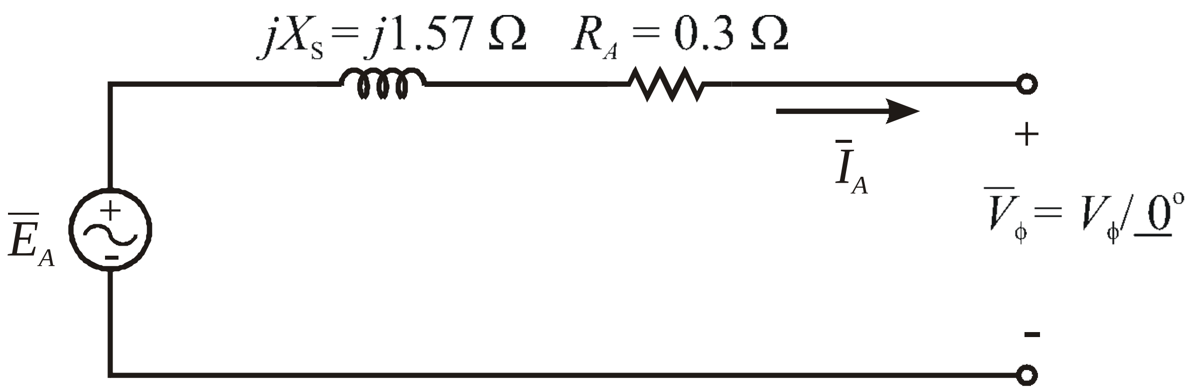
Example- The 1 MVA, 2.3 kVrms, 3-phase, Y-connected, 6-pole, 60 Hz, synchronous generator of the previous example is supplied the rated field current of 12 A and is turned by a steam turbine at 1200 RPM. If the core losses are 15 kW and the friction and windage losses are 20 kW, determine the following:

a) What are the terminal voltage, phase voltage and induced voltage if the load draws the rated current at a power factor of 0.866 lagging? Assume we are looking at phase A with an assumed terminal voltage phase angle of zero (other phases will be at ±120°).



From (A-31),

$$I_{\text{rated}} = \frac{S_{\text{rated}}}{\sqrt{3}\, V_{\text{rated}}} = \frac{10^6}{\sqrt{3}\,(2300)} = 251.022\ \text{A}_{\text{rms}}$$

The phase/armature current angle is $\theta = \cos^{-1}(pf) = \cos^{-1}(0.866) = 30°$.

Then, the armature current is $\underline{\bar{I}_A = 251.022\angle -30°\ \text{A}_{\text{rms}}}$.

From the previous example, V_T = 2470.8 V_{rms} from the OCC at a field current of $I_f = 12$ A. For a Y-connection, then

$$\underline{V_{\phi,\text{OC}} = \frac{2470.833}{\sqrt{3}} = 1426.5363\ \text{V}_{\text{rms}}}.$$

a) cont.

By KVL,

$$\bar{E}_A = \bar{I}_A\left(R_A + jX_S\right) + V_\phi\angle 0$$

which yields

$$1426.5\angle\delta = \left(\ 251.022\angle -30°\right)\left(0.3 + j1.57\right) + V_\phi\angle 0$$

$$1426.5\, e^{j\delta} = 1426.5\cos\delta + j1426.5\sin\delta = 262.285 + j303.6379 + V_\phi$$

Equate imaginary parts to solve for δ-

$$j1426.5\sin\delta = j303.6379$$

$$\sin\delta = \frac{303.6379}{1426.5} \quad\Rightarrow\quad \delta = \sin^{-1}\left(\frac{303.6379}{1426.5}\right) = 12.2897°$$

Equate real parts to solve for phase voltage magnitude-

$$1426.5\cos\delta = 262.285 + V_\phi$$

$$V_\phi = 1426.5\cos\left(12.2897°\right) - 262.285$$

$$V_\phi = 1131.525\ \mathrm{V_{rms}}$$

Since, we assume the phase voltage is at zero degrees-

$$\underline{\bar{V}_\phi = 1131.525\angle 0°\ \mathrm{V_{rms}},}$$

and the line-to-line terminal voltage for the Y-connected generator

$$\underline{V_T = \left(\sqrt{3}\ \right)1131.525 = 1959.86\ \mathrm{V_{rms}}.}$$

b) What are the voltage regulation VR, input power P_{in}, output power P_{out}, armature/stator copper losses P_{SCL}, and efficiency η?

$$VR = \frac{V_{NL} - V_{FL}}{V_{FL}} * 100\% = \frac{2470.8 - 1959.86}{1959.86} * 100\%$$

$$\underline{VR = 26.1\%}$$

$$P_{\text{SCL}} = 3\left|\bar{I}_A\right|^2 R_A = 3\left(251.022\right)^2 0.3$$

$$\underline{P_{\text{SCL}} = 56,710.8 \text{ W} = 56.7 \text{ kW}}$$

$$P_{\text{out}} = S_{\text{out}} \cos\theta = 10^6 (0.866)$$

$$\underline{P_{\text{out}} = 866,000 \text{ W} = 866 \text{ kW}}$$

$$P_{\text{in}} = P_{\text{out}} + P_{\text{losses}} = P_{\text{out}} + \left(P_{\text{friction/windage}} + P_{\text{core}} + P_{\text{SCL}}\right)$$

$$\underline{P_{\text{in}} = 866 + 20 + 15 + 56.7 = 957.7 \text{ kW}}$$

$$\underline{\eta = \frac{P_{\text{out}}}{P_{\text{in}}} * 100\% = \frac{866}{957.7} * 100\% = 90.4\%}$$

c) What are the applied torque τ_{app} (from the prime mover), converted power P_{conv}, and the induced torque (acts against prime mover) τ_{ind}?

Now $P_{\text{in}} = \tau_{\text{app}}\, \omega_{\text{m}}$, where $\omega_{\text{m}} = n_{\text{m}}\left(\frac{\pi}{30}\right) = 1200\left(\frac{\pi}{30}\right) = 125.6637 \text{ rad/s}$.

So,

$$\underline{\tau_{\text{app}} = \frac{P_{\text{in}}}{\omega_{\text{m}}} = \frac{957,711}{125.6637} = 7621.2 \text{ N•m}}.$$

$$P_{\text{conv}} = P_{\text{in}} - P_{\text{friction/windage}} - P_{\text{core}}$$

$$\underline{P_{\text{conv}} = 957.7 - 20 - 15 = 922.7 \text{ kW}}$$

$$\underline{\tau_{\text{ind}} = \frac{P_{\text{conv}}}{\omega_{\text{m}}} = \frac{922,711}{125.6637} = 7342.7 \text{ N•m}}$$