THE INSTITUTION OF ENGINEERS, SRI LANKA

PART III EXAMINATION– November 2012

307 - ELECTRICAL MACHINES - II

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

Q1 (a) Describe how the Harmonic Elimination PWM is implemented in three-phase voltage source inverters for variable voltage variable frequency output. [04]

(b) Describe the harmonic spectrum of the output voltage for a single-phase sinusoidal PWM voltage source inverter. [08]

(c) A 3-phase square wave inverter running on 600 V dc input at a switching frequency of 60 Hz drives a 2 pole, three-phase cage rotor induction motor at 1710 rpm. Calculate the approximate slip of the motor and the rms value of the line voltage fundamental. What is the frequency of the induced rotor voltage due to 5th harmonic of stator voltage? [08]

Q2 (a) Give the arrangement of three-phase dual series full-bridge thyristor converter supplied by three-phase *Dd0y1* transformer with equal rms line voltages in the secondary and the tertiary windings. Describe the concurrent switching and sequential switching for this arrangement. [09]

(b) For a single three-phase full-bridge thyristor converter sketch the output voltage waveform for the following cases assuming continuous load current and 60° delay firing angle:

(i) When the 3-phase input is ideal [03]

(ii) When the 3-phase input has an internal inductance [03]

(iii) When the 3-phase input is ideal but the upper thyristor in phase-B is burnt (open) [05]

Q3 (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]

Q4 (a) Describe briefly how the transient/sub-transient reactances and time constant for a 3-phase synchronous generator can be estimated from the data of a standard three-phase short circuit test. [05]

(b) Describe the process of synchronization of a 400V, 50 Hz three-phase generator with a live busbar using dark-lamp-method. What should be the voltage rating of the lamps that are to be used in this process? [06]

(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? [07]

(d) A 3-phase synchronous generator has sub-transient *d*-axis and *q*-axis reactances of 0.025 pu and 0.023 pu respectively. Estimate the negative sequence reactance for the generator. [02]

Q5 (a) Explain briefly the followings:

(i) No load current of a single phase transformer is non sinusoidal [02]

(ii) Phase voltage of a *Yy* bank of 3-phase transformer with isolated neutrals is non sinusoidal but line voltage is sinusoidal. [02]

(ii) Phase voltage and line voltage both of a *Dy* transformer are sinusoidal. [02]

(iv) Load voltage will be collapsed in a *Yy* bank of 3-phase transformer with isolated neutrals if the load is connected between a line and the neutral [03]

(b) Explain briefly why the air gap flux in a 3-phase induction motor is often maintained constant at its rated value for frequencies below rated frequency but allowed to decrease for frequencies above rated frequency. [04]

Give typical variation of line voltage with frequency for a three phase induction motor drive from zero to well above rated frequency. [02]

(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. [05]

Q6 (a) What benefits an adjustable speed three phase induction motor drive offers in a large centrifugal pump system compared to a fixed speed three phase induction motor plus throttle-valve control? How do you compare three phase induction motor drives against dc drives in variable-speed applications and in servo applications? [04]

(b) Using block diagrams and appropriate characteristics describe the following three phase induction motor drives.

(i) Open loop adjustable speed drive below rated speed with terminal V & f control. [03]

(ii) Closed loop servo drive below rated speed with terminal V & f control, incorporating slip regulation. [03]

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

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. [07]

Q7 (a) Describe briefly the advantages and disadvantages of permanent magnet stepping motors and variable reluctance stepping motors, with reference to power/weight ratio and operating speed range. [04]

(b) Figure Q7(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 Q7(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 Q7(c). The motor acceleration time t_a and the deceleration time t_d are equal. Calculate:

(i) the number of steps required to move the table by 90° [03]
(ii) the maximum turntable speed in units of degree/s [03]
(iii) the minimum acceleration time t_a [04]
(iv) the time taken for the turntable to move through 90° [04]

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

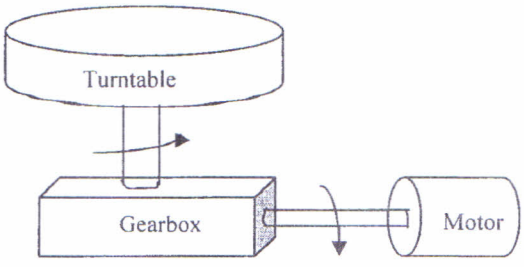

Figure Q7(a)

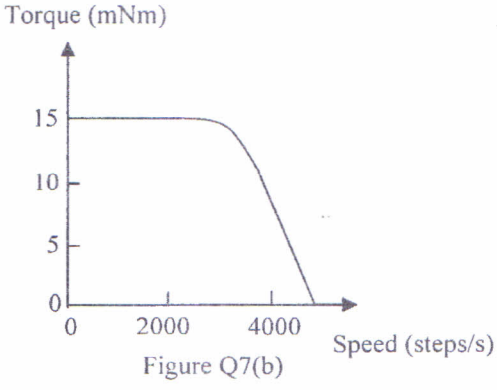

Figure Q7(b)

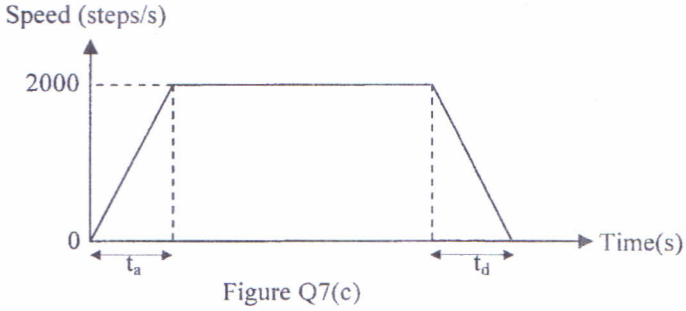

Figure Q7(c)

Q8 The cross section of a three-phase two-pole permanent magnet motor is shown in Figure Q8. The machine has surface-mounted radially-magnetized rotor magnets with a pole arc of 180°. 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) Sketch the variation of flux linkage with rotor position for the three phases. [03]

(b) Assuming the motor is rotating at a constant speed, sketch the motional emf of three phases with rotor position. [03]

(c) The motor phases are star-connected and the current to three phases are supplied by a three-phase transistor inverter. Sketch the waveform of phase currents with rotor position corresponding to constant torque independent of rotor position. [06]

(d) 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]

(e) Give the inverter switching pattern that produces the current waveforms in (c) above with constant dc voltage at the inverter input. [02]

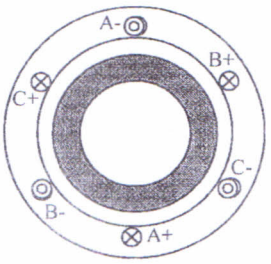

Figure Q8