EE4010
Electrical Power Systems

Three-Phase Synchronous Machine Problems

Q.1 A 1500 kVA, 6.6 kV, three-phase, star-connected, round-rotor synchronous machine has a phase resistance of $0.5\,\Omega/\text{phase}$ and a synchronous reactance of $5.0\,\Omega/\text{phase}$. Calculate the percentage change in the terminal voltage when the rated output of 1500 kVA at a power factor of 0.8 lagging is switched off. Assume that the machine is initially operating at rated voltage and frequency and that the speed and the excitation current remain unchanged.

[+12.43%]

Q.2 Two similar three-phase star-connected round-rotor synchronous generators, designated Set 1 and Set 2, are connected in parallel with each other. Each machine has a synchronous reactance of $j4.5\,\Omega/\text{phase}$ and negligible resistance. The field current excitation to each generator is adjusted until its internal emf has a magnitude of 1910 V/phase. The prime mover inputs are adjusted until it is found that the internal emf of Set 1 has a positive phase displacement of $30°$ relative to that of Set 2. Under these circumstances, calculate (i) the circulating current, (ii) the per-phase terminal voltage, (iii) the active power supplied from Set 1 to Set 2. Sketch the phasor diagram corresponding to this situation.

[109.8 A, 1845 V, 608 kW]

Q.3 The prime mover inputs to the two generator sets in the previous question are altered until their internal emf's are exactly in phase opposition. The field current excitation to Set 1 is adjusted until its internal emf has a magnitude of 2240 V/phase while that of Set 2 is adjusted until its emf is equal to 1600 V/phase. Calculate the circulating current and the per-phase terminal voltage of the machines under these circumstances. Sketch the phasor diagram corresponding to this situation.

[71.1 A, 1920 V]

Q.4 A three-phase, round-rotor synchronous generator is supplying 2.8 MW of power at a power factor of 0.7 lagging to a manufacturing plant. Under these operating conditions, this machine is at its full rated capacity. If the generator power factor is increased to unity by the installation of a three-phase synchronous motor, how much more active power can the generator supply and what must be the power factor of the synchronous motor assuming that this machine absorbs all of the extra real power obtainable from the generator.

[1.2 MW, 0.387 leading]

Q.5 A three-phase, 50 Hz, star-connected, round-rotor synchronous generator is driven by its prime mover at 1000 rpm and at this speed it develops an open circuit line voltage of 460 V when the field current is set to 16 A. The machine has a synchronous reactance of $j2.0\,\Omega/\text{phase}$ and negligible winding resistance. Calculate the driving torque required of the prime mover when the machine is supplying a current of 50 A/phase to a load at a power factor of 0.8 lagging. Assume that the field current and the speed remain constant at 16 A/phase and 1000 rpm, respectively. Neglect magnetic core losses and mechanical friction and windage losses.

[221.4 Nm]

Q.6 A three-phase round-rotor synchronous generator delivers 1.0 pu current at 1.0 pu terminal voltage and a power factor of 0.8 lagging to a set of infinite three-phase busbars. The synchronous reactance of the alternator is $j1.0$ pu and the phase winding resistance may be neglected.

(i) Calculate the internal emf of the machine, the load angle of the machine and the real and reactive power transfers to the set of infinite busbars.

[1.79. 26.56°, 0.8, 0.6]

(ii) If the excitation is now increased by 20% relative to that in (i), calculate the new load angle, the new armature current, the new operating power factor and the new real and reactive power transfers to the set of infinite busbars.

[21.88° 1.27, 0.627, 0.8, 0.992]

(iii) If the excitation were reduced again to that of Case (i), and the mechanical output power from the primer mover is increased by 20%, calculate the new values of the alternator load angle, the armature current and the operating power factor and the real and reactive power transfers to the set of infinite busbars.

[32.45° 1.087, 0.883, 0.96, 0.509]

Q.7 Derive expressions for the real power P and the reactive power Q delivered by a three-phase, round-rotor synchronous generator to an infinite system in terms of the terminal voltage V_t, the generated back-emf, E_f, the synchronous reactance X_s and the load angle δ. Resistive losses, hysteresis and eddy current losses and magnetic saturation may be neglected.

Prove that if the locus of the real and reactive powers are plotted in the complex power plane, $\overline{S} = P + jQ$, then the locus will be a circle of radius

$$r = \frac{E_f V_t}{X_s}$$

with a centre

$$c = \left(0, -\frac{V_t^2}{X_s}\right)$$

on the Q axis. Draw loci corresponding to two values of E_f. For a given operating point, indicate the load angle δ and the power factor angle ϕ on the complex plane. On this plane, draw curves indicating the limits due to armature heating and field current heating.

Q.8 A three-phase synchronous generator operating at 0.6 p.u. load is connected to the grid through an interconnector such that the power/load angle curve is $P(\delta) = 1.3Sin(\delta)$. A three-phase fault occurs on the interconnector which changes the power curve to $P_1 = 0.1Sin(\delta)$ until the fault is cleared when the system reverts to the original load/angle curve. Calculate the critical clearing angle to maintain transient stability.

[87°]

Q.9 A 500 MVA generator with 0.2 p.u. reactance is connected to a large power system via a transformer and overhead line which have a combined reactance of 0.3 p.u. The generator delivers 450 MW to the power system. All p.u. values are on a 500 MVA base. The magnitude of the voltage at both the generator terminals and at the large power system is 1.0 p.u. Calculate the excitation voltage of the generator and the critical clearing angle to maintain transient stability for a three-phase short circuit at the generator terminals.

[86°]