INDIAN INSTITUTE OF ENGINEERING SCIENCE AND TECHNOLOGY, SHIBPUR

M.E. (Electrical) 2nd Semester Final Examination, May 2014

Subject: Power Electronics II (Subject Code No.: **EE 1013**)

Time: 3 hours

Full Marks: 70

(i) The questions are of equal value
(ii) Answer any ***two*** questions taking two from Group A and ***one*** from Group B
(iii) One mark reserved for brief and precise answers.

Group A

1. (a) Explain, with a schematic block diagram, closed loop slip speed-controlled PWM VSI-fed 3-phase squirrel cage induction motor (IM) drive, below and above base speed.
(b) A 460V, 60 Hz, 4 pole, 1760 rpm, Y-connected 3-phase cage IM has the following equivalent circuit parameters: $R_S = 0.14\ \Omega$, $X_S = 0.4\ \Omega$, $R_r' = 0.08\ \Omega$, $X_r' = 0.8\ \Omega$, $X_m = 15\ \Omega$. The motor is fed by a 6-step inverter, which in turn, is fed from a 6-pulse fully controlled rectifier with a 3-phase AC supply of 460V, 60 Hz. The motor is operated at constant rated air-gap flux by variable frequency control.
   (i) Calculate the inverter frequency, motor input current and rectifier firing angle, when the motor runs at 1200 rpm delivering the rated torque.
   (ii) Calculate the motor speed, input current and rectifier firing angle for an inverter frequency of 30 Hz, while delivering the rated torque.
   (iii) If the minimum inverter frequency is restricted to 6 Hz, calculate the starting torque and the motor current as a ratio of their values when the motor is started at the rated voltage and rated frequency.

The approximate per phase steady state equivalent circuit of 3-phase IM may be assumed for the solution. [8 + 15 = 23]

2. (a) A 400V, 50 Hz, 4 pole, 1485 rpm, Y-connected 3-phase squirrel cage Induction Motor (IM) has the following equivalent circuit parameters: $R_S = 0.03\ \Omega$, $X_S = 0.32\ \Omega$, $R_r' = 0.024\ \Omega$, $X_r' = 0.48\ \Omega$, $X_m = 7\ \Omega$. The motor is fed from a '120 degree conduction' CSI, which is in turn fed from a 3-phase fully controlled rectifier with a 3–phase AC supply of 440V, 50 Hz. The DC link choke has an ESR of 0.001 ohm. The motor is operated at constant air-gap flux of rated value.
   (i) Calculate the stator current, DC link current and rectifier firing angle, when the motor operates at rated torque and at 50 Hz.
   (ii) Calculate the inverter frequency, DC link current, and rectifier displacement power factor for a speed of 1200 rpm when the motor delivers 80% of rated torque.

(b) Present the schematic block diagram of a static Scherbius drive employing a slip-ring IM and its phasor diagram while delivering rated torque. Hence explain the need of employing a transformer between the line-side phase-controlled converter and the utility lines. [12 + 11 = 23]

3. (a) What is meant by indirect rotor flux oriented control of a squirrel cage Induction Motor (IM)?
(b) Assuming the D-axis and Q-axis equivalent circuits of a 3-phase cage IM in arbitrary rotating reference frame, deduce the relationships to show how an IM behaves as a conventional DC motor under rotor flux oriented control.
(c) Explain the feed-forward compensation that needs to be incorporated for a rotor flux oriented controlled IM drive. [4 + 9 + 10 = 23]

4. (a) Give reason why a three phase to three matrix converter can be modeled as a voltage source rectifier and voltage source inverter in cascade?
(b) Explain with a schematic block diagram and waveforms, if required, an LCI-fed synchronous motor drive. How does commutation take place for the machine-side converter devices in low speeds?

(c) A 3-phase, 5 MW at unity power factor, 6600V, 6-pole, 50 Hz. Y-connected, wound field synchronous motor is operated under self-synchronous mode from an LCI. Its $X_S = 10\ \Omega$ and $X_S'' = 1.8\ \Omega$. Stator resistance, core loss, friction and windage losses may be neglected. The field is controlled to maintain rated constant flux below base speed and rated terminal voltage above base speed. The machine is operated at a constant commutation lead angle of 50^0. Calculate the margin angle, displacement power factor, developed power and torque at rated armature current and speed.

[10 + 8 + 5 = 23]

Group B

5. (a) How is (i) a three phase phase-controlled converter (ii) a chopper, modeled as a transfer function block? Give reasons in support of your answer.
(b) Show how the range of firing angle can be determined from given torque requirements at maximum and minimum speed, for a converter-controlled dc motor. (You may use steady state analysis). How is the resolution of control voltage derived from this?
(c) What are the consequences of 'discontinuous' current conduction in a dc motor drive? In this connection, what is 'critical triggering angle'(α_c) for a three phase phase-controlled converter?
(d) Draw the block diagram for closed-loop speed control of phase-controlled converter-fed separately excited dc motor. Assuming a PI-type current controller, derive the transfer function for the current loop. Hence derive an expression for the current loop gain.

[(2 + 2) + (5 + 2) + (2 + 2) + (2 + 4 + 2) = 23]

6. (a) What is meant by harmonic resonance, as applied to a phase-controlled dc motor drive connected to a power system network? How can it be eliminated?
(b) If I_{max} is the maximum allowable current in a dc machine, compare the following between a three phase converter and a two-quadrant chopper:
- The RMS current rating of each switch
- the voltage rating of each switch

(c) For a four-quadrant chopper driving a motor load, draw the load voltage, load current and supply current waveforms when the motor is regenerating. Point out the conduction sequence of the switches/diodes.
(d) A single quadrant chopper controls a dc motor with the following parameters:
2 hp, 48 V, 2000 rpm, $R_a = 0.02\ \Omega$, $L_a = 4$ mH, $K_b = 0.075$ V/rad/sec, chopping frequency = 1 kHz.
Find the range of duty cycle for a requirement of constant 1 p.u. load when speed varies from 0 to 1 p.u. (use average analysis and assume that the device has a on-state drop of 1 V).
(e) Why is sensorless control preferred? Briefly explain how speed can be estimated from line quantities using direct flux synthesis.

[(2 + 2) + 4 + (3 + 2) + 5 + (2 + 3) = 23]