Q1)

Ea is proportional to flux x frequency. So, higher frequency implies the need for less flux in order to produce the same amount of induced voltage. The need for less flux means the need for a smaller field winding, a smaller exciter, and hence a smaller rotor. This, in turn, implies a smaller machine.

Q2)

(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

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

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.

(f) The input power to this generator is equal to the output power plus losses. The rated output power is

$$P_{OUT} = (50\text{ MVA})(0.9) = 45\text{ MW}$$

$$P_{CU} = 3I_A^{\,2}R_A = 3(2092\text{ A})^2(0.2\ \Omega) = 2.6\text{ MW}$$

$$P_{F\&W} = 1 \text{ MW}$$

$$P_{core} = 1.5 \text{ MW}$$

$$P_{stray} = (\text{assumed } 0)$$

$$P_{IN} = P_{OUT} + P_{CU} + P_{F\&W} + P_{core} + P_{stray} = 50.1 \text{ MW}$$

Therefore the prime mover must be capable of supplying 50.1 MW. Since the generator is a four-pole 60 Hz machine, to must be turning at 1800 r/min. The required torque is

$$\tau_{APP} = \frac{P_{IN}}{\omega_m} = \frac{50.1 \text{ MW}}{(1800 \text{ r/min})\left(\frac{1 \text{ min}}{60 \text{ s}}\right)\left(\frac{2\pi \text{ rad}}{1 \text{ r}}\right)} = 265,800 \text{ N}\cdot\text{m}$$

Q3)

Consider the phasor diagram of Fig. 6.17a and equivalent circuit of Fig. 6.14e.

$$V_t = \frac{11000}{\sqrt{3}} = 6350.9 \text{ V}$$

$$I_a = \frac{25 \times 10^6}{\sqrt{3} \times 11 \times 10^3} = 1312.2 \text{ A}$$

$$\theta = \cos^{-1} 0.85 = 31.8°$$

$$I_a = 1312.2 \angle -31.8° \text{ A}$$

The excitation voltage E_f is

$$E_f = 6350.9 \angle 0° + 1312.2 \angle -31.8° \,(0.45 + j4.5) = 11020.3 \angle 25.3° \text{ V}$$

Q4)

$$V_t = 6350.9 \text{ V}$$

$$I_a = 1312.2 \angle -31.8° \text{ A}$$

$$E_f = V_t \angle 0° - I_a \angle \theta_{I_a} \cdot (R \;\; + jX \;\;)$$

$$= 6350.9 \angle 0° - 1312.2 \angle -31.8° \,(0.45 + j4.5)$$

$$= 5445.4 \angle -59.8° \text{ V}$$

Q5)

The key to this problem is to think of the combination of X_s and the transmission lines as an equivalent X_s'. Then the problem is to work to find $\boldsymbol{E_a}$ (note, E_f could be used instead of E_a in calculations - different subscript for same quantity, open circuit voltage) before the outage, then the new value of δ after the outage.

Before the outage, the current supplied to the infinite bus is

$$\left|\bar{I}_a\right| = \frac{S_\phi}{V_\phi} = \frac{100MVA/3}{25kV/\sqrt{3}} = 2.31kA$$

The angle is

$$\theta = -\cos^{-1} pf = -\cos^{-1} 0.8 = -36.9°$$ (which seems to be a popular angle)

The original value of $\boldsymbol{E_a}$ is

$$\bar{E}_a = \bar{V}_t + j\bar{I}_a X_s' = \frac{25}{\sqrt{3}} + j2.31\angle -36.9 \cdot 3.5$$

Note that $X_s' = 3.5\Omega$

$$\bar{E}_a = 14.4 + 8.08\angle 53.1° = 14.4 + 4.85 + j6.46 = 19.25 + j6.46 = 20.3\angle 18.6° kV$$

Now consider what happens when the line trips. X_s' goes up, and becomes $X_s'' = 4.5\Omega$. The torque does not change, so the real power stays constant. The field current does not change, so the magnitude of E_a does not change. The power angle δ must therefore change. (This problem illustrates the danger of learning rules like the locus of constant power. That locus assumes that X_s stays constant. In this problem, X_s changed.)

So

$$P = \frac{E_a V_t}{X_s'}\sin\delta = \frac{E_a V_t}{X_s''}\sin\delta'$$

$$\sin\delta' = \frac{X_s''}{X_s'}\sin\delta = \frac{4.5}{3.5}\sin 18.6° = 0.41$$

$$\delta' = \sin^{-1} 0.41 = 24.2°$$

Let's just note that

$$P = S \cdot pf = 1MVA \cdot 0.8 = 800MW$$ and does not change. Reactive power Q, however, changes.

The new Q, Q', is

$$Q' = \frac{E_a V_t}{X_s''}\cos\delta' - \frac{V_t^2}{X_s''} = \frac{20.3 \cdot 14.4}{4.5}\cos 24.2 - \frac{14.4^2}{4.5} = 65 \cdot 0.91 - 46 = 13.2MVAR$$

Now, line to neutral voltage values were used in this calculation, so this is actually the per-phase reactive power. The total reactive power is

$$Q_{3\phi}' = 3 \cdot 13.2 = 39.6MVAR$$

Complex power

$$S = 800 + j39.6MVA = 801MVA\angle 2.83°$$

or 801 MVA at a power factor of 0.999 current lagging - the outage has improved the power factor the generator and line deliver to the infinite bus.