National Exams December 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- Snubbers are used extensively in power electronic circuits. Explain what they are and their function [5 points]

A single-phase, 120 V (rms,) 60-Hz source supplies a full-wave a.c voltage controller. The controller powers a 2.5 hp motor operating at 0.85 power factor, (i.e. $\phi = 31.788^o$). The value of the delay angle is adjusted to $\alpha = 75.9^o$.

b- Write an equation that allows us to find the corresponding conduction angle γ. Verify that $\gamma = 135^o$, and find the effective (rms) output voltage of the controller. [10 points]

c- 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- List and discuss five factors that influence the duration of the turn-off interval of an SCR. [5 points]

The ac supply voltage to a half-wave controlled rectifier is 120 V. The load circuit consists of a resistance R in series with an inductance L. The power factor of this load is 0.707.

b- Find the value of the delay angle α when the conduction angle is $\gamma = 140^o$. Find the load resistance R when the average value of the dc output current is 20 A. [7.5 points]

c- Assume that the conduction angle is adjusted to $\gamma = 150^o$, find delay angle α and the average value of the dc output current under the conditions of part (b) [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 load consists of a series combination of R = 1.2 Ω and an inductance L=0.3x10^{-3} H. The ratio of minimum to maximum values of the output current is 0.75. It is required to find:

b- The period of the chopper, given that the on-time of the chopper is 2 ms.. [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 how harmonics arise in an electric power distribution system, and list three ways of mitigating their effects. [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 fifth harmonic to third harmonic component is given by:

$$\frac{b_5}{b_3} = \frac{3}{5}\left[\frac{5\sin\frac{\delta}{2} - 20\sin^3\frac{\delta}{2} + 16\sin^5\frac{\delta}{2}}{3\sin\frac{\delta}{2} - 4\sin^3\frac{\delta}{2}}\right]$$

[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 fifth harmonic to third harmonic components of the voltage output is 0.3. Find the ratio of the third 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]

Useful Trig Identities:

$\sin 3\theta = 3\sin\theta - 4\sin^3\theta$

$\sin 5\theta = 5\sin\theta - 20\sin^3\theta + 16\sin^5\theta$

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 15 mH, negligible resistance, and operates from a constant volt per Hz drive.

b- Find the maximum output torque and line current at a speed of 1500 rpm, when the supply voltage (line-to-line) is 460 V and the frequency supplied to the stator is 60 Hz. [7.5 points]

c- Assume that the leakage reactance is changed so that the motor draws a line current of 50 A, when the stator input frequency is 65 Hz. Find the required value of leakage inductance, the line voltage and the corresponding 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- Explain the principle of speed control in a dc drive below base speed and how does it differ from control above base speed.[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 230 V (line-to-line). The motor draws an armature current of 165 A all the time.

b- Find the armature voltage when the firing angle of the rectifier circuit is 48° 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]

Marking Scheme

PROBLEM 1

(a) 5 Points (b) 10 Points (c) 5 Points

PROBLEM 2

(a) 5 Points (b) 7.5 Points (c) 7.5 Points

PROBLEM 3

(a) 5 Points (b) 5 Points (c) 5 Points (d) 5 Points

PROBLEM 4

(a) 5 Points (b) 5 Points (c) 5 Points (d) 5 Points

PROBLEM 5

(a) 5 Points (b) 7.5 Points (c) 7.5 Points

PROBLEM 6

(a) 5 Points (b) 5 Points (c) 5 Points (d) 5 Points