National Exams May 2004

98-Elec-B9, Power Electronics and Drives

Open Book examination

3 hours duration

NOTES

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit, with the answer paper, a clear statement of any assumptions made.
2. Any non-communicating calculator is permitted. This is an Open Book examination. Note to the candidates: you must indicate the type of calculator being used, i.e. write the name and model designation of the calculator on the first inside left hand sheet of the exam work book.
3. Any five questions constitute a complete paper. Only the first five questions as they appear in your answer book will be marked.
4. All questions are of equal value.

PROBLEM 1

a- Explain the effect of load inductances on the output voltage of an ac controller. [5 points]

A single-phase, 120 V (rms,) 60-Hz source supplies a full-wave a.c voltage controller. The controller powers a 5-hp motor, and the delay angle is adjusted to $\alpha = 66^o$. The corresponding conduction angle is $\gamma = 150^o$.

b- Verify that the load power factor is 0.8 (i.e. $\phi = 36.87^o$). [5 points]

c- Find the effective (rms) output voltage of the controller. [5 points]

d- Assume that the efficiency of the motor is 0.92; find the average current through each of the thyristors of the controller. [5 points]

PROBLEM 2

a- Explain why is it necessary to use a free-wheeling diode in power electronic circuits [5 points]

The a.c. supply voltage to a controlled half-wave rectifier is 120 V. The load circuit consists of a resistance R = 10 Ω in series with an inductance L and a d.c. source E_c. The power factor of the R-L combination is 0.8 and the ratio of the counter emf E_c to the maximum ac voltage V_m is given by $E_c/V_m = 0.17$. Assume that the delay angle $\alpha = 30^o$

b- Find an expression that allows us to find the corresponding conduction angle, and verify that the solution in this case is very close to $\gamma = 175^o$ [7.5 points]

c- Find the average value of the output voltage and current. [7.5 points]

PROBLEM 3

a- Explain the reasons for using series smoothing reactors in inverter circuits. [5 points]

The voltage input to a basic chopper circuit is V_i = 24 V. The period of the chopper is 2.4 ms. The load consists of a series combination of R = 0.12 Ω and an inductance $L=0.35 \times 10^{-3}$ H. The ratio of minimum to maximum values of the output current is 0.75. It is required to find:

b- The time constant of the load circuit, and the on time. [5 points]

c- The maximum and minimum values of the output current. [5 points]

d- The time domain expressions of the chopper output currents, and the value of the output current at t= 1 ms [5 points]

PROBLEM 4

a- Explain the principle of operation of sinusoidal pulse width modulation (PWM) for inverter output voltage control. [5 points]

b- It is known that the n^{th} Fourier Series coefficient for the output side of a single-phase full wave bridge single pulse modulation inverter is given by:

$$b_n = \frac{4V_d}{n\pi}\sin\frac{n\delta}{2}$$

Show that the ratio of the third harmonic to fundamental component is given by:

$$\frac{b_3}{b_1} = \frac{1}{3}\left[3 - 4\sin^2\frac{\delta}{2}\right]$$

[5 points]

The dc supply to a single-phase full wave bridge single pulse modulation inverter is 220 V. The load is an ac motor. The motor is represented by an R-L series combination whose value at fundamental frequency is given by:

$R = 8\,\Omega$ $\qquad\qquad$ $\omega L = j6\Omega$

c- The modulation angle δ is selected such that the ratio of the third harmonic to fundamental components of the voltage output is 0.2. Find the ratio of the fifth harmonic to fundamental components of the voltage output. [5 points]

d- Find the fundamental, third, and fifth harmonic components of the inverter output current (feeding the motor). [5 points]

PROBLEM 5

a- List at least three undesirable effects of using high frequency PWM drives. [5 points]

A three-phase, four-pole induction motor has a total leakage inductance of 1.5 mH, negligible resistance, and operates from a constant volt per Hz drive.

b- Assume that the maximum output torque is 280 N.m. at a speed of 1500 rpm, when the frequency supplied to the stator is 60 Hz. Find the required supply voltage (line-to-line), and the motor's line current. [7.5 points]

c- Assume that the motor draws a line current of 200 A, when the stator input frequency is 65 Hz. Find the required supply voltage (line to line,) and the maximum output torque. [7.5 points]

Use the following approximation for the value of maximum developed torque:

$$T_{\max} = \frac{[V_{LL}]^2 P}{4[\omega_i]^2 L_T}$$

Here P is the number of poles, L_T is the total leakage reactance, and

$\omega_i = 2\pi f_i$

PROBLEM 6

a- Give a list of the three types of dc drives based on the input supply. What are the variables to be controlled in a dc variable speed drive? [5 points]

A three-phase full wave bridge rectifier circuit feeds the armature terminals of a separately excited dc motor. The ac voltage source is 220 V (line-to-line). The motor draws an armature current of 195 A all the time.

b- Find the armature voltage when the firing angle of the rectifier circuit is 40° and speed is 1750 rpm.[5 points]

c- To drive the motor at a speed of 1000 rpm, a firing angle of 60° is required. Find the resistance of the armature circuit, the output power and torque under these conditions. [5 point]

d- The firing angle is adjusted to 65°. Find the corresponding speed of the motor. [5 points]