5–17 A 25-MVA, three-phase, 13.5-kV, two-pole, 60-Hz synchronous generator was tested by the open-circuit test, and its air-gap voltage was extrapolated with the following results:

Open-circuit test					
Field current, A	320	365	380	475	570
Line voltage, kV	13.0	13.8	14.1	15.2	16.0
Extrapolated air-gap voltage, kV	15.4	17.5	18.3	22.8	27.4

The short-circuit test was then performed with the following results:

Short-circuit test					
Field current, A	320	365	380	475	570
Armature current, A	1040	1190	1240	1550	1885

The armature resistance is 0.24 Ω per phase.

a. Find the unsaturated synchronous reactance of this generator in ohms per phase and in per-unit.

b. Find the approximate saturated synchronous reactance X_S at a field current of 380 A. Express the answer both in ohms per phase and in per-unit.

c. Find the approximate saturated synchronous reactance at a field current of 475 A. Express the answer both in ohms per phase and in per-unit.

d. Find the short-circuit ratio for this generator.

➢ Assume Y-connected synchronous generator.

For a Y-connection, $V_\phi = V_{LL} / \sqrt{3}$ and $I_A = I_L$.

a) Per (5-23), $Z_S = \sqrt{R_A^2 + X_S^2} = \dfrac{E_{A,OC}}{I_{A,SC}} = \dfrac{V_{\phi,OC}}{I_{A,SC}}$. We will use the air-gap line voltage to get the unsaturated synchronous reactance. Arbitrarily using $I_f = 320$ A values, we get

$$\sqrt{0.24^2 + X_S^2} = \frac{18{,}300/\sqrt{3}}{1240} \quad \Rightarrow 0.24^2 + X_S^2 = 72.6 \quad \Rightarrow X_S = \sqrt{72.6 - 0.24^2}$$

$$\Rightarrow \quad \underline{\boldsymbol{X_S = 8.1572\ \Omega}}.$$

Use (3-102) to calculate the base impedance

$$Z_{\text{base}} = 3\,(V_{\phi,\text{base}})^2 / S_{\text{rated}} = 3(13{,}500/\sqrt{3})^2 / 25\times10^6 = 7.29\,\Omega.$$

Then, the per-unit unsaturated synchronous reactance is

$$X_{S,\text{pu}} = X_S / Z_{\text{base}} = 8.1572 / 7.29 \qquad \Rightarrow \quad \underline{\boldsymbol{X_{S,\text{pu}} = 1.119}}.$$

b) Per (5-23), $Z_S = \sqrt{R_A^2 + X_S^2} = \dfrac{E_{A,OC}}{I_{A,SC}} = \dfrac{V_{\phi,OC}}{I_{A,SC}}$. Using I_f = 320 A line values, we get

$$\sqrt{0.24^2 + X_S^2} = \frac{14{,}100/\sqrt{3}}{1240} \quad \Rightarrow 0.24^2 + X_S^2 = 43.1 \quad \Rightarrow X_S = \sqrt{43.1 - 0.24^2}$$

$$\Rightarrow \quad \underline{\boldsymbol{X_S = 6.56\ \Omega}}.$$

Then, the per-unit synchronous reactance is

$$X_{S,\text{pu}} = X_S / Z_{\text{base}} = 6.56 / 7.29 \qquad \Rightarrow \quad \underline{\boldsymbol{X_{S,\text{pu}} = 0.900}}.$$

c) Per (5-23), $Z_S = \sqrt{R_A^2 + X_S^2} = \dfrac{E_{A,OC}}{I_{A,SC}} = \dfrac{V_{\phi,OC}}{I_{A,SC}}$. Using I_f = 475 A line values, we get

$$\sqrt{0.24^2 + X_S^2} = \frac{15{,}200/\sqrt{3}}{1550} \quad \Rightarrow 0.24^2 + X_S^2 = 32.0555 \quad \Rightarrow X_S = \sqrt{32.0555 - 0.24^2}$$

$$\Rightarrow \quad \underline{\boldsymbol{X_S = 5.657\ \Omega}}.$$

Then, the per-unit synchronous reactance is

$$X_{S,\text{pu}} = X_S / Z_{\text{base}} = 5.657 / 7.29 \qquad \Rightarrow \quad \underline{\boldsymbol{X_{S,\text{pu}} = 0.776}}.$$

d) The short circuit ratio is defined as

SCR = (I_f to get V_{rated} on OCC) / (I_f to get I_{rated} on SCC).

The rated line voltage is 13.5 kV. Interpolating between I_f = 320 A for V_{LL} = 13 kV and I_f = 365 A for V_{LL} = 13.8 kV, we get I_f = (13.5-13)/(13.8-13)(365-320)+320 = **348.125 A**.

Per (2-31), the rated line current is

$$I_L = S_{\text{rated}}/(\sqrt{3}V_{LL}) = 25\times10^6/\ (\sqrt{3}\times13{,}500) = 1069.167\ \text{A}_{\text{rms}}.$$

Interpolating between I_f = 320 A for I_L = 1040 A_{rms} and I_f = 365 A for I_L = 1190 A_{rms}, we get I_f = (1069.167-1040)/(1190-1040)(365-320)+320 = **328.750 A**.

Calculate the short circuit ratio SCR = 348.125 / 328.75 $\Rightarrow$ **SCR = 1.0589**.