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?

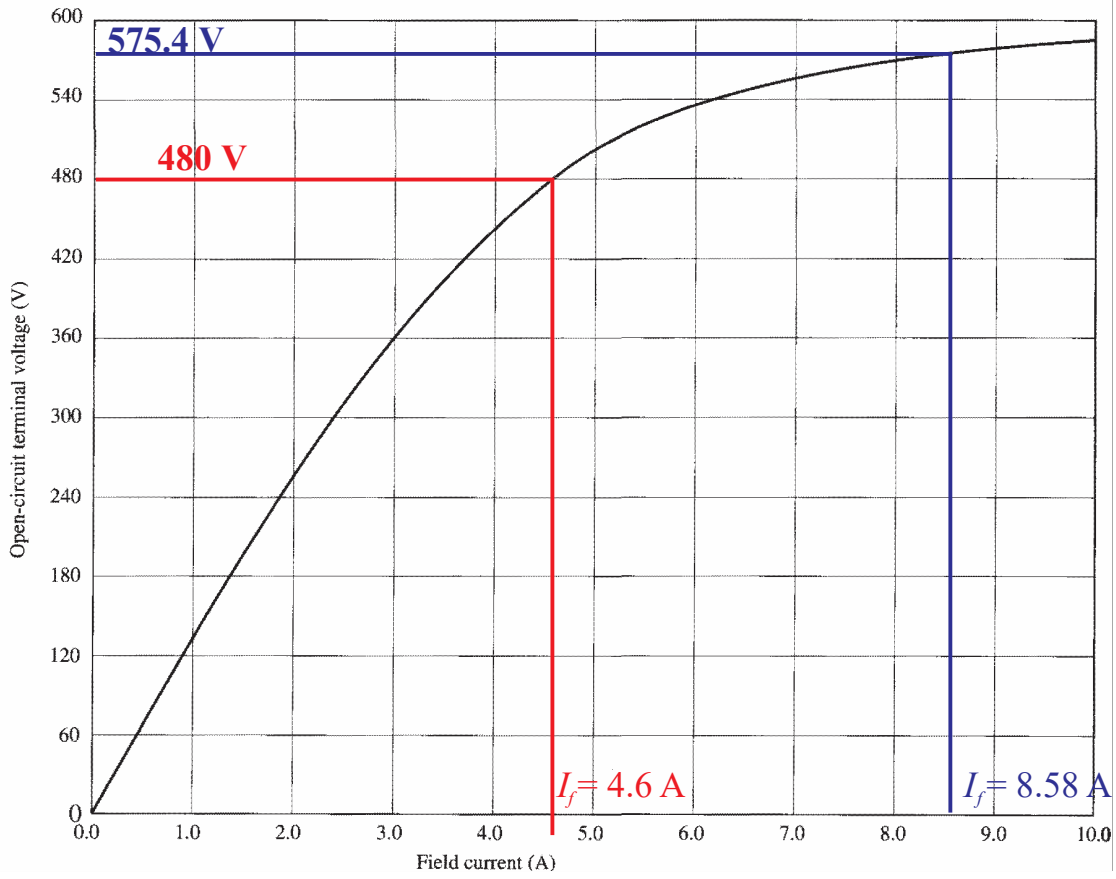
c. How much field current is required to make V_T equal to 480 V when the generator is running at rated conditions?

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

➢ Let $X_S = 0.3\ \Omega$.

a) Per figure (red lines), to get $V_T = 480$ V we need a field current of ⇒ **$I_f = 4.6$ A**.

Figure P5–1 The open-circuit characteristic for the generator in Problem 5–2.



b) At rated conditions, V_T = 480 V. For a Y-connection, V_ϕ = 480/√3 = 277.128 V_{rms}.

Let $\angle V_\phi = 0°$. Use (2-29), $P = \sqrt{3} V_{LL} I_L \cos\theta$ to find the line current magnitude

$$I_A = I_L = \frac{P}{\sqrt{3} V_{LL} \cos\theta} = \frac{200\times10^3 (0.8)}{\sqrt{3}(480)0.8} \quad \Rightarrow I_L = 240.5626 \text{ A.}$$

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

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

$$\Rightarrow \underline{\overline{E}_A = 332.216\angle 8.999° \text{ V}_{rms}}.$$

c) For E_A = 332.22, we will need an open-circuit terminal voltage of

$$V_{T,OC} = \sqrt{3}(332.216) = 575.41 \text{ V}_{rms}.$$

Per figure (blue), to get $V_{T,OC}$ = 575.4 V we need a field current of $\Rightarrow$ **$\underline{I_f = 8.58 \text{ A}}$**.

d) To find P_{in}, we need to calculate the losses and add to P_{out}.

At rated conditions, $P_{out} = S_{rated}\,PF_{rated} = 200\times10^3\,(0.8) = 160{,}000$ W.

Given: $P_{F\&W} = 6000$ W and $P_{core} = 4000$ W. Assume $P_{stray} = 0$ as we are not given any information. Last, we can calculate the copper losses (4-53) as

$$P_{Cu} = 3\,I_A^2\,R_A = 3\,(240.5626)^2\,0.04 = 6944.444 \text{ W.}$$

Then, the needed input power from the prime mover is then

$$P_{in} = P_{out} + P_{F\&W} + P_{core} + P_{stray} + P_{Cu} = 160{,}000 + 6000 + 4000 + 6944.444$$

$$\Rightarrow \underline{\boldsymbol{P_{in} = 176{,}944.444 \text{ W} = 176.9 \text{ kW}}}.$$

Per (4-23), $n_m = 120 f_e / P = 120(60) / 2 = 3600$ RPM. Then, the generator speed is

$$\omega_m = n_m\,(2\pi/60) = 3600\,(2\pi/60) = 376.9911 \text{ rad/s.}$$

The applied torque from the prime mover can now be found as

$$\tau_{app} = P_{in} / \omega_m = 176{,}944.444 / 376.9911 \Rightarrow \underline{\boldsymbol{\tau_{app} = 469.36 \text{ N-m}}}.$$