City & Guilds

9210-217
Level 7 Post Graduate Diploma in Engineering
Power electronics

Sample Paper

You should have the following for this examination
- one answer book
- non-programmable calculator
- pen, pencil, ruler

No additional data is attached

General instructions
- This paper consists of **eight** questions.
- Answer any **five** questions.

© The City and Guilds of London Institute 2016

1 Consider a three-phase full-bridged thyristor controlled AC-DC converter.

a) i) Give the circuit diagram of the converter. Using appropriate waveforms show that the mean output voltage is given by the following equation.

$$V_d = \frac{3\sqrt{2}}{\pi} V_{LL} \cos\alpha - \frac{3\omega L_S}{\pi} I_d$$

where V_{LL} is the line to line voltage of the ac supply, ω is the angular frequency, L_s is the supply inductance, α is the firing angle and I_d is the dc current. (7 marks)

ii) And show that the commutation angle, u is given by the following equation (3 marks)

$$u = \cos^{-1}\left[\cos\alpha - \frac{2\omega L_S}{\sqrt{2}V_{LL}} I_d\right] - \alpha$$

iii) Further, sketch the characteristics showing the variation of V_d against α, indicating on your sketch rectifier and inverter mode of operation. (2 marks)

b) The above converter is operating in the **inverter** mode with V_{LL} = 400 V at 50 Hz, L_s = 1 mH, V_d = 500 V and power flow is 50 kW. Calculate the following:

i) firing angle, α (2 marks)

ii) commutation angle, u and the extinction angle, γ (4 marks)

iii) peak inverse voltage across each thyristor. (2 marks)

2 A non-isolated buck dc-dc converter is to be designed to supply a regulated output voltage of 30 V to a variable load of 150 W ~ 1.5 kW at a switching frequency of 20 kHz. Assuming all components to be ideal.

a) Sketch the circuit diagram of the converter and draw the following waveforms for the continuous conduction mode. (2 marks)

i) Inductor voltage and current. (2 marks)

ii) Capacitor ripple current and ripple voltage. (2 marks)

iii) Switch current and diode current. (2 marks)

b) Calculate the minimum inductance required to keep the converter operating in a continuous conduction mode under all conditions if the input voltage, V_d varies in the range 45 V to 60 V. (6 marks)

c) Calculate the minimum capacitance required to limit the peak-to-peak output voltage ripple to 0.2% of the output voltage. (4 marks)

d) Calculate the diode maximum average current. (2 marks)

3 a) Explain briefly how a three-phase square wave PWM inverter is operated using PWM signals generated by a controller. Use circuit diagrams and waveforms as necessary to explain how switching signals are generated in the controller. (4 marks)

b) Draw clearly the carrier waveform and the reference waveform for phase A on the same graph for one complete cycle of the reference waveform. Assume that the inverter is operated with the carrier ratio 9, modulation index 0.6 and the output frequency is 50 Hz. Hence obtain the switching signal for the phase **A**. (6 marks)

c) Sketch the shape of line voltage waveform between phase **A** and phase **B** of the inverter. Indicate all necessary values. (6 marks)

d) What is meant by Gear changing in inverter operation? Explain when and how gear changing is applied in square wave PWM inverter operation. (4 marks)

© The City and Guilds of London Institute 2016

4 a) Draw the power circuit of single phase transformer tap changer (an application of AC voltage regulation) which uses two tapping positions to change the output voltage. What are the ranges of the output voltage which could be obtained by switching the thyristors in different patterns in the power circuit? (6 marks)

b) Identify the switching devices that conduct during different ranges of output voltage in part b) above. (4 marks)

c) Describe briefly the cycloconverter. Draw the power circuit of single phase cycloconverter which uses thyristors as switching devices. (4 marks)

d) A single phase cycloconverter is operated at 60 Hz ac input. The converter produces 30 Hz ac output and supplies a resistive load. Draw the following:

i) Output and input voltage waveforms for one cycle of output voltage waveform. (3 marks)

ii) Switching signals for positive and negative converters and gate signals for thyristors in the converter. (3 marks)

5 The armature of a separately excited dc motor is supplied by a three-phase, thyristor controlled full-bridged rectifier of 230 Vrms/50 Hz per-phase ac input. The field is supplied by a single-phase, full-bridged diode rectifier of 230 Vrms/50 Hz ac input. The parameters for the separately excited dc motor are as follows: Armature resistance: $R_a = 0.2\,\Omega$, Field resistance: $R_f = 150\,\Omega$, and Motor constant: $K_V = 2$ V/A-rad/s

a) Draw the complete power circuit diagram of the above motor-drive arrangement. (4 marks)

b) Derive equations for the average dc armature voltage, V_a and the average dc field voltage, V_f. (6 marks)

c) Assume that the inductance of the armature and field circuit is large enough to ensure continuous and ripple-free currents. If the delay angle of the armature converter $\alpha = 30°$ and the required armature current is 20 A, calculate the following:

i) Developed torque, τ_d (3 marks)

ii) Speed of the motor, ω (3 marks)

iii) Required delay angle of the armature converter in steady condition if the polarity of the field current is reversed for the same armature current of 20 A. (4 marks)

6 A voltage sourced switch-mode power electronics converter is required for a single-phase uninterruptible power supply (UPS) application.

a) Give the power circuit diagram of a suitable converter employing power MOSFETs that can be used for this application. Draw a block diagram of a UPS configuration where the load is normally connected to the ac main supply. (4 marks)

b) i) Explain how the necessary sinusoidal pulse-width modulation is achieved by natural sampling in the converter in which the bipolar PWM control is employed to switch the power MOSFETs. Use a block diagram of the PWM controller showing how the switching signals to the MOSFETs are generated to aid your explanation. (8 marks)

ii) Show typical waveforms and justify the relationship defining the dc input and ac output voltages from the modulating and carrier waves. (4 marks)

c) What is meant by over-modulation and how does it affect the harmonic spectrum of the output? (4 marks)

© The City and Guilds of London Institute 2016

See next page

7 A non-isolated boost (step-up) dc-dc converter operating in the continuous current conduction mode is to be designed for a particular application.

a) Give the circuit diagram of the converter. Show the typical waveform of the inductor voltage and current, the switch current, the diode current and the capacitor current for continuous conduction mode. Indicate all the significant symbolic values in their usual notations in the waveforms. (6 marks)

b) Using the inductor voltage waveform, derive the output voltage, V_o to input voltage, V_d transformation ratio in terms of the switch duty ratio D. (2 marks)

c) i) Using the inductor current waveform at the boundary between continuous and discontinuous modes, show that the average output current at the boundary, I_{OB} for a regulated output voltage, V_O is given by the following equation (4 marks)

$$I_{OB} = \frac{T_S V_O}{2L}(1-D)^2 D$$

ii) Hence plot the graph of I_{OB} versus D. (2 marks)

d) Derive the design equations for the minimum inductor and minimum capacitor values in terms of the input dc voltage $V_{d,min} \leq V_d \leq V_{d,max}$, the regulated output voltage V_o, the maximum peak to peak output voltage ripple ΔV_o, the switching frequency f_s, and the output current $I_{o,min} \leq I_o \leq I_{o,max}$ for continuous conduction mode. Assume that the minimum duty ratio, D_{min} in the operating region is smaller than 1/3 whereas the maximum duty ratio, D_{max} is greater than 1/3. (6 marks)

8 a) Draw the typical power circuit of a three-phase half-bridge diode rectifier with negligible source inductance and sketch the waveforms of output voltage, output current, current through phase ***A*** diode and voltage across phase ***A*** diode. (4 marks)

b) Sketch the output voltage waveform of a three-phase half-bridge diode rectifier with significant source inductance. Determine the total reduction in the output dc voltage of the converter due to conduction overlap. (4 marks)

c) Voltage notches in the voltage waveforms at the point of common coupling of the converter due to source inductance should be reduced. Explain an action that can be taken to reduce the size of the deepest voltage notch. (2 marks)

d) A single-phase half-bridge square wave voltage source inverter has a resistive load of $R = 2\ \Omega$ and the dc input voltage is $V_d = 50$ V. Determine the following:

i) rms output voltage at the fundamental frequency (2 marks)

ii) output power (2 marks)

iii) average and peak currents of each switching device (2 marks)

iv) peak reverse blocking voltage of each switch (2 marks)

v) total harmonic distortion (THD). (2 marks)

© The City and Guilds of London Institute 2016