5–3 Assume that the field current of the generator in Problem 5–2 is adjusted to achieve rated voltage (480 V) at full load conditions in each of the questions below.

a. What is the efficiency of the generator at rated load?

b. What is the voltage regulation of the generator if it is loaded to rated kilovolt-amperes with 0.8 PF lagging loads?

c. What is the voltage regulation of the generator if it is loaded to rated kilovolt-amperes with 0.8 PF leading loads?

d. What is the voltage regulation of the generator if it is loaded to rated kilovolt-amperes with unity-power-factor loads?

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5–2 A 480-V, 200-kVA, 0.8 power factor lagging, 60-Hz, two-pole Y-connected synchronous generator has a synchronous reactance of 0.4 Ω and an armature resistance of 0.04 Ω. At 60 Hz, its friction and windage losses are 6 kW, and its core losses are 4 kW. The field circuit has a DC voltage of 200 V, and the maximum I_F is 10 A. The resistance of the field circuit is adjustable over the range from 20 to 200 Ω. The OCC of this generator is shown in Figure P5–1.

a. How much field current is required to make V_T equal to 480 V when the generator is running at no load?

b. What is the internal generated voltage of this machine at rated conditions?

c. How much field current is required to make V_T equal to 480 V when the generator is running at rated conditions?

d. How much power and torque must the generator's prime mover be capable of supplying?

➢ Let $X_S = 0.3\ \Omega$.

From problem 5.2 at the rated load w/ 0.8 lagging PF:

$\overline{V}_\phi = 277.127\angle 0°\ (V_{rms})$, $\overline{I}_A = 240.5626\angle -36.87°\ (A_{rms})$, and $\overline{E}_A = 332.22\angle 9°\ V_{rms}$.

$P_{out} = 160{,}000$ W, $P_{F\&W} = 6000$ W, $P_{core} = 4000$ W, $P_{stray} = 0$, $P_{Cu} = 6944.444$ W, and $P_{in} = 176{,}944.444$ W = 176.9 kW.

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a) At the rated load, the efficiency (4-51) is

$$\eta = P_{out} / P_{in} \times 100\% = 160{,}000 / 176{,}944.444 \times 100\% \quad \Rightarrow \quad \underline{\boldsymbol{\eta = 90.42\%}}.$$

b) At the rated load w/ 0.8 lagging PF, the voltage regulation (4-56) is

$$VR = (V_{NL} - V_{FL})/V_{FL} \times 100\% = (332.22 - 277.127) / 277.127 \times 100\% \Rightarrow \underline{\boldsymbol{VR = 19.88\%}}.$$

c) At the rated load w/ 0.8 leading PF, the

Use (2-29), $P = \sqrt{3} V_{LL} I_L \cos\theta$ to find the line current magnitude

$$I_A = I_L = \frac{P}{\sqrt{3} V_{LL} \cos\theta} = \frac{200 \times 10^3 (0.8)}{\sqrt{3}(480)0.8} \quad \Rightarrow I_L = I_A = 240.5626 \text{ A.}$$

Using PF = cos $\theta \Rightarrow \theta = \theta_V - \theta_I = \cos^{-1}(0.8) = -36.8699°$ (leading) $\Rightarrow \theta_I = 36.8699°$.

Per (5-9), $$\begin{aligned} \overline{E}_A &= \overline{V}_\phi + jX_S\overline{I}_A + R_A\overline{I}_A \\ &= 277.127\angle 0° + j0.3(240.5626\angle 36.87°) + 0.04\,(240.5626\angle 36.87°) \end{aligned}$$

$$\Rightarrow \overline{E}_A = 249.735\angle 14.73° \text{ V}_{\text{rms}}.$$

The voltage regulation (4-56) w/ 0.8 leading PF is

$$\text{VR} = (V_{\text{NL}} - V_{\text{FL}})/V_{\text{FL}} \times 100\% = (249.735 - 277.127)/277.127 \times 100\% \Rightarrow \underline{\textbf{VR = -9.88\%.}}$$

c) At the rated load w/ unity PF, the

The line current magnitude remains $\Rightarrow I_L = I_A = 240.5626$ A.

Using PF = cos $\theta \Rightarrow \theta = \theta_V - \theta_I = \cos^{-1}(1) = 0°$ (leading) $\Rightarrow \theta_I = 0°$.

Per (5-9), $\overline{E}_A = 277.127\angle 0° + j0.3(240.5626\angle 0°) + 0.04\,(240.5626\angle 0°)$

$$\Rightarrow \overline{E}_A = 295.693\angle 14.127° \text{ V}_{\text{rms}}.$$

The voltage regulation (4-56) w/ unity PF is

$$\text{VR} = (V_{\text{NL}} - V_{\text{FL}})/V_{\text{FL}} \times 100\% = (295.693 - 277.127)/277.127 \times 100\% \Rightarrow \underline{\textbf{VR = 6.70\%.}}$$