EE3124 Assignment 2 (Solution)

Name: **Student No.:**

Q1 – Specify the differences between Synchronous Motor and Asynchronous (Induction) Motor. (15 pts)

Solution: (Any 5 will be marked full point.)

Synchronous Motor	**Asynchronous (Induction) Motor**
Runs at synchronous speed	Runs on speed less than the synchronous speed
No slip i.e. the slip of synchronous motor is equal to 0	Slip in induction motor and it is always greater than 0
The speed of the motor depends on the supply frequency and the number of stator poles. $N_s = 120f / P$	The speed of the motor depends on the load, rotor resistance and the slip, s. it is always less than synchronous speed.
It is not self-start and require extra windings for starting the motor	Asynchronous motors are self-start and do not require extra mechanism.
Separately excited synchronous motor requires extra DC source to energize its rotor winding.	It does not require any extra source.
The fluctuations in the main supply voltage do not affect synchronous motor operation.	The mains voltage fluctuation affects its speed and operation.
It is operation is complicated.	It is operation is simple and user friendly.
By changing excitation the power factor can be adjusted accordingly as lagging, leading or unity.	Asynchronous motor runs only at a lagging power factor.

Q2 – How many major starting techniques for the starting single phase induction motors? And briefly explain the reason why the capacitor start and run motors can help to produce the start torque. (5 pts)

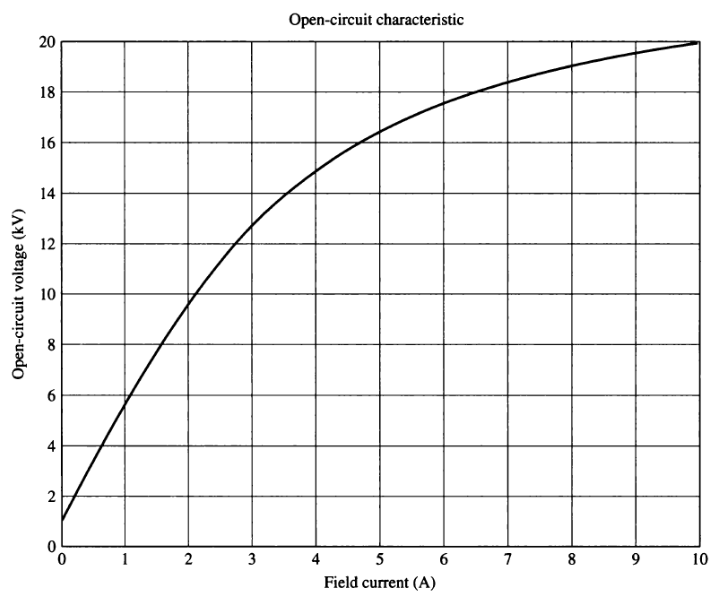
Solution

The three major starting techniques are

a. Split-phase windings
b. Capacitor-type windings
c. Shaded stator poles

In a capacitor-start motor, a capacitor is placed in series with the auxiliary winding of the motor. By proper selection of capacitor size, the magnetomotive force of the starting current in the auxiliary winding can be adjusted to be equal to the magnetomotive force of the current in the main winding, and the phase angle of the current in the auxiliary winding can be made to lead the current in the main winding by 90°. Thus, the rotating magnetic field will be produces as well as the starting torque.

Q3 - A 13.8-kV, 50-MVA, 0.9-power-factor-lagging, 60-Hz, four-pole Y-connected synchronous generator has a synchronous reactance of 2.5 Ω and an armature resistance of 0.2 Ω. At 60 Hz, its friction and windage losses are 1 MW, and its core losses are 1.5 MW. The field circuit has a DC voltage of 120 V, and the maximum I_F is 10 A. The current of the field circuit is adjustable over the range from 0 to 10 A. The OCC of this generator is shown as follows. (30 pts)



(a) How much field current is required to make the terminal voltage V_T (or line voltage V_L) equal to 13.8 kV when the generator is running at no load?

(b) What is the internal generated voltage E_A of this machine at rated conditions?

(c) What is the phase voltage V_ϕ of this generator at rated conditions?

(d) How much field current is required to make the terminal voltage V_T equal to 13.8 kV when the generator is running at rated conditions?

(e) Suppose that this generator is running at rated conditions, and then the load is removed without changing the field current. What would the terminal voltage of the generator be?

(f) How much steady-state power and torque must the generator's prime mover be capable of supplying to handle the rated conditions?

Solution

(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

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

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

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

$$\mathbf{E}_A = 7967\angle 0^\circ + (0.20\ \Omega)(2092\angle -25.8^\circ\text{ A}) + j(2.5\ \Omega)(2092\angle -25.8^\circ\text{ A})$$

$$\mathbf{E}_A = 11544\angle 23.1^\circ\text{ V}$$

(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

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

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

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

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

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

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

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

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

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

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

Q4 - A 480-V, 60 Hz, 298.4 kW, 0.8-PF-leading eight-pole Δ-connected synchronous motor has a synchronous reactance of 0.6 **Ω** and negligible armature resistance. Ignore its friction, windage, and core losses for the purposes of this problem. Assume that $|\mathbf{E}_A|$ is directly proportional to the field current I_F (in other words, assume that the motor operates in the linear part of the magnetization curve), and that $\mathbf{E}_A$ = 480 V when I_F = 4 A. When the motor is operating at rated conditions. (20 pts)

(a) What are the magnitudes and angles of E_A, I_A and I_F?

(b) Suppose the load is removed from the motor. What are the magnitudes and angles of E_A, I_A now?

Solution

(a) The line current flow at rated conditions 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

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

$$\mathbf{E}_A = (480\angle 0°\text{ V}) - j(0.6\ \Omega)(259\angle 36.87°\text{ A}) = 587\angle -12.2°\text{ V}$$

The field current is directly proportional to $|\mathbf{E}_A|$, with = 480 V when I_F = 4 A. Since the real $|\mathbf{E}_A|$ is 587 V, the required field current is

$$\frac{|\mathbf{E}_{A2}|}{|\mathbf{E}_{A1}|} = \frac{I_{F2}}{I_{F1}}$$

$$I_{F2} = \frac{|\mathbf{E}_{A2}|}{|\mathbf{E}_{A1}|} I_{F1} = \frac{587\text{ V}}{480\text{ V}}(4\text{ A}) = 4.89\text{ A}$$

(b) When the load is removed from the motor the magnitude of $|\mathbf{E}_A|$ remains unchanged but the torque angle goes to $\delta = 0°$. The resulting armature current is

$$\mathbf{I}_A = \frac{\mathbf{V}_\phi - \mathbf{E}_A}{jX_S} = \frac{480\angle 0°\text{ V} - 587\angle 0°}{j0.6\ \Omega} = 178.3\angle 90°\text{ A}$$

Q5 – A rated output power 67 hp, 460-V, 50-Hz, two-pole induction motor has a slip of 5 percent when operating a full-load conditions. At full-load conditions, the friction and windage losses are 700 W, and the core losses are 600 W. Find the following values for full-load conditions:

(a) The shaft speed n_m (10 pts)

(b) The output power in watts (5 pts)

(c) The load torque τ_{load} in newton-meters (5 pts)

(d) The induced torque τ_{ind} in newton-meters (5 pts)

(e) The rotor frequency in hertz (5 pts)

Solution

(a) The synchronous speed of this machine is

$$n_{\text{sync}} = \frac{120 f_{se}}{P} = \frac{120(50\text{ Hz})}{2} = 3000\text{ r/min}$$

Therefore, the shaft speed is

$$n_m = (1-s)\,n_{\text{sync}} = (1-0.05)(3000\text{ r/min}) = 2850\text{ r/min}$$

(b) The output power in watts is 50 kW (stated in the problem).

(c) The load torque is

$$\tau_{\text{load}} = \frac{P_{\text{OUT}}}{\omega_m} = \frac{50\text{ kW}}{(2850\text{ r/min})\left(\frac{2\pi\text{ rad}}{1\text{ r}}\right)\left(\frac{1\text{ min}}{60\text{ s}}\right)} = 167.5\text{ N}\cdot\text{m}$$

(d) The induced torque can be found as follows:

$$P_{\text{conv}} = P_{\text{OUT}} + P_{\text{F\&W}} + P_{\text{misc}} = 50\text{ kW} + 700\text{ W} + 0\text{ W} = 50.7\text{ kW}$$

$$\tau_{\text{ind}} = \frac{P_{\text{conv}}}{\omega_m} = \frac{50.7\text{kW}}{(2850\text{ r/min})\left(\frac{2\pi\text{ rad}}{1\text{ r}}\right)\left(\frac{1\text{ min}}{60\text{ s}}\right)} = 170\ \ \text{N}\cdot\text{m}$$

(e) The rotor frequency is

$$f_r = sf_e = (0.05)(50\text{ Hz}) = 2.5\text{ Hz}$$