THE INSTITUTION OF ENGINEERS, SRI LANKA

PART III EXAMINATION– OCTOBER/NOVEMBER 2008

307 - ELECTRICAL MACHINES - II

Answer FIVE questions only.
All questions carry equal marks — Time allowed: 03 hours

Q1. (a) Sketch *P-Q* operating chart for a 100MVA, 11 kV, 3-phase cylindrical rotor synchronous generator that has a synchronous reactance of 1.8 Ω/phase and maximum internal EMF of 2.2 pu.
Calculate the internal EMF and load angle when the generator is delivering 60 MW and 20 MVAR at rated terminal voltage. [07]

(b) An 11kV, 3-phase salient pole rotor synchronous generator has direct and quadrature axes synchronous reactances of 1.7 Ω/phase and 1 Ω/phase respectively. Calculate the internal EMF and load angle when the generator is delivering 60 MW and 20 MVAR at rated terminal voltage. [07]

(c) Two synchronous generators rated at 200 MW and 150 MW operate in parallel and deliver a common load of 250 MW at 50 Hz. The turbine-governor droops of the two generators are 5% and 4% respectively from no load to full load and they are preset to deliver rated power simultaneously. Determine the frequency when the total load is 350 MW. [06]

Q2. (a) A cylindrical rotor 3-phase, 50 Hz, synchronous generator has the following parameters with usual meanings.

$X_d = 1.80$ pu	$T_d' = 0.50$ s
$X_d' = 0.25$ pu	$T_d'' = 0.02$ s
$X_d'' = 0.20$ pu	$T_a = 0.17$ s

The generator is equipped with a circuit breaker that operates after 8 cycles following a short circuit fault. Determine the maximum likely per unit rms current that the breaker would interrupt. [12]

(b) State the conditions that must be satisfied before a generator circuit breaker is closed to the supply system. Describe briefly one method of synchronizing a generator with the supply system. [05]

(c) The slip test is conducted on a 4 pole, 50 Hz, 3-phase, salient pole rotor synchronous generator at 1490 rev/min. What is the frequency of the envelop of the phase current? [03]

Q3. (a) Draw the coil side arrangement of a double layer, 2-pole, 3-phase winding in 18 slots with coil pitch of 7 slots. Give the layout of coils in one phase assuming spiral connections.
Calculate the winding factors for the fundamental and the fifth space harmonic. [08]

(b) The winding in (a) above is connected in delta and supplied with a 15 A rms line current. Each coil of the winding has 24 turns and all the turns in a phase are connected in series.
(i) Sketch the resultant stepped MMF distribution in the air gap at the instant when phase-*A* current is at its positive peak.
(ii) Calculate the amplitude of the fundamental components of the MMF. [08]

(c) A 50 Hz, 4-pole, cage rotor induction motor runs at 1470 rev/min. Assuming all space harmonics to be negligible determine frequency of induced rotor EMF due to fifth and seventh harmonics of stator current. [04]

Q4 (a) Due to an error in manufacture, the air-gap of an induction motor emerged as 0.8 mm instead of 0.5 mm. If half of the reluctance of the magnetic circuit in a standard motor is attributable to the iron, estimate the percentage difference in the magnetizing current of this rogue machine when compared with the standard machine. [06]

(b) Explain briefly why the air gap flux in a 3-phase induction motor should be maintained constant at rated value for frequencies below rated frequency but allowed to decrease it for frequencies above rated frequency.
Give typical variation of line voltage of the motor with frequency from zero to well above rated frequency. [06]

(c) A *Yy* bank of 3-phase transformer without neutral produces significant third harmonic EMF in phases. Why is third harmonic EMF undesirable?
Explain briefly how third harmonic EMF gets cancelled when
(i) the neutral connection is given at input.
(ii) a tertiary is connected in delta. [08]

Q5. (a) Explain briefly why the permanent magnet (PM) brushless dc motor is an attractive alternative to the conventional dc motor in servo applications. Why is the trapezoidal brushless dc motor more popular than the sinusoidal brushless dc motor in industrial applications? [04]

(b) A certain positioning drive uses a sinusoidal brushless dc motor with a shaft mounted absolute encoder for position sensing. Describe a method of aligning the encoder to read out the instantaneous position of rotor *q axis* with respect to the stator *phase-A axis*.
Explain how the sensor output should be processed for (i) torque angle adjustment and (ii) reversal of the direction of motion. [08]

(c) A 100 V trapezoidal PM brushless dc motor has 180 turns per phase and all the turns in a phase are connected in series. Its axial length is 20 cm and the mean winding radius is 6 cm. Flux density due to magnet in the air gap is 0.4 T. It is operated in the bipolar current mode. What will be the speed of the motor when it is delivering a load torque of 12 Nm? Assume the Voltage drop across a conducting transistor to be 0.7 V and the resistance per phase to be 0.8 Ω. [08]

Q6 (a) Calculate the basic step angle for the following stepper motors:
(i) 12/8 pole, 3-phase, single stack VR motor
(ii) 4/6 pole, 2-phase, PM stepper motor
(iii) 4/36 pole, 3-phase, multi-stack VR motor
(iv) 4/9 pole, 2-phase, PM hybrid motor [04]

(b) Sketch typical *pullout-torque* versus *stepping-rate* characteristics for a stepper motor and give typical step responses in the modes of *multistep* and *slewing*. What do you understand by the terms *start rate* and *stop rate*? [07]

(c) A single stack VR stepper motor has 4-phases, 8 stator-poles and 6 rotor-teeth. Its stator phase induction varies sinusoidally between 3 mH and 7 mH as the rotor rotates. Derive an expression for the static-torque/angle relationship. [06]

(d) Give five possible power circuit arrangements for driving stepper motors and identify which of these can be used with PM hybrid stepper motors. [03]

Q7. (a) Describe the main differences between the magnetic fields produced by a single phase ac winding and a three phase ac winding. Explain briefly how the start-winding alters the magnetic field in a single phase induction motor and hence influence the motor performance. [07]

(b) What are characteristic differences among capacitor start and split phase single phase induction motors. [04]

(c) A 50 Hz, 2 pole, single phase induction motor has the following equivalent circuit parameters.
Stator impedance = $6 + j\,10\ \Omega$
Rotor referred-impedance = $4 + j\,10\ \Omega$
Magnetizing reactance = $20\ \Omega$
Draw per phase equivalent circuit for the motor, stating any assumptions you make. Calculate the mechanical power output when the motor is running at 2950 rev/min, drawing 2 A from the supply. [09]

Q8 (a) Describe the relationships between the size, torque, power and speed of an electrical machine. Comment on the need for machines with either a high or a low ratio of axial length to radius. [05]

(b) A manufacturer of a dc machine achieves specific magnetic and electric loadings of B = 0.4 T and I = 1200 A/m. The density of the rotor material is 7000 kg/m^3. A motor from the manufacturer's range is to be used in a speed servo. The moment of inertia of the mechanical load is $J = 0.0015$ kg m^2. Space restrictions limit the length of the machine to 0.1 m. Assume that the constant of proportionality that relates rotor volume, specific loadings and torque is unity. You may also assume that the rotor is a smooth cylinder.

(i) Express the rate of change of speed for this servo in terms of the rotor radius.
(ii) Find the rotor radius that will give the maximum rate of change of speed.
(iii) Calculate the rate of change of speed achieved and the moment of inertia of the rotor. Comment on the moment of inertia of the motor in comparison to that of the load. [15]