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THE NATIONAL UNIVERSITY OF IRELAND, CORK

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B.E. DEGREE (ELECTRICAL)

POWER ELECTRONICS AND ENERGY CONVERSION (EE4001)

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ATTEMPT FIVE QUESTIONS

3 HOURS

1. (i) Describe the overlap effect in a thyristor phase-controlled rectifier circuit. Express the d.c. voltage drop due to overlap in terms of the d.c. load current, assuming a highly inductive load and negligible transformer winding resistance,

   A three-phase **half-wave** thyristor phase-controlled rectifier is connected to a three-phase a.c. supply of 400 V and 50 Hz. Calculate the mean load voltage and the commutating inductance per phase when $\alpha = 25^0$, $u = 30^0$, and the d.c. load current is 40 A. The thyristor on-state voltage is 1.5 V.

   (ii) A three-phase fully-controlled thyristor **bridge** rectifier feeds a highly inductive load and overlap is negligible. Sketch the a.c. current waveforms in the three input lines and explain why the displacement power factor of the rectifier decreases as the firing angle is increased.

   What is the general definition of power factor? Determine its value for a three-phase fully-controlled thyristor bridge rectifier (a) when the firing angle is zero, and (b) when the firing angle is such that the rectifier delivers one-third of its maximum output voltage. Assume a highly inductive load and negligible overlap.

2. Explain the operation of the phase-controlled thyristor rectifier as an inverter. Sketch the voltage and current waveforms and indicate the overlap angle, margin angle, and angle of firing advance. Discuss the significance of the margin angle.

A three-phase fully-controlled thyristor bridge circuit is connected to a 415 V, three-phase, 50 Hz a.c. supply. The thyristor bridge is operating as an inverter with a delay angle of 145^0. The commutating reactance is 0.3 Ω per phase. If the d.c. supply has a source resistance of 0.1 Ω and delivers a level input current of 60 A to the inverter, determine

(a) the d.c. supply voltage

(b) the overlap angle, and

(c) the margin angle.

Assume the thyristor on-state voltage is 1.5 V.

3. (a) Draw the circuit of a typical d.c. link converter with a three-phase six-step voltage-source inverter (VSI). Indicate clearly the inverter firing sequence in the six-step VSI, and deduce the line-to-line output voltage waveforms.

(b) For a three-phase bridge inverter, derive the general voltage equations relating the inverter pole voltages and the line-to-neutral voltages for a balanced star-connected load. Use these general equations to derive the line-to-neutral voltage in the case of a balanced star-connected load fed by a six-step VSI.

4. In an adjustable-frequency induction motor drive, the airgap flux is maintained constant by means of a closed-loop control system with airgap flux sensors. Sketch the torque-speed characteristics and briefly discuss the practical implementation of such a control scheme. What are its advantages and disadvantages?

A three-phase, 400 V, 50 Hz, 4-pole, star-connected induction motor has the following equivalent circuit parameters at rated frequency:

$$R_1 = R_2' = 0.15\,\Omega$$

$$X_1 = X_2' = 0.95\,\Omega$$

(a) Calculate the torque at rated voltage and frequency for the rated slip of 3%.

(b) If the same torque is required at 150 rev/min, to what values must the supply voltage and frequency be adjusted if the airgap flux is to be the same as at the rated condition?

5. A three-phase induction motor is operated in an adjustable-frequency drive with a constant volts/hertz ratio below base speed and with a constant voltage above base speed. Sketch typical torque-speed characteristics above and below base speed. Also, explain how the low-speed performance can be improved.

A three-phase, 400 V, 50 Hz, 8-pole, star-connected induction motor has the following equivalent circuit parameters per phase at rated frequency:

$$R_1 = R_2' = 0.2\,\Omega;$$

$$X_1 = X_2' = 1.25\,\Omega$$

(a) Calculate the breakdown torque at rated voltage and frequency, and determine the corresponding value of slip.

(b) If the motor is operated with a constant volts/hertz ratio from zero to 50 Hz, determine the breakdown torque (i) at 50% voltage and frequency, and (ii) at 10% voltage and frequency. Determine what voltage is necessary at 10% frequency to give the same breakdown torque as is obtained for 400 V, 50 Hz operation.

(c) Above 50 Hz, the motor is operated with a constant stator voltage of 400 V. Determine the breakdown torque at 100 Hz.

6. Discuss the operation of the six-step current-source inverter (CSI). Indicate clearly the inverter firing sequence and deduce the output line current waveforms.

A six-step CSI feeds a three-phase induction motor with a controlled-current adjustable-frequency a.c. supply. Using the induction motor equivalent circuit, show that the magnetising current, I_m, can be held constant by suitably varying the rotor frequency, ω_2, and stator current, I_1. Derive the relationship between I_m, I_1, and ω_2.

The equivalent circuit parameters of a squirrel cage induction motor at its rated frequency of 50 Hz are:

$$R_1 = 0.8\,\Omega, \qquad X_1 = 1.25\,\Omega,$$

$$R_2' = 0.5\,\Omega, \qquad X_2' = 0.95\,\Omega,$$

$$X_m = 20.75\,\Omega.$$

The magnetising phase current, I_m, at the rated conditions of the motor is 8 A. The motor is being supplied from a six-step CSI and the slip frequency command is 2 Hz. What should be the stator current value in order to maintain the proper magnetising current in the motor?

7. Explain the basic relationships governing the division of airgap power in the rotor of a three-phase induction motor.

Sketch the circuit diagram of an induction motor slip-energy recovery scheme incorporating a three-phase naturally-commutated thyristor inverter. Derive an expression for the no-load slip, and show that motor torque is approximately proportional to d.c. link current, independent of speed.

A three-phase, 3300 V, 50 Hz, 8-pole, wound-rotor induction motor drives a variable-speed centrifugal pump in a slip-energy recovery scheme. When the motor is connected to the 3300 V a.c. network, the open-circuit standstill slip-ring voltage is 1500 V. A three-phase 3300/400 V transformer is connected between the a.c. line and the inverter. If the motor has to develop 800 kW at a speed of 600 rev/min, calculate for this speed:

(a) the d.c. link voltage and current

(b) the inverter firing angle, and

(c) the power in the d.c. link.