, star-connected synchronous machine.

I_f(A)	Open-Circuit Voltage (kV) (line-to-line)	Air Gap Line Voltage (kV) (line-to-line)	Short-Circuit Current (A)
100	9.0		
150	12.0		
200	14.0	18	490
250	15.3		
300	15.9		
350	16.4		

The armature resistance is 0.07 Ω/phase.

(a) Find the unsaturated and saturated values of the synchronous reactance in ohms and also in pu.

(b) Find the field current required if the synchronous generator is connected to an infinite bus and delivers rated MVA at 0.8 lagging power factor.

(c) If the generator, operating as in part (b), is disconnected from the infinite bus without changing the field current, find the terminal voltage.

Solution:

The data are plotted in Fig. E6.2.

$$\text{Base voltage} \quad V_b = \frac{14{,}000}{\sqrt{3}} = 8083 \text{ V/phase}$$

$$\text{Base current} \quad I_b = \frac{10 \times 10^6}{\sqrt{3} \times 14{,}000} = 412.41 \text{ A}$$

$$\text{Base impedance} \quad Z_b = \frac{8083}{412.41} = 19.6 \ \Omega$$

(a) From Eq. (6.8) and Fig. E6.2,

$$Z_{s(\text{unsat})} = \frac{E_{da}}{I_{ba}} = R_a + jX_{s(\text{unsat})} \quad (6.8)$$

$$Z_s|_{\text{unsat}} = \frac{18{,}000/\sqrt{3}}{490} = 21.21 \ \Omega$$

$$X_s|_{\text{unsat}} = \sqrt{21.21^2 - 0.07^2} = 21.2 \ \Omega$$

$$= \frac{21.2}{19.6} \text{pu} = 1.08 \text{ pu}$$

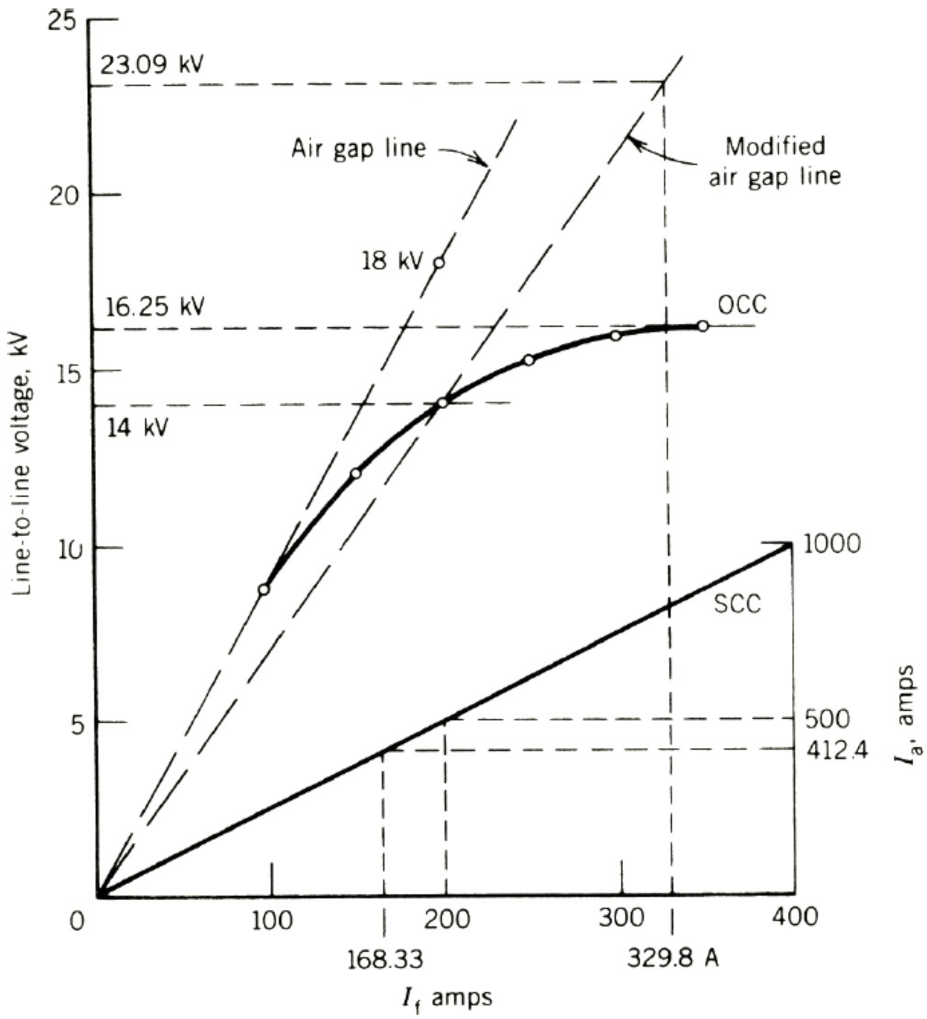

FIGURE E6.2

From Eq. (6.11) and Fig. E6.2, and because R_a is very small,

$$Z_{s(sat)} = \frac{14{,}000/\sqrt{3}}{490} = 16.5\ \Omega = (X_{s(sat)}^2 + 0.07^2)^{1/2}$$

$$X_{s(sat)} \simeq 16.5\ \Omega = \frac{16.5}{19.6} = 0.84\ \text{pu}$$

$$Z_{s(sat)} = \frac{E_{ca}}{I_{ba}} = R_a + jX_{s(sat)}$$

(6.11)

(b) It will be convenient to carry out the calculation in pu values rather than in actual values.

$$V_t = 1\angle 0^\circ \text{ pu}$$

$$\text{PF} = 0.8 = \cos 36.9^\circ$$

$$I_a = 1\angle -36.9 \text{ pu}$$

$$Z_s = 0.84\angle \tan^{-1}\frac{16.5}{0.07} = 0.84\angle 89.8^\circ \text{ pu}$$

Now

$$\begin{aligned} E_f &= V_t + I_a R_a + I_a jX_s \\ &= V_t + I_a Z_s \\ &= 1\angle 0^\circ + 1\angle -36.9^\circ \cdot 0.85\angle 89.8^\circ \end{aligned}$$

$$\begin{aligned} &= 1\angle 0^\circ + 0.84\angle 52.9^\circ \\ &= 1.5067 + j0.67 \\ &= 1.649\angle 24^\circ \text{ pu} \\ &= 1.649 \times 14\angle 24^\circ \text{ kV,} \quad \text{line-to-line} \\ &= 23.09\angle 24^\circ \text{ kV,} \quad \text{line-to-line} \end{aligned}$$

Note that $\delta = 24^\circ$ and is positive, as it should be for generator operation.

The required field current from the modified air gap line (Fig. E6.2) is

$$I_f = 1.649 \times 200 = 329.8 \text{ A}$$

(c) From the open-circuit data (Fig. E6.2) at $I_f = 329.8$ A, the terminal voltage is

$$V_t = 16.25 \text{ kV} \quad \text{(line-to-line)}$$

Q2):

6.4 The following test results are obtained for a 3ϕ, 25 kV, 750 MVA, 60 Hz, 3600 rpm, star-connected synchronous machine at rated speed.

I_f(A)	V_{LL}(kV) open-circuit test	I_a(A) short-circuit test	V_{LL}(kV) air gap line
1500	25	10,000	30

(a) Determine the number of poles of the synchronous machine.

(b) Determine the unsaturated and saturated values of the synchronous reactance in ohms and per unit.

(c) The short-circuit test is performed at constant field current (1500 A) but at different speeds—1000 rpm, 2000 rpm, 3000 rpm, and 3600 rpm. Determine the short-circuit current at these speeds.

(d) Determine the field current if the synchronous machine delivers rated MVA to an infinite bus at 0.9 lagging power factor.

Solution:

$\boxed{6.4}$ (a) $3600 = \frac{120 \times 60}{P} \rightarrow P = 2$

(b) $V_b = \frac{25}{\sqrt{3}} KV = 14,434.2\ V \quad I_b = \frac{750 \times 10^6}{\sqrt{3} \times 25 \times 10^3} = 17320 A$

$Z_b = \frac{14434.2}{17320} = 0.8334\,\Omega$

$X_s|_{unsat} = \frac{30KV/\sqrt{3}}{10KA} = 1.732\,\Omega = \frac{1.732}{0.8334}\ P.U. = 2.0782\ P.U.$

$X_s|_{sat} = \frac{25KV/\sqrt{3}}{10\,KA} = 1.4434\,\Omega = \frac{1.4434}{0.8334}\ P.U. = 1.732\ P.U.$

(c) $I_a = \frac{E_f}{X_s} = \frac{k_1 f}{k_2 f} = \frac{k_3 n}{k_4 n} = constant = \frac{30KV/\sqrt{3}}{X_s|_{unsat}} = \frac{30KV/\sqrt{3}}{1.732} = 10,000 A$

(d) $V_t = 1 PU, \quad I_a = 1 PU \angle -\cos^{-1} 0.9 = 1\angle -25.84^\circ\ P.U.$

$E_f = 1\angle 0^\circ + 1\angle -25.84^\circ \times 1.732\angle 90^\circ = 1 + 1.732\angle 64.16^\circ = 1 + 0.7549 + j1.5588$

$= 2.3473\angle 41.6133^\circ$