National Exams December 2009

07-Elec-B8, 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 principle of operation of ac controllers [5 points]

A single-phase, 575-V (rms,) 60-Hz source supplies a full-wave a.c voltage controller. The controller powers an ac motor, and the delay angle is adjusted to $\alpha = 53.54°$. The corresponding conduction angle is $\gamma = 158°$, and the average current through each thyristor is 65 A.

b- Verify that the load power factor is 0.85 [5 points]

c- Determine the rms value of the output voltage [5 points]

d- Find the equivalent resistance and inductive reactance of the motor. [5 points]

PROBLEM 2

a- Discuss three ways in which harmonics are introduced in the electric power distribution system. [4 Points]

The a.c. supply voltage to a single-phase full wave controlled rectifier is 120 V. The minimum permissible value of the delay angle is 15°. The load circuit consists of a back e.m.f. E_c in series with a resistance R = 2 Ω. The conduction angle γ is 145°.

b- Find the value of the load's counter e.m.f. E_c. [4 Points]
c- Find the delay angle α. [4 marks]
d- Find the value of the average load current. [4 Points]
e- Find the average power taken by E_c. [4 Points]

PROBLEM 3

a- Explain three harmful effects of harmonics in electric power distribution systems. [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:

$$R = 9\,\Omega \qquad\qquad \omega L = j5\Omega$$

c- The modulation angle δ is selected such that the ratio of the fifth harmonic to third harmonic components of the voltage output is 0.2. 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 4

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 1.8 ms. The load consists of a series combination of R = 1.6 Ω and an inductance L=0.4x10^{-3} H. The ratio of minimum to maximum values of the output current is 0.6. Determine the following:

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 values of the output current at t= 1 ms and t=2 ms, respectively [5 Points]

PROBLEM 5

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

a- Assume that the maximum output torque is 247 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]

b- Assume that the motor draws a line current of 180 A, when the stator input frequency is 63 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- What are the 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 230 V (line-to-line). The motor draws an armature current of 120 A all the time.

b- Find the armature voltage when the firing angle of the rectifier circuit is 42.5° and speed is 1720 rpm.[5 points]

c- To drive the motor at a speed of 1000 rpm, a firing angle of 57° is required. Find the resistance of the armature circuit, the output power and torque under these conditions. [5 points]

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