Benha University
Faculty of Engineering–Benha
Department : Electrical Engineering
3rd year : Power and Control
Exam : Final-Solution
Subject : Electrical Machines II

Date : Wednesday 15-6-2022
Time : 3.0 hrs.
Code : E1338
Examiner: Dr. Abdelnasser Nafeh

Answer the Following Questions

Question 1: [20 Marks]

1. A three-phase, six-pole, 460-V, 60-Hz induction motor rated at 15-hp, 1182 r/min is driven by a turbine at 1215 r/min and the motor parameters in ohms/phase are:

$R_1 = 0.2$	$X_1 = 1.2$	$X_M = 42$
$R_2 = 0.25$	$X_2 = 1.29$	$R_{fe} = 317$

Determine the active power that the machine delivers to the system.

2. The following data were obtained from no-load, and DC tests of a three phase, wye-connected, 40-hp, 60-Hz, 460-V, design **B** induction motor whose full load current is 57.8-A. the blocked rotor test was made at 15-Hz.

Blocked Rotor Test	No-Load Test	DC-Test
$V_L = 36.2$ V	$V_L = 460$ V	$V_{DC} = 12$ V
$I_L = 58$ A	$I_L = 32.7$ A	$I_{DC} = 59$ A
$P_{3\text{-Phase}} = 2573.4$ W	$P_{3\text{-Phase}} = 4664.4$ W	

Determine **(a)** the machine parameters in ohms/phase, and the combined core, friction, and windage loss.

(b) Express the no-load current as a percent of rated current.

Question 2: [20 Marks]

3. A 3-phase, 60-Hz, 460-V system supplies the following loads:

a. A six-pole, 60-Hz, 400-hp, 3-phase, wye-connected induction motor, operating at three-quarters rated load with an efficiency of 95.8 percent and power factor of 89.1 percent.

b. A 50-kW, delta-connected, 3-phase resistance heater.

c. A 300-hp, 60-Hz, 4-pole, wye-connected, cylindrical-rotor synchronous motor, operating at one-half rated load, with a torque angle of -16.4^{o}. Neglecting copper losses, the synchronous motor is operating at 96 percent efficiency, and its synchronous reactance is 0.667 Ω/phase.

Determine **(a)** system active power; **(b)** power factor of synchronous motor; **(c)** system power factor; **(d)** percent change in synchronous motor field current required to adjust the system power factor to unity (neglect saturation effects); **(e)** power angle of the synchronous motor for condition in **(d).**

4. A 1000 kVA, 11 kV, 3-phase star-connected synchronous motor has an armature resistance and reactance per phase of 3.5 Ω and 40 Ω respectively. ***Determine*** the induced emf and angular retardation of the rotor when fully loaded at **(a)** unity power factor, **(b)** 0.8 power factor lagging. **(c)** 0.8 power factor leading.

Question 3: [25 Marks]

5. A three-phase star connected 1200 kVA, 3300 V, 50 Hz, alternator has armature resistance of 0·25 ohm per phase. A field current of 40 A produces a short circuit current of 200 A and an open circuit emf of 1100 V between lines. ***Calculate*** regulation on full load 0·8 power factor lagging.

6. A 3-phase, 5 MVA, 11 kV, 60 Hz synchronous machine has a synchronous reactance of 10 ohms per phase and has negligible stator resistance. The machine is connected to the 11 kV, 60 Hz bus and is operated as a synchronous condenser.

1. Neglect rotational losses.

(a) For normal excitation, ***find*** the stator current. Draw the phasor diagram.

(b) If the excitation is increased to 150 percent of the normal excitation, **find** the stator current and power factor. Draw the phasor diagram.

(c) If the excitation is decreased to 50 percent of the normal excitation, **find** the stator current and power factor. Draw the phasor diagram.

2. If the rotational losses are 80 kW, **find** the stator current and excitation voltage for normal excitation. Draw the phasor diagram.

Question 4: [10 Marks] ……. Short Answer Required.

1. Classify 3-phase induction motors on the basis of their construction. Which one is generally preferred and why?
2. Why the rotor conductors of the squirrel cage rotor are short-circuited in the case of slip-ring induction motors, the rotor circuit is closed through resistors?
3. Does rotor resistance affect the maximum torque developed in the induction motor?
4. What are constant and variable losses in an induction motor?
5. Why two reaction theory is applied only to salient pole synchronous machines?

Question 5: [15 Marks] …Chose the correct answer, and Please, Draw Answer Table only for this Part.

1. A The direction of rotation of a 3-phase induction motor is clockwise when it is supplied with phase sequence R-Y-B. If its direction of rotation is to be reversed. The phase sequence of the power supply should be (a) Y-R-B (b) R-B-Y (c) B-Y-R (d) all of these.
2. The synchronous speed of an induction motor is 1000 rpm. What will be slip when it is running at a speed of 960 rpm? (a) +5%. (b) –5% (c) +4% (d) –3%.
3. If the rotor resistance is increased in a slip-ring induction motor, then (a) both starting torque and pf will increase. (b) both starting torque and pf will decrease. (c) starting torque decreases but pf increases. (d) starting torque increases but pf decreases.
4. The power input in blocked-rotor test performed on a 3-phase induction motor is approximately equal to (a) iron loss in the core. (b) hysteresis loss in the core (c) eddy current loss in the core (d) copper loss in the windings.
5. If the air-gap in an induction motor is increased, its (a) speed will reduce. (b) power factor will be lowered. (c) efficiency will improve. (d) breakdown torque will reduce.
6. The most widely used motor is (a) double cage induction motor. (b) slip-ring induction motor. (c) squirrel cage induction motor. (d) synchronous motor.
7. A syn. motor is switched on to supply with its field winding shorted on themselves. It will (*a*) not start (*b*) start and continue to run as an induction motor (*c*) start as Induction motor and then run as Syn. Motor (*d*) none of these.
8. Slip rings in a synchronous motor carry: (a) DC (b) AC (c) both a and b (d) no current.
9. The maximum value of torque that a syn. motor can develop without losing its synchronism is called: (a) slip torque (b) pullout torque (c) breaking torque (d) syn. torque.
10. Squirrel cage winding is provided on a synchronous motor to make it (a) noise free (b) self-starting (c) cheap. (d) quick start.
11. An exciter is nothing but a (a) DC shunt motor (b) DC series (c) DC shunt generator (d) DC series generator.
12. Synchronous reactance of an alternator represents (*a*) armature reaction reactance and leakage reactance. (*b*) leakage reactance and field winding reactance. (*c*) field winding reactance and armature reaction reactance (*d*) a reactance connected in series with a synchronous generator.
13. Which of the following is not an essential conditions for parallel operation of two alternators? (*a*) identical terminal voltage for two machines (*b*) same phase sequence for two machines (*c*) same kVA rating for two machines (*d*) same frequency of voltage generated.
14. An infinite bus-bar has (a) constant voltage. (b) constant frequency. (c) constant current (d) both (a) and (b).
15. An inductive load is shared by two identical synchronous generators A and B equally, if the excitation of alternator A is increased. (a) Alternator A will deliver more current and alternator B will deliver less current. (b) Alternator B will deliver more current and alternator A will deliver less current. (c) both will continue to deliver same current. (d) both will deliver more current.

Best wishes,

***Question 1*: [20 Marks]**

1. A three-phase, six-pole, 460-V, 60-Hz induction motor rated at 15-hp, 1182 r/min is driven by a turbine at 1215 r/min and the motor parameters in ohms/phase are:

$R_1 = 0.2$	$X_1 = 1.2$	$X_M = 42$
$R_2 = 0.25$	$X_2 = 1.29$	$R_{fe} = 317$

Determine the active power that the machine delivers to the system.

Solution

$$s = \frac{n_s - n_r}{n_s} = \frac{1200 - 1215}{1200} = -0.0125$$

$$Z_2 = \frac{R_2}{s} + jX_2 = -20.0 + j1.29 = 20.0416\angle 176.30^\circ\ \Omega$$

Note: The apparent equivalent resistance is negative ($R_2/s = -20$) when operating as an induction generator.

$$Z_0 = \frac{R_{fe} \cdot jX_M}{R_{fe} + jX_M} = \frac{317(42.0\angle 90^\circ)}{317 + j42.0} = 41.6361\angle 82.4527^\circ = 5.4687 + j41.2754\ \ \Omega$$

$$Z_P = \frac{Z_2 \cdot Z_0}{Z_2 + Z_0} = \frac{(20.0416\angle 176.30^\circ)(41.6361\angle 82.4527^\circ)}{(-0.20 + j1.29) + 5.4687 + j41.2754)}$$

$$Z_P = 18.5527\angle 149.91^\circ = -16.0530 + j9.301\ \ \Omega$$

$$Z_{in} = Z_1 + Z_P = (0.2 + j1.2) + (-16.0530 + j9.301) = 19.0153\angle 146.4802^\circ\ \ \Omega$$

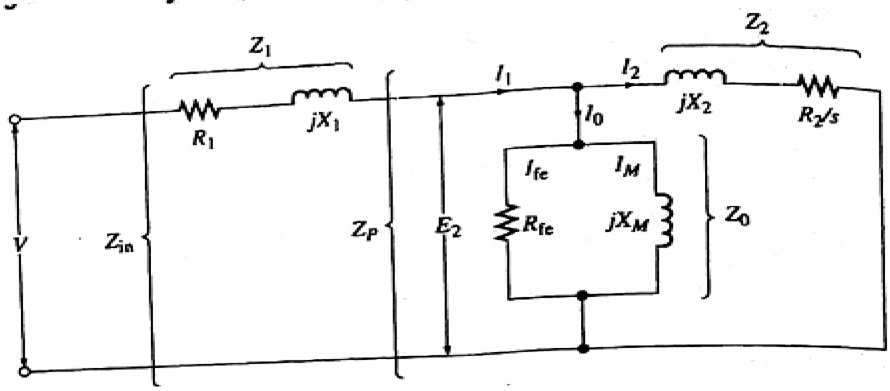
$$I_1 = \frac{V}{Z_{in}} = \frac{460/\sqrt{3}\angle 0^\circ}{19.0153\angle 146.4802^\circ} = 13.9667\angle -146.4802^\circ\ \ \text{A}$$

$$S = 3VI_1^* = 3(460/\sqrt{3}\angle 0^\circ)(13.9667\angle -146.4802^\circ)^* = 11{,}127.87\angle 146.48^\circ\ \ \text{VA}$$

$$S = -9277 + j6145\ \ \text{VA}$$

$$P = \underline{-9277\ \text{W}}$$

The negative sign indicates power flow *from* the induction machine *to* the electrical distribution system.



2. The following data were obtained from no-load, and DC tests of a three phase, wye-connected, 40-hp, 60-Hz, 460-V, design **B** induction motor whose full load current is 57.8-A. the blocked rotor test was made at 15-Hz.

Blocked Rotor Test	No-Load Test	DC-Test
$V_L = 36.2$ V	$V_L = 460$ V	$V_{DC} = 12$ V
$I_L = 58$ A	$I_L = 32.7$ A	$I_{DC} = 59$ A
$P_{3\text{-Phase}} = 2573.4$ W	$P_{3\text{-Phase}} = 4664.4$ W	

***Determine* (a)** the machine parameters in ohms/phase, and the combined core, friction, and windage loss.

(b) Express the no-load current as a percent of rated current.

Solution

(a) Converting the AC test data to corresponding phase values for a wye-connected motor,

$$P_{BR,15} = \frac{2573.4}{3} = 857.80 \text{ W}$$

$$V_{BR,15} = \frac{36.2}{\sqrt{3}} = 20.90 \text{ V}$$

$$I_{BR,15} = 58.0 \text{ A}$$

$$P_{NL} = \frac{4664.4}{3} = 1554.80 \text{ W}$$

$$V_{NL} = \frac{460}{\sqrt{3}} = 265.581 \text{ V}$$

$$I_{NL} = 32.7 \text{ A}$$

Determination of R_1:

$$R_{DC} = \frac{V_{DC}}{I_{DC}} = \frac{12.0}{59.0} = 0.2034\ \Omega$$

$$R_{1,\text{wye}} = \frac{R_{DC}}{2} = \frac{0.2034}{2} = \underline{0.102\ \Omega/\text{phase}}$$

Determination of R_2:

$$Z_{BR,15} = \frac{V_{BR,15}}{I_{BR,15}} = \frac{20.90}{58.0} = 0.3603\ \Omega$$

$$R_{BR,15} = \frac{P_{BR,15}}{I^2_{BR,15}} = \frac{857.8}{(58)^2} = 0.2550\ \Omega/\text{phase}$$

$$R_2 = R_{BR,15} - R_{1,\text{wye}} = 0.2550 - 0.102 = \underline{0.153\ \Omega/\text{phase}}$$

Determination of X_1 and X_2:

$$X_{BR,15} = \sqrt{Z^2_{BR,15} - R^2_{BR,15}} = \sqrt{(0.3603)^2 - (0.255)^2} = 0.2545\ \Omega$$

$$X_{BR,60} = \frac{60}{15} X_{BR,15} = \frac{60}{15}(0.2545) = 1.0182\ \Omega$$

From Table 5.10, for a design *B* machine,

$$X_1 = 0.4X_{BR,60} = 0.4(1.0182) = \underline{0.4073\ \Omega/\text{phase}}$$

$$X_2 = 0.6X_{BR,60} = 0.6(1.0182) = \underline{0.6109\ \Omega/\text{phase}}$$

Determination of X_M:

$$S_{NL} = V_{NL}I_{NL} = 265.581(32.7) = 8684.50 \text{ VA}$$

$$Q_{NL} = \sqrt{S^2_{NL} - P^2_{NL}} = \sqrt{(8684.50)^2 - (1554.8)^2} = 8544.19 \text{ var}$$

$$X_{NL} = \frac{Q_{NL}}{I^2_{NL}} = \frac{8544.19}{(32.7)^2} = 7.99\ \Omega$$

$$X_{NL} = X_1 + X_M \quad \Rightarrow \quad 7.99 = 0.4073 + X_M$$

$$X_M = \underline{7.58\ \Omega/\text{phase}}$$

Determination of combined friction, windage, and core loss:

$$P_{NL} = I_{NL}^2 R_{1,wye} + P_{core} + P_{f,w}$$

$$1554.8 = (32.7)^2(0.102) + P_{core} + P_{f,w}$$

$$P_{core} + P_{f,w} = \underline{1446 \text{ W/phase}}$$

(b)

$$\%I_{NL} = \frac{I_{NL}}{I_{rated}} \times 100 = \frac{32.7}{57.8} = \underline{56.6\%}$$

Note: The no-load current (exciting current) of a three-phase induction motor is large, generally 40% or higher in terms of rated current.

***Question 2**: [20 Marks]*

3. A 3-phase, 60-Hz, 460-V system supplies the following loads:

a. A six-pole, 60-Hz, 400-hp, 3-phase, wye-connected induction motor, operating at three-quarters rated load with an efficiency of 95.8 percent and power factor of 89.1 percent.

b. A 50-kW, delta-connected, 3-phase resistance heater.

c. A 300-hp, 60-Hz, 4-pole, wye-connected, cylindrical-rotor synchronous motor, operating at one-half rated load, with a torque angle of -16.4^o. Neglecting copper losses, the synchronous motor is operating at 96 percent efficiency, and its synchronous reactance is 0.667 Ω/phase.

Determine **(a)** system active power; **(b)** power factor of synchronous motor; **(c)** system power factor; **(d)** percent change in synchronous motor field current required to adjust the system power factor to unity (neglect saturation effects); **(e)** power angle of the synchronous motor for condition in **(d).**

Solution

The circuit diagram is shown in Figure 8.15(a) and the power diagram in Figure 8.15(b).

(a)

$$P_{ind\ mot} = \frac{400 \times 0.75 \times 746}{0.958} = 233{,}611.7 \text{ W}$$

$$P_{heater} = 50{,}000 \text{ W}$$

$$P_{syn\ mot} = \frac{300 \times 0.5 \times 746}{0.96} = 116{,}562.5 \text{ W}$$

$$P_{system} = P_{ind\ mot} + P_{heater} + P_{syn\ mot} = 400{,}174.19 \quad \Rightarrow \quad \underline{400.2 \text{ kW}}$$

(b)

$$V_T/\text{phase} = 460/\sqrt{3} = 265.581 \text{ V}$$

$$P_{in} = 3 \times \frac{-V_T E_f}{X_s} \sin\delta \quad \Rightarrow \quad E_f = \frac{-P_{in} \cdot X_s}{3 \cdot V_T \sin\delta}$$

$$E_f = \frac{-116{,}562.5 \times 0.667}{3 \times 265.581 \times \sin(-16.4°)} = 345.614 \text{ V}$$

$$\mathbf{E}_f = 345.614\underline{/-16.4°} \text{ V}$$

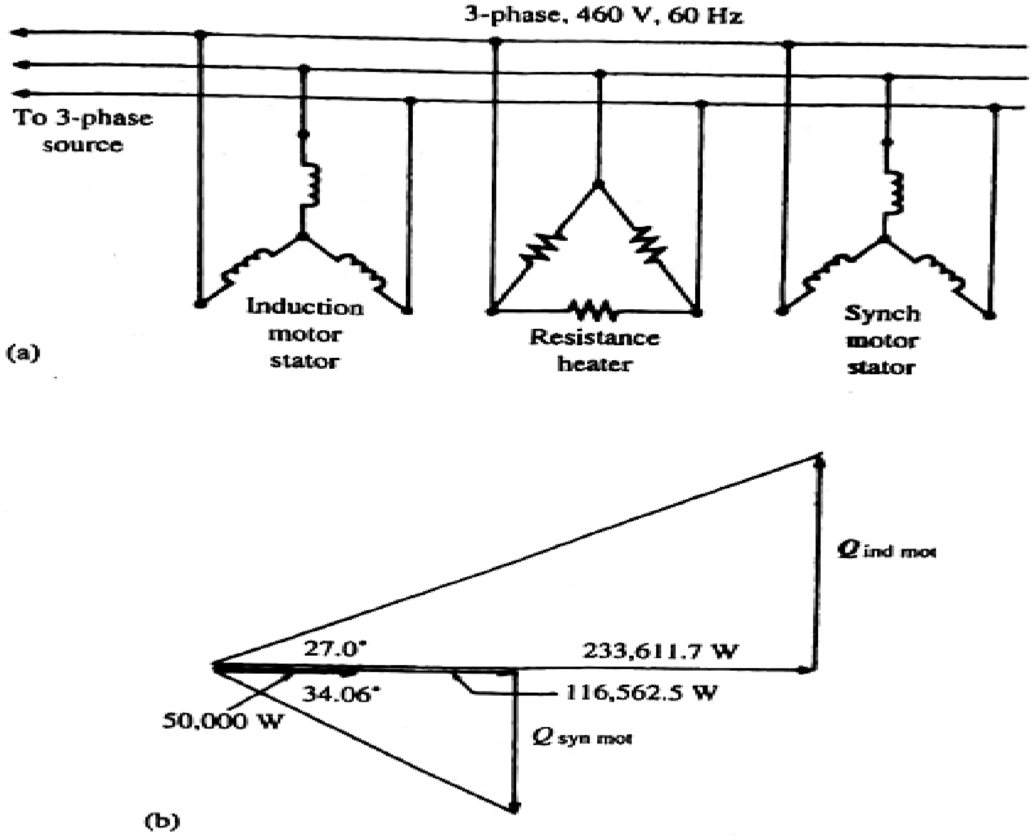


FIGURE 8.15
(a) Circuit diagram for Example 8.3; (b) power diagram.

$$\mathbf{E}_f = \mathbf{V}_T - \mathbf{I}_a jX_s$$

$$345.614\angle{-16.4^\circ} = 265.581\angle{0^\circ} - \mathbf{I}_a \times 0.667\angle{90^\circ}$$

$$117.79\angle{-55.94^\circ} = -\mathbf{I}_a \times 0.667\angle{90^\circ}$$

$$\mathbf{I}_a = 176.6\angle{34.06^\circ}\ \text{A}$$

$$\theta = (\theta_v - \theta_i) = (0 - 34.06) = -34.06^\circ$$

$$F_P = \cos(-34.06^\circ) = \underline{0.828\ \text{leading}}$$ [7]

(c) The power-factor angles for the respective loads are

$$\theta_{\text{ind mot}} = \cos^{-1} 0.891 = 27.0°$$
$$\theta_{\text{heater}} = \cos^{-1} 1.0 = 0.0°$$
$$\theta_{\text{syn mot}} = -34.06°$$

From the power diagram in Figure 8.15(b),

$$\tan 27.0° = \frac{Q_{\text{ind mot}}}{233{,}611.7} \quad \Rightarrow \quad Q_{\text{ind mot}} = 119{,}035.3 \text{ var}$$

$$\tan(-34.06°) = \frac{Q_{\text{syn mot}}}{116{,}562.5} \quad \Rightarrow \quad Q_{\text{syn mot}} = -78{,}800.1 \text{ var}$$

$$Q_{\text{sys}} = 119{,}035.3 - 78{,}800.1 = 40{,}235.2 \text{ var}$$
$$\mathbf{S}_{\text{sys}} = P + jQ = 400{,}174.19 + j40{,}235.2 = 402{,}191\underline{/5.74°} \text{ VA}$$
$$F_{P,\text{sys}} = \cos(5.74°) = \underline{0.995 \text{ lagging}}$$

(d) To obtain unity power factor, the synchronous motor must supply an additional $-40{,}235.2$ var. Thus,

$$\mathbf{S}_{\text{syn mot}} = 116{,}562.5 - j(78{,}800.1 + 40{,}235.2)$$
$$\mathbf{S}_{\text{syn mot}} = 166{,}602\underline{/-45.6°} \text{ VA}$$

For one phase,

$$\mathbf{S}_{\text{syn mot}} = \frac{166{,}602}{3}\underline{/-45.6°} = 55{,}534.0\underline{/-45.6°} \text{ VA}$$

$$\mathbf{S}_{\text{syn mot}} = \mathbf{V}_T \mathbf{I}_a^* \quad \Rightarrow \quad 55{,}534.0\underline{/-45.6°} = (265.58\underline{/0°})\mathbf{I}_a^*$$
$$\mathbf{I}_a^* = 209.10\underline{/-45.60°}$$
$$\mathbf{I}_a = 209.10\underline{/45.60°}$$
$$\mathbf{E}_f = \mathbf{V}_T - \mathbf{I}_a jX_s = 265.581\underline{/0°} - (209.10\underline{/45.60°})(0.667\underline{/90°})$$
$$\mathbf{E}_f = 265.581 + 99.65 - j97.58 = \underline{378.04/-14.96° \text{ V}}$$

Neglecting magnetic saturation, $E_f \propto \Phi_f \propto I_f$

$$\Delta E_f = \frac{378.04 - 345.614}{345.614} \times 100 = \underline{9.38\%}$$

(e)
$$\delta = \underline{-14.96°}$$

4. A 1000 kVA, 11 kV, 3-phase star-connected synchronous motor has an armature resistance and reactance per phase of 3.5 Ω and 40 Ω respectively. ***Determine*** the induced emf and angular retardation of the rotor when fully loaded at **(a)** unity power factor, **(b)** 0.8 power factor lagging. **(c)** 0.8 power factor leading.

Solution:

$$V = \frac{11 \times 1000}{\sqrt{3}} = 6351;\ I_L = \frac{kVA \times 1000}{\sqrt{3}\,V_L} = \frac{1000 \times 1000}{\sqrt{3} \times 11000} = 52.5 \text{ A}$$

(a) At unity power factor

$$\overline{V} = V\angle 0° = V \pm j0$$

$$\cos\phi = 1.0,\ \phi = 0°,\ \overline{I} = 52.49\ \angle 0° \text{ A}$$

$$\overline{E} = \overline{V} - \overline{I}\,(R + jX_S)$$

$$= 6351 - (52.49\ \angle 0°)\,(3.5 + j40) = 6351 - (183.7 + j2099.6)$$

$$E\ \angle\delta = 6167.3 - j2099.6 = 6515\ \angle{-18.8°} \text{ V}$$

E = 6515 V per phase; $E_L = \sqrt{3} \times 6515$ = **11.284 kV** (*Ans.*)

δ = **–18.8°** (*Ans.*)

(b) At 0.8 power factor lagging

$$\cos\phi = 0.8,\ \sin\phi = 0.6;\ \overline{I} = \overline{I}\ \angle -\phi$$

$$\overline{E} = \overline{V} - \overline{I}\,\overline{Z}_S = V - (I\angle -\phi)\,(R + jX_S) = V - (I\cos\phi - j\,I\sin\phi)\,(R + jX_S)$$

$$= (V - I\,R\cos\phi - I\,X_S\sin\phi) - j(IX_S\cos\phi - IR\sin\phi)$$

$$= (6351 - 52.49 \times 3.5 \times 0.8 - 52.49 \times 40 \times 0.6)$$

$$- j(52.49 \times 40 \times 0.8 - 52.49 \times 3.5 \times 0.6)$$

$$E\ \angle\delta = 4944 - j1569.5 = 5187\ \angle{-17.6°} \text{ V}$$

∴ E = **5187 V per phase**, δ = **– 17.6°** (*Ans.*)

Induced line voltage, $E_L = \sqrt{3} \times 5187$ = **8984 V** (*Ans.*)

(c) At 0.8 power factor leading

$$\overline{I} = I\angle +\phi$$

$$\overline{E} = \overline{V} - \overline{I}\,\overline{Z}_S = V - (I\angle +\phi)\,(R + jX_S)$$

$$= (V - IR\cos\phi + IX_S\sin\phi) - j\,(IX_S\cos\phi + IR\sin\phi)$$

$$= (6351 - 52.49 \times 3.5 \times 0.8 + 52.49 \times 40 \times 0.6)$$

$$- j(52.49 \times 40 \times 0.8 + 52.49 \times 3.5 \times 0.6)$$

$$E\ \angle\delta = 7463.8 - j1790 = 7675\ \angle{-13.48°} \text{ V}$$

E = **7675 V per phase** (*Ans.*)

δ = **–13.48°** (*Ans.*)

Induced line voltage,

$E_L = \sqrt{3} \times 7675$ = **13.3 kV** (*Ans.*)

Question 3: [20 Marks]

5. A three-phase star connected 1200 kVA, 3300 V, 50 Hz, alternator has armature resistance of 0·25 ohm per phase. A field current of 40 A produces a short circuit current of 200 A and an open circuit emf of 1100 V between lines. ***Calculate*** regulation on full load 0·8 power factor lagging.

Solution:

Here, Rated power $= 1200 \text{ kVA} = 1200 \times 10^3 \text{ VA}$

Terminal line voltage, $V_L = 3300$ V (*star connected*)

Armature resistance, $R = 0{\cdot}25\ \Omega$

At field current of 40 A;

Short circuit current, $I_{sc} = 200$ A

Open circuit *emf* (phase value), $E_{(ph)} = \dfrac{1100}{\sqrt{3}} = 635 \cdot 1$ V

$$\text{Synchronous impedance, } Z_s = \frac{E_{(ph)}}{I_{sc}} = \frac{635 \cdot 1}{200} = 3 \cdot 175\ \Omega$$

$$\text{Synchronous reactance, } X_s = \sqrt{Z_s^2 - R^2} = \sqrt{(3 \cdot 175)^2 - (0 \cdot 25)^2} = 3 \cdot 175\ \Omega$$

Full load, current, $I = \dfrac{1200 \times 10^3}{\sqrt{3} \times 3300} = 210$ A

Terminal phase voltage, $V = \dfrac{V_L}{\sqrt{3}} = \dfrac{3300}{\sqrt{3}} = 1905 \cdot 2$ V

Power factor, $\cos \phi = 0.8;\ \sin \phi = \sin \cos^{-1} 0{\cdot}8 = 0{\cdot}6$

Open circuit terminal voltage (phase value),

$$E_0 = \sqrt{(V \cos \phi + IR)^2 + (V \sin + IX_s)^2}$$

$$= \sqrt{(1905 \cdot 0 \times 0.8 + 210 \times 0 \cdot 25)^2 + (1905 \cdot 2 \times 0 \cdot 6 + 210 \times 3 \cdot 175)^2}$$

$$= 2400 \text{ V}$$

$$\% \text{ Reg.} = \frac{E_0 - V}{V} \times 100 = \frac{2400 - 1905 \cdot 2}{1905 \cdot 2} \times 100 = \mathbf{25{\cdot}98\%}\ (Ans.)$$

6. A 3-phase, 5 MVA, 11 kV, 60 Hz synchronous machine has a synchronous reactance of 10 ohms per phase and has negligible stator resistance. The machine is connected to the 11 kV, 60 Hz bus and is operated as a synchronous condenser.

1. Neglect rotational losses.

(a) For normal excitation, ***find*** the stator current. Draw the phasor diagram.

(b) If the excitation is increased to 150 percent of the normal excitation, **find** the stator current and power factor. Draw the phasor diagram.

(c) If the excitation is decreased to 50 percent of the normal excitation, **find** the stator current and power factor. Draw the phasor diagram.

2. If the rotational losses are 80 kW, **find** the stator current and excitation voltage for normal excitation. Draw the phasor diagram.

Solution

1. **(a)** Power $= 3V_tI_a \cos\phi$. For normal excitation, power factor $= \cos\phi = 1$. Hence V_t, and I_a are in phase. Since power is zero, I_a is zero. From Eq. 6.24, for no power transfer, δ is zero. If I_a is zero, both V_t and E_f are also the same in magnitude.

$$E_f = V_t = \frac{11}{\sqrt{3}}\,\text{kV/phase} = 6.35\ \text{kV/phase}$$

The phasor diagram is shown in Fig. E6.6*a*.

(b) Because power transfer is zero, δ is zero. Hence,

$$I_a = \frac{V_t\underline{/0^\circ} - E_f\underline{/0^\circ}}{jX_s} = \frac{6351 - 1.5\times 6351}{10\,\underline{/90^\circ}}$$

$$= 317.55\,\underline{/90^\circ}\ \text{A}$$

$$\text{PF} = \cos 90^\circ = 0 \quad \text{leading}$$

The phasor diagram is shown in Fig. E6.6*b*.

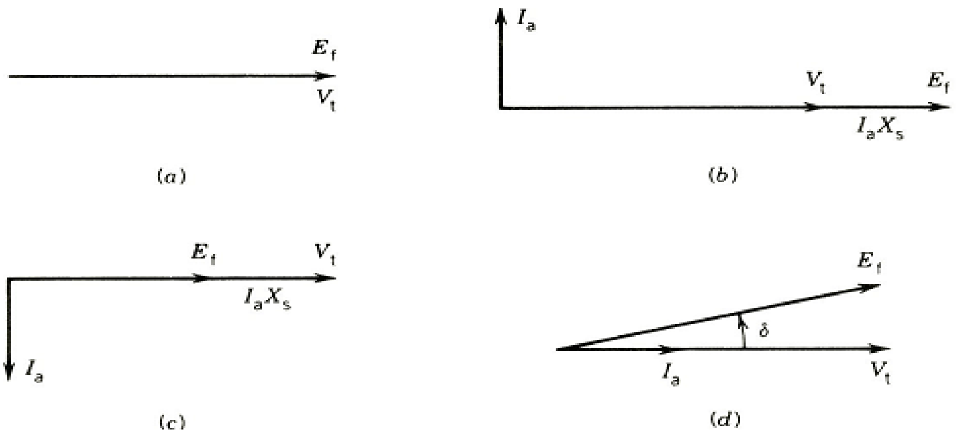


FIGURE E6.6

(c)

$$I_a = \frac{6351 - 0.5\times 6351}{10\,\underline{/90^\circ}} = 317.55\,\underline{/-90^\circ}\ \text{A}$$

$$\text{PF} = \cos 90^\circ = 0 \quad \text{lagging}$$

The phasor diagram is shown in Fig. E6.6*c*.

2. For normal excitation, power factor $= \cos\theta = 1$.

$$\text{Power} = 3V_tI_a\cos\theta = 80,000\ \text{W}$$

$$I_a = \frac{80{,}000}{3\times 6351\times 1} = 4.2\ \text{A}$$

$$E_f = V_t - I_a jX_s$$
$$= 6351 - 4.2\,\underline{/0^\circ}\cdot 10\,\underline{/90^\circ}$$
$$= 6351 - j42$$
$$\simeq 6351\,\underline{/0.4^\circ}\ \text{V/phase}$$

The phasor diagram is shown in Fig. E6.6*d*.

***Question 4*: [10 Marks] ……. Short Answer Required.**

1. **Classify 3-phase induction motors on the basis of their construction. Which one is generally preferred and why?**

   Ans. Three-phase induction motors may be classified as (*i*) squirrel cage induction motors and (*ii*) phase

   wound or slip-ring induction motor. Squirrel cage induction motor is generally preferred due to its low construction cost, low maintenance, high pf, high efficiency, robust construction etc.
2. **Why the rotor conductors of the squirrel cage rotor are short-circuited in the case of slip-ring induction motors, the rotor circuit is closed through resistors?**

   Ans. In induction motors, torque develops by the interaction of stator and rotor fields. The rotor field is developed only if current flows through the rotor conductors which is only possible if rotor circuit is

   closed or short-circuited.
3. **Does rotor resistance affect the maximum torque developed in the induction motor?**

   Ans. No, maximum torque developed in an induction motor is independent of rotor resistance.
4. **What are constant and variable losses in an induction motor?**

   Ans. The losses which remain constant from no-load to full-load are called constant losses. The losses which vary with the load are called variable losses.
5. **Why two reaction theory is applied only to salient pole synchronous machines?**

   Ans. In case of salient pole machines, the air-gap is not uniform and its reactance varies with the rotor position. Because of this non-uniformity of the reactance of the magnetic paths, the mmf of the armature

   is divided into two components called direct-acting component along the field pole axis *i.e* direct-axis and quadrature-component along the axis passing through the center of the two consecutive salient poles i.e., quadrature axis.

Question 5*: [15 Marks] ……*Chose the correct answer, and Please, Draw Answer Table only for this Part.

1. The direction of rotation of a 3-phase induction motor is clockwise when it is supplied with phase sequence R-Y-B. If its direction of rotation is to be reversed. The phase sequence of the power supply should be (a) Y-R-B (b) R-B-Y (c) B-Y-R (d) all of these
2. The synchronous speed of an induction motor is 1000 rpm. What will be slip when it is running at a speed of 960 rpm? (a) +5%. (b) –5% (c) +4% (d) –3%.
3. If the rotor resistance is increased in a slip-ring induction motor, then (a) both starting torque and pf will increase. (b) both starting torque and pf will decrease. (c) starting torque decreases but pf increases. (d) starting torque increases but pf decreases.

4. The power input in blocked-rotor test performed on a 3-phase induction motor is approximately equal to (a) iron loss in the core. (b) hysteresis loss in the core
(c) eddy current loss in the core (d) copper loss in the windings
5. If the air-gap in an induction motor is increased, its (a) speed will reduce. (b) power factor will be lowered. (c) efficiency will improve. (d) breakdown torque will reduce
6. The most widely used motor is (a) double cage induction motor. (b) slip-ring induction motor. (c) squirrel cage induction motor. (d) synchronous motor.
7. A syn. motor is switched on to supply with its field winding shorted on themselves. It will
(*a*) not start (*b*) start and continue to run as an induction motor (*c*) start as Induction motor and then run as Syn. Motor (*d*) none of these.
8. Slip rings in a synchronous motor carry: (a) DC (b) AC (c) both a and b (d) no current.
9. The maximum value of torque that a syn. motor can develop without losing its synchronism is called: (a) slip torque (b) pullout torque (c) breaking torque (d) syn. torque.
10. Squirrel cage winding is provided on a synchronous motor to make it (a) noise free (b) self-starting (c) cheap. (d) quick start
11. An exciter is nothing but a (a) DC shunt motor (b) DC series (c) DC shunt generator (d) DC series generator
12. Synchronous reactance of an alternator represents
(*a*) armature reaction reactance and leakage reactance. (*b*) leakage reactance and field winding reactance. (*c*) field winding reactance and armature reaction reactance (*d*) a reactance connected in series with a synchronous generator.
13. Which of the following is not an essential conditions for parallel operation of two alternators?
(*a*) identical terminal voltage for two machines (*b*) same phase sequence for two machines (*c*) same kVA rating for two machines (*d*) same frequency of voltage generated.
14. An infinite bus-bar has (a) constant voltage. (b) constant frequency. (c) constant current (d) both (a) and (b).
15. An inductive load is shared by two identical synchronous generators A and B equally, if the excitation of alternator A is increased. (a) Alternator A will deliver more current and alternator B will deliver less current. (b) Alternator B will deliver more current and alternator A will deliver less current. (c) both will continue to deliver same current. (d) both will deliver more current.

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
d	**c**	**a**	**d**	**b**	**c**	**b**	**a**	**b**	**b**	**c**	**a**	**c**	**d**	**a**

Best wishes,