THE INSTITUTION OF ENGINEERS, SRI LANKA

PART III EXAMINATION– November 2013

307 - ELECTRICAL MACHINES - II

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

Q1 (a) Draw the coil side arrangement for 18 slots, 2 pole, 1-layer fully pitched 3-phase winding. Draw the coil arrangement of phase-*a* only assuming lap winding connection. Calculate the winding factor for the fundamental. [07]

(b) The winding in (a) above is the stator winding of a three-phase alternator. It is connected in star and delivers three-phase 50 Hz, 30 A rms line current. The number of turns per coil is 18. Calculate the peak values of the fundamental mmf in the air gap and its rotational speed. [07]

(c) Describe the main difference between the air-gap magnetic field produced by the stator of a single phase induction motor and that of a three-phase induction motor. Explain how an auxiliary winding can be used in the single phase motor to change its air-gap field similar to that of the three-phase motor. [06]

Q2 The cross section of a three-phase two-pole permanent magnet motor is shown in Figure Q2. The machine has surface-mounted radially-magnetized rotor magnets with a pole arc of 120°. The armature has a balanced three-phase elementary (concentrated) winding as shown in the figure. The rotor diameter is 30 mm, axial length is 50 mm and the air-gap flux density at the magnet pole faces is 0.6 T. The number of turns per phase is 80 and the resistance per phase is 1.5 Ω.

(a) Assuming that the motor is rotating at a constant speed, sketch the motional emf of three phases against rotor position. [06]

(b) Sketch the waveform of phase currents against rotor position corresponding to constant torque independent of rotor position. [06]

(c) Calculate the torque produced by the motor and the total copper loss, assuming the amplitude of current waveforms given in (c) above is 3A. [06]

(d) The motor phases are star-connected and the current to three phases are supplied by a three-phase transistor voltage source inverter. Give the inverter switching pattern that produces the current waveforms in (c) above. [02]

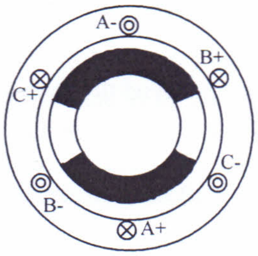

Figure Q2

Q3 (a) Figure Q3 (a) shows a turntable with radius 0.25 m, driven through a 100:1 reduction gearbox by a 200 steps per revolution permanent magnet stepping motor. A test showed that a tangential force of 2 N must be applied at the outer radius of the turntable to make it move and this force was independent of speed. The turntable inertia is 3×10^{-2} kg m^2, the stepping motor inertia is 2×10^{-6} kg m^2 and the inertia of the gearbox can be neglected. The motor has the pull-out characteristic shown in Figure Q3 (b).

The motor stepping rate ramps up linearly to a maximum stepping rate of 2000 steps/s. then ramps down linearly as shown in Figure Q3(c). The motor acceleration time t_a and the deceleration time t_d are equal.

(i) Calculate the minimum acceleration time t_a and the corresponding total time taken for the turntable to move through 90°. [08]

(ii) Sketch the motor-torque against time for the operation in (i) above. [03]

(b) (i) Explain why it might be preferable to use a larger value for t_a than that calculated in part (a) above. [02]

(ii) If t_a and t_d each is increased to 4 times the value in (a) above, what will be the total time taken for the turntable to rotate through 90°? [04]
Sketch the corresponding motor-torque against time. [03]

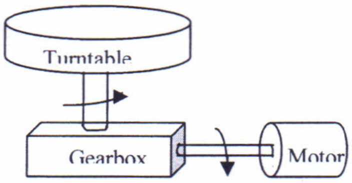

Figure Q3(a)

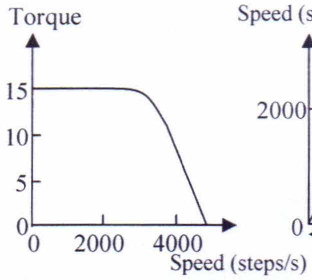

Figure Q3(b)

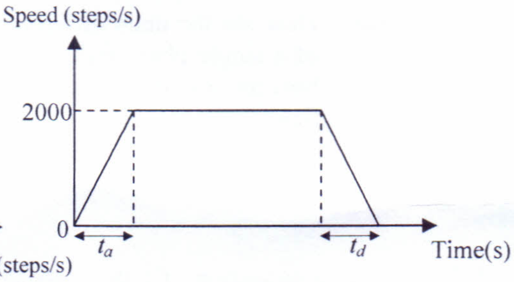

Figure Q3(c)

Q4 (a) Three phase, 50 Hz, synchronous generator has the following parameters in usual notation.

X_d	= 1.40 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
X_q''	= 0.20 pu		

The generator is equipped with a circuit breaker that operates after 6 cycles following a short circuit fault. Determine the maximum likely per unit rms current that the breaker would interrupt. [08]

(b) Find the *positive sequence reactance* and the *negative sequence reactance* for the generator described in (a) above. [04]

(c) Two synchronous generators rated at 200 MW and 150 MW operate in parallel and deliver a common load of 350 MW at 50 Hz without an overload. The turbine-governor droops of the two generators are 5% and 4% respectively from no load to full load. What will be the frequency if the load is decreased down to 150 MW? [08]

Q5 (a) (i) Define the terms *displacement factor*, *power factor* and *total harmonic distortion* as applied to the input of power electronic equipment fed from utility ac system. [03]

(ii) A power electronic converter operating on utility AC system has a displacement factor of 0.62 and power factor of 0.55. What is its total harmonic distortion? [03]

(b) A 3-phase full-bridge thyristor AC to DC converter connected to 50 Hz, 400 V, 3-phase ac system delivers 4 kW of power to an inductive load. The load current can be considered to be constant and ripple free. The supply side inductance can be ignored. The converter is operated at delay firing angle $\alpha = 40°$. Converter can be assumed to be lossless.

Calculate the followings:

(i) Mean value of load voltage. [02]

(ii) Peak-peak value of ripple in load voltage. [03]

(iii) Input displacement factor. [02]

(iv) Total harmonic distortion of input line-current. [04]

(v) Total reactive power absorbed by the rectifier from the supply. [03]

Q6 (a) With the aid of a graph explain how the voltage applied to a three phase induction motor should be varied with the frequency. [03]

(b) Give block diagrams of the arrangement of the following three phase induction motor speed control drives.

(i) Open loop drive with frequency control incorporating ramp limiter. [03]

(ii) Closed loop drive with frequency control incorporating slip regulation. [03]

(c) (i) What are *constant torque mode, constant horsepower mode* and *high-speed mode* of control of a three-phase induction motor? [03]

(ii) A 4 pole, 50 Hz, 3-phase induction motor has full load slip of 4% and pull out slip of 10%. Calculate the range of speed for the constant-torque mode, constant horsepower mode and high-speed mode. Assume 8 times rated speed as the maximum allowable speed. [08]

Q7 (a) (i) Draw the vector diagram and the winding connection diagram for *Dy*11 and *Dz*0 3-phase transformers. [04]

(ii) A 400/200 V, *Dz*0 3-phase transformer is reconnected as *Dy*11 transformer after the halves of each phase of the secondary winding are connected in series. What is the voltage rating of the new transformer? [04]

(b) Explain briefly the followings:

(i) Phase voltage of a *Yy* bank of 3-phase transformer exhibits distortions when the neutrals are isolated. [04]

(ii) *Dy* transformer is the best transformer to serve consumers on the distribution system. [04]

(c) Give the per-unit equivalent circuit for a 3-phase 3-winding transformer and describe clearly how its parameters can be estimated by conducting tests on the transformer. [04]

Q8 (a) Draw the power circuit of a DC motor drive that operates on a single quadrant transistor chopper. What are the operational limitations of this type of drive? [03]

(b) A separately excited dc motor has a torque constant of 1.2 Nm/A, an armature inductance of 5 mH and an armature resistance of 0.8 Ω. The motor is controlled by a single-quadrant transistor-chopper with 200 V DC at the input. The chopper is operating at a switching frequency of 20 kHz. All components can be assumed ideal and speed fluctuations can be ignored.

(i) Find is the switching duty factor when the motor is operating at 1000 rpm delivering 24 Nm, determine [04]

(ii) Estimate the peak to peak ripple in the armature current for the operation in (i) above [04]

(iii) What is the lowest load torque that guarantees continuous armature current for all speeds in the full range? [04]

(c) A similar DC motor as in (b) above is driven by a three phase semi-bridge thyristor converter, operating on 240 V, 50 Hz three phase supply. What should be the delay-firing angle α to obtain 1000 rev/m speed at 24 Nm load torque? [05]