EE 577 - M3A1

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4-2

A 13.8-kV, 50-MVA, 0.9-power-factor-lagging, 60-Hz, four-pole Y-connected synchronous generator has a synchronous reactance of 2.5 Ω and an armature resistance of 0.2 Ω. At 60 Hz, its friction and windage losses are 1 MW, and its core losses are 1.5 MW. The field circuit has a dc voltage of 120 V, and the maximum I_F is 10 A. The current of the field circuit is adjustable over the range from 0 to 10 A. The OCC of this generator is shown in Figure P4-1.

a) How much field current is required to make the terminal voltage V (or line voltage) equal to 13.8 kV when the generator is running at no load?

Looking at the OCC curve, the OCV of 13.8 kV is about **3.5A**.

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

At rated conditions, $I = \frac{50\text{MVA}}{13.8\text{kV},line\ line} = \frac{50\text{MVA}}{\sqrt{3}13.8\text{kV},phase} = 2.09\text{kA}$ on each output line.

$V_{\text{phase}} = V_{\text{line line}}\sqrt{3} = 7.967\text{kV}$

The generator has phase reactance $X = 2.5\Omega$ and resistance $R = 0.2\Omega$. To make the terminal voltage 13.8 kV (7.967 kV phase) the internal voltage needs to be higher: $E = V_T + I \cdot (R + jX) = 7.967\text{kV} + 2.09\angle 25.8°\text{kA}(0.2 + j2.5)\Omega = 11.547\ \text{kV}_{\text{phase, internal}} = 20\ \text{kV}_{\text{line}-\text{line, internal}}$

c) The phase voltage V_Φ of this generator at rated conditions, assuming the field current is adjusted properly, is $V_\Phi = V_{\text{line}-\text{line}}/\sqrt{3} = 11.547kV$.

d) To make the internal OCV 20 kV, and terminal voltage 13.8 kV according to the OCC requires a the maximum field current of **10A**.

4-6

The internal generated voltage E_A of a 2-pole Δ-connected, 60 Hz, three phase synchronous generator is 14.4 kV, and the terminal voltage V_T is 12.8 kV. The synchronous reactance of this machine is 4 Ω, and the armature resistance can be ignored.

a) If the torque angle of the generator δ = 18°, how much power is being supplied by this generator at the current time?

$P = VI = 3V_\Phi(E/X)\sin(\delta) = 3 \cdot 12.8 \cdot (14.4/4)\sin(18°) = 42.72\text{MW}$

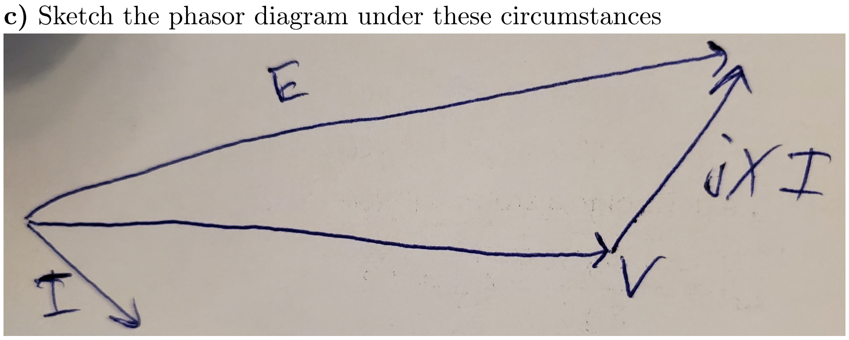
b) What is the power factor of the generator at this time?

$pf = \cos(\angle V - \angle I) = \cos(\angle I)$

$I = \frac{14.4\angle 18° - 12.8\text{kV}}{j4\ \Omega} = 1.1348\angle\{-11.375°\}\text{kA}$

$pf = \cos(-11.375°) = 0.9804$ lagging

c) Sketch the phasor diagram under these circumstances



d) Ignoring losses in this generator, what torque must be applied to its shaft by the prime mover at these conditions?

$P = \omega T$

$T = \frac{P}{\omega} = \frac{42.72\text{MW}}{2\pi 60} = 113.3\text{kN} \cdot \text{M}$

4-7

A 100-MVA, 14.4-kV, 0.8-PF-lagging, 50-Hz, two-pole, Y-connected synchronous generator has a per-unit synchronous reactance of 1.1 and a per-unit armature resistance of 0.011

$V_\Phi = 14.4\text{kV}/\sqrt{3} = 8.3138\text{kV}$

a) What are its synchronous reactance and armature resistance in ohms?

$R = \frac{R_{\text{pu}}}{Z_{\text{base}}} = 0.011 \cdot (14.4\text{kV})^2/100\text{MVA} = 22.81\ \text{m}\Omega$

$X = \frac{X_{\text{pu}}}{Z_{\text{base}}} = 1.1 \cdot (14.4\text{kV})^2/100\text{MVA} = 2.281\ \Omega$

b) What is the magnitude of the internal generated voltage E at the rated conditions? What is its torque angle δ at these conditions?

$\theta = \arccos 0.8 = 36.87°$

$E = V + I \cdot Z = \frac{14.4}{\sqrt{3}}\text{kV} + (\frac{100\text{MVA}}{\sqrt{3} \cdot 14.4\text{kV}}\angle - 36.87°) \cdot (0.02281 + j2.281)$

$E = 15.66\angle 27.626°\text{kV}$

c) Ignoring losses in the generator, what torque must be applied to its shaft by the prime mover at full load?

$P = VI\cos\theta = 0.8 \cdot 1000 = 80\text{MW}$

speed $n_{\text{sync}} = \frac{120 f_{\text{sync}}}{Poles} = \frac{120 \cdot 50\text{Hz}}{2} = 3000\text{rev/min} = 50\text{rev/s}$

torque applied $\tau = \frac{P}{\omega} = \frac{80\text{MW}}{2\pi \cdot 50\text{rad/s}} = 254,650\ \text{N} \cdot \text{m}$

4-8

A 200-MVA, 12-kV, 0.85-PF-lagging, 50-Hz, 20-pole, Y-connected water turbine generator has a per-unit synchronous reactance of 0.9 and a per-unit armature resistance of 0.1. This generator is operating in parallel with a large power system (infinite bus).

a) What is the speed of rotation of this generator's shaft?

$n_{\text{sync}} = \frac{120 f_{\text{sync}}}{Poles} = \frac{120 \cdot 50\text{Hz}}{20} = 300\text{rev/min}$

b) What is the magnitude of the internal generated voltage E at rated conditions?

$\theta = \arccos 0.85 = 31.788°$

$E_{\text{pu}} = V_{\text{pu}} + Z_{\text{pu}} \cdot I_{\text{pu}} = 1 + (0.1 + j0.9) \cdot 1\angle 31.788° = 1.7141\angle 24.555°\ \text{V}_{\text{pu}}$

$E_A = 1.7141\angle 24.555°\text{V}_{\text{pu}} \cdot 12\text{kV}/\sqrt{3} = 11.876\angle 24.555°$ kV per phase internal voltage

c) What is the torque angle of the generator at rated conditions?

The torque angle is the angle δ between the internal and external voltage.

$\delta = 24.555°$

d) What are the values of the generator's synchronous reactance and armature resistance in ohms?

We are given the per unit, so we can just multiply by the base impedance.

$X_s = 0.9 \cdot \frac{(12\text{kV})^2}{200\text{MVA}} = 0.648\ \Omega$

$R = 0.1 \cdot \frac{(12\text{kV})^2}{200\text{MVA}} = 0.072\ \Omega$

e) If the field current is held constant, what is the maximum power possible out of this generator? How much reserve power or torque does this generator have at full load?

P\approx3\frac{V_\Phi E_A}{X_s}\sin\delta

The maximum occurs at $\delta = 90°$: $P_{\max} = 3\frac{12/\sqrt{3} \cdot 11.876}{0.648} = 380.92$ kW

The generator has $380.92 - 200 \cdot 0.85 = 210.92$kW reserve power.