The volume per phase is
\[ V = 118.07 \text{ V} \]
\[ \text{The radian load current is} \]
\[ I = 78.526.32 \text{ W} \]
\[ = \frac{\theta \cdot 105 \text{ V} \cdot \text{A}}{\text{W}} \]
\[ = \theta \cdot 0.099 \text{ V} \]
\[ (\text{For a hp}, 7.16 \text{ hp}) \]
\[ \text{Example 7.5} \]

SOLUTION:

(c) The maximum torque is

(b) The torque angle is

(a) The internal generated voltage is

1. Determine the following:

(a) Power factor of 0.8, the motor efficiency is 0.95. Determine the following:

A three-phase, 100-Hz, 480-V, 4-pole, five-connected, cylindrical synchronous motor has an armature resistance of 0.15 and a synchronous reactance of 1.5. The load and a leading current load of 5.7 A. The synchronous power and torque-angle characteristics of a synchronous generator are as follows:

The superimposed power and torque-angle characteristics of a synchronous generator are as follows:

\[ \text{Figure 7.16} \]

\[ \text{The superimposed power and torque-angle characteristics of a synchronous generator} \]
SELECTED REFERENCES

(c) Since the synchronous speed is

\[ n_s = \frac{60f_1}{p} \]

Thus, the stiffness can be expressed as

\[ K_s = \frac{\Delta P}{\Delta \delta} \]

Example 7.6

Consider the synchronous generator given in Example 7.4 and assume that the machine has eight poles. Determine the following:

(a) The power factor angle \( \delta \) for \( P_s = 1.4316 \) MW per electrical degree.

(b) The power factor angle \( \delta \) for \( P_s = \frac{3E_d \phi}{X_s} \cos \delta \)

(c) The synchronizing power in MW per electrical degree.

(d) The synchronizing torque in MW per mechanical degree.

(e) The synchronizing power is

\[ P_s = 2.48 \times 11.08 \times \frac{3E_d \phi}{X_s} \]

(f) The synchronizing torque is

\[ T_s = 1.27 \times 11.08 \times \frac{3E_d \phi}{X_s} \]

Thus, the stiffness is referred to as synchronizing power. Of course, at pull-out the stiffness of the machine is zero.

The maximum stiffness is referred to as synchronizing power. Of course, at pull-out the stiffness of the machine is zero.
Example 6.3

Understanding

Refer to Figure 6.12. It shows a diagram with power and angle relationships, indicating how power and angle change with respect to each other. The system is illustrated in the diagram, where the power is represented by the angle δ. The system is balanced, and the angles are adjusted to maintain equilibrium.

The conclusion is clear: there is a strong interaction between the system variables. The diagram shows how changes in one variable affect the others, highlighting the interconnection and the balance required for a stable system.

Figure 6.12. Simplified system diagram.
(17%) decrease \[ 1.78' = \left[ \frac{(0.01)(0.89) \sin \phi}{(0.01)(0.89)} \right]^{-1} \sin = \]

\[ \left( \frac{A^{1/2}}{P^1/4} \right)^{-1} \sin = 1 \phi \]

(20%) increase \[ 1.18' = (1.133)(1.133) = 1.39 \]

(11%) increase \[ \left( \frac{L_0}{z(0.1)} \right) - \left( \frac{L_0}{(0.1)(3.5)} \right) = \]

\[ \frac{p_X}{zA} - \frac{p_X}{(0.1)(3.5)} = 1 \phi \]

(5%) increase \[ 2.6' = \left( \frac{(0.01)(3.5)}{L_0} \right)^{-1} \sin = \]

\[ \left( \frac{A^{1/2}}{P^1/4} \right)^{-1} \sin = 1 \phi \]

(20%) increase \[ 1.73' = (1.733)(1.733) = 1.96 \]

(20% decrease) \[ 0.09' = \left( \frac{L_0}{(0.1)(1.5)} \right) - \left( \frac{L_0}{(0.1)(3.5)} \right) = \]

\[ \frac{p_X}{zA} - \frac{p_X}{(0.1)(3.5)} = 0 \phi \]

0.08' = \[ \left( \frac{L_0}{(0.1)(1.5)} \right) - \left( \frac{L_0}{(0.1)(3.5)} \right) = \]

\[ \frac{p_X}{zA} = 0 \phi \]

6.3 The Turbine-Generator-Exciter System
6.4 Operating Limits on Synchronous Generators

A generator is modeled as shown in Figure 6.11 and has $X_p = 1.2$ pu.

Example 6.4

Let $S = 100$ MVA and $I_p = 1$ pu. Calculate the power output of the generator.

\[
\frac{\cos(\theta)}{\frac{L^0}{r}} - \left(0.99\right) = \frac{L^0}{r}
\]

\[
\frac{\cos(\theta)}{A} \frac{L^0}{r} = \frac{\cos(\theta)}{A}
\]

Figure 6.14: Solution to Example 6.3 (a) Initial phasor diagram.

6.4.1 Operating Limits on Synchronous Generators

The synchronous machine is characterized by the following properties:

- The terminal voltage is proportional to the terminal current.
- The terminal current is limited to a certain maximum value.
- The terminal power is limited to a certain maximum value.
- The terminal power factor is limited to a certain maximum value.

We are interested in the synchronous generator as a power source, and there-
Power and Torque Characteristics

The per-phase equivalent circuit for the synchronous generator is shown in Figure 6.24.

Solution

In Figure 6.24, the per-phase equivalent circuit for the synchronous generator is shown.

For the field current as in (a) the prime mover power is supplied by the machine.

If the field excitation current is now increased by 20 percent with the field current as in (a) the prime mover power is supplied by the machine.

The field excitation current is shown in Figure 6.24. Draw the phasor diagram where the field excitation is shown in Figure 6.24.

From Figure 6.24, the power angle is positive.

Power angle

\[ \phi = 2.5^\circ \]

Excitation voltage

\[ E = 206.9 \angle 36.9^\circ \]

\[ E = \sqrt{E_1^2 + X_1} \]

\[ E = \sqrt{120^2 + 0.9^2} \]

\[ E = 206.9 \angle 36.9^\circ \]

For the field excitation angle of 0.8, the field excitation is shown in Figure 6.24.

In power and torque characteristics, the angle is

\[ \frac{d}{dz} \frac{1}{\cos \phi} \sin \phi = \frac{d}{dz} \]

In Figure 6.24, the torque is

\[ \frac{d}{dz} = \frac{d}{dz} \frac{d}{dz} = \frac{d}{dz} \]

The torque-speed characteristic is shown in Figure 6.24.

\[ \text{Field and Torque Characteristics} \]

Synchronous Machines

\[ \text{Power and Torque Characteristics} \]
EXAMPLE 6.4

Power factor = \cos 30.1^{\circ} = 0.869 \text{ Leading}

\text{Example 6.3 is repeated as a synchronous machine.}

\text{Power factor} = \cos 30.1^{\circ} = 0.869 \text{ Leading}

\text{Synchronous machine in Example 6.3 is operated as a synchronous machine.}

\text{Solution}

\text{The motor can deliver more torque than the maximum torque (i.e., pull-out torque) that the field excitation is held constant and the shaft load is slowly increased. Determine the maximum torque.}

\text{If the field excitation is held constant and the shaft load is slowly increased, the torque delivered by the motor can exceed the pull-out torque.}

\text{Find the excitation voltage and the power angle. Draw the phasor diagram for this condition.}

\begin{align*}
\text{From the supply:} & \quad V = 206.9 \text{ V}, \quad I = 0.869 \text{ A}, \quad \phi = 30.1^{\circ} \text{ Leading} \\
\text{From the two triangles abc and add.} & \quad A = \left(120^2 + 206.9^2 + 120 \times 206.9 \times \frac{8}{120} \right)^{1/2}
\end{align*}

\begin{align*}
\rho & = \frac{\text{power}}{\text{lag}} = \frac{\text{delta}}{\text{lag}} \\
\phi & = \frac{\text{phi}}{\text{lag}} = \frac{\text{phi}}{\text{lag}} \\
\rho & = \frac{\text{power}}{\text{lag}} = \frac{\text{delta}}{\text{lag}}
\end{align*}

\text{From the phasor diagram, quadrature with \(I_x\), \(V_x\), \(E_x\) is the voltage drop \(I_x E_x\), and the current phasor \(I_x\) is in series with \(V_x\) and \(E_x\). The voltage \(V_x\) leads \(V\) by 90\(^\circ\). The distance \(I_x E_x\) between \(I_x E_x\) and \(I\) is the distance between \(I_x E_x\) and \(I\). Because \(I_x + I\) is \(90\(^\circ\), \(I\) leads \(E\) by 90\(^\circ\).}

\text{The phasor diagram for the maximum power transfer condition.}

\text{The stator current and power factor can also be obtained by drawing the phasor diagram as shown in Figure 6.3.}

\begin{align*}
\text{Power factor} & = \cos 30.1^{\circ} = 0.869 \text{ Leading} \\
\text{Stator current} & = I = 29.9 \text{ A}
\end{align*}