THE INSTITUTION OF ENGINEERS, SRI LANKA

PART III EXAMINATION– September 2011

307 - ELECTRICAL MACHINES - II

Answer FIVE questions only.
All questions carry equal marks

Time allowed: 03 hours

Q1 (a) A 3-phase Square-Wave (six-step) Voltage-Source Inverter with an input voltage of 600V dc is operated at a switching frequency of 60 Hz. Calculate the rms value of the fundamental component of phase-voltage. Determine the THD (total harmonic distortion) of phase voltage. [04]

(b) Describe briefly the advantages of operating a 3-phase Voltage Source Inverter (VSI) in Sinusoidal PWM mode, compared to six-step mode. Describe briefly the sinusoidal PWM and voltage Vector PWM for a three phase inverter. [08]

(c) A 3-phase full-bridge thyristor ac to dc converter is operating on 50 Hz, 400 V, 3-phase ac input. Calculate the mean value of the output dc voltage for 60° delay firing angle assuming continuous output current. Sketch the output voltage waveform indicating relevant values.
How does the output voltage waveform modify when the ac input has some significant inductance? [08]

Q2 (a) Draw the coil side arrangement over one pole pair for a 36 slots, 4 pole, 3-phase, 2-layer winding with coil span of 7 slots. Draw the coil arrangement of phase-*a* only assuming concentric winding connection. Sketch the pattern of mmf for stator phase-*a* only. [06]

(b) The winding in (a) above is the stator winding of a three-phase induction motor. It is connected in delta and supplied with three-phase 50 Hz, 30 A rms line current. The number of parallel paths per phase is 2 and the number of turns per coil is 18. Calculate the peak values of the fundamental mmf in the air gap due to the stator. [08]

(c) What are the frequencies of the induced emf in the rotor due to the 5^{th} and 7th harmonic stator mmf created by 5^{th} harmonic component of stator current, given that the rotor speed is 1440 rev/min? [06]

Q3 (a) Using block diagrams describe *three* different methods of excitation applied to three phase synchronous generators. Why are generators often operated overexcited? [05]

(b) Derive expressions for the real and reactive power outputs of a salient pole rotor synchronous generator in terms of terminal voltage, internal emf, load angle and machine reactances. [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) Describe the slip test for a three phase synchronous generator. [02]

Q4 (a) Explain briefly why the induced voltage and magnetizing current cannot both be sinusoidal simultaneously in a transformer. A *Yy* bank of 3-phase transformer without neutral produces significant third harmonic emf in phases. How does this third harmonic emf cancelled when the neutral connection is given at input or a tertiary is connected in delta? [07]

(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 for a three phase induction motor with frequency from zero to well above rated frequency. [(

(c) 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]

Q5 (a) Describe briefly the types of permanent magnets used in the construction of electrical machines. [04]

(b) A certain speed servo uses a sinusoidal brushless dc motor with a shaft mounted absolute encoder for position sensing. With the aid of a block diagram describe the arrangement of the complete drive system. What is the advantage of incorporating torque-angle control and what are its constraints? [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 *detent torque* and *holding torque*?
[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 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]

Q8 (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?
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.
[03]
[07]