6-1. A 480-V 400-kVA 0.85-PF-lagging 50-Hz four-pole Δ-connected generator is driven by a 500-hp diesel engine and is used as a standby or emergency generator. This machine can also be paralleled with the normal power supply (a very large power system) if desired.

(a) What are the conditions required for paralleling the emergency generator with the existing power system? What is the generator’s rate of shaft rotation after paralleling occurs?

(b) If the generator is connected to the power system and is initially floating on the line, sketch the resulting magnetic fields and phasor diagram.

(c) The governor setting on the diesel is now increased. Show both by means of house diagrams and by means of phasor diagrams what happens to the generator. How much reactive power does the generator supply now?

(d) With the diesel generator now supplying real power to the power system, what happens to the generator as its field current is increased and decreased? Show this behavior both with phasor diagrams and with house diagrams.

SOLUTION

(a) To parallel this generator to the large power system, the required conditions are:

1. The generator must have the same voltage as the power system.
2. The phase sequence of the oncoming generator must be the same as the phase sequence of the power system.
3. The frequency of the oncoming generator should be slightly higher than the frequency of the running system.
4. The circuit breaker connecting the two systems together should be shut when the above conditions are met and the generator is in phase with the power system.

After paralleling, the generator’s shaft will be rotating at

$$n_a = \frac{120 f_e}{P} = \frac{120(50 \text{ Hz})}{4} = 1500 \text{ r/min}$$

(b) The magnetic field and phasor diagrams immediately after paralleling are shown below:

(c) When the governor setpoints on the generator are increased, the emergency generator begins to supply more power to the loads, as shown below:
Note that as the load increased with $|E_A|$ constant, the generator began to consume a small amount of reactive power.

(d) With the generator now supplying power to the system, an increase in field current increases the reactive power supplied to the loads, and a decrease in field current decreases the reactive power supplied to the loads.

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6-2. A 13.5-kV 20-MVA 0.8-PF-lagging 60-Hz three-phase Y-connected steam-turbine generator has a synchronous reactance of 5.0 Ω per phase and an armature reactance of 0.5 Ω per phase. This generator is operating in parallel with a large power system (infinite bus).

(a) What is the magnitude of $E_A$ at rated conditions?

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

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

(d) At the absolute maximum power possible, how much reactive power will this generator be supplying or consuming? Sketch the corresponding phasor diagram. (Assume $I_F$ is still unchanged.)
SOLUTION

(a) The phase voltage of this generator at rated conditions is

\[ V_\phi = \frac{V_f}{\sqrt{3}} = \frac{13.5 \text{ kV}}{\sqrt{3}} = 7794 \text{ V} \]

The armature current per phase at rated conditions is

\[ I_A = \frac{S}{\sqrt{3} V_f} = \frac{20,000,000 \text{ VA}}{\sqrt{3} (13,500 \text{ V})} = 855 \text{ A} \]

Therefore, the internal generated voltage at rated conditions is

\[ E_A = V_\phi + R_A I_A + jX_A I_A \]

\[ E_A = 7794 \angle 0^\circ + (0.5 \text{ } \Omega)(855 \angle -36.87^\circ \text{ A}) + j(5.0 \text{ } \Omega)(855 \angle -36.87^\circ \text{ A}) \]

\[ E_A = 11,160 \angle 16.5^\circ \text{ V} \]

The magnitude of \( E_A \) is 11,160 V.

(b) The torque angle of the generator at rated conditions is \( \delta = 16.5^\circ \).

(c) Ignoring \( R_A \), the maximum output power of the generator is given by

\[ P_{\text{MAX}} = \frac{3 V_\phi E_A}{X_\phi} = \frac{3(7794 \text{ V})(11,160 \text{ V})}{5 \text{ } \Omega} = 52.2 \text{ MW} \]

(d) The phasor diagram at these conditions is shown below:

Under these conditions, the armature current is

\[ I_A = \frac{E_A - V_\phi}{R_A + jX_A} = \frac{11,650 \angle 90^\circ \text{ V} - 7794 \angle 0^\circ \text{ V}}{0.5 + j5.0 \text{ } \Omega} = 2790 \angle 39.5^\circ \text{ A} \]

The reactive power produced by the generator is

\[ Q = 3 V_\phi I_A \sin \theta = 3(7794 \text{ V})(2790 \text{ A}) \sin (0^\circ - 39.5^\circ) = -41.5 \text{ MVAR} \]

The generator is actually consuming reactive power at this time.
**Problem 3:**

\[
Z_n = \frac{(E_n)^2}{S_n} = \frac{(19000)^2}{(722 \text{ M})} = 0.5 \text{ Ohms}
\]

\[
X_s = 1.3 \times 0.5 = 0.65 \text{ Ohms}
\]

\[
E_0 = 1.2 \times 19 \times (3)^{1/2} = 13.16 \text{ kV}
\]

\[
E = \frac{19}{(3)^{1/2}} = 11 \text{ kV}
\]

a. \[P = \frac{(E \times E_0)}{X_s} \sin \delta = \frac{(11 \times 13.16)}{0.65} \sin 20 = 76.17 \text{ MW} \times 3 = 228.5 \text{ MW}\]

b.

![Diagram showing power flow with \(E_0 = 13.16 \text{ kV}\) and \(X_s = 0.65 \Omega\).]

c.

![Diagram showing voltage and current angles with \(E_0 = 13.16\) kV, \(E = 11 \text{ kV}\), \(I = 7230 \text{ A}\), and \(\angle I = 20\) degrees; \(\angle II = 16.88\) degrees.]
\[ E_0 = 13.16 \angle +20 \quad E = 11 \angle 0 \]

\[-E_0 + j IX_s + E = 0\]

Therefore, \( I = \frac{j(E-E_0)}{X_s} \)

\[ I = \frac{j(11-13.16 \cos 20 - j 13.16 \sin 20)}{0.65} \]
\[ = 7230 \angle -16.88 \text{ A.} \]

**Problem 4:**

a) \( V = 1 \angle 0 \text{ degree} \)

\[ \psi_0 = \frac{1}{\cos (0.8)} = 36.9 \text{ degrees} \]

Therefore

\[ I_0 = 1 \angle -36.9 = 0.8 - j0.6 \]

\[ E_{fo} = j X d . I_0 + V \]
\[ = j 0.7(0.8-j0.6)+1 \]
\[ = 1.42 + j 0.56 \]
\[ = 1.53 \angle 21.5 \text{ degrees} \]

Therefore,

\[ E_{fo} = 1.53 \]

\[ \delta_0 = 21.5 \text{ degrees} \]

\[ P_0 = \frac{(E_{fo} \cdot V)}{(X_d)} \cdot \sin \delta_0 \]
\[ = \frac{(1.53)(1.0)}{0.7} \cdot \sin (21.5) = 0.800 \]

\[ Q_0 = \frac{(E_{fo} \cdot V)}{X_d} \cdot \cos \delta - \frac{(V^2)}{X_d} \]
\[ = \frac{(1.53)(1.0)}{0.7} \cdot \cos (21.5) - (1.0)^2 / 0.7 \]
\[ = 0.60. \]

b) \( P_1 = 1.2 \)

\[ P_0 = 1.2(0.8) = 0.96 \ (20\% \ increase) \]

\[ E_{f1} = E_{fo} = 1.53 \ (no \ change) \]

Therefore

\[ \delta_1 = \text{inverse of sin} \ [\frac{(P_1 \cdot X_d)}{(E_{f1} \cdot V)}] \]
\[ = 26.1 \text{ degrees } \ (21\% \ increase) \]
Q1 = \[Efo \cdot \frac{V}{Xd} \cos(\delta_i) - \left(\frac{V^2}{Xd}\right)\]

= 0.535 (11% decrease)

c) P1 = P0 = 0.8 (no change)

Ef1 = 1.2 Ef0 = 1.2(1.53) = 1.84 (20% increase)

\[\delta_1 = \text{inverse of } \sin \left(\frac{P1 \cdot Xd}{Ef1 \cdot V}\right)\]

= 17.8. (17% decrease)

Q1 = \(\frac{Ef1 \cdot V}{Xd} \cos \delta - \left(\frac{V^2}{Xd}\right)\)

= 1.07 (78% increase).

Phasor Diagrams:

a) Initial Phasor Diagram:

b) 20% increase in P
\[ i_1 = \delta \, l; \]

c) 20\% increase in \( E_f \)