King Fahd University of Petroleum & Minerals
Electrical Engineering Department
EE 360: Solution -Home Work #4

4-2)

(a) If the no-load terminal voltage is 13.8 kV, the required field current can be read directly from the open-circuit characteristic. It is 3.50 A.

(b) This generator is Y-connected, so $I_L = I_A$. At rated conditions, the line and phase current in this generator is

$$I_A = I_L = \frac{P}{\sqrt{3}\, V_L} = \frac{50\text{ MVA}}{\sqrt{3}\,(13800\text{ V})} = 2092\text{ A at an angle of } -25.8°$$

The phase voltage of this machine is $V_\phi = V_T / \sqrt{3} = 7967\text{ V}$. The internal generated voltage of the machine is

$$\mathbf{E}_A = \mathbf{V}_\phi + R_A\mathbf{I}_A + jX_S\mathbf{I}_A$$
$$\mathbf{E}_A = 7967\angle 0° + (0.20\ \Omega)(2092\angle -25.8°\text{ A}) + j(2.5\ \Omega)(2092\angle -25.8°\text{ A})$$
$$\mathbf{E}_A = 11544\angle 23.1°\text{ V}$$

(c) The phase voltage of the machine at rated conditions is $V_\phi = 7967\text{ V}$

From the OCC, the required field current is 10 A.

(d) The equivalent open-circuit terminal voltage corresponding to an E_A of 11544 volts is

$$V_{T,oc} = \sqrt{3}\,(11544\text{ V}) = 20\text{ kV}$$

From the OCC, the required field current is 10 A.

(e) If the load is removed without changing the field current, $V_\phi = E_A = 11544\text{ V}$. The corresponding terminal voltage would be 20 kV.

4-6)

SOLUTION

(a) If resistance is ignored, the output power from this generator is given by

$$P = \frac{3V_\phi E_A}{X_S}\sin\delta = \frac{3(12.8\text{ kV})(14.4\text{ kV})}{4\ \Omega}\sin 18^\circ = 42.7\text{ MW}$$

(b) The phase current flowing in this generator can be calculated from

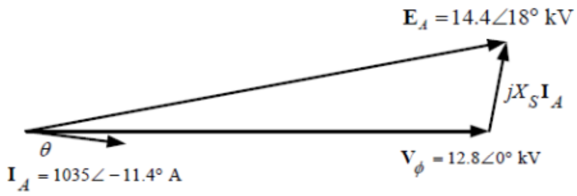
$$\mathbf{E}_A = \mathbf{V}_\phi + jX_S\mathbf{I}_A$$

$$\mathbf{I}_A = \frac{\mathbf{E}_A - \mathbf{V}_\phi}{jX_S}$$

$$\mathbf{I}_A = \frac{14.4\angle 18^\circ\text{ kV} - 12.8\angle 0^\circ\text{ kV}}{j4\ \Omega} = 1135\angle -11.4^\circ\text{ A}$$

Therefore the impedance angle $\theta = 11.4^\circ$, and the power factor is $\cos(11.4^\circ) = 0.98$ lagging.

(c) The phasor diagram is



(d) The induced torque is given by the equation

$$P_{\text{conv}} = \tau_{\text{ind}}\omega_m$$

With no losses,

4-13)

SOLUTION

(a) The unsaturated synchronous reactance of this generator is the same at any field current, so we will look at it at a field current of 380 A. The extrapolated air-gap voltage at this point is 18.3 kV, and the short-circuit current is 1240 A. Since this generator is Y-connected, the phase voltage is $V_\phi = 18.3\text{ kV}/\sqrt{3} = 10{,}566\text{ V}$ and the armature current is $I_A = 1240\text{ A}$. Therefore, the *unsaturated* synchronous reactance is

$$X_{Su} = \frac{10,566 \text{ V}}{1240 \text{ A}} = 8.52 \ \Omega$$

The base impedance of this generator is

$$Z_{\text{base}} = \frac{3 \ V_{\phi,\text{base}}^{\ 2}}{S_{\text{base}}} = \frac{3(7044 \text{ V})^2}{25,000,000 \text{ VA}} = 5.95 \ \Omega$$

Therefore, the per-unit unsaturated synchronous reactance is

$$X_{Su,\text{pu}} = \frac{8.52 \ \Omega}{5.95 \ \Omega} = 1.43$$

(b) The saturated synchronous reactance at a field current of 380 A can be found from the OCC and the SCC. The OCC voltage at I_F = 380 A is 14.1 kV, and the short-circuit current is 1240 A. Since this generator is Y-connected, the corresponding phase voltage is $V_\phi = 14.1 \text{ kV}/\sqrt{3} = 8141 \text{ V}$ and the armature current is $I_A = 1240 \text{ A}$. Therefore, the *saturated* synchronous reactance is

$$X_S = \frac{8141 \text{ V}}{1240 \text{ A}} = 6.57 \ \Omega$$

and the per-unit unsaturated synchronous reactance is

$$X_{S,\text{pu}} = \frac{8.52 \ \Omega}{5.95 \ \Omega} = 1.10$$

(c) The saturated synchronous reactance at a field current of 475 A can be found from the OCC and the SCC. The OCC voltage at I_F = 475 A is 15.2 kV, and the short-circuit current is 1550 A. Since this generator is Y-connected, the corresponding phase voltage is $V_\phi = 15.2 \text{ kV}/\sqrt{3} = 8776 \text{ V}$ and the armature current is $I_A = 1550 \text{ A}$. Therefore, the *saturated* synchronous reactance is

$$X_S = \frac{8776 \text{ V}}{1550 \text{ A}} = 5.66 \ \Omega$$

and the per-unit unsaturated synchronous reactance is

$$X_{S,\text{pu}} = \frac{5.66 \ \Omega}{5.95 \ \Omega} = 0.951$$

(d) The rated voltage of this generator is 12.2 kV, which requires a field current of 275 A. The rated line and armature current of this generator is

$$I_L = \frac{25 \text{ MVA}}{\sqrt{3}(12.2 \text{ kV})} = 1183 \text{ A}$$

The field current required to produce a short-circuit current of 1183 A is about 365 A. Therefore, the short-circuit ratio of this generator is

$$\text{SCR} = \frac{275 \text{ A}}{365 \text{ A}} = 0.75$$

(e) The internal generated voltage of this generator at rated conditions would be calculated using the saturated synchronous reactance, which is about $X_S = 6.57 \ \Omega$ if the field current is 380 A. Since the power factor is 0.9 lagging, the armature current is $\mathbf{I}_A = 1183\angle -25.8° \text{ A}$. The phase voltage is $V_\phi = 12,200/\sqrt{3}\angle 0° \text{ V} = 7044\angle 0° \text{ V}$. Therefore,

$$\mathbf{E}_A = \mathbf{V}_\phi + R_A \mathbf{I}_A + jX_S \mathbf{I}_A$$
$$\mathbf{E}_A = 7044\angle 0° + (0.60 \ \Omega)(1183\angle -25.8° \text{ A}) + j(6.57 \ \Omega)(1183\angle -25.8° \text{ A})$$
$$\mathbf{E}_A = 12,930\angle 31.2° \text{ V}$$

(f) If the internal generated voltage is 12,930 V per phase, the corresponding line value would be $(12,930 \text{ V})(\sqrt{3}) = 22,400 \text{ V}$. This would require a field current of about 470 A.

5-1)

SOLUTION

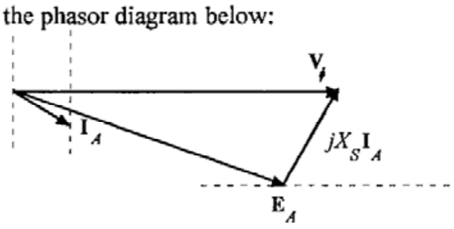
(a) The speed of this motor is given by

$$n_m = \frac{120 f_{se}}{P} = \frac{120(60 \text{ Hz})}{8} = 900 \text{ r/min}$$

(b) If losses are being ignored, the output power is equal to the input power, so the input power will be

$$P_{\text{IN}} = (400 \text{ hp})(746 \text{ W/hp}) = 298.4 \text{ kW}$$

This situation is shown in the phasor diagram below:



The line current flow under these circumstances is

$$I_L = \frac{P}{\sqrt{3}\, V_T \text{ PF}} = \frac{298.4 \text{ kW}}{\sqrt{3}(480 \text{ V})(0.8)} = 449 \text{ A}$$

Because the motor is Δ-connected, the corresponding phase current is $I_A = 449/\sqrt{3} = 259 \text{ A}$. The angle of the current is $-\cos^{-1}(0.80) = -36.87°$, so $\mathbf{I}_A = 259\angle -36.87° \text{ A}$. The internal generated voltage $\mathbf{E}_A$ is

$$\mathbf{E}_A = \mathbf{V}_\phi - jX_S\mathbf{I}_A$$

$$\mathbf{E}_A = (480\angle 0° \text{ V}) - j(0.6\ \Omega)(259\angle -36.87° \text{ A}) = 406\angle -17.8° \text{ V}$$

(c) This motor has 6 poles and an electrical frequency of 60 Hz, so its rotation speed is n_m = 1200 r/min. The induced torque is

$$\tau_{\text{ind}} = \frac{P_{\text{OUT}}}{\omega_m} = \frac{298.4 \text{ kW}}{(900 \text{ r/min})\left(\frac{1 \text{ min}}{60 \text{ s}}\right)\left(\frac{2\pi \text{ rad}}{1 \text{ r}}\right)} = 3166 \text{ N}\cdot\text{m}$$

The maximum possible induced torque for the motor at this field setting is the maximum possible power divided by ω_m

$$\tau_{\text{ind,max}} = \frac{3V_\phi E_A}{\omega_m X_S} = \frac{3(480 \text{ V})(406 \text{ V})}{(900 \text{ r/min})\left(\frac{1 \text{ min}}{60 \text{ s}}\right)\left(\frac{2\pi \text{ rad}}{1 \text{ r}}\right)(0.6\ \Omega)} = 10{,}340 \text{ N}\cdot\text{m}$$

The current operating torque is about 1/3 of the maximum possible torque.

(d) If the magnitude of the intemal generated voltage E_A is increased by 30%, the new torque angle can be found from the fact that $E_A \sin\delta \propto P = \text{constant}$.

$$E_{A2} = 1.30\ E_{A1} = 1.30(406\ \text{V}) = 487.2\ \text{V}$$

$$\delta_2 = \sin^{-1}\left(\frac{E_{A1}}{E_{A2}}\sin\delta_1\right) = \sin^{-1}\left(\frac{406\ \text{V}}{487.2\ \text{V}}\sin(-17.8°)\right) = -14.8°$$

The new armature current is

$$\mathbf{I}_{A2} = \frac{\mathbf{V}_\phi - \mathbf{E}_{A2}}{jX_S} = \frac{480\angle 0°\ \text{V} - 487.2\angle -14.8°\ \text{V}}{j0.6\ \Omega} = 208\angle -4.1°\ \text{A}$$

The magnitude of the armature current is 208 A, and the power factor is cos (-24.1°) = 0.913 lagging.

5-3)

SOLUTION

(a) If this motor is assumed lossless, then the input power is equal to the output power. The input power to this motor is

$$P_{\text{IN}} = \sqrt{3}V_T I_L \cos\theta = \sqrt{3}(230\ \text{V})(40\ \text{A})(1.0) = 15.93\ \text{kW}$$

The rotational speed of the motor is

$$n_m = \frac{120 f_{se}}{P} = \frac{120(50\ \text{Hz})}{4} = 1500\ \text{r/min}$$

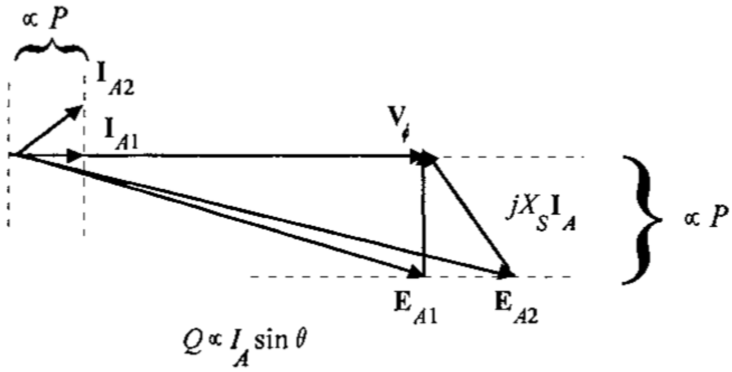
The output torque would be

$$\tau_{\text{LOAD}} = \frac{P_{\text{OUT}}}{\omega_m} = \frac{15.93\ \text{kW}}{(1500\ \text{r/min})\left(\frac{1\ \text{min}}{60\ \text{s}}\right)\left(\frac{2\pi\ \text{rad}}{1\ \text{r}}\right)} = 101.4\ \text{N}\cdot\text{m}$$

In English units,

$$\tau_{\text{LOAD}} = \frac{7.04\ P_{\text{OUT}}}{n_m} = \frac{(7.04)(15.93\ \text{kW})}{(1500\ \text{r/min})} = 74.8\ \text{lb}\cdot\text{ft}$$

(b) To change the motor's power factor to 0.8 leading, its field current must be increased. Since the power supplied to the load is independent of the field current level, an increase in field current increases $|\mathbf{E}_A|$ while keeping the distance $E_A \sin\delta$ constant. This increase in E_A changes the angle of the current $\mathbf{I}_A$, eventually causing it to reach a power factor of 0.8 leading.



(c) The magnitude of the line current will be

$$I_L = \frac{P}{\sqrt{3}\ V_T\ \text{PF}} = \frac{15.93\ \text{kW}}{\sqrt{3}(230\ \text{V})(0.8)} = 50.0\ \text{A}$$